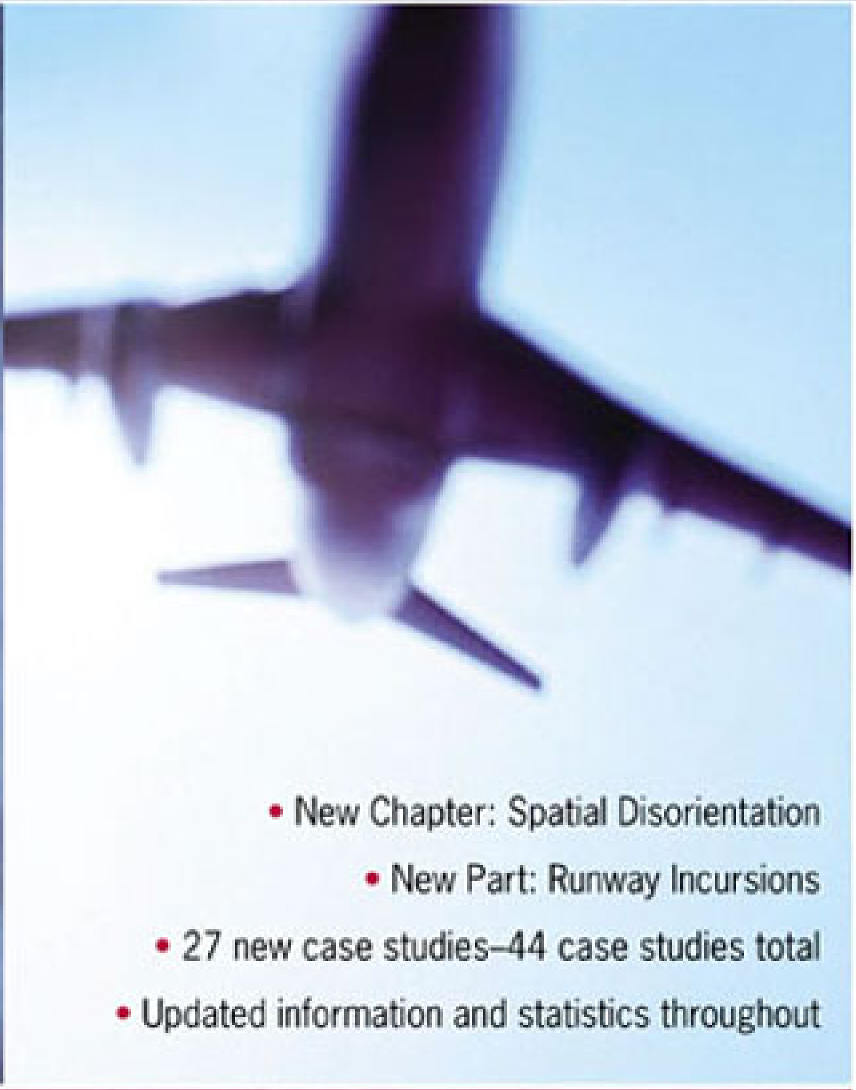
Aircraft Safety

Accident Investigations, Analyses & Applications

Second Edition



- New Chapter: Spatial Disorientation
- New Part: Runway Incursions
- 27 new case studies–44 case studies total
- Updated information and statistics throughout

Shari Stamford Krause, Ph.D.

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Introduction

The contents of this book present a unique blend of research material and instructional guidelines against the backdrop of actual aircraft accident cases. Additional references are used to expound on the National Transportation Safety Board's analyses and to fill in any gaps. The purpose is to provide pilots and aviation professionals, regardless of experience levels, the clear and realistic lessons that have evolved from these accidents. In turn, the reader will learn ways to customize those lessons into practical techniques suitable for any flight environment.

The book is divided into five comprehensive parts: Human Factors, Runway Incursions, Weather, Mid-Air Collisions, and Mechanical and Maintenance. Where appropriate, a part includes a complete study of issues that relate to the particular area of concentration. Each part contains case studies, detailed analyses of accidents that coincide with the topic.

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PART I

Human Factors

Errors committed within the broad category of human factors remain the leading causes of aircraft accidents. Topics examined in Part I are those most representative of human factors errors: judgment and decision-making, situation assessment, crew resource management, and spatial disorientation.

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Judgment and Decision-Making

You can't solve a problem unless (a) you recognize you've got a problem and (b) you understand the nature of the problem.
Judith Orasanu, Ph.D., NASA-Ames Research Center

Good judgment and thus good decision-making are mental skills that every pilot can learn. There is indisputable evidence from accident reports, safety studies, and exhaustive academic research that illustrate breakdowns of judgment skills by pilots on accident flights. Some pilots experience momentary lapses in these skills, brought on by isolated cases of fatigue or stress. Others exhibit a more pervasive and consistent lack of judgment skills caused by disruptive or submissive personality traits or by social influence. The encouraging news is that a pilot has the cognitive ability to learn good judgment skills and therefore make sound decisions, regardless of how or why he lacks those skills in the first place.

Principles of Good Judgment and Decision-Making

There are two fundamental principles of good judgment and thus good decision-making: *perception* and the *ability to distinguish between correct and incorrect solutions.* Dissecting the definitions of

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perceive and distinguish reveals the many layers of mental skills that go into good judgment. You perceive—become aware, observe, detect, understand—a situation and are able to *distinguish*—recognize, see clearly, understand distinctions—between correct and incorrect alternatives to a solution.

Judgment is the cognitive process through which a decision is made. Therefore, a *good decision* is the correct solution based on knowledge, keen perception, and the ability to recognize an appropriate course of action. Never assume that every positive outcome (i.e., landing safely after foolishly flying through a thunderstorm) is the result of an appropriate decision. Chalk those up to luck or divine intervention. Good judgment, however, will always produce good decisions.

Good Judgment and Decision-Making in Practice

There is no better way to encapsulate all the layers of defining good judgment than in Orasanu's statement at the opening of this chapter. Most of the accident case studies in this book have a common thread—pilots missing a problem altogether, pilots recognizing a problem too late, or pilots not understanding the nature of the problem even after recognizing that there is a problem.

So how does a pilot learn to recognize that there is a problem and subsequently chose an appropriate course of action? The answers are found in the two fundamental principles of good judgment—the accurate perception of a situation and the ability to distinguish between correct and incorrect alternatives to a solution.

Principle One: Perception

Developing accurate perception requires four essential skills: a vigilant sense of awareness, observation, detection, and understanding. A pilot must be intellectually *aware* of her surroundings through her knowledge and ability to process information. A pilot must make the commitment to being a lifetime student. Don't become lax in your knowledge of systems and aerodynamic characteristics, new software, or emergency procedures. The information you process is only as good as the knowledge you feed your brain.

A pilot must have a keen ability to *observe* his surroundings with careful attention to detail while resisting unnecessary distractions. The quality of your observations determines the quality of the information that you are incrementally processing in this phase of perception. And what you do with that information is equally important. The crash of Eastern Flight 401 (Historical Case Study I-10) is just one disturbing example of experienced flight crews failing to observe their surroundings and thus failing to recognize a dangerous situation.

Once a pilot is observant of her surroundings, the layers of perception, particularly recognition, quickly narrow to the *detection* and *decisive understanding* of a problem. Detection—to discover the existence and nature—of a problem is dramatically linked to whether or not a pilot understands the nature of the problem.

AIR FLORIDA FLIGHT 90

The 1982 crash of Air Florida Flight 90 is a profound illustration of how the lack of perception on the part of both the captain and first officer resulted in poor judgment and ultimately a fatal decision. Flight 90, a B-737, was exposed for over two hours to a nearly continuous moderate to heavy snowfall as it waited for departure from Washington National Airport. The flight crew failed to turn on the engine anti-ice which allowed ice to form in the engine compressor inlet (Pt2). On a few occasions, the first officer questioned an intermittent fluctuation of the engine pressure ratio (EPR) instrument setting, including the comment, "I don't know why that's different [EPR settings]." The anomaly appeared again during the takeoff roll. The first officer's sense of frustration with the problem was evident in his urgent and final statements, "…look at that thing [EPR setting], that doesn't seem right…I don't think that's right…maybe it is…I don't know." The captain either dismissed or ignored all the comments made by the first officer.

The 737 operations manual clearly states, "…the Pt2 probe will ice up in icing conditions if anti-ice is not used; and an erratic EPR readout may be an indication of engine icing…when the Pt2 probe becomes solidly blocked, EPR fluctuations will cease."

The captain never exhibited any perception skills. The first officer, however, was generally aware of a problem and continued to observe the EPR fluctuations but was unable to detect and understand the nature of the problem. The flight crew failed to demonstrate the four essential skills of perception—awareness, observation, detection, and understanding—and therefore was unable to recognize and solve the problem.

Principle Two: Distinguish

The second fundamental principle of good judgment is the ability to distinguish between correct and incorrect alternatives to a solution. The ability for a pilot to successfully distinguish—recognize, see clearly, understand distinctions—between various alternatives is the culmination of conscientiously applying the four essential skills of perception.

UNITED FLIGHT 232

The flight crew of United Flight 232 (Case Study V-5) provides an exemplary model of accurate perception and distinguishing skills. The DC-10 was at a cruise altitude of 37,000 feet (also referred to as flight level 370, or FL 370) when a catastrophic separation of the stage 1 fan disk ripped apart the tail-mounted number two engine, destroying the entire hydraulic system that powered the airplane's flight controls. The flight crew, plus an off-duty United DC-10 captain, took command of the crippled aircraft and began a systematic evaluation of the situation. They had no prior training for such an event because an emergency of this magnitude was considered extremely remote. Collectively, the flight crew pooled their vast knowledge of the DC-10 and maintained a vigilant observation of the situation, while avoiding unnecessary distractions. Based upon their expert knowledge of the systems and flight characteristics of the DC-10 and careful observation of the emergency, they were able to detect multiple and overlapping problems. As a result of their keen perception, the flight crew recognized and understood the nature of their dire situation.

Supported by their accurate perception and understanding of the nature of the emergency, the flight crew was able to distinguish between correct and incorrect solutions. For example, the DC-10 was designed to stay trimmed in level flight. Because Flight 232 had been trimmed at a 270-knot cruise speed before the engine failed, the aircraft automatically attempted to maintain that configuration throughout the emergency, despite the control inputs from the flight crew. Furthermore, the explosive damage to the aircraft caused it to become displaced along the longitudinal axis, resulting in nearly constant longitudinal oscillations, known as *phugoids*. In order to maintain controlled flight, the flight crew oftentimes added large amounts of thrust. This action raised the nose of the aircraft, but caused it to automatically retrim and therefore enter into repeated phugoids. The aircraft did not respond to normal, phugoid-suppression techniques, and without aggressive thrust control, the aircraft would have rolled over. By experimenting with conservative trial-and-error methods, the flight crew was able to distinguish between correct and incorrect alternatives, which prevented them from losing control of the aircraft.

Ultimately, the flight crew was able to accurately recognize the problems that faced them that day through keen perception skills—awareness, observation, detection, understanding. In turn, they successfully distinguished between correct and incorrect alternatives, preventing a catastrophic loss of life.

Influences That Affect Judgment

Although a pilot may attempt to demonstrate good judgment skills, as discussed in the previous section, there may be overarching influences that prevent a positive outcome. The influences that can interrupt or bias the judgment process typically fall into at least one of the following seven categories:

Cognitive. Capacity to process information; the ability to recall knowledge

Moral. Influences of ethical values, breaking laws, ignoring regulations or standard operating procedures (SOPs)

Emotional. Stress, anxiety, fear, boredom

Physiological. Fatigue, illness, alcohol, medication, illegal drugs

Social. Pressure to agree or go along with a superior's decision, peer pressure

Personality. Ingrained traits

Attitude. How a person reacts to a situation

Elements within some of these categories, such as intellectual capacity and personality traits, are inherent to the individual and thus difficult to change completely. Nevertheless, it is still possible for a pilot to recognize the presence of most negative influences that affect the judgment process and thereby learn how to stop or alter those circumstances.

Recognizing Negative Influences That Affect Judgment

COGNITIVE

A pilot must understand every mechanical system and the aerodynamic characteristics of the aircraft. The stronger the base of knowledge a pilot possesses, the better intellectually equipped he is to solve a problem.

MORAL

Flight instructors and the Federal Aviation Administration (FAA) are generally successful at weeding out pilots who blatantly and willfully break laws, ignore regulations, and are an overall danger to society. But then there are other pilots who settle comfortably into what they consider a gray area of ethical values, quite simply, because they believe their "minor" infraction doesn't really constitute breaking the law. No harm—no foul. These are pilots who sneak through a few miles of controlled airspace with their transponders turned off, fly lower and faster than regulations allow, or fly briefly in instrument conditions when they are not instrument rated. Regardless how often pilots slip past flight regulations or dismiss standard operating procedures, this negative pattern ultimately shapes their judgment processes.

EMOTIONAL

Documented studies from as far back as 1908 have shown that optimal performance requires mental stimulation. Moderate degrees of mental stimulation, including controlled feelings of stress, cause heightened awareness. Experiencing too little mental stimulation can cause boredom and complacency, resulting in a dulling of perception and other important judgment skills. Conversely, dealing with excessive amounts of mental stimulation can create sensory overload, causing confusion and an inability to process information. Feeling a sense of boredom or near-panic can produce similar negative outcomes by diverting a pilot's attention away from a cohesive judgment process.

PHYSIOLOGICAL

Any abnormal physiological condition can negatively affect a pilot's judgment. Fatigue is a common condition for pilots, caused most often by sleep deprivation, weariness or exhaustion linked to long duty hours, or boredom.

Flying when sick naturally inhibits a pilot's cognitive ability to process information and remain perceptive of potential problems. Likewise, flying while taking FAA-approved medication, particularly when not feeling well, is generally not associated with peak performance.

SOCIAL

Yielding to peer pressure is probably the most common social influence that we experience at a young age, but by the time we become adults we are more apt at recognizing the pitfalls of such influences. Still, accidents occur when pilots buckle under overt pressure, many times from nonpilot passengers, to fly in ways they normally would not. The underlying factor that tends to influence these pilots is the concern of looking weak or unable to handle the aircraft in any situation.

Pilots can also be swayed by the subtle pressures of going along with a superior's erroneous decision. Typically, this occurs when a pilot is either unsure of his own perception and judgment of the situation or defers the entire decision-making process to the more experienced pilot, regardless if that person is correctly dealing with the situation.

PERSONALITY AND ATTITUDE

In practice, the influences associated with these two categories become entwined. This is best illustrated by the following compelling exercise, which highlights personality traits and related attitudes and how those thought patterns can negatively affect the judgment and decision-making processes. Although the "wrong" answers may be intuitively obvious or dismissed by reason of, "I'd never do that," everyone has shades of some of these traits and attitudes—whether or not you still act upon them. Thus, the exercise can still be helpful for self-reflection and overall awareness toward certain tendencies.

Hazardous Thought Patterns Exercise

Instructions

1. Read over each of the situations and the choices. Decide which one is the most likely reason why you might make the choice that is described. Place a numeral 1 in the space provided on the answer sheet.
2. Continue by placing a 2 by the next most probable reason, and so on until you have filled in all five blanks with 1, 2, 3, 4, and 5.
3. Fill in each blank in all 10 situations even though you might disagree with all the choices listed. Remember, there are no correct or "best" answers.
   Example:
   __5__ a. (your most likely response)
   __3__ b.
   __1__ c. (your least likely response)
   __2__ d.
   __4__ e.

Attitude Inventory

SITUATION 1

As you near the end of a long flight, your destination airport is reporting a ceiling of 600 feet and 1/2 mile visibility, fog, and haze. You have just heard another aircraft miss the approach [instrument landing system (ILS) minimums are 200 and 1/2]. You decide to attempt the ILS approach. Why do you make the attempt?

____a. Ceiling and visibility estimates are often not accurate.

____b. You are a better pilot than the one who just missed the approach.

____c. You might as well try; you can't change the weather.

____d. You are tired and just want to land.

____e. You've always been able to complete approaches under these circumstances in the past.

SITUATION 2

You plan an important business flight under instrument conditions in an aircraft with no deicing equipment. You'll be flying through an area in which light to moderate rime or mixed icing in clouds and precipitation above the freezing level have been forecast. You decide to make the trip, thinking:

____a. You believe that your altitudes en route can be adjusted to avoid ice accumulation.

____b. You've been in this situation many times and nothing has happened.

____c. You must get to the business meeting in two hours and can't wait.

____d. You do not allow an icing forecast to stop you; weather briefers are usually overly cautious.

____e. There's nothing you can do about atmospheric conditions.

SITUATION 3

You arrive at the airport for a flight with a friend and plan to meet his friend who is arriving on a commercial airplane at your destination. The airplane you scheduled has been grounded for avionics repairs. You are offered another airplane equipped with unfamiliar avionics. You depart on an instrument flight without a briefing on the unfamiliar equipment. Why?

____a. If the avionics are so difficult to operate, the fixed-base operator (FBO) would not have offered the plane as a substitute.

____b. You are in a hurry to make the scheduled arrival.

____c. Avionics checkouts are not usually necessary.

____d. You do not want to admit that you are not familiar with the avionics.

____e. You probably won't need to use those radios anyway.

SITUATION 4

You arrive at your destination airport to pick up a passenger after the fuel pumps have closed. Your calculations before departing determined that there would be enough fuel to complete the trip with the required reserves. The winds on the trip were stronger than anticipated, and you are not certain of the exact fuel consumption. You decide to return home without refueling since:

____a. You can't remain overnight because you and your passenger have to be at the office in the morning.

____b. The required fuel reserves are overly conservative.

____c. The winds will probably diminish for the return trip.

____d. You don't want to admit to your lack of planning in front of anyone else.

____e. It's not your fault the airport services are not available; you will just have to try to make it home.

SITUATION 5

You have been cleared for the approach on an instrument flight rules (IFR) practice flight with a friend acting as safety pilot. At the outer marker, air traffic control (ATC) informs you of a low-level windshear reported for your intended runway. Why do you continue the approach?

____a. You have to demonstrate to your friend that you can make this approach in spite of the wind.

____b. It has been a perfect approach so far; nothing is likely to go wrong.

____c. These alerts are for less experienced pilots.

____d. You need two more approaches to be current and want to get this one completed.

____e. The tower cleared you for the approach, so it must be safe.

SITUATION 6

You are about to fly some business associates in a multi-engine aircraft. You notice a vibration during run-up of the left engine. Leaning the mixture does not reduce the vibration. You take off without further diagnosis of the problem. Why?

____a. You need to be at your destination by five o'clock and are behind schedule. The aircraft can be checked there.

____b. You have encountered the vibration before without any problem.

____c. You don't want your business associates to think you can't handle the aircraft.

____d. The requirement for two perfectly smooth running engines is overly conservative.

____e. The shop just checked this plane yesterday. The mechanics would not have released it if there were a problem.

SITUATION 7

You are in instrument meteorological conditions (IMC) and receiving conflicting information from the two very high frequency omnidirectional radio (VOR) receivers. You determine that the radios are out-of-tolerance and cannot determine your position. You believe ATC will soon suggest that you are off course and request a correction. You are thinking:

____a. Try to determine your position so ATC won't find out that you are lost.

____b. You will continue to navigate on the newer VOR receiver. It should work just fine.

____c. You will get out of this jam somehow; you always do.

____d. If ATC calls, you can be noncommittal. If they knew all, they would only make things worse.

____e. Inform ATC immediately that you are lost and wait impatiently for a response.

SITUATION 8

During an instrument approach, ATC calls and asks how much fuel you have remaining. You have only two minutes before reaching the missed approach point, and wonder why they have inquired as to your fuel status. You are concerned about severe thunderstorm activity nearby and assume that you might be required to hold. You believe that:

____a. Your fuel status is fine, but you want to land as soon as possible before the thunderstorm arrives.

____b. You are in line with the runway and believe that you can land, even in any crosswind that might come up.

____c. You will have to complete this approach; the weather won't improve.

____d. You won't allow ATC to make you hold in potentially severe weather; it's not their neck.

____e. The pilot who landed ahead of you completed the approach without any problems.

SITUATION 9

You are a new instrument pilot conducting an instrument flight of only 20 miles. The turn coordinator in your airplane is malfunctioning. The visibility is deteriorating, nearing approach minimums at your destination. You continue this trip thinking:

____a. You've never had a need to use the turn coordinator.

____b. You recently passed the instrument flight test and believe you can handle this weather.

____c. Why worry about it; ATC will get you out of a bad situation.

____d. You had better get going now before you get stuck here.

____e. Backup systems are not needed for such a short trip.

SITUATION 10

You encounter clear-air turbulence. You are not wearing a shoulder harness and do not put it on. Why not?

____a. Putting on a shoulder harness might give the appearance that you are afraid—you don't want to alarm your passengers.

____b. Shoulder harness regulations are unnecessary for en route operations.

____c. You haven't been hurt thus far by not wearing your shoulder harness.

____d. What's the use in putting on a shoulder harness; if it's your time, it's your time.

____e. You need to maintain aircraft control; there's no time for shoulder harnesses.

Interpreting Your Attitude Inventory

Transfer the numbers from your questionnaire onto the Attitude Inventory Scoring Key (Table 1-1). The higher scores indicate the thought patterns and attitudes that you are susceptible to expressing. Remember, they do not indicate how your attitudes compare with anyone else, and it in no way represents a personality test.

Table 1-1. The Attitude Inventory Scoring Key

SITUATION	SCALE I	SCALE II	SCALE III	SCALE IV	SCALE V	TOTAL
1	a	d	e	b	c	15
2	d	c	b	a	e	15
3	c	b	e	d	a	15
4	b	a	c	d	e	15
5	c	d	b	a	e	15
6	d	a	b	c	e	15
7	d	e	c	a	b	15
8	d	e	c	a	b	15
9	e	d	a	b	c	15
10	b	e	c	a	d	15
Total						150

The sum of your scores across should be 15 for each situation. If it is not, go back and make sure that you transferred the scores correctly and check your addition. The grand total should be 150.

SOURCE: Adapted from the Jensen FAA/DOT Study: Aeronautical Decision-Making—Cockpit Resource Management, January 1989.

The Five Hazardous Thought Patterns

SCALE I: ANTI-AUTHORITY

This attitude is found in pilots who resent any external control over their actions. They have a tendency to disregard rules and procedures. "The regulations and SOPs are not for me."

SCALE II: IMPULSIVITY

This attitude is found in pilots who act too quickly. They tend to do the first thing that pops in their head. "I must act now; there's no time to waste."

SCALE III: INVULNERABILITY

This attitude is found in pilots who act as though nothing bad can happen to them. Many pilots feel that accidents happen to others but never to them. Those who think this way are more likely to take chances and run unwise risks. "It won't happen to me." Famous last words.

SCALE IV: MACHO

This attitude is found in pilots who continually try to prove themselves better than others. They tend to act with overconfidence and attempt difficult tasks for the admiration it gains them. "I'll show you. I can do it."

SCALE V: RESIGNATION

This attitude is found in pilots who believe that they have little or no control over their circumstances. They might feel, "What's the use?" These pilots might also deny that a problem is as it appears and believe, "It's not as bad as they say." It's unlikely that they would take charge of a situation, and they might even go along with unreasonable requests just to be a nice guy. Another common feeling is, "They're counting on me; I can't let them down."

Countering Hazardous Thought Patterns and Attitudes

Granted, we all have bits and pieces of these nasty thought patterns and attitudes; that's what, in part, makes up our individual personalities. But the degree to which we display these patterns, especially in the cockpit, is where the real problem lies. This is how the attitude inventory fits in. One of the best ways to begin eliminating, or at least alleviating, these patterns is by simply recognizing what thought pattern and attitude you are most vulnerable to.

The Hazardous Thought Pattern Exercise

Now that you have a better understanding of the five hazardous thought patterns, try this exercise to test your ability to spot each specific pattern. As we discussed earlier, being able to recognize these attitudes in yourself and others is half the battle. This exercise is also an excellent guide in helping you develop and enhance good judgment abilities. Remember, sound judgment leads to correct decisions.

THE ANTI-AUTHORITY HAZARDOUS THOUGHT PATTERN

From the five choices following each situation, pick the *one* choice that is the best example of an anti-authority hazardous thought pattern. Check your answers before you continue to the next situation. If you don't choose the correct answer, select another until you choose the correct one.

Situation 1

You do not conduct a thorough preflight. On takeoff you notice that the airspeed indicator is not working; nevertheless, you continue the takeoff roll. Your passenger feels strongly that you should discontinue the flight and return to the airport. You then become upset with your friend. Which of the following options best illustrates the *anti-authority* reaction?

a. You tell your passenger to "cool it" for butting in.

b. You start banging on the airspeed indicator to get it working.

c. You think that the preflight check is something thought up by bureaucrats just to waste a pilot's time.

d. You tell the passenger that nothing dangerous will happen on the flight.

e. Your passenger continues to become more upset, but you do nothing, because you feel there is no use trying to calm your friend down.

Response Options

a. *Macho.* By acting in a superior way, you are being macho. “I can do it.” Go back to Situation 1 and select another option.

b. *Impulsive.* By becoming upset and banging on the airspeed indicator, and by not thinking about the situation, you are being impulsive. “Quick! Do something!” Go back to Situation 1 and select another option.

c. *Anti-authority.* Yes. You selected the correct response. Looking at rules and procedures as just a waste of time, instead of taking them seriously, is an indication of an anti-authority attitude. Go on to Situation 2.

d. *Invulnerable.* Thinking that nothing will happen to you shows an invulnerable tendency. Go back to Situation 1 and select another option.

e. *Resignation.* By assuming that what you do has no effect on the passenger, the pilot is illustrating a tendency toward resignation. Go back to Situation 1 and select another option.

Situation 2

You have been cleared for an approach to a poorly lighted airport. You are not sure if this is the airfield where you want to land. The surrounding buildings do not look familiar, but it has been more than a year since your last visit. A much larger, more familiar airport is 15 miles away. Which of the following options best illustrates the *anti-authority* reaction?

a. You decide to land anyway, thinking, “Of course I can handle this situation.”

b. Rather than confuse yourself by thinking about options, you decide to land and get the flight over with.

c. You feel nothing will happen since you have gotten out of similar jams before.

d. You decide to land since the controller cleared you.

e. You decide to land because the regulations do not really apply in this situation.

Response Options

a. *Macho.* Thinking that you can handle the situation, even when there is reason to be concerned, is an example of a macho attitude. Go back to Situation 2 and select another option.

b. *Impulsive.* "Quick! Do something! Anything!" Go back to Situation 2 and select another option.

c. *Invulnerable.* Thinking that nothing will happen to you, even in a problem situation, is illustrating a tendency toward invulnerability. Go back to Situation 2 and select another option.

d. *Resignation.* A pilot with the belief that "the controller is watching over me" has just relieved herself of duty as pilot-in-command. That pilot has given in to the resigning thought of, "What's the use?" Go back to Situation 2 and select another option.

e. *Anti-authority.* Well done. You chose the correct response. Go on to the next hazardous thought exercise.

THE IMPULSIVITY HAZARDOUS THOUGHT PATTERN

From the five choices following each situation, select the *one* option that is the best example of an impulsivity hazardous thought pattern. Check your answers from the response list, and keep selecting until you have made the correct choice.

Situation 1

As you enter the pattern, you normally lower the flaps. The tower suddenly changes the active runway. Distracted, you forget to use the before-landing checklist. On short final you find yourself dangerously low with a high sink rate. Glancing back, you realize that you forgot to extend the flaps. Which of the following options best illustrates the *impulsivity* reaction?

a. You feel that nothing is going to happen because you've made intentional no-flap landings before.

b. You laugh and think, "Boy, this low approach will impress people on the ground."

c. You think that using a checklist is a stupid requirement.

d. You immediately grab the flap handle and add full flaps.

e. You think, "It's all up to whether I get an updraft or downdraft now."

Response Options

a. *Invulnerable.* "Nothing bad can happen to me." Go to Situation 1 and select another option.

b. *Macho.* When you're thinking more about impressing people on the ground than flying the airplane, look out. Go back to Situation 1 and select another option.

c. *Anti-authority.* Thinking that checklists are stupid is an invitation for disaster. Go back to Situation 1 and select another option.

d. *Impulsivity.* You're right. Immediately adding full flaps without thinking about the consequences is a clear example of an impulsive thought pattern. Go on to Situation 2.

e. *Resignation.* The answer's not blowing in the wind; go back to Situation 1 and select another option.

Situation 2

Landing at an unfamiliar airport for fuel, you tell the lineman to "fill it up," and run inside the terminal to use the rest room. Returning, you pay the bill and take off without checking the aircraft, the fuel caps, or the fuel. Which of the following options indicates an *impulsivity* reaction?

a. You feel that it's a silly requirement to preflight an aircraft which you've just flown.

b. You just want to get under way, quickly.

c. You know that you have skipped preflights before and nothing bad ever happened.

d. You have every confidence that a pilot with your skill level could handle, in flight, anything that might have been overlooked on the ground.

e. You feel that since you paid top dollar for the fuel, it's the responsibility of the lineman to ensure the airplane was refueled properly.

Response Options

a. *Anti-authority.* Thinking that regulations requiring a preflight inspection are nonsense suggests a definite anti-authority attitude. Go back to Situation 2 and select another option.

b. *Impulsivity.* Bingo. Having that itch to get a move on shows great impulsivity. Go on to the next hazardous thought exercise.

c. *Invulnerability.* Just because you got away with it before doesn't mean that it's safe. "It won't happen to me." Go back to Situation 2 and select another option.

d. *Macho.* Even though you might think, "I can do it," you'll find yourself turning gray by your 25th birthday. Go back to Situation 2 and select another option.

e. *Resignation.* Feeling that everything is up to someone else is a resigning attitude. Go back to Situation 2 and select another option.

THE INVULNERABILITY HAZARDOUS THOUGHT PATTERN

From the five choices following each situation, select the *one* option that is the best example of an invulnerability hazardous thought pattern. Check your answers with the appropriate response list, and keep selecting until you have made the correct choice.

Situation 1

You are making a pleasure flight with four friends, all of whom are drinking. You refuse to drink, but your friends remind you that you have flown this route many times and that the weather conditions are excellent. They begin to tease you for not drinking with them. Which of the following options best illustrates the *invulnerability* reaction?

a. You decide to drink, thinking that a little liquor will not have any bad effect on you.

b. You believe that the government is far too rigid in its regulations about drinking and flying.

c. You resent your friends' insults and start drinking, saying to yourself, "I'll show them."

d. You bend to their will saying to yourself, "If my time is up, it's up whether I drink or not."

e. You suddenly decide to take a drink.

Response Options

a. *Invulnerability.* You are correct. Liquor affects everybody, and pilots who believe that it will not bother them, consider themselves invulnerable. Go on to Situation 2.

b. *Anti-authority.* Considering the authority of the government as too rigid is another way of thinking, "Those rules are much more strict than they need to be, so I can disregard them." Go back to Situation 1 and select another option.

c. *Macho.* The need to prove yourself, or show off to total strangers, is definitely a macho thought pattern. Go back to Situation 1 and select another option.

d. *Resignation.* Thinking that you have nothing to do with the outcome of a flight is a resigning attitude. Go back to Situation 1 and select another option.

e. *Impulsivity.* Making the foolishly sudden decision to drink is an impulsive thought pattern. Go back to Situation 1 and select another option.

Situation 2

The control tower advises you to land on a runway other than the one you prefer. You see larger planes using the runway of your choice and wonder why you have been denied permission. Since the tower-recommended runway is on the far side of the airport, you radio the tower and ask for reconsideration. Which of the following options best illustrates the *invulnerability* reaction?

a. Before you receive a reply, you start making your approach to the unauthorized runway.

b. You feel that if other pilots can land their airplanes on the other runway, so can you.

c. You think that nothing dangerous will occur because you believe wake turbulence is very unlikely.

d. Regardless what the tower tells you, you are going to do what you want to.

e. You figure there is no sense in waiting for instructions because the tower is going to do whatever it pleases, regardless of your wishes.

Response Options

a. *Impulsivity.* Rushing into an action without thinking about the consequences is an impulsive attitude. Go back to Situation 2 and select another option.

b. *Macho.* Thinking that you can do anything, anytime, anywhere, with any configuration is a macho attitude. Go back to Situation 2 and select another option.

c. *Invulnerability.* This is the correct response. Disregarding a potentially hazardous situation, like wake turbulence, and thinking there's nothing to worry about is an invulnerable thought pattern. Go on to the next hazardous thought exercise.

d. *Anti-authority.* "I'll do what I want to do" regardless of the consequences is an anti-authority thought pattern. Go back to Situation 2 and select another option.

e. *Resignation.* Believing that nothing you do will make any difference is a resigning attitude. Go back to Situation 2 and select another option.

THE MACHO HAZARDOUS THOUGHT PATTERN

From the five choices following each situation, select the *one* option that is the best example of a macho hazardous thought pattern. Check your answers from the appropriate response list, and keep selecting until you have made the correct choice.

Situation 1

Visibility is barely more than 3 miles in blowing snow with a 1000-foot ceiling. Earlier you cleared the airplane of snow, but takeoff has been delayed for 15 minutes. Snow and ice are forming again, and you wonder if you will be able to take off. Which of the following options best illustrates the *macho* reaction?

a. You feel that there is no use getting out and removing the snow since it's only going to form again.

b. You believe that you can take off in these conditions and think of how impressed your friends will be when they hear of it.

c. You take off immediately, thinking that any further delay will worsen the problem.

d. You reason that you can do it because other pilots have done it and nothing happened to them.

e. You resent being delayed 15 minutes and decide you are not going to clear the snow and ice again for anybody.

Response Options

a. *Resignation.* When you don't think what you do affects what happens, you are displaying a resigning thought pattern. Go back to Situation 1 and select another option.

b. *Macho.* Correct. You want to show off to others and want to prove yourself. Definitely a macho attitude. Go on to Situation 2.

c. *Impulsivity.* You take off immediately. No thinking and no planning show a great impulsive thought pattern. Go back to Situation 1 and select another option.

d. *Invulnerability.* "Nothing happened to them, so nothing will happen to me." Go back to Situation 1 and select another option.

e. *Anti-authority.* Pilots who resent using appropriate safety precautions show an anti-authority attitude. Go back to Situation 1 and select another option.

Situation 2

The weather forecast calls for freezing rain. En route you notice ice accumulating on the wings. You are not sure what to do because you have never encountered this problem before. Because the airplane is still flying well, you are tempted to do nothing. A passenger suggests you might radio for information. Which of the following options best illustrates the *macho* reaction?

a. You feel that there probably will not be any problem since you have always come out of difficult situations rather well.

b. You feel that there is nothing you can really do because radio information won't change the weather conditions.

c. You quickly tell the passenger to stop butting in.

d. You tell the passenger that you are the boss and will handle the problem your way.

e. You radio for information but decide to ignore the advice since the airplane continues to fly well enough.

Response Options

a. *Invulnerability.* When you think that since nothing has ever happened before, nothing will happen in the future, you're displaying an invulnerable thought pattern. Go back to Situation 2 and select another option.

b. *Resignation.* "What's the use?" Go back to Situation 2 and select another option.

c. *Impulsivity.* Acting without thinking is impulsive. Go back to Situation 2 and select another option.

d. *Macho.* This is the correct answer. "We'll do it my way" is a good indication of a macho attitude. Go on to the next hazardous thought exercise.

e. *Anti-authority.* Those who ignore information or advice show an anti-authority attitude. Go back to Situation 2 and select another option.

THE RESIGNATION HAZARDOUS THOUGHT PATTERN

From the five choices following each situation, select the *one* option that is the best example of the resignation hazardous thought pattern. Check the answers from the appropriate response list, and keep selecting until you have made the correct choice.

Situation 1

You would like to arrive early for an important business meeting. If you stick to your flight plan, you will just about make it, assuming there are no problems. Or, you can take a route over the mountains, which will get you there much earlier. If you choose the route through the mountain passes, it means you might encounter low hanging clouds while good weather prevails over the planned route. Which of the following options best illustrate the *resignation* reaction?

a. You take the mountain route even though the weather briefer has advised against it.

b. You take the mountain route, thinking that a few clouds in the passes will not cause any trouble for this flight.

c. You feel it will be a real victory for you if you can take the mountain route and arrive early.

d. You tell yourself that there is no sense sticking to the planned route because "There's nothing else to do to be sure to make it early."

e. You quickly choose the mountain route, deciding that you just must get there early.

Response Options

a. *Anti-authority.* Not accepting the advice of a weather briefer is an example of an anti-authority attitude. Go back to Situation 1 and select another option.

b. *Invulnerability.* "It won't happen to me." Go back to Situation 1 and select another option.

c. *Macho.* Making potentially dangerous situations into personal challenges is a macho thought pattern. Go back to Situation 1 and select another option.

d. *Resignation.* Good choice. Thinking that there is nothing you can do is an example of a resigning thought pattern. Go on to Situation 2.

e. *Impulsivity.* A quick decision isn't always the right decision. Go back to Situation 1 and select another option.

Situation 2

The weather briefer advises you of possible hazardous weather conditions at your destination, but you elect to go anyway. En route you encounter a brief snowstorm and increasingly poor visibility. Although you have plenty of fuel to return to your departure point, you have a hunch that the weather will improve before you reach your destination. Which of the following options best illustrates the *resignation* reaction?

a. You feel there is no need to worry about the weather since there is nothing one can do about Mother Nature.

b. You immediately decide to continue, and block the weather conditions out of your mind.

c. You feel nothing will happen to you since you have plenty of fuel.

d. You think that the weather people are always complicating your flights, and sometimes, such as now, it's best to ignore them.

e. You fly on, determined to prove that your own weather judgment is better than the forecaster's.

Response Options

a. *Resignation.* You picked the correct answer. A "what will be, will be" attitude in the cockpit can get you killed.

b. *Impulsivity.* Quickly blocking important matters out of your mind is impulsive. Go back to Situation 2 and select another option.

c. *Invulnerability.* Having plenty of fuel does not mean that all is well in the world. Go back to Situation 2 and select another option.

d. *Anti-authority.* Disregarding sound advice is the same as ignoring regulations. They're both an anti-authority thought pattern. Go back to Situation 2 and select another option.

e. *Macho.* Showing off again. Go back to Situation 2 and select another option.

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CHAPTER 2

Accurate Situation Assessment Leads to Good Situation Awareness

Situation assessment—a process of recognition and evaluation through monitoring and challenging—leads to good situation awareness. Much research and attention have been directed to monitoring and challenging errors on accident flights. One such study conducted by the National Transportation Safety Board (NTSB) states that a significant factor in accidents is attributed to "inattention due to poor monitoring vigilance." The same study cites a nearly 80 percent monitoring and challenging error rate during the approach-to-landing phase of flight. Why then, with the increased focus on monitoring and challenging vigilance do pilots still find themselves in precarious, or far worse, situations? The premise is quite simple: Monitoring is effective only if pilots recognize and understand the accuracy, or inaccuracy, of what they are monitoring. Thus, a more accurate description of monitoring is situation assessment—a process of recognition and evaluation—much like the fundamental skills associated with judgment and decision-making discussed in Chap. 1. Quality situation assessment further depends on the appropriate challenging of events or behavior detrimental to the safety of a flight.

Accurate and timely situation assessments are achieved by attentive perception and recognition skills and the full comprehension of the nature of a problem through processing knowledge and critical

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thinking. Vigilant monitoring skills and appropriate challenging techniques are traits that intrinsically prudent aviators routinely rely upon, and are valuable lessons for all aviation professionals.

Phase 1: Recognition

When pilots become distracted or are otherwise inattentive to assessment vigilance, they are far less likely to recognize potential problems—that is intuitively obvious. Astute pilots will remedy problem situations immediately. The broader concern is whether or not pilots recognize potential problems during routine situation assessments. Are they actively observing the progress of the flight and recognizing the accuracy of individual occurrences or are they unwittingly watching and not comprehending the dynamic flow of events? This is an important distinction that is often overlooked.

National Aeronautics and Space Administration (NASA) researchers support the importance of recognition by noting that the initial *perception of cues* that signal a problem drives the situation assessment process. Failing to recognize these cues prevents timely and accurate evaluation, thereby allowing manageable problems to escalate.

Early warning signs, or cues, are frequently missed because pilots do not recognize the significance of specific cues. For example, a common mistake some multi-engine pilots make is misinterpreting "matched needles" as correct instrument readouts. This was true in the case of the 1982 crash of Air Florida Flight 90. Ice blocked both engines on the B-737 as indicated by the lower than normal readouts of the engine and fuel flow instruments. If the flight crew had comprehended the readouts as erroneous—rather than scanning over the matched needles—the crash would most assuredly have been averted.

Phase 2: Evaluation

Carefully evaluating a problem once it is recognized can only be achieved if the pilot *understands the nature* of the problem. Thus, the combination of recognition and evaluation are essential to timely and accurate situation assessment. As in the case of Air Florida Flight 90, the flight crew failed to recognize the erroneous instrument readouts because they did not understand the nature of the problem—ice blocking the compressor inlet (Pt2) and the Pt2 probe in both engines. The operations manual for the B-737 clearly states, in part, that the engine pressure ratio (EPR) instrument will show erratic fluctuations as the Pt2 probe is icing over; and those fluctuations will cease when the Pt2 probe becomes solidly blocked with ice. The first officer was apparently confused and unsure of the cause of those anomalies, as reflected by numerous comments he made during taxi and takeoff. The captain remained mostly silent during this time except for an occasional utterance which further confused the situation.

After observing many flight crews in full-mission simulations, NASA researchers noted that the "quality of decision making depended on the quality of a crew's understanding of the problems they faced." They further reported that only through "active monitoring and information gathering [were pilots] assured an accurate and updated definition of the situation."

Situation Awareness through Monitoring and Challenging

At the end of this linear process is situation awareness—the by-product of situation assessment. Good situation awareness—similar to the ability to distinguish between correct and incorrect alternatives to a solution—occurs when a pilot accurately perceives his surroundings, decides how to manage those external factors, and then takes the best course of action. The most proactive means to achieve situation awareness is by appropriately monitoring and challenging routine and relevant events.

In an attempt to understand the factors that contribute to monitoring and challenging errors, researchers from NASA and the Georgia Institute of Technology conducted several unique studies that concentrated on the interplay between flight crew position and communication.

Researchers developed a simulator study, enlisting Boeing 747-400 pilots to fly full-mission flight scenarios. In each two-person crew, one study-subject pilot flew with a trained research pilot who assumed the role of either captain or first officer, depending on the actual status of the study-subject pilot. Once under way, the research pilot introduced a variety of errors into the mission that were monitoring and challenging related. Errors committed by the research pilot—lapses in skill and judgment—necessitated a direct challenge from the study-subject pilot, creating a potentially "threatening" confrontation between the captain and first officer. As a result, the lowest error-detection rate (~35 percent) occurred when first officers (study-subject pilots) faced high-challenging threats while in high risk to flight safety situations. This suggests that because of a fear of the social ramifications associated with challenging a captain's skill or judgment a first officer may not challenge a captain even when the safety of the flight is at risk.

Conversely, first officers (study-subject pilots) in this study had their highest error-detection rate (~90 percent) when confronted with low-challenging-threat sources, such as air traffic control. This outcome was true during high risk to flight safety situations. A low-challenging threat combined with a low risk to flight safety situation produced an error-detection rate slightly below 50 percent. These data suggest that first officers may be less reluctant to challenge an error when the social threat of that challenge is low. Most compelling is the notion that real or perceived implications of challenging a captain are so great that a first officer may ineffectively communicate in a high risk to flight safety scenario.

Researchers noted that study-subject pilots who were captains were more likely to detect and correct errors than first officers; and they were apt at being proactive in high risk to flight safety situations. In many cases, the preemptive actions of the study-subject captains prevented potentially serious situations from occurring. In this study, the error-detection rate for captains in a high-challenging-threat, high risk to flight safety scenario was ~60 percent. For a low-challenging-threat, high risk to flight safety scenario, it was ~75 percent. In contrast, the error-detection rate for a high-challenging-threat, low risk to flight safety scenario was equal to the first officer's rate at ~50 percent. For a low-challenging-threat, low risk to flight safety scenario, it was close to 70 percent.

The overall error-catch rate for first officers and captains—when factoring each combination of challenging threat and level of risk to the safety of the flight—was approximately 62 percent. Researchers interviewed the study-subject pilots at the conclusion of the simulator study to gather their reasons as to why they missed certain types of errors or failed to challenge them.

The captains had a higher incidence of admitting that they noticed a problem but tended to minimize its severity and thus said nothing to their first officers—likewise, first officers were prone to the same reaction, albeit at a slightly less rate of incidence. First officers were most likely to explain that company procedures were the cause of their lack of responses, but both first officers and captains gave this reason substantially more often than any other.

The NASA report on situation awareness dovetails with an NTSB safety study that reviewed the causes of flight crew–involved major U.S. air carrier accidents occurring from 1978 through 1990. The NTSB cites that the causal and contributing factors associated with the majority of fatal air carrier accidents were the result of actions or inactions by the flight crew. Specifically, of the 302 errors identified in the 37 accidents analyzed, the NTSB determined that 84 percent were monitoring and challenging errors; 90 percent of those were challenging errors that were causal or contributing to the accident. It is important to note that none of the flight crews was handling an emergency at the time the error occurred in the accidents reviewed—all were routine flights.

The NTSB study also cited that nearly 80 percent of the monitoring and challenging errors occurred during the approach-to-landing phase of the flight and by first officers who were the nonflying pilots on that flight segment. Overall flight experience or hours in the accident aircraft were not recognized factors. For the majority of accident flights, the NTSB identified two significant breakdowns in situation assessment: (1) inattention due to poor monitoring vigilance, and (2) errors in decision-making that went unchallenged by the nonflying pilot. In many cases, the captains on these accident flights flew an unstabilized approach, which resulted in excessive airspeed and a subsequent runway overrun landing. With few exceptions, the nonflying first officers never commented on either the unstabilized approach or excessive airspeed—final-approach airspeeds that in some instances were 50 to 60 knots too high.

The SOPs of most major air carriers define the methods of monitoring flight crew actions. Yet, a "failure to execute a go-around or missed approach during an unstabilized approach" was the most common of tactical errors committed by the flying pilot. Tactical decision errors (e.g., improper decision making, failure to change course of action), and situation awareness errors (e.g., improper descent before being established on the localizer, failure to establish a time limit for beginning approach) accounted for over 58 percent of those errors that went unchallenged by the nonflying pilot. Though prescribed in SOPs, it is clear that monitoring without appropriate challenging is an ineffective method to inhibit costly flight mistakes.

Airborne Express DC-8—
Breakdown in Situation Awareness

The accident sequence of an Airborne Express DC-8 presents a unique example of the futility of monitoring when a flight crew does not recognize nor understand the nature of a problem. According to Code of Federal Regulations (CFR) Part 91.407, a functional evaluation flight (FEF) is required following maintenance "that may have appreciably changed [the airplane's] flight characteristics or substantially affected its operation in flight…" Following major modifications on the DC-8 (cockpit, avionics, cargo handling system, and engine upgrades for stage III noise level requirements) at an FAA-certified repair station, Airborne Express scheduled a routine FEF.

A hydraulic system malfunction on the airplane pushed the FEF back a day, and additional maintenance problems further delayed the flight several hours from a daytime departure to the early evening. The flight eventually departed Greensboro, North Carolina, at 1740 (Eastern Standard Time) and arrived five minutes later at their preassigned block altitude of 13,000 to 15,000 feet. They received an instrument flight rules (IFR) clearance to fly their two-hour planned route over parts of West Virginia, Kentucky, and Virginia.

Shortly after leveling off, the flight crew remarked that the airplane had flown briefly in and out of the clouds at the same time they encountered ice buildup. Ground Doppler radar showed a scattered area of light rain along the airplane's flight path, in addition to cloud tops ranging between 13,100 and 13,500 feet. The upper freezing level in the accident area was about 7,600 feet.

Several minutes after the pilot-flying (PF) commented that "we just flew out of it [ice]…," the flight crew performed landing gear, hydraulic, and engine system checks. At 1805, the flight engineer said, "Next thing is our stall series." According to Airborne Express, the purpose of the stall series was to verify the integrity of the airplane's flight characteristics, specifically the flight control surfaces (flaps and ailerons), and to check the operation of the stall warning and stick shaker systems. The flight engineer used an evaluation flight profile form required to identify and record the speed at which the stick shaker activated and the speed of the stall.

Beginning around 1805, the entire flight crew engaged in a couple minute discussion concerning stall-entry techniques and how the data would be recorded on the form. At 1807:51, the PF and pilot-not-flying (PNF) attempted to coordinate the onset of a stall using pitch-up control inputs and increased engine power settings (to provide adequate acceleration during the stall recovery). Seconds later, the PF announced "some buffet" (at 151 knots) and the PNF noted how quickly it had occurred. Rattling sounds were heard on the cockpit voice recorder (CVR), and at 1808:11, the flight engineer said, "That's a stall right there …no [stick] shaker" (at 145 knots). The PF called, "Set max power," which was followed by several seconds of popping sounds. According to the Safety Board, the flight crew had recognized the incipient stall and the PF made a timely decision to terminate the "clean" stall and begin the stall recovery. However, from 1808:13 through 1808:21, the PF maintained the airplane's pitch attitude between 10 and 14 degrees nose up as the airspeed continued to decrease resulting in the airplane entering into a fully developed stall. The PF never eased on the pitch angle which placed the airplane deeper in the stall. The Safety Board believed that if the flight crew had been monitoring the airspeed indicator, vertical speed indicator, and altimeter, they would have recognized the sizable sink rate and, most importantly, the stall.

The airplane began a series of roll reversals and remained in an aerodynamic stall all the way to impact because the PF held significant back pressure on the control column. Each time the airplane encountered a large nose-down pitch rate (combined with airspeed reductions), the PF responded with additional back pressure. The appropriate pilot response to a stall is forward movement of the control column.

The airplane struck mountainous terrain in a 52-degree left wing low and 26-degree nose-down attitude. The stall sequence—from the initial buffet to impact—took 1 minute and 32 seconds. There was no evidence of flight control jams or malfunctions.

In part, the Safety Board determined that the probable causes of this accident were the inappropriate control inputs applied by the PF during a stall recovery attempt and the failure of the nonflying pilot in command (PIC) to *recognize, address,* and *correct* these inappropriate control inputs.

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CHAPTER 3

Crew Resource Management: The Integration of Interpersonal Skills and Technical Proficiency

I am firmly convinced that CRM played a very important part in our landing at Sioux City with any chance of survival.
Capt. Alfred C. Haynes, United Airlines Flight 232, 1989

The broad objective of crew resource management (CRM) training is to enhance the decision-making process by improving the performance of flight crews, specifically in the areas of interpersonal communication, teamwork, and leadership. In effect, CRM blends the judgment and decision-making skills and personality traits and attitudes of the individual pilot with those of other pilots in a group dynamic. The interpersonal aspect of CRM is ultimately integrated with a pilot's technical proficiencies—flying skills and aeronautical knowledge.

A disruption or breakdown of any component of CRM will interrupt a flight crew's performance and negatively affect the safety of that

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flight. The old adage, "A team is only as effective as its weakest member," is unacceptable for a flight crew.

Interpersonal Communication

As discussed in Chap. 1, acquiring and processing information are essential to good judgment and decision-making. The following are key steps in achieving quality interpersonal communication in a CRM environment.

1. *Inquiry.* A request for information, a systematic investigation of information
2. *Advocacy.* An assertiveness to state facts or express feelings
3. *Active listening.* To vigorously participate in the collection of information, including open discussion, acknowledging ideas, and agreeing or disagreeing with the presented facts and opinions
4. *Conflict resolution.* To determine the causes of conflict and appropriately establish the correct course of action
5. *Critique.* To properly evaluate personal performance and the overall situation through feedback

Crew Effectiveness

To assist flight crew members in their understanding and practice of CRM, many airlines have developed checklists that identify important components of CRM. Continental Airlines, for example, structured its checklist with crew effectiveness markers—a format of concise points to remember.

Overall Technical Proficiency

- Set a professional example.
- Adhere to SOP, FARs, sterile cockpit, etc.
- Demonstrate high level of flying skills.
- Be adept at normal and abnormal procedures.
- Maintain thorough systems knowledge.

Briefing and Communication

- Set an open tone.
- Fully brief flight crew and cabin crew on operational/safety issues.
- Explicitly encourage participation.
- All are obligated to seek and give information.
- State how SOP deviations will be handled.
- Include cabin crew.

Leadership and Teamwork

- Balance authority and assertiveness.
- Promote continual dialogue.
- Adapt to the personalities of others.
- Use all available resources.
- Must share doubts with others.

Situational Awareness

- Monitor developments (fuel, weather, ATC, etc.).
- Anticipate required actions.
- Ask the right questions.
- Test assumptions, confirm understanding.
- Monitor workload distribution and fellow crew members.
- Report fatigue, stress, and overload in self and others.

Decision-Making

- Fly the aircraft.
- Obtain all pertinent information.
- All crew members should state recommendations.
- Better idea suggested? Abandon yours.
- Clearly state plan or intentions.

- Establish "bottom lines."
- Resolve conflicts and doubts quickly.

Crew Self-Evaluation

- Debrief key events.
- Continuously provide information to self-correct.
- Openly discuss successes and mistakes.
- Ask, "How could we have done better?"
- Discuss what is right, not who is right.

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CHAPTER 4

Spatial Disorientation

The Air Safety Foundation of the Aircraft Owners and Pilot's Association reports that 90 percent of spatial disorientation accidents are fatal! Spatial disorientation is a person's inaccurate perception of her position, attitude, and motion or acceleration with respect to the earth—confusion with regard to her positional relationship to the actual environment. Furthermore, spatial disorientation can be recognized or go unrecognized by the affected person. In some severe cases, even if recognized, the pilot may not be able to recover due to physiological and emotional forces. Generally, however, if a case of spatial disorientation is recognized early, it is more likely to be survivable. Therefore, a discussion of spatial disorientation is important to any study of aircraft or aviation safety.

Flying is not a natural state for the human body—we were not designed to fly. In fact, many of our instincts and senses may become confused during the "unnatural" act of flying. There are several reasons for this confusion, such as angular acceleration, linear acceleration, vibration, unique light and motion perceptions, and movements complicated by the human brain's penchant for being tricked into believing what it expects to see versus what is actually happening to it. These and other causalities may create conditions where the human brain and the human body are reacting differently or unexpectedly, resulting in a breakdown in the mind-body interface. This breakdown can result in consequences from momentary misperception to complete disorganization of thinking and perception, resulting in an aircraft accident caused by spatial disorientation.

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It is important for aviation professionals to be aware of the possibilities of spatial disorientation. The positive effects of increased awareness; new and better instrumentation; improved placement of controls and equipment in the aircraft; attention to detail in the cockpit; reduced incidence of unrecognized spatial disorientation through better recognition of its onset by pilots; and recognition of the conditions that encourage or exacerbate the possibility of spatial disorientation can help pilots and air traffic managers cooperate to avoid or safely handle potentially disorientating situations. Therefore, to increase the safe interface of humans and aircraft, it is worthwhile to have a working knowledge of spatial disorientation. To this end, this chapter focuses on the visual and vestibular senses, illusions pervasive in spatial disorientation studies, and prevention issues.

Senses and Spatial Orientation

Spatial disorientation is generally a result of information provided by the sensory organs—eyes, inner ears, and proprioceptors or the somatosensory system ("seat of the pants")—being misinterpreted by the brain. These sensory organs detect linear acceleration; angular acceleration in the pitch, yaw, and roll axes; a simultaneous change in both direction and speed; radial or centripetal acceleration (which is a change in direction without a change in speed that can occur during sustained, level, constant-speed turns); and changes in visual, auditory, and other muscular or body cues. The direction of motion and acceleration (and gravity) on the human body, and the brain's perception of those sensations, combine to produce a certain perception of the world, a frame of reference.

The normal forward, backward, up, and down motions that a person is comfortable with are complicated by roll, pitch, and yaw, which provide angular acceleration. Furthermore, acceleration due to thrust—linear acceleration—may be perceived as the "eyeballs in" feeling associated with forward acceleration or the "eyeballs out" feeling caused by deceleration, or rapidly slowing down without a change in direction. Additionally, gravity provides another complicating factor. Although it is an acceleration humans are comfortable with and expect, gravity may provide confusion when combined with strange body positions and accelerations experienced in flight, such as inverted flight or a constant turn over a long period of time.

Basic physiological mechanisms that commonly describe the primary human sensors affecting a pilot's perception of his environment include visual, vestibular, auditory, and proprioceptive or somatosensory. Many experts believe that vision is the most important sense that helps humans maintain their orientation in a world of sensory stimulation, particularly in flight operations. In any case, the visual and vestibular systems are closely linked and their interaction produces common sensory illusions for pilots. Moreover, the proprioceptive or somatosensory system, comprised of reactions and perceptions gained from interpreting changes of pressure on joints, muscles, bones, ligaments, internal organs, and the skin, is closely associated with the vestibular system and somewhat to the visual system. However, all the senses can contribute to confusing aviators due to the inherently unnatural environment of humans in flight.

Visual and Vestibular Senses

Humans generally have both object recognition capabilities and spatial orientation aspects to their vision. Focal vision is the mode that processes object recognition. Think of it as answering the question, "What am I looking at?" This is generally the center 30 degrees of the visual field for each eye and helps humans orient themselves with respect to an object. Ambient vision, in contrast, helps humans orient themselves to their environment by answering the question, "Where am I?" Ambient vision is typically peripheral vision, and testing has shown that it is largely independent from focal vision.

The ability to move our eyes helps humans maintain visual orientation in normal and unusual situations. Because we can move our eyes, we can orient ourselves in a dynamic and rapidly changing environment. Saccadic, or jerky, eye movements are generally involuntary and used to find an object, while smooth eye movements are used to track objects. Humans also have a visual-vestibular convergence, or a connection between processing of visual stimulation and the inner ear's sensory input to the brain telling a human where his or her body is in three dimensions with respect to the effects of acceleration.

The vestibular system is important for spatial reference and is closely linked with vision. It is responsible for maintaining balance and equilibrium and coordinates inputs from the inner ear, eyes, and muscles in the neck, trunk, and limbs. The vestibular organs in the inner ear are roughly less than the size of a matchbook, and the brain determines the body's position by sensing the motion of fluid within the organs of the inner ear.

Three main parts make up the vestibular bony labyrinth: the cochlea, the vestibule, and the semicircular canals (see Fig. 4-1). The cochlea converts sound to impulses sent to the brain. The vestibule contains the two otolith sensory organs, the utricle and saccule. These otolith organs respond to gravity and linear acceleration, telling the brain information about head tilt and lateral motion. The semicircular canals sense changes in angular acceleration in roll, pitch, and yaw through recognizing the movement of a fluid, perilymph, which moves in response to acceleration. The movement of this fluid stimu-

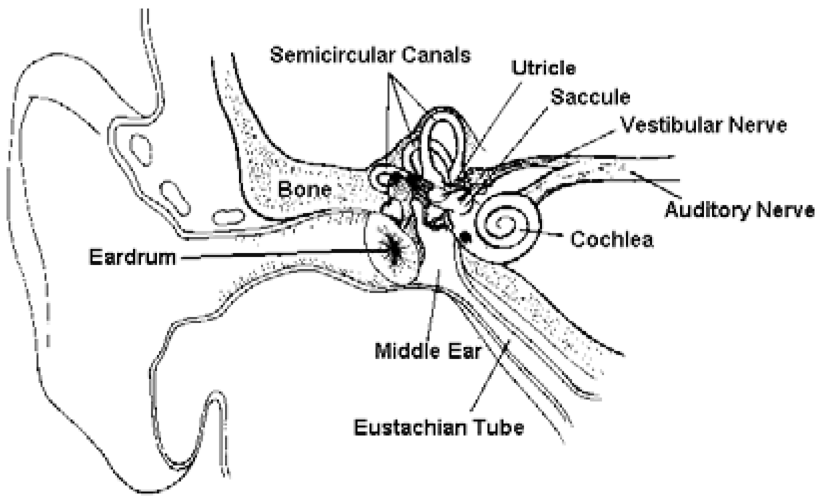

Fig. 4-1. Inner ear or labyrinth.

lates the cilia, the tips of small hair-cells in the inner ear. The motion of the cilia provides sensory clues to the brain. These clues are merged with visual and cognitive cues and give the pilot an idea of her position in three-dimensional space.

However, because flying is unnatural to the human sensory system, there may be enough difference between what the brain expects and contrasting sensory inputs from the visual and vestibular systems that a pilot becomes confused or disoriented. Yet, through recognizing the possible misinterpretation of the senses in the visual and vestibular realms, it is possible to train pilots to accurately interpret and rely on their flight instruments. By recognizing a sensory illusion or spatial disorientation, a pilot can take corrective action. The 90 percent fatality figure for aircraft accidents caused by spatial disorientation is considerably related to the lack of proper recognition of spatial disorientation or lack of proper (or late) corrective actions. Therefore, recognition can mitigate the effects of a pilot's unique environment and ultimately enhance aircraft safety.

Sensory Illusions

The leading cause of spatial disorientation episodes are illusions that originate from motion-sensing systems in each inner ear. The combination of in-flight motion and head and body movements can create hazardous illusions. There are dozens of illusions involving a combination of numerous conditions and mistaken sensory cues. This section introduces and discusses several common illusions.

Vestibular Illusions

SOMATOGYRAL ILLUSIONS

Somatogyral illusions occur when angular acceleration stimulates the cilia in the semicircular canals. This creates a false sensation for the pilot of rotation along one or more of the aircraft's axes when the aircraft is not actually experiencing that action or of the absence of rotation when the aircraft is in fact rotating on at least one axis. Some common somatogyral illusions are presented here.

Graveyard Spiral

The fluid in the inner ear will stop moving in a prolonged, coordinated constant-rate turn with at least moderate or greater bank. In the absence of any sensation of motion, a pilot will have the illusion of a wings-level descent when the aircraft is actually in a tightly descending turn. The pilot may pull back on the controls and perhaps add power to level off or to regain altitude. In reality, with those actions, the pilot just tightens the descending spiral. If the pilot successfully stops the spiral, he will likely have the sensation of turning in the opposite direction. If the pilot fails to recognize this situation, he may reenter the spiral.

Graveyard Spin

Similar to the spiral, when in an intentional or unintentional spin for several seconds, the sense of motion will reach equilibrium and no motion will be perceived. Then, after successfully recovering from the spin, the deceleration sensed by the change in fluid direction in the semicircular canals causes the perception of entering a spin in the opposite direction. Without proper reference to the horizon, ground references, and flight instruments, the pilot may reenter the spin in the original direction. This was a killer of several World War I era pilots, who, without good instrumentation, frequently penetrated a cloud layer by putting the aircraft into a spin, recovering after emerging beneath the clouds. With insufficient visual references, they reentered the spin with too little altitude remaining for recovery.

Coriolis Illusion

Some consider this the most dangerous of the vestibular illusions because it can create tremendous disorientation and may be difficult to counteract even if recognized. During a prolonged climbing or descending turn, the fluid in the affected semicircular canal reaches equilibrium and the pilot perceives a steady state of acceleration. An abrupt head movement made during a prolonged constant-rate turn sets the fluid in all the canals in motion. This can create the strong illusion of turning or accelerating in an entirely different axis or maybe different perceptions of movement in all axes at once. The pilot can erroneously maneuver the aircraft in an attempt to correct this illusionary movement, causing further accelerations, leading to further confusion between visual references, flight instruments, and vestibular sensations.

The Leans

The leans are probably the most common vestibular illusion, particularly at night, and may last several seconds, even if recognized. In a prolonged bank, the fluid in the inner ear can reach equilibrium. Upon rolling out of the bank, the abrupt change in attitude can set the inner ear fluid in motion, creating an illusion for the pilot that she is banking in the opposite direction. The pilot will feel compelled to "lean" in the intended direction, banking the aircraft to "correct" the misperception. In reality, the aircraft never physically banked in the opposite direction, so the pilot in reality overbanks the aircraft. Experienced pilots safely fly through the leans by referencing their flight instruments or using a reference outside of the cockpit, such as the horizon.

SOMATOGRAVIC ILLUSIONS

Somatogravic illusions occur when linear acceleration stimulates the otolith organs. These illusions are characterized by the pilot sensing a change in attitude during acceleration or deceleration. Some common somatogravic illusions are presented here.

Oculogravic

When an aircraft accelerates ahead in a linear plane, such as when pushing forward throttles while maintaining a steady altitude, the inertia from the linear acceleration causes the otolith organs to sense that the nose is climbing. Visual cues outside the flight deck can mitigate this illusion. Without good visual cues, like a clearly defined horizon or focusing proper attention on the flight instruments, a pilot may push forward on the stick or yoke when feeling the climb sensation during acceleration and inadvertently place the aircraft in a dive. On the other hand, if the pilot rapidly decelerates, such as when extending a speed-brake, he may see his instruments appear to move down as his eyes move up, and he will experience a feeling of a nose-down pitch.

The pilot will then sometimes pull back against the illusion and actually unintentionally climb. This oculoagravic illusion can be considered a visual component adding to the somatogravic sensation of tilting forward (diving) during deceleration or back (climbing) during acceleration.

Elevator Illusion

An abrupt upward vertical acceleration (such as in an updraft) can shift a pilot's vision downward, through the effects of inertia on the eyes. Simultaneously, the visual reference moves upward. This can create the illusion of climbing, and the pilot may push the aircraft into a nose-low attitude. Some experts do not consider this a somatogravic illusion although the otolith organs are affected in the inner ear.

Inversion Illusion

This is a very disconcerting type of somatogravic illusion. An abrupt change from climb to straight-and-level flight can excessively stimulate the sensory organs for gravity and linear acceleration, creating the illusion of tumbling backward. The pilot may push the control yoke or stick forward, causing the aircraft to dive abruptly in a nose-low attitude.

Nystagmus

Violent and abrupt angular accelerations, like those felt by the pilot entering into a spin or during certain aerobatic maneuvers, like maximum deflection aileron rolls, can result in the vestibular system being unable to stabilize vision. During and for a short time after such maneuvers, the eyes may oscillate uncontrollably (nystagmus). In certain unfavorable conditions, the nystagmus may persist too long to permit recovery of the aircraft.

Visual Illusions

AUTOKINESIS

In the dark, a stationary light will appear to move about when stared at for many seconds. According to one study, after 6 to 12 seconds of focusing on a single light while in a dark room, participants observed it moving at up to 20 degrees per second in one or many directions. When flying, a pilot could lose control of the airplane in attempting to align it with the false movements of the light. Military pilots have been known to attempt to rejoin in formation flying toward Venus or a star, and civilian pilots have done evasive maneuvers to avoid stars. The autokinetic effect helped convince them that stars were moving aircraft lights. Radars, radios, and collision avoidance systems help provide cues to avoid taking incorrect actions in flight due to the autokinetic effect.

BLACK HOLE

When in a situation without peripheral cues, such as landing on a very dark runway or in a snow or sand storm, pilots must rely on focal vision when a combination of focal and ambient vision would be preferable. In a black-hole situation over water, when there is no visible horizon or only the runway lights are visible, or a black-hole situation complicated by landing on a dark night with a distant town on a hill rising beyond a runway, a pilot may feel that the aircraft is stable but the runway is moving or is in an incorrect position. Landing short is the common fatal mistake from failing to recognize and correct the aircraft's position in time.

WHITEOUT APPROACHES

Like the black-hole approach, the whiteout approach causes disorientation and incorrect pilot responses due to the lack of peripheral or ambient cues. An atmospheric whiteout occurs when there is no visible horizon because the white snow-covered terrain blends in with the overcast or solid white sky. In this case, visibility might be "unrestricted," but visual cues are lacking. Similarly, blowing snow or sand may create a whiteout (or gray-out), but this is due to poor visibility causing lack of peripheral cues. Helicopters hovering low or attempting to land may cause a whiteout through rotor wash.

SIZE CONSISTENCE

Commonly a depth-perception issue, size consistence is particularly a factor in landing, when a pilot perceives her distance from a runway based on the width and distance from a runway. For example, when accustomed to a certain size runway, a pilot approaching a narrow runway may perceive that the aircraft is higher than it actually is. This results in a low approach and a late flare, and usually a hard landing. Conversely, a wide runway can lead a pilot to perceive that he is too close to the runway, causing him to make a high approach and early flare, resulting in a dropped-in landing or excessive floating and a long landing (see Fig. 4-2).

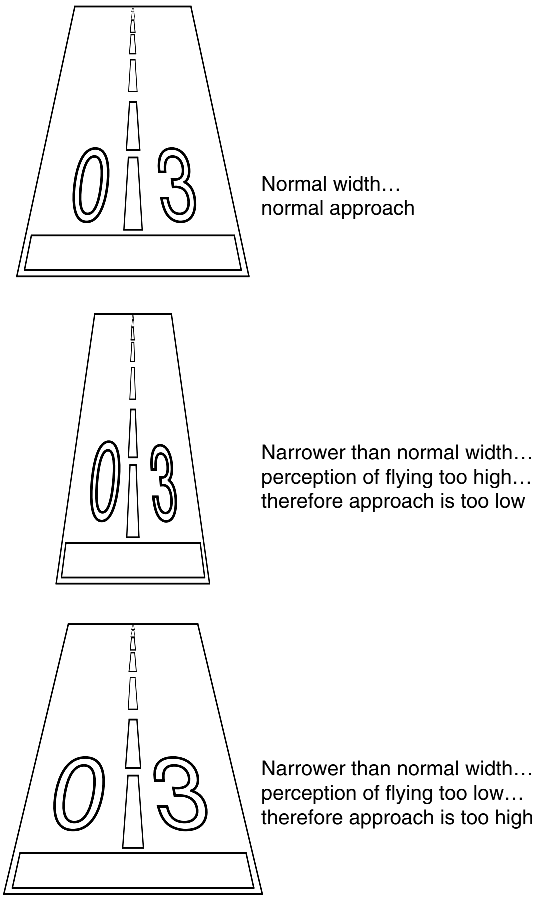

Fig. 4-2. **Size consistence example.**

SHAPE CONSISTENCE

An example of this visual illusion is when a runway is not level and either slopes up or down from the approach end. When the runway slopes up from the approach end, the pilot perceives that the approach is too high and, therefore, flies too low of an approach. The opposite is true of a runway that slopes down from the approach end (see Fig. 4-3).

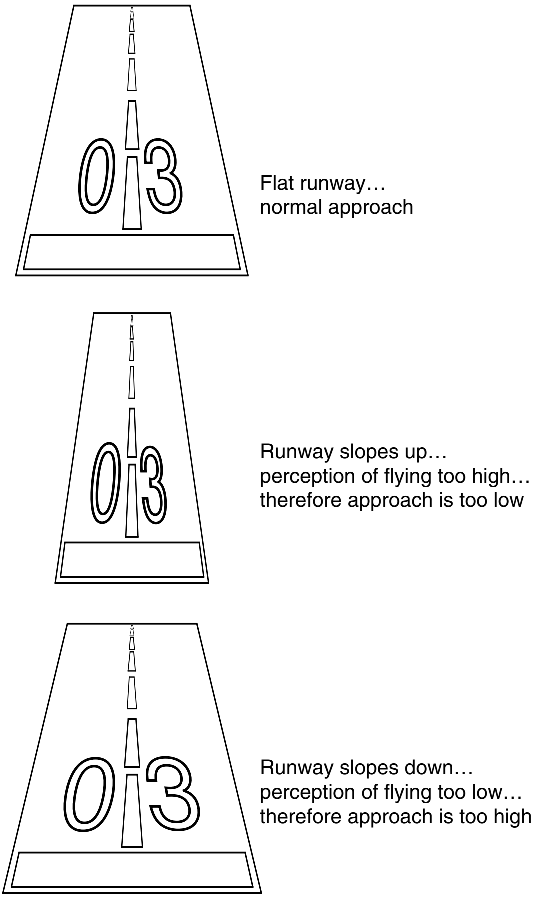

Fig. 4-3. **Shape consistence example.**

FALSE HORIZON

A sloping cloud deck, or the lights of a town lying on a slope viewed at night, can create the perception of appropriate visual cues resulting in inappropriate control inputs. When correcting the aircraft's flight to match the misperception of a false horizon, slow corrections may result in equilibrium in the vestibular system. This creates a sensation of straight-and-level flight that matches the visual perception, when the aircraft is actually in a bank. These illusions may create significant confusion when the brain is sure that a horizon is real but the flight instruments, in contrast, show a bank (see Fig. 4-4).

HEIGHT PERCEPTION ILLUSION

When flying over terrain with poor visual cues or references, such as the sea or a barren desert, or when flying over repetitive terrain such as a forest, in the dark, a pilot may perceive the attitude of the aircraft to be much higher than it actually is.

Fig. 4-4. False horizon—sloping cloud deck. Microsoft Clipart.

Somatosensory Illusions

GIANT HAND

In some spatial disorientation situations, the pilot may want to initiate a control input to correct her condition, but feels as if a hand is pushing against her in the opposite direction. This "giant hand" phenomenon is a subconscious result of cognitive dissonance; the mind and trained reflex pattern are fighting one another in an extremely disorientating situation.

Types of Spatial Disorientation

Spatial disorientation cases are frequently divided into three types based on the pilot's awareness and reaction.

Type I

This is a condition where the pilot does not recognize the spatial disorientation. It is the most deadly type because, since the disorientation is unrecognized, the pilot takes incorrect actions or makes inappropriate control inputs. Flying in what appears to be a wings-level attitude above a gently sloping cloud deck but without noticing the frequent input of trim to maintain the apparent wings attitude is an example. Upon looking back inside the cockpit, the pilot may find that he had trimmed in 5 degrees of right turn to maintain wings-level with the cloud deck beneath the aircraft. This Type I spatial disorientation situation was caused by a false horizon.

Type II

In this case, a pilot recognizes that something is wrong but has not recognized that the problem is caused by spatial disorientation. For example, a pilot increases speed to one assigned by the controller to maintain good separation from another aircraft. After setting the new speed, the pilot then notices that he has descended several hundred feet and is still descending. He climbs and rechecks his instruments. The pilot may have experienced an oculoagravic illusion.

Type III

This is the most severe level of spatial disorientation and occurs when a pilot knows that something is wrong but cannot take corrective action due to physiological and emotional responses to the disorientation. A pilot flying a high-performance sailplane may see a graveyard spiral developing as she rapidly descends between storm cells with an obscured horizon. But, when attempting to level off, the pilot feels that an excessive amount of trim and stick pressure is required and cannot exert enough force to correct. As a result, the pilot either crashes or bails out of the sailplane. This is a graveyard spiral with a giant hand fighting the recovery.

Prevention

Spatial disorientation is definitely a human factor that affects flight safety. However, it is frequently predictable, and test and anecdotal evidence points to the fact that recognition (through familiarization, training, and situational awareness) and early action may prevent or mitigate the occurrence of flight accidents caused by spatial disorientation. Many human factors, though, must be considered with reference to incidents of spatial disorientation. Depending upon the situation, these might include cockpit or flight deck design, noise, cabin pressure, fatigue, alcohol or drug use, smoking, instrumentation, night vision, visual acuity, circadian rhythm (time in a human's 24-hour biological cycle), nominal state of stress and anxiety, reactions to situations producing hypoxia, carbon monoxide or other aircraft contamination, reaction to G forces, and overall health.

Flight tests conducted by the FAA with qualified instrument pilots revealed that it can take as long as 35 seconds for a pilot to establish full control by instruments after a loss of visual reference. When surface references or the natural horizon are obscured, a disoriented pilot, not trained or accustomed to trusting the instruments, can place the airplane in a dangerous attitude intensifying the sensory illusion.

According to a study by the Air Safety Foundation, the majority of spatial disorientation accidents result when pilots qualified only for visual flight fly into meteorological conditions requiring the use of instruments. The second highest cause of spatial disorientation accidents occurred at night, when pilots without an instrument rating encountered conditions requiring the use of instruments.

Indeed, awareness and training may perhaps reduce flight accidents caused by spatial disorientation. However, each accident and case must be analyzed thoroughly for other contributing factors since spatial disorientation, without other distractions or in-flight problems, is a difficulty usually solved through education and training. When compounded by additional mechanical, weather, or human factors, spatial disorientation in flight is often fatal.

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Part 1 Case Studies

Case Study 1-1: American Airlines Flight 1420

Safety issues: Flight crew performance, flight crew decision-making, pilot fatigue

On 1 June 1999, American Airlines Flight 1420, an MD-82, crashed after it overran the end of runway 4R during landing at Little Rock National Airport, Arkansas.

Probable Cause

The NTSB determined that the probable causes of this accident were the flight crew's failure to discontinue the approach when severe thunderstorms and their associated hazards to flight operations had moved into the airport area and the crew's failure to ensure that the spoilers had extended after touchdown.

Contributing to the accident was the flight crew's (1) impaired performance resulting from fatigue and the situational stress associated with the intent to land under the circumstances, (2) continuation of the approach to a landing when the company's maximum crosswind component was exceeded, and (3) use of reverse thrust greater than 1.3 engine pressure ratio (EPR) after landing.

Flight Crew Experience

The captain had 10,234 total flying hours, including 7,384 as a company pilot-in-command. He had 5,518 hours in the MD-80. In July 1998, the captain was promoted to check airman on the MD-80. The

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MD-80 fleet manager stated that the captain was recommended for this position by the Chicago-O'Hare base manager and another check airman because of his technical competence, performance as a line pilot, and ability and desire to instruct. In January 1999, the captain was promoted to chief pilot at the Chicago-O'Hare base because of his flying background, company achievements, and leadership skills. American Airlines policy requires chief pilots to fly one month per year as line pilots. The Chicago-O'Hare base manager, however, encouraged chief pilots to fly once a week as line pilots. The captain had flown 54, 46, 14, and 12 hours in the previous 90, 60, 30, and 7 days, respectively.

The first officer had 4,292 total flying hours, 182 hours in the MD-80. He was serving a one-year probation period required of new company hires. The first officer had flown 176, 112, 65, and 7 hours in the previous 90, 60, 30, and 7 days, respectively.

History of Flight

Flight 1420 was a regularly scheduled flight from Dallas/Ft. Worth International Airport, Texas, to Little Rock, Arkansas. There were 2 flight crew members, 4 flight attendants, and 139 passengers on board.

The airplane originally intended to be used for the flight was delayed in its arrival to Dallas/Ft. Worth because of adverse weather in the area. At approximately 2150 Central Daylight Time, the first officer telephoned the flight dispatcher to suggest that he get another airplane for the flight or cancel it. Another airplane was substituted, and Flight 1420 departed at 2240—2 hours and 12 minutes late.

Accident Sequence

About 2254, the flight dispatcher sent the flight crew an in-flight message indicating that the weather around Little Rock might be a factor during the arrival. The dispatcher suggested that the flight crew expedite the arrival to beat the thunderstorms if possible, and the flight crew acknowledged the message. During the postaccident interview, the first officer stated that "there was no discussion of delaying or diverting the landing" because of the weather. The captain was the flying-pilot for the flight into Little Rock.

At 2304, the Ft. Worth air route traffic control center (ARTCC) broadcast a National Weather Service (NWS) convective SIGMET (significant meteorological information) weather advisory for an area of severe thunderstorms that included the Little Rock airport area. About 20 minutes later, as the flight crew remarked that the city of Little Rock and the airport were in sight, the captain said, "We got to get over there quick." The first officer replied, "I don't like that…lightning."

After passing through the Memphis ARTCC, the flight was handed off to the Little Rock tower at 2334. The controller advised the flight crew that a thunderstorm located northwest of the airport was moving through the area and that the wind was 280 degrees at 28 knots gusting to 44 knots. The first officer told the controller that the captain and he could see the lightning. Shortly thereafter, the captain and first officer discussed the crosswind limitations for the landing conditions—20 knots.

At 2339, the flight was cleared to descend to 3,000 feet (above) mean sea level (msl) and the controller asked the flight crew about the weather conditions along the runway 22L final approach course. The first officer said that they could barely see the runway and confirmed that the storm was moving toward them. The controller offered a visual approach, but the first officer declined, "…we're gonna have to stay with you as long as possible." The controller provided the flight crew with the latest windshear alert report—centerfield wind 340 degrees at 10 knots; north boundary wind 330 degrees at 25 knots; northwest boundary wind 010 degrees at 15 knots. The flight crew then requested runway 4R in order to land with a headwind.

Over the next minute, the captain and first officer engaged in focused conversation to find the runway. The first officer apparently had the runway in sight for most of the approach, guiding the captain with verbal directional commands. When the airport appeared at their 3 o'clock position and about 4 miles, the first officer accepted a visual approach for runway 4R. At 2343, the first officer said, "…there's the airport," as the captain lost sight of it. The controller cleared the flight to land with the winds at 330 degrees at 21 knots. Concerned, the captain said, "…we're losing it…I don't think we can maintain visual." A cloud obscured the field, and the first officer requested an instrument landing system (ILS) approach.

At 2345, the first officer told the controller, "We're getting pretty close to this storm…we'll keep it tight if we have to." The airplane was 3 miles from the outer marker (5.9 miles from the airport) when the captain stated, "Aw, we're goin' right into this." At the same time, the controller reported that there was heavy rain at the airport, visibility was less than 1 mile, and the runway visual range (RVR) for runway 4R was at 3,000 feet. The flight was cleared to land with the winds 350 degrees at 30 knots gusting to 45 knots. The first officer acknowledged the information. After the captain expressed concern that they couldn't land with an RVR of 3,000 feet, the first officer noted that the lowest authorized RVR for runway 4R was 2,400 feet and the captain answered, "Okay, fine." Seconds later, the controller reported the RVR was down to 1,600 feet and the captain indicated that the flight was established on final approach. [If the weather is reported below published minimums, the FAA and American Airlines allow airplanes that are established on the final approach segment to continue the approach to the appropriate decision height (DH) or minimum descent altitude (MDA) and land in accordance with the conditions for the type of approach being conducted.]

The controller repeated the clearance to land and updated the airport conditions—wind 340 degrees at 31 knots; north boundary wind 300 degrees at 26 knots; and northeast boundary wind 320 degrees at 25 knots. The flight crew extended the flaps to 40 degrees as they received another wind advisory—330 degrees at 28 knots. The captain said, "This is a can of worms," as the first officer remarked, "There's the runway off to your right, got it?" The captain replied, "No," to which the first officer stated, "I got the runway in sight. You're right on course. Stay where you're at." The captain then stated, "I got it. I got it." Seconds later, an unidentified voice in the cockpit said, "Aw…we're off course." (In a postaccident interview, the first officer said that he thought the approach was stabilized until about 400 feet above the field, at which point the airplane drifted to the right. The first officer also said that he told the captain to "go around" but not in a very strong voice, and when he looked at the captain to see if he had heard him, the captain was intent on flying and was doing "a good job.")

At 2350, the first officer stated, "We're way off." The captain lost sight of the runway and regained visual contact about three seconds later. Just after touchdown, the first officer said, "We're sliding."

According to the flight data recorder (FDR), the flight spoilers did not deploy symmetrically and the engine thrust reversers were not fully deployed at touchdown. The captain applied brakes and attempted to redeploy the thrust reversers. At 2350:44, the cockpit voice recorder (CVR) recorded the sounds of the initial impact after the airplane departed the runway.

FLIGHT CREW PERFORMANCE AND SITUATIONAL STRESS

According to the Safety Board, the flight crew should have initiated a go-around during the final approach segment when the company's maximum landing-crosswind component (20 knots) was exceeded. Further, because of the flight crew's failure to adequately prepare for the approach—delaying the landing flap configuration—combined with the rapidly deteriorating weather conditions, the approach should have been abandoned.

The Safety Board added that the flight crew's intention to expedite the landing despite the weather diverted their attention away from other activities during the final minutes of the flight. As a result, the flight crew failed to properly assess the situation and make appropriate decisions.

Fatigue also degraded the performance of the flight crew. Both pilots had been awake continuously for over 16 hours at the time of the accident. Their decision-making capabilities were notably altered: (1) neither discussed diverting the landing, (2) the first officer did not ensure that the autospoilers had been armed for landing, and (3) the captain did not realize that he had not called for the flap configuration for landing until the first officer reminded him.

LANDING PERFORMANCE

The Safety Board determined that the airplane touched down 2,000 feet down the 7,200-foot runway. Analysis showed that the airplane could have stopped about 700 feet before the end of the runway if the spoilers had been deployed and the flight crew had maintained a constant reverse thrust during landing. Thus, the Safety Board concluded the "single most important factor" in the flight crew's inability to stop the airplane within the available runway length was due to the flight crew's failure to deploy the spoilers.

Lessons Learned and Practical Applications

1. *Before a bad situation becomes worse—stop!* Recognize and accept the situation, and then rely on good judgment and timely decisions.
2. *Avoid tunnel vision.* It takes away your ability to appropriately assess the situation.
3. *Complete the entire checklist and then double-check.* This is especially important when stressed or working an emergency.

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Case Study I-2: TWA Flight 843

Safety issues: CRM, cockpit discipline, stall-warning system malfunction, maintenance records, pilot training, "quiet cockpit" concept

On 30 July 1992, a TWA L-1011 caught fire after an aborted takeoff from John F. Kennedy (JFK) International Airport, New York.

Probable Cause

The NTSB determined that the probable causes of this accident were (1) the design deficiencies in the stall-warning system that permitted a defect to go undetected, (2) the failure of TWA's maintenance program to correct a repetitive malfunction of the system, and (3) the inadequate crew coordination between the captain and first officer that resulted in their inappropriate response to a false stall warning.

History of Flight

Flight 843 was a regularly scheduled passenger flight from JFK International to San Francisco, California. The L-1011 departed at 1740 Eastern Daylight Time with 280 passengers and 12 crewmembers on board.

Pilot Experience

The captain had 20,149 total flight hours, 2,397 in the L-1011 and 1,574 as captain. He passed his last annual line check three weeks before the accident.

The first officer had 15,242 total flight hours, 2,953 in the L-1011. He had passed his annual line check almost four months prior to the accident.

The second officer had 3,922 total flight hours and was a rated check airman with 2,266 hours in the L-1011. His last line check was two months before the accident.

Weather

The weather was visual flight rules (VFR) and not a factor.

The Accident

The takeoff roll was uneventful until eight seconds after the captain called VR. The airplane had just lifted off when the first officer said, "Gettin' a stall. You [the captain] got it." The captain replied, "Okay," and took the controls. Immediately thereafter, the first officer said, "Abort, get it on," quickly followed by the second officer's comment, "Get it off." The first officer repeated, "Get it on," and the second officer again said, "Get it off." In the confusion, the captain asked, "What was the matter?" to which the first officer replied, "Getting a stall." As the captain turned the airplane off the runway to avoid hitting the blast fence, the first officer said, "Stay with it. Stay on the brakes, stay on the brakes." The airplane finally stopped in an open, grass-covered area and was destroyed by fire.

Impact and Wreckage Path

Pilots who witnessed the accident told investigators that the airplane appeared to have landed fast and far down the runway. One witness, who was near the touchdown point, said that the aircraft experienced an "extremely hard landing," which caused a "great deal of strut compression and wing flex." Most of the witnesses remembered seeing flying debris and a "mistlike substance" coming from the underside of the airplane or right wing area as it continued down the runway. A large fireball then developed on the outside of the fuselage.

Investigators noted tire marks and blackened streaks that led off the runway and into the dirt area. The airplane came to rest 296 feet to the left of the departure end of runway 13R, upright, and on fire. Before the blaze could be extinguished, it consumed the entire aft fuselage, causing two large sections to fall to the ground.

ACCIDENT SURVIVABILITY

There were no fatalities and only 10 reported injuries. A total of 14 flight attendants, 5 of whom were off duty, assisted with the successful evacuation in less than two minutes.

The Investigation

Based upon the information derived from the FDR and CVR, the Board investigated two specific areas: (1) a malfunction in the stall-warning system and (2) flight crew performance.

STALL-WARNING SYSTEM

On the L-1011, the stickshaker will vibrate in both control columns when the airplane's angle of attack (AOA) approaches an aerodynamic stall for a given flap/slat configuration. The sensors that measure the AOA are tubular probes that protrude from the jet. One is located on either side of the fuselage below the cockpit side windows. There are two rows of holes through the wall of the tube that are separated by an angle of about 90 degrees. A diaphragm is one of the basic components in the system that senses the differential pressure relative to the direction of the airstream. An electric signal goes to a servomotor that rotates the tubular probe until the pressure across the diaphragm is balanced and the signal is nulled. Thus, the angular position of the probe is an indication of the direction of the airflow relative to the fuselage, which in turn correlates to the airplane's AOA. That information is then interpreted by the stall-warning system.

The crew of Flight 843 testified that when they did the ground test of the system, everything appeared normal. After examination of the unit, the Board determined that because the ground test electrical signal drives the AOA probe servomotor, a failure or short within the circuitry between the differential pressure diaphragm and the servomotor would not be detected during routine preflight checks. Therefore, such a failure would result in an erroneous AOA signal to the system while on the ground and would not cause the "fail light" to go on in flight.

MAINTENANCE HISTORY

TWA maintenance records showed that on 8 July 1992, a pilot logged a problem with the aircraft's right AOA indicator. In part, the entry read, "Control column shakes during rotation and in flight for no apparent reason, and [autothrottle system] light on. Fault isolated to stall-warning system 2…Reset on approach O.K." Maintenance replaced the computer and noted that it was properly functioning.

Investigators discovered that from 1989, the right AOA sensor had been written up eight times while it had been installed on a different aircraft. It was later reinstalled on the accident airplane and had been in service for 1,467 flight hours before 30 July 1992.

FLIGHT CREW PERFORMANCE

According to the captain, the rotation was smooth and normal when the stickshaker suddenly activated and the first officer "stated something to the effect of it's not flying or it won't fly, you've got it." He told investigators that he felt the jet sinking and had to make a split-second decision either to continue the takeoff or to abort. Since he saw a considerable amount of runway remaining, he chose the latter. The captain added, that although the aircraft had the proper attitude and airspeed, he "positively did not believe that the airplane would fly."

The captain then closed the thrust levers and put the aircraft back on the runway. The captain quickly applied full reverse thrust and maximum braking, but the jet did not slow down as fast as he expected. With only 1,500 feet of runway remaining, and an airspeed of 100 knots, he was forced to turn the airplane off the runway to avoid hitting the blast fence. He noted that he was able to maintain directional control throughout the landing.

The first officer recalled feeling the stickshaker activate as the airplane lifted off the ground. When he sensed a loss of performance and felt the jet sinking, he immediately gave control of the jet over to the captain.

Information obtained from the FDR revealed that the airplane had reached about 16 feet above ground level (agl) in six seconds before descending back to the runway. Based on the evidence, the Board believed that the jet was performing normally, had accelerated well above V2 (the minimum takeoff safety speed), and could have made a successful climbout.

The first officer told investigators that when he felt the stickshaker activate, he perceived that an emergency situation existed. Although the Board understood the crew's need to immediately respond, it did not believe that a stall warning automatically represented an emergency. Since the captain had been monitoring the airspeeds, when the warning sounded, he should have been aware that the airplane had sufficient power to sustain flight. The Board noted that had the captain properly evaluated the situation, this accident could have been avoided.

Investigators also addressed the crew's concerns that the "airplane didn't seem to want to fly." Following several ground and flight tests, the Board believed that the "sinking" feeling experienced by the pilots was most likely caused by the first officer relaxing the back pressure on the control yoke. It was possible that the sensory input of both the stickshaker and the sinking sensation gave the crew the impression that they were stalling. The Board noted that it was unable to identify any other aerodynamic or mechanical explanation.

In the Board's opinion, the first officer "inexplicably" reacted to the stickshaker by immediately deciding that the captain should be flying and passing over control of the aircraft without appropriate warning or coordination. This "improper and untimely action" occurred when the airplane was about 15 feet agl and approximately 14 knots above V2 speed. They believed that the decision and subsequent action of the first officer to give up control of the airplane, instead of the captain taking control, was not consistent with the nearly universal practice in the aviation community regarding transfer of control in two-pilot aircraft. Therefore, investigators examined TWA's training program and its procedures.

PILOT TRAINING

The Board learned that TWA's training and operational procedures, including CRM, was based on the quiet cockpit concept. This philosophy was based on the fact that each pilot was trained in a particular skilled position and was expected to perform the duties for that position at the appropriate time. Therefore, crewmember briefings were not believed to be necessary. As a result, investigators noted that this practice promoted a higher probability of cockpit confusion and poorer crew coordination.

Lessons Learned and Practical Applications

1. *Never give up the controls.* Always coordinate the transfer between you and the other pilot. In this case, the first officer told the captain, "You got it," around 15 feet agl. This forced the captain to make an unnecessary and possibly unwise split-second decision.

Since we're on the subject of control transfer, let's look at a few good tips and examples.

a. Don't attempt this at extremely low altitudes. As an additional reference, I would recommend studying NTSB Aircraft Accident Report 94-01 (NTIS/PB94-910402). When the first officer of an American DC-10 descended to about 50 feet agl over the runway threshold at Dallas/Ft. Worth Airport, Texas, he announced that he was going to initiate a go-around. The captain misunderstood the cause of the go-around and immediately took over the controls. He ended up landing 1,300 feet beyond the maximum touchdown point and on a wet runway. The aircraft slid off the side of the runway.

b. Clearly and directly communicate your intentions. "Your airplane," followed by "My jet," is one example of how the transfer of control should be handled. Avoid using "You got it," "It's yours," and "Okay."

2. *Fully evaluate the situation.* According to the Board, a stall warning does not automatically indicate an emergency condition. It believed that if the first officer had stayed with the airplane, which would have allowed the captain to have monitored the engine and flight instruments, he could have maintained control.

3. *Don't confuse the situation.* Once the captain had resumed command, the first officer and second officer had the following exchange of comments: "Abort, get it on." "Get it off." "Get it on." "Get it off." Such confusing remarks did nothing to aid the captain. Keep quiet, unless you're going to be an effective crewmember and offer sound guidance.

4. *Always practice CRM.* When done correctly, confusion, chaos, and misunderstandings can be avoided.

5. *Actively participate in preflight briefings.* In this case, TWA had a quiet cockpit philosophy, which was based on the assumption that each crewmember knew a particular set of standards. But, there were no means to ever review the standards before a flight. Make sure that preflight briefings are routinely conducted with the entire crew. This is your best guarantee that everyone is thinking the same way—before an emergency.

References

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Case Study I-3: Korean Air Flight 801

Safety issues: Monitoring and challenging errors, situation awareness

On 6 August 1997, a Korean Air Boeing 747 crashed into high terrain about 3 miles southwest of the A.B. Won Guam International Airport, Agana, Guam, while on an approach to runway 6L.

Probable Cause

The NTSB determined that the probable cause of this accident was the captain's failure to adequately brief and execute the nonprecision approach and the first officer's and flight engineer's failure to effectively monitor and cross-check the captain's execution of the approach.

Contributing to these failures were the captain's fatigue and Korean Air's inadequate flight crew training. Also contributing to the accident was the FAA's intentional inhibition of the minimum safe altitude warning (MSAW) system at Guam and the agency's failure to adequately manage the system.

History of Flight

Korean Air Flight 801 was a regularly scheduled passenger flight with 237 passengers and a crew of 17 on board. At 2005 (Seoul local time), Flight 801 departed Kimpo International Airport, Seoul, Korea, for Guam. Less than five hours later, at 0142 (Guam local time), Flight 801 crashed after it had been cleared to land on runway 6L.

Captain Experience

The captain of Flight 801 had previously been a pilot in the Republic of Korea Air Force, until he was hired by Korean Air in 1987. He had 8,932 total flight hours, 1,718 as a 747 captain. According to the 747 chief pilot of Korean Air, the captain had received a flight safety award three months before the accident from the company president for successfully handling an in-flight emergency involving an engine failure at a low altitude.

The captain received an "excellent" evaluation during his last simulator proficiency check on 11 June 1997. The captain later received an "above standard" evaluation on his last route check—three weeks before the accident. He had also passed the company's Level 3 Pilot English Test (written, listening, and oral sections) required of all Korean Air pilots.

CAPTAIN SAFETY INITIATIVE

A month before the accident, the captain had flown a flight between Seoul and Guam. According to the first officer on that flight, the captain called him the day before and proposed that they obtain a charter briefing for Guam because Korean Air did not regularly conduct 747 operations at that airport. Consequently, the captain and first officer arrived several hours before the departure time and received a charter briefing from a Korean Air instructor, even though the briefing was not required. The captain and first officer watched the Guam airport familiarization video presentation and studied the approach charts for the airport. During that time, the captain commented that the area where the NIMITZ VOR is located was mountainous and required extra attention—referring to this area as a "black hole."

CAPTAIN'S PREACCIDENT DUTY SCHEDULE

The captain had flown a round-trip from Seoul to San Francisco, California, from 28 July to 30 July 1997. He was off-duty until 2 August, when he flew two round-trip domestic flights between the hours of 1100 and 2000. On 3 August, he flew an international trip to Hong Kong that arrived in the early evening. The return flight was delayed because of inclement weather, so the captain remained in Hong Kong overnight and flew back to Seoul the next morning, arriving about 1230.

On the day of the accident, the captain had originally been scheduled to fly to Dubai, United Arab Emirates, but due to inadequate crew rest for that trip, he was reassigned the shorter trip to Guam.

First Officer Experience

The first officer of Flight 801 was previously a pilot in the Republic of Korea Air Force until he was hired by Korean Air in 1994. He had 4,066 total flight hours, 1,560 as a 747 first officer. His last route check was conducted in 1995, and his last simulator proficiency check occurred five months before the accident. In the overall simulator evaluation, the first officer received an "above standard" for his control skills and knowledge. He also received a "standard" for his nonprecision VOR approaches with the remark, "altitude management on nonprecision approach [was] somewhat less than desirable." Another instructor noted, "somewhat slow to carry out directions."

The first officer passed the Level 3 Pilot English Test but did not attend CRM training.

FIRST OFFICER PREACCIDENT DUTY SCHEDULE

The first officer returned from an international trip to the United States on the afternoon of 2 August 1997. He was off duty the next day and then flew a round-trip domestic flight on 4 August, between 0930 and 1245. He was off duty until the accident flight.

Flight Engineer

The flight engineer was hired by Korean Air in 1979. He had 13,065 total flight hours, 1,573 on the 747. He had received "above standard" and "excellent" evaluations, with his control skills, knowledge, and crew coordination. He had passed the Level 3 Pilot English Test and attended CRM training.

FLIGHT ENGINEER PREACCIDENT DUTY SCHEDULE

The flight engineer had returned to Seoul on 3 August 1997, after completing a three-day international trip to Anchorage, Alaska, and San Francisco. He was off duty until the accident flight. The first officer had never flown into Guam before Flight 801.

Background of Air Traffic Controllers

The controller on duty at the combined center/radar approach center (CERAP) at Guam had received his training while serving in the U.S. Navy. He was hired by the FAA in 1982 and transferred to Guam in 1995 where he became certified as a full-performance-level controller.

The Agana (Guam) Airport tower controller had received his training while serving in the U.S. Navy. In 1995, he was hired as an air traffic controller at the Guam federal control tower by a nonfederal contract ATC service company. He was fully certified on all positions of operations in the tower facility.

Airport Information

The A.B. Won Pat Guam International Airport is located 3 nautical miles (nm) northeast of Agana on the west-central coast of Guam, at an elevation of 297 feet msl. The airport is leased to the Guam International Airport Authority by the U.S. Navy, and the associated navigational facilities are owned and operated by the FAA.

The airport has two parallel runways—runway 6R/24L, which is 8,001 feet long and 150 feet wide, and runway 6L/24R, which is 10,015 feet long and 150 feet wide. Runway 6L is equipped with high-intensity runway edge lights, a medium-intensity approach lighting system with runway alignment indicator lights, and a four-box visual approach slope indicator (VASI) calibrated for a 3-degree visual glidepath angle. Runway 6L is not equipped with end identifier lights, centerline lights, or touchdown zone lights. The touchdown elevation of runway 6L is 256 feet but rises to 297 feet at the departure end of the runway.

The tower controller told investigators that at the time of the accident, the lights for runway 6L were on step 2, and the medium-intensity approach lights were on step 1 (the lowest of three approach light intensity settings).

Weather

Guam's climate is relatively uniform throughout the year. The island averages 247 days each year with measurable amounts of rain, and most days begin with scattered layers of clouds that become broken to overcast by afternoon. From August to October, visual meteorological conditions (VMC) prevail about 80 percent of the time, and instrument meteorological conditions (IMC) occur predominately during the afternoon hours. The rainy season lasts from July to November.

A weather synopsis prepared by the Guam NWS on the day of the accident stated:

> …a weak low pressure trough is moving slowly [through] the Mariana Islands…resulting in gentle to moderate easterly winds and scattered showers. The effects of the upper level low far to the northeast have diminished during the past 12 hours or so. Light to moderate showers should be expected except for isolated afternoon thunderstorms due to solar heating.

About 0122, the flight crew received the current Automatic Terminal Information Service (ATIS) information.

> …wind calm, visibility seven [clouds] one thousand six hundred scattered, two thousand five hundred scattered, temperature two seven [Celsius], dew point two four, altimeter two niner eight six, runway six in use. NOTAMs [Notices to Airmen], *runway six left ILS glideslope out of service until further notice…* [emphasis added].

The special surface weather observation for 0132 was:

> Wind 090 degrees at 6 knots; visibility—7 miles; present weather—shower vicinity; sky condition—scattered 1,600 feet, broken 2,500 feet, overcast 5,000 feet; temperature—27 degrees C; dew point—25 degrees C; altimeter setting 29.85 inches Hg; remarks—showers vicinity northwest-northeast.

Approximately 30 minutes before Flight 801 crashed, an Air Micronesia Boeing 747 landed at Guam. The flight crew stated that visibility was "excellent" from PAYEE intersection (located 240 nm north of NIMITZ VOR) and that scattered thunderstorms were occurring around the area. Their on-board radar depicted rain showers over the NIMITZ VOR but not over the airport. The flight crew noted the visibility was "good" under 2,000 feet and that they maintained visual contact with the airport throughout the approach.

The NTSB examined the NWS surface weather observation logs and found that intermittent light rain showers were reported with periods of heavy rain showers—the heaviest rainfalls were reported at the airport between 0020 and 0029, between 0114 and 0116, and again between 0153 and 0158. Weather radar showed an area of precipitation over higher terrain, including Nimitz Hill. The maximum wind speed recorded at the airport was about 10 knots, between 0130 and 0150.

This observation is consistent with the statements made by the CERAP radar controller. He noticed a "relatively small cell," which he believed to be of light to moderate intensity, extending about 3 to 5 miles on the final approach course and about 2 to 3 miles across. He did not advise the flight crew or the Agana tower controller because he had assumed that the flight crew was using cockpit radar—a system more sophisticated than that of the ATC facility—and because the flight crew had asked him twice for deviations around weather.

The Agana tower controller told investigators that although it was not raining at the airport when Flight 801 was inbound, a rain shower was moving in from the northeast over the airport and down the runway to the southwest. He estimated that the visibility was 7 miles and stated that there were no low clouds.

U.S. Navy Weather Observer

A certified U.S. Navy weather observer on Nimitz Hill, about 3/4 mile northwest of the accident site, stated that at approximately 0142 the cloud ceiling was about 700 to 800 feet above ground level (agl) or 1,300 to 1,400 feet mean sea level (msl), during a heavy rain shower. He added that the visibility was about 200 to 300 meters, and the wind speed never exceeded 10 knots. The observer told investigators that the night was "pretty routine" for Guam.

Additional Real-Time Weather Observations

The flight crew of a Ryan International flight, which landed shortly after the accident, stated that the visibility was sufficient to see the lights of Guam from about 150 nm away. The first officer told investigators that the onboard weather radar depicted showers northeast of the airport but no thunderstorms. Relating their own approach experience, the flight crew initially requested a visual approach when the flight was about 15 nm from the NIMITZ VOR, but the airplane encountered clouds and rain on the approach to runway 6L. The airplane remained in the clouds until it was in proximity of the VOR, at which time the airplane broke out and the flight crew was able to maintain visual contact with the airport. The captain stated that, although clouds and rain were over the island's shoreline, the air around the airport and in the vicinity of the accident site was smooth.

The captain of the Ryan flight was a check airman based at Guam. He told investigators that he "noticed that once [flight] crews are given a visual approach [into Guam] they have a tendency to press on even when they lose visual contact—in hopes of regaining visual contact again… That's because so many approaches are visual and the clouds and rain showers are so localized."

In addition, a hunter was a witness to the accident. He was standing on Nimitz Hill when Flight 801 passed over his head—100 feet north of the VOR beacon. He said that while there had been intermittent rain showers shortly before the accident, it had stopped by the time Flight 801 flew overhead and he could see stars directly over the accident site, moments later. He added that the visibility was "very good" at the time of the accident and that, although he could not see the airport lights, he could see the lights from the nearby town, 3 to 4 miles northeast of his location.

Accident Sequence

At 0138, Flight 801 was vectored to join the runway 6L localizer course. With the glideslope out of service, a localizer-only approach to Guam used the NIMITZ VOR as a step-down fix. A step-down approach procedure requires pilots to cross specific navigational fixes at or above several altitudes while descending to the minimum descent altitude (MDA)—at which point the pilot either lands or executes a missed approach.

According to the instrument approach chart for Guam, a localizer-only approach to runway 6L required the flight crew to maintain at least 2,000 feet from the FLAKE intersection (7 DME from the VOR) to the outer marker/final approach fix, located 1.6 DME from the VOR. After passing the outer marker, the flight crew was required to maintain at least 1,440 feet msl until crossing the VOR. After passing the VOR, the next step-down fix was to 560 feet—the MDA—which the flight crew was required to maintain until 2.8 DME—the missed approach point—from the VOR.

During the approach descent, the first officer called out "approaching fourteen hundred [feet]" when the airplane was passing 5 DME at 2,400 feet msl. The Safety Board was unclear why the first officer made such a callout except that he may have confused 2,400 feet with 1,400 feet on the altimeter. Another possibility was that the first officer may have thought the DME was located on the airport and that the airplane was approaching a distance at which they could descend to 1,440 feet. In any event, from the first officer's callout, the captain believed that they had already passed through their first step-down altitude restriction—2,000 feet—and had reached the outer marker at the 1.6 DME fix. The captain therefore instructed the first officer to reset the altitude selector to the next step-down altitude—1,440 feet and continued the descent. The approach procedure specified that at least 1,440 feet be maintained after passing the outer marker and until passing the VOR. Flight 801 had already descended below 1,440 feet about 2.1 DME and before reaching the VOR. According to flight crew discussion, there was no suggestion that the captain was aware the airplane was descending prematurely below the required intermediate altitudes. At 0141, the captain instructed the first officer to set 560 feet—the MDA—in the altitude selector.

EXPECTATION OF A VISUAL APPROACH

The most current ATIS information available to Flight 801 indicated that visual conditions (scattered cloud decks and 7-mile visibility) existed at the airport. Moreover, the captain and first officer reviewed the Korean Air, Guam Airport familiarization video a month before the accident—in preparation for an upcoming flight into Guam. The video depicts the weather conditions in Guam as favorable for visual approaches most of the year and states that even though IMC is likely during the rainy season from June to November, "you [the pilot] will be guided from over Apra Harbor to the localizer. You will then perform a visual approach...."

The Safety Board believed that the captain's anticipation of a visual approach probably became a strong expectation after the flight crew's initial sighting of Guam when they were 150 nm from the airport. Although the captain most assuredly recognized the possibility that pockets of IMC may appear along the approach path, he may have expected to rely on the VASI system to provide visual guidance over the terrain once he was vectored on the final approach. Thus, the Safety Board concluded that the captain's expectation of a visual approach was a factor in his incomplete briefing of the localizer approach.

The Safety Board expressed additional concerns that the Guam Airport familiarization video did not satisfactorily explain the challenging conditions for pilots, including the high terrain along the approach course or in the vicinity of the airport. Further, the presentation did not describe the complexity of the Guam nonprecision approaches, specifically the multiple step-down fixes, the use of two separate navigation facilities (the localizer and the VOR), and the unique countdown/count up DME procedure. By emphasizing the visual aspects of the approach, the Safety Board believed that company flight crews were inadequately prepared for the range of hazards associated with operations into Guam.

CONFUSION OVER THE GLIDESLOPE

Despite several comments made by the flight crew indicating that they were aware of the inoperative glideslope, between 0139 and 0141, they engaged in a lively discussion concerning its operational status. The flight engineer asked, "Is the glideslope working?" The captain responded, "Yes, yes it's working," immediately followed by an unidentified voice in the cockpit inquiring, "Check the glideslope, if working?" Another unidentified voice responded, "Why is it working?" The first officer replied, "Not useable." Again, an unidentified voice stated, "Glideslope is incorrect," followed by the captain's statement, "Since today's glideslope condition is not good, we need to maintain one thousand four hundred forty [feet]." About a minute later, and after the airplane crossed the outer marker (1.6 DME from the VOR) the captain remarked, "Isn't glideslope working?"

The Safety Board considered whether the flight crew may have misinterpreted some cockpit instrumentation indications as a valid glideslope capture signal. During the localizer approach into Guam, both pilots' horizontal situation indicators (HSIs) would have appeared centered; the captain's would have captured the localizer, and the first officer's would have captured the VOR radial. With VOR/LOC selected, the localizer captured, and the pitch commands set to VERT SPEED (the most likely setting), the captain's flight director (FD) command bars would have shown some vertical horizontal movement, similar to an FD that was responding to a captured localizer and glideslope. The captain's attitude director indicator (ADI) and HSI glideslope needles should have been covered by "off" flags. Further, there would have been no glideslope capture annunciator on the glideslope bar.

The Safety Board also considered whether the flight crew may have observed intermittent movement of the glideslope needles during the approach, thereby creating confusion about the glideslope. An FAA navigation expert testified that spurious radio signals could cause a sporadic or intermittent glideslope indicator deviation in the absence of a valid glideslope signal. However, he stated that the glideslope "off" flag would still appear on the HIS and ADI glideslope needles and that, when the "off" flag appears, any movement of the glideslope needle should be considered unreliable.

Although it is possible that spurious radio signals caused some erratic movement of the glideslope needles, it was unlikely that the navigation receivers could have been subjected to a steady spurious signal of a duration that would have resulted in a continuous glideslope needle activation and flag retraction over a period of minutes or several miles. Therefore, the Safety Board concluded that, although the captain apparently became confused about the glideslope status, the flight crew had sufficient information to understand that the glideslope was unusable and any movement of the needles should have been ignored.

CONFUSION ABOUT DME

At 0140, and when the airplane was descending through 2,400 feet msl, the captain told the first officer, "Since today's glideslope condition is not good, we need to maintain one thousand fourteen hundred forty [feet], please set it." This statement suggests that the captain was attempting to comply with the restrictions of the localizer-only approach and believed that he had passed the outer marker step-down fix. However, the CVR recorded no discussion between the captain and the first officer about DME values or their position in relation to the next step-down fix—the VOR—or the airport.

Investigators reviewed the approach charts and other material that Korean Air provided the flight crew during training and check rides. The charts depicted the DME located on the Guam airport, not the actual site—3.3 nm southwest of the airport. Therefore, the flight crew may have had a misconception that the DME information referred to the distance from the airport and thus believed that the airplane was much closer to the airport than it actually was. Confusing matters further may have been the countdown/count up DME procedure, which is rarely encountered on a localizer approach, but is used at Guam. This procedure was not included in any of the Korean Air simulator training scenarios.

The Safety Board noted that if the captain had flown under the assumption that the DME was on the airport it "suggests strongly" that he was not recognizing the DME values which were clearly marked on the approach chart. Thus, the Safety Board concluded that the captain may have mistakenly believed that the airplane was closer to the airport than its actual position; however, if the captain had conducted the flight's descent on this basis, he did so in disregard of the DME fix definitions shown on the approach chart.

CAPTAIN PERFORMANCE

Shortly after the captain appeared to become preoccupied with the status of the glideslope, he allowed the airplane to descend prematurely below the required intermediate altitudes of the approach. Thus, the captain may have failed to track the airplane's position on the approach because he believed that he would regain visual conditions, the airplane was receiving a valid glideslope signal, and/or the airplane was closer to the airport than its actual position.

The captain conducted the approach without properly cross-referencing the positional fixes defined by the VOR and DME with the airplane's altitude. Therefore, the Safety Board concluded that, as a result of his confusion and preoccupation with the status of the glideslope, failure to properly cross-check the airplane's position and altitude with the information on the approach chart, and continuing expectation of a visual approach, the captain lost awareness of Flight 801's position on the approach and improperly descended below the intermediate approach altitudes of 2,000 and 1,440 feet, which was causal to the accident.

FLIGHT CREW MONITORING

The first audible ground proximity warning system (GPWS) callout occurred about 0141, with the "one thousand [feet]" altitude call. A second GPWS callout of "five hundred [feet]" occurred about 15 seconds later—when the airplane was descending through about 1,200 feet msl. The flight engineer responded with an astonished, "eh?" However, FDR data indicated that no change in the airplane's descent profile followed and the CVR indicated that the flight engineer continued to complete the landing checklist. The first officer also dismissed a GPWS "Sink rate" alert by stating, "Sink rate okay." Seconds later, the flight engineer called "two hundred [feet]," followed immediately by the first officer saying, "Let's make a missed approach." The flight engineer concurred, "Not in sight [runway]," and the first officer repeated, "Not in sight, missed approach."

The GPWS minimum callout occurred about 12 seconds before impact, when the airplane was descending through 840 feet msl. The first officer's first missed approach callout occurred six seconds before impact. The captain initiated a missed approach two seconds later. Although the captain was increasing thrust, he did not immediately begin the climb until just before impact. According to the Safety Board, if a missed approach had been initiated 12 seconds before impact, it was likely that the airplane would have cleared the terrain by about 450 feet. FDR analyses further support the Safety Board's assertion that it was possible for the airplane to clear the terrain as late as six seconds before impact, if the captain had executed an "aggressive missed approach."

The Safety Board noted that although the first officer properly called for a missed approach six seconds before impact, he failed to challenge the errors made by the captain earlier in the approach when the captain would have had more time to react. Significantly, the first officer did not challenge the captain's premature descents below 2,000 and 1,440 feet. Moreover, the Safety Board concluded that the captain failed to "react properly" to the callouts.

The Safety Board suggested that the captain's failure to brief the localizer approach could have adversely affected the flight crew's preparation for monitoring the approach. Although the Safety Board was unable to resolve the precise reasons why the flight crew did not adequately monitor and challenge the captain's performance, it did however determine that the failure was causal to the accident.

FLIGHT CREW FATIGUE

The accident occurred after midnight—about 0042 in the flight crew's home time zone. Research has found that this time of day is often associated with degraded alertness and performance, resulting in a higher probability of errors and accidents. The arrival time for Flight 801 was several hours after the captain's normal bedtime (2200 to 2300 Seoul local time) and a time at which his body would have been primed for sleep.

The captain stated that he was "…really…sleepy." He had been awake for 11 hours at the time of the accident—another documented factor in fatigue-related accidents. Regardless of daytime naps in preparation for a night flight, the Safety Board has found that any disruption of a normal sleep pattern can degrade a pilot's performance. Additionally, the captain had been diagnosed on 27 July with bronchitis and had been prescribed a medication that could be used as a sleeping aid. On 28 through 30 July, the captain flew an international round-trip between Korea and the United States. The combined effects of the captain's illness and his long trip across numerous time zones were likely to have caused disruptions in his sleeping schedule that may have continued to affect him at the time of the accident. Therefore, the Safety Board concluded that the captain was fatigued, which degraded his performance and contributed to his failure to properly execute the approach.

PILOT TRAINING

Investigators examined Korean Air's Boeing 747 pilot training and proficiency checking program to determine what effect, if any, it may have had on the performance of the flight crew. They discovered that the only nonprecision approach practiced in simulator sessions was the VOR/DME approach to runway 32 at Seoul's Kimpo Airport, an approach that was quite different than that at Guam.

CONTROLLER PERFORMANCE

The Safety Board concluded that the CERAP controller's performance was "substandard" in that he failed to provide the flight crew with a position advisory when he cleared the flight for the approach, to inform the flight crew or the Agana tower controller that he had observed a rain shower on the final approach path, and to monitor the flight after the frequency change to the tower controller. It could not be determined whether these oversights and procedural errors contributed significantly to the accident, but the Safety Board concluded that strict adherence to ATC procedures by the CERAP controller may have prevented the accident or reduced its severity.

Lessons Learned and Practical Applications

1. *Avoid preconceptions.* The flight crew expected a visual approach and was unprepared when that did not occur. The Safety Board believed this was causal to the accident.
2. *Avoid preoccupation with specific events.* The Safety Board believed that this too was causal to the accident.
3. *Conduct thorough, two-way briefing.* The captain and first officer were out of sync with their understanding of the approach charts. Update and modify your briefing as conditions change inflight.
4. *Avoid confusion—ask and verify.* The flight crew was confused about whether or not the glideslope was operating. The controller could have provided that information.
5. *Monitor and challenge.* The Safety Board was unable to determine why the first officer did not challenge the captain over

errors committed during the approach. The Safety Board believed this was causal to the accident.

6. *Recognize the effects of fatigue.* It seems intuitively obvious that fatigue will denigrate mental alertness and hands-on skill—but many pilots dismiss these problems, perhaps from years of experience in dealing with flying while fatigued.

Reference

National Transportation Safety Board. Aircraft Accident Report: Controlled Flight into Terrain, Korean Airlines Flight 801, Boeing 747-300, HL7 7468. Nimitz Hill, Guam. August 6, 1997.

Case Study I-4: Northwest Airlink Flight 5719

Safety issues: CRM, ADM, situation assessment, situation awareness, cockpit discipline, distraction, intimidation, airmanship, pilot training, flight procedures, airline oversight, and FAA surveillance

On 1 December 1993, a Northwest Airlink Jetstream BA-3100 commuter crashed while on the localizer back course approach to runway 13 at Hibbing, Minnesota.

Probable Cause

The NTSB determined that the probable causes of this accident were the captain's actions that led to a breakdown in crew coordination and the loss of altitude awareness by the flight crew during an unstabilized approach in night IMC. Contributing factors to the accident included the failure of the company management to adequately address the previously identified deficiencies in airmanship and crew resource management of the captain; the failure of the company to identify and correct a widespread, unapproved practice during instrument approach procedures; and the FAA's inadequate surveillance and oversight of the air carrier.

History of Flight

Flight 5719 was a regularly scheduled passenger flight from Minneapolis/St. Paul, Minnesota, to International Falls, Minnesota, with an intermediate stop in Hibbing. The aircraft and crew were assigned to Express II Airlines and operated as a Part 135 Northwest Airlink commuter flight under a marketing agreement with Northwest Airlines. The Jetstream BA-3100 departed Minneapolis/St. Paul 48 minutes late at 1858 Central Standard Time with 16 passengers and 2 crewmembers on board.

Pilot Experience and Performance History

The captain had 7,852 total flight hours, 2,266 in the BA-3100. In 1987, he was hired by Express I Airlines as a first officer on the Saab SF-340 turboprop. Two years later he upgraded to captain on the BA-3100, and in 1990 he qualified as captain on the SF-340. He remained in that position until 1992, when the company reorganized its pilot bases. In order to stay in Minneapolis, he felt forced to become a reserve captain on the BA-3100.

In early 1993, Express I was divided into two companies, Express I and Express II. The airlines were not mutually exclusive so pilots could bid back and forth between the two, as both were covered by the same Airline Pilots Association (ALPA) contract. Since the operations base for Express II was in Minneapolis, the captain switched hats and began flying under the new company name.

The captain's last line check was successfully completed three weeks before the accident. However, the Safety Board noted a history of poor performance dating back to 1980. The captain had failed numerous proficiency checks in both the SF-340 and BA-3100 aircrafts. His flight records showed a series of unsatisfactory remarks from several check airmen and instructors, including: "Poor communication with nonflying pilot," "Head-strong, argumentative, and thought that he was always right," "Seemed to have intimidated first officer candidate," "Weak CRM skills," "Unsatisfactory in crew coordination, powerplant failure, rapid-depressurization-emergency descent," "Captain seemed rushed on emergency descent, did not fly proper profile, weak crew coordination."

About six months before the accident, the captain failed a proficiency check given in a BA-3100 simulator. The check airman found him to be unsatisfactory in "crew coordination, command-judgment, holding, approach to stalls, and stall warning." The captain was retrained and passed the check later the same day.

The captain's personnel record contained several letters of warning by his superiors, and one involved a three-day suspension in 1989. Among other things, the suspension was related to an improper engine start while a ramp agent was standing nearby and to accepting an airplane when the maintenance was incomplete.

The first officer had 2,019 total flight hours, 65 in the BA-3100. He was hired by Express II less than three months before the accident. Records showed that of the six first officer candidates in his training class, he was the only one to have passed his simulator check ride on the first try. He received his initial operating experience in October 1993, and the check airman remarked that "he flew the BA-3100 very well and that he was familiar with line operating procedures."

Weather

At the time of the accident, the Hibbing weather was as follows: sky partially obscured, estimated ceiling 400 feet overcast, visibility 1 mile; light, freezing drizzle, light snow, fog obscuring five-tenths of the sky; temperature/dewpoint; 29°F/27°F.

The Accident

Flight 5719 arrived in the Hibbing area around 1930. The Duluth approach controller gave the crew the option of making either a VOR procedure turn entry to final approach or an arc to the final course. The captain chose the 20-mile arc and told the first officer that the approach is "gonna be…tight…since it's four hundred and one [400-foot ceiling and 1 mile visibility]." The captain then spent close to two minutes explaining the specifics of the approach to the first officer.

At 1944, the controller told the crew that they were "established on the two zero mile arc, you're cleared for the localizer back course one-three approach to Hibbing." The flight's last transmission came from the first officer when he repeated the clearance. Express II provided only one cockpit copy of approach plates to its crews, and since the captain of Flight 5719 was flying, the first officer was assigned to answer questions concerning the progress of the approach.

Consequently, the captain had to ask the first officer, "…since we're established, what altitude can we go down to?" The first officer replied, "Thirty-five hundred."

Although the flight had been cleared to "descend at pilot's discretion, maintain five thousand," more than 10 minutes earlier, the captain had not yet begun the descent. Therefore, the first officer asked, "…you just gonna stay up here as long as you can?" The answer was, "Yes." Radar data showed that the airplane remained at 8,000 feet until 1947:54, when the captain intercepted the localizer approximately 19 nm from the Hibbing VOR.

The captain began the descent as he and the first officer read through the before-landing checklist. The aircraft descended at an average vertical speed of 2,250 fpm, and was 1,200 feet above the minimum altitude when it passed over the final approach fix (FAF) at 1949:30. Seconds later, the aircraft's radar return was recorded at 12.3 DME and 3,000 feet, when the first officer called, "One to go [1,000 feet above the 2,040-foot step-down fix altitude]." The captain was confused by that remark, and asked for clarification.

Immediately thereafter, he instructed the first officer to turn on the runway lights: "Did you…click the…airport lights, make sure the common traffic advisory frequency is set." By this time the aircraft had descended through the 2,040-foot step-down altitude and was continuing to pass through 1,800 feet at 2,500 feet per minute (fpm).

Within seconds, the captain again instructed the first officer to "click it seven times." The first officer responded, "…yeah, I got it now." Approximately one-half second later the CVR picked up sounds similar to metal scraping along an object, followed by the tape abruptly ending at 1950.

Impact and Wreckage Path

The aircraft struck several groups of aspen trees and two ridge lines before it flipped over. The first tree was hit about 1,200 feet from where the main wreckage came to rest. The impact created a huge ground scar that was 66 feet long by 5 feet wide. Although a piece of the right wing leading edge was found embedded in the side of a large aspen tree, the majority of other fragmented debris was scattered along the ground scar. The right side of the fuselage was crushed and destroyed from the nose radome to the aft fuselage area.

ACCIDENT SURVIVABILITY

According to the Safety Board, this accident was not survivable due to the longitudinal impact forces and the breakup of the airplane.

The Investigation

Although weather conditions were conducive for airframe icing, the Board determined that the aircraft did not accumulate enough ice to have caused this accident. Therefore, the primary focus of the investigation was on flight crew performance.

HIGH DESCENT RATE

The reports of light to moderate icing in the clouds around Hibbing appeared to have influenced the captain to stay above the icing conditions until he was closer to the airport. The Board believed that he probably intended to descend at higher than normal rates of speed to minimize the time spent flying in the clouds. All the Express II pilots who were interviewed during the investigation said that it was common practice for them to descend rapidly through icing conditions. The Board noted that this procedure was contrary to the manufacturer's guidelines and violated Express II's policy on stabilized approaches.

In the case of Flight 5719, the crew flew the airplane at a high rate of descent through the FAF. Their actions were directly against the procedures described in the "Climb and Descent Crew Coordination" section of the airline's manual, which specifically details the duties of the flying and nonflying pilots from the top of the descent to the runway-in-sight point. The section stated that the nonflying pilot shall call out 1,000 feet and 300 feet above all assigned altitudes, and 500 feet and 100 feet above the decision height or MDA. Furthermore, "the sink rate should be called out any time it exceeds 1000 fpm after reaching initial approach altitude." Based on the flight's CVR tape, the first officer never made any of those callouts, nor did he call out the MDA when the airplane passed through it.

The Board found a discrepancy between the crew coordination section of the manual and a particular Express II SOP, which might have caused some confusion on the part of their pilots. The descent guidelines from the manual clearly stated, "1000 fpm will be considered the maximum usable rate of descent inside the FAF. Excessive rates of descent shall be cause to abandon the approach." However, the SOP for a "nonprecision straight-in two-engine approach" stated, "During descents, the power should be reduced to maintain a descent rate of at least 1000 fpm." The Board believed that the guidance from the SOP might have allowed pilots to expedite their descents during progressive, step-down, nonprecision approaches so as to reach the MDA within visual range of the airport. Nevertheless, the Board noted that a high descent rate was unnecessary for the localizer (back course) runway 13 approach into Hibbing. Even though there was a conflict between the two sections of the manual, investigators believed that the strong wording in the crew coordination section should have prompted the pilots to have favored those guidelines over those in the SOPs.

In the Safety Board's opinion, the captain did not consider the consequences of a high rate of descent, nor did he take appropriate precautions once he committed himself to such an approach. On the other hand, the first officer never commented on the excessive descent rate inside the FAF, thereby allowing the captain's actions to go unchecked.

CREW PERSONALITY AND INTERACTION

The investigation revealed that the captain was described as being angry with Express II. Although he had been with the company for more than six years, he had to give up his captain's position on the larger SF-340, as well as 12 percent of his salary, and fly the BA-3100 in order to remain based in Minneapolis. The Board interviewed five first officers who had flown with the captain, and they all said that they had felt intimidated by him. One told investigators that he had been hit by the captain when he had mistakenly left the intercom on.

The first officer was much younger than the captain, and because of his probationary status and the captain's intimidating reputation, the Board believed that the first officer might have been reluctant to challenge the captain's decision to fly such an improper and unsafe approach. Coworkers described the first officer as having a positive attitude and being very excited about his new job with Express II. Therefore, he might have perceived that any resistance or opposition toward the captain could jeopardize his career with the airline.

The CVR transcript showed that most of the captain's interactions with the first officer were extremely patronizing. For even the simplest of tasks—such as how to place the approach plate on the yoke clip—the captain was either correcting him or instructing him. The tone of the first officer appeared to always be in a questioning manner, whereas the captain's demeanor sounded aggressive and less receptive. In the final seconds of the flight that attitude proved significant in that the captain was telling the first officer how to turn on the runway lights when the aircraft struck the first tree.

CREW COORDINATION

The Board noted that the captain had the responsibility to foster and maintain effective crew coordination. Since at least 1987, however, he had received unsatisfactory marks for communication, judgment, and cooperation. Those problems were still evident six years later in the cockpit of Flight 5719.

Although the captain spent nearly two minutes discussing the approach procedures to the first officer, he never included the time frame in which he expected certain tasks to be completed. He also did not fly the approach as briefed; therefore, the Board believed that the first officer was kept "out of the loop" and was not adequately prepared to assist the captain during the approach.

The Board determined that the cumulative actions of the captain led to numerous distractions between the captain and the first officer during the critical phase of the approach. These actions subsequently caused a breakdown of crew coordination. As a result, the pilots experienced a loss of altitude awareness that was ultimately created by the captain's poor airmanship and interpersonal skills.

Lessons Learned and Practical Applications

1. *Don't get intimidated by the situation.* As a young or inexperienced pilot, this might be easier said than done. But just remember, you were hired as a crewmember, not a passenger.
2. *Be assertive and challenge.* When you see an unsafe situation developing, speak up!
3. *Maintain cockpit discipline.* Avoid deviating from SOPs and other prescribed flying guidelines.
4. *Avoid distractions at critical phases of flight.* Watch out for anything that takes you away from flying the airplane. Don't compromise the safety of the flight over a minor detail.

Reference

National Transportation Safety Board. 24 May 1994. Aircraft Accident Report: Controlled Collision with Terrain. Express II Airlines, Inc./Northwest Airlink Flight 5719, Jetstream BA-3100, N334PX. Hibbing, Minnesota. December 1, 1993.

Case Study I-5: Avianca Flight 052

Safety issues: CRM, fuel management, role of ATC, traffic flow management, nonstandard phraseology, foreign carrier operations

On 25 January 1990, an Avianca 707 crashed while making a second attempt to land at John F. Kennedy (JFK) International Airport, New York.

Probable Cause

The NTSB determined that the probable cause of this accident was the failure of the flight crew to adequately manage the airplane's fuel load. Furthermore, they did not communicate an emergency fuel situation to ATC before fuel exhaustion occurred. Contributing to the accident was the flight crew's failure to use an airline operational control dispatch system to assist them during the international flight into a high-density airport in poor weather. Additional factors included the inadequate traffic flow management by the FAA and the lack of standardized, understandable terminology for pilots and controllers for minimum and emergency fuel states.

History of Flight

Avianca Flight 052 operated as a regularly scheduled passenger flight from Bogota, Colombia, South America, to JFK International Airport, New York, with an intermediate stop at Medellin, Colombia, South America. The 707 took off from Medellin at 1508 Eastern Standard Time with 149 passengers and 9 crewmembers aboard.

Pilot Experience

The captain had 16,787 total flight hours, 1,534 in the 707. He had been a 707 captain since June 1987. The first officer had 1,837 total flight hours, 64 in the 707. His initial line check for the airplane was one month prior to the accident. The second officer had 10,134 total flight hours, 3,077 in the 707. He requalified in the jet three months prior to the accident.

Weather

According to the NWS, at 0700 a deep low-pressure area was centered over northeastern Illinois. A stationary front extended eastward through Indiana and Ohio, curved northeastward through parts of Maryland, over Long Island, New York, and into eastern Massachusetts. Another stationary front was positioned from central Georgia to as far north as coastal Virginia. As a result, the skies were reported as overcast with rain over all the mid-Atlantic states from southern Virginia to extreme southeastern New York.

An International Airdrome Forecast (IAF) for JFK was activated at 1300 and remained valid for 24 hours. The weather conditions were expected to be: visibility 1 mile; light rain; ceiling 400 feet. Winds southeast at 15 knots with gusts to 25 knots. 8/8 stratus. An IAF for Boston-Logan International Airport (Flight 052's field alternate) was also activated for the same period as the JFK report. The forecast included: visibility 1 mile; light rain; ceiling 800 feet; winds southeast at 15 knots. 8/8 nimbostratus.

ACTUAL WEATHER CONDITIONS

Less than 45 minutes prior to the accident, surface observations at JFK and Boston-Logan were as follows:

JFK 2100: Special; ceiling indefinite; 200 feet obscured; visibility 1/4 mile; light drizzle and fog; wind 190 degrees at 21 knots.

Boston 2050: Ceiling indefinite; 0 feet obscured; visibility 1/8 mile; light drizzle and fog; wind 100 degrees at 9 knots.

The Accident

Flight 052 arrived in Medellin at 1404 following an uneventful 54-minute flight from Bogota. The aircraft was refueled and departed at 1508 for the 4-hour and 40-minute flight to JFK.

Due to the poor weather in the New York area, there were numerous and lengthy flight delays into JFK. The northeast corridor was so congested with traffic that Flight 052 was instructed to enter a 19-minute hold over Norfolk, Virginia. At 1943, Flight 052 was again cleared to hold, this time for 29 minutes at the BOTON intersection, near Atlantic City, New Jersey. The flight crew entered their third and final hold for 29 minutes at the CAMRN intersection, 39 nm south of JFK.

At 2044, while Flight 052 was holding at the CAMRN intersection, New York center advised the crew to "expect further clearance [EFC] at 2105." This had been their third EFC since they had begun holding at CAMRN. The first officer notified center that, "…I think we need priority…" The controller promptly asked, "…roger, how long can you hold and what is your alternate [airport]?" The first officer responded, "…we'll be able to hold about five minutes. That's all we can do." He then added, "…we said Boston, but…it is…full of traffic, I think." When the controller asked him to repeat his alternate, the first officer replied, "…it was Boston, but we can't do it now, we …don't…we run out of fuel now."

A hand-off controller, who was assisting the center controller by monitoring the radio, overheard the fuel situation that Flight 052 had described and called the New York TRACON (terminal radar control), the next control facility that the crew would contact. At 2046, a TRACON controller was notified that, "Avianca 052 just coming on CAMRN, can only do five more minutes in the hold. Think you'll be able to take him, or I'll set him up for his alternate?" After a brief discussion concerning the aircraft's current speed, the TRACON controller told the hand-off controller to, "…slow him to one eight zero knots and I'll take him. He's…radar three [nm] southwest of CAMRN." The entire discussion took only 20 seconds.

After the center controller was informed of the coordination with the TRACON, he advised Flight 052, "…cleared to the Kennedy Airport via heading…maintain one one thousand, speed one eight zero." After the first officer acknowledged the clearance, the flight was handed off to Kennedy approach. Once Flight 052 made initial contact with ATC on the new frequency, the crew was given routine radar services, including altitude and heading changes. At 2054, the controller cleared Flight 052 to a new heading and told the crew that, "…I'm going to have to spin you [360 degree turn]…." A couple of minutes later, Flight 052 was advised of a "…windshear…increase of 10 knots at 1500 feet…increase of 10 knots at 500 feet reported by seven twenty seven." The advisory was acknowledged.

At 2103, Flight 052 was handed off to the Kennedy final controller. The second officer, apparently concerned about the fuel state, reviewed the "go-around procedure with a maximum of 1000 pounds of fuel in any tank." About five minutes later, as Flight 052 descended to 3,000 feet, the crew discussed their landing priority status. There seemed to be some confusion on the part of the captain, and he pressed the issue with the first and second officers. At 2109, the first officer told the captain that "…they [ATC] accommodate us." The second officer added, "They already know that we are in bad condition…they are giving us priority."

When the final controller advised Flight 052 that they were, "…one five miles from the outer marker…cleared ILS two-two left," the captain told the first officer, "select the ILS on my side." For the next few minutes, the crew continued the landing checklist.

At 2115, they contacted JFK tower and were informed that they were "number three to land." Shortly thereafter, the crew was instructed to increase their airspeed by 10 knots. The captain then made a request to the first officer: "Tell me things louder because…I'm not…hearing it." By 2119, they were nearing the outer marker, had intercepted the glideslope, and had lowered the gear. Less than a minute later JFK tower cleared Flight 052 to land.

As the crew completed the checklist, the captain requested, "Give me fifty [degrees of flaps]," and asked, "Are we cleared to land?" The first officer replied, "…we are cleared to land." He added that they were "below glideslope." Seconds later, the controller asked, "…can you increase your airspeed one zero knots at all?" The first officer answered, "Yes, we're doing it."

Less than 3 miles from the approach end of runway 22L, the aircraft encountered windshear. The first and second officers made several "glideslope" and "sink rate" callouts as the GPWS sounded 11 "whoop pull up" voice alerts. Four "glideslope deviation" voice alerts immediately followed. By this time, they were 1.3 miles from the approach end of 22L and at an altitude of 200 feet. The captain urgently asked, "The runway, where is it?" The first officer replied, "I don't see it." The captain commanded, "…landing gear up" and began to execute a missed approach.

The final controller instructed Flight 052 to, "climb and maintain two thousand [feet], turn left heading one eight zero." The first officer acknowledged the clearance, as the crew discussed their surprise over not seeing the runway. About 30 seconds later, the controller asked Flight 052 if they were turning to the new heading, but by that time the captain realized the seriousness of the fuel situation, and told the first officer to "tell them we are in emergency." At 2124, the first officer erroneously repeated the heading clearance ("right turn," instead of a left turn) back to ATC and added, "…we'll try once again, we're running out of fuel." The controller replied, "Okay." Seconds later, the captain pressed the first officer to "advise him we are emergency," and "Did you tell him?" The first officer replied, "Yes sir, I already advised him."

At 2124:55, the first officer contacted the TRACON and informed the controller that, "…we just missed a missed approach…maintaining two thousand.…" The controller cleared them to "climb and maintain three thousand." The captain again told the first officer to "advise him we don't have fuel." At 2125:10, the first officer acknowledged the clearance to "climb and maintain three thousand" and added, "We're running out of fuel." When the captain asked the first officer if he had,

"…advise[d] that we don't have fuel," he answered, "Yes sir. I already advise him hundred and eighty on the heading. We are going to maintain three thousand feet, and he's going to get us back." The captain replied, "Okay."

About one minute later, the final controller told Flight 052, "…I'm going to bring you about 15 miles northeast and then turn you back on for the approach. Is that fine with you and your fuel?" The first officer responded, "I guess so, thank you very much." However, by 2129:11 the aircraft's fuel supply was so low that the first officer asked the controller, "…can you give us a final now?" The controller immediately replied, "Affirmative," and gave him a new heading. Several seconds later the controller told Flight 052 to "climb and maintain three thousand," but the first officer answered, "…negative…we just running out of fuel, we okay three thousand now, okay?" As the crew received yet another heading change, they proceeded to set the flaps and monitor the flight instruments.

At 2131:01, the controller advised Flight 052 that they were "…number two for the approach. I just have to give you enough room so you make it without…having to come out again." Just more than a minute later the second officer exclaimed, "Flame out, flame out on engine number four. Flame out on engine number three, essential on number two or number one." At 2132:49, the captain said, "Show me the runway."

The first officer immediately told ATC, "…we just…lost two engines and…we need priority, please." The final controller advised him that they were 15 miles from the outer marker, and to "maintain two thousand until established on the localizer, cleared for ILS two-two left." At 2133:23, the first officer replied, "It is ready on two." That was the last radio transmission from Flight 052.

Impact and Wreckage Path

The airplane crashed on an up-sloping hill in a wooded residential area. Refer to Fig. I-A. The main section of the fuselage came to rest 21 to 25 feet after impact. The cockpit and forward cabin separated from the remainder of the fuselage and stopped 90 feet in front of the main wreckage.

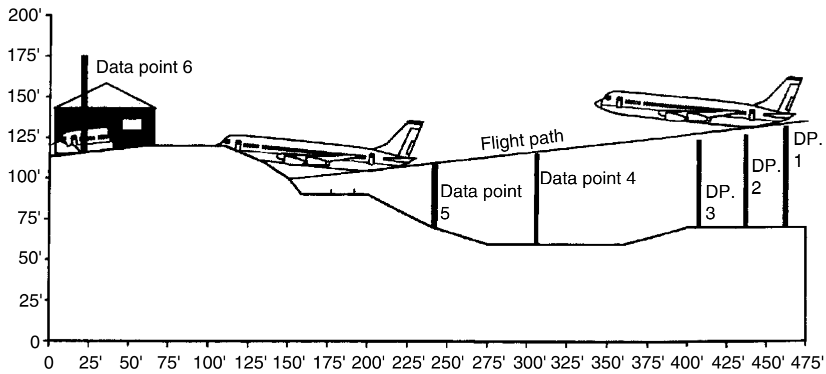

Fig. I-A. Side view of terrain impact. Adapted from NTSB.

The fuselage was found partially separated into three sections. Debris from the cabin, including passenger seats, parts of the galley, and overhead bins, was scattered along the wreckage path. Some of the debris was found as far as 100 feet beyond the cockpit section.

The cockpit was substantially damaged when the right side struck a huge oak tree (with a 42-inch diameter), which penetrated the flight crew compartment. There was also considerable damage near the midsection of the cabin, caused by a fracture in the longitudinal floor track beam. Consequently, the floor dropped 3 inches on the right side, shearing the outboard legs of numerous seat assemblies. Those passenger seats were found outside of the cabin, just forward of the wing. The damage inside the aft cabin section was extensive. The cabin had rolled slightly to the left and had cracked open. Most of the seat assemblies had separated from the floor tracks and were thrown from the fuselage.

ACCIDENT SURVIVABILITY

The flight crew sustained fatal injuries, along with 5 flight attendants, 65 passengers, and 1 infant. The Board could not determine where all the passengers were seated at the time of impact because the airline assigned seats to only a small percentage of passengers. It was also noted that since the aircraft was not full, passengers freely changed their seats throughout the flight. For those reasons, the Board was unable to accurately develop an individual injury diagram for each passenger.

Of the 74 survivors, most of those who received serious injuries sustained multiple fractures of the lower extremities, hips, and spine. They also suffered head trauma, bone dislocations, lacerations, and contusions. According to investigators, there were three nearly simultaneous events that occurred at the time of impact that would account for these types of injuries. Most likely, as the passengers' legs were jolted upward against the bottom of the seat units in front of them, the seats collapsed and twisted downward. The seat assemblies then separated from their floor attachments, which caused each seat to be pushed forward. While this domino effect was still in motion, passengers were thrown into other passengers, seat units, and various wreckage debris.

Of the 10 surviving infants on board, 8 sustained serious injuries. The Board determined that all the infants were either being held by an adult or belted into the same seat with the passenger. Each adult who was holding an infant at the time of impact stated that the child was ejected from his or her grasp and was unable to be located in the dark.

According to the lead flight attendant, there was no warning from the cockpit crew regarding the low fuel status, loss of engines, or impending emergency landing. Therefore, the passengers had not been recently briefed on brace positions, nor were they given pillows and blankets to help cushion the force of the impact. The Board believed that if either of these procedures had been carried out, some passengers might not have suffered as severe injuries.

FAA VS. ICAO STANDARDS

Since 1980, the FAA has required cockpit seats to be equipped with combined seat belts and shoulder harnesses; however, the International Civil Aviation Organization (ICAO) failed to address those types of restraint systems. Seats for the captain and first officer on Flight 052 did not have shoulder harnesses. All three crewmembers died from blunt force head and upper torso trauma.

In 1988, the FAA *required* the installation of emergency path lights on the cabin floor, whereas, ICAO had only *recommended* installation of such lights. According to the Board, those lights might have been useful during the rescue operation of Flight 052, since the piles of debris and the dark cabin hampered emergency workers' efforts.

The Investigation

The evidence gathered during the early days of the investigation confirmed that Flight 052 crashed due to fuel exhaustion. Beyond the obvious clues left by the crew on the CVR tapes, the Board noted that there was no fire at the accident site, and there was only residual fuel found in the airplane. There was no rotational damage to any of the four engines from impact forces, which indicated that they had stopped operating before hitting the ground. Furthermore, the investigation team observed no engine or fuel system component malfunction that would have caused either premature fuel exhaustion or an interruption of the fuel supply to the engine.

WEATHER PLANNING

Although weather data provided to the flight crew before departure from Medellin was 9 to 10 hours old, it still showed that JFK and Boston-Logan were forecast to have low ceilings and restricted visibility for that evening. The Syracuse and Buffalo, New York, airports were expecting weather at the required minimums; however, neither was listed as possible alternates on the documentation that the crew received. During the investigation, it was learned that Boston was chosen as the alternate as part of a computer-generated flight plan created for all flights bound for JFK without regard to weather forecasts.

Because Avianca was a foreign carrier and its Flight 052 operated in U.S. airspace, the crew was required to comply with all applicable ICAO standards and FARs. According to FAR Part 121.625, "No person may list an airport as an alternate…unless the appropriate weather reports or forecasts…indicate that the weather conditions will be at or above the alternate weather minimums specified in the [airline's] operations specifications for that airport when the flight arrives." Similarly, ICAO Annex 6, 4.3.6.1 states, in part, "A flight shall not be commenced unless taking into account both the meteorological conditions and any delays that are expected in flight.…"

The operations' specifications issued to Avianca by the FAA provided detailed criteria for standard weather minimums at alternate airports. According to the document, "…weather minima applicable to [flights] designated for dispatch…are 600 [ceiling] and 2 [visibility in sm] at airports served by precision approach procedures." However, the airline's policy manual stated, "…when an afternoon or evening takeoff, with a night landing is scheduled, the requirements for the destination, alternate…airports are a 1000 foot ceiling and 10 km (6.2 sm) visibility." JFK and Boston-Logan did not meet any of the minimum criteria throughout the entire day. The Board believed that although the flight crew should have taken a more active role in determining their planned alternate, the inadequacies of Avianca's dispatch services might have affected the crew's performance.

FUEL PLANNING

United States federal and ICAO regulations are similar in content and are very specific about fuel supply requirements. FAR Part 121.645 indicates:

> …no person may release for flight or takeoff a turbine-engine powered airplane, unless, considering wind and other weather conditions expected, it has enough fuel:
>
> (1) To fly to and land at the airport to which it is released;
>
> (2) After that, to fly for a period of 10 percent of the total time required to fly from the airport of departure to, and land at, the airport to which it was released;
>
> (3) After that, to fly to and land at the most distant alternate airport specified in the flight release;
>
> (4) After that, to fly for 30 minutes at holding speed at 1500 feet above the alternate airport.

Furthermore, an excerpt of FAR Part 121.621(b) states, "…the weather conditions at the alternate airport must meet the requirements of the air carrier's operations specifications."

The ICAO Annex 6, 4.3.6.4 closely parallels the regulations in FAR Part 121 when it states, "In computing the fuel and oil required…the following shall be considered: meteorological conditions forecast…expected air traffic control routings and traffic delays…one instrument approach at the destination aerodrome, including a missed approach and…any other conditions that may delay the landing of the airplane or increase fuel and/or oil consumption."

Airline personnel stated that pursuant to standard operating procedure, a dripstick, in addition to the fuel bay and cockpit fuel panel gauges, was used to ensure that the requested fuel was properly loaded into the tanks.

According to the Board, the airplane had sufficient fuel to complete its flight safely, provided there were no extensive delays. But as we already know, Flight 052 encountered weather and traffic delays totaling one hour and seven minutes.

FLIGHT CREW COMMUNICATIONS

It is important to note that all the intracockpit conversation was spoken in the flight crew's native Spanish language. Although their radio communication with ATC was in English, it was mostly regarded as broken. This was especially true as the crew's stress level rose and critical information had to be discussed in a hurried manner.

The first indication that the flight crew had some concerns about weather, and possibly the fuel state, occurred about 2009. After being in a holding pattern for 26 minutes, the crew asked the Washington center controller about delays into Boston. He told them that Boston was open and accepting traffic, but they could expect an additional 30 minutes of holding in the New York center airspace.

Unfortunately, the CVR tape saved only the final 40 minutes of intracockpit conversations prior to the accident; therefore, the Board was unable to learn whether the crew discussed their fuel situation as they held at CAMRN. However, it was apparent from the air-to-ground communication that by 2045 the crew knew they could no longer hold and asked for "priority." The first officer responded to the New York center controller inquiries by informing him that they were "able to hold about five minutes, that's all we can do." He added that Boston was their alternate, but "we can't do it…we run out of fuel now."

Although the center and TRACON controllers coordinated a quick hand-off for Flight 052, they were unaware of the criticality of the aircraft's fuel because the crew never directly told them how serious it was. At 2054, the crew was given a routine 360-degree turn for sequencing and spacing with other arrival traffic, which, in the Board's opinion, should have alerted the crew that they were not getting priority handling. At that time if they had declared an emergency, or at least requested direct routing to the final approach, the Board believed that Flight 052 would have been able to arrive with an acceptable minimum fuel level.

At 2103, without prior discussion, the second officer led the review of the missed approach procedure with less than 1,000 pounds of fuel in any tank. About six minutes later the first officer made the comment, "They [ATC] accommodate us," followed by the second officer replying, "They already know we are in bad condition." When the captain questioned the descent clearance, the first officer told him that they were cleared to "one thousand feet," to which the captain replied, "Ah, yes." The Board believed that from his response and the tone of his voice, he had understood the controller to be giving them special handling. The second officer reinforced this notion when he answered, "They are giving us priority." This conversation suggested to the Board that the flight crew thought ATC was aware of their critical situation and that they were receiving "priority." However, from the time that had elapsed and the seemingly routine nature of the vectoring, it should have been apparent to the flight crew that they were not receiving an expeditious approach clearance. No direct inquiries, though, were ever made to verify their priority status.

Shortly after the captain initiated the missed approach, he told the first officer, "Tell them we are in emergency." But instead, the first officer explained to ATC that "…we'll try once again, we're running out of fuel." Seconds later, at 2124, the captain again told the first officer to "advise him we are emergency." When the captain pressed him for an answer, "Did you tell him?" he replied, "Yes sir, I already advised him." The first officer never used the word "emergency" as instructed by the captain, so, therefore, he failed to communicate the urgency of the situation.

Less than a minute later, the captain told the first officer, "Advise him we don't have fuel." After a second inquiry, "Did you already advise that we don't have fuel?" the first officer said, "Yes sir, I already advise[d] him…and he's going to get us back." At 2126, the approach controller asked the crew if they could accept a base leg of 15 miles northeast of JFK, to which the first officer replied, "I guess so." However, three minutes later, and without prompting from the captain, the first officer said to the controller, "…can you give us a final now…" From the lack of vital information associated with the sudden request, the controller continued to provide Flight 052 with routine vectors. The crew never challenged those vectors or told ATC of their emergency fuel status.

According to the Safety Board, the intracockpit conversations indicated a "total breakdown in communications by the flight crew in its attempts to relay the situation to ATC." The Board noted that even though the crew had obvious limitations in their ability to use the English language, they were also unable to communicate effectively among themselves in Spanish.

Although the captain repeatedly told the first officer to tell ATC they had an emergency situation, the first officer never conveyed that message. The evidence strongly suggested that the captain was unaware, at times, of the content of the first officer's transmissions, and that he did not hear or understand the ATC communications. The captain might have been preoccupied with flying the airplane and paid little attention to the first officer's radio calls. Regardless, the Board believed it was more likely that his limited command of the English language prevented him from effectively monitoring the content of the transmissions. Furthermore, the Board believed that this deficiency might have been a factor in the accident, particularly if the captain thought the first officer had adequately expressed the criticality of the fuel state when they left the holding pattern at CAMRN.

Another point of significance was the crew's possible confusion between the terms *priority* and *emergency.* Avianca flight crews were trained primarily with the use of Boeing manuals. In one such bulletin it stated, "…during any operation with very low fuel quantity, priority handling from ATC should be requested." Similar procedures were published in the airline's own manuals. During the investigation, several Avianca pilots testified that the Boeing-trained flight and ground instructors conveyed the impression that the words *priority* and *emer-*

gency were interchangeable with standard ATC phraseology. That assumption might have explained why the first officer said to the approach controller, "…we just…lost two engines…we need priority, please." It might also have accounted for the first officer's positive responses to the captain when asked if he had advised ATC of their emergency situation.

FLIGHT CREW PERFORMANCE

According to the Board, three key factors contributed to the inability of the captain to remain on the glideslope when he attempted the first ILS approach. First, the prevailing weather conditions and subsequent low-level wind shear activity near 22L caused abnormally high headwind components at Flight 052's final approach fix altitudes. The wind speed was at least 60 knots at 1,000 feet, about 50 knots at 500 feet, and almost 20 knots at the surface. As the captain intercepted the glideslope he called for 40 degrees of flaps followed less than a minute later with 50 degrees of flaps. He also made thrust and pitch adjustments to establish a rate of descent that would have been normal for a light headwind component rather than the actual and more severe conditions. As a result of these inappropriate configurations, the airplane immediately descended below the glideslope. The FDR revealed that the captain delayed in his reaction and "chased" the glideslope with progressively greater control inputs. From this data it was determined that the captain never established a stabilized descent.

Second, the Board believed the captain showed signs of fatigue due to the rigors of such a tedious flight. It was also possible that maintenance problems with the autopilot and flight director might have caused the crew to manually fly the aircraft from Medellin, and forced the captain to attempt the first ILS approach without the aid of a flight director. It was observed that from the time Flight 052 was on the final vector to the localizer until the missed approach, there were nine distinct incidents of the captain asking for instructions to be repeated, or for confirmation of the airplane's configuration. There was also one request from the captain for the first officer to speak louder.

And third, the captain's performance might have been compromised from the steady increase in aggravated stress levels. The critical fuel state obviously caused stress to the entire flight crew; however, the captain had made repeated attempts to ensure that the first officer was advising ATC of their situation. The captain became progressively insistent that ATC be told, “We have emergency,” and because of his limited English speaking skills, he might have felt restricted in having to rely on the first officer for all the communications.

A BILINGUAL BREAKDOWN IN CRM

Regardless of the fact that the flight crew had a language barrier with ATC, the final 40 minutes of intracockpit conversations revealed a breakdown in effective communication in their own native tongue. According to the transcripts, the captain never led a discussion on any decisive measures that would be necessary to ensure a safe landing. He depended on the first officer for all the communications and clearance information. Even though the flight did not seem to be receiving expeditious handling, the captain did not perform an adequate crosscheck of the first officer’s duties. And, although the captain repeatedly told the first officer to use the word *emergency,* he never once recited that command to ATC. Therefore, the first officer appeared to have assumed a slightly more influential role in the cockpit than the captain. There was also no reference in the transcripts of the second officer providing the captain with important fuel burn calculations—nor was he ever asked.

Granted, the crew’s limited command of the English language was a detriment to the safety of the flight; however, their own inability to effectively communicate as a cohesive team, with a strong leader, most likely created a weak CRM environment. It was possible if the crew had actively worked together to make a clear plan of action, that this message could have been conveyed to ATC, even if it could only be delivered in broken English. Vague and ambiguous statements (“Can only do five more minutes.” “[Can’t do] Boston, full of traffic, I think.” “Running out of fuel.”) and inappropriate requests (“We need priority, please.”) would most likely have been replaced with something to the effect of, “Emergency! Low fuel! Must land now!”

ATC COMMUNICATIONS

Considering the information ATC personnel had received from Flight 052, the Board concluded that ATC had handled the flight in an appropriate manner. During the investigation, the Board had some concern over the seemingly lack of significance many controllers placed on the term *priority*. Although the controllers stated that the word *priority* does not require them to provide emergency responses, the Board noted that it is defined in the ATC Handbook as a request that provides "precedence, established by order of urgency or importance."

The New York center controller testified that he felt he had adequately assisted the flight since the crew said they could only hold for five more minutes, and he coordinated the hand-off to the TRACON in less than a minute. He had interpreted Flight 052's statement to mean that they needed to leave the holding pattern within five minutes. He further testified that he did not hear the crew add, "…we can't do it now [fly to Boston], we run out of fuel now." Consequently, when the hand-off controller contacted the TRACON about accepting the aircraft for JFK, he advised that Flight 052 was near the CAMRN intersection and that they could only "do five more minutes in the hold." Therefore, when the TRACON controller set up Flight 052 for the approach he was unaware of any fuel problems or requests for special handling.

The Board believed that, although the TRACON and JFK tower controllers should have clarified the crew's comments about "running out of fuel," put in context, the statements were not reinforced by any indication of an emergency situation. In fact, at 2126, when the TRACON controller was providing Flight 052 with vectors for the second ILS approach, he asked the crew, "I'm going to bring you about 15 miles northeast and then turn you back for the approach. Is that fine with you and your fuel?" The first officer replied, "I guess so, thank you very much." Moments later, the first officer refused a vector to climb and said, "…we…running out of fuel…we okay three thousand.…" Even at that point, he did not convey the situation clearly to ATC. In less than three minutes the engines began to flame out.

EFC CONFUSION

The Board also believed that the flight crew might have misunderstood the purpose of the three EFCs issued by ATC. An EFC is strictly a time reference so a pilot knows when to expect the next clearance. However, in the case of Flight 052 it was possible that they assumed they would receive approach vectors instead of additional holding clearances at the specific times of their issued EFCs.

FLOW CONTROL AND THE WEATHER

The Board discovered that on the day of the accident, the FAA's Central Flow Control Facility had a traffic management program in effect for JFK that was designed to accept 33 arrivals per hour on 22L/R. Although engineered performance standards for the airport revealed that this number was quite high in IFR conditions, it was noted that it was based upon the assumption that the volume of expected flight cancellations would offset the acceptance rate of 33 aircraft.

Meanwhile, the NWS failed to advise the traffic management personnel of the severe wind conditions at JFK, which prevented ATC from providing appropriate separation in the approach control airspace. Therefore, the combination of ill-informed controllers and the deteriorating weather caused extensive airborne holds of more than one hour.

The Board determined that even though numerous aircraft had executed missed approaches on 22L because of poor weather, flow control personnel still allowed an acceptance rate of 33 airplanes per hour. In the Board's opinion, flow control did not react appropriately or timely enough to prevent the large numbers of aircraft from being stacked in holding patterns. When flow control did implement a ground stop for traffic destined for JFK, the action was too late to alleviate the airborne holding problem that had already begun.

THE PILOT AND CONTROLLER CONNECTION

Although the pilot-in-command is the one who is ultimately responsible for the safety of a flight, air traffic controllers also share in that responsibility. In this case it was apparent to ATC that they were working with a foreign carrier and talking with a pilot who spoke in broken English. Between 2044 and shortly before impact, the first officer asked for "priority" twice. On four separate occasions, during the same period, he advised ATC that they were low on fuel, yet no controller directly asked him to clarify his statements. Regardless of the fact that ATC was very busy that evening, it would seem reasonable and logical for a controller to question a foreign pilot who makes the statement, "We're running out of fuel."

There were numerous accumulative factors that proved significant in the events that led to this accident, one of which might have been a breakdown in the pilot-controller team effort. Quite simply, the philosophy of this concept is to look out for each other, and when one drops the ball the other is there to pick it up. In the case of Flight 052, it was especially critical because half of the "team" had a limited English vocabulary and was using nonstandard ATC phraseology.

Lessons Learned and Practical Applications

1. *Communicate clearly and directly.* Don't mince words. If you have an emergency or precautionary situation, then say so. Let ATC know the seriousness of your problem and make specific requests.
2. *Use standard phraseology.* This prevents misinterpretations and second-guessing.
3. *Speak up.* If you've already followed lesson 1, and you still think ATC is not getting the message, tell them again until you're sure they understand.

Reference

National Transportation Safety Board. 30 April 1991. Aircraft Accident Report: Avianca, the Airline of Colombia, Boeing 707-321B, HK 2016. Fuel Exhaustion. Cove Neck, New York, January 25, 1990.

Case Study I-6: American Eagle Flight 3379

Safety issues: Pilot judgment, pilot decision-making, airmanship, CRM, training, hiring practices, FAA surveillance

On 13 December 1994, an American Eagle Jetstream J-3201 commuter crashed while attempting to land at Raleigh-Durham International Airport (RDU), North Carolina.

Probable Cause

The NTSB determined the probable causes of this accident were (1) the captain's improper assumption that an engine had failed, and (2) the captain's subsequent failure to follow approved procedures for engine failure, single-engine approach and go-around, and stall recovery. Contributing to the cause of the accident was the failure of the AMR Eagle/Flagship management to identify, document, monitor, and remedy deficiencies in pilot performance and training.

History of Flight

Flight 3379 was a regularly scheduled commuter flight from Greensboro, North Carolina, to RDU. The aircraft and crew were from Flagship Airlines, which operates as an American Eagle commuter under a marketing agreement with American Airlines. The J-3201 departed Greensboro at 1753 Eastern Standard Time with 18 passengers and 2 crewmembers on board.

Weather

The weather forecast for RDU after 1800 was as follows: 800 feet scattered, 2,500 feet broken; visibility at 5 miles with fog; winds from 040 degrees at 10 knots; occasional 800 feet broken, visibility 3 miles; light rain, light drizzle, and fog up to 2100.

The 1551 surface observation for RDU included: Measured 500 feet broken, 2,000 feet overcast; visibility at 2 miles with light drizzle and fog; temperature/dewpoint, 36°F/33°F; winds from 010 degrees at 10 knots.

Pilot Experience and Background

The captain had 3,499 total flight hours, 2,294 in turboprop aircraft. He had accumulated 457 hours in the J-3201 as pilot-in-command (PIC). In 1990, he was hired by another commuter airline, Comair.

During the one year that he spent as a probationary first officer on the Saab 340, he received numerous unsatisfactory reports in his flying records. Some of these reports indicated problems in the following areas: takeoff with simulated powerplant failure, ILS approach-normal, ILS approach-manual, no-flap approach, crosswind landing, landing from an ILS, no-flap landing, and judgment. Various check airmen also wrote comments such as: “Still needs some work on his landings and operational procedures,” “Still having some problems judging approach and landing procedures. Final approach is weak and landing flair needs a lot of work,” and “Flat landing, had to help.”

Comair records also contained three evaluation reports regarding his performance. One was written by a Comair captain, which stated, “Flight skills expressed some concern…most always on instrument approaches…some abrupt inputs. Occasionally produces departures from heading or altitude.” Another report noted that he “often lost situational awareness,” and there was concern that he would “freeze up or get tunnel vision in an emergency situation.”

At the conclusion of the one-year probationary period, the captain did not show signs of substantial improvement and was, therefore, dismissed from the company. The captain was allowed to resign in lieu of the termination of his employment.

The captain was hired by Flagship Airlines four days later. He completed his initial training as first officer in the J-3201 and remained assigned to that airplane for the next year. In January 1992, he was selected for captain upgrade training in the Shorts (SD3-60) aircraft. According to company records, he received unsatisfactory progress marks in nondirectional (radio) beacon (NDB) approaches, single-engine/nonprecision approaches, airspeed control while flying ILS, crosswind takeoff and landing, engine failure, and single-engine missed approaches. After additional training sessions, he finally passed his check ride.

In September 1992, he began upgrade training on the J-3201. A month later, he failed his type check ride given in the simulator. The flight examiner believed that he cut the ride short because there were so many unsatisfactory marks early on. He passed his check ride a few weeks later.

The first officer of Flight 3379 had 3,452 total flight hours, 677 in the J-3201. He was hired by Flagship in December 1993. Interviews with check airmen and pilot peers indicated that he was an above-average pilot.

The Accident

Around 1814, the crew contacted RDU approach and advised the controller they were maintaining 9,000 feet and had the current ATIS information. They were told to expect the ILS approach to runway 5L. About nine minutes later, the crew was instructed to descend to 6,000 feet. After contacting the final controller, the crew was subsequently cleared for the ILS 5L approach at or above 2,100 feet. At 1832, the local controller cleared Flight 3379 to land on runway 5L. That was the last transmission from the crew.

Impact and Wreckage Path

The airplane crashed in a heavily wooded area at 1838. Based on FDR analysis, the Board determined that the aircraft struck the trees at about 170 knots and at a descent rate of more than 10,000 fpm. It came to rest approximately 4 miles from the runway threshold, just south of Interstate 40. The fuselage broke into two distinct sections, each about 25 feet from the other. Wreckage was scattered over a 500-yard area.

ACCIDENT SURVIVABILITY

The flight crew and 13 passengers sustained fatal injuries.

The Investigation

According to the CVR transcripts, after the flight passed the outer marker, the captain called for the landing gear to be extended and flaps set at 20 degrees. The first officer complied. As the captain increased the propeller's revolutions per minute (RPMs), an automatic ignition annunciator lit, which prompted him to ask the first officer, "Why's that ignition light on? We just had a flame out?" The first officer replied, "I'm not sure what's going on with it." At that, the captain declared, "We had a flame out."

The Board noted from the sounds recorded on the CVR that the propeller synchronization seemed to have been interrupted for at least eight seconds. The captain was flying the airplane when, the Board believed, he thought one of the engines had failed. Neither pilot, apparently, had identified which unit was the problem.

Investigators suspected that the low-frequency sounds might have indicated that one engine's negative torque sensing (NTS) system had activated. On this particular Jetstream engine, a negative torque condition occurs when power decreases significantly and the propeller attempts to drive the engine. Cyclic operation of the NTS results in a fluctuating RPM of the propeller. The NTS also activates the automatic ignition system.

The Board believed that in response to the ignition annunciator, the first officer prepared to start both engine ignition systems and commented that it appeared the left engine had failed or lost power. The captain agreed, as the first officer asked, "What do you want me to do? You going to continue [the approach]?" The captain initially decided to proceed with the approach, but three seconds later changed his mind and told the first officer they would execute a missed approach.

Less than two seconds later, the CVR recorded a sound similar to that of the aircraft's stall-warning system. The first officer told the captain to "lower the nose, lower the nose, lower the nose." Additional stall alarms sounded, indicating that both wings were about to stall, when the first officer repeated the phrase again. He asked the captain, "You got it?" The captain answered, "Yeah." The first officer then told the captain: "It's the wrong, wrong foot, wrong engine." Both propellers were out of synchronization for about four seconds, as the stall-warning horns continued to sound until the airplane crashed.

Investigators discovered that the engines and propellers were rotating at impact. Based on a spectral study of the recorded engine noises, the propellers were rotating between 96 and 101 percent of their RPM limit.

Lessons Learned and Practical Applications

1. *Stay ahead of the airplane.*
2. *Monitor and cross-check instruments.*
3. *Understand and memorize what the normal instrument readings should be.* This reduces the possibility of performing incorrect procedures (i.e., shutting down the good engine) in an emergency.

4. *Know your airplane's particular flight characteristics and limitations.*
5. *Be an effective crewmember.* Inexperience is not a legitimate excuse.

Reference

National Transportation Safety Board. NTSB Identifier: DCA95MA006, Flagship Airlines (D.B.A. American Eagle), December 13, 1994.

Case Study 1-7: John F. Kennedy, Jr.

Safety issues: Spatial disorientation, pilot judgment and decision-making, night flying over water, weather conditions

On the evening of 16 July 1999, a private pilot crashed into the Atlantic Ocean near Martha's Vineyard, Massachusetts, after experiencing spatial disorientation.

Probable Cause

The NTSB determined that the probable cause of this accident was the pilot's failure to maintain control of the airplane during a descent over water at night, which was a result of spatial disorientation. Factors in the accident were haze and the dark night.

History of Flight

The flight was arranged for a pleasure trip from Essex County Airport, New Jersey, to Hyannis, Massachusetts, with an intermediate stop in Martha's Vineyard. The pilot had planned to drop off his sister-in-law in Martha's Vineyard; he and his wife would then continue to Hyannis.

Pilot—Relevant Medical Background

According to medical records, the pilot fractured his left ankle in a hang gliding accident on 1 June 1999, and underwent surgery the next day to repair the damage. On 23 June, the pilot's leg was removed from a cast and placed in a more functional cast until doctors removed that cast on 15 July. The following day—the day of the accident—the pilot was given a straight cane and a note was placed in his medical records stating, "[pilot] full-weight bearing with mild antalgic gait."

The pilot's physical therapist told investigators that the pilot did not have full dorsiflexion (bending upward of the foot) restored and he could not determine whether the pilot's gait was caused by his slight limitation of motion or by mild pain.

The pilot's orthopedic surgeon, however, stated that at the time of the accident he believed the pilot would have been able to apply the type of pressure with his left foot that would normally be applied by the right foot when breaking in a car.

According to Title 14 of the Code of Federal Regulations (14 CFR), Section 61.53, "Prohibition on Operations during Medical Deficiency," a person shall not act as pilot-in-command when he or she knows…of any medical condition that would make the person unable to meet the requirements for the medical certificate necessary for the pilot operation." An FAA medical doctor told investigators that a pilot with this type of ankle injury would not usually be expected to receive approval from an FAA medical examiner before resuming flying activities.

Pilot Experience

The pilot's estimated actual flight experience was 310 hours, of which 55 hours were at night and 72 hours were without a certified flight instructor (CFI) on board. The pilot's estimated flight time in the accident airplane was about 36 hours, of which 9.4 hours were at night. Approximately 3 hours of that flight time were without a CFI on board, and 0.8 hour of that time was flown at night, which included a night landing. In the 15 months before the accident, the pilot had flown about 35 flight legs between the Essex County/Teterboro, New Jersey, area and the Martha's Vineyard/Hyannis area. The pilot flew over 17 of these legs without a CFI on board, including at least 5 at night. The pilot's last known flight in the accident airplane without a CFI on board was 28 May 1999.

In 1982, the pilot began flight instruction and over the next six years logged 47 hours, 46 hours of which were dual instruction. Investigators discovered the pilot did not make any logbook entries for over a nine-year period, until December 1997 when he enrolled in Flight Safety International in Vero Beach, Florida, to obtain his private pilot certificate. For the next four months, the pilot flew 53 hours, 43 hours of which were dual instruction. According to his primary CFI, the pilot had "very good" flying skills for his level of experience. The pilot passed his private pilot check ride in April 1988 and returned to New Jersey to fly his personal Cessna 182 and continue with flight instruction from local CFIs. During the calendar year of 1998, the pilot flew approximately 179 hours, including 65 hours without a CFI on board.

In March 1999, the pilot passed his FAA instrument written exam, and a few weeks later he returned to Flight Safety International to begin an airplane instrument rating course. The pilot's primary CFI stated that the pilot's progression was normal and that he grasped all the basic skills needed to complete the course; however, the CFI recalled the pilot having difficulty completing the course lesson on VOR and NDB operations. The CFI noted that it took four attempts before the pilot satisfactorily completed the lesson and added that the pilot had trouble managing multiple tasks while flying, a situation the CFI felt as normal for the pilot's level of experience. Otherwise, the CFI stated that the pilot's basic instrument flying skills and simulator work were excellent.

The pilot received his instrument training in Vero Beach primarily on weekends, and for the three weeks that he attended the program, he accrued 13 flight hours with a CFI on board and nearly 17 hours of simulator time.

The pilot returned to New Jersey to continue his instrument training in his newly purchased Piper Saratoga, the accident airplane. Between May 1998 and July 1999, the pilot flew with three different CFIs. One of the CFIs had accumulated 57 hours of flight time with the pilot, including 17 hours of night flight and 8 hours flown in IMC. The CFI had made six or seven flights to Martha's Vineyard with the pilot in the accident airplane. The CFI told investigators that most of the flights were conducted at night and that the pilot had no trouble flying the airplane. From his observations of the pilot, the CFI believed he was methodical about his flight planning and very cautious about his aviation decision-making. The CFI added that the pilot had the capability to conduct a night flight to Martha's Vineyard provided there was a visible horizon.

A second CFI flew with the pilot on three occasions. One of the flights was on 25 June 1999 from Essex County Airport to Martha's Vineyard. Although the flight was in VMC, an instrument approach was required into Martha's Vineyard in which the CFI demonstrated a coupled ILS approach to runway 24. The pilot performed the landing, but the CFI had to assist with the rudders because of the pilot's injured ankle. The CFI remarked that the pilot's ability to handle multiple tasks while flying were average for his level of experience.

A third CFI had accumulated 39 flight hours with the pilot, including 21 hours of night flight and 0.9 hour flown in IMC. He too had flown with the pilot to Martha's Vineyard, the last time on 1 July 1999. The CFI told investigators that the flight was conducted at night and had turned IMC at the Martha's Vineyard airport. He added that because the pilot was wearing a functional cast on his leg, he had to taxi the airplane and assist the pilot with the landing. The CFI further stated that while the pilot was not ready for an instrument check ride on 1 July, he believed that he had the ability to fly the airplane without a visible horizon but may have had difficulty performing additional tasks under such conditions. Moreover, the CFI told investigators that he would not have felt comfortable with the pilot conducting a night flight in weather conditions similar to those that existed on the night of the accident. He had spoken with the pilot on the day of the accident and offered to fly with him on the accident flight, but the pilot replied that "he wanted to do it alone."

Weather Conditions

According to Weather Service International briefing logs, the pilot made two weather requests from the company's PILOTbrief website around 1833 on the day of the accident. He requested both a radar image and a route briefing from Teterboro to Hyannis with Martha's Vineyard as an alternate. The pilot received enroute weather observations from 11 locations, with visibilities varying from 4 miles in haze at Essex County to 10 miles along the route. Excerpts from these observations included the following:

- *Nantucket, Massachusetts (ACK).* 1753: Clear skies; visibility 5 miles in mist; winds 240 degrees/16 knots. ACK is located 27 nm east-southeast of MVY.

- *Hyannis, Massachusetts (HYA)*. 1756: Few clouds at 7,000 feet; visibility 6 miles in haze; winds 230 degrees/13 knots. HYA is located 22 nm northeast of MVY.
- *Martha's Vineyard, Massachusetts (MVY)*. 1753: Clear skies; visibility 6 miles in haze; winds 210 degrees/11 knots.

The website information also included the terminal forecasts for ACK and HYA [the National Weather Service (NWS) does not prepare terminal forecasts for MVY]:

- *ACK*. July 16 from 1400 to 2000: Clear skies; visibility greater than 6 miles; winds 240 degrees/15 knots.
- *HYA*. July 16 from 1400 to 2200: Clear skies; visibility greater than 6 miles; winds 230 degrees/10 knots.

According to the website logs, the pilot did not access the NWS Area Forecast. Additional information attached to the NWS Area Forecast included:

- July 16 about 2045 and valid until July 17 about 0200—Coastal waters (including MVY); scattered clouds at 2,000 feet. Occasional visibility 3 to 5 miles in haze. Haze tops 7,000 feet.

Additional information attached to the NWS Terminal Forecast included:

- *ACK*. Issued July 16 about 1930 covering July 16 at 2000 to July 17 at 0200: Winds at 240 degrees/15 knots; visibility 4 miles and mist; scattered clouds at 25,000 feet. Temporary changes from July 16 at 2100 to July 17 at 0100: clouds 500 feet scattered; visibility 2 miles and mist.
- *HYA*. Issued July 16 about 1930 covering July 16 at 2000 to July 17 at 0200: Winds 230 degrees/10 knots; visibility 6 miles and haze; scattered clouds at 9,000 feet. Temporary changes from July 16 at 2000 to July 17 at 0000: Visibility 4 miles and haze.

SURFACE WEATHER OBSERVATIONS

The surface weather observations were broadcast on the automated surface observing system (ASOS) and included the conditions in the following areas:

- *MVY.* 2053: Clear at or below 12,000 feet; visibility 8 miles; winds 250 degrees/7 knots; temperature 23°C/dewpoint 19°C; altimeter 30.09 inches of Hg.
- *MVY.* 2153: Clear at or below 12,000 feet; visibility 10 miles; winds 240 degrees/10 knots, gusts to 15 knots; temperature 24°C/dewpoint 18°C; altimeter 30.10 inches of Hg.
- *HYA*. 2056: Few clouds at 7,000 feet; visibility 6 miles and mist; winds 230 degrees/7 knots; temperature 23°C/dewpoint 21°C; altimeter 30.07 inches of Hg.
- *HYA*. 2156: Few clouds at 7,500 feet; visibility 6 miles and mist; winds 230 degrees/8 knots; temperature 23°C/dewpoint 22°C; altimeter 30.08 inches of Hg.

The controller at Martha's Vineyard tower on duty the night of the accident, told investigators,

> The visibility…and sky condition at the approximate time of the accident was probably a little better than what was being reported.…I remember aircraft on visual approaches saying they had the airport in sight between 10 and 12 miles out. I…recall being able to see those aircraft and I…remember seeing the stars out that night…To the best of my knowledge, the ASOS was working…with no reported problems or systems log errors.

PILOT WEATHER OBSERVATIONS

Three pilots who had flown over the Long Island Sound on the night of the accident were interviewed by investigators. One of the pilots had scheduled to fly his twin turboprop airplane from Teterboro to Nantucket. He had planned to arrive at the airport in enough time so that he could conduct the entire flight during daylight; however, the unusually heavy rush-hour traffic from New York City delayed his departure and caused his flight to be conducted partially at night. Before he reached the airport, the pilot obtained current weather observations and forecasts for Nantucket and other points in Massachusetts. He also spoke with a briefer at the Flight Service Station. According to the pilot, "I asked [the briefer] if there were any adverse conditions for the route [between] Teterboro and Nantucket. I was told emphatically: 'No adverse conditions. Have a great weekend.' I queried the briefer about any expected fog and was told none was expected and the conditions would remain VFR with good visibility. Again, I was reassured that tonight was not a problem."

After departing Teterboro midevening, the pilot climbed his airplane to 17,500 feet and proceeded toward Nantucket. He told investigators that he encountered good flight conditions and reasonable visibility and could pick out landmarks at least 5 miles away. However, during his descent to Nantucket he flew directly over Martha's Vineyard [verified by his global positioning system (GPS) indication] and when he looked down, "…there was nothing to see. There was no horizon and no light…I turned left toward Martha's Vineyard to see if it was visible but could see no lights of any kind nor any evidence of the island…I thought the island might [have] suffered a power failure." The pilot added, "I had no visual reference of any kind yet was free of any clouds or fog." As he approached Nantucket, he maintained a distance of 3 to 4 miles from the island because he lost sight of it at 5 miles. Furthermore, the pilot stated that when the tower controller instructed him to do a 310-degree turn for spacing, "I found that I could not hold altitude by outside reference and had to use my VSI [vertical speed indicator] and HIS to hold altitude and properly coordinate the turn."

Another pilot had flown from Bar Harbor, Maine, to Long Island, New York, and crossed the Long Island Sound around 1930. Although the FSS briefer informed him that his flight would be in VMC, the pilot filed an instrument flight rules (IFR) flight plan and conducted the flight at 6,000 feet. He told investigators that he encountered visibilities of 2 to 3 miles throughout the flight because of haze. The pilot also stated that there were no clouds below 6,000 feet, but the lowest visibility was over water, between Cape Cod, Massachusetts, and eastern Long Island.

A third pilot departed from Teterboro around 2030 and was destined for Groton, Connecticut, with an intermediate stop at Martha's Vineyard. He told investigators that he climbed to 7,500 feet and that the entire flight was VFR, with a visibility of 3 to 5 miles in haze. He stated that, over land, he could see lights on the ground when he looked directly down or slightly forward; however, he observed that, over water, there was no horizon to reference. The pilot did not encounter any cloud layers or ground fog during descent, but there was still no horizon to reference between Block Island, Massachusetts, and Martha's Vineyard. He recalled beginning to see Martha's Vineyard in the vicinity of Gay Head but did not remember seeing the Gay Head marine lighthouse. He stated that he was about 4 miles from Martha's Vineyard when he first observed the airport's rotating beacon and had an uneventful landing about 2145. The pilot departed Martha's Vineyard 15 minutes later (as the tower was closing for the night) to continue to his final destination. He stated that the visibility was the same—3 to 5 miles in haze.

The Accident Flight

On the day of the accident, the pilot told an employee at an Essex County FBO that he would arrive at the airport between 1730 and 1800; however, due to extremely heavy rush-hour traffic leaving New York City, the pilot and his passengers arrived much later than expected. Witnesses told investigators that the pilot was using crutches and loading luggage into the airplane.

According to the ATC transcripts and radar data from the Essex County tower, the pilot departed at about 2040—no further communications between the pilot and ATC exist, including the tower at Martha's Vineyard. The pilot began a routine climb out and eventually turned eastward toward his destination. About 6 miles northeast of White Plains, New York, the pilot leveled off at 5,500 feet and proceeded to fly along the Connecticut and Rhode Island coastlines.

AIRPLANE SYSTEMS

The airplane was equipped with an automatic flight control system (AFCS) that included several safety features. Specifically, the AFCS had an altitude hold mode that the pilot could select to maintain altitude, and a vertical trim rocker switch that would allow the pilot to change the airplane's pitch without disconnecting the autopilot. Additionally, the AFCS installed on the airplane had a flight director that would maintain wings level and the pitch attitude; a navigation mode to intercept and track VOR and GPS courses; a heading select mode that would command the airplane to that heading at a bank angle of about 22 degrees; a control wheel steering button mounted on the control yoke that allowed the pilot to maneuver the airplane in pitch and roll without disengaging the autopilot; and a trim system fault disconnect that would warn the pilot and automatically return control of the airplane back to the pilot.

According to the FAA and Bendix/King, the manufacturer of the AFCS, once a pilot tested the system during preflight, it could be engaged or disengaged either manually or automatically. Several conditions would cause the autopilot to automatically disengage: roll rates greater than 14 degrees per second; pitch rates greater than 8 degrees per second; power failure; internal flight control system failure; or loss of a valid compass signal.

Investigators conducted microscopic examinations of the AFCS lightbulbs for the autopilot engage mode, flight director, and trim failure annunciator panel. They found no evidence of filament stretch which suggested that the pilot had not activated the autopilot and flight director, nor had he experienced a trim failure at the time of the crash.

Aircraft Performance Study

Using radar data, investigators conducted a performance study of the accident airplane target for the last seven minutes of the flight. At 2133 and about 34 miles west of Martha's Vineyard, the airplane began a descent from 5,500 feet. The speed during the descent was about 160 KIAS, and the descent rate varied between 400 and 800 fpm. About five minutes after the airplane began the descent, it passed through 3,000 feet and started to bank in a southerly direction with a near-constant right-wing-down (RWD) roll angle of 13 degrees. Approximately 30 seconds later the airplane leveled off at 2,200 feet and began a climb that lasted another 30 seconds. At about 2139, the airplane leveled off at 2,500 feet and flew in a southeasterly direction. About 50 seconds later, the airplane entered a left turn while slightly increasing altitude to 2,600 feet. The airplane reached a maximum bank angle of 28 degrees left-wing-down (LWD) and a vertical acceleration of 1.2 Gs. The airplane entered a 900-fpm descent rate which was maintained for about 15 seconds until the airplane leveled off at 2140:07 and was heading toward the east. At 2140:15 the airplane maintained its heading and began a descent rate of 900 fpm while increasing its bank angle in a RWD direction. By 2140:25, the bank angle exceeded 45 degrees, the vertical acceleration was 1.2 Gs, and the airspeed increased through 180 knots. The flight path angle was close to 5 degrees nose down. After 2140:25, the airplane's airspeed, vertical acceleration, bank angle, and dive angle continued to increase, and the right turn tightened. The airplane's rate of descent eventually exceeded 4,700 fpm about the time it hit the water around 2141.

Wreckage

The airplane wreckage was located by U.S. Navy divers on 20 July 1999, approximately 7 1/2 miles southwest of Gay Head, Massachusetts. The debris field was located at a depth of 120 feet below the Atlantic Ocean and was 120 feet long. The main cabin area was found in the middle of the debris field.

Investigation

After comprehensive testing of the recovered wreckage, investigators found no evidence of preexisting jams or failures in any of the major systems and components of the airplane. Investigators discovered impact marks on one of the propeller blades and on the top of the engine, witness marks inside the propeller, and the engine controls and instruments in the cockpit indicating "high engine power output."

Lessons Learned and Practical Applications

1. *Become fully aware of your limitations.*
2. *Recognize when the situation is beyond your ability—or your aeronautical rating.*
3. *There's no shame in flying with an instructor.* On the contrary, good aviators understand their limitations and when they are rusty.

Case Study 1-8: Delta Airlines Flight 106

Safety issues: Spatial disorientation, dark night with no horizon

On the evening of 30 March 2000, Delta Airlines Flight 106, a Boeing 767-332, departed John F. Kennedy (JFK) International Airport, New York, and was in a straight and level climb out over water when the airplane rolled 65 degrees to the right.

Probable Cause

The NTSB determined the probable cause of this incident was the first officer's failure to maintain control of the airplane during climb out over water at night, which was a result of spatial disorientation. Factors in the incident were the cloud layer and dark night.

History of Flight

Delta Airlines Flight 106 was a regularly scheduled flight from JFK to Frankfurt, Germany, with 212 passengers and 13 crewmembers on board.

Pilot Experience

The captain had 19,500 total flight hours, 700 hours in the 767, of which 220 hours were in the last 90 days. He completed his last proficiency check three months before the incident. Prior to his transition into the B-767/757, he had flown several transport-category aircraft including the DC-8, B-737, and L-1011.

The first officer had 9,000 total flight hours, 404 hours in the 767, of which 103 hours were in the last 90 days. He had completed his initial B-767/757 operational experience in July 1999 and had received unusual attitude training during his initial qualification at Delta. Prior to his transition into the B-767/757, he had flown the B-727 and B-737 aircraft. Previous to his employment with Delta, he served as an F-15 fighter pilot in the U.S. Air Force (USAF) and was extremely familiar with unusual attitude recovery.

Weather

JFK weather at 2051 (25 minutes after the incident): Wind from 350 degrees at 15 knots, gusting to 22 knots; visibility 10 miles, ceiling

8,000 feet broken; temperature 9°C/dew point 3°C; altimeter setting 29.97 inches of Hg.

According to the captain, there was a thin deck of clouds at 6,500 feet and it was a dark night with no moon. The first officer told investigators that there was no horizon, stars, or moon visible—all he saw was darkness. An international relief pilot was sitting in the cockpit jump seat, and he also stated that there was no discernible horizon.

Incident

The first officer was hand flying the airplane with the autopilot disengaged. While climbing through 6,500 feet, ATC cleared the flight direct to the BETTE intersection (35 nm east-southeast of JFK) and the captain entered the information into the flight management system (FMS). He hit the execute button and engaged the lateral navigation mode on the flight director, which showed an appropriate 20- to 25-degree left turn. The captain then turned his attention to organizing his departure and en route charts.

According to the first officer, after the captain entered the BETTE intersection information into the FMS, he followed the flight director and began a gentle turn to the left while looking outside the captain's left forward window to scan for traffic. He then checked his instruments and saw his attitude director indicator (ADI) in a 60-degree bank turn to the right. The captain looked up and saw the first officer "wrestling" with the airplane, and the ADI was "lying on its side" in the right-wing-down position. At the same time, the international relief pilot, who had been reviewing the flight plan, felt the airplane yaw and then roll to the right. He looked up and saw the ADI at 60 degrees right wing down, and observed ground lights and a scattered cloud layer below the airplane.

The first officer told investigators that he immediately responded with full left aileron followed by left rudder, which returned the airplane to level flight. He estimated five to six seconds elapsed between the time the captain entered the information into the FMS and when he first noticed the right bank on the ADI.

Digital Flight Data Recorder (DFDR) Analyses

It is important to note how rapidly spatial disorientation events can occur.

2024:59 to 2025:28. Airplane maintains a heading of about 100 degrees while climbing from 5,100 to 6,300 feet.

2025:29. Control wheel input to right aileron, and the airplane begins a roll to the right.

2025:32.5. Control wheel input to right aileron increases until it reaches 63.7 degrees right wing down with a bank angle of 39.4 degrees right wing down.

2025:33. Control wheel input to 20 degrees left.

2025:33.5. Control input to 34 degrees left and elevator moved to a 2-degree nose-down position. Roll angle reaches 48 degrees right.

2025:34. Control wheel input switches from a left to right position.

2025:34 to 2025:37. Control wheel input moves between 18.8 degrees right to 40.7 degrees left. Airplane's roll value increases from 62.9 to 65.5 degrees right wing down.

2025:37.3. First application of left rudder.

2025:43. Rudder values change from 1.6 degrees right to 4.9 degrees left as the roll angle decreases from 65.5 degrees right wing down to wings level. Control wheel input varies between 3.4 and 34.1 degrees wing down. With the application of nose-up control inputs, the pitch attitude values increase from 5-degrees nose down to 0.9 degree nose up and a decrease in climb.

Incident Analyses

The DFDR did not register any unusual or anomalous readings during the remainder of the flight. Investigators and Delta Airlines personnel found no engineering, systems, or maintenance anomalies on the airplane during postincident inspections and testing.

At the time of the event, Delta's B-767 flight operations manual addressed unusual attitude recovery procedures. If an upset were to occur, the pilot was instructed to roll the wings level, but the manual made no mention of using the rudder to assist in the recovery. During the year prior to this event, Delta had developed an unusual attitudes training procedure for its B-767 training manual. Referred to as critical aircraft situational training (CAST) maneuvers, the training was implemented two days after the Flight 106 event. Those procedures instructed the pilot to coordinate the use of aileron and rudder inputs during upset recoveries.

Lessons Learned and Practical Applications

The sudden physiological effects of spatial disorientation can be dramatic, causing inappropriate reactions regardless of flight experience. Believe your instruments!

Reference

National Transportation Safety Board. Scheduled 14 CFR Part 121 operation of Air Carrier DELTA AIRLINES (D.B.A. COMMERICIAL AIRLINE). Incident occurred Thursday, March 30, 2000 at New York City, NY. Aircraft: Boeing 767-332, registration N182DN.

International Case Study I-9: Singapore Airlines Flight 006

Safety issues: Situational awareness, airport markings and signage, night operations in poor weather

Synopsis of Accident

On 31 October 2000, Singapore Airlines Flight 006, a Boeing 747-400, was a scheduled passenger flight from Taipei, Taiwan, to Los Angeles, California, with 3 pilots, 17 cabin crewmembers, and 159 passengers. In inclement weather, believing that they were on the correct runway, the flight crew mistakenly commenced their takeoff on runway 05R instead of runway 05L. The flight crew was unaware that a portion of runway 05R was closed for construction. Concrete barriers and heavy construction equipment were positioned just over a kilometer from where the flight crew began their takeoff roll—a distance that was out of their visual range and hindered by the weather conditions at night.

At approximately 2317 (local time), Flight 006 collided with the construction equipment and broke into two sections—the aircraft was subsequently destroyed by the postcrash fire resulting in 83 fatalities.

Pilot Experience

The captain had 11,235 total flight hours.

Weather

Typhoon Xangsane was about 360 kilometers south of Taipei's Chiang Kai-Shek Airport, moving north-northeast toward the airport at 12 knots per hour. At 2312, ATIS was broadcasting that the surface winds were from 020 degrees at 36 knots, gusting to 56 knots. The runway visual range (RVR) was 450 meters on runway 05L.

The flight crew received two additional wind speed updates by ATC prior to making their decision to take off. When they were cleared for takeoff at 2315, the winds were from 020 degrees at 28 knots, gusting to 50 knots. The automated weather observation system at the airport recorded the following wind directions and speeds during Flight 006's takeoff roll:

2315. Wind from 029 degrees at 29.6 knots

2316. Wind from 013 degrees at 29.3 knots

2317. Wind from 360 degrees at 20.5 knots

Background to the Investigation—Annex 13

Flight 006 was the first major accident investigation for Taiwan's Aviation Safety Council (ASC)—an independent government agency created in 1998. Although Taiwan was not a contracting state under the International Civil Aviation Organization (ICAO), it agreed to conduct the investigation under Annex 13 to the Chicago Convention on International Civil Aviation. Annex 13 details the standards and recommended practices for contracting states regarding accident investigation.

Under the provisions of Annex 13, Singapore was entitled to appoint an accredited representative to participate in all aspects of the investigation. In this case, the representative was appointed by the Singapore Ministry of Transport (MOT) and was assisted by investigators and advisors from different organizations, including the Civil Aviation Authority of Singapore (CAAS), the ministry of defense, Singapore Airlines, and universities. Subsequently, Singapore requested that ICAO provide specialist consultants to aid the MOT team—the former director of the Australian Bureau of Air Safety Investigation, and the then deputy chief inspector of the United Kingdom Air Accidents Investigation Branch were appointed by ICAO to assist the MOT team.

Investigative Process

The Taiwanese ASC filed its accident report in April 2002, separate from the analyses provided by the Singapore MOT team. According to a series of letters directed to the investigator-in-charge of Flight 006, the ICAO accredited representative for Singapore was disappointed that his team's findings and analyses were not considered in the ACS's final report. The representative noted in a March 2002 summary letter,

> Contrary to the provisions of Annex 13, the ASC did not permit the Singapore Accredited Representative and his advisors to participate in the deliberations related to the analysis, findings, causes and safety recommendations. In February 2001, ASC informed the Singapore team that it would not be permitted to participate in the ASC analysis, and it could instead proceed with its own analysis if it so desired…Between February 2001 and March 2002, requests made by the Singapore team to participate in the deliberations were turned down by the ASC…the ASC made it clear that the Singapore team would not be allowed to ask questions, to ask for feedback on the Singapore team's inputs or participate in any discussion during the presentations.

The Singapore team carried out its own analyses with the objective of providing it to the ASC, but according to the accredited representative, "…the ASC draft Final Report forwarded to Singapore in January 2002 did not consider fully the Singapore team's inputs…the ASC draft Final Report presented an incomplete account of the SQ [Singapore Airlines] 006 accident."

ASC Draft Final Report and Singapore MOT Analyses Report

1. *ASC finding-probable cause.* "At the time of the accident, heavy rain and strong winds from typhoon 'Xangsane' prevailed and the wind direction was 020 degrees with a magnitude of 36 knots, gusting to 56 knots. RVR [runway visual range] was 450 meters on Runway 05L"

Singapore MOT team comment. "It is not clear how this finding relates to a 'probable cause' of the accident. The weather conditions on the night of the accident were a factor in the environment in which the accident occurred. They did not 'cause' the accident. Furthermore, the winds quoted in this ASC finding are not correct. These are not the wind speeds 'at the time of the accident' [2317]…the wind speeds and directions…in the ASC finding were those…broadcast on the ATIS at 2312, four minutes 41 seconds before the commencement of the takeoff…The crew based their decision to take off on the latest advice given to them by ATC. [The wind speeds recorded at 2315, 2316, and 2317 are not referenced in the ASC finding.]…which indicates that very close to the time of the accident, the winds were rapidly changing direction and in fact decreasing in strength."

2. *ASC finding-probable cause.* "On August 31, 2000, CAA [Civil Aviation Authority] of ROC [Republic of China] issued a Notice to Airman (NOTAM) A0606 indicating that a portion of the Runway 05R between Taxiway N4 and N5 was closed due to work in progress from September 13 to November 22, 2000. The flight crew of SQ 006 was aware of the fact that a portion of Runway 05R was closed, and that Runway 05R was only available for taxi."

Singapore MOT team comment. "It is not clear how this finding can be considered a 'probable cause.' This ASC finding omits to mention that the INTAM and the other NOTAM that were also provided to the crew…on the night of the accident. These documents gave no clear indication of the actual status of the runway markings, lighting and signage on runway 05R—for example, whether or not any work had been done in removing the runway markings from runway 05R (as stated in the INTAM) before the postponement of the redesignation of runway 05R to a taxiway, as stated in NOTAM 0740."

3. *ASC finding-probable cause.* "The aircraft did not completely pass the Runway 05R threshold marking area and continued to taxi towards Runway 05L for the scheduled takeoff. Instead, it entered Runway 05R and…CM-1 [captain of Flight 006] commenced the takeoff roll. CM-2 [first officer] and CM-3 [second officer] agreed with CM-1's decision to take off."

Singapore MOT team comment. "This finding is misleading because it provides no information as to the context in which the crew made the turn onto, and commenced takeoff on Runway 05R. The evidence shows that the crew of SQ 006 followed the continuous line of green taxiway centerline lights leading from Taxiway N1 onto Runway 05R. On lining up, they were presented with a picture of a brightly lit active runway. In the absence of any indications at the Runway 05R threshold the runway was closed, the crew…entered Runway 05R and commenced the take-off roll. This finding [ASC probable cause] also implies that a verbal statement of 'agreement' from CM-2 and CM-3 was required before takeoff. This was not the case. In accordance with established airline practices, if any member of the crew had not been comfortable with the take off decision, he would have spoken up, as the crew members indicated in their evidence to the investigation."

4. *ASC finding-probable cause.* "The flight crew had CKS [Taipei's Chiang Kai-shek] Airport charts available when taxiing from the parking bay to the departure runway. However, when the aircraft was turning from Taxiway NP to Taxiway N1 and continued turning onto Runway 05R, none of the flight crew verified their taxi route in accordance with the airport chart, which would have shown the need to make a 90 degree turn from Taxiway NP and then taxi straight ahead on Taxiway N1…rather than to make a continuous 180 degree turn onto Runway 05R…none of the flight crewmembers confirmed orally whether the runway they entered was Runway 05L."

Singapore MOT team comment. "This finding [probable cause] is misleading because it ignores the context in which the crew's actions took place. The evidence shows that the crew…had navigated their way accurately to the end of taxiway NP using their Jeppesen airport charts. Having reached this point, and having received the take off clearance from ATC, the final stages of the taxi were carried out using the external visual cues offered by the taxiway and runway lighting. This manner of operation was in accordance with normal airline practice. Foremost among these visual cues was the single continuous clear line of green lights that provided taxiway guidance. These green centerline lights formed a continuous pathway onto the runway.

There was no alternative continuous line of lights to Runway 05L, as there would have been if CKS Airport had conformed to ICAO Annex 14 standards and recommended practices."

5. *ASC finding-probable cause.* "The flight crew did not build a mental picture of the taxi route to Runway 05L that included the need for the aircraft to pass Runway 05R before taxiing onto Runway 05L."

Singapore MOT team comment. "The existence or otherwise of an internalized 'mental model' is at best only a hypothesis. It therefore cannot be an unequivocal 'finding related to probable cause'…at best, such a hypothesis is a statement of probability. This finding is not supported by empirical evidence."

6. *ASC finding-probable cause.* "The moderate time pressure to take off before the inbound typhoon closed in around CKS Airport, and the high workload of taking off in a strong crosswind, low visibility, and slippery runway conditions subtly influenced the flight crew's decision-making and ability to maintain situational awareness."

Singapore MOT team comment. "This finding is not supported by the evidence…CM-1 reported that he 'felt no time pressure on the evening of the accident…[stating further] if the winds had exceeded the company operating limits, he would have postponed the take-off.'…the ASC draft Final Report…stated that the captain instructed the crew to 'take their time and to be careful with the checklists and procedures.' In view of such evidence, this finding can neither be substantiated nor cited as a probable cause [in reference to high workload]…this assertion is not supported by the evidence. The B747-400 is designed and certified to be operated by a two-man crew. The presence of CM-3 on the flight deck of SQ 006 provided an additional resource to the normal crew complement. By allocating the tasks of monitoring the weather and calculating the crosswind component during the taxi to CM-3, CM-1 was able to reduce the workload on CM-2 and himself."

7a. *ASC finding-probable cause.* On the night of the accident, the information available to the flight crew regarding the position of the aircraft was:

- CKS Airport navigation chart: "The crew had the Jeppesen chart for the airport…there was no yellow page supplement which would have provided additional information on the works in progress on Runway 05R."

- Aircraft heading indicators: "[According to the ASC draft Final Report, page 143], the crew…stated, 'The aircraft heading was around 050 degrees on line-up, which was the expected direction for take-off.…'"
- Runway and taxiway signage and marking: "Warning signs, markings, lights, and physical barriers are defenses to prevent human errors…if such defenses had been in place as they should have on the night of the accident, the crew…would have been alerted that they were entering the wrong runway…physical barriers would have made it impossible for the aircraft to commence its takeoff on Runway 05R. The absence of these essential warning signs, markings, and physical barriers was the single most important factor which contributed to the accident."
- Taxiway N1 centerline lights leading to Runway 05L: "[The deficiencies in these lights are well described in the ASC's draft Final Report], which states, 'There should have been sixteen centerline lights spaced 7.5 meters apart along the straight segment of Taxiway N1 where the curved taxiway centerline markings from Taxiway NP meets Taxiway N1 up to the Runway 05L holding position—rather than the four centerline lights spaced at 30 meters, 55 meters, 116 meters, and 138 meters.' The fact that there were only four lights, not all of which were serviceable, meant that there was no alternative line of lights to those leading onto Runway 05R. There was only one visible path.…"
- Color of the centerline lights (green) on Runway 05L: "…CM-1 stated that, 'as the aircraft was lining up, the image before him was that of a runway. He reported that he could see the centerline lights running down the runway.' In his evidence, CM-2 said, 'The runway picture was correct. He recalled seeing lights down the middle of the runway and they were very bright…the visual cues indicated that the aircraft was on an active runway.'"
- Runway 05R edge lights most probably not on: "This evidence is not supported by the factual evidence. The evidence of CM-1, together with the analysis of recorded ATC communications, as

well as data from the metallurgical tests carried out on runway edge light wires, indicate that the Runway 05R edge lights probably were illuminated at the time of the accident."

- Width difference between Runway 05L and Runway 05R, if the Runway 05R edge lights were on: "Pilots do not have an expectation of runway width as a primary visual cue to identify runways, as they operate to airports world wide which have runways of differing widths. Of more critical importance is that if the Runway 05R edge lights were on, a possibility which is acknowledged in this ASC finding, and which is supported by the factual evidence, it would have indicated an active runway."
- Lighting configuration differences between Runway 05L and Runway 05R: "Both Runway 05R and 05L had centerline lights. The captain selected Runway 05L because it was a Category (Cat) II runway [which have centerline lights]…he would have been expecting to line up on a runway with centerline lights…as opposed to Runway 06, which was the normal runway used by Singapore Airlines. Runway 06 has no centerline lights. On lining up on Runway 05R, the bright centerline lights confirmed his belief that the aircraft had lined up on the correct runway."
- Parallel visual display (PVD) showing aircraft not properly aligned with the Runway 05L localizer: "This statement is misleading as it implies that the PVD will at all times 'show' aircraft alignment with the runway localizer. This is not the case…SQ 006, the PVD remained shuttered. Consequently, there was no display showing a displacement from the localizer. This could have been a possible cue to the crew regarding the position of the aircraft.
- Primary flight display (PFD) information: "As stated in the ASC draft Final Report, 'pilots routinely use the ILS localizer indicator and the rising runway symbol on the PFD as a runway alignment reference during landing. This could have been a cue to the crew regarding the position of the aircraft. However, there were no procedural requirements for the flight crew to check these indications before take-off.'"

7b. *ASC finding-probable cause.* "The flight crew did not comprehend the available information. They lost situational awareness and commenced takeoff from the wrong runway."

Singapore MOT team comment. "This finding presents a distorted picture of the situation in which the crew…were operating…it ignores the significant deficiencies in the information available to the crew.…This statement…implies that the pilots were totally to blame for the accident…Maintenance of situational awareness by flight crews is dependent upon the quality of information on which it is based…if this information is not available, or is difficult to detect or perceive, or if it is misperceived, the situational awareness of a crew may not correspond to their actual situation. In the case of SQ 006, the primary information upon which the crew was relying for situational awareness was defective—for example, the runway lighting, signage, and markings. On lining up on Runway 05R, they firmly believed they were on Runway 05L. The CVR [cockpit voice recorder] confirms this…the evidence shows that the crew…did comprehend the information available to them, and based their situational awareness on this information. Unfortunately, the information available to them was flawed resulting in their comprehension being flawed without their knowledge. The summary statement of this particular finding implies blame, contrary to the provisions of Annex 13 [paragraph 3.1: 'The sole objective of the investigation of an accident or incident shall be the prevention of accidents and incidents.'] It is not the purpose of this activity to apportion blame or liability."

Lessons Learned and Practical Applications

1. *Verify your location on the airfield.* This is especially critical when operating around parallel runways and taxiways.
2. *Verify correct runway before takeoff.*
3. *Recognize poor airport markings and understand the potential for confusion, particularly in bad weather.*

Reference

Singapore Airlines Flight 006, Taipai, Taiwan. 31 October 2000. Available on-line at *www.sq006.gov.sg/analysis/summary.htm.*

Historical Case Study I-10: Eastern Airlines Flight 401

Safety issues: Distraction, cockpit discipline, CRM

On 29 December 1972, an Eastern L-1011 crashed in the Everglades while circling to land at Miami International Airport, Florida.

Probable Cause

The Board determined that the probable cause of this accident was the failure of the flight crew to monitor the flight instruments during the final four minutes of flight and to detect an unexpected descent soon enough to prevent impact with the ground. The Board also noted that preoccupation with a malfunction of the system indicating the position of the nose landing gear distracted the crew's attention from the instruments and allowed the descent to go unnoticed.

History of Flight

Flight 401 operated as a regularly scheduled passenger flight from JFK International Airport, New York, to Miami, Florida. The aircraft departed JFK at 2120 Eastern Standard Time with 163 passengers and 13 crewmembers on board.

Pilot Experience

The captain had 29,700 total flight hours, 280 in the L-1011. He had been a qualified L-1011 captain for five months before the accident, although he had been a rated captain with Eastern on other types of aircraft since 1951.

The first officer had 5,800 total flight hours, 306 hours in the L-1011. He had held that position for nearly seven months prior to the accident.

The second officer had 15,700 total flight hours, 53 hours in the L-1011. He began his L-1011 training in September 1972 and successfully completed his line check 10 days before the accident.

Weather

Ceiling 2,500 feet scattered; visibility 10 miles; no moon.

The Accident

Around 2330, the crew of Flight 401 began an approach into Miami International Airport. When they lowered the landing gear, the nose gear light failed to illuminate, which prompted the crew to tell Miami tower, "We're gonna have to circle, we don't have a light on our nose gear yet." Moments later they were cleared to "climb…to two thousand [feet], go…to approach control.…" The crew checked in with approach, told them of their problem, and was instructed to maintain 2,000 feet.

Within two minutes of reaching their assigned altitude, the captain directed the first officer, who was flying the aircraft, to engage the autopilot. He complied. As they continued to circle, the crew focused their full attention on the nose gear problem. Because there was a possibility that the gear was really down and locked, and that the instrument panel light was actually the malfunctioning system, the captain and first officer spent nearly four minutes troubleshooting and discussing the panel-light lens assembly.

Meanwhile, the captain instructed the second officer to go down into the forward electronics bay, which is beneath the flight deck and can be entered from a trapdoor in the cockpit, to visually check the nose gear. This can be done through an optical sight positioned just forward of the nose wheel well. When two specific rods on the landing gear linkage are aligned, then the nose gear is fully extended and locked.

As the captain and first officer were concluding their discussion about the lens assembly, an aural altitude alert sounded in the cockpit. This warning chimes when the aircraft deviates 250 feet from the selected altitude, which had been set at 2,000 feet. No crewmember, however, commented on the caution alert. Seconds later, at 2341, the second officer raised his head into the cockpit and said, "I can't see it [the nose gear], it's pitch dark…" An Eastern maintenance specialist, who happened to be riding in the jump seat, then went down into the electronics bay to assist the second officer.

About a minute later, the Miami approach controller observed that Flight 401's altitude reading was at 900 feet, not the assigned 2,000 feet. He then asked the Eastern crew, "…how are things comin' along out there?" The reply was, "Okay, we'd like to turn around and come…back in." The controller granted the request to change their heading. About 20 seconds later the first officer said, "We did something to the altitude." The captain replied, "What?" This was quickly followed by the first officer asking, "We're still at two thousand, right?" The captain immediately exclaimed, "Hey, what's happening here?" In less than five seconds the aircraft, which was in a 28-degree left bank, crashed into the Everglades.

Impact and Wreckage Path

Flight 401 crashed in a flat marshland that was covered with soft mud under 6 to 12 inches of water. At impact, a flash fire was ignited from the ruptured fuel cells and penetrated parts of the passenger cabin. The wreckage path was scattered over an area 1,600 feet long by 300 feet wide.

It appeared that the outer portion of the left wing struck the ground first, immediately followed by the number one engine and the left main landing gear. The fuselage broke into four large parts, although there were no complete circumferential cross sections of the main cabin left intact.

ACCIDENT SURVIVABILITY

The force of the impact caused 96 passengers and 5 crewmembers, including the captain, first officer, and second officer to sustain fatal injuries, primarily from crushing trauma to their chests. Most of those victims were discovered in the center of the wreckage path.

The survivors were located near the cockpit, midcabin, and the overwing and empennage sections. Many received various injuries including fractures of the ribs, spine, and lower extremities. Due to the flash fire and burning fuel, 14 of them suffered skin burns. Seventeen survivors received only minor injuries and did not require hospitalization.

The Board also noted that the design of the passenger seats "materially contributed" to the survival of many of the occupants. Each seat had an energy absorber built into the support structure and was then bolted to a platform attached to the actual aircraft frame. This prevented a great number of seats from separating from their leg braces and becoming projectiles at impact. However, the seat units that did break away were caused by the collapse and severe damage to the floor structure itself.

Although the Board could not fully explain the high survival rate, the members ultimately believed it was due to one of two occurrences: the passenger seats remained attached to the main floor or the occupants were thrown clear of the wreckage at considerably reduced velocities.

The Investigation

Physical evidence found in the cockpit revealed a chilling discovery: The nose gear warning light lens assembly had been jammed and twisted out of position, obviously caused by the repeated attempts from the crew to verify its malfunction, as opposed to a faulty gear mechanism. The investigators quickly uncovered that both bulbs in the unit were, indeed, burned out.

The Board then sought to determine why the crew made a very slow, undetected, controlled descent into the ground. According to the Board's findings, there were four factors at work: First, the altitude-hold function of the autopilot system had been inadvertently disengaged. Second, a combination of throttle reductions and control column force inputs had caused the initial descent. Third, although ATC observed Flight 401's altitude on their data block as much lower than their assigned altitude, the controller did not pursue the situation. And fourth, the crew had become completely distracted by the nose gear malfunction.

THE ANALYSES OF A SLOW, UNDETECTED DESCENT

The Board believed that it was highly likely that the captain accidentally disengaged the autopilot. How does that happen without it being noticed by at least one crewmember?

At the time of the accident, this type of autopilot system was relatively new on the L-1011. During the investigation, the Board learned that due to certain training restraints, many pilots lacked the knowledge to fully understand all its capabilities and features. The Board also noted that flight crews were unaware of the minor control column inputs needed to effect a change in the aircraft's attitude. Because those findings did not appear to be isolated, the Board suggested that the crew of Flight 401 also might not have realized the differences in the new system over the previous one.

The crew had set the autopilot's altitude and attitude modes to the "on" position. In the L-1011, it takes 15 pounds of pressure on the captain's side or 20 pounds of pressure on the first officer's side for the pitch computers to be overridden. About five minutes prior to impact, the FDR readout showed a descent rate of 200 fpm at the same time the captain was telling the second officer to go down into the electronics bay. The Board believed that the captain might have inadvertently bumped the yoke when he had turned to speak with the second officer. This might have been enough pressure to disengage the altitude-hold function. The autopilot was still on, but only the attitude-hold mode was engaged.

This led to a second point. When the altitude and attitude functions are on, two separate lights illuminate on the annunciator panel. In this case, when the altitude mode was disengaged, the light indicating that simply went out. According to the Board's determination, there was absolutely no indication, other than a light going out, to warn the pilots that a critical mode of their autoflight system had become disengaged.

Once the altitude mode was off, even a slight pressure against the yoke could cause a change in attitude. Because there was so much physical movement between the captain and first officer, the Board speculated that one or both might have accidentally bumped the throttles. Since the FDR readout showed several increases in airspeed, followed by a series of small adjustments in the throttle setting only 160 seconds before impact, it was believed that the crew noticed the higher airspeed and pulled back the throttles. It was also likely that they referred only to the airspeed indicators, probably thinking the autoflight system was still maintaining altitude. Therefore, the Board believed that no other instruments were cross-checked.

ATC ACTIONS

Less than two minutes from impact, the Miami approach controller noticed an altitude reading of 900 feet, instead of the assigned 2,000 feet, on Flight 401's data block. He immediately asked the crew, "Eastern 401, how are things comin' along out there?" The controller later testified that he was not concerned about the safety of the flight since momentary deviations in altitude information on the radar display are rather common. The crew responded, "Okay, we'd like to turn around and come…back in," which reinforced the controller's decision to not pursue the matter any further. He assumed the crew was on top of things.

THE FINAL DISTRACTION

According to the Board, because the crew was preoccupied with an undetermined system malfunction, their attention was diverted away from flying the airplane. It's interesting to note how one distraction can lead to a catastrophic ending. Why did the autoflight system become disengaged in the first place? A distraction in the cockpit. Why didn't the first officer notice that the altitude mode function had been turned off? A distraction in the cockpit. When the crew realized an increase in airspeed, why didn't they cross-check the other instruments? A distraction in the cockpit. And what took the third crewmember—a third pair of eyes and ears—out of the cockpit for the final five minutes of the flight? A distraction in the cockpit.

Lessons Learned and Practical Applications

1. *Fly the airplane.* No matter what—always remain in control of the airplane. Aviate, navigate, communicate.
2. *Be decisive with the delegation of responsibilities.* Who's going to fly the airplane? In this case, there was no clear determination or direction as to who would actually take over the duty of monitoring the flight.
3. *Isolate an unavoidable distraction.* When a minor problem arises, contain it and don't allow it to turn catastrophic.

Reference

National Transportation Safety Board. 14 June 1973. Aircraft Accident Report: Eastern Air Lines, Inc., L-1011, N310EA. Miami, Florida. December 29, 1972.

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PART II

Runway Incursions

A runway incursion is any occurrence on an airport runway involving an aircraft, vehicle, person or object on the ground that creates a collision hazard, or results in a loss of required separation with an aircraft taking off, intending to take off, landing, or intending to land.

Official definition, FAA

The FAA conducted a four-year study between 1997 and 2000 to determine the leading trends that cause runway incursions and the severity of those incursions. The study included the over 450 towered airports in the U.S. National Airspace System which handle more than 180,000 airport operations (takeoffs and landings) a day. In the time period of the study, the number of airport operations neared 266 million with a reported 1,369 runway incursions—three resulting in accidents. Although runway incursions have produced a historically small percentage of accidents, the potential risk for a catastrophic disaster is substantial and therefore must be considered an important safety issue.

According to the FAA Runway Safety Report, the nature of runway incursions range from relatively minor events where there is little or no chance of a collision to major breaches of communication protocols that

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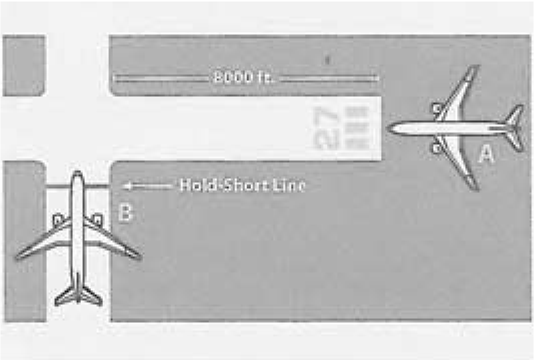
result in a near-miss or an accident. Nationwide, this analysis found that 81 percent of the runway incursions were minor in severity—accounting for the majority of runway incursions in 2000. The number of runway incursions regarded as major in severity remained stable during the four-year period studied.

Based on the broad definition of what constitutes a runway incursion, the FAA expressed concern that it can be difficult to capture an accurate portrayal of runway incursion trends. Note the following runway incursion profiles:

Aircraft A is on approach to runway 27, an 8,000-ft runway. (See Fig. II-1.) Aircraft B is taxiing to a parking area on the north side of the airport and has been instructed by air traffic control to "hold short of runway 27" in anticipation of the arrival of Aircraft A. When Aircraft A is on a quarter-mile final approach, Aircraft B's pilot informs the controller that he has accidentally crossed the hold-short line for runway 27. Although the aircraft is not on the runway, the aircraft's nose is across the hold-short line, usually 175 feet from the runway.

A runway incursion has occurred since separation rules require that a runway be clear of any obstacle before an aircraft can land or take off on that runway. The controller instructs Aircraft A to "go around." The potential for a collision is nonexistent, presuming that the pilot of Aircraft B, who has already recognized his error, remains in place. By definition, however, a runway incursion has officially occurred. The FAA notes that this situation exemplifies the most frequently reported runway incursions.

Figure II-2 shows a runway incursion where the potential for a collision is high. Aircraft A has been cleared to taxi into position and hold on runway 9 following Aircraft B which has just landed on the same runway and is rolling out. Aircraft B is instructed to turn left onto a taxiway. Aircraft B acknowledges. The controller observes Aircraft B exiting the runway and clears Aircraft A for takeoff. A moment later the controller notices too late that Aircraft B has not fully cleared the runway and in fact appears to have come to a complete stop with much of the aircraft still on the runway. Aircraft A has accelerated to the point where it cannot stop and must fly over the top of Aircraft B.



Aircraft A is on approach to Runway 27, an 8,000-foot runway. Aircraft B is taxiing to a parking area on the north side of the airport and has been instructed by air traffic control to "hold short of Runway 27" in anticipation of the arrival of Aircraft A. When Aircraft A is on a quarter mile final approach, Aircraft B's pilot informs the controller that he has accidentally crossed the hold-short line for Runway 27. Although he is not on the runway, the aircraft's nose is across the hold-short line, usually 175 feet from the runway.

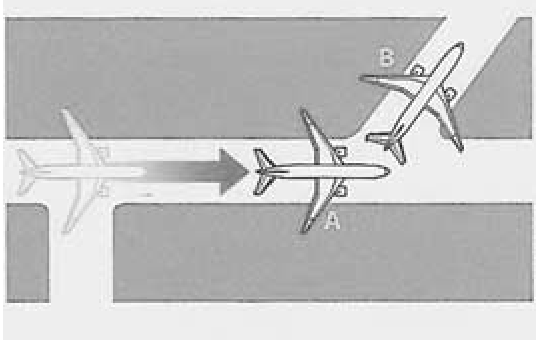
A runway incursion has occurred since separation rules require that a runway be clear of any obstacle before an aircraft can land or take off on that runway. The controller instructs Aircraft A to "go around."

- The potential for a collision is low, but by definition, a runway incursion has taken place.
- This case exemplifies most frequently reported runway incursions.

Fig. II-1. Runway incursion profile: no threat.
FAA Runway Safety Report.

CASE 2

This is a severe situation where the margin of safety is so low that a collision is barely avoided.



Aircraft A has been cleared to taxi into position and hold on Runway 9 following Aircraft B who has just landed on the same runway and is rolling out. Aircraft B is instructed to turn left at a taxiway. Aircraft B acknowledges. The controller observes Aircraft B exiting the runway and clears Aircraft A for takeoff. A moment later the controller notices too late that Aircraft B has not fully cleared the runway and in fact appears to have come to a complete stop with much of the aircraft still on the runway.

Aircraft A has accelerated to the point it cannot stop and has only the option to fly over the top of Aircraft B.

- The potential for a collision is high and typifies the common perception of a runway incursion.
- This case is more severe but occurs infrequently.

Fig. II-2. Runway incursion profile: severe threat.
FAA Runway Safety Report.

Increasing Severity

Category D	Category C	Category B	Category A	Accident
Little or no chance of collision but meets the definition of a runway incursion	Separation decreases but there is ample time and distance to avoid a potential collision	Separation decreases and there is a significant potential for collision	Separation decreases and participants take extreme action to narrowly avoid a collision	An incursion that resulted in a *runway collision*
Available Reaction Time: Not a factor; adequate time to consider multiple alternatives	**Available Reaction Time:** Adequate; sufficient time to smoothly execute an unplanned action	**Available Reaction Time:** Minimal. Barely adequate to take an emergency action	**Available Reaction Time:** None. Instantaneous reaction was required	
Need for Evasive/ Corrective Action: Evasive/Corrective action not necessary	**Need for Evasive/ Corrective Action:** Advisable. Definitive action was taken (or could have been taken)	**Need for Evasive/ Corrective Action:** Essential. Time-critical action required (or should have been taken) to ensure safety	**Need for Evasive/ Corrective Action:** Critical. Radical evasive action was the only reason that a collision was avoided	
Environmental Conditions: Good. Played no role in the event	**Environmental Conditions:** Fair. Minimal influence on operational performance	**Environmental Conditions:** Marginal. Likely a factor but not overridingly important	**Environmental Conditions:** Poor. Definitely a factor	
Aircraft / Vehicle Speed: Slow. Aircraft were traveling slowly; speed not a factor	**Aircraft/Vehicle Speed:** Moderate. Aircraft/ vehicle were moving fast enough to be of concern; speed was not a significant factor	**Aircraft/Vehicle Speed:** High. Potential for significant damage and injury	**Aircraft/Vehicle Speed:** Extreme. One or both aircraft/vehicle traveling at a speed sufficient to reduce pilot or ATC reaction time. Potential to cause catastrophic damage/loss of life in the event of a collision.	
Proximity of Aircraft/ Vehicle: Close. Aircraft/vehicle did not approach one another	**Proximity of Aircraft/ Vehicle:** Close. Aircraft / vehicle approached one another at a low/ moderate rate of speed	**Proximity of Aircraft/ Vehicle:** Very Close. Aircraft / vehicle approached one another at a high rate of speed	**Proximity of Aircraft/ Vehicle:** Near-Miss. Aircraft/ vehicle traveling at high speed narrowly missing one another	

Fig. II-3. The five operational dimensions of runway incursion severity.
FAA Runway Safety Report.

Although severe runway incursions like these are infrequent, the rise in traffic volume at busy airports portends a potential for more close calls. One such event occurred to the pilots of a passenger jet taking off at night from Dallas/Ft. Worth International Airport, Texas. The pilots were forced to lift off early to avoid a cargo jet that had inadvertently taxied onto the active runway—narrowly clearing it by 10 feet, according to witnesses. The cargo jet had been given permission to taxi from a hangar across two runways to a parking area. In the dark, the pilots made a wrong turn back onto the active runway—directly in the path of the passenger jet.

Runway Incursion Severity Categories

The FAA produced an evaluation guide using five operational dimensions representative of runway incursion severity. See Fig. II-3.

Reported Runway Incursions by Severity

There was a marked increase of runway incursions during the last two years of the FAA study. The number of runway incursions rose from 321 in 1999 to 431 in 2000. The vast majority (96 percent) of the additional incursions in 2000 was minor in severity—Categories C and D. There was also an increase in Category B incursions from 39 in 1999 to 47 in 2000. A small decrease in Category A incursions—26 in 1999 to 21 in 2000—brought the total to the same level reported in 1997 and 1998. It is worth noting the causes of the incursions reported in 2000: pilot deviations (60 percent), operational errors by air traffic control (20 percent), and vehicle or pedestrian deviations (20 percent).

Distribution by Aircraft Type and Combination

Reported runway incursions were distributed among aircraft operations consistent with the operations' representation in the National Airspace System: commercial operations (38 percent), general aviation operations (60 percent), and military operations (2 percent).

From 1997 through 2000, runway incursions primarily involved two general aviation operations and were predominately in Categories C and D. There has been a steady rise of incursions between general aviation aircraft. The FAA attributes this trend to an increase in pilot deviations. Runway incursions involving a jet transport and a general aviation aircraft have also increased during this period.

Conclusions

The FAA conducted this analysis to gain a better understanding of runway incursion trends and severity levels. Based on the official definition of a runway incursion, the event can range from a nonthreat to an accident, the majority of which are minor in level of risk. Nevertheless, it is important to focus on persistent trends in minor runway incursions because they may be harbingers for more severe events. The FAA continues to note that if minor events are allowed to proliferate, the likelihood of Category A and B incursions will increase. Therefore, trends in minor runway incursions signify opportunities for improving runway safety by targeting the more frequently occurring errors.

It is essential for pilots and air traffic controllers to follow rigorous communication protocols when operating anywhere on the airfield, particularly in the taxiway and runway environment. Vigilance, attention to detail by all concerned, and good situational awareness are the keys to preventing runway incursions.

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Part II Case Studies

Case Study II-1: USAir Flight 1493 and Skywest Flight 5569

Safety issues: Situational awareness, distraction, role of ATC, cockpit discipline

On 1 February 1991, a USAir 737-300 while landing on runway 24L at Los Angeles, California, International Airport collided with a Skywest Metroliner.

Probable Cause

The NTSB determined that the probable cause of this accident was the failure of the Los Angeles Air Traffic Facility Management to implement procedures that provided redundancy comparable to the requirements contained in the National Operational Position Standards. It also found a failure of the FAA Air Traffic Service to provide adequate policy direction and oversight to its ATC facility managers. These failures created an environment in the Los Angeles control tower that ultimately led to the failure of the local controller 2 (LC2) to maintain an awareness of the traffic situation, culminating in the inappropriate clearances and subsequent collision of the USAir and Skywest aircraft. Contributing to the accident was the failure of the FAA to provide effective quality assurance of the ATC system.

History of Flights

USAir Flight 1493 was a regularly scheduled passenger flight from Columbus, Ohio, to Los Angeles (LAX). The 737 departed Columbus

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at 1317 Eastern Standard Time with 89 passengers and 6 crewmembers on board.

Skywest Flight 5569 was a regularly scheduled passenger commuter flight from Los Angeles to Palmdale, California. The Metroliner departed the gate area around 1758 Pacific Standard Time with 10 passengers and two crewmembers on board.

Pilot Experience

The USAir captain had 16,300 total flight hours, 4,300 in the 737. He was upgraded to 737 captain in 1985, and had completed his last proficiency check the month before the accident.

The USAir first officer had 4,316 total flight hours, 982 in the 737. He had been with the airline since 1988 and had completed his last proficiency check two months prior to the accident.

The Skywest captain had 8,808 total flight hours, 2,107 in the Metroliner as pilot-in-command. He had been with the company since 1985 and had completed recurrent training and proficiency checks two month before the accident.

The Skywest first officer had 8,000 total flight hours, 1,363 in the Metroliner as second-in-command. He had flown for Skywest since 1989 and completed his last proficiency check about seven months before the accident.

Weather

A special local weather observation was taken at 1816. The reported conditions were 30,000 feet thin scattered and visibility at 15 miles. Official sunset at LAX occurred at 1723. The official end of twilight was at 1748.

The Accident

The nearly five-hour USAir flight was uneventful, and the crew set up for the approach into LAX. At 1759, the captain told the controller that he had the airport in sight. The airplane was about 25 miles from the field, and the first officer was at the controls. Seconds later, the crew was "cleared visual approach runway two-four left...." The captain acknowledged the clearance. Close to a minute later, the captain reconfirmed the correct runway with ATC, and at 1803 the crew was told to contact Los Angeles tower.

The first officer said he remembered the horizon was dark during the approach and landing. He lined up visually for runway 24L, and used the ILS glideslope for 24R for initial vertical flight path guidance since there was no operating ILS or VASI for 24L. He recalled configuring the airplane for landing approximately 12 miles from the threshold, and told the captain that he had the runway in sight.

About five minutes later, at 1758, the Skywest crew began their taxi to runway 24L. Shortly thereafter, the ground controller instructed them to "…turn right on Tango [taxiway] and then at Forty-Five [taxiway intersection] transition to Uniform [taxiway], taxi to runway two-four left.…" At 1803:44, the crew changed to the tower frequency of 133.9, and advised the LC2 that, "Skywest…at forty five, we'd like to go from here if we can." The LC2 responded, "…taxi up to and hold short of two-four left." The clearance was acknowledged.

Nearly one minute later, the USAir captain called the LC2 on 133.9 and told her that aircraft's location. Although the transmission was received, the LC2 did not respond. She did, however, tell the Skywest crew to "…taxi into position and hold runway two-four left, traffic will cross downfield." At 1804:49, the Skywest crew made a last transmission and replied, "Okay, two-four left position and hold, Skywest.…"

Another Metroliner was waiting to cross runway 24L, but the crew had inadvertently tuned to a different frequency, preventing the LC2 from issuing the clearance to them. The crew eventually returned to the tower frequency and was given permission to cross the runway at 1805:16. Meanwhile, the Skywest flight remained at the intersection of taxiway 45 and the center of runway 24L.

At 1805:29, the USAir captain made a second call to the LC2 and said, "USAir…for…two-four left." The controller responded with, "USAir…cleared to land runway two-four left." Followed by the captain's reply, "Cleared to land two-four left.…" That was Flight 1493's last transmission.

The LC2 then began working with other departing traffic. At 1806:08, a Wings West Metroliner was ready for takeoff, but the controller could not locate its flight progress strip. The strip had been misfiled and was finally found about 22 seconds later.

The USAir first officer recalled hearing a conversation between the tower and another airplane, concerning its location on the field. He did not remember hearing a hold or takeoff clearance for any aircraft for runways 24L or 24R. He told investigators that he looked down to the runway and saw the lights and overall landing environment. He noted that the cockpit interior lighting was normal, and that he had not been distracted during the approach.

The first officer further described the approach as stable, and heard the captain call out "500 feet." He confirmed that the landing light switches were "on" and that the aircraft crossed the threshold at approximately 130 knots. The main landing gear touched down about 1,500 feet from the approach end of the runway and on the centerline. He deployed the thrust reversers, but was not sure if they had fully deployed before the collision. As he lowered the nose of the airplane, he saw the Metroliner directly in front of and below him. He noticed the red light on its tail as the jet's landing lights reflected off the propellers.

Although the first officer tried to apply the brakes before the accident, there was not enough time for evasive action. He believed that the initial point of impact was directly on the nose of the 737 and the Skywest's tail. There was an explosion and fire at the moment of contact.

Impact and Wreckage Path

The left underneath side of the 737 crushed a major portion of the Metroliner. Refer to Fig. II-A. Both aircraft skidded 600 feet down runway 24L before veering to the left another 600 feet into a vacant fire station. A total of 19 gouge marks were made from the propellers, along the collision route. Parts of the Metroliner were scattered along the wreckage path, but the only sections of the jet that separated were the nose cone, nose gear doors, and left pitot tube.

The 737, however, was destroyed by fire when the aft fuselage collapsed. The impact of the jet with the building caused heavy damage

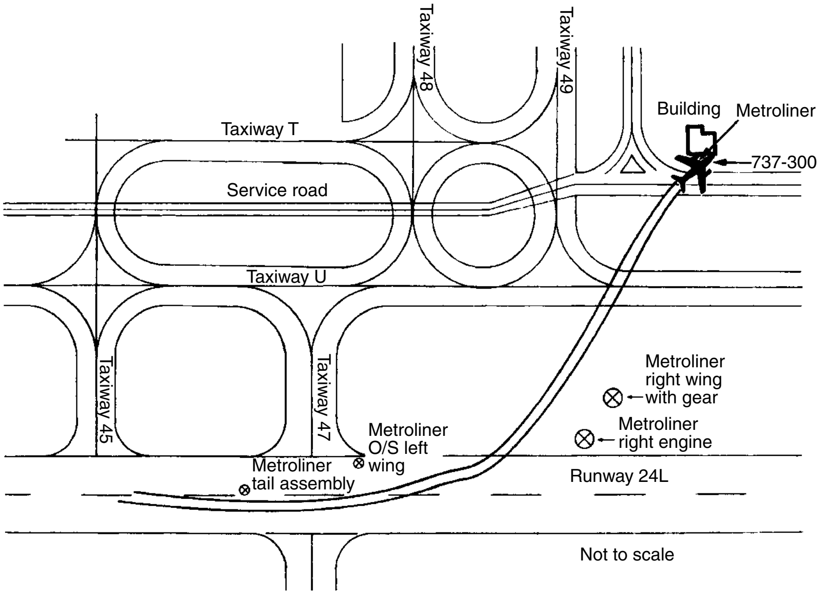

Fig. II-A. Ground track and wreckage distribution of USAir flight 1493 and Skywest Flight 5569. Adapted from NTSB.

to the left side of the cockpit, the left engine, and the leading edge of the left wing. Several propeller slashes were on the lower right side of the jet's fuselage, near the forward galley door.

ACCIDENT SURVIVABILITY

The collision was not survivable for the occupants of the Metroliner. The USAir captain, 1 flight attendant, and 21 passengers aboard the 737 sustained fatal injuries.

Many survivors said the cabin filled with thick, black smoke within seconds of hitting the building. There was a delay in opening the right overwing exit because a nearby passenger "froze" which prompted an altercation between two other passengers. Eleven victims, including the flight attendant, were found lined up in the aisle from 4½ to 8 feet from the overwing exits. According to the Board, they most likely collapsed from smoke and particulate inhalation while waiting to evacuate.

Witnesses agreed that both airplanes were ablaze shortly after initial contact on the runway. Investigators found the 737's crew oxygen

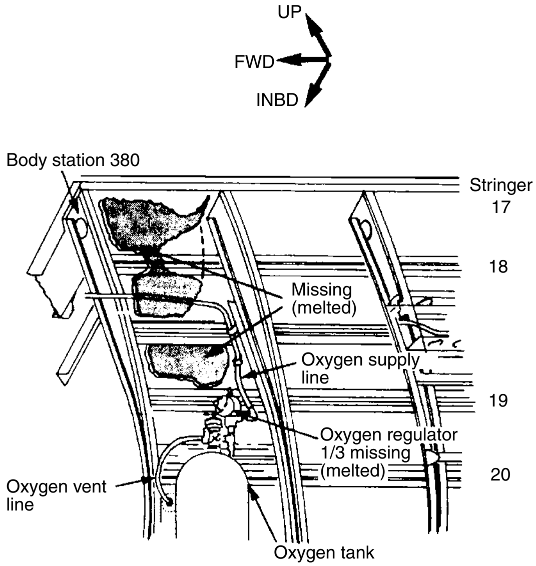

Fig. II-B. Fuselage damage at crew oxygen system location. Adapted from NTSB.

cylinder, which was installed in the forward cargo compartment, depleted, and the low-pressure oxygen supply line broken. Refer to Fig. II-B. The discovery suggested that the oxygen contributed to the fire because there were several holes found in the fuselage near the cylinders. Boeing confirmed that a full cylinder would bleed down in about 90 seconds.

Survivors told investigators that thick, black smoke filled the cabin within 45 seconds. Based on that information, as well as data obtained from other accidents, the Board requested the FAA conduct "burn tests" to determine the effects of compressed gaseous oxygen on cabin fires. Baseline tests were initially conducted that did not include the introduction of compressed gaseous oxygen. In those cases, the fire and smoke spread into the cabin in about five minutes. However, the release of such elements was proven to "exacerbate the rate at which the fire and smoke spread into the cabin." In two sets of tests, the forward cabin area became totally engulfed by flames and smoke in less than two minutes.

The Investigation

The Safety Board analyzed ATC-related factors and flight crew performance with regards to this accident.

ATC PROCEDURES

In an effort to reduce the workload at the ground control position, LAX ATC procedures did not specify the use and handling of flight progress strips at that duty level. As a result, aircraft could request intersection departures directly from the local controller. The ground controller was thereby relieved from coordinating with the local controller and marking flight strips accordingly. Although intended to lessen the ground controller's workload, the procedures eliminated redundancies that were built into the system and consequently increased the local controller's workload. Without the information from the flight progress strip, the only way the local controller could keep track of taxiing aircraft was by contacting the flight crew and relying on memory or observation as to their particular movement on the field. If the controller was unable to remember the details of an aircraft's intended taxi route, or could not distinguish which airplane was assigned what flight number (a real problem when working similar aircraft from the same airline), then the probability for serious errors rose significantly.

A review of the communications transcript of the LC2 provided valuable insight to the Safety Board as to the controller's activities just prior to the accident. At 1803:38, the Skywest crew told her that they were, "at forty five, we'd like to go from here." In later testimony, she stated that she did not hear the "at forty five" portion of the radio call. The Board was unable to conclusively determine whether or not she heard the transmission in its entirety. However, investigators noted from her subsequent taxi instructions to other aircraft, that she was aware of the Skywest's position on runway 24L as late as 1805:16.

UNNECESSARY DISTRACTIONS

Between 1804:11 and 1804:52, the LC2 attempted to contact the Wings West Metroliner four times. The crew had mistakenly turned off the active ground control frequency as they waited clearance to cross runway 24L. Not until 1805:09 was the controller able to resume communication with the crew. The Board believed that this generated additional workload for the LC2, and the subsequent unnecessary and extraneous conversation with them created a distraction. This was evident from the fact that at one point she identified the Wings West flight as an aircraft that she had cleared to another runway more than four minutes earlier. The Board further believed that as the LC2 worked to correct the problem, she became preoccupied and forgot that the Skywest was on the runway.

She appeared to still be a bit confused when at 1806:08, the Wings West crew called for takeoff clearance. She immediately asked them, "You at forty seven [intersection] or full length?" The Board noted that instead of clarifying everyone's positions, she became involved with searching for the flight's progress strip. This situation created yet another distraction that took the LC2 away from her duty to scan the runway. If the progress strip had been at her station to begin with, this diversion would not have occurred.

As a result of the demanding workload and a lack of "memory aids" such as the progress strip, the Board believed that she "forgot" that Flight 5569 was on the runway. To further complicate matters, she misidentified the Wings West aircraft for the Skywest. When she saw the Wings West Metroliner pass in front of her on taxiway Uniform, she thought the runway was empty, so she cleared the USAir flight to land.

ATC NONCOMPLIANCE

The Safety Board believed that the LC2's performance was related to facility procedures that did not allow for human error. The LC2 was required to assume full responsibility for flight progress strip marking and position determination, in addition to departure and arrival sequencing. As a result, the situation created an "abnormal burden" on the controller.

Furthermore, the Board discovered a discrepancy between the FAA's Operational Position Standards order (referred to as National OPS) and the LAX Facility OPS guide. In Chapter 23 of the National OPS, it states, "[the GC position] shall handle the flight progress strips…and mark the runway the aircraft is assigned." The LAX OPS manual states that "strips are not required" for the GC position. The assistant division manager of the Air Traffic Terminal Procedures Branch in Washington, D.C., testified that LAX was in compliance with the National OPS because the handbook states that the progress strips will be forwarded to the "appropriate position." Since the LAX ATC management decided that the appropriate position was at the LC level, they believed the facility was "in compliance with the intent of the National Order." However, the Board noted that the authors of the National OPS recognized the potential for unique circumstances to arise (such as gate holds) that would preclude the established progress strip procedures. It was under those conditions that a facility was allowed to modify a procedure. It was not considered a cause to permanently change it for routing operations.

The Board believed that the decision made by LAX management to remove the GC from the flight progress strip marking and forwarding loop caused a breakdown in redundancy for aircraft tracking. Based upon that information, the Board concluded that the LAX tower was not in compliance with the National OPS Order.

AIRPLANE CONSPICUITY

As part of the investigation, an airplane conspicuity test was conducted for runway 24L in night VMC. An identical Metroliner was positioned at the same location as Flight 5569. The runway edge and centerline lighting were set on low intensity. The tests revealed that during visual approaches, cockpit observers found it difficult to distinguish between the Metroliner and the runway environment.

The design of the Metroliner's anticollision beacon added to the problem. Although it is positioned on top of the vertical stabilizer, the rudder cap obstructs the light when viewed from behind. A representative from the aircraft's manufacturer testified that as the USAir descended below 100 feet over the runway surface, "It is very possible he couldn't see the beacon." When investigators asked the first officer why he was unable to see the Metroliner earlier, he replied, "It wasn't there. It was invisible."

TEST RESULTS

The Safety Board noted that an aircraft should hold about 3 feet off the runway centerline lighting for best rear-view detection. The use of high-energy strobe lights was also considered beneficial in these cases.

FLIGHT CREW VIGILANCE

Because runway incursions are relatively uncommon, the Board expressed concern that flight crews might relax their scanning vigilance for ground traffic. A state of shared responsibility between pilot and controller might also be a factor. In any event, the Board reminded pilots that they need to pay attention to all ATC communication, not just those calls that directly pertain to them.

The Skywest aircraft had been holding on runway 24L for nearly two minutes before the USAir flight had been cleared to land. In that time, there were about 20 ATC and pilot transmissions to the tower frequency, many of which concerned the Wings West flight. Therefore, the Board noted that the Skywest crew should have contacted the LC2 when seemingly less important matters were being discussed—after all, they were the ones sitting on an active runway. They should also have been more cognizant of the other radio calls and been immediately alerted when they heard, "…cleared to land—24L."

COMMUNICATION PHRASEOLOGY

In review of the LC2's communication transcripts, the Board found numerous instances where pilots used vague and ambiguous terms, for example, "We'll take forty-seven [intersection 47]," "We'd like to go from here," and "For the left side, two-four left." Since the LC2 testified that she did not hear the Skywest crew tell her they were at the taxiway 45 intersection, the Board believed that more standard phraseology might have prevented that from occurring. They recommended the following: "Cessna 12345 request intersection takeoff from runway 24 left at taxiway 45." The controller's response would then be, "Cessna 12345, taxi into position and hold runway 24 left at intersection 45."

Lessons Learned and Practical Applications

1. *Be vigilant about situational awareness.* This is especially critical in a high traffic environment and without question while sitting on an active runway. In this case, the phrase, "cleared to land two-four left," was spoken twice over the radio. Yet, there was no response from the Skywest crew. Listen to the radio.
2. *Don't be programmed to hear only your call sign.* Many pilots tune out the background chatter, responding exclusively to their own flight number. A method that was taught to pilots for years was to listen to every fourth word. Not a good practice around busy airport traffic areas or while taxiing on an expansive airfield.
3. *Use standard phraseology.* When everyone is speaking the same language, operational errors and oversights are dramatically reduced. Avoid made-up phrases.

4. *When in doubt, ask.* If you're in a critical phase of flight, or sitting on an active runway, and you *think* you heard a suspicious radio call, immediately check with ATC.
5. *Communicate clearly and specifically.* Review the Board's suggestions mentioned under the Communication Phraseology section in this case study.

Reference

National Transportation Safety Board. 22 October 1991. Aircraft Accident Report: Runway Collision of USAir Flight 1493, Boeing 737 and Skywest Flight 5569, Fairchild Metroliner, Los Angeles, California. February 1, 1991.

Case Study II-2: TWA Flight 427 and a Cessna 441

Safety issues: Pilot and ATC communication, situational awareness, active listening, night operations

On 22 November 1994, TWA Flight 427, an MD-82, collided with a twin-engine Cessna 441 at the intersection of runway 30R and taxiway Romeo at the Lambert-St. Louis International Airport (STL), Missouri.

Probable Cause

The NTSB determined that the probable cause of this accident was the mistaken belief of the Cessna 441 pilot that his assigned departure runway was runway 30R, which was being used by the MD-82 for its departure. Contributing to the accident was the lack of Automatic Terminal Information Service (ATIS) and other air traffic control information regarding the occasional use of runway 31 for departure.

History of Flights

TWA Flight 427 was a regularly scheduled passenger flight from STL to Denver, Colorado. The flight was scheduled to depart St. Louis at 2134 (Central Standard Time) but was 15 minutes late leaving the gate. There were 132 passengers on board the aircraft, plus 5 flight attendants, 2 on-duty flight crew members, and 1 off-duty flight crew member in the cockpit jump seat.

Superior Aviation, Inc., of Iron Mountain, Michigan, operated the Cessna 441 (N441KM) for its on-demand charter business. The pilot arrived at STL around 2140 to drop off a charter passenger at Midcoast Aviation. The pilot, who was also traveling with a pilot-passenger, left Midcoast around 2158 for a return flight to Iron Mountain.

Pilot Experience

The captain of Flight 427 had 18,651 total flight hours, 3,178 in DC-9/MD-82 aircraft. He worked in the company training center from 1987 to 1993 and was involved in developing and instructing the crew resource management course. His vision was corrected to 20/20 for both distant and near vision.

The first officer of Flight 427 had 10,353 total flight hours, 251 in DC-9/MD-82 aircraft. He passed his last line check in July 1994. His vision was 20/20 uncorrected for both distant and near vision.

The pilot of the Cessna 441 had 7,940 total flight hours, 2,060 in the 441. He passed his last proficiency check shortly before the accident and had logged 64 flight hours in the preceding month. According to the pilot's logbook, he had flown into St. Louis once before, in January 1994 and during daylight hours.

The pilot-passenger held a private pilot certificate and was a traveling companion on the round-trip flight. He sat in the right seat as an observer and did not participate in any of the flight duties.

Air Traffic Controller Experience

The local controller was hired by the FAA in 1984, after previously serving as an air traffic controller in the U.S. Air Force. She transferred to STL in 1990, where she achieved Full Performance Level (FPL) status in 1991. She held a current FAA Class II Medical Certificate with no limitations or waivers.

The ground controller was hired by the FAA in 1988, after previously serving as an air traffic controller in the U.S. Air Force. He transferred to STL in 1993, where he achieved FPL status in April 1994. He held a current FAA Class II Medical Certificate with no limitations or waivers.

Weather

The STL surface weather at 2151 was clear skies and 25 miles visibility. The temperature was 33°F and the winds were out of 270 degrees at 8 knots.

The Accident

At 2158, the pilot of the Cessna 441 advised ground control that he was ready to taxi. The ground controller issued taxi instructions, "…back-taxi into position hold runway 31, let me know this frequency when you're ready for departure." The pilot replied, "Kilo Mike." He did not repeat the taxi instructions nor was he required to.

At 2201, the local controller cleared Flight 427 for takeoff on runway 30R. The first officer confirmed the clearance, and the airplane taxied onto runway 30R.

One minute later, the pilot of the Cessna advised the local controller, "…Kilo Mike's ready to go on the right side [30R]," and then taxied onto runway 30 at the intersection of taxiway Romeo. The local controller told the pilot, "Roger, I can't roll you simultaneously with the…traffic departing the right. Just continue holding in position. I'll have something for you in just a second." The pilot replied, "Kilo Mike."

The flight crew began the takeoff roll. About two seconds after the captain made the 80-knot callout, the off-duty pilot in the jump seat yelled, "There's an airplane!" The captain and first officer told investigators that they saw the Cessna at that same instant. Both pilots pressed the brakes, and the captain applied left rudder in an attempt to steer the airplane away from the Cessna. A couple of seconds elapsed before the right wing of Flight 427 struck the Cessna.

According to the flight crew and off-duty pilot, they never saw the Cessna during their takeoff roll until the landing lights of the MD-82 illuminated the airplane holding in position for departure.

Impact and Wreckage

The Cessna was on the runway heading at impact. The right wing of the MD-82 sheared off the tail and entire upper fuselage of the Cessna, approximately 2 inches above the bottom of the cabin windows.

The MD-82 sustained damage to the right wing, causing a 600-gallon fuel spill. There was additional damage to the right main landing gear and the number two engine. An outboard section of the Cessna's left wing was found wrapped around the right main landing gear strut of the MD-82.

ACCIDENT SURVIVABILITY

The pilot and pilot-passenger on board the Cessna sustained fatal injuries. There were no injuries reported from Flight 427 as a result of the collision.

The Investigation

There were several factors central to the investigation: airport layout, pilot performance and communication, ATC procedures and communication, and airport night operations.

AIRPORT LAYOUT

STL runways: 12R/30L (11,019 × 200 feet), 12L/30R (9,003 × 150 feet), and 6/24 (7,602 × 150 feet). Runway 13/31 (6,289 × 75 feet) is a converted parallel taxiway for runway 12L/30R. Runway 31 is used as a "departure-only" runway.

Flight 427 was cleared to take off on runway 30R; the Cessna pilot was cleared to take off on runway 31. The Cessna pilot took taxiway Whiskey (150 feet long) on his outbound taxi from the Midcoast Aviation ramp. Unlike the more typical airport layout in which a ramp exit leads to a parallel taxiway en route to the runway, in this setup, taxiway Whiskey intersects with runway 31. Several local pilots told investigators that the close proximity of runway 31 to the Midcoast ramp caused pilots to inadvertently enter onto runway 31 without recognizing that they were on a runway. While rescue personnel found the airport diagram in the cockpit area of the Cessna, investigators believed that because the outbound taxi route to runway 30 was obvious, the Cessna pilot may not have paid much attention to the diagram.

The markings, signage, and lighting for runway 31 were consistent with FAA airport certification requirements. However, several aspects were slightly different and in the Safety Board's opinion may have triggered the Cessna pilot's preconception that runway 30R was his assigned departure runway.

Runway 31 is 75 feet wide, typical for taxiways at STL. In contrast, runways 30R and 30L are 150 feet and 200 feet wide, respectively. At the time of the accident, runway 31 had a 1,838 displaced threshold. The 800-foot-long portion of runway 31 on which the Cessna pilot back-taxied consisted of a series of white arrows pointing toward the numbers. The runway 31 numbers were located at the end of the displaced threshold, an area that the pilot did not see.

Along the displaced threshold, the runway lights had split red and white lenses situated so that the white side of the lens was facing the Cessna pilot as he back-taxied. This would have been a cue to the pilot that he was on a runway. However, the red side of the lens would have been visible to an airplane on approach for the runway or to a pilot holding in position for departure. Because of the displaced threshold marking scheme, the Cessna pilot could not have seen the numbers for runway 31. Had he seen the numbers, the pilot most likely would have realized that he was on a runway and not a taxiway and thus notified the controller to resolve the matter. The Safety Board did not consider the runway markings and lighting as factors in this accident, except to the extent that they may have provided the pilot with adequate cues.

At the time of the accident, the white runway edge lights of runway 31 were operating at a dimmer setting than those of runways 30R and 30L, which is standard practice at STL. The Safety Board believed that the dimmer lights on runway 31 were not sufficient to distract the pilot from his preconception that runway 30R was his intended departure runway.

CESSNA PILOT PERFORMANCE

According to the Safety Board, the pilot had a reputation as being conscientious and safety-oriented. The passenger who had chartered the flight to St. Louis told investigators that she had flown with the pilot many times and recalled his habit of holding the airport diagrams on his lap for reference during ground operations. The passenger described one charter flight during which the pilot became unsure of his position on an airport, stopped the airplane, and did not proceed until he confirmed his location on the field.

The Safety Board believed the pilot had adequate sleep, including an afternoon nap on the day of the accident. He was observed to be in good humor and conducted his duties in a routine manner. Although the pilot did not seem unduly rushed to leave St. Louis, the passenger and Midcoast Aviation personnel remembered that he mentioned a snowy forecast for Iron Mountain, and he and the pilot-passenger needed to be on their way.

Investigators considered the possibility that the pilot intended to take off from runway 31, as directed, but became lost on the airport. However, the pilot did not indicate confusion in his radio responses to the taxi clearance, and radar data showed no hesitation in his taxi route. Rescue personnel found the current STL airport diagram in the cockpit area, suggesting that he was following the diagram per his routine.

The Safety Board believed it was more likely that the pilot had a preconception about departing on runway 30R and thus did not mentally register the ground controller's clearance to runway 31. In addition to the visual cues of the airport layout, investigators noted other cues which may have influenced the pilot's actions.

First, the pilot had landed on runway 30R just 18 minutes prior to his outbound taxi. All arrivals and departures were using either runway 30R or 30L. Second, the current ATIS identified runways 30R and 30L as the active runways at STL. Investigators discovered that STL controllers did not typically identify runway 31 on the ATIS as a departure-only runway or that it was used occasionally as an active runway. Additionally, the controllers did not handle runway 31 as if it were an active runway when it was not in use. Case in point, when the Cessna pilot cleared runway 30R on his inbound flight, his taxi clearance to the Midcoast Aviation ramp did not include a clearance to cross runway 31, even though the controller knew that was the only possible route.

Lastly, the pilot proceeded from taxiway Romeo into position on runway 30R. He did not request an intersection takeoff nor did the ground controller indicate that he should expect an intersection departure. Therefore, the Safety Board believed that the Cessna pilot missed perhaps his "final cue" when he entered the wrong runway.

GROUND COMMUNICATIONS

At STL, as with many other airports, there are multiple ground control and local control frequencies used to communicate with aircraft taxiing, landing, and taking off on different parts of the airport. Specifically at STL, there are separate ground control positions in the tower and separate radio frequencies for the north and south operations of the airport. Thus when the tower is fully staffed, air carrier pilots taxiing from the south side (Flight 427) of the airport would normally be unable to hear tower communications with aircraft taxiing from the general aviation ramp (Cessna 441) on the north side. Consequently, the flight crew told investigators that they were unaware of the Cessna 441 operating from the north side of the airport. The captain of Flight 427 added, "We…only hear part of the conversation [two-way ATC dialogue] and don't know where the other aircraft are.…That effectively destroys our situational awareness.…"

Furthermore, it was a common practice for STL to reduce the staffing in the tower cab during certain traffic levels. The ground and local controllers told investigators that their workload was moderate at the time of the accident. The ground controller was thereby working four positions (north and south sides of the airport, clearance delivery, and flight data), each of which is normally staffed by a separate controller when the tower is operating during times of peak traffic. At the time of the accident, the ground controller was monitoring seven different frequencies. It was evident from ATC tapes and interviews with the flight crew of Flight 427 that the use of multiple frequencies can occasionally result in incomplete communications and confusion. Investigators reviewed 90 minutes of ATC tapes from the evening of the accident and noted several instances of simultaneous (known as "stepped on") transmissions by other pilots. According to investigators, the multiple frequencies were congested with nearly continuous communication and stepped-on transmissions in the 20 minutes preceding the accident.

The Cessna pilot did not state the departure runway in any of his clearance readbacks nor was he required to. Although the FAA believed that clearance readbacks during flight were critical to safety, at the time of the accident, there were no statements in the Airman's Information Manual (AIM) that addressed the necessity for clearance readbacks on the ground. The Safety Board believed that as a result of this oversight, and the occasional nonstandard radio communications between the pilot and the controllers, neither side was able to effectively clarify their intentions or expectations. In any event, if the flight crew had heard the taxi clearance for the Cessna, they would have believed the aircraft was proceeding to runway 31 and would not have considered it a potential danger.

PASSIVE LISTENING

There were a number of ATC and pilot transmissions which undoubtedly reinforced the Cessna pilot's preconception that his departure runway was 30R. His mindset was of particular importance because he had been described as conscientious and safety-oriented and was therefore someone who was clearly following what he believed were the correct taxi instructions. The pilot's perception of ground operations that evening, combined with his lack of clearance readbacks, in effect, negatively altered his communication and listening skills. He may have lapsed into a "passive" state of listening—not comprehending the aural and visual cues—which ultimately caused him to not mentally register the fact that he was taxiing to the wrong runway. Exacerbating the situation was the failure of the ground controller to use standard phraseology in his initial taxi clearance.

The following are the simultaneous ATC and pilot communications.

Outbound ground control (GO) (2158:19): "One Kilo Mike…back-taxi into position, hold runway three-one, let me know this frequency when you're ready for departure."

Cessna (2158:23): "Kilo Mike."

TWA (2201:22): "…TWA four twenty-seven's ready."

North local controller (NL) (2201:24): "TWA…runway three zero right…cleared for takeoff."

TWA (2201:30): "…cleared to go…"

GO (2201:34): "…Kilo Mike you ready for departure?"

Cessna (2201:38): "…Kilo Mike…we're ready" (unintelligible).

GO (2201:50): "Roger that…Kilo Mike, hold on position on runway three-one and monitor the tower.…"

Cessna (2202:01): "…understand position and hold monitor the tower, Kilo Mike."

Cessna (2202:29): "…Kilo Mike's ready to go on the right side."

NL (2202:30): "Roger, I can't roll you simultaneously with the… traffic departing the right. Just continue holding in position, I'll have something for you in just a second."

Cessna (2202:37): "Kilo Mike."

NL (2202:48): "…Kilo Mike… use caution for the MD-eighty that's…departing thirty right for possible wake turbulence…continue holding in position."

TWA (2203:01): "TWA…hit the other airplane on the…runway, roll the emergency equipment."

ATC STAFFING AND WORKLOAD

The Safety Board believed that, considering the workload at the time of the collision, the clearance delivery position should have been staffed rather than being combined at the ground control position. It further believed that had the clearance delivery position been staffed, the ground controller would have had more time for other functions, such as tracking the Cessna. Subsequent to the accident, the STL tower staffing schedule was changed to retain an additional controller and supervisor until 2230.

VISUAL DETECTION OF THE CESSNA

The Cessna was not equipped with a rotating red anticollision light on the tail, but did have wing tip–mounted anticollision/strobe lights. Investigators noted that the Cessna navigation lights were of little use for detection when viewed against other lights in the runway environment. When the airplane was positioned for takeoff, the single red navigational light would have blended into the other red lights on the runway.

The Safety Board believed that the Cessna pilot did not turn on his wing-mounted landing light until he moved onto the runway, as is customary. Rescue personnel reported that the nose wheel taxi light was illuminated when they arrived at the airplane.

Controllers who work in the tower told investigators that it is often difficult to see small airplanes operating on the north side of the airport, especially on the far end of runway 31, at night. Given the added demands of seeing general aviation airplanes at night in that area of the airport, the Safety Board believed that the ground and local controllers should have heightened their vigilance when they lost sight of the Cessna. However, the Safety Board also believed that based on the pilot's radio communications, the controllers perceived the pilot as confident and familiar with the surroundings.

Lessons Learned and Practical Applications

1. *Become excruciatingly aware of your surroundings, especially at complex airports.*
2. *Listen, repeat, and log ATC instructions in your mind.*

Reference

National Transportation Safety Board. 30 August 1995. Aircraft Accident Report: Runway Collision involving Trans World Airlines Flight 427 and Superior Aviation Cessna 441, Bridgeton, Missouri. November 22, 1994.

Case Study II-3: United Express 5925 and a Beechcraft King Air A90

Safety issues: Scanning techniques, radio communication discipline, monitoring common traffic advisory frequencies

On 19 November 1996, at 1700 Eastern Standard Time, a United Express Beechcraft 1900 C collided with a Beechcraft King Air at

Quincy Municipal Airport, Illinois. United Express Flight 5925 was completing its landing roll on runway 13 and the King Air was in its takeoff roll on runway 04 when the aircraft collided at the intersection of the two runways.

Probable Cause

The NTSB determined that the probable cause of this accident was the failure of the pilots of the King Air to effectively monitor the common traffic advisory frequency or to properly scan for traffic, resulting in their commencing a takeoff roll when United Express Flight 5925 was landing on an intersecting runway.

Contributing to the cause of the accident was the interrupted radio transmission from a third aircraft (Piper Cherokee), which led to the United Express pilots misunderstanding the transmission from the King Air pilots indicating that they would not take off until after Flight 5925 had cleared the runway.

History of Flights

Flight 5925 was a scheduled passenger flight from Burlington, Illinois, to Quincy, Illinois. The flight was operated by Great Lakes Aviation, Ltd., doing business as United Express. The Beech 1900 had 10 passengers and 2 crewmembers on board. On the day of the accident, the flight crew checked in for duty at Quincy Municipal Airport at 0415 for a one-day trip, which was to consist of eight legs for a total of 5.36 flight hours. After the fifth leg (Bloomington, Indiana, to Terre Haute, Indiana), a mechanical problem required the flight crew to ferry the airplane to Chicago-O'Hare, where the flight crew swapped to the accident airplane for the remaining legs.

This placed Flight 5925, 2 hours and 45 minutes behind schedule, resulting in the cancellation of one of the legs and combining passengers from two United Express flights. At 1500, the flight crew departed Chicago-O'Hare for Quincy.

The King Air PIC and pilot-passenger had flown four prospective buyers of the airplane on a demonstration flight from Quincy to Tulsa, Oklahoma, and back to Quincy. The King Air pilots had dropped off the passengers at Quincy and were returning to their home base.

Pilot Experience

The captain of Flight 5925 had 4,000 total flight hours, 700 in the Beech 1900. She had been with Great Lakes Aviation since 1993 and upgraded to captain nine months before the accident. She had logged 91 hours in the 30 days prior to the accident and had passed her last proficiency check in September 1996.

The first officer of Flight 5925 had 1,950 total flight hours, 800 as second-in-command of the Beech 1900. He had logged 103 hours in the 30 days prior to the accident and passed his last proficiency check in September 1996.

The King Air PIC was a retired Trans World Airlines (TWA) captain. He had 25,647 total flight hours, 22 in the accident airplane. After retiring from TWA in 1992, he flew as a part-time flight instructor at the Scott Air Force Base (IL) Aero Club. He also flew as a part-time on-demand air taxi pilot. His last CFR Part 135 instrument proficiency check was in July 1996.

NTSB investigators discovered that in 1991, while still employed by TWA, the King Air PIC was transferred from the status of captain to flight engineer due to “flying deficiencies” which resulted in a failed proficiency check and a failed special line check. Six months before the runway collision in Quincy, the King Air PIC was involved in a gear-up landing incident in a Cessna 172RG while giving instruction to a student commercial pilot. As a result, the FAA initiated an enforcement action against him, but subsequently allowed him to take remedial training in place of the enforcement action. The PIC had not completed that training at the time of the accident.

The King Air pilot-passenger had 1,462 total flight hours. The accident flight was the first time she had flown a King Air. She was employed by Flight Safety International Airline Center as a ground instructor, primarily teaching orientation and indoctrination classes to airline customers. She was also a part-time flight instructor at the Scott Air Force Base Aero Club. She held a certified flight instructor certificate for single-engine and multi-engine aircraft, and it was believed that she was building flight time toward an Airline Transport Pilot (ATP) rating.

The King Air PIC reportedly provided opportunities for the pilot-passenger to gain flight experience in multi-engine aircraft and, presumably, that is why the pilot-passenger was on the accident flight.

The pilot of the Piper Cherokee received his private pilot license in February 1996 and had 80 total flight hours. His passenger received his private pilot license two weeks before the accident and had 44 total flight hours.

Weather

A special surface weather observation for Quincy was reported at 1709.

> Winds 070 degrees at 9 knots; visibility 12 miles; few clouds near the surface, ceiling 14,000 broken, 20,000 overcast; temperature 2 degrees C; dew point −3 degrees C.

The Accident

At 1652, the captain of Flight 5925 stated on the Quincy common traffic advisory frequency (CTAF) that the airplane was about 30 miles north of the airport and that they would be landing on runway 13. She also asked that "any traffic in the area please advise." There were no replies to this request.

At 1655, the King Air pilot-passenger announced, "Quincy traffic, King Air one one two seven Delta's taxiing out…takeoff on runway four." Seconds later, the pilot of a Piper Cherokee, who was taxiing behind the King Air broadcast, "Quincy traffic, Cherokee seven six four six Juliet back-taxi…taxiing to runway four, Quincy." Upon hearing the Cherokee pilot, the captain of Flight 5925 commented to the first officer, "They're both using [runway] four." The captain then asked, "You're planning on one three still, right?" The first officer replied, "Yeah, unless it doesn't look good then we'll just do a downwind for four but…right now plan one three."

A minute later, the captain announced over the CTAF, "Quincy area traffic, Lakes Air two fifty one is a Beech airliner currently ten miles to the north of the field. We'll be inbound to enter on a left base for runway one three at Quincy; any other traffic please advise." They received no response.

Meanwhile, a Piper Cherokee had taxied out behind the King Air and according to the pilot of the Cherokee, he taxied into the runup area of runway 4 after the King Air taxied into position on the runway.

At 1659, the King Air pilot-passenger broadcast, "Quincy traffic, King Air…holding short of runway four. Be…takin' the runway for departure and heading…southeast, Quincy." The captain of Flight 5925 remarked, "She's takin' runway four right now?" The first officer replied, "Yeah," causing the captain to announce, "Quincy area traffic, Lakes Air two fifty one is a Beech airliner…just about to turn…five mile final for runway one three at Quincy." Followed shortly thereafter with, "On short final for runway one three…the aircraft gonna hold in position on runway four or you guys gonna take off?" The King Air pilots did not answer.

However, the pilot of the Cherokee replied, "Seven six four six Juliet…holding…for departure on runway four." The CVR then recorded an interruption in this transmission by a mechanical "two hundred" alert announcement from the ground proximity warning system (GPWS) in the Beech 1900. The CVR then recorded the last part of the transmission from the Cherokee as "[unintelligible word] on the uh, King Air." The captain of Flight 5925 replied, "OK, we'll get through your intersection in just a second sir [unintelligible word] we appreciate that."

According to witnesses, Flight 5925 had its landing lights on and made a normal landing on runway 13. Aircraft performance and visibility studies conducted by the Safety Board indicated that the King Air began its takeoff roll about 13 seconds before Flight 5925 touched down on the runway. The occupants of the Cherokee told investigators that the King Air had been in position on the runway for about one minute before beginning the takeoff roll. The pilot of the Cherokee further stated that he did not hear a takeoff announcement from the King Air over the CTAF, and none was recorded on Flight 5925's CVR.

At 1701, during Flight 5925's landing rollout, the airplane collided with the King Air at the intersection of runways 13 and 04. The passenger in the Cherokee told investigators that he was watching the two airplanes, but he thought they would miss each other. The pilot of the Cherokee later stated that he was unaware that the two runways intersected.

Impact and Wreckage

Both airplanes came to rest with their wings interlocked, along the east edge of runway 13.

BEECH 1900C WRECKAGE

Investigators noted continuous tire skid marks for 475 feet, ending at the point of collision. Fire destroyed the majority of the airplane's upper fuselage, including the cockpit area and both wings. The nose of the fuselage separated from the forward cockpit area, while the tail assembly remained intact. Fire also destroyed the forward air stair door. Investigators found the door latches and control handle assemblies either partially or fully latched.

KING AIR A90 WRECKAGE

According to the tire scuff marks, the pilots of the King Air veered sharply to the right for about 260 feet before colliding with the Beech 1900C. Except for the outboard sections of the right wing and the right horizontal stabilizer, the King Air was consumed by the postcrash fire.

Survival Aspects

The Safety Board determined that the impact forces were at a survivable level for the occupants of both airplanes. However, investigators believed the speed and intensity with which the fire engulfed the King Air prevented the pilot and pilot-passenger from escaping. The bodies of both pilots were found behind the seats in the cockpit, indicating that they were overcome by the smoke and fire before reaching the exit.

RESCUE ATTEMPTS

The Beech 1900C has five exits: two over the right wing, one over the left wing, and the main cabin door.

A pilot employed by the airport's fixed-base operator (FBO) and two Beech 1900C–qualified United Express pilots who were waiting for Flight 5925 to arrive were the first people to reach the accident scene. All three told investigators that the King Air and the right side of the Beech 1900C were intensely on fire when they arrived at the site. A United Express pilot said that he opened the left aft cargo door of the Beech 1900C and black smoke poured out. The FBO pilot noted that he could not see the interior of the cabin through the passenger windows because the cabin appeared to be filled with dark smoke. Both pilots ran to the forward left side of the fuselage where the FBO pilot said he saw the captain's head and arm protruding from her window on the left. She asked them to "get the door open."

The FBO pilot stated that he found the forward air stair door handle in the 6 o'clock (unlocked) position. He said that he attempted unsuccessfully to open the door by moving the handle in all directions and pulling on the door. The United Express pilot then intervened, appropriately depressing the button above the handle while rotating the handle from the 3 o'clock (locked) position downward to the unlocked position. He stated that the handle felt "normal" as he rotated it, but the door still did not open.

The body of the captain was found in the cockpit area, and the body of the first officer was found between the air stair door and the forward right overwing exit. Because the right overwing exits were near the fire on the right side of the cabin, the first officer most likely proceeded toward the left overwing exit but was overcome by the effects of the smoke and fire before he could reach it. Witnesses did not observe smoke coming from the left overwing exit, indicating that it was not opened.

Analysis: United Express Flight Crew Performance

The Beech 1900C was visible to other airport traffic during its approach. Witnesses, including the occupants of the Cherokee taxiing behind the King Air, said that they could see the airplane and that it had its landing lights on.

The captain made frequent position reports and requests for traffic advisories during the approach. Furthermore, the flight crew discussed the fact that two airplanes were planning to take off on runway 04, and they had an alternate plan to use runway 04 if necessary. The captain's request at 10 miles out for other traffic to "please advise" gave them sufficient time to revert to this alternate plan if needed. After observing the King Air entering runway 04, the captain took the precaution of asking, "…aircraft gonna hold position on runway 04 or you guys gonna take off?" Although it would have been prudent of the captain to refer specifically to the "King Air," the Safety Board concluded that her transmission was "sufficiently specific" that she could reasonably expect to be understood.

The Cherokee pilot's transmission ("seven six four six Juliet uh, holding, uh, for departure on runway four…[interrupted transmission] on the uh, King Air") immediately followed the captain's inquiry and appeared to be in response to her question. The transmission was interrupted by the GPWS alarm in the Beech 1900C. Although it would have been prudent for the captain to ask that the transmission be repeated, her reply ("OK, we'll get through your intersection in just a second sir…we appreciate that") made it clear that she believed she was communicating with the airplane that was to take off next on the runway, and it would have been reasonable for her to expect a clarification if that was not the case.

Subtle cues indicated that the transmission did not come from the King Air. Specifically, the speaker gave a different "N" number, and the gender of the speaker was different than heard in previous transmissions from the King Air. However, because the pilots were most likely preoccupied with landing the airplane, and because the speaker said "King Air" but did not say "Cherokee" and the pilots had no reason to expect a response from any aircraft other than the King Air, they probably did not notice or focus on those cues. Having received what they believed was an assurance from the airplane on the runway that it was going to hold, the pilots may have become less concerned about continuing to watch the King Air during their landing.

The Safety Board concluded that the flight crew made appropriate efforts to coordinate the approach and landing through radio communication and visual monitoring.

Analysis: King Air Pilot and Pilot-Passenger Performance

Investigators believed that the pilot was giving instruction to the pilot-passenger on the accident flight. Reportedly, the pilot had previously offered flying opportunities to the pilot-passenger in multi-engine aircraft and had provided instruction. The King Air passengers, who had just returned to Quincy, confirmed that the pilot seemed to be giving instruction to the pilot-passenger and, therefore, it was most likely that the pilot continued providing instruction on their return flight from Quincy.

The last known radio transmission from the King Air occurred at 1659, when the pilot-passenger announced, "…takin' the runway for departure…Quincy." The airplane remained on runway 04 for about one minute before taking off. Investigators found no evidence to suggest the pilot-passenger made a takeoff announcement. There was no such transmission on the Beech 1900C's CVR nor did others monitoring the CTAF, including the Cherokee pilot, hear a takeoff announcement from the King Air.

The pilot-passenger had used the CTAF frequency only a minute before her takeoff roll to announce that she was "takin' the runway… for departure," and since there was no reason for her to change the frequency, it was most likely that the radio equipment was functioning properly. Investigators believed that even if there had been sudden problems with outgoing transmissions, it would not have affected the pilots' ability to hear incoming transmissions over the CTAF.

Analysis: Cherokee Pilot Performance

According to the Safety Board, the radio communications of the Cherokee pilot reflected his inexperience. In his initial transmission, "…back taxi uh, taxiing to runway four, Quincy." The term *back-taxi* refers to taxiing on a runway opposite the traffic flow, which he clearly was not doing. This comment prompted the captain of Flight 5925 to tell the first officer, "They're [the King Air and Cherokee] both using [runway] four."

The pilot further complicated matters by responding to the question the captain had directed to the King Air, "…the aircraft [King Air] gonna hold in position on runway four, or you guys gonna take off?" The pilot of the Cherokee told investigators that he thought the pilot of the King Air was speaking to him, causing him to reply, "Seven six four six Juliet…holding…for departure on runway four… uh, King Air." According to the Safety Board, his response was unnecessary and inappropriate because he was not the first in line for takeoff, nor would there have been any reason for the King Air pilot to ask this question of the Cherokee pilot.

In addition, the pilot failed to precede his "N" number with his airplane model ("Cherokee"), as recommended in the Airman's Information Manual (AIM). He should have been alerted by the captain's response ("OK, we'll get through your intersection.…") and realized that she had mistakenly understood his transmission as that of the

King Air. He further reinforced the misunderstanding by not correcting it, which misled the flight crew into believing that the King Air would continue holding on runway 04.

Both the Cherokee pilot and the passenger (who was a licensed pilot) saw the two airplanes converging, yet failed to warn either Flight 5925 or the King Air. The Cherokee pilot told investigators that he did not realize the runways intersected, and the passenger thought the airplanes would miss each other. The Safety Board concluded that because of the pilot's inexperience, he probably did not realize that a collision between the two airplanes was imminent, and therefore he did not broadcast a warning.

Visibility Studies

Investigators conducted several visibility studies to determine the line-of-sight visibility and conspicuity of the Beech 1900C in sunset and dusk conditions. They also conducted a photographic visibility study to determine the locations of the airplanes as they would have appeared in the pilots' fields of vision.

CONSPICUITY/VISIBILITY TESTS

Three days after the accident, between 1637 and 1708, and in weather conditions similar to those at the time of the accident, two investigators sat in an airport service truck and positioned themselves in the runup area of runway 04. They observed a King Air making a downwind entry and land on runway 13 and reported that the landing lights were conspicuous throughout the entire sequence. The investigators further observed a multi-engine aircraft and a corporate jet taxi out and take off from runway 13, with no ground obstructions to visibility.

Investigators conducted additional visibility tests on the same day, between 1800 and 1930, using a Beech 1900 and a King Air. The Beech 1900, carrying two test pilots and an investigator seated in the jump seat, took off, performed a left pattern, and landed on runway 13. Meanwhile, another investigator observed from the left seat of a King Air, positioned at the approximate location as the accident airplane.

During the landing sequence of the Beech 1900C, the investigator in the King Air noted obstructions to his direct view of the Beech caused by the rear side window post in the King Air. In a second and third test, an investigator sat in the right seat, and then in the left seat of the King Air, which was positioned about 100 feet forward of its previous position on the runway. When the Beech was on final approach, at approximately 200 feet, the test pilot of the King Air began a fast taxi along runway 04. In both tests, the Beech appeared close to the King Air pilot's forward window post.

PHOTOGRAPHIC VISIBILITY STUDY

Photographic data collected in taxi tests revealed that both the captain and first officer of Flight 5925 would have had a partially obscured view of the King Air, beginning 10 to 30 seconds before touchdown and lasting until impact.

As the King Air held in position on runway 04, the pilot had an unobstructed view of nearly 72 degrees to the left. But as noted from the study, when the King Air began its takeoff roll, the pilot and pilot-passenger's view of the runway environment continuously swapped, meaning that when the pilot's view was clear, the pilot-passenger's view was obstructed, and vice versa.

Air Stair Door

The Safety Board concluded that the most likely reason why the air stair door could not be opened was that the accident caused a deformation of the door/frame system, creating slack in the door control cable. According to Raytheon, the manufacturer of the Beech 1900C, as little as ¼ inch of slack in the door control cable could prevent the cams from fully rotating, thus prohibiting the door from opening.

Lessons Learned and Practical Applications

1. *Use standard radio communication phraseology.* For example, "Takin' the runway for departure" is not a takeoff announcement and is open for numerous interpretations.
2. *Don't interject unnecessary and inappropriate radio communication.* It is confusing and breaks down everyone's ability for good situation awareness.

3. *Understand radio terminology before speaking.* The Cherokee pilot reported that he was "back-taxiing" when he was not, which caused a breakdown in situation awareness for the pilots of Flight 5925.
4. *Familiarize yourself with the entire airfield layout.* Draw a quick diagram if you're having trouble visualizing the ramp/taxiway/runway layout. The Cherokee pilot and pilot-passenger remarked to investigators that they saw Flight 5925 and the King Air seemingly converge but failed to notify them because they didn't think that the runways intersected.

Reference

National Transportation Safety Board. 1 July 1997. Aircraft Accident Report: Runway Collision, United Express Flight 5925 and Beechcraft King Air A90, Quincy Municipal Airport, Quincy, Illinois. November 19, 1996.

Case Study II-4: Northwest Flights 1482 and 299

Safety issues: CRM, cockpit discipline, pilot role reversal, communication, role of ATC, judgment, and aeronautical decision-making (ADM)

On 3 December 1990, a Northwest 727 and a Northwest DC-9 collided near the intersection of runways 09/27 and 03C/21C at the Detroit Metropolitan Airport, Michigan.

Probable Cause

The NTSB determined that the probable cause of this accident was a lack of proper crew coordination, including a virtual reversal of roles by the DC-9 pilots. This led to their failure to stop taxiing their airplane and alert the ground controller of their positional uncertainty in a timely manner before and after intruding onto the active runway.

Contributing to the accident were problems with ATC, surface markings at the airport, and company training. The Safety Board specifically cited deficiencies in the ATC services provided by the Detroit tower. This included the failure of the ground controller to take timely action to alert the local controller to the possible runway incursion and inadequate visibility observations. The controller also did not provide progressive taxi instructions in low-visibility conditions. Rather, he issued inappropriate and confusing taxi instructions that were compounded by inadequate backup supervision for the level of experience of the staff on duty. The Board also found deficiencies in the surface markings, signage, and lighting at Detroit Metropolitan Airport. The FAA was faulted in not detecting or correcting any of these problems. And lastly, the Board cited failure of Northwest Airlines to provide adequate cockpit resource management training to their line aircrews.

History of Flights

Flight 1482 was a regularly scheduled passenger flight from Detroit, Michigan, to Pittsburgh, Pennsylvania. The DC-9 had 40 passengers and 4 crewmembers on board.

Flight 299 was a regularly scheduled passenger flight from Detroit to Memphis, Tennessee. The 727 had 146 passengers and 8 crewmembers on board.

Pilot Experience

The captain of Flight 1482 had 23,000 total flight hours, 4,000 in the DC-9. He had been on a six-year medical leave which required him to complete the DC-9 Initial Pilot Training Course before resuming command. He passed his line check three days before the accident.

The first officer had 4,685 total flights hours, 185 in the DC-9. He was a former U.S. Air Force B-52 and T-38 instructor pilot and had been with Northwest just a little longer than six months.

Weather

About 25 minutes before the accident, the local controller stated that he had made a prevailing visibility observation of ¼ mile. The tower supervisor testified that she had confirmed the visibility within "minutes" prior to the runway incursion. Neither controller had referenced the Federal Meteorological Handbook, which provides guidelines for hazardous weather conditions, or the current NWS report.

Sometime in the 15 minutes before the accident, an off-duty controller made a visibility observation using the handbook reference chart. She had determined that the prevailing visibility was ⅛ mile. Following her observation, she asked the local controller whether he wanted to change the visibility reading, and he responded that the ¼-mile call was still current. The east ground controller stated that he had concurred with the ¼-mile call; however, he admitted that he was unable to see certain airport landmarks that were closer than ¼ mile.

The Accident

As Flight 299 left gate F11, the west controller cleared the crew to runway 3C via a right turn from the gate, and to hold short of Oscar 7, a taxiway just before the C concourse. (Refer to Fig. II-C to follow locations and sequence of events.) Although the current ATIS weather information reported ¾-mile visibility, the crew noted that the visibility began to deteriorate during their taxi.

The crew was instructed to contact the east ground controller when they neared Oscar 9, proceed to runway 3C by way of Oscar 6 and the Foxtrot taxiway. They were to report crossing runway 9/27. By this time, an updated ATIS was reporting ¼-mile visibility, which was the company takeoff minimum for runway 3C. As they taxied through the Oscar 6 area, the crew noticed Flight 1482 taxiing eastbound on the outer taxiway toward Oscar 4. The captain later testified that he had lost sight of the DC-9 as it taxied away and into seemingly thicker fog. Shortly thereafter, the crew remembered hearing a discussion on the east ground control frequency concerning an airplane that had missed the Oscar 6 intersection.

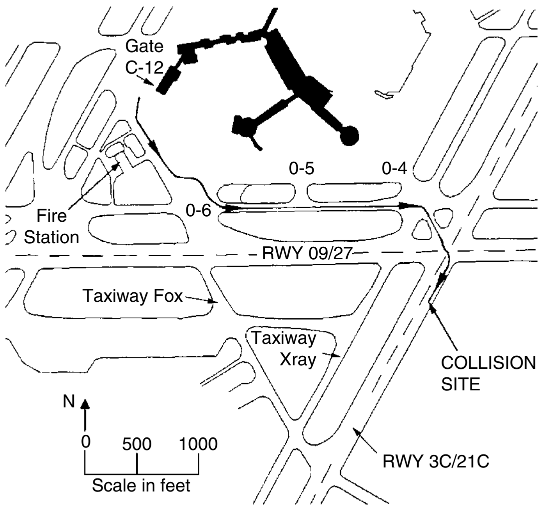

Fig. II-C. Taxi route of Flight 1482 at Detroit Metropolitan Airport. Adapted from NTSB.

The crew of Flight 299 advised ATC when they had cleared runway 9/27 and turned onto taxiway X-ray. The captain noted that he could see about 1,800 feet ahead of him, when the second officer commented on the rapidly deteriorating weather. The crew stopped at the hold line for runway 3C. At 1345:03, they began their takeoff roll. Five seconds later, the first officer remarked, "Definitely not a quarter mile, but…at least they're [ATIS] callin' it." The captain testified that he could still maintain the runway centerline, and because ATIS was reporting ¼-mile visibility, he believed that his decision to take off was correct.

When the airplane reached about 100 knots, the captain stated that a DC-9 suddenly appeared on the right side of the runway, directly in the path of the 727's right wing. He then shouted and moved his body to the left while pulling the yoke to the left and slightly aft. The aircraft stuck the DC-9, and the captain rejected the takeoff and managed to stop at the end of the runway. The collision occurred 1 minute and 25 seconds after the tower had cleared Flight 299 for takeoff.

THE TAXI OF FLIGHT 1482

Flight 1482 left gate C18 and was cleared to a "right turn out of parking, taxi runway 3 center, exit ramp at Oscar 6, contact ground…." The captain testified that he was able to follow the yellow taxiway centerline, but the first officer had commented, "It looks like it's goin' zero zero out here." Moments later, the ground controller requested Flight 1482's position, and the first officer replied that they were abeam the fire station. The controller then gave the crew an additional clearance of, "Taxi Inner, Oscar 6, Fox, report making the right turn on X-ray." About 30 seconds later, the first officer stated, "Guess we turn left here." When the captain expressed some doubt about the left turn, the first officer replied, "Near as I can tell…I can't see…out here."

Shortly thereafter, the captain called for "flaps twenty and takeoff check when you get the time." The first six items on the checklist were completed when the first officer told the controller, "approaching the parallel runway on Oscar 6…headed eastbound on Oscar 6." Seconds later, he added that they had missed Oscar 6 and were then following the "arrows to Oscar 5, think we're on Foxtrot now." The controller replied, "…you just approached Oscar 5 and you are…on the Outer?" The first officer answered, "Yeah, that's right." Based on that information, the controller cleared Flight 1482 to "continue to Oscar 4, then turn right on X-ray."

The final three minutes of cockpit conversation was a revealing account of the confusion and role reversal that had taken place. Following are selected transcripts from the CVR tape, which represent the foundation for the lessons that will be discussed later.

The excerpts begin with the captain slowly taxiing the aircraft eastbound on the Outer taxiway and approaching the Oscar 4 intersection. The estimated visibility was 500 to 600 feet.

1342:00

Capt: This a right turn here…?

F/O: That's the runway.

Capt: (possibly a questioning tone) Okay, we're goin' right over here then.

F/O: Yeah, that way.

About 1342:30

F/O: Well, wait a minute. Oh…this…I think we're on…X-ray here now.

Capt: Give him [ground control] a call and tell him.…

F/O: …we're facing one six zero…cleared to cross it.

Capt: When I cross this, which way do I go? Right?

F/O: Yeah.

Capt: This is the active runway here, isn't it?

F/O: …should be nine and two-seven. It is. Yeah, this is nine-two seven.

Capt: Follow this…we're cleared to cross this thing. You sure?

F/O: That's what he said…Is there a taxiway over there?

At this point (1343:24), the captain set the parking brake. The crew of Flight 299 was about one-and-a-half minutes from starting their takeoff roll.

Capt: …I don't see one [taxiway]. Give him a call and tell him that…we can't see nothin' out here.

About 48 seconds later, the captain released the parking brake.

Capt: Now, what runway is this? This is a runway.

F/O: Yeah, turn left over there. Nah, that's a runway, too.

Capt: …tell him we're out here. We're stuck.

F/O: That's zero-nine [runway].

1344:47

The captain attempted to contact ground control, but because he was initially talking on some unknown frequency or over the intercom, he was unable to reach them until 11 seconds later, 5 seconds before the crew of Flight 299 added takeoff power.

Capt:…[unsuccessful transmission] Hey, ground…we're out here…we can't see anything out here. Ground?

ATC:…just to verify that you are proceeding southbound on X-ray now and you are across nine two-seven.

Capt:…we're not sure, it's so foggy out here, we're completely stuck here.

ATC:…are you on a taxiway or on a runway?

Capt: We're on a runway, we're right by…zero four.

ATC:…are you clear of runway 3 center?

Capt:…it looks like we're on 21 center here.

ATC:…you are on 21 center?

Capt: I believe we are, we're not sure.

F/O to Capt: Yes, we are.

ATC:…if you are on 21 center, exit that runway immediately, sir.

The two aircraft collided seven seconds later.

Impact and Wreckage Path

The 727's right wing initially sliced the DC-9 just under the first officer's right window. The cut continued in a straight line below the cabin windows along the right side of the airplane. Small pieces of debris from the wing tip of the 727, including shards of green glass from the right navigation-light lens, were found in the cockpit of the DC-9. The right engine was knocked off its pylon by the 727. The majority of the DC-9's fuselage was destroyed by fire from just aft of the cockpit to the aft bulkhead.

Approximately 13.5 feet of the 727's outboard wing had been sheared off at impact. Most of the leading-edge devices were broken off and found in and around the DC-9. The 727 sustained no other damage except several cuts on the right tires.

ACCIDENT SURVIVABILITY

None of the passengers or crew of Flight 299 were injured. However, seven passengers and one flight attendant on Flight 1482 sustained fatal injuries.

Following the collision, the captain of Flight 1482 shut off the fuel control levers and ordered an evacuation. The two forward doors were opened, but the left evacuation slide had not been inflated prior to the crewmembers exiting the airplane. One passenger and a flight attendant attempted to deploy the tailcone exit, but due to a malfunctioning release mechanism, it would not open and both succumbed to smoke inhalation.

The Investigation

The Safety Board focused the investigation on the performances of ATC and the flight crew.

ATC PERFORMANCE

The east ground controller testified that the first time he realized that he was unsure of Flight 1482's whereabouts was when the crew told him that they were "completely stuck here." He soon became even more concerned when the crew added that they were "right by Oscar 4." Since he knew that Oscar 4 led onto runway 3C, he said that he loudly announced to the local controller, "I've got a lost aircraft out here, he might be on the runway." At that, he remembered the area supervisor stood up and told everybody to stop their traffic.

According to the local controller, he heard the east ground controller say that an aircraft was lost and possibly on the runway. He believed that Flight 299 was already airborne because he remembered hearing engine sounds, and that nearly a minute had elapsed from their takeoff clearance. Therefore, he made no attempt to contact the crew.

The area supervisor stated that she was seated at a desk doing paperwork when she heard the east ground controller say something to the effect of "I think this guy's lost." She immediately directed the controllers to "Stop all traffic." When the east-ground controller added that the airplane might be on the runway, she loudly exclaimed, "I said stop everything." She did not remember hearing any engine noises of an aircraft taking off.

In a subsequent interview, investigators asked her why the local controller had not contacted Flight 299 in light of her order to stop traffic. She believed that he was the only person who knew where the airplane was and, therefore, the only one who could make the decision.

Although the local controller thought Flight 299 was already airborne, it was apparent to the Board that there was no basis for that assumption. The controller did not verify the aircraft's departure visually or on radar. In fact, he had cleared another airplane into position before the 727 began its takeoff roll. Therefore, the Board believed that the controller should have requested a "rolling" report from Flight 299. This would have enhanced his situational awareness and might have prompted him to contact the crew when the order was issued to stop traffic.

At the time of the accident, controller workload was considered light, which freed the area supervisor to complete her paperwork. However, the Board believed that had she been monitoring the developing situation with Flight 1482, she might have detected the crew's confusion much earlier. The problem might have been corrected sooner, or at the very least, Flight 299 could have been warned before it was too late.

With regards to the visibility observation, the Board further suggested that the supervisor might have questioned the accuracy of a ¼-mile reading had she been more directly involved. It was noted that in the 30 minutes prior to the accident, there were patches of fog in which visibility ranged from ⅛ to ¾ mile. None of the controllers who believed the conditions were at ¼ mile looked at the observation reference guide, even though some at the time had visual indications that proved to the contrary. However, the off-duty controller did refer to the handbook and determined that the visibility was at ⅛ mile. Her query was quickly dismissed when she asked the local controller if he was going to change the official visibility report from ¼ mile. The Board believed that a more conscientious approach to gathering visibility information should have been maintained.

FLIGHT CREW PERFORMANCE

The Safety Board believed that a nearly complete and unintentional reversal of command roles took place in the cockpit of Flight 1482. As a result, the captain became overly reliant on the first officer and essentially shifted the leadership position to him.

According to investigators, the breakdown began when the first officer implied to the captain that he was very familiar with the airport layout. The Board believed that the first officer did not want to appear inexperienced, but at the same time realized that the captain might need help. When the captain asked him for assistance with taxi clearances, he seemed to eagerly take on that responsibility. As the airplane left the gate, the first officer had already begun to dominate the decision-making in the cockpit.

The Board noted numerous examples of this domination in the early stages of the taxi:

About 1322, the first officer explained to the captain the most accurate way to determine weight and balance.

At 1325, the first officer told the captain that he had ejected from airplanes twice, and that he was a retired lieutenant colonel. The Board could find no basis for either statement in his military records.

At 1331, the first officer explained to the captain the details concerning takeoff data for contaminated runways.

At 1336, as they were initially looking for the yellow taxi line, the first officer said, “Just kinda stay on the ramp here.” The captain replied: “Okay, until the yellow line, I guess?” The Board believed this conversation to be significant because the airplane was never positioned on the taxiway centerline that paralleled the ramp area and led to the open area at Oscar 6.

About 1338, as the incorrect decision to turn left at the Oscar 6 sign was being made, the captain asked a series of questions about which way to turn. The first officer appeared to convince himself about their location, and then told the captain to turn left because they were on Oscar 6. The airplane was actually on the Outer taxiway.

There was no evidence to suggest that either pilot ever referred to his directional indicator to help determine their position. If they had checked the aircraft heading, they would have noticed that they were taxiing due east—Oscar 6 lies northwest/southeast. The Board believed that those cues should have been sufficient for the crew to orient themselves and ask for ATC assistance. However, by the time the aircraft was on the Outer taxiway, the captain apparently felt that the first officer knew what he was doing and where the airplane was located.

In the Board's opinion, had the pilots admitted to themselves and to ground control that they were lost, this accident could have been prevented. Although the captain finally tried to assert his authority around 1344:47, and notify ATC, it was too late.

Lessons Learned and Practical Applications

1. *Ask for a progressive taxi.* Get help especially if the visibility is poor or you are not familiar with the airport, or both.
2. *When in doubt, ask.* Don't meander around an airport in hopes of finding the correct runway, taxiway, or gate. Swallow your pride, and ask ATC for help!
3. *Maintain cockpit discipline.* In this case, the nearly complete role reversal between the pilots was a direct result of the lack of cockpit discipline and CRM principles. There should always be a clear division of authority and responsibility.
4. *Avoid role reversal.* The term is *pilot-in-command,* not *pilot-who-sits-in-left-seat.* If you're new, then study the pubs, refresh your

memory on airport layout and ATC frequencies, and review the departure/approach procedures *before* you get in the airplane.

5. *Don't mislead crewmembers.* Be careful not to leave the impression that you might know an important piece of information, when, in fact, you don't.

Reference

National Transportation Safety Board. 25 June 1991. Aircraft Accident Report: Northwest Airlines, Inc., Flights 1482 and 299. Runway Incursion and Collision. Detroit Metropolitan Wayne County Airport, Romulus, Michigan. December 3, 1990.

Case Study II-5: Eastern Flight 111 and a Beechcraft King Air 100

Safety issues: ATC procedures, runway environment

On 18 January 1990, at about 1904 Eastern Standard Time, an Eastern Airlines Boeing 727 collided with an Epps Air Service King Air 100 while the Eastern was landing on Runway 26R at Atlanta-Hartsfield International Airport, Georgia, and as the King Air was preparing to turn off the runway after having landed ahead of the Eastern.

Probable Cause

The NTSB determined that the probable causes of this accident were (1) the failure of the FAA to provide air traffic control procedures that adequately took into consideration human performance factors, such as those which resulted in the failure of the north local controller to detect the developing conflict between the King Air and Eastern Flight 111, and (2) the failure of the north local controller to ensure the separation of arriving aircraft which were using the same runway.

Contributing to the accident were the failure of the north local controller to follow the prescribed procedure of issuing appropriate traffic information to Flight 111 and the failure of the north final controller and the radar monitor controller to issue timely speed reductions to maintain adequate separation between aircraft on final approach.

History of Flights

Eastern Flight 111 was operating as a regularly scheduled passenger flight from LaGuardia Airport, New York, to Atlanta-Hartsfield, Georgia. There were 149 passengers, 5 flight attendants, and 3 flight crew members on board.

The Epps Air Service King Air had departed from DeKalb-Peachtree Airport, Georgia, at about 1850 for the eight-minute flight to Atlanta-Hartsfield. Once at Atlanta-Hartsfield, the pilot and copilot were scheduled to pick up passengers as a CFR Part 135, on demand air taxi, and fly them to Albany, New York. The pilot and copilot were the only occupants in the King Air at the time of the collision.

Pilot Experience

The captain of Flight 111 had 13,320 total flight hours, 1,839 as a 727 captain. The first officer of Flight 111 had 7,388 total flight hours, 92 in the 727. The second officer of Flight 111 had 5,430 total flight hours, 128 hours as second-in-command in the 727.

The pilot of the King Air had 1,653 total flight hours, 230 in the King Air. He held an Airline Transport Rating certificate. The copilot of the King Air was employed by Epps Air Service as a charter pilot in the Piper Navajo aircraft at the time of the accident. He was flying in the right seat of the King Air for aircraft familiarization.

Air Traffic Control Experience

The Atlanta tower north (local) controller had worked as an FAA controller since 1982 and been assigned to Atlanta-Hartsfield in 1988. He was facility-rated in 1989.

The Atlanta approach north final controller had worked at the Atlanta facility since 1968 and been facility-rated in 1971.

The Atlanta approach radar monitor controller had worked at the Atlanta facility since 1979 and been facility-rated the same year.

Weather

The reported weather before the accident was 500 feet scattered, 3,500 scattered, estimated ceiling 10,000 feet overcast, visibility 3 miles with fog. Official sunset was at 1755, and the end of twilight was at 1822.

VISIBILITY OF THE RUNWAY ENVIRONMENT

The flight crew of Eastern Flight 111 told investigators that the lower cloud deck was very scattered and that they could see the runway from a distance. According to the CVR, the flight crew saw the runway a few seconds after passing the initial approach fix, which is 12 nm from the end of the runway. However, the flight crew also stated during the investigation that although the runway lights were clearly visible, they did detect a hazy glow around the airport. The remarks on the CVR tape supported that statement. One of the flight crew members said that the lights looked fuzzy but that he did not think there was any associated fog. After the airplane passed the final approach fix, another flight crew member commented, “Well, it is a little scuddy [scud are light clouds driven by the wind] down there.”

The Accident

At 1858, the King Air was cleared for the ILS runway 26R approach to Atlanta-Hartsfield Airport. The pilots were instructed by Atlanta approach control to maintain 180 knots until over the outer marker. They were then told to switch to the Atlanta tower frequency, where that controller gave them three speed reductions—160, 150, and 140 knots. According to the ground speed radar data, the pilot complied with each of the speed reductions, eventually slowing the airplane to 140 knots approaching the final approach fix. Now on the final approach, the pilot slowed the airplane to a ground speed of 100 knots. Landing data computations indicated that an approach speed of approximately 94 knots (KIAS) was required for the landing.

Upon arrival in the Atlanta area, Eastern Flight 111 was vectored for a final approach and cleared for the ILS runway 26R approach at Atlanta-Hartsfield Airport. Atlanta approach control instructed them to maintain 180 knots until arrival over the outer marker. The FDR and ATC radar data confirmed that the captain (the flying-pilot) had maintained 180 knots until shortly before the final approach fix. At that time, Atlanta approach control instructed Flight 111 to decrease to final approach speed—the only speed reduction given during the approach. At the outer marker, the FDR recorded the airspeed at 165 knots and within seconds of the captain’s “1,000 feet” call, the airspeed stabilized at 145 knots. The flight crew computed the approach speed of 140 to 145 knots based on their landing gross weight and flaps setting.

The local controller cleared the flight to land at 1902. The flight crew told investigators that they flew the glideslope and localizer to the runway landing point—approximately 1,200 feet down the runway. They said that after touchdown, they manually deployed the spoilers and the captain lowered the nose of the airplane to the runway. As the captain reached for the thrust reversers, the flight crew caught the first glimpse of the King Air when their landing lights illuminated it.

The first officer told investigators that while still in the landing roll, the captain steered the airplane to the left of the centerline in an attempt to miss the King Air, but the right wing of the 727 struck the tail of the King Air. The captain maneuvered the 727 back across the runway and exited on the B3 high-speed taxiway and stopped.

Impact and Wreckage

Ground scars from the collision indicated that the King Air had moved to the right side of runway 26R in preparation to exit taxiway D, the primary taxiway for general aviation airplanes. The turnoff was about 3,800 feet from the approach end of the runway.

The right wing of the 727 struck the King Air just below the horizontal stabilizer, severing the empennage and left wing and causing the landing gear to collapse. The momentum of the 727 sliced off the top of the King Air's fuselage from the point of impact forward to the frame of the cockpit windshield. The King Air came to rest at the taxiway D turnoff with the engines still running. There was no postimpact fire.

The 727 sustained damage to the right wing, including several prop slashes. When parked on the B3 high-speed taxiway, the flight crew noticed the reservoir of hydraulic system A had depleted, and a passenger reported seeing some loss of some type of fluid from the right wing. The captain shut down the number three engine and decided that an evacuation was not warranted.

Some passengers on board Flight 111 told investigators that they saw the King Air on the runway seconds before impact. They described the collision as a slight jolt; however, most of the passengers interviewed said that the captain's evasive maneuvers were more apparent than the actual collision.

Accident Survivability

The copilot of the King Air survived, but the pilot sustained fatal injuries. There were no injuries reported on Flight 111.

Analyses

There were three overlapping events that occurred between 1855 and 1904—a decrease in separation between the King Air and Flight 111, an anticipated arrival of an in-flight emergency, and communication difficulties between ATC and a Continental Airlines DC-9. The latter event occurred at a critical moment when the north local controller was attempting to maintain visual separation between the King Air and Flight 111. As a result, the Safety Board examined the controllers involved and individual flight crew performances to determine what role each played in the loss of adequate traffic separation between the accident aircraft.

ROLE OF AIR TRAFFIC CONTROL

The final controller was responsible for maintaining separation of airplanes on the approach to the outer marker. The monitor controller was responsible for maintaining separation of airplanes on the approach from the outer marker to within 1 mile of the runway. According to the Safety Board, it was evident by the airspeed reductions that were issued by the monitor controller to the King Air, that he was attempting to achieve additional separation between a Continental Airlines DC-9 (preceding the King Air) and the King Air, prior to the King Air crossing the runway threshold of 26R. A 4-mile minimum was the required separation standard; however, the separation between the Continental and the King Air never exceeded 3½ miles. The monitor controller also failed to compensate for the added closure rate between the King Air and Eastern Flight 111—Flight 111 was flying about 45 knots faster than the King Air—per ATC instructions.

Flight 111 was about 4 miles behind the King Air at the initial approach fix. Neither the final controller nor monitor controller issued a "timely and sufficient" speed reduction to Flight 111, and, therefore, they were unable to accomplish the desired sequencing of Flight 111 trailing the King Air.

Once inside the final approach fix, the required separation between Flight 111 and the King Air was 2½ miles. According to the Safety Board, it appeared that the monitor controller was late in recognizing the potential separation conflict. About 6 miles from the runway, he instructed Flight 111 to "reduce to your final approach speed." This does not adhere to the FAA ATC Handbook which states, "…a controller shall advise an aircraft to increase or decrease to a specified speed in knots." In addition, the flight crew failed to acknowledge the speed reduction, and thus, the monitor controller should not have assumed that the instruction had been received and complied with. Therefore, in the Safety Board's opinion, the monitor controller initiated a sequence of events that caused the final approach interval spacing to quickly decrease to 2½ miles. The Safety Board believed that the monitor controller's action contributed to Flight 111's overtaking speed that ultimately was a factor in the accident. However, the monitor controller was relieved of direct responsibility when the north local controller subsequently told Flight 111 that he had the airplane in sight—effectively transferring responsibility. At the time of the north local controller's clearance, the separation was rapidly decreasing and less than 2½ miles by the time the King Air reached the runway threshold.

The north local controller, in an effort to continue the landing sequence and avoid a go-around for Flight 111, attempted to maintain visual separation between the King Air and Flight 111—even though he never issued a speed reduction for Flight 111 and separation was already less than 2½ miles. In order for the visual separation to work, the north local controller would have had to closely monitor both airplanes—and in doing so, follow the ATC Handbook regulation stating that an aircraft cannot cross the runway threshold until that runway is clear of other aircraft. This would prove difficult since Flight 111 was bearing down on the King Air with a 45-knot closure rate.

SIMULTANEOUS IN-FLIGHT EMERGENCY AND COMMUNICATION CONFUSION

Minutes earlier, an Eastern Airlines 727 had reported an in-flight emergency after experiencing a total hydraulic failure. The flight was being diverted to Atlanta-Hartsfield and was expected to land on runway 26L at 1910. Fire and rescue personnel were dispatched at 1855 resulting in a considerable number of rescue vehicles parked near runway 26R, north of taxiway D. The flashing amber, red, and blue lights, and the blue strobe lights affixed on top of the rescue vehicles made the runway environment more difficult to discern from the tower.

Meanwhile, at the most critical phase of visual separation between the King Air and Flight 111, the north local controller became distracted with what he believed to be the unknown intentions of the Continental Airlines DC-9, which had just landed in front of the King Air and was now parked on taxiway B2—located between the two active runways—26L and 26R. Upon landing at 1902, the north local controller had provided the Continental flight crew their taxi instructions, "…half right, stay on Bravo, go to two-six left at the end." The flight crew neither responded nor moved. Concerned that the Continental flight crew may inadvertently cross 26L while another flight was in position-and-hold for departure, and the need to clear 26L for the arriving in-flight emergency—the north local controller took his attention away from the King Air and Flight 111.

1901:11. Continental Airlines DC-9 is cleared to land.

1901:15. King Air is cleared to land.

1901:57. "Eastern…you are in sight, cleared to land two-six right."

1902:04. "Eastern…cleared to land two-six right."

1902:38. "Continental…half right, stay on Bravo, go to two-six left at the end."

1902:49. (After no response from the Continental) "Continental…tower."

1903:03. "Tower, Continental…Bravo two, holding short."

1903:06. "[Continental]…continue straight ahead to the end and hold short of two-six left."

1903:12. (Safety Board believed the Continental may have responded, "Yeah, rog.")

1903:13. "[Continental]…hold short of two-six left at the departure end."

Around this time, the ground controller noticed the Continental not moving and radioed them on the ground frequency. After two attempts, the flight crew responded. The ground controller told them to switch back to the north local controller frequency, which they did.

1903:21. "Continental…how do you hear?"

1903:25. "…Continental…say again."

1903:28. "Taxi to the end of the runway and hold short, Continental.…"

1903:47. "Continental…tower."

1903:49. Continental flight responds with an abbreviated call sign.

1903:50. "Continental—taxi straight ahead and hold short of two-six left at the end, over."

1904:04. Continental flight responds with call sign.

1904:21. "Continental…tower."

1904:37. Sound of impact recorded on Flight 111's CVR.

1904:48. "Tower, …Eastern one-eleven…we just hit an aircraft on the runway."

1904:51. "Say again."

1904:52. "There was an aircraft on the runway two-six right."

1905:05. "Tower, Continental.…"

1905:11. "…[Continental] hold short of two-six left right there."

At approximately 1904, the rescue personnel standing by for the emergency arrival heard the collision between Flight 111 and the King Air. Some were as close to the accident site as 100 yards, but none of them witnessed the actual collision.

The north local controller told investigators that he was preoccupied with the Continental jet because he had issued specific taxi instructions that had not been acknowledged, a situation that he considered was a problem. He also admitted that while he had not forgotten about the King Air the communications problems with the Continental flight crew distracted him from the higher-priority traffic, preventing him from focusing on the arrival area of runway 26R when the accident occurred.

LIGHTING ON THE KING AIR

The flight line maintenance technician who serviced the King Air before its departure from the DeKalb-Peachtree Airport told investigators that as the airplane taxied out of the ramp area, he noticed the anticollision light atop the vertical stabilizer was not on and flashing. He also observed during takeoff that the aft strobe light, located on the tail cone was inoperative. The remaining navigation position, anticollision, and strobe lights, however, appeared to be functioning properly.

After the accident, investigators were told that the beacon switch that controls the red anticollision lighting on the tail and on the lower fuselage was reported inoperative the day before the accident. According to the Epps Air Service maintenance management personnel, the repair was deferred until a later hangar visit—and there was no reference made in the maintenance logs.

The ramp technician, who was assigned to service the King Air at Atlanta-Hartsfield, saw the airplane land and taxi on runway 26R. Although he did not witness the collision, he remembered that the strobe lights and red anticollision lights were not operating when the King Air landed. The navigation and landing lights were the only lights the technician saw on the airplane. This was later corroborated by the flight crew of Flight 111 shortly after the accident. In shocked disbelief, the captain and first officer had this exchange:

Capt: “God almighty…he had no lights.”

F/O: “He had no lights.”

Capt: "I didn't see him till he was right there."

F/O: "He was…yeah…there were no lights."

Postaccident examination of the lighting components on the King Air revealed that the belly anticollision light was different from what was specified in the Beechcraft general assembly drawing for the 100 model aircraft. In addition, the inside of the lens had been sprayed with red paint which muted the light intensity. From the physical evidence, investigators determined that the navigation lights were indeed on at impact, but the anticollision light atop the vertical stabilizer was not.

Per CFR 91.33 and 91.73, "…an approved aviation red or aviation white anticollision light system on the airplane is required if it is operated between sunset and sunrise, or under instrument flight rules." The latter regulation further states, "…the anticollision lights need not be lighted when the pilot in command determines that, because of operating conditions, it would be in the interest of safety to turn the lights off."

The Safety Board determined that the King was not in compliance with airworthiness requirements due to the deficiencies in the anticollision lighting system. While the Board was unable to establish whether or not the pilot was aware of these lighting problems, they do assert that exterior lighting is part of the preflight checklist. Therefore, the deficiencies would have become apparent during a properly conducted preflight inspection.

FLIGHT CREW PERFORMANCE

At 1858, the flight crew of Flight 111 heard the approach controller inform the King Air pilots that they were 1 mile from the initial approach fix, maintaining 180 knots and inbound to land on runway 26R. This radio transmission was the only one that could have provided the flight crew with an indication of their actual distance behind the King Air. Flight 111 was more than 5 miles from the initial approach fix at that time and the flight crew did not recall the transmission as significant. The flight crew of Flight 111 was informed 90 seconds later that they were 2 miles from the initial approach fix and was directed to maintain 180 knots to the outer marker. In the Safety Board's opinion, the time interval between these transmissions could have led the flight crew to believe that there was adequate spacing between them and their traffic. Further, the flight crew had no indication of what type of aircraft they were following and thus were unaware that it was a considerably slower airplane in a landing configuration.

After switching to the tower frequency, the flight crew could have heard three more transmissions directed to the King Air: a speed reduction to 150 knots, a further speed reduction to 140 knots, and a clearance to land. During this entire time, Flight 111 was still cleared to maintain 180 knots, approaching the outer marker. The Board believed that the transmissions to the King Air could have alerted the flight crew of a pending overtaking situation. However, because the controllers never provided additional position reports for the King Air, and the normal assumption of the flight crew that the monitor controller was adequately spacing the traffic, the flight crew told investigators that they were not overly concerned.

At 1901, around 1½ miles outside of the outer marker, the flight crew was instructed to "reduce to final approach speed." They did not immediately respond or comply until a second transmission from the monitor controller; however, only 12 seconds elapsed between the initial call and the beginning of a speed reduction, as identified on the FDR. The Safety Board believed that because the transmission, "Reduce to final approach speed," did not provide a specific airspeed (as required in the Air Traffic Control Handbook) or any other indication that the reduction was needed for spacing behind the preceding aircraft, it did not contain sufficient information to convey the need for more immediate action to slow the airplane. Flight 111 passed the outer marker at 1902:15, at an airspeed of about 165 knots.

The Safety Board noted that the flight crew was given a clearance to land at 1901:57 and was advised by the north local controller that they were in sight at 1902:04. No indication was given that they were number two for landing behind another airplane. The Safety Board believed that flight crews are conditioned to receive such information, as required in the Air Traffic Control Handbook procedures relating to anticipating separation. In the Safety Board's opinion, if the north local controller had provided traffic information to Flight 111, the flight crew's sense of situational awareness and motivation to search for a potential traffic conflict most likely would have increased. Lacking such information, it appeared that the flight crew proceeded through their normal task of completing a routine night landing on a runway to which they had been cleared, unaware that there was another airplane on the runway.

The fact that Flight 111 had received a landing clearance did not relieve the flight crew of responsibility to "see and avoid" other aircraft in their vicinity. However, in the absence of conspicuous lighting on the King Air and without prompting from ATC to direct their attention to traffic ahead, in the Safety Board's opinion, it would have been extremely difficult, if not impossible, for the flight crew to detect the King Air on the runway. Therefore, the Safety Board found no evidence to indicate less than expected vigilance by the flight crew and concluded that their actions were not causal to the accident.

Lessons Learned and Practical Applications

1. *Ask ATC what type of aircraft is your traffic.* If ATC does not provide this information, as required, then ask. This is essential for creating a good situation awareness environment, particularly during a critical phase of flight.

2. *Don't be part of the problem.* The Continental flight crew needlessly diverted the controller's attention away from time-critical events—emergency and landing traffic. Listen up! And get out of the way.

Reference

National Transportation Safety Board. 29 May 1991. Aircraft Accident Report: Runway Collision of Eastern Airlines Boeing 727, Flight 111 and Epps Air Service Beechcraft King Air A100. Atlanta-Hartsfield International Airport, Atlanta, Georgia, January 18, 1990.

Historical-International Case Study II-6: Pan American Flight 1736 and KLM Flight 4805

Safety issues: monitoring and challenging errors, ATC and pilot communications, judgment and decision-making, CRM, weather

On 27 March 1977, a KLM-Royal Dutch Airlines Boeing 747 collided with a Pan American Boeing 747 in poor visibility at the Los Rodeos Airport, Tenerife, Canary Islands.

Probable Cause

The Subsecretaria de Aviacion Civil Report gave the probable cause of this accident:

> The KLM aircraft had taken off without take-off clearance, in the absolute conviction that this clearance had been obtained, which was the result of a misunderstanding between the tower and the KLM aircraft. This misunderstanding had arisen from the mutual use of usual terminology which, however, gave rise to misinterpretation. In combination with a number of other coinciding circumstances, the premature take-off of the KLM aircraft resulted in a collision with the Pan Am aircraft, because the latter was still on the runway since it had missed the correct intersection.

CONTRIBUTING FACTORS

"Considered factors" which contributed to the accident were (1) inadequate language, i.e., nonstandard phraseology from the KLM first officer and tower controller, (2) the Pan Am flight crew missing the correct taxiway, and (3) unusual traffic congestion, which required back-taxi operations on the active runway.

Background

As both flights neared their original destination of Las Palmas, Canary Islands, at approximately 1315 local time, a small bomb exploded in the Las Palmas terminal concourse, injuring a number of bystanders. A terrorist group seeking Canary Islands independence from Spain claimed responsibility and told the airport administration that a second bomb was planted elsewhere in the terminal building. Local police had no alternative than to close the airport while they conducted a thorough search.

As a result of the airport closure, Las Palmas ATC diverted all inbound traffic to Los Rodeos Airport on the island of Tenerife. Los Rodeos was 50 nm to the northwest of Las Palmas and was designated an alternate airport for Las Palmas. Los Rodeos had a single runway, and its aircraft parking areas could not accommodate the number of international flights arriving in a short span of time. Under the circumstances, however, Los Rodeos was the only possible option and authorities did not expect Las Palmas to be closed for long.

Weather

Because of its altitude (2,073 feet agl) and location in a hollow between mountains, Los Rodeos Airport has distinctive weather conditions, with a frequent presence of low-lying clouds.

On the day of the accident, light rain and patchy low clouds covered the Los Rodeos Airport most of the early afternoon, when the KLM and Pan Am flights arrived. Fog and light rain persisted over the runway for the 30 minutes prior to the accident.

CONDITIONS AT APPROACH END OF RUNWAY 30

1630. Runway visibility, 3 kilometers; intermittent light rain and fog at distance

1645. Runway visibility, 2 to 3 kilometers; intermittent light rain and fog patches

1650. Runway visibility, 2 to 3 kilometers; light rain and fog patches

1702. Runway visibility, 300 meters; light rain and fog patches

History of Flights

KLM Flight 4805 was a chartered flight that originated from Amsterdam's Schiphol Airport on the morning of the accident. The flight carried 234 holiday passengers, most of whom were Dutch, bound for the Las Palmas Airport, Grand Canary Island. The flight from Amsterdam to Las Palmas was four hours.

PAA Flight 1736 was a chartered flight that originated in Los Angeles, California, on the afternoon of 26 March. There, 364 passengers, mostly retirees, boarded for the first leg of their trip to Las Palmas, Grand Canary Island. From Grand Canary, they were to embark on a 12-day Mediterranean cruise. Flight 1736 made a refueling stop at John F. Kennedy Airport, New York, for a crew change and where 14 additional passengers boarded. The Los Angeles to New York leg was just under five hours, and the New York to Las Palmas leg was six hours.

KLM Flight 4805 was one of the first diverted flights that landed at Los Rodeos. The parking area and main taxiway were already full with airplanes that had been previously diverted by the time Flight 4805 cleared the runway.

The captain of PAA Flight 1736 asked the Las Palmas controller if, instead of diverting to Los Rodeos, they could continue holding over Las Palmas. They had adequate reserve fuel, and the captain sensed from the controller that Las Palmas would reopen in a reasonably short period of time. The controller refused the captain's request and diverted the flight to Los Rodeos. PAA Flight 1736 landed at Los Rodeos at 1345 and was instructed to park directly behind KLM Flight 4805.

Pilot Experience

The captain of KLM Flight 4805 had a total of 11,700 flight hours, 1,545 in the Boeing 747. He was KLM's chief training captain for the 747 and was featured in company advertisements, including those in in-flight magazines. The captain had spent recent years in the 747 training facility and did not typically fly much on scheduled flights.

The first officer of KLM Flight 4805 had a total of 9,200 flight hours, 95 in the Boeing 747. He had been a DC-8 captain prior to transitioning to the 747. As training captain, the captain of Flight 4805 had given him his recent check ride in the 747.

The second officer of KLM Flight 4805 was a professional flight engineer with 17,031 total flight hours, 543 in the Boeing 747.

The captain of Pan Am Flight 1736 had a total of 21,043 flight hours, 564 in the Boeing 747.

The first officer of Pan Am Flight 1736 had a total of 10,800 flight hours, 2,796 in the Boeing 747.

The second officer of Pan Am Flight 1736 was a professional flight engineer with 15,210 total flight hours, 559 in the Boeing 747.

Language Barrier

The Spanish controllers at Los Rodeos had difficulty communicating in English. This was evident from the numerous misunderstandings and communication breakdowns between them and the KLM and Pan Am flight crews. Furthermore, the Dutch first officer, who was communicating on behalf of the KLM flight, used nonstandard ATC phraseology, some of which were most likely linked to his speaking English as a second language.

Analyses—Flight Crew Judgment and Decision-Making

Because of instances in previous years in which pilot fatigue seriously jeopardized the safety of a number of flights, the Dutch civil aviation authority required flight crews to observe rigid duty times, without exception. Captains who exceeded the restrictions were threatened with legal prosecution. These new rules were a dramatic departure from those in the past when a captain, at his or her own discretion, could extend the flight crew's duty time in order to complete "the service." Complicating matters further were recent changes to the new legislation which made flight crews use several factors when calculating precise duty time limitations. The system was so complex that KLM told their flight crews to contact the company for guidance if questionable circumstances arose.

From cockpit conversations, the KLM captain was worried about these restrictions and wanted to avoid the burden of remaining overnight with hundreds of passengers. He contacted the operations office in Amsterdam and was told that he had until 1830 to arrive back to Amsterdam. Shortly thereafter, ATC notified the waiting aircraft that Las Palmas Airport had just reopened.

The captain's worries were still not over. He needed to refuel prior to the flight into Amsterdam and with the dozens of aircraft soon arriving at Las Palmas, many presumably requiring refueling, the captain decided to refuel before departing Los Rodeos.

The Pan Am flight crew prepared to taxi but was told by the tower controller that while there was no delay in obtaining a departure clearance, the only way to the active runway was to maneuver around the KLM, which by that time had begun refueling. Undoubtedly frustrated, the Pan Am first officer radioed the KLM flight crew and asked how long the refueling would take. They were abruptly told, “About 35 minutes.” The first officer and second officer climbed down to the ground to determine if there was enough room to clear the KLM jet, but soon realized that the KLM had them blocked in and they would have to wait for the KLM to finish refueling.

Meanwhile, the weather at Los Rodeos began to deteriorate with poor surface visibility and light rain, adding to the stress already mounting for both flight crews. Moreover, the flight crews were most assuredly feeling tired—the Pan Am flight crew had been on duty for over 9 hours and the KLM flight crew for over 11 hours.

By 1625, the KLM jet was refueled and the flight crew was directed to back-taxi on runway 12 in preparation for departure on runway 30. As the KLM proceeded to move out of the congested area, the Pan Am flight crew received clearance to taxi a similar route as the KLM. When the Pan Am reached the holding point for runway 12, the foggy conditions had worsened over the runway and the flight crew asked the tower controller, “…we were instructed to contact you and also to taxi down the runway…is that correct?” The controller replied, “Affirmative…taxi into the runway and…leave the runway third [third taxiway]…third to your left.” The Pan Am first officer repeated the instructions, and the controller confirmed the accuracy. However, the captain, having difficulty understanding the controller, told the first officer that he thought the controller had directed them to the first taxiway, instead of the third. The first officer asked the controller for clarification at the same time that the KLM flight crew was requesting an explanation to their own taxi instructions. The Pan Am flight crew heard the following exchange. Tower: “KLM 4805…how many taxiway…ah…did you pass?” KLM: “I think we passed Taxiway 4 now.” Tower: “OK…at the end of the runway make one eighty and report… ready for ATC clearance.”

The Pan Am flight crew, taxiing in the fog and at some distance from the KLM, was still having difficulty understanding their taxi instructions. Reviewing the airport diagram, much like a road map, they continued their back-taxi on runway 12. After getting their bearings when passing the first taxiway (C1), the first officer noticed on his diagram that the second (C2) and third taxiways (C3) were at a 135-degree turn from their direction—taxiways C2 and C3 were high-speed taxiways for runway 30. The last taxiway (C4) was a high-speed taxiway for runway 12—an easy 45-degree turn from their direction. The first officer called the ground controller, "Would you confirm that you want us to turn left at the *third* intersection?" The controller replied, "The third one, Sir…one, two, three…third one." The Pan Am flight crew began their pre-takeoff checklists as they continued searching for the third taxiway. The ground controller told them to report leaving the runway, and the first officer acknowledged the instructions.

Meanwhile, the KLM flight crew had reached the end of the runway and had made their 180-degree turn for the departure heading on runway 30. The Pan Am flight crew heard the KLM pilot ask the controller to turn on the runway centerline lights. The controller replied to both the KLM and Pan Am flight crews that the lights were out of service.

Shortly thereafter, at 1705, the KLM captain allowed the aircraft to roll forward. The first officer stopped him and said, "Wait a minute, we don't have an ATC clearance." The captain stepped on the brakes and replied, "No…I know that. Go ahead and ask." The first officer then contacted the tower controller, "KLM 4805 is now ready for takeoff…we're waiting for our ATC clearance." The tower controller replied with their departure clearance, "KLM 4805…you are cleared to the Papa beacon…climb to and maintain Flight Level 90…right turn after takeoff…proceed with heading 040 until intercepting the 325 radial from Las Palmas VOR."

As the first officer began to read back the clearance to the tower controller, the captain released the brakes and started the takeoff roll saying, "Let's go." By the time the first officer completed the readback, the aircraft was six seconds into the takeoff roll, so he added, "We are now at takeoff." The tower controller interpreted the comment that the KLM was *ready* for takeoff. He told the flight crew, "OK…standby for takeoff…I will call you."

Upon hearing that the KLM jet was "at takeoff," the Pan Am first officer called the controller and said, "We are still taxiing down the runway." The tower controller replied, "Roger, Clipper [universal Pan Am call sign] 1736, report the runway clear." The first officer responded, "OK…will report when we are clear." The tower controller acknowledged, "Roger papa alpha 1736, report the runway clear." Inexplicably, the controller used "papa alpha," a call sign that would not typically register to other flight crews as a Pan Am Clipper jet. Compounding this ambiguous remark, and unbeknownst to the Pan Am flight crew and the tower controller, when the first officer made his urgent call to tell the controller that they were still taxiing on the runway, he "stepped on" the final portion of the controller's transmission to the KLM flight crew. All they heard was "…k," followed by a three-second, high-pitched squeal. Instead of, "OK…standby for takeoff…I will call you."

About 20 seconds into their takeoff roll, the KLM second officer asked the captain and first officer, "Did he not clear the runway then?" The captain asked, "What did you say?" The second officer repeated, "Did he not clear the runway, that Pan American?" Both pilots answered unequivocally that the Pan Am had cleared the runway.

The Pan Am jet was still taxiing on the runway after the flight crew missed the intersection for the third taxiway. The captain, apparently uneasy about remaining on an active runway in poor visibility, told his crew, "Let's get the hell right out of here!" Equally concerned about the intentions of the KLM flight crew, the Pan Am first officer answered, "Yeah…he's [KLM] anxious, isn't he?" The second officer added, "After he's held us up for all this time, now he's in a rush."

A few seconds later, the Pan Am flight crew saw the diffused landing light of the KLM jet begin to shake through the fog bank, indicating that the aircraft was moving down the runway. The Pan Am captain exclaimed, "There he is…look at him…[expletives]…coming!" Pushing the throttles full forward and turning a hard left, the captain made a desperate attempt to get off the runway. The first officer frantically yelled, "Get off! Get off! Get off!"

The Pan Am jet was at a 45-degree angle relative to the runway centerline. The KLM first officer called "V1" most likely at the precise moment that his captain saw the Pan Am jet directly in front of him. The KLM captain instantaneously rotated, scraping the tail for a distance of 65 feet. Fully airborne, its nose gear narrowly passed over the Pan Am, but there was not enough clearance and the main landing gear slammed broadside against the Pan Am. The impact sheered off the fuselage, destroying the upper deck just behind the flight deck. Both aircraft caught fire. The KLM jet remained airborne for a few seconds before hitting the ground 150 meters past the crash site and then sliding another 300 meters on the runway. The aircraft violently burst into a raging inferno.

Accident Survivability

A total of 583 passengers and crew perished between both aircraft, making it the most deadly accident in aviation history. There were 234 passengers and 14 crew on board KLM Flight 4805; none survived.

On Pan Am Flight 1736, there were 335 fatalities, including nine members of the cabin crew. There were 77 survivors, including the flight crew. The impact destroyed the first-class lounge on the upper deck, causing the lounge floor to collapse onto the first-class section in the main cabin. None of those in the first-class lounge survived. With no alternative, the flight crew was forced to jump down from the flight deck to the main cabin where they and those survivors from the forward part of the aircraft escaped through a hole behind the L1 door exit.

According to some survivors, the shock of impact was not excessively violent, leading them to believe that the cause was an explosion. They jumped to the ground through openings in the left side of the fuselage or through the L2 door exit. The number one and two engines were still operating, and there was a fire under the left wing. Yet, a large number of survivors escaped off the left wing, amidst the sounds of numerous explosions.

Many of the Pan Am passengers who were seated on the right side of the aircraft were killed instantly from the initial impact. Dozens more, who were seated in the center and aft of the fuselage, survived the impact but became trapped by the twisted metal and debris and thus were unable to escape the spreading fire. There were reports of other passengers who survived the impact but who became incapacitated from the shock and fell into catatonic states, unable to move from their seats and flee the burning aircraft.

Wreckage and Aftermath

While the tower controllers and ground personnel heard the explosions, the dense fog prevented them from seeing the exact location of the collision. Even flight crews from nearby parked aircraft were unable to provide specific information. The tower controllers notified the airport fire department of the crash, but because there was no position report, the controllers told them to stand by. Shortly thereafter, an airport ground employee ran into the fire station and told the rescue personnel that the fire was "to the left of the aircraft parking area."

With a vague location of the fire and the hindrance of congested taxiways, it took several minutes for the rescuers to maneuver their vehicles around the tarmac to reach the crash site. They located the blaze by seeing the fire illuminating the fog and feeling the intense heat. While battling the fire-ravaged KLM jet, the rescuers saw a separate fire some distance away through a slight break in the fog. They assumed that the fire was part of the KLM wreckage, but soon realized that it was the Pan Am jet. Until then, no one knew that there had been a runway collision between two Boeing 747s.

The firefighters concentrated their efforts on the Pan Am jet when it became apparent that there were no survivors on the KLM. In turn, this helped prevent the left side of the Pan Am jet from being completely consumed by the flames.

Analyses and Lessons Learned

Communication errors, a rushed departure, monitoring and challenging errors, and poor visibility proved a deadly combination of factors that culminated with a disaster of historic proportions. While individually these factors posed a threat to safety, the most critical error committed that day was when the KLM captain departed without takeoff clearance, in the fog, when he knew that under the unusual circumstances other aircraft would be back-taxiing to the departure end of the runway.

1. The Pan Am flight crew could not immediately understand their taxi instructions. The first officer believed the controller said to take the "third" taxiway exit, but the captain heard "first." Even after the controller clarified his instructions ("The third one…one two three…third one."), the flight crew did not believe the verbal instructions matched the airport diagram or what they saw as they back-taxied down the runway. As the flight crew pointed out what they considered the second taxiway, the first officer referenced the airport diagram. After a brief discussion, the flight crew believed that according to the diagram, the next taxiway was C3. The first officer remarked, "Maybe he counts these as three." They were most likely contemplating that because taxiways C2, C3, and C4 were similarly shaped high-speed taxiways, perhaps the controller was counting those as "one, two, three." The controller never identified the taxiways as C1 through C4, nor did the flight crew. Furthermore, taxiway C4 was the logical route for the Pan Am to take because it was the only taxiway that provided an easy 45-degree turnoff from the runway. Hence, when the flight crew reached C3 and noticed that it, like C2, would require a difficult turn while C4 would provide a reasonable turnoff, they very likely assumed that the controller meant that C4 was the third taxiway.

2. Seconds before the KLM captain began the takeoff roll, the controller referred to the Pan Am jet as "papa alpha 1736" instead of the standard "Clipper 1736." It is possible that this ambiguous statement did not register with the KLM captain and first officer, who were clearly engrossed in their cockpit duties. The KLM second officer, however, may have caught the radio transmission based on his inquiry, "Did he not clear the runway, that Pan American?" By this time, the captain had commenced the takeoff roll and he and the first officer were positive that the Pan Am jet had cleared the runway.

3. Earlier, when the KLM jet was taxiing, the tower controller attempted to provide the flight crew with their departure clearance. The flight crew told the controller that they would accept it later, presumably because they were engaged in completing their pre-takeoff checklists. This decision resulted in them positioned for takeoff and still needing both takeoff and departure clearances.

4. When the captain allowed the jet to roll slightly, the first officer, unaware of the captain's intentions, cautioned him by saying, "Wait…we don't have an ATC clearance." He then called the tower controller and said, "KLM 4805 is now ready for takeoff and we are waiting for our ATC clearance." When the controller began transmitting the departure clearance, the captain evidently believed that it was also their takeoff clearance. The first officer was still reading back the departure clearance as the captain proceeded with the takeoff. The first officer hurriedly added, "We are now at takeoff." This nonstandard phraseology naturally alarmed the Pan Am flight crew ("We are still taxiing down the runway.") and was misinterpreted by the tower controller, who believed that the KLM flight crew was *ready* for takeoff, not actually taking off.

5. The accident report asserted a possible link between "route and pilot-instruction experience" and the KLM captain's decision to take off without proper clearance. It notes that although the captain had flown for many years on European and international routes, he had been an instructor for more than 10 years, which diminished his familiarity with route flying. During simulated-instructional flights, the training pilot normally assumes the role of tower controller, which includes issuing takeoff clearances. In many cases, no communication whatsoever takes place in simulated flights, thereby eliminating the routine of air traffic control entirely. The report concluded that because the captain was mentally preparing for an expedited takeoff (they were lined up and ready to go), and that receiving clearances was not part of his daily norm, he instinctively accepted the departure clearance as his takeoff clearance.

6. Although the KLM first officer challenged the captain when he thought the captain may be taking off without clearance ("Wait, we don't have an ATC clearance."), he allowed the takeoff to become rushed which may have gone against his better judgment. Based on a radio transmission seconds earlier ("…now ready for takeoff, and we're waiting for our ATC clearance."), it appeared that the first officer understood that he expected two separate clearances—takeoff and departure. Investigating teams from the United States, Spain, and The Netherlands who heard the ATC tapes for the first time said they

understood the transmission to mean exactly what the first officer said, "*ready* for takeoff" not actually taking off.

The safety analysts believed it was possible that the first officer, who had only 95 hours in the 747, and who was flying with the KLM chief 747 instructor, may have become intimidated by the captain's legendary status. The first officer had been an experienced DC-8 captain just months before transitioning to the 747, so the combination of being new in the jet and crewed with someone so well-respected may have caused him to second-guess the circumstances.

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PART III

Weather

Weather is a major factor in aircraft accidents. While technological advancements in airborne and ground-based radar and weather forecasting have improved over the years, meteorological conditions still pose a significant threat to flight safety.

This part covers practical meteorology as it pertains to flight operations including air masses and fronts, cloud formation, thunderstorms, downbursts, low-level windshear, icing, and turbulence. Meteorological phenomena such as wake-vortex turbulence and the effects of heavy rain on airfoils are also comprehensively examined.

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CHAPTER 5

Air Masses and Fronts

Air Masses

An air mass is a body of air extending over a large area of at least 1,000 miles across. Properties of temperature and moisture are fairly constant throughout the air mass. Horizontal changes of these properties are usually very gradual. The terrain surface beneath the air mass is the primary factor in determining air mass characteristics.

Air Mass Classification

cP. Continental polar. Air stagnating over northern continental regions forms arctic air masses. They are cold and dry, and very stable.

mP. Maritime polar. The air masses form over northern oceanic areas. They are normally not as cold as cP air masses, especially in the winter; have a higher moisture content; and can be either stable or unstable.

mT. Maritime tropical. The air masses develop over warm oceanic areas nearer to the equator. They are very humid and generally are the most unstable of all.

cT. Continental tropical. These air masses originate from arid, continental regions that are hot, dry, and unstable. Due to the absence of water vapor, they produce very few rain showers.

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Fronts

Fronts are transition zones between air masses that have different densities. The density of air is primarily controlled by the temperature and humidity of the air. Therefore, fronts in the mid-latitudes usually form between tropical and polar air masses.

Frontal zones, which are normally many miles in width, are most easily detected when the air masses have vastly different properties. They are mostly determined by a change in temperature, moisture, and wind direction and velocity. Specific weather conditions precede and follow a front as it moves through an area. Furthermore, weather associated with one section of a front frequently is different from the weather in other sections of the same front.

Cold Fronts

A cold front is the leading edge of an advancing cold air mass. Colder air overtakes the warmer air, wedging underneath it and forcing it aloft. Surface friction slows the air in contact with the surface, creating a bulge in the frontal slope. This tends to give the front a steep slope near its leading edge. Cold frontal slopes average about 1:80 miles. This means 80 miles behind the front's surface position, the frontal boundary is about 1 mile above the ground. A steep-sloped front (1:40) results in a narrow band of active weather, while a shallower-sloped front (1:100) results in a wide band of weather.

SQUALL-LINE FORMATION

Squall lines form rapidly when cold air downdrafts flowing ahead of the cold air lift the warm, unstable air. The uplifted air develops its own updrafts and downdrafts and starts the thunderstorm development cycle. As the thunderstorm continues development, a squall line will form, often moving at speeds of up to 50 knots. Under certain atmospheric conditions, a squall line composed of thunderstorms may develop 50 to 200 nm ahead of and parallel to a fast-moving cold front.

Thunderstorms associated with a squall line are particularly violent, with the cloud tops much higher in altitude than during most thunderstorms. Severe weather conditions including large hail, damaging winds, and tornadoes are typical signs of a cold front–squall line thunderstorm.

Squall lines eventually lose momentum and energy, dissipating after a life cycle of several hours. Sometimes a new squall line re-forms and moves through approximately the same location as the dissipating one, requiring a pilot's vigilance. Squall lines are usually most intense during the late afternoon and early evening hours just after maximum daytime heating. They are generally associated with cold fronts but may also appear in low-pressure troughs or lines where sea breezes converge against mountain barriers.

FLYING HAZARDS

Squall lines produce strong turbulence, potentially in the severe or extreme categories. Windshear, thunderstorms, lightning, heavy rain, hail, icing, and tornadoes all may be present in and around a squall line. Such dangerous weather conditions can cause sudden fluctuations in altimeter settings, some as abrupt as 0.06 to 0.12 inches of Hg in minutes.

Warm Fronts

The edge of an advancing warm air mass is called a warm front; warmer air is overtaking and replacing colder air. Since the cold air is more dense than the warm air, it tends to be slow at dissipating. This produces a gradual, warm frontal slope that usually averages 1:200 miles.

If the advancing warm air is moist and stable, stratiform clouds will develop. Often the progression of cirrus, cirrostratus, altostratus, and nimbostratus clouds indicate such a front. Precipitation usually increases slowly with the approach of this type of warm front, and normally continues until it passes.

If the advancing warm air is moist and unstable, altocumulus and cumulonimbus clouds, including thunderstorms, will be embedded in the cloud masses that normally accompany the warm front. The presence of these thunderstorms is often unknown to pilots until they fly into one. Precipitation in advance of the front is usually in the form of showers.

FLYING HAZARDS

One of the most serious hazards is the presence of low-level windshear that can linger for longer than six hours prior to the passage of a warm front. The widespread precipitation area ahead of a warm front often causes low stratus and fog. When this occurs, the precipitation raises the humidity of the cold air to saturation. This can produce low ceilings and poor visibility over thousands of square miles. The frontal zone itself might have extremely low ceilings and near zero visibilities over a wide area.

If the cold air has subfreezing temperatures, the precipitation might take the form of freezing rain or ice pellets. In summer months, thunderstorm activity is quite likely.

Stationary Fronts

Sometimes the opposing forces exerted by adjacent air masses of different densities are such that the frontal surface between them shows little or no movement. Surface winds tend to blow parallel to the front rather than away from it. Since neither air mass is replacing the other, the front is considered stationary.

Although there is no movement of the front's surface position, an upglide of air can occur along the frontal slope. The angle of this flow of air in relation to the surface position of the front, and the intensity of the upgliding wind, determines the inclination of the frontal slope.

The weather conditions associated with the stationary front are similar to those found with a warm front but are usually less severe. Since the weather pattern is stationary, poor weather might persist and hamper flights in one area of the country for several days.

Frontal Waves

Frontal waves are primarily the result of the interaction of two air masses. They usually form on slow-moving cold fronts or stationary fronts. During the initial stage of development, the winds on both sides of the front blow parallel to the front. Any small disturbance in the wind pattern, such as uneven local heating or irregular terrain, may start a wavelike bend in the front. These waves can intensify in size, producing a dangerous cyclonic circulation.

One section of the front begins moving as a warm front, while the section next to it begins moving as a cold front. This deformation area is called a frontal wave. As the pressure at the peak of the frontal wave falls, a low-pressure center forms. The cyclonic circulation strengthens, causing the winds in the cold front to move faster than those in the warm front.

Frontal waves are not obvious on the weather chart and are, therefore, difficult to detect.

National Airlines DC-6

Severe frontal waves have caused in-flight breakups. One such event occurred to a National Airlines DC-6 in February 1953. The flight, with 41 passengers and 5 crewmembers, took off from Tampa, Florida, for a late afternoon flight to New Orleans, Louisiana. The aircraft was flying over the Gulf of Mexico at a cruise altitude of FL 145 (14,500 feet), when it encountered severe turbulence. The flight crew slowed the airplane and requested a descent to 4,500 feet. That was their final communication. The wreckage was later found 16 nm from Mobile, Alabama.

The probable cause of the crash was listed as, "The loss of control followed by the in-flight failure and separation of portions of the airframe structure, while the aircraft was traversing an intense frontal-wave type storm of extremely severe turbulence. The severity and location of which the pilot had not been fully informed."

Occlusions

Occlusions are the result of one frontal system overtaking another frontal system. Typically, the cyclonic circulations of a frontal wave push the faster-moving winds of a cold front until they join with a warm front. The two fronts merge and become an occlusion, or an occluded front. The intensity of the frontal wave cyclone is at maximum strength.

An occluded front exhibits characteristics from both the cold front and warm front. As the occlusion expands in length, the low-pressure area weakens and the frontal movement slows. At this point, a new frontal wave may begin to form on the long, westward-trailing portion of the cold front. In the final stage, the occlusion begins to disappear and the two fronts form a single stationary front.

Occlusion Weather

Weather associated with occlusions is a combination of that which is found in cold fronts and warm fronts. A line of rain showers and thunderstorms typically develop as the cold front merges with low ceilings of the warm front. Precipitation and low visibilities are widespread over a large area on either side of the surface position of the occlusion. Strong winds will occur around an intense low at the northern end of the occlusion.

Flying Hazards

The location of the occlusion is significant for pilots because the most severe weather, including low ceilings and visibilities, is generally located in an area 100 nm south to 300 nm north of the frontal intersection. Pilots should be aware of dramatically changing weather conditions, particularly in the early stages of development.

The visual cues when flying toward an approaching occlusion can be misleading. The cloud pattern is very similar to that of a warm front, but the weather can be characteristic of a cold front. Therefore, a pilot may experience fog and low ceilings, followed by a thunderstorm. The reverse is also true. When a pilot approaches an occlusion from behind, the cloud structure may resemble a cold front, but once inside the occluded front, the pilot may find conditions associated with warm fronts, such as extensive cloud decks.

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CHAPTER 6

Cloud Formation

A basic understanding of cloud types is key to identifying approaching and existing weather conditions. There are four "families" or categories of clouds: low, middle, high, and extensive vertical development.

Low Clouds

The group of low clouds consists of stratus, stratocumulus, and cumulus. The bases of these clouds range from near the surface to about 6,500 feet agl. If the clouds form below 50 feet, they are reclassified as fog.

These kinds of clouds are made almost entirely of water, and depending on the temperature, can be filled with ice crystals or supercooled water droplets. Therefore, the potential for icing must always be considered as a threat when flying in or near these conditions.

Stratus

The slow lifting of a fog layer often results in the formation of stratus. Stable air rising over sloping terrain can also produce this low-hanging, uniform looking cloud. Stratus is usually associated with fog or precipitation and contains little or no turbulence. When temperatures dip near freezing, hazardous icing conditions can be present.

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Stratocumulus

Stratocumulus clouds can form when a layer of stable air that is being lifted is mixed by blowing wind over rough terrain. They can also develop from the breaking up of a stratus layer or from the spreading out of cumulus clouds. Higher ceilings and better visibilities usually are associated with these types of clouds. They often appear as large, dirty puffs of cotton.

Cumulus

Cumulus clouds form in convective currents caused by the heating of the ground. They can also develop as a cold air mass is warmed by passing over a relatively warm surface. These clouds are characterized by flat bases and dome-shaped tops. Fair weather cumulus indicate a shallow layer of instability. Some turbulence, but no significant icing or precipitation, can be expected. Although cumulus do not show extensive vertical development, continued growth might lead to towering cumulus and cumulonimbus clouds.

Middle Clouds

The middle clouds include altostratus, altocumulus, and nimbostratus. The height of the bases of these clouds range from 6,500 feet to about 20,000 feet agl. These clouds might be composed of ice crystals or supercooled water droplets. Therefore, middle clouds might contain significant icing conditions.

Altostratus

Altostratus clouds are usually so dense that even through their thinner areas sunlight is seen as very dim. They appear as relatively uniform gray to blue sheets that cover the entire sky. They might gradually form into cirrostratus clouds, which rarely contain turbulence. However, moderate icing might be present.

Altocumulus

These clouds often develop from dissolving altostratus, and appear as white or gray patches of solid mass. They are composed of water droplets and at very low temperatures ice crystals might form. Some turbulence and small amounts of icing will occur in altocumulus.

Nimbostratus

The massive gray and dark-layered nimbostratus clouds are generally associated with continuous rain or snow. These clouds pose a serious icing problem if temperatures are near freezing. As conditions weaken, nimbostratus might merge into low stratus or stratocumulus-type clouds.

High Clouds

High clouds in this family include cirrus, cirrostratus and cirrocumulus. The height of the bases range from about 16,000 to 45,000 ft in mid-latitudes. In the tropics, the upper limits of these clouds might reach 60,000 feet. A cirroform cloud is composed of ice crystals and, therefore, does not present a significant icing hazard.

Cirrus

Cirrus clouds often evolve from the upper part of thunderstorms or cumulonimbus clouds. They can blow away from the main cloud, or the core of the cloud might evaporate, leaving only the ice crystal top portion. These featherlike clouds are spread in patches or narrow bands. If cirrus clouds are arranged in bands or connected with cirrostratus or altostratus, it might be a sign of approaching bad weather.

Cirrostratus

Cirrostratus clouds occur only in stable layers; therefore, no turbulence and little icing can be expected. However, any cirroform cloud might produce restricted visibility. They appear across the sky as a thin, whitish veil.

Cirrocumulus

Cirrocumulus clouds might develop from the lifting of a shallow, unstable layer of air. Heat loss by radiation occurs from the top of the cirrus layer, and the cooler air on top sinks into the cloud. As a result, shallow convective currents can be produced within the layer. Due to the lifting movements, some turbulence could be experienced. Cirrocumulus appear as small, white flakes of cotton.

Extensive Vertical Development

Clouds in this family include towering cumulus and cumulonimbus. The height of their bases ranges from those in the low category all the way to the highest.

Towering Cumulus

Although similar in nature to the cumulus, towering cumulus clouds have greater vertical development. They are often associated with the presence of thunderstorm formation, turbulence, and icing.

Cumulonimbus

Water droplets form the major portion of cumulonimbus clouds, but ice crystals usually appear in the upper limits. These clouds are synonymous with thunderstorms and produce strong winds, lightning, and intermittent showers. The well-developed cumulonimbus might be the parent of the hailstorm and the tornado.

Flying Hazards

Avoid flying near or directly under towering cumulus and cumulonimbus clouds. They can rapidly develop in groups or lines and become embedded in stratiform clouds, resulting in hazardous instrument-flight conditions. Turbulence and icing might be severe enough to cause structural damage to the aircraft.

Special Cloud Types

Because these types of clouds have unique characteristics, they do not fall into any formal classification.

Altocumulus Standing Lenticular

Altocumulus standing lenticular clouds develop on the crests of waves created by barriers in the wind flow. Condensation in the rising portion of the wave forms the clouds. In the descending section of the wave, the cloud evaporates. Thus, the cloud appears not to move, although the wind can be quite strong and dangerous blowing through it. These clouds must be avoided.

Rotor Clouds

Rotor clouds form on the lee side of mountains. The rotor looks like a line of small cumulus clouds parallel to the mountain. Sometimes a person is able to see the rapid swirling motion of the rotor at ground level. Severe turbulence can be encountered in the vicinity of a rotor cloud. The threat of erroneous pressure instrument readings is also a possibility.

Virga

These streaks of water or ice particles, called virga, are usually seen hanging from altocumulus and altostratus clouds. Precipitation that falls from these high-based clouds evaporates and cools the air, creating a downdraft. Do not fly near virga.

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CHAPTER 7

Thunderstorms

There are three basic requirements necessary for the formation of a cumulonimbus (thunderstorm) cloud: unstable air, lifting action, and a high moisture content in the air.

Unstable Air

Air will become unstable when it reaches an altitude where it turns warmer than its local environment. Warm air will continue to rise until it has cooled to the temperature of the surrounding air.

Lifting Action

Some type of external lifting action is needed to bring the warm air from near the surface to the point where it will continue to rise. That latter stage is called *free convection.* A strong lift is usually generated by mountainous terrain, fronts, low-level heating, or an atmospheric convergence. A convergence is when air coming from different directions merges and the force that's created by the collision pushes the air upward in a swift, vertical motion.

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Moisture

The mere lifting of warm air will not necessarily cause free convection. Clouds can still form when moisture condenses, but they will not grow significantly unless the air is lifted to the level of free convection. The higher the moisture content, the easier it is for the air to reach free convection. Once a cloud develops, the latent heat of condensation that is released by the change of state, vapor to liquid, tends to make the air even more unstable.

Life Cycle of a Thunderstorm Cell

A thunderstorm cell progresses through three stages during its life cycle: cumulus, or growth; mature; and dissipating. Often a cluster of cells will be embedded inside a thunderstorm. Since each cell might be in a different stage of the life cycle, the outward appearance of the cloud could be quite deceiving. The life cycle of a thunderstorm might last from 20 minutes to 3 hours, depending on the number of cells contained and their stage of development. It's virtually impossible for a person to visually detect the transition from one stage to another, so a pilot should never try to outguess the system and fly near a building thunderstorm.

Cumulus Stage

Although most cumulus clouds don't become thunderstorms, the initial stage of a thunderstorm is always a cumulus cloud. The main feature of this stage is a rapidly moving updraft, that might originate near the ground and extend several thousand feet about the visible cloud top. The greatest updraft occurs at higher altitudes late in the cumulus stage, when it could reach speeds in excess of 3,000 fpm.

As the cloud forms, water vapor changes to liquid and/or frozen particles. This results in a release of heat that provides a source of energy for the developing cloud. It is this release of heat that helps keep the cloud growing.

During this early stage, cloud droplets are very small, but turn into raindrops as the cloud builds upward. The raindrops might remain in a liquid state as the updraft pushes them well above the freezing level, which in the most intense storms could be more than 40,000 feet. There is usually no falling precipitation during this stage because the water drops and ice particles are still being carried aloft by the ascending air currents.

Mature Stage

The beginning of falling rain or hail from a cloud indicates that a downdraft has developed, and the cell has entered the mature stage. The raindrops and ice particles in the cloud have grown too large for the updraft to continue to support them. By this time, the average cell has reached a height of about 25,000 feet, although at high latitudes, tops might be as low as 12,000 feet.

As the drops start to fall, the surrounding air begins a downward motion. Since the air is unstable, the cold air accelerates and forms a downdraft. The velocity of a downdraft can easily reach speeds of 2,500 fpm, as it spreads outward near the ground. This produces a sharp decrease in temperature and strong, gusty surface winds. The leading edge of this wind is called the *gust front*.

Early in the mature stage, any remaining updrafts will continue to gain speed and might exceed 6,000 fpm. The violent flow of updrafts and downdrafts near each other create the vertical shears that can cause severe turbulence. All thunderstorms have reached their greatest intensity at this time.

Dissipating Stage

Throughout the mature stage, the downdrafts continue to develop as the updrafts begin to weaken. As a result, the entire thunderstorm cell ultimately becomes an area of downdrafts. Since updrafts are necessary to produce condensation and latent heat energy, the thunderstorm begins to dissipate. Don't be fooled, though, into thinking a weakening thunderstorm can't still hold a punch or two. Strong upper-level winds will typically push the top of the cloud into an anvil shape. Although this can be *one* sign that a thunderstorm is dissipating, severe weather can still be present in many systems with a well-defined anvil.

The most intense thunderstorms occasionally do not dissipate in the manner just described. Although they are technically considered in the dissipating stage, they behave more like a prolonged mature stage. If horizontal wind speeds dramatically increase with altitude, the storm clouds will shift into a tilted position. Precipitation will fall through a small portion of the rising air. This will be followed sometime later with it falling through the relatively calm air near the updraft, or even completely outside the cloud itself.

The updrafts produced by this prolonged mature stage can continue until their source of energy is exhausted. The thunderstorm, therefore, might dissipate without going through the normal process of tremendous downdraft activity. However, precipitation falling from the tilted cloud might cause downdrafts to form in the clear air, just outside the storm's boundary.

Types of Thunderstorms

There are several types of thunderstorms that can develop, each presenting unique and potentially dangerous flying conditions.

Warm Front Thunderstorms

Due to the shallow slope of a warm front, thunderstorms in those areas are usually the least severe of all frontal-type storms. Nevertheless, thunderstorms might still be found hidden within the stratiform clouds that are normally associated with a warm front. You might be able to spot them poking through the hazy layers if you're flying high enough, or become aware of their presence from sudden and loud spurts of static over the radio.

Cold Front Thunderstorms

These storms are quite severe, and usually form in a continuous line that is easy to recognize. These thunderstorms are generally most active during the warmer afternoon hours.

Stationary Front Thunderstorms

Occasionally, thunderstorms will develop in stationary fronts and become widely scattered.

Occluded Front Thunderstorms

These thunderstorms are particularly dangerous because they are not well-developed, but can become embedded in stratiform clouds, making them difficult to detect.

Squall-line Thunderstorms

A squall line is a nonfrontal, narrow band of active thunderstorms. It often develops 50 to 300 miles ahead of a rapidly moving cold front in moist, unstable air. The existence of a front, however, is not absolutely necessary for a squall line to form.

The thunderstorms in a squall line are fast-building and are generally more violent than storms associated with a cold front. Severe weather, including heavy hail, destructive winds, and tornadoes are characteristic of a squall line.

Air Mass Thunderstorms

Thunderstorms can form within warm, moist air that is not part of a front. This usually occurs from surface heating and convergence that takes place over land during the middle and late afternoon. Along coastal regions, air mass thunderstorms tend to reach their maximum intensity throughout the night and early morning when the cool air flowing off the land is heated by the warmer water surface. As a result, these thunderstorms often form a short distance offshore. Whether they develop over land or water, air mass thunderstorms are usually isolated or widely scattered over a large area.

Orographic Thunderstorms

Thunderstorms will form on the windward side of a mountain if the wind forces moist, unstable air up the slope. The storm activity is usually scattered along the individual mountain peaks, but occasionally there will be a long, unbroken line of thunderstorms. Stratus and stratocumulus clouds frequently enshroud the mountain peaks and obscure the storm.

Meteorological Observations

Thunderstorms are categorized by levels of echo intensity and rainfall rate.

Level 1: Light precipitation. Light to moderate turbulence is possible with lightning.

Level 2: Moderate precipitation. Light to moderate turbulence is possible with lightning.

Level 3: Heavy precipitation. Severe turbulence is possible with lightning.

Level 4: Very heavy precipitation. Severe turbulence is likely with lightning.

Level 5: Intense precipitation. Severe turbulence is likely with lightning, organized wind gusts, and hail.

Level 6: Extreme precipitation. Severe to extreme turbulence is likely with large hail, lightning, and extensive wind gusts.

Aircraft Performance in Heavy Rain

Heavy rain can penalize aircraft performance in three ways:

1. Some amount of rain adheres to the airplane and increases its weight.
2. The raindrops striking an airplane must take on the velocity of the aircraft and the resulting exchange of momentum reduces the velocity of the airplane.
3. The rain forms a water film on the wing, roughens its surface, and decreases the aerodynamic efficiency of the wings.

Research has shown that the landing weight of a large transport aircraft will increase by only 1 to 2 percent when flying through heavy rain. Thus, the added weight is not a significant factor.

The momentum penalty is clearly detrimental to aircraft performance. When raindrops strike the surface of a fuselage, they cause the airplane to decelerate. The amount of velocity that is lost is dependent on the following factors:

1. Airspeed
2. Rainfall amount

3. Raindrop size
4. Size distribution
5. Water content of the air
6. Airplane configuration

The penalty is most severe any time the leading and trailing edge devices are extended, as in a landing or takeoff configuration. The penalty becomes significant when rainfall rates approach 500 millimeters per hour. At those levels the rainfall could reduce airspeed at a maximum rate of about ½ knot per second.

The most dangerous penalty is the formation of water film on the wing. A change in boundary layer flow—the fluid layer adjacent to the airfoil surface—is likely to develop. The surface roughness would cause the boundary layer to transition prematurely from a smooth laminar flow to turbulent flow, resulting in skin friction drag. An increase of 10 to 20 percent in drag is likely, and depending on rainfall rate, a lift penalty will increase as the angle of attack (AOA) increases. Therefore, the stall AOA could occur before the activation of the stall-warning system. A rainfall rate between 150 to 500 millimeters per hour can produce enough surface roughness to cause these penalties.

The roughening of an airfoil in heavy rain can also cause the acceleration of splashed-back droplets. When raindrops hit an airfoil, some fraction of the mass is splashed back to form what is called *droplet ejecta fog* near the leading edge while the remainder forms a thin water film on the airfoil surface. The vast majority of droplets near the airfoil are due to splash-back. The formation of a highly concentrated area similar to the ejecta fog can significantly deform the shape of the airfoil. Researchers have determined that "for a chord length of one meter, the thickness of this layer varies from approximately two centimeters (cm) at the leading edge of the airfoil to approximately 10 cm further downstream along the upper surface."

The AOA is also affected by heavy rain. For example, an aircraft with an AOA of 4 degrees causes the stagnation point to be slightly below the leading edge. Thus, splash-back droplets from raindrops impacting the leading edge tend to be carried over the upper surface of the airfoil more than the lower surface. The drag produced by these splash-back droplets acts as a "sinking" momentum near the leading edge of the airfoil, creating the potential to deenergize the boundary layer. Therefore, the combination of a momentum penalty and airfoil roughness is the most likely cause for the degradation of aircraft performance in heavy rain.

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CHAPTER 8

Downbursts and Low-Level Windshear

A downburst is a strong downdraft that induces an outburst of highly diverging winds on or near the ground. A downburst is subdivided into macrobursts and microbursts.

Macroburst: A large downburst with its outburst winds extending in excess of 4 kilometers (2.5 miles) in horizontal dimension. An intense macroburst often causes widespread, tornado-like damage. Damaging winds, lasting 5 to 30 minutes, could be as high as 60 meters per second, or 134 mph.

Microburst: A small downburst with its outburst, damaging winds extending only 4 kilometers or less. In spite of its small horizontal scale, an intense microburst could induce damaging winds as high as 75 meters per second, or 168 mph.

Macrobursts

A macroburst is characterized by a big layer of cold air that is created by a succession of downdrafts beneath the parent rain cloud. Since a dome of cold air is heavier than the warm air surrounding it, the atmospheric pressure inside the dome is higher than that in its environment. The pressure gradient force, pointing outward from the

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dome area, pushes the cold air outward, inducing gusty winds behind the leading edge of the cold air outflow. The gust front denotes the leading edge of gusty winds which push the dome boundary away from the subcloud region. Those conditions produce a violent clash between the cool outflowing air and the warmer thunderstorm. This usually causes a windshift and drop in temperature that precedes a thunderstorm.

Microbursts

Very strong outbursts of winds over an area less than 2.5 miles are the two basic characteristics of microbursts. Interestingly, while the core of a microburst is quite severe, its boundary propagates outward rather slowly. Photographic evidence has shown that a downflow of wind might be traveling at 40 knots. When a swirling horizontal vortex near the ground encircles the downflow center, it forms a vortex ring. The outbursting winds beneath this ring are accelerated and might reach 100 knots. This outburst continues to gain speed as the ring expands and stretches.

Types of Microbursts

Not all microbursts are alike; some are accompanied by heavy rain, while others form beneath small virga. The first major classification is based on the amount of precipitation that reaches the ground. The second is distinguished by a change in temperature. Refer to Fig. 8-1.

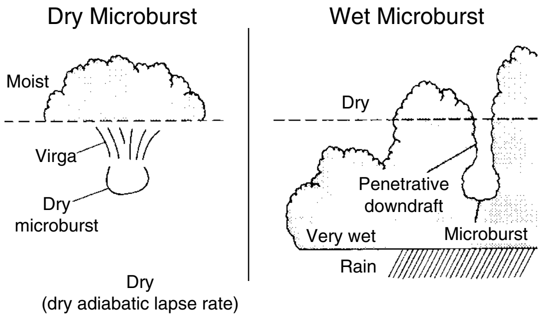

Fig. 8-1. Environmental conditions associated with microbursts. Adapted from NOAA.

Wet Microburst

The environment in which a wet microburst typically forms is marked by a deep, nearly saturated layer of air, a moist adiabatic lapse rate, and topped by an elevated dry layer of air. This mixture can produce enough negative buoyant potential energy to drive a severe downdraft. A descending wet microburst might first appear as a darkened mass of rain falling through an area of lighter rain. A strong downdraft pushes rain toward the surface at a much faster rate than it can fall at terminal velocity through still air. As the downdraft approaches the ground, it decelerates in the vertical, allowing a heavy load of water to accumulate just above the surface. The most pronounced visual indicator of a potential microburst is a descending, high-density globular mass of rain and a clearing out of precipitation in its wake.

Dry Microburst

In an extremely dry environment, where moist convection is just barely possible, cumulus clouds with very high bases can form. Below the cloud layer is a deep and dry adiabatic lapse rate. The storms might not produce lightning, even though the cumulus have a fibrous appearance and a prominent anvil-shaped top. At first glance, the weather might appear good and nonthreatening, but conditions can change in a matter of minutes. A dry microburst becomes visible when the expanding ring of dust under a virga shaft descends from a high-based cumulonimbus. The precipitation mostly evaporates before reaching the surface, so rainfall is probably no more than a trace. As the microburst develops, the ring of dust spreads out over the ground.

Anvils of large, dry-line thunderstorms might also produce high-level virga, which can result in dry microbursts. These conditions could develop far away from the parent hail storm and its associated heavy radar echo.

Traveling Microburst

The traveling motion of a microburst distorts the airflow from a circular to elliptical shape. The front-side wind intensifies, while the back-side wind weakens, resulting in a crescent-shaped area of high winds.

Radial Microburst

Radial streamlines are seen if microburst winds are not rotating.

Twisting Microburst

When a microburst descends inside a cyclonic airflow at the surface, it curves and twists. This type has been observed during tornadoes that were spawned by supercell thunderstorms. Frequently, damage maps of tornadoes reveal a widening of paths prior to the tornadoes dissipation. When the end of a tornado's path becomes 2 to 3 miles wide, the flow pattern becomes similar to that of a twisting microburst.

Surface Microburst

No microbursts form on or near the ground. But when one touches the ground, it's called a *surface microburst*. When it spreads out over a large area, the downflow keeps supplying the mass until it sinks to the ground. After that, a microburst flattens and its expansion terminates.

Outflow Microburst

A slow-traveling outflow microburst is often characterized by a vortex ring encircling it. The ring keeps stretching as a surface microburst gets older, until it reaches its limit. Thereafter, the vortex is cut into several pieces of roll vortices, each with a horizontal axis. It eventually turns into a rotor microburst.

Rotor Microburst

When those vortex rolls "run away" from their source region, bands of high winds are produced. They can last two or three minutes. This type of microburst behaves like a tornado with a horizontal vortex axis. It usually creates a narrow, but severe, damage path. It's also frequently accompanied with a roaring sound and is often misidentified as a tornado. In 1981, Fujita called this rotor microburst swath a "burst swath."

Types of Parent Clouds

Anvil

Many microbursts form beneath virga descending from anvil-shaped clouds.

Supercell

These thunderstorms are likely to produce strong tornadoes. Microburst activity is almost always found in the vicinity of such storms.

Bow Echo

Usually, high winds push out of a strong thunderstorm to form the shape of a bow (as in archery). During the mature stage of a bow echo, tornadoes and microbursts could occur simultaneously. The outburst winds tend to dissipate rather quickly, thereby drying the source region.

Isolated Shower

An isolated shower, with or without thunder, can induce microbursts. The microburst that caused the accident described in Case Study III-1 was from an isolated shower that was relatively small and short-lived.

Cumulus

Large cumulus and altocumulus, which produce rain or snow, can produce microbursts one of three ways.

Mushroom cloud. Due to the echo top being much higher than the inflow height, the mount-shaped top is not affected by the downflow. In turn, the shape of a mushroom remains during the microburst.

Sinkhole cloud. This is a cumulus cloud with a small vertical growth. The entire cloud is embedded inside the inflow layer of an induced microburst. A sinkhole develops atop the cloud and directly above the microburst downflow in mature and postmature stages.

Giant anteater cloud. This is a cumulus or altocumulus cloud with a glaciated top. When a downflow forms on the upwind side of the cloud, the cloud base lowers, turning into the shape of giant anteater head. A microburst descends from the head section, which keeps lowering until it reaches the ground. When a surface microburst forms, the entire head section descends to the ground, turning into a headless giant anteater. I think some scientists let their imaginations run wild with this one.

Temperature Parameters

Most macrobursts are accompanied by a dome of high pressure, induced by rain-cooled air. Along the leading edge of the front of a macroburst, a pressure surge or jump takes place, as well as gusty winds and a temperature drop.

In microbursts, however, a strong downflow descends very close to the ground before spreading. The downflow air warms up dry-adiabatically, all the way to the ground, unless embedded raindrops evaporate fast enough to maintain a moist-adiabatic descent. However, this is very unlikely in a strong microburst. The air temperature in microbursts can be either warmer or colder than the environment. The surface pressure can also be higher or lower than the environmental pressure, because the outburst winds lose their pressure head while being accelerated outward from the microburst center. Thus, the changes in the meteorological parameters in microbursts are very complicated.

Low-Level Windshear

Windshear is a change in wind speed, direction, or both over a short distance. There are several weather phenomena that produce such conditions. These include thunderstorms, fronts, radiation inversions, funneling winds, and mountain waves.

Thunderstorms

As discussed in the previous section, a downdraft exiting the base of a thunderstorm spreads outward in all directions. This forms a gust front that can extend 10 to 15 miles away from the source region. Extreme windshears of 10 knots per 100 feet of altitude have been measured immediately behind a gust front, while horizontal windshears of 40 knots per mile have been recorded across such an area. The most severe thunderstorms can produce directional shears of 90 to 180 degrees.

An aircraft passing through the gust front and downdraft would encounter not only a rapid change in the horizontal wind field but also a downward vertical motion. The latter motion can add or subtract hundreds or even thousands of feet per minute to the descent or climb rate of the airplane.

Fronts

Winds can be significantly different in the two air masses that meet to form a front. Those most conducive to windshear are fast moving, 30 knots or more, have at least a 10°F (5°C) temperature differential, or both.

Windshear can occur with a cold front after the front passes. Because cold fronts have a greater slope and normally move faster than warm fronts, the duration of low-level windshear is usually less than two hours. However, windshear associated with a warm front is more dangerous due to the strong winds aloft. This might cause a rapid change in wind direction and speed where the warm air overrides the cold, dense air near the surface. Windshear might persist for more than six hours ahead of the warm front because of the front's shallow slope and slow movement.

Radiation Inversion

This condition can start to form at sundown and reaches its maximum intensity just before sunrise. It then dissipates, caused by daytime heating. The cooling of the earth creates a calm, stable dome of cold air that is 300 to 1,000 feet thick, known as an *inversion layer.* Speeds of 30 knots are common above the top of this layer, and speeds in excess of 65 knots have been reported. Anytime a radiational inversion is present, the possibility of low-level windshear exists.

Funneling Winds and Mountain Waves

When strong prevailing winds force a large mass of air through a narrow space, such as a canyon, it accelerates and spills out into a nearby valley or open space. These winds sometimes reach velocities in excess of 80 knots. Chapter 10 explores these phenomena in detail.

Indicators of Windshear

1. A recent cold frontal passage or an impending warm frontal passage might produce a windshear. The isobars around the frontal system at the surface yield a good approximation of the directional shear that will be encountered. For example: The surface winds at airport A are reported to be 320 degrees at 25 knots. The surface winds at airport B are reported to be 040 degrees at 20 knots. The direction of the isobars in the warm sector (from about 220 degrees) is an estimation of the wind direction above both the cold- and warm-frontal surfaces.

Therefore, a pilot flying in or out of either airport can expect winds to be from about 220 degrees above the frontal surfaces. Shearing should be encountered from around the same direction, but below the frontal surfaces.

2. Abnormal power setting and rate of descent signal a possible windshear. Fluctuations in the indicated airspeed and the vertical velocity indicator always accompany windshear. Another determinant is a large difference between indicated airspeed and groundspeed. Any rapid changes in the relationship between the two represent a windshear.

3. Inertial navigation system (INS) comparisons are good indicators. Crews can compare the wind at the initial approach altitude with the reported runway surface wind to see if there is a windshear situation present. But remember, INS winds are in degrees true; tower winds are in degrees magnetic. This will make little difference at airfields where the variation is only a few degrees, but it makes a considerable difference when the variation is 20 degrees or greater.

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CHAPTER 9

Icing Conditions

Stratiform Clouds

Icing in middle and low-level stratiform clouds usually is confined to a layer between 3,000 and 4,000 feet thick. The intensity of the icing generally ranges from a trace to light rime or mixed, with the most significant amounts occurring in the upper portions of the cloud. The primary hazard lies in the great horizontal extent of some of these cloud decks. High-level stratiform clouds are composed mostly of ice crystals and produce little icing.

In thick stratified clouds, concentrations of water droplets are usually greatest where there are warmer temperatures. Therefore, the potential for significant icing can normally be found at or slightly above the freezing level. In layer-type clouds, continuous icing conditions are rarely present at more than 5,000 feet above the freezing level and are ordinarily 2,000 or 3,000 feet thick.

Cumuliform Clouds

Cumuliform clouds characteristically build vertically; therefore, icing conditions can be found at a greater range of altitude than with other cloud types. The most common forms are clear and mixed and usually develop in the upper level of maturing cumulus. Depending on a

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particular cloud's stage of growth, the spectrum of icing intensities can be a trace in a small puffy cumulus to severe in a large towering cumulus or cumulonimbus.

The unstable conditions associated with cumuliform clouds can produce and maintain larger water droplets that are conducive to the formation of clear ice. The powerful updraft can carry a sizable amount of liquid water well above the freezing level. There have been occasional reports of pilots encountering ice between 30,000 and 40,000 feet where the free-air temperature was colder than −40°C.

Cirriform Clouds

Aircraft icing rarely occurs in cirrus clouds even though some contain a small level of water droplets. However, light icing has been reported in the dense, cirrus, anvil-tops of cumulonimbus where updrafts might maintain considerable water at rather low temperatures.

Structural Icing

Two conditions must be present for structural icing to form on an airplane in flight. First, the aircraft must be flying through visible liquid water. Clouds are the most common form of this moisture. Although icing can occur when the humidity level is very high, it most likely takes place when supercooled water droplets are present. Second, the free-air temperature and the aircraft surface temperature must be 0°C or below.

Supercool Conditions

A supercool water droplet forms in subfreezing temperatures and is considered to be in an unstable liquid state. When it hits the surface of an already cold airplane, part of the drop freezes instantly, thereby creating a rapid rate of ice accretion on exposed surfaces.

Research studies have shown that water droplets in the free air do not freeze at 0°C. Instead, their freezing level varies from −10 to −40°C. The smaller the droplet, the lower the freezing point. Although a common line of reference is that severe icing conditions are rare in clouds with temperatures below −20°C, pilots should never totally rely on such a general rule. As long as there is visible moisture and the temperature is below freezing, the potential for icing still remains.

Free-Air Temperature

Scientists have discovered during wind-tunnel experiments that when saturated air flows over a stationary object, ice might form on the object when the free-air temperature is as high as 4°C. This happens because the temperature of the object is cooled by evaporation and pressure changes in the moving air currents. Conversely, the object is heated by the friction and impact of the water droplet. Therefore, where an aircraft travels at less than 400 knots true airspeed (TAS), the cooling and heating effects tend to neutralize, which causes the possibility that structural icing will occur at or below 0°C.

Types of Structural Icing

There are four basic types of structural icing: clear, rime, mixed, and frost. How each type is formed depends upon the size of the water droplet and the temperature. When a supercooled water droplet freezes to a surface, the latent heat, the quantity of heat released by a substance undergoing a change of stage, that was generated by the fusion process raises the temperature of the unfrozen portion of the droplet to the melting point. Aerodynamic effects, such as airspeed and wind velocity, might cause that unfrozen portion to freeze. The way in which that occurs determines the type of icing.

CLEAR ICE

Clear ice is easily recognizable for its shiny, glazed appearance and can freeze with either a smooth or rough texture. Formation is most likely to occur in the presence of large raindrops and when the temperature is between 0 and −10°C. However, the temperature can be as cold as −25°C if favorable conditions are encountered in any cumuliform cloud. Clear ice can be found in widespread, winter systems that produce altostratus and nimbostratus cover. The continuous rain associated with such conditions can spread over thousands of square miles, causing the long-term potential for ice formation.

After large, supercooled droplets make contact with the aircraft, they tend to flow out over the surface, gradually freezing as a smooth sheet of solid ice. Clear ice is considered to be the most serious type of structural ice because it sticks so firmly to an object as it spreads beyond the surfaces of the aircraft that are protected by deice/anti-ice systems. For clear ice to form rough and irregular edges on a surface, it must be mixed with either snow, ice pellets, or small hail. The whitish layer of deposits is usually shaped with blunt, uneven protrusions that bulge out against the airflow.

It should be noted that clear ice can occur on an aircraft still on the ground. Obviously, exposure to freezing precipitation is the most common means; however, water or slush that is splashed on an unprotected surface can just as easily turn into a coating of clear ice.

RIME ICE

Rime is the most common type of icing and is usually encountered in lower-level stratus clouds. It forms into a milky, opaque, and granular consistency that leaves a rough surface. It develops when small, supercooled droplets, which are found in stratiform clouds, fog, or light drizzle, instantaneously freeze on impact. For the ice to accumulate, the temperature is generally between −15 and −20°C, although it can form when temperatures are as low as −40°C in cumulus-type clouds and near thunderstorms.

Because the droplets retain much of their spherical shape and freeze so rapidly, large amounts of air become trapped, giving the ice a milky-opaque appearance. The trapped air accounts for the granular texture, which is quite brittle to the touch. The rough residue is a result of the droplets colliding into each other and freezing.

The particular design of the ice formation depends on the airflow over the aircraft's surface and the length of time that the conditions are favorable for an appreciable accumulation. If there is a heavy buildup of ice, the distortion around the airfoil will change or deflect a droplet's impact pattern, which, in turn, will further distort the surface of the airfoil. A common occurrence is when the ice accumulates above and below the leading edge of the airfoil, causing a design similar to the horns on a ram.

Although rime ice significantly degrades the airflow over control surfaces, it rarely spreads like clear ice. Therefore, it tends to remain localized and is relatively easy to remove by conventional methods. Nevertheless, the development of rime ice, as with all types of ice, should always be monitored closely and regarded as a serious threat to the safety of a flight.

MIXED ICE

Mixed ice is a combination of clear and rime ice that can form rapidly when the supercooled droplets vary in size or when liquid drops merge with snow or ice particles. These ice particles can then become embedded in a layer of clear ice, creating a very rough surface. The temperature range is usually between −10 and −15°C. Sometimes it takes on a unique mushroom shape on the leading edge of wings or covers unprotected surfaces.

FROST

Frost is created by crystalline ice and usually leaves a thin layer of clear or whitish residue. It forms on aircraft when the temperature of an exposed surface is below freezing while the free-air temperature is slightly warmer. The ice usually forms during night radiational cooling which explains the scraping nightmare that sometimes awaits us when we arrive to our airplanes for an early morning flight.

A common misconception is that frost appears only at ground level. It can form in flight when a cold aircraft descends from subzero temperatures to a warmer and moist altitude below. The air is chilled suddenly to a subfreezing temperature by contact with the cold aircraft. Sublimation, the formation of ice crystals directly from water vapor, then occurs, possibly causing frost to develop over the windshield or other exposed surfaces.

Frost is truly a deceptive form of icing because we often disregard it as inconsequential to the safety of a flight. In reality, surface contamination can affect the lift/drag ratio of an airplane. Never assume that it will blow off or melt on takeoff.

Cold Soaking

As a result of the routine exposure to below-freezing ambient temperatures that high-performance jets encounter at cruise altitude, the fuel in the wing tanks will naturally cool to very low temperatures. The fuel becomes *cold-soaked*.

After landing, the remaining fuel in the wing tanks can cool the lower surface of the wing to subfreezing temperatures. If the ground-level humidity is high, moisture in the air will condense to create frost on the wings, specifically over the cold-soaked fuel in the wing tanks. If the frost partially melts, the water can refreeze in the form of clear ice. Due to the dihedral of the wing, the area of clear ice is typically larger than the original frost patch and has a tendency to slide toward the fuselage.

Scandinavian Airlines System (SAS) Flight 751

In December 1991, SAS Flight 751, an MD-81, crashed shortly after departure from Stockholm, Sweden. The Scandinavian Civil Aviation Supervisory Agency (STK) determined that clear ice had formed on the wings overnight and had gone undetected. Chunks of ice separated from the wings during rotation and were ingested into both engines.

The aircraft had arrived in Stockholm at 2200, the night before the accident, amidst snow, light drizzle, and periods of rain. There was a thin layer of slush on the runway with a temperature of 33°F. During the night, the precipitation turned to light snow and rain, with a moderate snowfall that lasted for a few hours. Each wing tank was approximately 40 percent empty upon arrival into Stockholm. The aircraft remained at the gate overnight.

By 0700 on the morning of the accident, the temperatures were hovering between 31 and 32°F, where they remained through 0830, the scheduled departure time. There was a light, intermittent snowfall with winds steady at 11 knots out of the north.

Around 0830, a ground crew member checked the forward part of the wings but did not detect any ice. Ground personnel refueled and deiced the aircraft without further inspection for ice.

Flight 751 began its takeoff roll at 0847. Seconds after rotation, the flight crew heard "bangs and vibrations" and noticed surges of the number two engine instruments. As soon as the flight crew powered back the number two engine, the automatic thrust restoration (ATR) system increased the throttle and altitude settings. This in turn intensified the surging in the number two engine, and 39 seconds later, the number one engine began to surge. The flight crew was busy making an unsuccessful attempt at switching over to the autopilot and missed the surges taking place in the number one engine.

The aircraft was climbing through 3,200 feet at 196 knots indicated airspeed (KIAS) when the stage 1 stators of the number one and number two engines simultaneously broke, causing dual engine failure. The number one engine caught fire but was quickly suppressed.

An off-duty SAS captain was traveling in the passenger cabin and hurried to the cockpit to assist the flight crew. As the aircraft made a gliding left turn, descending through 1,360 feet and still in the clouds, the assisting captain gradually extended the flaps. Flight 751 broke through the clouds around 900 feet and the flight crew chose a nearby field for an emergency landing.

The aircraft struck a group of trees on its approach to the field, breaking off a major portion of the right wing. The fuselage broke into three large and relatively intact sections when it hit the ground. All 129 passengers and crew survived.

Ice Formation on Fixed-Wing Aircraft

Propeller-driven airplanes and helicopters tend to be more susceptible to structural icing than jet aircraft due to their lower airspeeds, which result in less aerodynamic heating. Besides the physical characteristics of slower aircraft, they are subjected to poor weather conditions over longer period of flight time, partly because they operate at altitudes that are more conducive to those hazards.

Wing Surfaces

Ice buildup on a wing or tail surface disrupts the airflow around those airfoils. This results in a loss of lift and increase in drag and causes the aircraft to stall at a higher airspeed than normal. A heavy and rapid accumulation can add a lot of weight to the airplane, but the increase in weight *alone* most likely will not cause the aircraft to go down.

Research has shown that only ½ inch of ice on the leading edge of an airfoil can be enough for some aircraft to lose as much as 50 percent of its lifting power and increase its drag by the same amount. Under fairly common conditions, ice can accumulate to a dangerous level in less than two minutes. Consequently, the aircraft might stall much sooner than would be expected, putting the pilot in a very precarious and possibly unrecoverable position.

Horizontal Tail Surfaces

Tailplane icing can lead to a sudden stall and must be seriously considered during winter operations. As of 1993, the FAA believed the potential for icing induced tailplane stalls was so great on certain turboprops that the agency issued an Airworthiness Directive (AD) for the EMB-110, Saab SF-340, ATR-42, Jetstream 3101, and YS-11 computer aircraft.

According to research presented at the FAA- and NASA-sponsored 1991 International Tailplane Icing Workshop, aviation author Dan Manningham compiled an informative analysis concerning this safety hazard. He stated that any time the weather is conducive to a rapid accumulation of ice, tail surfaces are likely to ice up before the wings, and at a faster rate, because the surfaces are much smaller. The size and shape of an airfoil are key to the susceptibility of ice accretion. Furthermore, many tailplanes are engulfed in a high-velocity propwash, causing the surfaces to have a lower ambient temperature than the wings.

Due to those two factors, tailplanes have been known to collect ice three to six times thicker than ice on the wings, and 50 percent thicker than on the windshield-wiper arms. Therefore, if a pilot sees 1 inch of ice on the wings before turning on the deicing system, there might be up to 6 inches of ice already on the tail.

Tailplanes generate lift in a downward direction. As a result, they respond to the AOA opposite the wings. The wings need a positive AOA to produce lift. Conversely, the tailplane requires a negative AOA to create its downward lift. Therefore, a loss of lift causes the tail to rise. When the negative AOA exceeds a certain limit, airflow separation occurs on the lower surface and the tailplane stalls.

Since the wing greatly influences the tailplane's AOA, any change in configuration can exacerbate the situation, most notably by flap extensions. According to the research, the "net effect is that every increment of wing flap adds to the tailplane's negative AOA and moves it closer to a stall."

Airspeed affects negative AOA. Combined with the increased downwash of flap extension, the tail can come even closer to stalling. Not surprising then, is the fact that the highest negative AOA is usually produced during a landing approach.

Because tailplane stalls occur often, but not exclusively, at low altitudes, it's important to understand the warning signs. Most likely, there will be a buffet through the airframe, yoke, or both. Another indicator is a light feel in the elevator control.

For specific guidance with regards to tailplane icing on your particular type of aircraft, contact a representative from the manufacturer. And, get some tips from pilots who have experienced such an event. Although tailplane icing is not often talked about, except from those who have come through it, it's a very real and potentially fatal safety hazard. Be prepared.

Propellers

The accumulation of ice on the propeller hub and blades reduces the efficiency of the propeller, thereby causing a loss in airspeed. Depending on the severity of the icing, increasing the power setting will not necessarily produce enough thrust to maintain flight. It will, however, burn more fuel, which is not a good situation either.

The greatest danger associated with this type of icing is from propeller vibration, caused by the uneven distribution of ice on the blades. The propeller is meticulously balanced, and even a small amount of ice can create an imbalance. The resulting vibration, therefore, places stress on the engine mount as well as the propeller itself. Propellers operating with a low RPM setting are more susceptible to icing than those spinning at higher RPMs. Ice also usually forms faster on the hub of the propeller than on the blade because the differential velocity of the blade causes a temperature increase from the hub to the propeller trip.

Pitot Tube and Static Pressure Ports

When icing is observed on any part of the aircraft, the pilot should assume that the static ports are accumulating ice, possibly even faster than on the external surfaces. Icing of the pitot tube and other static pressure ports will often form into solid blocks of ice that will cause erroneous readouts of the altimeter, airspeed, vertical velocity, and certain engine instruments.

Frontal Zones

About 85 percent of all icing conditions reported occur in the vicinity of frontal zones. For severe icing to form above the frontal surface, the warm air must be lifted and cooled to saturation at temperatures below freezing, causing it to contain supercooled water. If the warm air is unstable, icing might be sporadic; if it is stable, icing might be continuous over an extended area. Icing could form in this manner over either a warm frontal or a shallow cold frontal surface. A line of showers or thunderstorms along a surface cold front might produce icing, but here the icing will be in a comparatively narrow band along the front.

Icing below a frontal surface outside of the clouds occurs most often in freezing rain or drizzle. Precipitation forms in the relatively warm air above the frontal surface at temperatures above freezing. It falls into the subfreezing cold air below the front, becomes supercooled, and subsequently freezes on impact with the aircraft. Freezing drizzle and rain occur with both warm fronts and shallow cold fronts. Icing in freezing precipitation is especially hazardous since it often extends horizontally over a broad area and can extend downward to the surface.

Terrain

Icing is more probable and more severe in mountainous regions than over other terrain. Mountain ranges cause upward air motions on their windward side, and these vertical currents support large water droplets that would fall as rain over level terrain. The movement of a frontal system across a mountain range combines the normal frontal life with the upslope effect of the mountains to create extremely dangerous icing zones.

Seasons

Icing can occur during any season of the year, but in the temperate climates of the contiguous United States it is most frequent in the winter. The freezing level is nearer to the ground in the winter months than in summer, leaving a smaller low-level layer of airspace free of icing conditions. Frontal activity is more common in winter due to the widespread and extensive cloud systems.

Geographic regions at higher altitudes, such as Canada and Alaska, normally have the more severe icing conditions in spring and fall. During winter, the air is usually too cold in the polar regions to contain heavy concentrations of moisture necessary for icing. Furthermore, most cloud systems are stratiform and composed of ice crystals.

Induction Icing

Ice frequently forms in the air intake of an engine, preventing a sufficient amount of air from entering to maintain combustion. Induction icing is particularly insidious because it doesn't need visible water droplets to develop and, therefore, can appear even on a clear and warm day. The range in temperature changes varies considerably with different types of engines (piston vs. jet), but generally speaking, if the free-air temperature is 10°C or below, and the relative humidity is high, the potential for induction icing exists.

Carburetor Icing

This type of ice forms during vaporization of fuel combined with the expansion of air as it passes through the carburetor. If the relative humidity of the outside air being drawn into the carburetor is high, ice can develop inside the carburetor when the temperature is as high as 22°C (72°F). The temperature drop in the carburetor is usually 20°C or less but can go as low as 40°C.

Provided a certain level of moisture is present, ice will form in the carburetor passages if cooling is sufficient to bring the temperature inside the carburetor down to at least 0°C. It is likely that ice will develop at the discharge nozzle, in the venturi, or around the butterfly valve.

The carburetor heater is an anti-icing device, not a deicing system; therefore, its primary function is to prevent icing. When the heater is turned on, the air is heated before it reaches the carburetor and keep the fuel-air mixture above the freezing point. It might be able to melt small amounts of ice and snow as they enter the intake. Because carburetor heating can adversely affect aircraft performance, use it only as outlined in your OPS manual.

Fuel System

Water easily mixes with jet fuel; therefore, the fuel absorbs considerable water when the air humidity is high. Occasionally, enough water is absorbed to create icing of the fuel system when fuel temperature is at or below the freezing temperature of water.

Induction System

There is a potential for ice to form in the induction system any time atmospheric conditions are favorable for structural icing, meaning visible liquid moisture and freezing temperatures. It can develop in clear air when the relative humidity is high and the free-air temperatures are around 10°C or cooler.

Air Intake Ducts

Duct icing can develop under conditions similar to carburetor icing: the presence of supercooled water droplets or humid and above freezing temperatures.

The air pressures going into the intake system are much lower when taxiing and during takeoff and climb out. Therefore, the temperature can drop to produce either condensation or sublimation. As a result, ice can form in the duct which decreases the radius of the opening and limits the air intake.

Inlet Guide Vanes

As supercooled water droplets freeze into ice on the inlet guide vanes, the airflow is reduced to the powerplant. This causes a decrease in engine thrust and, in extreme cases, the eventual failure of the engine. Once this icing condition develops, there's a real threat that chunks of ice ahead of the compressor inlet might be ingested into the engine, resulting in severe damage.

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CHAPTER 10

Turbulence

Turbulence is created from a change in the flow of air currents over a short distance. A knowledge of the location and causes of turbulence is helpful in minimizing its effects or avoiding it altogether.

Convective Turbulence

Convective currents are a common cause of turbulence, especially at low altitudes. These currents are localized, vertical air movements in ascending and descending motion. For every rising current, there is a compensating downward current. Those downward currents frequently occur over a wide area and, therefore, usually have a slower vertical speed than the rising currents.

Distinct and well-formed convective currents are most active on warm, summer afternoons when the winds are light. Those currents usually dissipate, however, when there are strong gusts. Heated air at the surface creates a shallow, unstable layer, and the warm air rises. Convection increases in strength and to greater heights as surface heating increases. Barren surfaces, such as sandy or rocky wastelands and plowed fields become hotter than open water or ground covered with vegetation. Thus, air at or near the surface heats unevenly. Because of this, the strength of the convective currents can vary considerably within short distances.

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As air moves upward, it cools by expansion. A convective current continues upward until it reaches a level where its temperature cools to the same as that of the surrounding air. If it cools to saturation, a cloud forms. Pilots should, therefore, associate thermal turbulence with cumulus and cumulonimbus clouds. As a general rule, turbulence might be severe beneath or in the clouds, while the air above the clouds is usually smoother. Remember too, that dry air can also produce convective currents even though moist conditions do not exist for the presence of cumulus clouds. Pilots will have little indication of those currents until they encounter the turbulence.

Mechanical Turbulence

Turbulence can occur when air near the surface flows over rough terrain or other obstructions. The higher the wind speed and the rougher the ground surface, the greater the turbulence intensity. Unstable air allows larger eddies to form than those in stable air, but the instability breaks up the eddies quickly, while in stable air they dissipate slowly.

Variability of wind near the surface is an extremely important consideration during takeoff and landing. If the wind is light, eddies tend to remain as rotating pockets of air near the windward and leeward sides of nearby buildings. But, if the wind speed exceeds about 20 knots, the flow might be broken up into irregular eddies, which are carried a sufficient distance downstream to create a hazard in the landing area.

Mountain Range Turbulence

When winds blow across rugged hills or mountains, the resulting turbulence might increase as the wind speed increases. Extreme caution is necessary when crossing mountain ranges under strong wind conditions. Severe downdrafts can be expected on the lee side. Pilots should allow for this possibility when approaching mountain ridges against the wind. If the wind is strong, and the ridge line is sharp, pilots should climb their aircraft to a crossing altitude several thousand feet higher than the highest obstruction.

It is important to climb well before reaching the mountains to avoid having to climb, or not climb at all, in a menacing downdraft. Attempting to cross at a lower altitude will also subject the aircraft to much greater turbulence and sudden crosswinds caused by winds blowing suddenly parallel to the valley instead of in the prevailing direction.

When the wind blows across a valley or canyon, a downdraft will occur on the lee side, while an updraft will be present on the windward side. The mountains funnel winds into valleys, thus increasing wind speed and intensifying turbulence. Although canyon flying should never be attempted, if you do find yourself in such a precarious situation, the safest flight path is along the windward side.

If the wind blows across a narrow canyon or gorge, it will veer down into the canyon. Turbulence will be found near the middle and downwind side of the canyon. Pilots must avoid the downwind side of narrow canyons because they could encounter an unrecoverable rate of descent.

Mountain Wave Turbulence

When stable air blows across a mountain range, a phenomenon known as a *mountain wave* might occur. It usually develops when the wind component flowing perpendicular to the top of the mountain exceeds 25 knots. The waves, which resemble ripples, remain almost stationary while the wind blows through them. Although they are usually associated with high mountain ranges, particularly the Colorado and Canadian Rockies in North America, the development of mountain waves can be found above any mountain with a crest of at least 300 feet.

The most dangerous features of a mountain wave is the extreme turbulence and high-velocity updrafts and downdrafts found on the lee side of a mountain range. Researchers have documented areas of updrafts and downdrafts that have extended over 70,000 feet and as far as 300 miles downwind from the mountain range. The velocity and intensity of the waves, however, decrease the further they are from the primary source region.

Three kinds of cloud formations are associated with the presence of a mountain: cap, rotor, and lenticular.

Cap Cloud

A cap cloud is a low hanging cloud with its base near the peak of a mountain. Although most of the cloud is visible on the windward side, it appears to have fingers pointing downward when viewed from the leeward side of the mountain.

Rotor Cloud

A rotor cloud looks like a line of cumulus clouds floating parallel to the ridge line of a mountain. Depending on your vantage point, you can actually see the air current rotating in a swirl of turbulence. The cloud is usually stationary but is constantly forming updrafts and downdrafts of up to 5,000 fpm. Downdrafts just to the lee of the mountain ridges and to the lee of the rotor cloud itself are the areas with the most severe turbulence.

Lenticular Cloud

Many pilots associate the lens-shaped lenticular cloud with a mountain wave. Like the mountain wave, lenticular clouds are stationary and constantly forming in bands parallel to the mountain. Lenticulars tend to form at fairly regularly spaced intervals, horizontally or vertically, on the leeward side. These clouds are normally found above 20,000 feet and are turbulent whether they are smooth or ragged in appearance.

Besides the obvious hazards of severe turbulent conditions, significant pressure altimeter errors are also associated with mountain waves. Due to the venturi effect of high winds over a mountain range, barometric pressures are considerably lower in a wave. Therefore, if a pilot is encountering a strong wave, the altimeter readout might be as much as 2,500 feet higher than the actual altitude.

Turbulence in Narrow Canyons and Gorges

When wind blows across a narrow canyon or gorge, it naturally veers down into the canyon. Expect turbulence near the middle and downward side of the canyon or gorge.

Funnel Winds

Mountainous terrain can force wind into passes and valleys, where the wind speed quickly increases. This funneling or channeling effect on the winds can reach speeds of up to 80 knots, creating hazardous shear and turbulent conditions when the wind flows out of the mountain valleys and toward flat areas.

Japan Airlines 747, Flight 46E

In March of 1993, a Japan Airlines (JAL) 747 encountered an in-flight engine separation shortly after takeoff from Anchorage International Airport, Alaska. The NTSB determined that the number two engine pylon had separated due to severe or possibly extreme turbulence.

WEATHER OBSERVATIONS

On the day of the accident, the interaction of strong easterly winds with the mountains east of Anchorage produced moderate to severe mountain wave and mechanical turbulence. The winds flowed around the mountains and through the valleys before reaching Anchorage. The funneling effect caused the winds to accelerate rapidly in the lower layers of the atmosphere and created severe turbulence at an altitude of a few thousand feet.

About 45 minutes before the encounter, the NWS issued a SIGMET for moderate and frequent severe turbulence from the surface to 12,000 feet. It included a warning for moderate and severe mountain wave turbulence from 12,000 feet to FL 390 within a widespread area south of the airport. The local NWS also issued an AIRMET for low-level windshear associated with the strong surface winds.

Powerful winds, with gusts of 62 knots, were recorded 10 miles southeast of the airport and at an elevation of 2,500 to 3,000 feet. Witnesses observed a “funnel of rotating debris” 7 miles northeast of the airport, at a height of 500 to 1,000 feet.

Ten minutes before the JAL 747 departed Anchorage, the pilot of a U.S. Marshall Service Cessna 310 took off from a nearby airport and encountered a downdraft at 300 feet agl. The pilot stated that the airspeed dropped from 120 to 90 knots, and the airplane lost about 200 feet in altitude. He managed to get out of the downdraft and climb to

900 feet but quickly entered an updraft of 4000 fpm. While keeping his throttles at idle, the pilot could not maintain an airspeed below 160 knots. He was able to return to the airport and later stated in a written report, "…in 20 years of flying up here, this was the worst turbulence I have encountered, and it was the first time I have ever wondered if I would make it back because, at times, I was not really flying this airplane."

HISTORY AND PILOT EXPERIENCE OF JAL FLIGHT 46E

Flight 46E was operating as a scheduled cargo flight from Tokyo-Narita Airport, Japan, to Chicago-O'Hare, Illinois, with an intermediate stop at Anchorage. The aircraft was leased under an agreement with Evergreen International Airlines and, thus, was piloted by an Evergreen flight crew.

The captain had 10,000 total flight hours, 750 in the 747. The first officer had 10,500 total flight hours, 600 in the 747. The second officer had 2,600 total flight hours, 1,201 in the 747.

THE ACCIDENT

The flight crew taxied the airplane toward runway 6R and tuned into the latest ATIS information. The ceiling was estimated at 8,000 feet overcast, visibility was 60 miles, temperature/dewpoint were 49°F/21°F, and winds were 90 degrees at 7 knots. The flight crew acknowledged receiving the current SIGMET. The ground controller advised them, "Pilot reports severe turbulence leaving 2,500 [feet] climbing on the KNIK [standard instrument departure (SID)] off runway 6R by company B-747."

As the captain climbed through 1,000 feet, the departure controller informed Flight 46E to "expect severe turbulence 2,500 [feet] reported by 747…continuous moderate [turbulence] 3,000 to 10,000 [feet]." The flight crew reported encountering moderate "bumps" at 1,500 feet, followed by "large wave action…with large vorticity."

At about 2,000 feet, the captain initiated a left 20-degree-bank turn to a heading of 330 degrees as directed by the SID. While in the turn, the airplane entered an uncommanded left bank to approximately 50 degrees. Simultaneously, the airspeed fluctuated about 75 knots, between 170 knots and 245 knots. The flight crew also reported a "huge" yaw, at which time the number two throttle slammed to its aft stop, the number two reverser indicator showed thrust reverser deployment, and the number two engine electrical bus failed. The flight crew immediately shut down the engine but were initially unaware that it had separated from the aircraft.

Several witnesses on the ground told investigators that the airplane went into several severe pitch and roll oscillations before the engine separated. The pilots of two U.S. Air Force F-15s were flying in the local area when they noticed something large had fallen from the 747. They contacted the nearby Elmendorf Air Force Base tower controllers who then notified Anchorage departure control. The flight crew was still going through their emergency procedures when they were told, "…something large just fell off your airplane." The first officer replied, "…we know that…we're…declaring an emergency." The controller then provided vectors for their return to Anchorage.

After over 20 minutes of struggling with flight control problems and continuous moderate to severe turbulence, the captain safely landed the aircraft; it was 100,000 pounds over maximum landing weight.

Flying Guidelines around a Mountain Wave

Primary rule: Avoid areas that you suspect may be producing a mountain wave. Guidelines to follow:

1. Avoid flying in the vicinity of cap, rotor, or lenticular clouds.
2. As a minimum, fly at an altitude at least 50 percent higher than the height of the mountain range. This might keep the aircraft out of the worst turbulence and could provide a margin of safety if a strong downdraft is encountered.
3. Approach the mountain range at a 45-degree angle. This enables you to make a quick getaway if you encounter a strong downdraft.
4. Be aware of possible pressure altimeter errors.
5. Penetrate turbulent areas at airspeeds recommended for your aircraft.

Clear-Air Turbulence

The rough, bumpy air that sometimes buffets an airplane in a cloudless sky is referred to as *clear-air turbulence* (CAT). Contrary to the name, studies have shown that only 75 percent of all CAT encounters are in clear weather. Pilots can also experience this turbulence in cirrus clouds and haze layers, but there are usually no visual signs indicating such activity.

Clear-air turbulence is usually found above 15,000 feet and in association with a drastic change in wind speed, most notably horizontal or vertical windshears. The presence of CAT is often in the vicinity of the jet stream and can occur in patches averaging about 2,000 feet deep, 20 miles wide, and 50 miles long. Although the most severe cases of CAT are usually reported along the jet stream or near an upper-level trough, there is always the potential for less dramatic encounters.

Flying Guidelines for CAT

Over the years, the results of CAT research have provided a few guidelines for pilots to follow when experiencing turbulence near the jet stream. Most pilots try to immediately find smoother air, but without the help of recent in-flight reports, a decision to climb or descend might be delayed. Here's an easy tip: Watch your temperature gauge for one to two minutes. If the temperature is rising, then climb; if it's falling, then descend. If the temperature remains steady, you can either climb or descend.

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CHAPTER 11

Wake-Vortex Turbulence

Every aircraft in flight generates a certain level of wake-vortex turbulence, produced by counter-rotating vortices trailing from each wing tip. The intensity of the vortex is dependent upon the aircraft's weight, speed, wing span and shape, angle of attack, and certain atmospheric conditions. The strongest vortex usually occurs where the generating aircraft is heavy, clean (gear, flaps, leading-edge devices, etc., are retracted), and slow. These vortices are extremely dangerous since they can cause a following aircraft to roll out of control. Specific instances will be discussed later in the chapter.

Wake-Vortex Motion

According to the results of studies presented at a 1991 wake-vortex conference and the notable accomplishments of researchers Veillette and Decker, a vortex develops in five generally recognized stages. The first, is when a vortex initially forms over the wing as a series of vortices. A dominating pair of vortices absorb the weaker ones, thereby curling up into a "trailing edge vortex sheet." This roll-up occurs within two to four wing spans behind the aircraft. The vortices are not centered at the wingtips because the core of a vortex varies depending on wing design and flap configuration. A trailing vortex wake is created

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the moment the nose wheel lifts off the ground during rotation and ends when it touches down on landing.

The second stage pertains to how each vortex affects the other. The vortex from the left wing causes the right wing's vortex to fall, and vice versa. This is due to the generation of lift on the wing that results in an equal and opposite reaction on the airflow and, in turn, induces a downward motion. The actual rate at which the vortices settle will vary. A joint U.S. Air Force, FAA, and NASA flight test study established that a heavy jet (300,000 pounds maximum gross weight) with a 140-foot wing span and a 150-knot approach speed created vortices that dropped at 350 fpm. Whereas, a light transport (35,000 pounds) with a 95-foot wing span and a 100-knot approach speed produced vortices that settled at 150 fpm.

A study conducted by NOAA found that sink speeds of vortices generated by 727, 757, and 767 aircraft depended on aircraft configuration, atmospheric conditions, and airplane/vortex proximity to the ground. For example:

AIRCRAFT	GROUND EFFECT	ALTITUDE (FEET)	SINK RATE (FPM)
727	Dirty	65	642
727	Clean	42	492
757	Dirty	74	594
757	Clean	49	444
767	Dirty	82	558
767	Clean	61	372

The third stage vortex development depends on the growth of the vortex rotational axis. Although turbulence can be a significant factor in the breakup of a vortex, it is in no way a guarantee that hazardous vortices have dissipated. The core, the airflow diameter around the wing tip, can range in distance from 25 to 50 feet and have a velocity of more than 90 knots. These currents usually remain close together until the vortex dissipates.

In the fourth stage, the core of the vortex intensifies and becomes well-defined. Before this stage is over, however, the tangential speed is decreased. Vortices will often change orientation and become distorted in the final moments of this stage. The exact cause of this event is unknown at this time, but research is aggressively ongoing.

The fifth stage is the creation of the distorted vortex rings. This is considered to be the least hazardous part of the wake-vortex turbulence.

Atmospheric Factors

It has been documented that as vortices reach ground effect at a height of about half that of the aircraft's wingspan, they will push outward. The outflow and downward speed will then be nearly equal. A vortex also tends to bounce up when it touches the ground. In many cases, it will "jump" well over a height of two wingspans of the generating aircraft. Scientists have also determined that if the wind gradient, windshear, or both are weak, the downwind vortex rebounds higher. In strong vertical shears, the upwind vortex bounces even higher. German researchers of this phenomenon believe that this is more or less common, and not a rarity. Therefore, pilots can get caught in a bouncing vortex if they're not anticipating such an event.

Further studies have found that vortices formed in ground effect do not tend to sink. While some experts contend that these vortices might dissipate faster, others have presented data demonstrating that the very complex nature of vortex movement depends on additional factors, not just origin.

Winds significantly affect the motion of vortices. NOAA researchers have learned that the longest-lived vortices are upwind, which usually linger at the approach end of an active runway, and during a crosswind. This is caused because the wind increases the vortex's rotational energy. When the ambient wind speed is greater at the top of the vortex than at the bottom, it supports the upwind vortex rotation. Conversely, the rotation of the downwind vortex is opposite to the wind gradient, thus diminishing the strength of such a vortex.

Researchers also found that downwind vortices had a tendency to climb while moving, which would place a vortex at a higher altitude than most pilots would anticipate, and possibly into the flight path of an aircraft thought to be high enough to avoid a wake vortex. Pilots should be particularly cognizant of a wake environment near closely spaced parallel runways.

A series of NOAA flight tests revealed the correlation between vortex presence and vortex lateral movement. In the first test, scientists used C-130, C-141, and C-5 military aircraft to determine that vortices were most persistent when winds were 3 to 10 knots. Vortices that lasted for as long as 60 seconds were generated in these low-velocity winds. A second test using 727, 757, and 767 aircraft corroborated the previous data. All the vortices that remained for over 85 seconds were generated when the wind speed was less than 5 knots. When the wind speed was between 5 and 10 knots, all the vortices hung for more than 35 seconds. The tangential velocities for those vortices were greater than 200 fps.

Temperature also affects the life of a vortex. Scientists at the Idaho Nuclear Engineering Laboratory determined that vortices that were long-lived, of higher intensity, or both were generated under stable atmospheric conditions. This is most common during the dissipation of a temperature inversion. As the sun begins to warm the layer of air next to the ground, that layer will begin to convect heat away from the surface and into the surrounding layer of air. All the NOAA flight test data that contained a vortex life cycle greater than 100 seconds, and tangential velocities of more than 240 fps, were found under stable atmospheric conditions.

Flying Guidelines

Note: Refer to the current Airman's Information Manual for the latest updates on wake-vortex turbulence avoidance guidelines. A few basic points are discussed below.

Vortices tend to sink immediately below the flight path at a rate of 400 to 500 fpm and can normally peak at 800 to 900 fpm. Therefore, a general rule is that pilots should fly at or above the preceding aircraft's altitude. When vortices sink into ground effect, they move laterally over the ground at a speed of about 5 knots. A crosswind will influence this lateral movement often to the point where the downwind vortices might gain speed, whereas the upwind vortices remain at the slower speed. On the other hand, a gusty and stronger crosswind might blow the vortex movement across a parallel taxiway or runway.

Therefore, it's important to be aware of the type of departing traffic on different runways so you can plan your takeoff or landing accordingly.

Wake-Vortex Research

Wake-vortex turbulence continues to be a serious threat to the safety of all flights, regardless of the type of aircraft involved. As part of a recent study, the NTSB noted that between 1983 and 1993 there were at least 51 accidents and incidents in the United States that results from "probable encounters" with wake vortices. The casualty rate included 27 fatalities and 8 seriously injured. Forty airplanes were substantially damaged or destroyed.

Authorities from the United Kingdom have perhaps the most comprehensive database on wake turbulence. Between 1982 and 1990, there were 515 recorded incidents at London's Heathrow Airport. Researchers have since discovered that there were two separate blocks of altitude, in which the majority of these encounters occurred. One block was between 100 and 200 feet above the runway threshold, and the second was between 2,000 and 4,000 feet. The latter was attributed to crews leveling off to intercept the localizer.

The British data also indicated that 747s and 757s as the generating aircraft produced significantly higher incident rates. Following aircraft most affected were DC-9s, 737s, and BAC-111s. The authors of the study also concluded that "the main effect of increasing wake separation distances is to decrease the risk of an incident, rather than its severity."

In a French government study, researchers determined the following facts common to wake turbulence incidents in that country:

1. The surface winds did not exceed 8 knots in all wake-vortex encounter incidents.
2. The trailing aircraft was VFR, and the pilot knew of the presence of the preceding aircraft.
3. In 80 percent of all cases, ATC informed the pilot of the preceding aircraft.
4. All the pilots involved with wake encounters held commercial or ATP licenses.

Boeing 757 Safety Concern

According to the NTSB, a unique and potential safety hazard has developed concerning the wake vortices generated by Boeing 757 aircraft. From December 1992 to March 1994 there have been several accidents and incidents in which an airplane on approach encountered severe wake-vortex turbulence while flying behind a 757. Thirteen occupants died in two of the three accidents. In each mishap, the velocity of the core vortices of the 757 were so strong and violent that they were able to force the following airplanes into an unrecoverable loss of control. In two additional and separate instances, the wake vortex of 757s threw an MD-88 and a 737 into a severe, induced roll. The crews were able to successfully recover, but not before the aircraft dropped dangerously close to the ground.

In light of the recent accidents and incidents, the Safety Board conducted a special investigation to examine the circumstances associated with 757 wake-vortex turbulence. The purpose of the report was to determine what improvements might be needed in existing procedures to reduce the likelihood of wake-vortex encounters.

Wake-Vortex Accidents

A common misconception among pilots is that wingtip vortices mostly affect light general aviation aircraft, and leave the big jets alone with not much more than a few bounces over the threshold. But, as the following accidents and incidents illustrate, no aircraft is completely safe from the powerful, and even deadly force, of wake-vortex turbulence.

Note: The FAA classifies airplanes as small, large, and heavy based on their maximum takeoff weight. Small airplanes are those that weigh up to 12,500 pounds. Large airplanes weigh between 12,500 and 300,000 pounds. Heavy airplanes weigh more than 300,000 pounds. The NTSB refers to these classifications in the following wake-vortex accident and incident reports.

Case Study 11-1

18 December 1992: A Cessna Citation 550 crashed while on a visual approach to runway 27R at the Billings Logan International Airport, Montana.

Air traffic control provided to the Citation pilot the standard IFR separation of greater than 3 nm from his traffic, a 757 also landing at Billings. About 4½ minutes prior to the accident, and at a distance of 4.2 miles from the 757, the Citation pilot received his clearance for a visual approach. He increased his speed while the crew of the 757 decreased their speed in preparation for landing. The controller advised the pilot of the Citation that the 757 was slowing and gave him the option to make a right turn to increase separation. Although the pilot never asked the controller about his distance from the 757, he apparently recognized how close he was getting to his traffic from a comment taped on the CVR, "Almost ran over a seven fifty-seven," about 40 seconds prior to the wake-vortex encounter.

The Citation suddenly and violently entered an uncontrolled left roll about 2.78 nm (74 seconds) behind the 757. Witnesses reported seeing the airplane roll and hit the ground in a near vertical dive. The two crewmembers and six passengers were killed.

According to the investigation, the Citation's path was at least 300 feet below that of the 757 during the last 4 miles of the approach. The only clue available to the Citation pilot to determine his flight path relative to that of the 757 would have been his visual alignment of the airliner and objects on the ground. However, there could still have been a discrepancy depending on how the 757 pilot was lined up with the runway. For example, if the 757 was aimed at the touchdown zone, then the Citation would have had a similar flight path. If the 757 was aligned with the far end of the runway, the flight path of the Citation would have been below the larger jet. Or, if the 757 was positioned with the approach lights, then the flight path of the Citation would have been above the airliner.

The data revealed that the induced roll started when the Citation was just less than 3 nm from the 757. Investigators determined that had the Citation been exactly 3 nm, or an additional six seconds farther from the 757, the strength of the vortex would not have diminished enough to prevent the wake turbulence. As a result, the Safety Board concluded that lighter-weight airplanes in the large category, such as the Citation, require a greater separation distance than 3 nm when following heavier airplanes in the same classification.

The Safety Board believed that the failure of the Citation pilot to ensure an adequate separation distance from the 757 strongly suggested that he did not realize the potential danger of severe wake vortices. Although the AIM recommends that the pilot of the following airplane should remain above the flight path of the preceding aircraft, the Safety Board noted that their agency was unaware of existing training material that discussed techniques for determining the relative flight paths of airplanes on approach.

Case Study 11-2

1 March 1993: A Delta Airlines MD-88 suddenly encountered an uncommanded 13-degree roll while on a visual approach to runway 18R at Orlando International Airport, Florida.

The Delta jet was more than 4 miles behind a 757 when the crew received their visual approach clearance. They quickly increased their speed and closed the separation to 2½ miles. Shortly thereafter, the Delta crew reported a strong roll to the right. Data collected from the FDR indicated that at about 110 feet agl, the roll angle reached 13 degrees right wing down. The pilot made a rapid correction which deflected the ailerons about 10 degrees and the rudder at 23 degrees. The crew regained control and successfully landed.

The recorded radar data showed that at the point of upset, the MD-88 was trailing the 757 by 65 seconds and slightly below its flight path. Both aircraft were descending at a 3-degree angle. The Safety Board determined that had the Delta crew maintained a distance of 3 nm, an additional 13 seconds of separation would have existed between the two airplanes. Nevertheless, the Delta jet was still below the flight path of the 757, so even with a small increase in distance, they still might have encountered a significant wake vortex.

Case Study 11-3

24 April 1993: A United Airlines 737 encountered an uncommanded roll of 23 degrees while on a visual approach to runway 26L at Denver-Stapleton International Airport, Colorado.

The flight crew reported that at about 1,000 feet agl, the airplane rolled violently to the left with no yaw, the pitch decreased 5 degrees, and they lost 200 feet in altitude. They promptly initiated a go-around, and they successfully landed without further incident.

According to the FDR, the pilot rapidly corrected the induced roll with 60 degrees of aileron and 7 degrees of rudder. The collected evidence also showed that at the point of upset, the airplane was at 900 feet agl, and in two seconds its roll angle reached 23 degrees left wing down.

The recorded radar data indicated that the flight path of the United jet was about 100 feet below and 1.35 nm, 32 seconds, behind that of a 757 landing on a parallel runway. The wind was blowing from the north at around 10 knots gusting to 16 knots. Both airplanes had a flight path angle of 3 degrees.

Runway 26L is displaced 900 feet south of runway 26R. The threshold of 26L is offset about 1,300 feet to the east of the threshold of 26R, resulting in a flight path to 26R that is about 70 feet higher than the flight path to 26L. Under the existing wind conditions at the time of the upset, a wake vortex from the 757 would sink and move to the south, toward a standard flight path to runway 26L.

Air traffic controllers are required to provide a 3-nm separation to IFR flights that are approaching 26L and 26R because the runways are divided by less than 2,500 feet. However, the United crew accepted a visual approach. Therefore, within 12 nm from the runway both airplanes were on converging courses, prompting ATC to issue a series of S-turns to the United crew for spacing. After completing those maneuvers, the separation distances were still not ideal. Laterally, the two airplanes were 4.55 miles apart, but longitudinally they were only 0.65 nm. Furthermore, the distance between both final approach paths had been reduced to 0.15 nm. As each aircraft converged to its respective runway alignments, the longitudinal component increased to an in-trail separation of 1.35 nm.

The Safety Board believed that the controller should have recognized the problems associated with tight spacing between parallel runways and have issued additional S-turn maneuvers to the 737 crew in order to maintain a more acceptable 3 nm in-trail separation.

Case Study 11-4

10 November 1993: A Cessna 182 encountered a sudden, uncommanded 90-degree roll and pitch up while on a visual approach to runway 32 at Salt Lake City International Airport, Utah.

The pilot of the Cessna reported that he was instructed by ATC to proceed "direct to the numbers" of runway 32 and pass behind a "Boeing" that was on final approach to runway 35. There was no evidence to suggest that the pilot was advised that his traffic was a 757.

The pilot of the Cessna further stated that while on final approach the airplane experienced a "burble" and then the nose pitched up. The aircraft suddenly rolled 90 degrees to the right, as the pilot immediately applied a full-left deflection of the rudder and aileron and full-down elevator in an attempt to level out. As the airplane began to recover, the pilot realized that he was near the ground and pulled the yoke back into his lap. He crashed short of the threshold to runway 32, veered to the northeast, and came to a rest on the approach end of runway 35. The pilot and the two passengers suffered minor injuries, and the airplane was destroyed.

The approach ends of runways 32 and 35 are about 560 feet apart. The recorded radar data indicated that the Cessna was less than 100 feet agl when it crossed the flight path of the 757. The airliner had passed that point just 38 seconds prior to the Cessna. Although the exact position of the upset was not determined, radar evidence suggested that the 182 was flying slightly above the flight path of the 757.

As mentioned earlier in the chapter, when wake vortices get caught in a ground effect, they tend to spread outward at a speed of 3 to 5 knots, plus the wind component. In this case, the left vortex of the 757 typically would have spread 200 to 300 feet to the west. The core might have been located about 75 feet above the ground, although researchers have noted the vortex has the potential to "bounce" twice as high as the steady-state height. Furthermore, the diameter of the vortex's flow field is usually about equal to the wing span of the generating airplane. Therefore, the 182 could have been affected by the vortex at any altitude between ground level and 200 feet agl.

Although the Cessna's flight path was above that of the 757, the Safety Board believed that the pilot did not adequately compensate for the height of the vortex.

Case Study 11-5

15 December 1993: A Westwind corporate jet encountered a sudden, uncommanded roll and pitch down while on a night, visual approach to runway 19R at the John Wayne Airport, Santa Ana, California.

According to the recorded radar data, the Westwind suddenly rolled and pitched down at a 45-degree angle just prior to impact. The two crewmembers and three passengers were killed. At the point of upset, the aircraft was at 1,200 feet msl and 3.5 nm from the end of runway 19R. A 757 was on a final approach for the same runway, 2.1 nm and 60 seconds ahead of the Westwind, and on a flight path that was 400 ft above the smaller jet.

In reference to the CVR tape, the Westwind pilots were aware they were close to a higher-flying Boeing aircraft, and after experiencing a little buffet from its wake decided to fly their own approach at 3.1 degrees of glide slope instead of the standard 3 degrees. There was no evidence that the crew was advised specifically that they were following a 757.

Since both aircraft were flying in an easterly direction when the crews received vectors to the airport, each airplane had to make a converging right turn in order to set up for the 19R approach. Radar data and ATC voice transcripts showed that the Westwind was 3.8 nm northeast of the 757 when cleared for a visual approach. The Westwind started its right turn from a ground track of 120 degrees while the 757's ground track remained at about 90 degrees. As a result, the closure angles started at 30 degrees and became greater as the Westwind continued its turn.

About 23 seconds later, the 747 was cleared for the visual approach. The average ground speeds of the Westwind and the airliner were about 200 to 150 knots, respectively. The Westwind was established on course 37 seconds prior to the 757. Although the combination of the closure angle and the faster speed of the Westwind reduced the separation distance from about 3.8 nm to around 2.1 nm in 46 seconds, the primary factor in the decreased separation was the converging ground tracks. The only way the pilot of the Westwind could have maintained adequate separation was to execute major aerial maneuvers.

Based on radar data, at the time the visual approach clearance was issued, the separation distance was rapidly approaching the 3 nm required for IFR separation. To prevent a violation, the controller would have had to change the Westwind's track or ensure that the pilot accepted the visual approach within 29 seconds.

B-757 WEIGHT CRITERIA ANALYSIS

In 1992, NOAA conducted flight tests to determine the characteristics of wake vortices produced by the 757. The results indicated that the 757 generated the highest vortex tangential velocity, 326 fps, of any tested aircraft, including the 747, 767, and C-5A. The most common theory to explain the occurrence was that the 757 wing flap design is different from the other aircraft. Most larger transport category airplanes have gaps between the trailing edge flaps that disrupt the uniform development of the vortex, whereas the 757's flaps are continuous from the fuselage to the ailerons, a design that is believed to be more conducive to the formation of a wake vortex.

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Part III Case Studies

Case Study III-1: USAir Flight 1016

Safety issues: Microburst, low-level windshear, weather dissemination, role of ATC, CRM

On 2 July 1994, a USAir DC-9 crashed after it encountered a windshear near Charlotte, North Carolina.

Probable Cause

The NTSB determined that the causes of this accident were (1) the flight crew's decision to continue an approach into severe convective activity that was conducive to a microburst, (2) the flight crew's failure to recognize a windshear situation in a timely manner, (3) the flight crew's failure to establish and maintain the proper airplane attitude and thrust setting necessary to escape the windshear, and (4) the lack of real-time adverse weather and windshear hazard information dissemination from air traffic control. These factors led to an encounter with a microburst-induced windshear that was produced by a rapidly developing thunderstorm located at the approach end of runway 18R.

Contributing to the accident were (1) the lack of air traffic control procedures that would have required the controllers to display and issue ASR-9 radar weather information to the pilots of Flight 1016, (2) the Charlotte tower supervisor's failure to properly advise and ensure that all controllers were aware of and reporting the reduction in visibility, the runway visual range information, and the low-level windshear alerts that had occurred in multiple quadrants, (3) the inadequate

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remedial actions by USAir to ensure adherence to standard operating procedures, and (4) the inadequate software logic in the airplane's windshear warning system that did not provide an alert upon entry into the windshear.

History of Flight

Flight 1016 was a regularly scheduled passenger flight from Columbia, South Carolina, to Charlotte. The DC-9 departed Columbia at 1823 Eastern Daylight Time, with 52 passengers and 5 crewmembers on board.

Pilot Experience

The captain had 8,065 total flight hours, 1,970 in the DC-9. He had been with USAir since 1985 and upgraded to DC-9 captain in 1990. At the time of the accident, he was an F-16 flight lead and mission commander in the U.S. Air Force Reserves.

The first officer had 12,980 total flight hours, 3,180 in the DC-9. He was hired by Piedmont Airlines in 1987 and had been with USAir ever since the two airlines merged.

Weather

Note: The TRACON did not broadcast arrival ATIS information Zulu. The Charlotte tower received the 1840 special weather observation at 1844—two minutes after the accident. No SIGMETs (significant meteorological information) were in effect for the area at the time of the accident.

1836: Arrival information Zulu was current: Special. Measured ceiling 4,500 feet broken; visibility of 6 miles in thunderstorm, light rain shower, and haze; temperature 88°F, dewpoint 67°F; winds from 170 degrees at 9 knots. The weather observation disseminated on the Automated Weather Information System (AWIS): Special. [Same information as Zulu.] Thunderstorm overhead, occasional lightning cloud to cloud.

1840: Special. Measured ceiling 4,500 feet overcast; visibility 1 mile in thunderstorm, heavy rain showers, haze; winds from 220 degrees at 11 knots; altimeter 30.02 inches of Hg; thunderstorm overhead, occasional lightning cloud to ground.

1850: Measured ceiling 4,500 feet overcast; visibility 6 miles in thunderstorm, heavy rain showers, haze; temperature 77°F, dewpoint 73°F; winds 80 degrees at 5 knots; altimeter 30.02 inches of Hg. Thunderstorm began 1833; thunderstorm north occasional lightning in cloud, cloud to ground; breaks in the overcast; rain began 1834.

Ground Witnesses

Several air carrier flights were in the process of departing the terminal area at the time of the accident. All the crewmembers who observed the storm approaching the airport described the precipitation as a "wall of water." A USAir first officer waiting for pushback from the gate observed two cloud-to-ground lightning strikes to the east, southeast of the airport. He told investigators that he saw a "wall of water approach from the south, about third of the way up runway 36L," prompting him to advise the tower that there was a thunderstorm over the airport.

The captain of another USAir jet parked near the approach end of runway 18R turned on his aircraft radar and saw a small isolated cell to the south-southeast of the threshold of 36L. He stated that visibility decreased rapidly and the rain became very heavy—reducing visibility to almost zero but with no noticeable indication of wind. He also told investigators that the rain stopped falling with the same abruptness that it had started.

Another captain awaiting departure from the gate area stated that the sky turned from sunshine to darkness very quickly, with heavy rain. During his taxi to runway 18R, he turned on the radar and checked the 5, 10, 20, 40, and 80 mile ranges and did not see any weather returns. Although radar did not indicate any precipitation, the captain noted that during their taxi they experienced the "heaviest rain [the captain] had been through in a long time" and further described the precipitation as a "wall of water."

In-flight Witnesses

The captain of a USAir flight that landed ahead of Flight 1016 told investigators that as his aircraft approached runway 23, the flight crew observed a rain shower in the vicinity of runways 18R and 23, with lighter precipitation falling to the north. They watched the shower move to the north at a slow speed and did not consider it to be a problem because visibility was still good. The captain stated that according to his radar, the cell appeared to be 2 to 3 miles wide and located south-southeast of the airport center. By the time they had touched down, however, the rain had become very heavy and the taxiway and ramp were covered with standing water and puddles.

A USAir Express commuter aircraft was following Flight 1016 for the approach to runway 18R. According to onboard radar, the flight crew confirmed a small weather cell south-southeast of the airport center with the heaviest rain slightly east of the airport center. A band of heavy rain showers extended west toward the airport boundary, northwest past the threshold of runway 18R to the airport boundary, and south to the midpoint of runway 18R. Although the radar had painted some red color (highest intensity of precipitation) in the cell to the east of the runway, the captain's general impression was that the rain shower was not a threat to their approach. The captain stated that he heard the low-level windshear alert system (LLWAS) issued by the tower but understood it to say that it was the northwest boundary showing 90 degrees from the centerfield wind. He further stated that the precipitation increased from moderate to heavy almost immediately. The flight crew characterized their "ride" as smooth until they penetrated the precipitation, at which time they encountered moderate turbulence that continued to increase as they descended. The tower instructed the flight to execute a missed approach when the airplane was approximately 600 feet agl. The captain told investigators that the airspeed during the missed approach was 145 knots (normal airspeed should have been 130 knots), and that he and his first officer had decided that the most expeditious route out of the rain was to alter course to the right of runway 18R. The flight broke out of the heavy precipitation about ½ mile to the west and one-third of the way down the runway.

The Accident

During the flight from Columbia to Charlotte, the flight crew told investigators that they saw no significant weather, although they did avoid some buildups. About 30 minutes from Charlotte, the flight crew performed their preliminary checklist, briefed for a visual approach, and obtained the ATIS information. According to the captain, ATIS was calling for a broken ceiling of 4,500 and 5,500 feet and indicated that it was hazy and hot and visual approaches were in progress.

The flight crew began their descent profile and was vectored on the west side of the airport for the downwind leg of an approach pattern to runway 18R. While south-southwest of the airport, they noticed two cells: one was south of the field and the other was a very small cell east of the airport that they considered not to be a factor to the flight. The airborne weather radar showed the cell to the south as red in the center and surrounded by yellow. The flight crew said it did not look threatening and that there were no other cells on either side of it.

As they joined the localizer, the captain and first officer discussed the cell south of the airport. They decided that if they had to execute a go-around, they would turn right rather than fly straight ahead, as was called for in the published missed approach procedure. That way, they would avoid the cell. Shortly thereafter, the crew turned onto the final approach course and could see the airport and the runway environment. The first officer was manually flying the airplane and maintained a speed of Vref + 10 knots. He continued to reference the instruments, while the captain was looking outside. The captain was also checking the radar and was monitoring the cell south of the airport.

As the flight passed the outer marker, the crew completed the final checklist and set the flaps to 40 degrees. They could see a rain shower trailing from the clouds between their aircraft and the runway, but they could still see through it. The captain asked for a wind check and learned the wind had changed direction. There was no turbulence as the jet entered the rain. However, the captain asked ATC for any pilot reports (PIREPs) from the aircraft that were ahead them. The response was, "smooth rides."

As the crew continued the approach, there was still no turbulence, despite very heavy rain. The captain stated that he had not previously experienced rainfall as heavy. Seconds later, at 1,200 feet msl, the captain commanded a go-around. He said that his decision was based on the sudden deterioration of visibility, the intense rain, the wind shift, and the potential hazards in landing on a wet runway with a crosswind.

The captain saw the first officer advance the throttles. As a procedural habit, the captain voiced the go-around setting of maximum power and flaps 15 degrees. The first officer was still manually flying the aircraft. Neither the captain nor the first officer was using the flight director.

The first officer went to maximum power, climbed and turned to the right, bringing the nose up to 15 degrees as he made the turn. He called for flaps to be positioned to 15 degrees. They were in heavy rain when he noticed a rapid decrease in airspeed. The captain called for firewall power as he placed his hand over the first officer's hand, which was already on the throttles. The first officer could not recall if the engine spooled up because the entire event happened so quickly.

Both pilots described feeling as though the aircraft had dropped out from under them. The captain said that he took control of the aircraft from the first officer, without announcing that he was doing so. He said this was not a conscious decision but that he perceived the situation was going badly. When asked if the first officer could also have been on the controls, he said that he did not believe so, because he did not feel any contrary inputs. The first officer, however, believed that he retained control of the aircraft.

Neither pilot remembered seeing a positive rate of climb on the vertical speed indicator, and they did not recall raising the landing gear. The captain could not give a rate of descent, but said there was a rapid decrease in airspeed.

The crew heard the stickshaker activate, and the captain said he checked the yoke to recover. From the airspeed indication, the captain believed that they were experiencing a windshear. He looked out and saw that they were below the treetops, as the ground proximity warning system's (GPWS) aural warning alerted, "terrain." The captain said he knew that they would hit the trees, but he tried to keep the wings level and control the aircraft.

The captain described the initial impact as not too hard. Then he saw the ground and the road. He noticed the nose dip and tried to pull back the yoke to keep from hitting in a nose-down attitude. The aircraft then struck the ground "extremely hard," followed by another impact, and then stopped. The crash was recorded at 1842:55.

Wreckage

The airplane initially touched down in a grassy field located within the airport boundary fence, about 2,180 feet southwest of the threshold for runway 18R. The aircraft broke up in a wooded area and sections of the forward fuselage came to rest on a street near a private residence.

ACCIDENT SURVIVABILITY

Thirty-seven passengers sustained fatal injuries. The captain and one flight attendant received minor injuries. The first officer, 2 flight attendants, and 15 passengers suffered serious injuries.

The Investigation

Investigators determined that the onboard windshear warning system did not activate (for unknown reasons) which placed Flight 1016 at a higher risk. Flight 1016 encountered a microburst windshear while on a missed approach from runway 18R. The microburst was determined to have been approximately 3.5 kilometers in diameter and was capable of producing a rainfall rate of about 10 inches per hour. The total wind change near the ground was about 75 knots—and at 300 feet, the winds were 86 knots. The strongest downward vertical winds below 300 feet agl were between 10 and 20 fps.

The airplane encountered a windshear seven to eight seconds after the flight crew initiated the missed approach. During the climb, the wind shifted from a headwind of about 35 knots to a tailwind of 26 knots in 15 seconds. The vertical velocity increased from about 10 to 25 fps down, and increased further to 30 fps down as the airplane attained its maximum altitude and transitioned into a descent.

AIR TRAFFIC CONTROL WEATHER DISSEMINATION

According to the Safety Board, the radar and tower controllers had indications of deteriorating weather when Flight 1016 was 16 miles from the runway but failed to disseminate the pertinent information.

The Safety Board believed that the combination of ATC procedures and a breakdown in communications within the Charlotte ATC tower prevented the flight crew from receiving time-critical information.

At 1836, the terminal radar approach control (TRACON) controller advised the flight crew that they "may get some rain just south of the field, might be a little bit comin' off north." The Safety Board believed that "some rain" may have been interpreted by the flight crew as the level of intensity. The characterization may have led the flight crew to think that the rainfall was insignificant and did not pose a threat.

At 1839, while Flight 1016 was 7½ miles from the runway, the flight crew of a departing USAir flight contacted the local west controller and said, "There's a storm right on top of us." The controller responded but did not relay the information to Flight 1016 because "the weather was not impacting runway 18R and another airplane had circled from runway 23 and landed on runway 18R in front of USAir 1016."

The Safety Board believed that it would have been prudent for the local west controller to issue the information regarding deteriorating weather conditions to the pilots of Flight 1016. The Safety Board further determined that all three control positions—ground, local west, FRW (final radar west)—failed to issue windshear alerts after receiving such indications by 1840. Specifically, the local west controller failed to recognize the rapidly deteriorating weather conditions, including lightning in the vicinity of the airport and a sudden decrease in visibility from 6 miles to 1 mile. Therefore, the Safety Board concluded that it was the local west controller's responsibility to provide the flight crew with the most accurate and timely information possible.

FLIGHT CREW PERFORMANCE

During the approach, the captain commented, "If we have to bail out, it looks like we bail out to the right…chance of shear." Shortly after encountering the intense rain on the final approach, the captain called, "Take it around, go to the right." The first officer executed a normal missed approach rather than a windshear escape maneuver. About eight seconds after the first officer pitched the airplane nose-up 15 degrees and rolled into a 17-degree-bank turn to the right, the CVR recorded the captain saying, "Down, push it down." Although the captain and first officer testified that they did not recall making or hearing the comment, the Safety Board determined that the cockpit transcripts and FDR correlated to the statement and pitch attitude.

Although the captain testified that the airplane was at an altitude of about 450 feet agl when they began the missed approach, FDR data showed the altitude was 200 feet agl. When the captain said, "Down, push it down," the flight crew could not see the ground due to the heavy rain. Therefore, investigators sought to understand why the captain gave such a command at 200 feet agl and why the first officer did not challenge such a directive.

Examination of the circumstances during the last minute of flight strongly suggested that the captain, upon losing his visual cues instantaneously when the airplane encountered heavy rain, could have experienced a form of spatial disorientation. Consequently, the captain may have believed that the aircraft was climbing at an excessively high rate and that the pitch attitude should be adjusted to prevent an aerodynamic stall. The Safety Board believed that the captain's improper command resulted in the first officer's significant lowering of the airplane's pitch attitude. The resulting change in pitch caused the airplane to descend, thus eliminating the altitude margin that would have been necessary to escape the windshear.

The Safety Board also concluded that the first officer should have been fully aware of the airplane's proximity to the ground when the captain called for the missed approach, and when he commanded, "Down, push it down." Thus, the first officer's immediate reaction should have been to challenge the impropriety of the command rather than reacting first.

WEATHER RADAR

The WSR-88D Doppler radar is located 77 nm from runway 18R at Charlotte and was operating normally at the time of the accident.

An NWS meteorologist presented the following summary and analyses to the Safety Board:

At 1823, a weak echo to the south-southwest of the Charlotte Airport was detected. Although precipitation was probably not reaching the ground yet, it showed evidence that the thunderstorm or shower was growing. The echo top was somewhere around 20,000 or 25,000 feet—indicating that while the storm was in the growth phase, no particular attention would have been made by the forecaster.

By 1829, the cell had become a strong echo and located south-southeast of the center of the airport. The intensity of the radar returns was indicative of a thunderstorm rather than a rain shower. Heavy rain was most likely to occur in about 5 to 10 minutes. The echo top was between 25,000 and 30,000 feet and still growing.

At 1835, the radar return was showing a level 5 echo which was probably causing "significant if not heavy rain" at ground level. The storm was still growing with the strongest gradient toward the north-northwest. Part of the storm was now off the northwest edge of the runway. Nevertheless, there was nothing remarkable about the storm and it would have been considered a "routine summer thunderstorm." There was nothing to indicate that the storm would produce severe weather conditions including hail or high winds. While the storm was still strong, it was showing signs of starting the decay cycle. According to the meteorologist, "There's nothing…in the [Doppler] data that would either confirm or invalidate the idea of a microburst."

At 1841, the storm was well into the decay phase. The speed of the outflow could not be quantified with the Doppler data but according to the meteorologist, depending on the size of the outflow, it could have been classified as a microburst. Still, the forecaster would have detected nothing remarkable as the magnitude of the storm was no longer considered threatening.

At 1847, the storm was continuing to decrease in intensity and the mid-level core was then north-northwest of the runway. The echo tops had dropped to 25,000 feet.

The meteorologist stated, "It's a decent thunderstorm, summer thunderstorm, with heavy rain…there was not anything of particular significance to the fact that the storm was a…level 5 or 6 and the radar tops were only 30,000 feet…a level 5 or 6 thunderstorm in the southeast [of the U.S] during the summer is not atypical…."

WEATHER ANALYSIS

The NASA Langley Research Center later analyzed the microburst and windshear activity that Flight 1016 had encountered. The study found that a rain shaft, approximately 1 to 3 nm in diameter, preceded the downburst. The microburst produced a peak windshear of about 70 knots over a distance of ½ mile. The downward vertical winds were around 14 knots, or 1,400 fpm. The microburst reached peak intensity within two minutes of starting, just as Flight 1016 entered it. Within five minutes, the microburst had essentially dissipated.

Researchers also calculated the Charlotte microburst by using an F-factor. This is a nondimensional value used to quantify the effect of a microburst on aircraft performance and is a function of horizontal shear, vertical velocity, and airplane velocity. F-factors are given as 1-kilometer averages. The Charlotte microburst had an F-factor of 0.3. The FAA considers an F-factor of 0.1 to be hazardous. By comparison, the microburst that caused the crash of Delta Flight 191 (refer to case study III-3) was calculated to have an F-factor of 0.25.

The NTSB investigation also exposed the delay in the installation of the new, state-of-the-art terminal Doppler weather radar (TDWR) system at Charlotte. Designed to detect windshear and microburst activity, it was originally scheduled to be installed in early 1993. The field had been "number 5" on an FAA list of 41 U.S. airports slated to have a TDWR installed, but was slipped to "number 38" after several problems. The primary difficulty was due to private land acquisition for the TDWR site.

Lessons Learned and Practical Applications

1. *Conduct crew briefings.* The captain and first officer anticipated a go-around long before the situation arose. Therefore, they had the luxury of discussing modified procedures that they believed would meet their requirements to maintain a safe flight. It's very important to plan ahead of time, in order to minimize miscommunication and miscoordination.

2. *Never underestimate thunderstorm cells.* Convective activity can spawn dangerous conditions in a matter of seconds. Level 2 or 3 cells can quickly turn into Level 4 or 5 cells.

3. *Microbursts are sneaky.* As we've discussed in other case studies, aircraft flying ahead of the accident airplane often have uneventful rides.
4. *Typical "clues" may be absent.* Even though an airplane is about to enter a microburst and is already in rain, there may be little turbulence. This catches many pilots off guard into thinking that the storm is not that severe.
5. *Issue PIREPs.* Although in this case, ATC did not relay this information to Flight 1016, it's still a good reminder as to the importance of pilot reports.

Reference

National Transportation Safety Board. 4 April 1995. Aircraft Accident Report: Flight into Terrain during Missed Approach. USAir Flight 1016, DC-9-31, N954VJ. Charlotte/Douglas International Airport, Charlotte, North Carolina. July 2, 1994.

Case Study III-2: American Eagle Flight 4184

Safety issues: Icing conditions, aircraft design, safety research

On 31 October 1994 an American Eagle ATR-72 commuter crashed in a farmer's field near Roselawn, Indiana, after it went out of control in flight.

Probable Cause

The Safety Board determined that the probable cause of this accident was the crew's loss of control of the aircraft, attributed to a sudden and unexpected aileron hinge moment reversal that occurred after a ridge of ice accreted beyond the deice boots because (1) Avions de Transport Regional (ATR) failed to completely disclose to operators, and incorporate in the ATR-72 airplane flight manual, flight crew operating manual, and flight crew training programs, adequate information concerning previously known effects of freezing precipitation on the stability and control characteristics, autopilot, and related operational procedures when the ATR-72 was operated in such conditions; (2) the French

Directorate General for Civil Aviation's inadequate oversight of the ATR-42 and ATR-72, and its failure to take the necessary corrective action to ensure continued airworthiness in icing conditions; and (3) the French Directorate General for Civil Aviation's failure to provide the FAA with timely airworthiness information developed from previous ATR incidents and accidents in icing conditions, as specified under the Bilateral Airworthiness Agreement and Annex 8 of the International Civil Aviation Organization (ICAO).

Contributing to the accident were (1) the FAA's failure to ensure that aircraft icing certification requirements, operational requirements for flight into icing conditions, and FAA published aircraft icing information adequately accounted for the hazards that can result from flight in freezing rain and other icing conditions not specified in Code 14 of Federal Regulations, Part 25, Appendix C; and (2) the FAA's inadequate oversight of the ATR-42 and ATR-72 to ensure continued airworthiness in icing conditions.

Weather Conditions

The surface weather and upper air conditions recorded at 1600 over the accident area were a low-pressure center in the area of west-central Indiana, with "cloud ceilings of less than 1,000 feet and/or visibilities of less than 3 miles, in rain" occurring in northern Indiana. Further, a moderate cold front extended from the low-pressure center and extended in a southwesterly direction. A moderate stationary front was also present and extended eastward from the center of the low-pressure area. In addition, precipitation in the form of rain and rain showers* associated with this system were occurring to the north (ahead) of the stationary front and west of (behind) the cold front. The accident site was north of the stationary front, where surface temperatures of 7°C were being reported.

The National Weather Service (NWS) analysis for 1800 Eastern Standard Time, recorded at 5,000 feet msl, showed the temperatures were near 3°C with moisture evident in the area where Flight 4184 was holding. Above 10,000 feet msl, there was an area of low pres-

Rain is constant precipitation with water drops greater than 0.5 millimeter in diameter. A *rain shower* is precipitation from a convective cloud, characterized by sudden beginning and ending, changes in intensity, and rapid change in the appearance of the sky.

sure, with the center located in northern Illinois, and a southwesterly flow over the accident area. Temperatures were near −4°C with moisture evident in northern Illinois. Above 18,000 feet, the temperatures were near −18°C with moisture evident in the area.

Surface weather observations in Gary, Indiana, 32 miles north of the accident site were as follows: the 1645 weather was 800 feet scattered, estimated ceiling 1,700 feet overcast; visibility 5 miles; light rain showers, fog; temperature 43°F; winds 20 degrees at 18 knots—gusts to 43 knots; altimeter setting 29.65 inches of Hg; ceiling ragged.

History of Flight

Flight 4184 was a regularly scheduled flight from Indianapolis, Indiana, to Chicago-O'Hare International Airport, Illinois. The aircraft and crew were assigned to Simmons Airlines, which operates as an American Eagle flight under a marketing agreement with American Airlines. The ATR-72 departed Indianapolis at 1456 Central Standard Time with 64 passengers and 4 crewmembers on board.

Pilot Experience

The captain had 7,867 total flight hours, 1,548 in the ATR. The first officer had 5,176 total flight hours, 3,657 in the ATR.

The Accident

At 1518, the crew was cleared to enter a holding pattern at 10,000 feet due to weather-related traffic delays. They were told to expect a hold time of 12 minutes. According to the traffic manager coordinator at O'Hare, the number of flights that the facility was able to accept earlier in the day was 80 per hour. As the weather conditions deteriorated, including strong, shifting winds, the acceptance rate was dropped to 72 per hour. When the winds began gusting to more than 45 mph, runway 9R became unusable. Operations then continued to slow to 65 flights per hour. Since the heaviest volume of arriving traffic was coming from the west, those airplanes were given landing priority. In the meantime, aircraft from the east, including Flight 4184, were directed to holding patterns. Eventually, Flight 4184 was alone in holding as jets were sequenced to land.

At 1519, ATC extended the flight's hold time to 1545 (the hold was eventually extended to 1600). As the crew leveled off at 10,000 feet the first officer slowed the aircraft to 175 KIAS. While in holding, the first officer commented, "I'm showing some ice now." It was assumed that he was referring to the relatively small section of wing that he could see from his seat in the cockpit. The flaps were lowered to 15 degrees at 1548. Later, at 1555, the first officer again remarked, "We still got ice." Because the deice/anti-ice system was on and functioning properly, the obvious buildup of ice is now a focal point of the accident investigation.

By 1556, the crew was cleared to descend to 8,000 feet and told to expect another "ten minutes…till you're cleared in." The pilot responded with, "Thank you," which became the flight's last radio contact. As the crew began their descent, they maintained their speed of 175 KIAS. The flaps remained in the 15-degree position until the flap-overspeed alarm sounded at around 180 KIAS. This indicated the airplane was going too fast to have its flaps extended, so the crew retracted them to the 0-degree position (full up).

According to the DFDR, within seconds, and while passing through 9,400 feet, the autopilot disengaged and the ailerons fully deflected to the right-wing-down position causing the airplane to enter a sharp, 77-degree right-wing-down bank. Only 1.5 seconds after the initial deflection, the ailerons moved to a full left-wing-down position, resulting in a decrease of the right roll to the 59-degree right-wing-down position. The ailerons again deflected in a full right-wing-down position, which led the airplane to roll 1½ times, before stopping on its back. Despite the crew's efforts to regain control, the aircraft plunged to the ground in a 425-mph, 65-degree, inverted, nose-down attitude.

Investigators found evidence of a preimpact separation of 10 feet of the outboard section of both wings and horizontal tail. It was estimated that the aircraft encountered 5.2 Gs immediately before impact.

Wreckage and Impact

The airplane impacted the ground in a nose-down, partially inverted position at a high rate of speed. Fragmented airplane wreckage was found in and around three impact craters.

The Investigation

The Safety Board concluded that Flight 4184 encountered a mixture of rime and clear airframe icing in supercooled cloud and drizzle/raindrops, while in the holding pattern at the LUCIT intersection. The supercooled drops in the area were estimated to be greater than 100 microns in diameter, with some as large as 2,000 microns. The liquid water content was estimated to have varied from less than 0.1 to nearly 1.0 gram per cubic meter. The ambient air temperature in the area of the holding pattern (10,000 feet) was about $-3°C$, with the freezing level between 7,000 and 8,000 feet; and the cloud tops between 19,000 and 30,000 feet. Additionally, there were ice crystals present in the atmosphere along the flight path.

ATR-72 DEICE/ANTI-ICE SYSTEM

The deice/anti-ice system on the ATR-72 is composed of electric heaters and pneumatic boots. The heaters protect the propellers, instruments, and windshields. The pneumatic boots are positioned on the leading edges of the wings and horizontal stabilizer and on the engine inlets. These boots use bleed air from the engines to inflate and dislodge ice.

The ATR uses a probe on the lower leading edge of the left wing to sense if the airfoil is contaminated. Reportedly, this probe senses icing, and onboard systems recognize and report icing as the probe becomes contaminated with ice. If the crew has the boots turned off and the probe detects icing, a cockpit light illuminates and a chime rings to alert the crew. When the boots are on, or activated via cockpit switch selection, the light illuminates in the cockpit but the chime does not sound.

The boots are activated when icing is expected and are typically turned off when icing conditions are no longer a factor. In such a case, the probe itself might still be contaminated with ice, resulting in a condition in which the cockpit icing-indicator light is on but the pneumatic deicing boots are deactivated.

ICING RESEARCH

Scientists at NASA's Lewis Research Center conducted icing tunnel tests, icing computer simulations, and airflow simulations to study the ice accretion characteristics of the ATR-72 airfoils, as group members of the NTSB investigation. They determined that icing conditions consistent with those encountered by Flight 4184 would likely have caused ice accretion aft of the deice boots on the ATR-72-210. The scientists concluded that a "double-horn" ice formation on the outer wing had rapidly developed in about nine minutes. This accretion was so severe that under similar conditions NASA researchers had "observed total [airflow] separation from the upper surface [of the wing] at low AOA which could result in control surface reversal." Therefore, they confirmed that certain conditions could result in trailing edge flow separation at lower than normal AOA on the ATR-72. The scientists also discovered two important trends pertaining to ice accretion: (1) ice accretion moves aft with increased temperature, and (2) ice accretion moves aft with increased drop size.

FLIGHT CREW PERFORMANCE

According to the Safety Board, the flight crew's apparent lack of concern regarding the prolonged operations in icing conditions may have been influenced by their extensive experience of safely flying commuter aircraft in winter weather conditions. In addition, they were probably confident in the ability of the airplane deicing system to adequately shed the ice that had been accumulating on the wings and in their ability to perform safely under the existing circumstances. However, they were operating outside the limits set forth in 14 CFR, Part 25, Appendix C, resulting in a complete loss of aircraft control. The Safety Board recognized that the insidious nature of the icing conditions was such that the ice accumulation on the observable portions of the wings, windshield, and other airframe parts was most likely perceived by the flight crew as nonthreatening throughout the holding period. Moreover, the flight crew was undoubtedly unaware that the icing conditions exceeded the Appendix C limits and most likely had operated in similar conditions many times prior to the accident, since such conditions occur frequently in the winter throughout the Great Lakes and northeastern parts of the United States.

Further, the flight crew entered the holding pattern with the belief that the holding would be of a short duration, unaware that it would be continually extended in short increments for a total of 39 minutes. Therefore, the Safety Board concluded that if a significant amount of ice had accumulated on the wing leading edges so as to burden the ice protection system, or if the pilots had been able to observe the ridge of ice building behind the deice boots, it is probable that they would have exited the conditions.

UPSET RECOVERY

According to the Safety Board, the lack of unusual attitude training may have significantly hampered the immediate recovery of the airplane once the upset occurred. Investigators believed that the flight crew was not aware that icing conditions could cause a sudden autopilot disconnect, rapid and uncommanded aileron and control wheel deflections to near their full travel limits with unusually high, unstable control wheel forces. Therefore, the pilots were confronted with a situation that could have been mistaken as induced by the autopilot, a structural failure, or a mechanical malfunction. Because the upset occurred suddenly and without warning, the flight crew did not have time to assess the situation and determine the appropriate corrective actions before the roll attitude exceeded 90 degrees.

Lessons Learned and Practical Applications

1. Understand the insidious nature of ice accumulation, particularly the susceptibility of ice forming away from precipitation devices.
2. Don’t accept prolonged holds in precipitation that are conducive to icing conditions.

Reference

National Transportation Safety Board. 9 July 1996. Aircraft Accident Report: In-flight Icing Encounter and Loss of Control. Simmons Airlines, d.b.a. American Eagle Flight 4184. Avions de Transport Regional (ATR), Model 72-212, N401AM. Roselawn, Indiana. October 31, 1994.

Case Study III-3: Delta Airlines Flight 191

Safety issues: Microburst, low-level windshear, weather dissemination, ATC factors, PIREPs, ADM, CRM

On 2 August 1985, a Delta L-1011 crashed while attempting to land during a thunderstorm at Dallas/Ft. Worth International Airport (DFW), Texas.

Probable Cause

The NTSB determined that the probable causes of this accident were (1) the flight crew's decision to initiate and continue the approach into a cumulonimbus cloud, which they observed to contain visible lightning, (2) the lack of specific guidelines, procedures, and training for avoiding and escaping from low-altitude windshear, and (3) the lack of definitive, real-time windshear hazard information. This resulted in the aircraft's encounter, at low altitude, with a microburst-induced, severe windshear from a rapidly developing thunderstorm located on the final approach course.

History of Flight

Flight 191 was a regularly scheduled passenger flight between Fort Lauderdale, Florida, and Los Angeles, California, with an intermediate stop at DFW. The L-1011 departed Fort Lauderdale at 1510 Eastern Daylight Time with 152 passengers and 11 crewmembers on board.

Pilot Experience

The captain had logged 29,300 total flight hours, 3,000 in the L-1011. He had been with Delta since 1954 and had completed his last recurrency training and line check 11 months before the accident.

The first officer had accumulated 6,500 total flight hours, 1,200 in the L-1011. He had been employed by Delta since 1970 and had passed his last proficiency check and recurrency training about four months prior to the accident.

The second officer had 6,500 total flight hours, 4,500 in the L-1011. He had been a flight engineer with Delta since 1976 and had passed his last proficiency check and recurrency training about five months before the accident.

Weather

The NWS terminal forecast for the DFW Airport indicated a slight chance of a thunderstorm with a moderate rain shower. The NWS area forecast called for isolated thunderstorms with moderate rain showers for northern and eastern portions of Texas. There were no SIGMETs or severe watches or warnings in effect for the time and area of the accident.

The Delta dispatch and meteorology departments provided similar information to the flight crew prior to the flight's departure.

Weather radar photographs taken by the NWS station in Stephenville, Texas, about 72 nm from the approach end of DFW's runway 17L, revealed the following: At 1748, a Level 2 cell (referred to as cell "A") developed about 6 nm northeast of the end of the runway. By 1752, the cell had intensified to a Level 3. At the same time, a Level 1 cell (referred to as cell "B") had developed 2 nm northeast of the end of the runway. In about four minutes, cell "B" had become a Level 3 storm and had moved to just north of the runway threshold. Cell "A" was stationary.

At 1800, cell "B" appeared to be the dominant echo and was still located near the end of the runway. By 1804, cell "B" had intensified to a Level 4 storm, and cell "A" was no longer displayed on the radar scope.

The Accident

The flight was uneventful until it passed New Orleans, Louisiana, when the crew noticed that a line of weather along the Texas-Louisiana gulf coast had intensified. They elected to change their route of flight to the north, to avoid the developing storms in the south. Consequently, they were issued a 10- to 15-minute hold at the Texarkana, Arkansas, VORTAC for arrival sequencing at DFW.

At 1735, the crew received the ATIS information that stated, "…6000 scattered, 21,000 scattered, visibility 10, temperature 101, dew point 67, wind calm…visual approaches in progress.…" By 1743, the crew had been cleared to descend to 10,000 feet and to change their heading to 250 degrees. The controller also told them, "We have a good area to go through." The captain replied that he was looking at a "pretty good size" weather cell "at a heading of 255…and I'd rather not go through it. I'd rather go around it one way or the other." The controller obliged, and a couple of minutes later the crew was given another clearance.

Shortly thereafter, the captain told the first officer, "You're in good shape. I'm glad we didn't have to go through that mess. I thought sure he was going to send us through it." The second officer remarked, "Looks like it's raining over Fort Worth." The flight was then instructed to contact approach control.

Moments later, the east-approach controller transmitted the following: "Attention, all aircraft listening…there's a little rain shower just north of the airport and they're starting to make ILS approaches…tune up [frequency] for 17 left [runway]." The crew made a lighthearted comment about the rain as they informed the controller that they were at 5,000 feet. At 1800, the controller asked the crew of an American Airlines flight, which was two airplanes ahead of the Delta, if they were able to see the airport. The reply was, "As soon as we break out of this rain shower, we will." Less than a minute later, the crew of Flight 191 was given further instructions for the approach and was sequenced behind a Lear 25 jet.

At 1802, the crew was advised that they were 6 miles from the outer marker and "cleared for ILS 17 left approach." The crew made a normal reduction in airspeed and was then informed by the controller, "…we're getting some variable winds out there due to a shower…north end of DFW." The information was acknowledged, and one of the crewmembers commented, "Stuff is moving in."

Seconds later, the crew switched to the tower frequency and the captain told the controller, "…out here in the rain, feels good." They were cleared to land and advised that the winds were "090 at five, gusts to 15." The first officer called for the "before-landing" checklist, and the crew confirmed that the gear was down and the flaps were set at 33 degrees.

Almost immediately thereafter, the first officer said, "Lightning coming out of that one." The captain asked, "What?" and the first officer repeated "Lightning coming out of that one." The captain then asked, "Where?" to which the first officer replied, "Right ahead of us."

Less than a minute later, the captain called out "1,000 feet" and he cautioned the first officer to watch his indicated airspeed. The sound of rain had already begun, when at 1805:21 the captain warned the first officer, "You're gonna lose it all of a sudden, there it is." The captain immediately added, "Push it up, push it way up." At 1805:29, the sound of engines at high RPM was heard on the CVR, and the captain said, "That's it."

About 20 seconds later, the ground proximity warning system's (GPWS), "Whoop, whoop, pull up," alert activated and the captain commanded, "TOGA." This is an acronym that stands for "takeoff/go around." When the airplane is flown manually, the pilot can actuate a TOGA switch that provides flight director command bar guidance for an optimum climb out maneuver. At 1805:48, the GPWS again sounded, followed by other noises and the takeoff warning horn. When the controller saw the aircraft emerge from the rain at 1805:56, he told the crew to "go around." The CVR stopped recording at 1805:58.

Impact and Wreckage Path

The airplane initially touched down in a plowed field about 360 feet east of the extended centerline of runway 17L and 6,336 feet north of the threshold. Witnesses on or near State Highway 114, north of the airport, saw Flight 191 descend from the clouds about 1.25 miles from the approach end of runway 17L. The nose gear came down in the westbound lane, the airplane bounced back in the air, and then knocked over a light pole and collided with an automobile. Surviving passengers then saw fire enter the left side of the mid-cabin area. Pieces of the number one engine inlet cowling were found in the car, and fragments of the car were discovered in the number one engine compressor inlet.

The airplane yawed significantly to the left when it crossed the highway. The jet began to break up as it skidded along the ground and toward two water tanks located on the airport. A 45-foot by 12-foot crater was found about 700 feet beyond the highway. Sections of the nose gear, left horizontal stabilizer, engine components, and various pieces from the wing were scattered along the wreckage path. The number one engine had separated from the airplane near the highway and had tumbled about 800 feet along the ground before coming to a stop.

The airplane grazed the north water tank and slammed into the second tank where the remaining fuselage broke apart. Amazingly, the jet had traveled 3,194 feet beyond its initial touchdown point in the field. The forward portion of the fuselage was destroyed and both wing sections had separated and were burned extensively. Parts of the engines and other major components were strewn as far a 1,125 feet past the second tank.

The aft fuselage section, containing the rear cabin and the empennage, came to rest in an upright position. Passengers and flight attendants recalled that this portion had originally stopped on its left side, but rolled upright by wind gusts. It was the only section that was found relatively intact.

ACCIDENT SURVIVABILITY

The flightcrew, 5 flight attendants, and 128 passengers sustained fatal injuries. The driver of the automobile that Flight 191 struck also died. After the aircraft hit the water tanks, the fuselage disintegrated from the nose section, aft to row 34. There were no survivors in the first 12 rows of seats. Some of the passengers in the mid-cabin area were ejected from the wreckage, many still strapped to their seats. Occupants in the rear of the cabin received mostly survivable injuries. Except for one flight attendant and three passengers, all were able to escape, unaided, through the large breaks and holes in the airframe.

The Investigation

Based on the evidence, the Safety Board centered the investigation in several areas, including atmospheric conditions, airplane and flight crew performance, air traffic control factors, and weather personnel considerations.

WEATHER ANALYSIS

Researchers at the National Oceanic and Atmospheric Administration (NOAA) conducted a multi-scale analysis of the weather conditions at the time of the accident. They concluded that the microburst-producing storm occurred almost in the center of a large-scale, high-pressure area that extended through a deep layer of the troposphere. It was interrupted only near the surface by a thermal low-pressure area in combination with a low-pressure trough that was associated with a weak frontal boundary.

A computer-generated analysis of the pattern of deep tropospheric forcing revealed that a high lapse rate in the lower troposphere was generated by a pattern of vertical motion that tended to stretch the atmospheric column. At levels above 500 millibars (mb), the forcing was upward; at 700 mb, it was downward. The lapse rate also would have been enhanced by strong solar heating. Weak subsidence above the surface boundary layer tended to cap it and preserve relatively high dew point temperatures near DFW, while heating southwest of the area tended to produce much drier surface conditions. Furthermore, a dry layer above 700 mb provided an elevated source of potentially cold air that would fuel strong downdrafts, which, penetrating into a deep, mixed subcloud layer, found a very favorable environment in which to become severe. In those two ways, the vertical thermodynamic structure of the DFW environment was a hybrid of a type that favored both dry and wet microbursts. The very weak front that lingered over DFW had resurged southward at about the time of the accident and lifted the shallow, moist surface layer. As a result, a line of discrete thunderstorm cells was triggered, one of which was located along the approach end of runway 17L. It was a microburst out of that storm that brought down Flight 191. See Fig. III-A.

Further evidence was provided by the FDR, which proved that the wind field within a microburst had a very complex structure of embedded small-scale vortices. These vortices were so severe that once the jet penetrated the microburst and windshear environment, it caused serious control problems. During the final 38 seconds the airplane encountered a horizontal windshear of 72 knots. There were also six rapid reversals of vertical winds, in part causing the right wing to dip down 20 degrees. These events were indicative of a vortical wind flow.

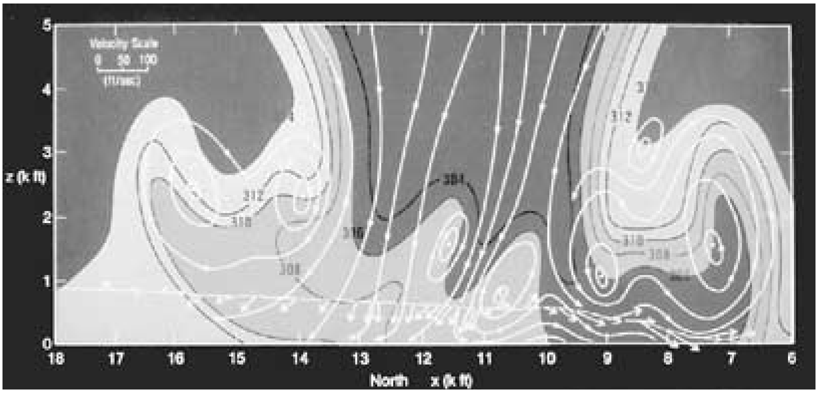

Fig. III-A. A vertical cross section through the microburst involved in the 2 August 1985 airplane crash at Dallas/Ft. Worth International Airport, constructed from the digital flight recorder data and based on the conceptual model. Adapted from NOAA.

DELTA METEOROLOGY AND DISPATCH

The Delta dispatcher told investigators that he had tried unsuccessfully to contact the Stephenville radar site between 1745 and 1750. Since he had no new or different weather information to provide to the crew of Flight 191, he did not attempt to call the crew as they approached DFW.

FORT WORTH FORECAST OFFICE

The aviation forecaster on duty became aware of the storm cell northeast of DFW at about 1804. But this was only after he had overheard the radar specialist at Stephenville describe the cell to the public and state forecaster. He then observed the cell on his television monitor.

The forecaster testified that during the day, he had watched numerous cells build to Level 4 and then dissipate. The cell northeast of DFW did not, in his judgment, seem any different from those he had observed earlier. Therefore, he decided not to issue an Aviation Weather Warning to DFW. He further stated that he had considered the intensity of a radar weather echo to be “merely an indicator” of the severity of a storm and that in the absence of on-scene reports for verification, he would not label a Level 4 echo a thunderstorm. Based upon that testimony, the Board believed his actions to have been reasonable.

CENTER WEATHER SERVICE UNIT

The Fort Worth Center's CWSU was staffed by an NWS meteorologist and an assistant traffic manager serving as the weather coordinator. Since the ATC personnel assigned to that position are not trained or qualified to interpret the weather, no one was available to monitor the weather radar when the meteorologist took a 45-minute dinner break. According to the meteorologist, before he left his station he had made sure that there were no threatening thunderstorms to any of the area airports. Radar photographs later confirmed his evaluation of the situation.

However, during his absence, cells "A" and "B" developed and intensified. The meteorologist told investigators that he would have issued a warning if he had witnessed the rapid growth of the storms. Nevertheless, even if he had been on duty to notify the TRACON and tower personnel, routine notification procedures would have taken 5 to 10 minutes, or after the accident had already occurred. He also stated that given the nature of the storm intensity he would have probably called the tower directly. The information would have reached ATC around 1802 or 1803. Although not optimum, the Safety Board did not believe that the NWS-to-ATC-to-pilot method of weather dissemination was a factor in this accident.

ATC DECISIONS

The primary sources of weather information for approach controllers comes from the NWS, surface observations, PIREPs, eyewitness accounts by tower controllers, and precipitation returns on the radar. The radar returns are rather difficult, however, because precipitation degrades the returns, masking the actual intensity of the storm. In turn they must rely on other means, mostly from the tower controllers and pilots.

The Safety Board also noted that the approach controllers might have misled the crew into thinking that the conditions weren't as severe as they actually were. At 1756, the controllers issued an "all aircraft listening" transmission describing "a little rain shower just north of the airport." In the Controller's Handbook, the standard phraseology should have been light, moderate, or heavy. The controller later told investigators that he meant "a little area of precipitation," not the intensity of the rain.

TOWER

AT 1803, the crew contacted the tower controller and said, "…in the rain, feels good." The controller testified that he didn't advise the crew of the storm because they were obviously as aware of it as he was. Although a few controllers saw lightning, they did not pass the information along to the weather observer, TRACON, or to flight crews.

PIREPS

Several crews saw lightning to the north of the airport. One pilot even thought he saw a tornado, and still another described flying through a waterspout. Yet, there were no pilot reports to either the TRACON or tower personnel. Controllers are required by regulation to immediately report a PIREP over the appropriate frequencies.

Investigators believed that because the tower controllers had not received any PIREPs or concern about the approach, they assumed the route was still acceptable. Based on that evidence the Safety Board concluded that the lack of PIREPs was causal to the accident.

FLIGHT CREW PERFORMANCE

The Safety Board believed that the captain had sufficient information to adequately appraise the weather along the approach path, despite the lack of PIREPs and other ATC advisements. When the crew entered the area of lightning and heavy rain, they were within 4 nm, or two minutes, of the runway. Investigators suggested that no reports from preceding pilots might have influenced them to continue for the short distance that was remaining. The Safety Board also noted that the captain was known to encourage cockpit participation with any decision making. As a result, they believed that the first and second officers would not have been intimidated to speak up if either had thought the conditions were too severe. Therefore, the Safety Board determined that the entire flight crew was responsible for the decision to penetrate the storm.

AIRPLANE PERFORMANCE

Most major air carriers, including Delta, have taught their crews to trade airspeed for altitude if they inadvertently encounter low-level windshear. The techniques were practiced in the simulators where pilots were instructed to increase pitch attitude and to add maximum thrust as necessary to control the airplane's flight path. In extreme cases the crews were also allowed to increase pitch to the point of activating the stickshaker. They were then to fly through the windshear area at a pitch angle that was just below that which would reactivate the stickshaker.

In the Safety Board's opinion, the first officer was apparently able to apply those techniques since the airplane remained on the glideslope as it entered the initial segment of the microburst. However, when the jet descended into the vortex, the combination of an airspeed loss of 20 KIAS and a strong updraft most likely caused the one-second activation of the stickshaker. Just for an instant the aircraft nosed over to a −8.5 pitch attitude with a 5,000 fpm descent rate. At about 1805:19, the airspeed dropped 44 knots in 10 seconds as the airplane traversed an area of increasing headwinds and downdrafts immediately followed by decreasing headwinds.

When the airplane was in the TOGA mode and the first officer was responding to a "fly-up" flight director command, the vertical wind changed from a 40-fps downdraft to a 10-fps updraft. The reversal in the wind component, combined with the substantial nose-up pitch rate, caused the AOA to rapidly increase. Since the aircraft's initial touchdown seemed to have been rather light, the Board speculated that the jet might have started to recover, albeit too late.

Lessons Learned and Practical Applications

1. *Don't underestimate thunderstorm activity.* This can't be stressed enough. Seemingly benign cells can quickly develop into dangerous Level 4 or 5 thunderstorms. Unfortunately, you can't always rely on your fellow pilots to provide PIREPs, or that the

NWS or ATC is going to have the latest weather information. So, you be the judge. Get out of the area if you see conditions conducive to microbursts, low-level windshear, lightning, and heavy rain.

2. *Provide PIREPs.* Reporting severe weather to ATC is imperative. Don't let your buds behind you get caught in something dangerous or even fatal. Controllers also need this information to coordinate safe approaches and departures and to determine if a runway change is in order.
3. *Be prepared with correct flying techniques.* If you can't practice in a simulator, study the AIM, talk with a CFI, and, if possible, pick the brains of several airline pilots. If you get in a predicament, it's vital that you're prepared with the proper procedures and techniques.

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National Transportation Safety Board. 15 August 1986. Aircraft Accident Report: Delta Air Lines, Inc., Lockheed L-1011-385-1, N726DA. Dallas/Fort Worth International Airport, Texas. August 2, 1985.

Case Study III-4: USAir Flight 405

Safety issues: Icing conditions, procedural deviation, aircraft performance, CRM

On 22 March 1992, Flight 405 crashed into Flushing Bay during takeoff from runway 13 at La Guardia Airport, New York.

Probable Cause

The NTSB determined that the probable causes of this accident were (1) the failure of the airline industry and the FAA to provide the flight crews procedures, requirements, and criteria compatible with departure delays in conditions conducive to airframe icing, and (2) the decision by the flight crew to take off without positive assurance that the airplane's wings were free of ice accumulation after 35 minutes of exposure to inclement weather following deicing. Contributing to the causes of the accident were the inappropriate procedures used by, and inadequate coordination between, the flight crew that led to a takeoff rotation at a lower than prescribed airspeed.

History of Flight

Flight 405 was a regularly scheduled passenger flight from Jacksonville, Florida, to Cleveland, Ohio, with an intermediate stop at La Guardia. The Fokker F-28 jet departed La Guardia at 2134 Eastern Standard Time with 47 passengers and 4 crewmembers on board.

Pilot Experience

The captain had 9,820 total flight hours, 2,200 in the F-28. He had logged 1,400 flight hours as an F-28 captain. He received his last proficiency check three months before the accident. USAir also required pilots to complete an annual nine-hour home study course on winterization, followed by a closed book examination. The captain passed the program in November 1991.

The first officer had 4,507 total flight hours, 29 in the F-28. He had been a 727 second officer for Piedmont Airlines/USAir from 1989 to 1 February 1992, when he was upgraded to first officer on the F-28. His last line check was completed during his initial operating experience three weeks before the accident. He passed the winterization program in November 1991.

Weather

At 2000, the terminal forecast for the La Guardia area was: A ceiling of 500 feet overcast, visibility ¾ mile with light snow and fog; winds 070 degrees at 10 knots; occasional ceiling 300 feet obscured; visibility ½ mile with moderate snow and fog; chance of ceiling at 1,100 feet overcast, visibility 2 miles with light snow and fog.

The following ATIS information was issued at 2124 and was the most current at the time of the accident: Indefinite ceiling, 700, sky obscured, ¾-mile visibility with light snow and fog. Temperature 31°, dewpoint 30°. Wind 110 degrees at 12 knots…Braking action advisories in effect. Runway 4/22 closed for snow removal. NOTAM: Runway 13/31 plowed 40 foot either side of centerline. Thin layer of wet snow on surface of runway has been sanded.

The Accident

Flight 405 arrived at La Guardia a little more than one hour behind schedule. After the crew took a break and prepared for the next leg they met back in the cockpit. Neither pilot performed a walkaround inspection of the aircraft, nor were they required to do so by USAir procedures. The first officer described the snowfall as "not heavy, no large flakes." He later told investigators that the windshield heat was on low and snow was sliding off the airplane. He also noticed the aircraft's nose had a watery layer as far as his arm could reach out the window.

USAir records showed that the jet was deiced with Type I fluid with a 50/50 water/glycol mixture at about 2026. One of the two deicing trucks broke down behind the airplane, resulting in a pushback delay of 20 minutes. The captain then requested a second deicing of the aircraft, which was completed around 2100.

At 2105, the flight was cleared to taxi to runway 13. The first officer, who was the nonflying pilot, recalled selecting engine anti-ice for both engines and that there were no visual or directional control problems. The captain announced that the flaps would remain up during the taxi, and he placed an empty coffee cup on the flap handle as a reminder. He later told the first officer that they would use an 18-degree flap setting and a reduced V1 speed of 110 knots, in accordance with the company's procedures for takeoff on a contaminated runway.

As the crew slowly taxied toward the active, the first officer remembered using the windshield wipers "a couple of times," and turning on the right wing inspection light "maybe ten times, but at least three." He told investigators that he looked at the wing, checked the upper surface and the black strip on the leading edge for ice buildup. Based on his observation, there was no contamination, nor had there been a heavy snowfall, so he didn't feel a need for a third deicing. He also recalled that as the airplane approached the number one spot for takeoff, the crew looked back at the wings several times.

At 2134:51, Flight 405 was cleared for takeoff, and about 26 seconds later the first officer made a callout of 80 knots. Shortly thereafter, the first officer called V1. The captain maintained a smooth, gradual rotation to 15 degrees at a normal rate. About seven seconds after VR (124 KIAS), the stickshaker activated, instantaneously followed by several stall-warning beeps. The first officer said that he was aware the main landing gear came off the runway, but just as they were entering ground effect he felt a strong buffet develop in the airframe. The aircraft began rolling to the left, "just like we lost lift." As the captain leveled the wings and they headed toward the water, the first officer joined the captain on the controls. He testified that there were "no heavy control inputs," and that they used the right rudder to maneuver the airplane back toward the ground and to avoid the water. The first officer further recalled that they tried to hold the nose up so as to lessen the impact, and he did not touch the throttles. The last thing he remembered was an orange and white building that disappeared under the nose. At 2135, there was a sudden flash and a hard jolt before the aircraft abruptly came to rest partially inverted at the edge of Flushing Bay

Impact and Wreckage Path

The initial ground scrape marks from the airplane were approximately 36 feet left of the runway centerline and ranged from 5 to 65 feet in length. Pieces of the left wing were found about 200 feet farther down the runway.

A portion of the aircraft from the nose to just aft of the fourth passenger row was found upside down and submerged under water. The left side and bottom of the forward section was crushed by the impact, and a hole was in the fuselage skin to the left of the captain's seat.

The section of fuselage between rows 4 and 11 was found floating in the water. The floor was torn and showed signs of fire damage. The remaining part of the cabin was under water, and portions of it had been burned or crushed. The vertical stabilizer and rudder assembly stayed attached to the empennage. However, various parts of the tail section were damaged by either fire or impact.

ACCIDENT SURVIVABILITY

The captain, 1 flight attendant, and 25 passengers sustained fatal injuries. The leading causes of death were drowning and blunt-force trauma. All the deceased passengers were seated between rows 4 and 11, near the overwing exits, and at row 13.

Nineteen passenger seats had separated from their floor attachments and were found scattered throughout the wreckage, some of which were damaged by fire. Nine seats were never recovered. The seats that were near the front of the cabin appeared to have been less damaged than those in the rear. Many of the survivors became disoriented in the darkened water and found it difficult to release their seatbelts and make their way to the surface. After the crash, passengers remembered seeing fires in the left forward and aft portions of the aircraft, as well as several small fires on the water. A number of survivors, including the lead flight attendant and first officer, escaped through a hole in the cabin floor.

Due to the snowy and foggy conditions, airport rescue units arrived near the scene about four minutes after the call. Because the aircraft was below a constructed dike, fire crews were initially unable to see the wreckage until they climbed to the top and looked down into the water. Divers from the New York Police Department were also notified, but by the time they were able to conduct an underwater search, the remaining survivors had already been found.

The Investigation

After thorough examination of the evidence, the Safety Board determined that the accident was not caused by an improper wing configuration or speedbrake deployment or mechanical defects. Therefore, the focus of the investigation was on weather-related issues and flight crew performance.

AERODYNAMIC PERFORMANCE OF THE F-28

The Safety Board evaluated simulation data provided by Fokker in order to determine the aircraft's rotation speeds and angle of attack (AOA) during takeoff. An F-28, without wing contamination should lift off about two seconds after the start of rotation, and accelerate about 7 knots. Therefore, at a normal pitch attitude of 1 degree and airspeed of 124 knots, the airplane should lift off as it reached 131 knots and 5 degrees of pitch. The data also showed that the AOA would peak at 9 degrees as the aircraft transitioned to the initial climb. With a stall AOA of 12 degrees in ground effect, an F-28 without wing contamination should have at least a 3-degree-AOA stall margin during the transition to climb. The margin would naturally increase as the airplane continues to accelerate and establishes a steady climb rate.

In the case of Flight 405, investigators heard sounds on the CVR that correlate with the extension of the main landing gear struts and the nose gear strut. They compared those sounds with the recorded timing data and were able to determine an accurate airspeed and AOA analysis. The Safety Board concluded that the captain initiated a takeoff rotation when the airplane reached 119 knots, about 5 knots slower than the proper rotation speed. Their analysis showed that the jet would have lifted off at about 128 knots with an AOA of 5.5 degrees. Under those conditions, the AOA probably exceeded 9 degrees as the aircraft transitioned to a normal climb.

According to Fokker wind-tunnel data, a wing upper surface roughness caused by particles of only 1 to 2 millimeters in diameter, and at a density of 1 particle per square centimeter, can result in a loss of lift on the F-28. This can occur 22 percent of the time when the aircraft is in ground effect. Furthermore, when the aerodynamic characteristics of the wing are significantly degraded from contamination, the stall AOA in ground effect was reduced from 12 degrees to 9 degrees. Therefore, the Safety Board believed it was probable that during the transition to climb, immediately after liftoff, Flight 405 reached an AOA beyond the stall limits, which produced a loss of both lift and lateral control effectiveness. The abrupt roll that occurred during takeoff was consistent with this analysis.

F-28 WING CONTAMINATION

Most wings are designed so the inboard sections will stall before the outboard portions. This design ensures that roll control can be maintained through use of the ailerons on the outboard wing sections. However, the variable disbursement of ice particles over shorter chord lengths of a wing can create an irregular stall distribution across the wing. A premature stall of the outboard sections usually occurs first, followed by a loss of lateral control. Although it is characteristic for a swept wing aircraft to have a significant nose-up pitching moment after its outboard wing stalls from contamination, wind-tunnel tests have proven otherwise for the F-28. The airplane's sweep angle is only 16 degrees; therefore, it is most likely that the aircraft would experience a nose-down pitch attitude.

In any event, it was apparent to investigators that flight 405 was unable to transition to a positive climb angle during the 11 seconds that it was airborne. The maximum airspeed that was recorded was 134 knots, just as the stickshaker activated. The airspeed then fluctuated between 128 and 130 knots until impact. According to the manufacturer's data, the aircraft should have been able to maintain a 3-degree AOA stall margin, *unless* it did not have clean wings. Since the airplane exhibited an abnormal flight performance, the Board considered that to be conclusive evidence that the wing's aerodynamic lift capability was "significantly degraded by an accumulation of frozen containment."

FOKKER TESTS

As a result of this accident, Fokker conducted further tests to determine if changes in the F-28 operating procedures could enable the aircraft to successfully take off with wing contamination. They first looked at modifying the rotation speed. Researchers found that if the rotation speed was increased by 10 knots, the peak AOA would decrease approximately 3 degrees, from 12 degrees to 9 degrees. When a relatively slow rotation rate of 2 degrees per second was used, the peak AOA decreased from 12 to 8 degrees. Concerned that a pilot should not be expected to control the rotation to such minute precision, Fokker believed that a change in the rotation rate alone might not be adequate.

The second consideration was to modify the target pitch attitude on takeoff. The data revealed that when pitch attitude was lowered from 15 to 10 degrees, the peak AOA decreased approximately 5 degrees, from 12 degrees to 7 degrees. Fokker believed that this procedure proved more effective at lowering the wing AOA than would a slower rotation rate, or increased rotation speed, without imposing associated runway length or takeoff weight performance penalties.

A 10-degree pitch attitude was already approved for the F-28 engine-out procedure. Therefore, with both engines operating, researchers believed that the airplane can successfully climb out of ground effect. Once that occurs, the jet should be able to maintain a 15-degree rotation rate and establish a positive climbout.

Based upon this data, the Safety Board would like to see Fokker conduct additional flight dynamics' studies on pitch attitude, rotation rate, AOA, and wing contamination. The Safety Board's primary concern is how to structure the takeoff maneuver to prevent pilots from stalling the airplane, especially when it has just lifted off and is still in ground effect.

DEICING OPERATIONS

The Safety Board found that the aircraft had been properly cleared of ice and snow during the two deicing procedures at the gate. However, approximately 35 minutes elapsed between the second deicing and the takeoff roll, during which the jet was exposed to continuous precipitation in below-freezing temperatures. Although investigators were unable to determine the exact amount of contamination on Flight 405, they did believe that some accumulation had to have occurred in the span of 35 minutes. Therefore, they concluded that ice contamination led to the control difficulty shortly after rotation.

FLIGHT CREW PERFORMANCE

Although the crew did not perform a walkaround inspection, the aircraft was checked by ground personnel after the first deicing. The Board believed that since the captain requested a second deicing after a 20-minute delay, this showed his level of concern and prudence in appropriately dealing with the situation. Following that deicing, the crew most likely was satisfied that the airplane was free of contamination.

When a delay exceeds 20 minutes, USAir procedures dictate a careful examination of the airplane's surfaces. The first officer stated—and passengers confirmed—after the accident that he had turned on the wing inspection light several times. However, the only related comment recorded on the CVR was nearly 30 minutes after departing the gate and about 5 minutes before takeoff, when the first officer said, "Looks pretty good to me from what I can see." The observation was made through the wet, closed cockpit window, 30 to 40 feet from the wing. Therefore, the Safety Board believed that this did not constitute a careful examination.

The Board recognizes the dilemma all crews face when confronted with the decision to either return to the gate and incur further delays or even cancellation, or proceed with the takeoff and accept the risks. Nonetheless, they believed that the crew of Flight 405 should have taken more assertive steps to assure a contamination-free wing, such as entering the cabin to look at the wing from a closer range. Although the detection of minimal amounts of icing might not have been possible even from that vantage point, it might have afforded the crew additional information that might have prompted them to return to the gate. The Safety Board concluded that the crew's failure to take such precautions, and the decision to attempt the takeoff when they were not positive of the icing conditions, led to this accident.

Furthermore, the Safety Board determined that a V1 speed of 110 knots was not authorized for takeoff. The first officer could not explain why the captain chose that speed, but assumed he was concerned about the airplane's stopping ability on a slick runway. As a result, the selection of a low V1 speed caused the first officer to call VR prematurely. He stated that because V1 and VR are normally the same speed, he inadvertently followed his standard procedure of calling VR immediately after V1.

Data obtained from the CVR and FDR showed that the VR call made by the first officer occurred at about 113 knots, approximately 11 knots below the correct rotation speed of 124 knots. The first officer noted that notwithstanding the premature VR call, the captain did not rotate the airplane until the appropriate speed. However, the analysis of the data revealed that the captain began the takeoff rotation 5 knots below the correct VR speed. The airspeed indicator bug was properly set for a VR of 124 knots, so the Safety Board speculated that the captain might have been reacting to the first officer's early VR callout without cross-checking his own airspeed indicator. As a result of the early rotation, the airplane lifted off at an AOA that was about 0.5 degrees higher than normal. Combined with the wing contamination, sufficient lift could not be maintained.

The first officer also stated that following the stickshaker activation and control problems, both he and the captain knew that the airplane was not going to fly. They then focused their efforts to stay over land and remain upright. Other than initially applying rudder, there were no corrective actions taken by the crew. According to the first officer, they used the yoke to "hold on" to the aircraft.

The Safety Board was unable to determine whether any specific actions could have been taken by the crew to have prevented the type of impact or level of severity. However, based on the corroborating evidence from the CVR and FDR, they concluded that seconds after liftoff, the airplane was in a stall regime from which recovery was not possible.

Lessons Learned and Practical Applications

1. *Maintain procedural discipline.* From his own admission, the first officer thought he might have been thrown off by the atypical V1 and VR speeds requested by the captain. It's much more difficult to be a coordinated, unified crew when one deviates from standard procedures.
2. *Ensure your airplane is free of contamination.* Even if it adds to a delay, the Board believes the consequences are too serious to ignore.

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International Case Study III-5: China Airlines Flight CI-012

Safety issues: Severe turbulence, cruise altitude/airspeed upset, pilot training, crew performance, aircraft design

On 7 December 1992, Flight CI-012, a McDonnell Douglas MD-11, encountered clear-air turbulence at FL 330. The aircraft momentarily went out of control as pieces of the outboard elevator assemblies were torn away.

Probable Cause

The NTSB determined the probable cause of this incident was the light control force characteristics of the MD-11 airplane in high-altitude cruise flight. The upset was induced by a moderate lateral gust and was exacerbated by excessive control defections. Contributing to the incident was a lack of pilot training specific to the recovery from high-altitude, high-speed upsets in the MD-11.

History of Flight

Flight CI-012 was a regularly scheduled passenger flight from Taipei, Taiwan, to Anchorage, Alaska. There were 246 passengers and 19 crewmembers on board. The incident took place at 1036 Coordinated Universal Time 35 miles northeast of the Shimizu, Japan, navigational fix at FL 330. The flight was 18 minutes from Kushimoto, Japan.

Pilot Experience

The captain had logged 18,241 total flight hours, 401 in the MD-11. He had flown 60 hours in the last 30 days. The first officer had 1,509 total flight hours, 279 in the MD-11. The relief captain had 14,939 total flight hours, 481 in the MD-11.

Weather

The 1200 surface weather analysis prepared by the Japan Meteorological Agency showed a low-pressure area centered near the location of the incident. A warm front extended east of the low, and a cold front dipped to the southwest. Convective activity was reported in the vicinity of the low.

Upper-air data was obtained from a facility located 84 miles east-northeast of where the incident took place. The recorded wind conditions for the area were as follows:

FL 240: 240 degrees at 47 knots.

FL 310: 240 degrees at 68 knots.

FL 350: 250 degrees at 89 knots.

FL 400: 270 degrees at 148 knots.

Significant vertical windshears were evident between FL 330 and FL 400.

Four PIREPs were given near the vicinity of Flight CI-012's encounter with the turbulence:

1. *1033.* A 767 at FL 390 reported moderate turbulence at the top of cumulonimbus clouds with a vertical windshear of 10 knots.
2. *1045.* A 767 at FL 370 encountered moderate turbulence 60 nm southwest of Kushimoto.
3. *1120.* A 747 at FL 370 reported severe turbulence 80 nm west of Kushimoto.
4. *1230.* A 747-400 at FL 330 experienced moderate turbulence 60 nm west of Kushimoto.

The Incident

The captain told investigators that the crew had received a complete weather briefing before taking off from Taipei. He said that some light-to-moderate turbulence and windshear were forecast along the route, but added that those conditions were normal for the area. When the aircraft was about 18 minutes from Kushimoto, it suddenly encountered severe turbulence.

The captain explained that the airplane began a series of pitch and roll maneuvers that lasted for about 10 minutes and, at times, possibly exceeded 30 degrees. He noted that the autopilot and autothrottles had been deactivated immediately. He continued to describe the incident as follows:

> We were fighting to keep control of the airplane. We had our shoulder harnesses on, or we might not have kept control. The vibration was so bad that we could not read any of the instruments. I could just see that the altitude was changing back and forth from FL 350 to FL 310; and airspeed was changing rapidly back and forth between lower and upper limits. I don't know if the high lift wing devices/slats were deployed or not, the vibration was too bad to tell. I did have to make a lot of manual throttle changes so the airplane wouldn't stall. I think

> it was close a few times. We had been talking with Tokyo Center, so I requested descent from FL 350 to FL 290, and told them about the turbulence.

The captain added that immediately after recovering from the turbulence, the crew reviewed the checklists and monitored the flight controls and primary systems. Nothing appeared to be damaged, so the crew decided to continue to Anchorage where they made an uneventful landing.

Aircraft Damage

Large areas of composite skin and several pieces of internal structure had separated from the left and right outboard elevators. Sections as big as 35 by 46 inches were discovered missing after the airplane landed.

Injuries

When the aircraft encountered light turbulence about five minutes before the upset, the captain had turned on the seatbelt lights. With the passengers and crew already seated, there were no reports of injuries.

The Investigation

According to information obtained from the FDR, the Safety Board determined that the airplane was cruising at FL 330 and at 290 KIAS. The pitch attitude and AOA were around 3 degrees nose up. About four minutes prior to the upset, the jet entered an area of light turbulence that registered 0.9 to 1.1 G. Less than three minutes later, the turbulence increased to moderate and ranged from 0.7 to 1.3 G. It lasted only for about 25 seconds, and then the turbulence settled down significantly for 15 seconds. It suddenly resumed at a moderate intensity for 45 seconds, followed by a 10-second period of rougher air. As a result, the autopilot commanded a change to one elevator panel from neutral to 2 degrees nose down.

The turbulence steadily and rapidly increased as the aircraft recorded a 0.25-G lateral acceleration to the right. Two seconds later, the jet rolled 30 degrees right wing down and the heading shifted 6 degrees to the left. This was attributed to a wind gust from the left of the flight path.

Within 4 seconds the captain was able to recover the aircraft to a wings-level attitude by using the rudder and aileron. However, 8 seconds later, the jet rolled 22 degrees left wing down and continued to 32 degrees. The four elevators changed to a 2.5-degree nose-up deflection that caused the airplane's pitch attitude to increase to 10 degrees nose up in about 7 seconds. As the pitch angle passed through 5 degrees, the AOA climbed to 7 degrees which activated the stall-warning system. From 10 to 20 seconds following the initial upset, the pitch angle rose as high as 16 degrees nose up, while the AOA decreased to 6.5 degrees.

In 33 seconds, the airplane climbed to about 35,800 feet and the indicated airspeed dropped from 290 to 160 knots. The stabilizer was trimmed to 0.2 degrees nose up as the pitch angle quickly peaked at 23 degrees. Although the captain continued to increase elevator deflection, soon after the slats were deployed the AOA and pitch angle decreased and the airplane stalled. Similar events were recorded between 66 and 118 seconds from initial upset that proved the airplane pitched down and stalled at least four times during the recovery. It took the captain about three minutes to regain control of the aircraft.

FLIGHT CREW ACTIONS

Based upon the data analysis, the Safety Board determined that after the aircraft encountered the lateral wind gust, the captain overcontrolled the aileron and elevator inputs, which resulted in the excessive roll and pitch moments. In turn, this caused at least four aerodynamic stalls.

The gust produced a nose-right sideslip which forced the airplane to naturally roll to the right and yaw to the left. The autopilot disconnected, probably from the large roll rate, and the captain applied left-wing-down wheel deflection to counteract the increasing right-roll angle. As the wings leveled, the captain did not ease off the inputs soon enough and the airplane went into a 25-degree left roll. He then quickly applied the aileron and elevator to stop the left roll, but the inputs produced a rapid acceleration of 1.65 G for about 8 seconds. The airplane went into a 7000-fpm climb for the next 30 seconds and then slowed to the 1-G stall speed. The captain continued to use excessive elevator deflection, which caused the jet to enter a G range of 0.6 to 1.6.

During the high-speed climb, the captain continuously trimmed the airplane in a nose-up configuration, which explained why the jet had a constant pitch-up moment even though the elevator was in the neutral position. The increase in pitch and AOA contributed to the first stall. As the aircraft pitched down, the captain added excessive nose-up elevator inputs that induced the subsequent stalls.

The airplane's stall-warning system sounded continuously for 2 minutes and 45 seconds. To override the system in the MD-11, a 50-pound control column force must be maintained to remain in a stall regime. The captain told investigators that since he was experiencing severe turbulence, he did not recognize that his inputs were creating the stalls. Therefore, the Safety Board believed that those reasonable sequences of events demonstrated the need for further pilot training that addresses aircraft handling during turbulence encounters and recovery procedures.

MD-11 FLIGHT CHARACTERISTICS

To achieve optimum efficiency, engineers designed the MD-11 to operate at an aft center of gravity (CG) that reduces aerodynamic download on the horizontal stabilizer. Although the design improves performance, it affects the airplane's longitudinal stability characteristics. Because of this the aircraft has a tendency to resist pitch disturbances, which results in a slower return to a neutral position when subjected to elevator movements. A pilot needs only a light touch on the control column to obtain the desired response, but this lessens the margin of stability more than on other similar transport-category airplanes. McDonnell Douglas refers to this as "relaxed stability."

The longitudinal stability characteristics of an airplane are gauged in static and dynamic terms. *Static* stability is measured as a function of the force required on the control column as the aircraft diverges from the initial trim speed. The "stick force" must increase as the trim speed differential increases. *Dynamic* stability is measured as the time that it takes for the airplane to regain equilibrium following an elevator control input without corrective pilot action. There are no tests to specifically assess the airplane's susceptibility to pilot overcontrol or out-of-phase–induced pitch oscillations.

McDonnell Douglas intentionally designed the MD-11 to be flown with minimum static longitudinal stability. Therefore, light-control column forces could produce larger than desired flight loads unless the pilot is very careful when applying those forces. To relieve some of the pilot's physical workload when the autopilot is disengaged, the manufacturer equipped the MD-11 with a longitudinal stability augmentation system (LSAS). This system provides conventional pitch-axis handling characteristics through elevator commands without control column movement. The LSAS is essentially a full-time attitude-hold system that uses the elevators to respond immediately to counteract externally induced pitch disturbances. To disengage the LSAS, the pilot needs only to apply 1.8 pounds of pressure on the control column. When the pilot lets go of the yoke, the LSAS re-engages.

The LSAS is also designed to assist the pilot with stall recovery. When the stall-warning system is activated, the LSAS commands a 5-degree nose-down elevator deflection. As mentioned earlier, the system can be overridden by 50 pounds of force on the control column and a nose-up elevator input. Regardless, the 5-degree nose-down elevator deflection is added to whatever input the pilot has manually commanded.

Normally, during cruise flight, the MD-11 is controlled by the autopilot, which commands the movement of the left inboard elevator to obtain a target pitch attitude. The flight computer defines the optimum attitude required to perform a specific maneuver, such as maintaining a constant pitch angle, altitude, or vertical speed. Any movement of the inboard elevator will back-drive the other three elevators through mechanical connections. The slaved elevators will then have less defection than the elevator driven by the autopilot.

If the pilot attempts to override the autopilot by direct control column force, all the elevators will move and the pilot will notice significant resistance. If the autopilot is disconnected while the pilot is exerting force on the column, an abrupt change in the elevator position will be induced by the pilot. McDonnell Douglas test pilots have noted that pilots typically react to this sudden elevator command by overcorrecting in the opposite direction, causing more elevator deflection than would have been commanded by the autopilot.

PILOT TRAINING

Based on information obtained from a NASA study on high-altitude maneuvering as well as their own research, the Safety Board noted that there have been numerous pilot-induced upsets involving MD-11s and other large transport aircraft. The most serious case occurred on an MD-11 four months after the incident of Flight CI-012. The pilot mishandled his response to the stall warnings, and because of the severe positive and negative G cycles two passengers sustained fatal injuries.

The Safety Board's concern over the matter was affirmed when the investigation revealed that neither McDonnell Douglas nor China Airlines had addressed the issue of high-altitude upsets and stall warnings in their training or flight manuals. Since the control forces on the MD-11 are much lighter than those on similar aircraft, the Board believed that pilots need hands-on training to become familiar with cruise-handling characteristics. In the Safety Board's opinion, it is imperative that the training be comprehensive enough that pilots can learn to differentiate between severe turbulence and a stall buffet.

Lessons Learned and Practical Applications

Since the Safety Board believed that the captain's actions were related to inadequate training in certain areas of flight characteristics, it was difficult to fairly measure the crew's performance. However, an interesting point was made by investigators. Since most MD-11 pilots had previously flown other wide-body airplanes, it became apparent that crews of newer-generation aircraft also needed a form of "differences training." In particular, a DC-10 operates with a CG that is farther forward than that of the MD-11, although the aircraft are similar. As a result, the control forces are not as light on the DC-10. Therefore, it is possible that a pilot who transitions from a DC-10 to an MD-11 might not fully recognize the implications of such characteristics.

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Historical Case Study III-6: Southern Airways Flight 242

Safety issues: Severe thunderstorm activity, radar attenuation, CRM, role of ATC, catastrophic dual engine failure

On 4 April 1977, a Southern DC-9 crashed while attempting an emergency landing on a highway near New Hope, Georgia.

Probable Cause

The NTSB determined that the probable cause of this accident was the total and unique loss of thrust from both engines while the aircraft was penetrating an area of severe thunderstorms. The loss of thrust was caused by the ingestion of massive amounts of water and hail into the engines, which in combination with thrust lever movement, induced severe stalling in, and major damage to, the engine compressors.

Major contributing factors included failure of the company’s dispatching system to provide timely severe weather information to the flight crew, the captain’s reliance on airborne weather radar for penetration of thunderstorm areas, and the limitations of the FAA’s ATC system, which precluded reporting real-time hazardous weather information to the flight crew.

History of Flight

Flight 242 operated as a scheduled passenger flight from Muscle Shoals, Alabama, to Atlanta, Georgia, with an intermediate stop at

Huntsville, Alabama. The DC-9 took off from Huntsville at 1554 Eastern Standard Time with 81 passengers and 4 crewmembers on board.

Pilot Experience

The captain had 19,380 total flight hours, 3,205 in the DC-9. He had been promoted to DC-9 captain six weeks before the accident. The first officer had 3,878 total flight hours, 235 in the DC-9. He had been a DC-9 first officer for three years, eight months.

Weather

The storm encountered by Flight 242 was considered to be one of the most severe systems in U.S. history. Two days before the accident, meteorologists began tracking the ominous weather conditions that were rapidly developing over a great portion of the country. Cold air was spreading snow in the Rockies, while to the southeast, air over the 75-degree water in the Gulf of Mexico was growing more humid. Computer forecasts showed a low-pressure center would form just east of the Rockies and strengthen as it moved eastward.

Those forecasts also predicted that on 3 April, jet stream winds would be moving faster than 100 mph from Texas to New England. As the winds intensified around the low-pressure area, dryer air from the west would be pushed across the Mississippi River, while the warm, extremely humid air from the Gulf would be pulled northward into the Ohio Valley.

By the morning of 3 April, conditions were perfect for the severe thunderstorms to hit, and as if right on schedule, the first tornado touched down in Indiana around 0930 Central Standard Time. For the next two days, a deadly path of tornadoes—127 in all—ripped through the Southeast and as far north as Michigan. Winds in at least six of the tornadoes were clocked faster than 261 mph, making them Category 5 storms. According to the NWS, that number of Category 5 storms would be normal for a decade.

In the aftermath of the now infamous super outbreak of tornadoes, 315 persons in 11 states were killed and 6,142 were injured. The storm had threatened nearly 490,000 square miles, yet only about 600 square miles were actually affected. Damages ran as high as $600 million.

On the morning of the accident, the NWS issued a weather forecast for Alabama, northwest Florida, and adjacent coastal areas. By 1400, conditions associated with a cold front were expected to cause low ceilings of less than 1,000 feet, and visibility at 3 miles in moderate rain showers and fog. Scattered and intense thunderstorms with moderate to severe mixed icing were also forecast. The NWS issued a similar forecast for the northern one-third of Georgia. Low ceilings and moderate rain showers associated with thunderstorm activity were likely until the following day. Moderate icing in towering cumulus and cumulonimbus with tops above 13,000 feet was included in the forecast.

SIGMETS AND TORNADO WATCHES

From 1120 to 1520 a SIGMET was in effect for parts of Alabama, Louisiana, and Tennessee. Scattered and severe thunderstorms were forecast.

At 1150, a tornado watch was issued that was valid from 1200 to 1800. The area included 70 statute miles on either side of a line from 20 statute miles east of Huntsville, Alabama, to 60 statute miles south of Jackson, Mississippi. This watch called for tornadoes and severe thunderstorms with hail up to 3 inches in diameter at the surface and aloft, extreme turbulence, surface wind gusts up to 70 knots, and a few cumulonimbus clouds with tops of 58,000 feet. The line of thunderstorms from southwest Mississippi to northern Alabama was also expected to intensify.

By 1317, severe weather had also developed farther north, prompting the NWS to issue another tornado watch. The area included parts of southern Tennessee and western North Carolina. The dangerous conditions were similar to those described in the watch issued for Alabama and Mississippi, and both watches remained in effect simultaneously.

The southern-most severe thunderstorm activity had continued to move eastward, and at 1520 a SIGMET was issued for a large area that covered northern Alabama and western Georgia. Numerous thunderstorms, including “a few that will be severe, possibly a tornado, with occasional tops above 45,000 feet,” were forecast until 1920.

ACTUAL WEATHER CONDITIONS

Shortly before Flight 242's departure from Huntsville, the NWS reported an area of very strong radar echoes that contained thunderstorms with heavy rain showers. Located 35 nm to the north-northeast of Huntsville, the cells quickly moved to the east-northeast at 55 knots.

Note: In this next discussion, you might identify several oversights in the reporting process of the observed weather conditions. Take careful consideration as to the discrepancies between what was reported and what was actually observed. The specifics will be addressed later in the case study.

At 1530, the NWS observer on duty at the Rome Airport (11 miles north of the Rome VOR) reported hearing continuous thunder from the southwest and northwest quadrants. She also saw "boiling" cumulonimbus clouds to the southwest. She notified the Atlanta forecast office and was told they had observed intense radar echoes and several hook echoes west of Rome. With that information, she issued a tornado warning for the Rome area.

Meanwhile, the Atlanta NWS station reported a possible line-echo-wave pattern centered along a line from 86 nm west to northwest of Atlanta. Hail was also expected to be present in those cells.

At 1601, the Athens, Georgia, NWS station reported "cells of intense echoes containing thunderstorms with intense rain showers." The center of one group of cells was 15 nm west of the Rome VOR and 10 nm in diameter. The cells were rapidly moving east-northeastward at 55 knots. Detectable precipitation reached levels of 51,000 feet.

Although the NWS station employee at the Rome Airport visually observed dangerous thunderstorm activity and subsequently issued a tornado warning some time after 1535, no special weather conditions were reported. Similarly, the actual weather observations at 1600 did not reflect the intensity of the storm that was rapidly approaching the airport.

At 1600: Sky 1800 scattered; ceiling 5,000 feet overcast; visibility 7 miles; thunderstorm, light rain showers; wind 210 degrees at 9 knots; continuous thunder southwest through northwest; pressure falling rapidly.

When this report was sent, a tornado was observed moving from southwest to northeast at 3 miles northwest of the Rome VOR. Consequently, the brunt of the thunderstorm appeared to have hit the Rome Airport only 10 minutes later.

At 1610: Special. Sky obscured; ceiling 500 feet; visibility ¾ mile; severe thunderstorm, heavy rain showers; wind 320 degrees at 28 knots, gusts at 50 knots; dark west quadrants; frequent lightning in clouds, frequent thunder.

Between 1605 and 1615, the Rome Airport reported 1.20 inches of rainfall. At 1612, large hail was detected in the western outskirts of Rome. Another "extremely intense" cell quickly followed at 1632. The Athens NWS station reported thunderstorms with "extreme rain showers" located about 13 nm north-northeast of the Rome VOR. The cells were rapidly moving east-northeastward at 56 knots.

The Accident

At 1554, Flight 242 departed Huntsville for the 25-minute flight to Atlanta's Hartsfield International Airport. Shortly thereafter, the crew was cleared direct to the Rome VOR. Their requested en route altitude was 17,000 feet. Seconds later, the captain remarked to the first officer, "…the radar is full of it, take your pick." At 1556, the controller notified Flight 242 that his radar was showing heavy precipitation and that the echoes were about 5 nm ahead of them. The crew responded, "…we're in the rain right now…it doesn't look much heavier than what we're in, does it?" The controller replied that it was "not a solid mass," but that it appeared to be a "little bit heavier than what you're in right now." The crew acknowledged the controller's remarks.

The first officer, who was flying the aircraft, discussed the significance of their airborne radar returns with the captain. At 1556:37, he said, "I can't read that, it just looks like rain…what do you think? There's a hole." The captain responded, "There's a hole right here. That's all I see." He added, "…coming over, we had pretty good radar. I believe…straight ahead…the next few miles is about the best way we can go."

Less than a minute later, the controller commented to Flight 242, "…you're in what appears to be about the heaviest part of it now, what are your flight conditions?" The captain replied, "…we're getting a little light turbulence and…moderate rain." The crew was then told to contact Memphis center. Once Flight 242 had checked in with the center, the captain told the first officer, "As long as it doesn't get any heavier, we'll be all right." The first officer responded, "Yeah, this is good."

At 1558:26, the Memphis center controller notified Flight 242 that a SIGMET was current for the vicinity of Tennessee, southeastern Louisiana, Mississippi, northern and western Alabama, and adjacent coastal waters. He advised them to monitor VOR broadcasts within a 150-nm radius of the SIGMET area. Seconds later, the flight was told to contact Atlanta center.

Flight 242 radioed the center at 1559:06 and informed them that they were "…out of eleven [11,000 feet] for seventeen [17,000 feet]." The captain and controller briefly discussed the expected profile descent, and at 1600:30, the sound of rain was recorded on Flight 242's CVR. A little more than two minutes later, the captain told the first officer, "I think we'd better slow it up right here in this." The first officer replied, "Got ya covered."

At 1603:01, an Atlanta center controller (sector 40) contacted an Eastern Airlines flight, which had just crossed the storm area northwest of Rome. He asked, "How would you classify your ride through that line up there? You recommend anyone else come through it?" The Eastern crew answered, "…it was not too comfortable, but we didn't get into anything we would consider the least bit hazardous." Rain was still being recorded on Flight 242's CVR, when they contacted the sector 40 controller to say, "…level at seventeen [17,000 feet]." At 1603:48, the captain remarked to the first officer, "Looks heavy, nothing's going through that." Six seconds later, he said, "See that?" The first officer responded, "That's a hole, isn't it?" The captain quickly replied, "It's not showing a hole, see it?" At 1604:08, the first officer asked, "Do you want to go around that right now?" The captain answered, "Hand fly it about 285 knots."

The sounds of rain and hail were recorded at 1604:30, and 20 seconds later the crew notified Atlanta center that they were reducing speed. At 1605:53, the first officer said, "Which way do we go—cross here or go out? I don't know how we get through there.…" The captain replied, "I know you're just gonna have to go out.…" The first officer responded, "Yeah, right across that band." Seconds later, the captain said, "All clear left…right now. I think we can cut across there now." At 1606:12, the first officer replied, "All right, here we go."

Meanwhile, the controller was discussing the weather conditions with a TWA flight when he remarked, "I show weather up…north of Rome, just on the edge of it.…" The TWA crew replied, "…we paint pretty good weather at one or two o'clock." After hearing that conversation, the first officer of Flight 242 said, "He's [the TWA flight] got to be right through that hole about now."

At 1606:53, the captain advised Atlanta center that, "242 down to 14 [14,000 feet]." Heavy hail or rain was recorded on the CVR, until 1607:57, at which time the tape stopped recording for 36 seconds. The controller made four unsuccessful attempts to contact Flight 242. At 1608:37, the first officer said, "Got it, got it back…got it back." The crew then told center to "stand by." Seconds later, the controller transmitted, "Roger, maintain fifteen thousand if you understand me, maintain fifteen thousand, Southern 242." At 1608:55, the crew replied, "We're trying to get it up there."

The sound of rain was still being recorded, when the captain reported to Atlanta center, "Okay…we just got our windshield busted and…we'll try to get it back to 15 [15,000 feet], we're 14 [14,000 feet]." At 1609:36, the first officer told the captain, "Left engine won't spool." The crew quickly notified the center that, "Our left engine just cut out." The controller replied, "…roger, and lost your transponder, squawk 5623." Within 10 seconds, the first officer told the captain that he was "squawking 5623" and "tell him I'm level 14."

At 1609:59, the captain turned the autopilot off and the first officer said, "I got it, I'll hand fly it." The center then cleared the flight to 13,000 feet. Four seconds later, the first officer exclaimed, "…the other engine's going, too.…" The captain reported to center, "…the other engine's going too." The controller replied, "…say again." The captain replied, "Stand by, we lost both engines."

The first officer said to the captain, "All right…get us a vector to a clear area." At 1610:16, the captain made that urgent request to

Atlanta center. The controller replied, "…continue present southeast bound heading, TWA's off to your left about 14 miles at 14,000 and says he's in the clear." The captain acknowledged the information.

Eleven seconds later, the center told Flight 242 to "…contact approach control…and they'll try to get you straight into Dobbins [Air Force Base]." The first officer immediately said to the captain, "…I'm familiar with Dobbins; tell them to give me a vector to Dobbins if they're clear." The captain requested, "…vector to Dobbins if they're clear." The controller told him to go over to approach control and "they'll give you a vector to Dobbins." The captain responded, "…okay."

At 1610:50, the first officer said, "Ignition override, it's gotta work.…" Six seconds later, the CVR again stopped recording, this time for two minutes and four seconds. Controllers from Atlanta center and Atlanta approach control and the crew of the nearby TWA flight tried unsuccessfully to contact Flight 242.

At 1613:00, the CVR began to record, followed by the captain making the comment, "There we go." The first officer reiterated his request for a "vector to Dobbins," and within seconds, Flight 242 was again in radio contact with approach control. At 1613:17, the aircraft was at 7,000 feet and 20 miles from the Air Force base. For the next minute, the crew received vectors for a straight-in approach at Dobbins.

The captain, at 1614:24, stressed the crew's concerns to the controller, "All right, listen, we've lost both engines, and…I can't…tell you the implications of this…we…only got two engines, and how far is Dobbins now?" Approach replied, "…19 miles." The captain answered, "Okay, we're out of…5800, 200 knots." The controller then asked, "…do you have one engine running now?" The reply was, "Negative, no engines."

At 1615:04, the captain told the first officer, "Just don't stall this thing out." The first officer answered, "No, I won't." The crew set the wing flaps and commented that they had hydraulics. The captain again asked for Dobbins weather and their distance from the base. The weather was "2000 scattered, estimated 7000 overcast, visibility 7 miles," and they were "approximately 17 miles west of Dobbins.…" At 1616:45, the captain informed the controller that, "I don't know whether we can make that or not."

After a brief discussion with the first officer, the captain asked the controller, "…is there any airport between our position and Dobbins?" He added, "I doubt we're going to make it, but we're trying everything to get something started." Approach control came back with, "…well there is Cartersville, you're approximately 10 miles south of Cartersville, 15 miles west of Dobbins." Although the captain asked for vectors to Cartersville and the runway information, at 1617:08, the captain said to the first officer, "…I'm picking out a clear field." The first officer replied, "…you've got to find me a highway." Twenty-seven seconds later, the captain said, "See a highway…no cars." The first officer also spotted it and asked, "…is that straight?" The captain replied, "No," but the first officer answered, "We'll have to take it."

As the crew was preparing to land on the highway, the controller gave them the runway information for Cartersville Airport. At 1618:02, the captain made the last transmission to approach control and said, "…we're putting it on the highway, we're down to nothing." From 1618:36 to 1618:43, crash sounds were recorded on the CVR.

Impact and Wreckage Path

As the aircraft approached State Spur Highway 92, near New Hope, Georgia, the outboard left wing section clipped two trees. A short distance later, the wings struck more trees and utility poles on both sides of the highway. When the main landing gear made contact with the pavement, the outer structure of the left wing hit an embankment, causing the aircraft to veer to the left and off the highway. As the aircraft traveled another 1,260 feet, it struck road signs, utility poles, fences, trees, shrubs, gasoline pumps at a service station, five automobiles, and a truck. The total wreckage area was about 1,900 feet long and 295 feet wide.

ACCIDENT SURVIVABILITY

The aircraft's fuselage broke into five major sections, some of which remained comparatively intact while others were destroyed. Therefore, according to the Safety Board, the accident was survivable for those passengers who were seated aft of the wings' leading edges, except for those who were too severely injured to escape without assistance.

The captain and first officer sustained fatal injuries, along with 61 of the 81 passengers. Nine persons on the ground also died. The remaining 20 passengers and 1 of the 2 flight attendants were seriously injured. The other flight attendant received minor injuries.

Nearly half of the survivors were ejected from the wreckage. The remaining survivors were not incapacitated and, therefore, were able to escape unaided. Many of them, however, sustained burns on their heads and extremities, and multiple bone fractures.

Flight Attendant Actions

Although the flight crew was preoccupied with a serious emergency, the Safety Board believed that they should have spared a few seconds to inform the flight attendants of the total engine failure and what type of emergency landing to expect. Since the cabin crew had no knowledge of the unusual circumstances, and that it was a possibility the aircraft would land short of the airport, they followed standard evacuation procedures. However, if they had been aware that a normal emergency landing was doubtful, they might have modified those procedures.

For example, the flight attendants instructed the passengers to take off their shoes. The reason for this is to prevent damage to the evacuation slides. Once the decision was made to land on the highway, the likelihood that those slides would have been used was minimal. As a result, the feet of a number of survivors were cut and burned because they were not wearing shoes for protection. Furthermore, pillows and blankets were not distributed to the passengers as part of cabin preparation. In the Safety Board's opinion, many passengers suffered unnecessary and more severe injuries due to the flight attendants' lack of information prior to impact. And in extreme cases, the Safety Board believed that some passengers became incapacitated because of the aggravated injuries and might have been able to escape the wreckage if additional precautions had taken place.

At 1607:22, after the aircraft encountered intense storm conditions, a flight attendant notified the passengers to, "Keep your seatbelts on and securely fastened; there's nothing to be alarmed about, relax, we should be out of it shortly." After Flight 242 experienced a 36-second power interruption, a flight attendant instructed the passengers to, "…check…all carry-on baggage is stowed…in the unlikely event…for an emergency landing…grab your ankles. I will scream from the rear of the aircraft. There is nothing to be alarmed but we have lost temporary APU [auxiliary power unit] power at times…unlikely need for an emergency you…hear us holler, please grab your ankles, thank you for your cooperation and just relax, these are precautionary measures only." A few minutes later, after the second power interruption, a flight attendant told the passengers to, "…check…seatbelts.…"

At 1616:28, the cabin crew had a conversation over the aircraft's intercom to try and determine how they should prepare the passengers for an emergency landing. The forward flight attendant had apparently gone into the cockpit earlier to ask for information. She told the aft flight attendant, "They would not talk to me…the whole front windshield is cracked." She added, "…he screamed at me when I opened the door just sit down so I didn't ask him a thing. I don't know…anything. I'm sure we decompressed." Both had already noticed that the aircraft had lost one engine, but neither of them realized that they were gliding powerless toward Dobbins. They discussed where they should stow their shoes, and one said that she had also taken off her socks to prevent "sliding." On that note, the conversation ended.

During the investigation, the aft flight attendant recalled that the aircraft struck the ground about six times before it came to rest. A fireball erupted after the first or second impact and traveled rearward along the ceiling. The fire then extended downward to the tops of the passenger seats. She saw passengers on fire before the aircraft stopped. After protecting her hand with her apron because the seatbelt release lever was hot, she unbuckled her seatbelt and stood up. A wall of fire was in front of her, and smoke filled the air. After trying unsuccessfully to open the rear bulkhead door, she turned and moved forward because the flames had diminished enough that she could walk out of the cabin and onto the ground. She then began to pull passengers from the wreckage until an explosion forced her away.

The Investigation

Due to the apparent dual engine loss when Flight 242 penetrated a severe thunderstorm, the Safety Board directed much of its investigation toward the JT8D-7 engine. A test program was conducted by the manufacturer to determine the integrity of its engine when exposed to water ingestion. Since the manufacturer's facility had a water flow limitation of 125 gallons per minute, the tests were performed at water-to-air ratios that might have been less than the actual conditions that Flight 242 had experienced.

At flight-idle thrust, and with ingestion rates exceeding 14 percent (by weight) water-to-air ratio, the high-pressure rotor RPM decelerated to below generator cut-out speed. The rotor speed continued to decrease as long as water was ingested. Upon completion of that part of the test, the rotor speed recovered to the set speed and remained stable. When engineers combined lower ingestion rates with higher power settings, the operation of the engine still remained stable. The engines did not surge or flame out anytime during the ingestion tests. These tests also showed that water did not collect in the air bleed cavities or compressor cases during high or low ingestion rates. Consequently, the compressor rotors were not damaged.

Another type of test was conducted to determine whether water trapped in the bleed cavities could hit the compressor blades hard enough to cause damage similar to that found in Flight 242's engines. Water jets were directed at the rotating compressor blades and rotors until the blades failed. All recorded failures were from high-frequency fatigue and occurred in the airfoil near the test platform. The field investigation of Flight 242, however, had determined that the aircraft's engine blades had failed from overload bending at random points on the airfoil. Many of the blade roots were torn from the disk slots, whereas none of the test engine's blades were torn from the slots.

The compressor damage in Flight 242's engines was compared to previous JT8D compressor damage from known and documented causes. The damage was found to be nearly identical to high-pressure compressor loss due to material that originated forward of the compressor. Static load testing of low-pressure compressor blades showed that the fourth-, fifth-, and sixth-stage blades could deflect enough to come in contact with the upstream vanes. However, further testing and calculations indicated that close to a 300 percent water-to-air ratio was needed to produce water deep enough to deflect the blade tips to the extent that they would touch the upstream vanes.

Analysis of test data and developmental information on the JT8D showed that during water ingestion the high-pressure compressor's sensitivity to stalls and surges is significantly increased. Calculations proved that, when water is ingested in large quantities, surging in the higher stages of the compressor could cause upstream overpressures and correspondingly increased aerodynamic forces. These forces could develop levels of such great intensity in the sixth stage of the compressor that the blades could deflect into the upstream stator vanes.

AIRCRAFT PERFORMANCE

Since a total engine loss was so rare, the Safety Board requested Douglas Aircraft Company to provide various glide ratios for a DC-9 with a similar configuration as Flight 242. Calculations were based on the following information: clean configuration, 88,400 pounds, inoperative engines, atmospheric conditions (but without consideration to the effects of winds aloft), and the indicated airspeed at which the maximum lift/drag ratio is achieved.

According to the manufacturer, the aircraft could glide about 34 miles in wings-level flight while descending from 14,000 to 1,300 feet. The time of descent would have been 9 minutes and 30 seconds. Under the same conditions and flight profile, while descending from 7,000 to 1,300 feet, the aircraft could glide about 12 miles. These results proved quite accurate, as the FDR and ATC radar data for Flight 242 indicated that the DC-9 flew about 32.5 miles as it descended from 14,000 to 1,300 feet.

AIRBORNE WEATHER RADAR

Flight 242's weather radar operated on a common X-band frequency with a 3.2-centimeter wavelength. A frequency band, and its associated wavelength, is very important to radar performance. Although a narrow beam provides greater amounts of concentrated power in a particular direction, and a fine angular resolution, there are trade-offs that pilots should be aware of. Atmospheric attenuation can be caused by two basic factors: absorption and scattering.

Absorption

Energy is absorbed from radio waves primarily due to oxygen and water vapor. The higher the band frequency, the more absorption increases.

For example, the center frequency for the X-band is at 10 gigahertz. Attenuation caused by absorption rises significantly with a frequency band that is above 5 gigahertz. The molecules of oxygen and water vapor have resonant frequencies, so when they get excited at the higher frequencies, they absorb more energy.

Scattering

Radio waves can scatter when they come in contact with particles suspended in the atmosphere. Raindrops are the primary cause of scattering, although hail is also a significant factor. Scientific studies proved that the X-band frequency radar is relatively susceptible to atmospheric attenuation by water vapor and precipitation. This might be particularly true when precipitation covers the antenna radome. The Board noted that these limitations were not clearly addressed in the radar manufacturer's operating manual and, therefore, the crew of Flight 242 might not have been fully aware of those problems.

The Safety Board believed that because of the possible lack of knowledge the crew had concerning weather radar, they might have misinterpreted the radar display. For that reason, the Safety Board recommended airborne radar never be used as an aid for storm penetration.

ENGINE FAILURE

Based on eyewitness testimony, radar-weather reports, and the CVR tape, it was determined that Flight 242 encountered heavy rain and hail for about 2½ minutes immediately before both engines lost power. From the results of the engine tests, the Safety Board believed that the intensity of that rain and hail was sufficient to cause the rotational speed of the engines to decrease below generator cut-out speed. This was supported by the 36-second loss of normal electrical power. Furthermore, the Safety Board concluded that engine rotational speed was lost shortly after the thrust levers were pulled back, most probably, to flight idle, in preparation for the descent from 17,000 to 14,000 feet.

The engine tests also proved that at low rotational speeds, ingestion of large quantities of water is likely to cause surging in the aft stages of the high-pressure compressors. Consequently, this could produce strong enough overpressures in the low-pressure compressors to cause the blades to deflect into the vanes of these compressors. When the throttles are advanced under these conditions, it tends to increase the likelihood of an engine surge and stall. The Safety Board believed that because Flight 242 had experienced loss of engine RPM while in a climb, it was most likely that the crew had increased the thrust. Therefore, it was determined that a loss in rotational speed, advanced power settings, and engine surges/stalls combined to cause the blades in the low-pressure compressors to collide with the vanes.

The Safety Board concluded that the damage to both low-pressure compressors was an indication that the sixth-stage blades deflected forward, touched the fifth-stage stator vanes, and broke pieces off the blades and vanes. This debris was then ingested into and caused excessive damage to the high-pressure compressors. The theory that hail contributed to this damage was dismissed because there were no signs of foreign object damage in the forward stages of the low-pressure compressors, which would be typical of such an event.

And finally, the Safety Board determined that if the thrust levers had remained at relatively high settings after the compressors were damaged, the combination of a high fuel flow with reduced compressor efficiency would cause the over-temperatures found in the turbine sections of the engines. Consequently the engines stopped operating, and there was an interruption of normal electrical power. This was the cause of the more than two-minute interruption of the CVR and FDR. The power was undoubtedly restored by the APU generator since those systems again began to record and remained on during the initial impact.

FLIGHT CREW PERFORMANCE

During the couple of minutes that the CVR stopped, the crew turned the aircraft about 180 degrees back toward the west-northwest instead of continuing in the direction of Dobbins Air Force Base. The Board could only speculate that after the loss of the engines the aircraft entered visual flight conditions. The pilots, busy trying to start the engines and APU, might have chosen to remain in a visual environment, and, therefore, made the turn. The theory was consistent with the first officer's initial request, "…get us a vector to a clear area." It was also possible that the crew did not turn on the emergency power, which might explain why they lost radio communication with ATC. Most likely, communication was restored when the APU began to operate.

In the Safety Board's opinion, the probability of Flight 242 successfully landing on a highway or at an airport without major damage or injury was extremely low. Although the Board believed that an accident was "most probably inevitable," they felt that the only viable chance the crew had in making a successful landing was if they could have reached the 10,000-foot runway at Dobbins.

WEATHER OBSERVATIONS

The final question of the Safety Board centered on the flight crew's decision to fly through a severe thunderstorm. It was noted that while the flight crew was on the ground at Muscle Shoals, they received the weather information that included the two initial tornado watches and SIGMETs. They were, therefore, aware of the hazardous conditions expected in northern Alabama and northern Georgia sometime between 1120 and 2000. However, according to a flight attendant, the crew remained in the cockpit during their stop in Huntsville. The only additional information given to them was by Southern flight dispatch, which was limited to a 1500 weather observations for selected terminals. Consequently, the information was of little value with regard to the actual flight conditions that were developing along their flight path to Atlanta. The Safety Board believed that since the crew had just flown that route, Atlanta to Muscle Shoals, two hours previous, they probably relied more on their personal experience of the actual conditions than on a forecast.

Nevertheless, when Flight 242 departed Huntsville, the flight crew apparently had little meaningful weather information to alter their impressions of conditions that existed two hours earlier between there and Atlanta. Furthermore, there was no evidence that showed, while en route, the crew ever tried to obtain information on the current conditions, especially on the thunderstorm activity near Rome. Hence, the Safety Board concluded that the crew failed to follow Federal Aviation Regulation (FAR) 91.5, which states, in part, "Each pilot in command shall, before beginning a flight, familiarize himself with all available information concerning that flight. This information must include: (a) For flight under IFR…weather reports and forecasts.…" Rather, the Safety Board believed that the pilots placed their confidence in their old, first-hand accounts of the weather conditions and that they relied heavily on the use of the aircraft's radar to provide en route weather-avoidance information.

Shortly after takeoff, the Huntsville departure controller told the crew that he was "…painting a line of weather which appears to be moderate to…possibly heavy precipitation starting about…5 miles ahead.…" The captain replied, "…we're in the rain right now…it doesn't look much heavier than what we're in, does it?" The Safety Board later determined that the controller's radar was set at about 40 miles, which indicated that he and the flight crew were commenting on a different area of weather—an area that did not include Rome. The only other known information provided to Flight 242 while en route was from Memphis center. That weather advisory, however, was given in general terms, "SIGMET, hazardous weather…northern and western Alabama…monitor VOR broadcast within a hundred fifty mile radius of the SIGMET area." According to the Safety Board, there was no evidence that the flight crew received the full text of that SIGMET.

As Flight 242 proceeded toward Atlanta in IFR conditions, the flight crew had no visual reference to the towering thunderstorm near Rome. However, when the crew was about 35 miles west-northwest of the Rome VOR, the captain said, "Looks heavy, nothing's going through that." The aircraft continued on the same heading for about one minute, before the first officer began a right turn.

For the next few seconds, the crew discussed a possible "hole" in the weather that was not showing on the radar return. Given the close proximity of the aircraft to the intense precipitation, there should have been a definite contour hole on the radar. However, because Flight 242 was already in the rain, combined with the steep gradients associated with a severe thunderstorm, the aircraft's radar returns might have been distorted by the effects of attenuation. The Safety Board believed that the captain might have interpreted the contour as an area free of precipitation, rather than the most intense part of the storm. Additional comments from the captain, "All clear left…right now…," and by the first officer, "He's [the nearby TWA flight] got to be right through that hole about now," came at the same time Flight 242 passed through the most dangerous region of the storm. This further suggested that the crew misinterpreted the radar.

As a side note, the radar indications that the crew was referring to were different from the actual conditions. Five minutes before their cockpit discussion, the same TWA flight had told Atlanta center, "…this is really not too good a corridor we're coming through here, it's too narrow between your limit [ATC restrictions] and this line [the line of thunderstorms]…we're getting…heavy moderate turbulence and quite a bit of precip in here." It was possible that if the crew of Flight 242 believed that a contour indication meant good weather, instead of severe conditions, they might not have realized the discrepancy between the radar return and the TWA pilot's warning. Therefore, they continued to fly toward the contour hole.

The Safety Board concluded that the crew of Flight 242 had no knowledge of the current weather conditions just west of the Rome VOR. Although the NWS had prepared numerous reports, one as late as 20 minutes before the flight departed Huntsville, concerning tornado watches and strong thunderstorm activity, that information was not appropriately disseminated to Flight 242. Nor were actual radar and visual observations of the intense thunderstorms and hail near Rome properly passed to the flight crew.

FLIGHT DISPATCH

The normal flow of weather information was through Southern's flight dispatch system. According to the Board, the central dispatchers were unaware of the severity of the storms until after the accident, even though thunderstorms were reported near Rome as early as 1459. It was determined that crews received from Southern's system limited weather reports from selected terminals along a proposed route instead of a complete and detailed analysis of conditions over a broader area. The investigation also revealed that the dispatchers did not comply with FAR 121.601(b), which states, in part, "During a flight, the aircraft dispatcher shall provide the pilot in command any additional available information of meteorological conditions…that might affect the safety of the flight." Ultimately, the Safety Board believed that this reflected a major flaw in Southern's dispatch system, an apparent inability to identify and monitor severe storm systems that affected the airline's route structure.

AIR ROUTE TRAFFIC CONTROL CENTER (ARTCC)

Another source of current weather information that should have been available to Flight 242 was from the en route ATC facilities. Except for the radar reports by the Huntsville departure controller and the SIGMET advisory from Memphis center, the flight crew did not receive, nor did they request, any weather information from ATC before entering the severe weather west of the Rome VOR. According to the controllers at Atlanta center, the crew had been given little information to confirm the severe weather in the Rome area. In fact, the only severe weather information distributed internally to the controllers was a report of a tornado near Gadsden, Alabama, and the SIGMET alerts. None of the radar reports from the NWS offices in Atlanta or Athens were made available to center personnel, and few definitive pilot reports about weather conditions were received.

Lessons Learned and Practical Applications

1. *Obtain an updated weather report before every flight.* Don't rely on old information as this might place you unnecessarily in dangerous conditions. In this case, the Board believed that the flight crew had assumed the weather had not drastically changed in the previous two hours and, therefore, had trusted their own personal observations rather than a forecast.
2. *Take severe weather forecasts seriously.* Although the crew did not ask for an updated weather report, they were aware of the SIGMETs for intense thunderstorm activity and possible tornadoes. They must also have noticed the rapid building of cumuliform clouds as they sat at the gate in Huntsville.

3. *Learn your radar system.* Understand its limitations and how certain weather activity will appear on the scope.

Reference

National Transportation Safety Board. 26 January 1978. Aircraft Accident Report: Southern Airways, Inc., DC-9-31, N1335U. New Hope, Georgia. April 4, 1977.

PART IV

Mid-Air Collisions

When weather conditions permit, regardless of whether an operation is conducted under instrumental flight rules or visual flight rules, vigilance shall be maintained by each person operating an aircraft so as to see and avoid other aircraft.

Federal Aviation Regulation 91:67

Pilots have long been trained in the rudimentary concept of *see-and-avoid*. The FAA has recommended pilots use various scanning methods over the years—side-by-side and front-to-side—for the obvious purpose of avoiding mid-air collisions. Yet, physical limitations can prevent even the most vigilant pilot from seeing other airplanes, particularly if they are on a collision course.

The see-and-avoid concept is composed of four elements—the first three of which are physical—eye perception, three-neuron reflex arc (how your eye and brain process information), muscle reflex, and limitations of the aircraft. Each of these four elements is commonly depicted on the recognition and reaction bar graph shown in Fig. IV-1. The figure illustrates the breakdown of recognition and reaction times in a see-and-avoid environment:

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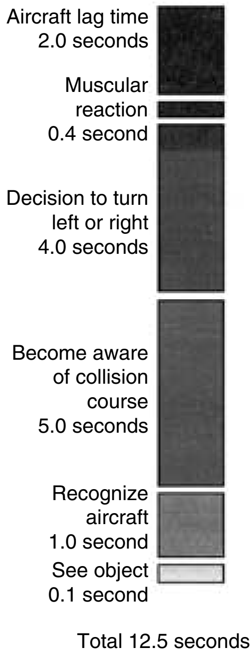

Fig. IV-1. Breakdown of recognition and reaction times in a see-and-avoid environment.
FAA Advisory Circular 90-48C.

See object (0.1 second). The time it takes for the eye to *see* but *not recognize* an object.

Recognize aircraft (1.0 second). The onset of the three-neuron reflex. The brain has processed that the object is an aircraft.

Become aware of collision course (5.0 seconds). Three-neuron reflex process continues with the brain recognizing that the aircraft is on a collision course.

Decision to turn left or right (4.0 seconds). Three-neuron reflex process continues with the brain determining which direction to turn.

Muscular reaction (0.4 second). Physical movement of the hands and feet to manipulate the flight controls.

The total time for these physical elements only—the aircraft has not yet moved from the collision course—is 10.5 seconds.

Aircraft lag time (2.0 seconds). Response time between beginning of physical inputs and mechanical maneuvering.

The total time needed to recognize and react, therefore, is 12.5 seconds. This recognition and reaction time is the minimum required to successfully execute an evasive maneuver. Numerous factors will cause a pilot to exceed this minimum time: task saturation, poor weather conditions, stress, fatigue, distractions in the cockpit, sleep deprivation, age, smoking, and legal medications.

There is much more to see-and-avoid than just looking out the window. Chapter 12 examines the physical limitations in detail and presents a practical alternative—*search-and-detect.*

Reference

Krause, Shari Stamford, Ph.D. 1995. *Avoiding Mid-Air Collisions*. Blue Ridge Summit, Pa.: McGraw-Hill.

CHAPTER 12

Mid-Air Collision Avoidance: From See-and-Avoid to Search-and-Detect*

In the United States, pilots are expected to avoid mid-air collisions by complying with U.S. Federal Aviation Regulation (FAR) Part 91.113(b), which states, "Vigilance shall be maintained by each person operating an aircraft so as to see-and-avoid other aircraft…." Under these guidelines, pilots depend on see-and-avoid as their primary way to avoid collisions.

But according to scientific and operational evidence, see-and-avoid is not necessarily the best technique. Instead, safety in visual meteorological conditions (VMC) depends on a pilot's use of specific, active visual-detection techniques. The evidence suggests that the standard-issue eyeball may be more effectively used to avoid mid-air incidents through a conscious search-and-detect—rather than see-and-avoid—plan.

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Most pilots know from experience that visually detecting another aircraft in airspace is difficult, and in some circumstances it is virtually impossible. Studies cited in this chapter suggest that the ability to spot another aircraft may be a skill that pilots can develop. The research points to four key elements of successful target acquisition:

- Ignoring conflicting or distracting close-up and peripheral stimuli
- Optimizing the eye-brain connection to visually imagine distant targets
- "Looking through" (or past) structured surfaces
- Using a distant object to adjust focus for search

To understand the problems associated with see-and-avoid, it is necessary first to examine the physical structure of the eye (Fig. 12-1).[1] At the front of the eye is the *cornea,* a thick, transparent tissue that forms the outer coat of the eyeball and covers the *iris,* the colored part of the eye. The *pupil,* the circular opening in the center of the iris, allows light to enter the eye. The iris and pupil rest against the front of the lens, which is held in place by thousands of elastic fibers. These fibers, and the muscles to which they are attached, enable the lens, by changing shape, to focus on objects at varying distances.

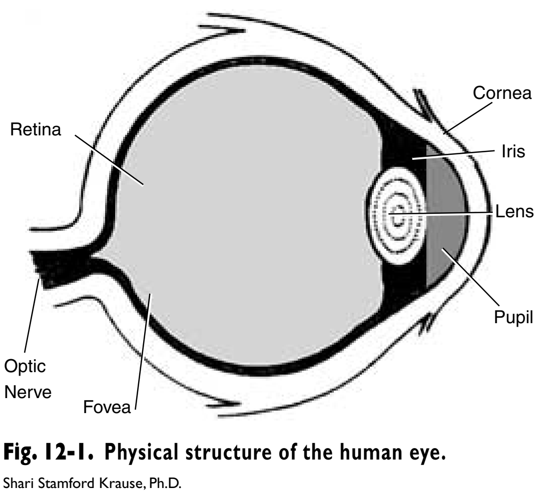


Fig. 12-1. Physical structure of the human eye.
Shari Stamford Krause, Ph.D.

The *retina,* the inner layer of the back of the eye, contains more than 125 million light-sensitive receptor cells that receive information about an object being viewed. Rods and cones are the two main types of light-sensitive cells found in the retina. Rods, which are approximately 20 times more numerous than cones, respond to darkness, faint light, shape, and movement. Thus rods, with their light-sensitive pigment (rhodopsin), are responsible for adaptation to darkness (night vision) and perception of shades of gray.

Cones, on the other hand, are stimulated by bright light and are responsible for our ability to perceive colors. Cones are concentrated in the highly sensitive central section of the retina, the *fovea*. Light entering the eye is focused directly on the fovea, making it the site of greatest visual acuity (sharpness of vision) and providing the ability to distinguish fine details.

Visual acuity depends not only on the proper focusing of the image on the retina, but also on the ability of the retina to distinguish between objects that are extremely close together. In this area of maximum resolving power, there are approximately 170,000 receptor cells per square millimeter (10.6 million receptor cells per square inch). This vast number of receptors makes it possible to discern tightly spaced, minute objects as separate visual targets.[2]

The optic nerve, which consists of some 1 million nerve fibers, connects each eye to the brain and supplies blood to the retina. The retina transforms the information about the patterns of light and dark received by the rods and cones into electrical impulses that travel through the optic nerve to the brain, where they are interpreted as an image.[3]

The optic nerve is joined to the eye in the retina at a point called the *optic disk*. Because the optic nerve contains no light-sensitive receptor cells, it is considered "blind" and renders the optic disk blind, as well—creating the area commonly referred to as the *blind spot*. Normally, the blind spot is between 5 and 10 degrees wide. The small size of the blind spot may make it sound insignificant, but it is enough to allow an aircraft to disappear from view, often before the eyes have detected it. The exercise in Fig. 12-2 demonstrates the blind spot.[4]

Eye-Brain Connection

Scientists have found neurophysiological evidence that establishes the importance of the eye-brain connection in collision avoidance. The evidence indicates that there are two separate and parallel visual channels in the brain, each of which is directly linked to the ability to search and detect. One channel responds to the visual functions of target detection and acquisitions (except in the most technical discussion, these terms are often used interchangeably). It contains both

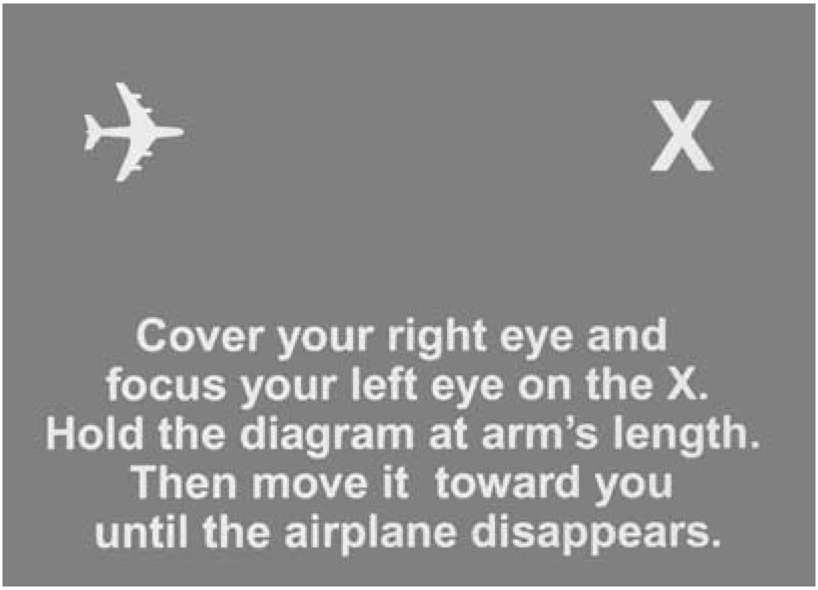


Fig. 12-2. Exercise for demonstrating the eye's blind spot. Shari Stamford Krause, Ph.D.

rods and cones and allows the brain to interpret peripheral (side) vision.

The second channel originates from the fovea, the area of sharpest acuity, making it possible to identify a target. These two channels converge in a third pathway, which researchers believe may integrate these peripheral and central inputs in a way that enables the eyes simultaneously to focus on and track a moving target.[5] This ability is a key to visual search-and-detect.

Eye Movement

In the absence of a visual stimulus (for example, empty airspace), the muscles in the eye relax, preventing the lens from focusing. This creates a problem for a pilot who is attempting to scan for traffic in a clear, featureless sky. Because the eye cannot properly focus on empty space, it remains in a state of unfocused, or blurred, vision. This phenomenon, known as *empty-field myopia,* hinders effective search and detection.

Another aspect of eye functioning that is relevant to visual searching is saccadic eye movement. When they are not tracking a moving target, the eyes do not shift smoothly; they shift in a series of jerky movements or jumps called *saccades.* See Fig. 12-3. As a result of saccadic eye movements, it is not possible to make voluntary, smooth eye movements while scanning featureless space.

Distant Visual Acuity

A study conducted at the U.S. Naval Aerospace Medical Research Laboratory (NAMRL) showed that when the eyes are in saccadic movement, visual acuity decreases sharply, leaving large gaps in the distant field of vision.[6] Refer to Fig. 12-3. Visual acuity is greatest for objects that are directly in front of the eye. But the fovea is a mere 2 degrees wide, which results in a very narrow high-acuity detection area and leaves as much as 178 degrees of the detection area in the realm of peripheral vision. This is one reason that we often tend to spot traffic or obstacles out of the "corner" of our eye.

Researchers at NAMRL found that optimizing peripheral-scanning skills is an important element in improving target-detection skills. The visual-detection lobe, as Fig. 12-4 illustrates, reveals the detection range for central vision is narrow but extends relatively far, whereas the detection range for peripheral vision includes a wider area but extends a much shorter distance. The visual-detection lobe represents the range in which detection is probable, not certain.

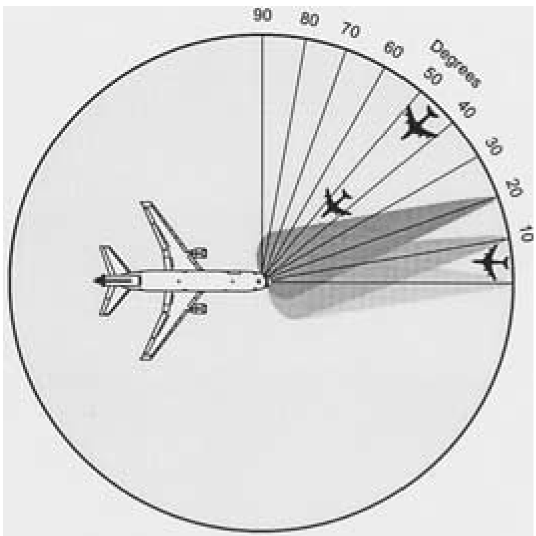


Fig. 12-3. Saccadic eye movement. Shari Stamford Krause, Ph.D.

The shaded areas in Fig. 12-4 depict how the visual-detection lobe relates to saccadic eye-movement scans. For distant searches using central vision the eyes must scan over a much larger field, compared to near searches, in a relatively short period of time. The spaces between the tips of the cone-shaped shaded areas shown in the figure are the

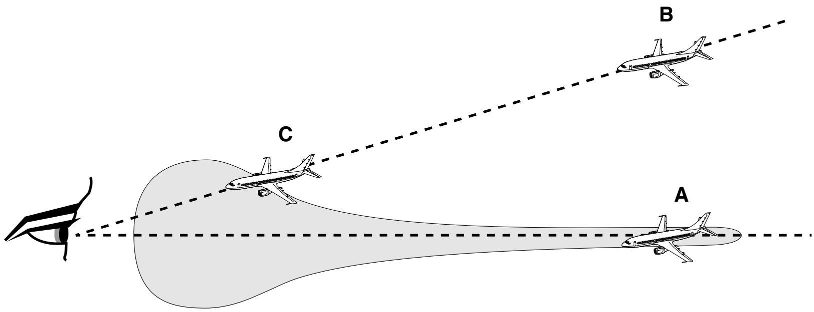


Fig. 12-4. Visual-detection lobe. Shari Stamford Krause, Ph.D.

visual gaps created by saccadic motion. These gaps cause a significant problem for a pilot who is scanning for traffic because aircraft can easily slip into those transition areas undetected. When searching for aircraft at a closer range, within 2 to 2½ miles (approximately 3.7 kilometers), for example, fewer "fixations" (focused scans) are required because of the increased probability of detecting a target through peripheral vision.

In Fig. 12-4, the same type of aircraft is shown in three positions—A, B, and C. Aircraft A, in the central field of vision, is likely to be detected. Aircraft B, although it is at the same range as Aircraft A, is outside the visual-detection lobe and unlikely to be detected. Aircraft C is the same number of degrees off the direct line of vision as Aircraft B; but because it is within the visual-detection lobe, it is likely to be detected through peripheral vision.

Depending on closure rate, crossing angle, and routine cockpit distractions, aircraft can seem to appear suddenly, leaving little time to react and avoid a collision. Researchers at the Massachusetts Institute of Technology (MIT) devised several mathematical models to analyze visual acquisition and to determine detection probabilities.[7] The parameters were restricted to bright daylight conditions, constant flight paths, and a constant rate of range decrease. No unusual visual environments were considered. Although the variables were carefully controlled, the calculations indicated that the probability of target detection was quite low in most cases.

Two examples illustrate that even under ideal conditions probability of detection is frequently remote.

Example 1

Target aircraft/airspeed. Single-engine Piper Dakota (PA-28-236); 130 knots (241 kilometers per hour).

Search aircraft/airspeed. Boeing 727; 180 knots (333 kilometers per hour), on approach.

Encounter. Head-on.

Detection probability. On a clear day with unlimited visibility, the crew of the B-727 would have a 12 percent probability of visual acquisition of the PA-28 twelve seconds before collision. At a distance of 2.6 miles (5.5 kilometers), the probability would decrease to 2.47 percent.

Example 2

The heading crossing angle is derived by subtracting the heading of Aircraft B from the heading of Aircraft A. See Fig. 12-5.

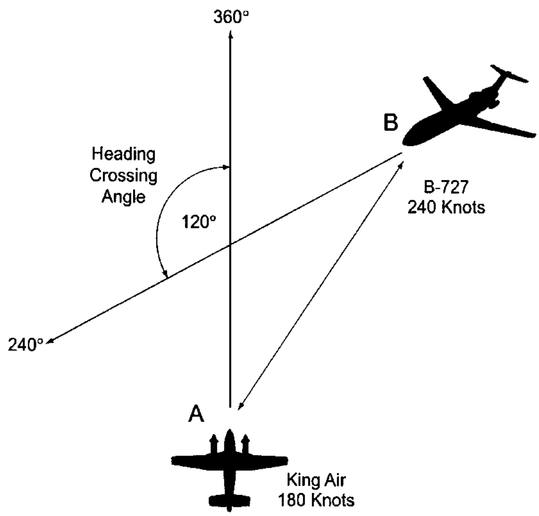


Fig. 12-5. Illustration of a heading crossing angle of 120 degrees. Shari Stamford Krause, Ph.D.

Target aircraft/airspeed. Boeing 727; 240 knots (444 kilometers per hour).

Search aircraft/airspeed. King Air; 180 knots (333 kilometers per hour).

Encounter. 120-degree heading crossing angle.

Detection probability. At a distance of 5¾ miles (9 kilometers), the King Air pilot would have a 76 percent probability of visual acquisition of the Boeing 727 twelve seconds before collision. At a distance of 2 to 2½ miles (3.7 kilometers), the probability would decrease to 28 percent.

A 120-degree heading crossing angle provides a larger cross section of the target aircraft and thus a higher probability of detection than in a head-on meeting between the same two aircraft.

The effectiveness of central and peripheral detection also depends on restrictions in the visual field. In an aircraft, the most common restriction is the visual boundary created by the overall structure of the cockpit. The visual field of each eye encompasses about 130 degrees. The visual field of each eye overlaps with that of the other eye, which creates our "binocular" (two-eyed) vision.

Because each eye has a different viewing angle, the images formed on the two retinas are not identical. The brain combines the two images into a single, three-dimensional perception of the object. Thus the perception of depth is a particular feature of binocular vision. Conversely, if only one eye is viewing an object (monocular vision), the image is perceived in a single dimension, with no depth perception.[1]

Cockpit Creates Monocular Visual Areas

The restricted visual field of the cockpit can interfere with a pilot's ability to detect targets. In a study that included nine subjects, each with at least 20/20 corrected or uncorrected vision, a viewing booth was designed to simulate a cockpit windshield; and through this "windshield," a binocular field 25 degrees high and 38 degrees wide could be seen by the participants.[8] Because of the distance between the observers' eyes, slightly different fields were seen by the right and left eyes. This created monocular visual borders—areas at the extreme right and extreme left edges of the visual field where an object in that area could be seen only with one eye (the right and left eye, respectively).

The target was a dark disk with a diameter of 1.2 meters (4 feet) against a white background screen that had a uniform brightness contrast of nearly 80 percent. There were 45 possible target positions varying from 0, 5, and 10 degrees above and below the visual center; and 0, 5, 10, 15, and 18 degrees left and right of center. The targets at 18 degrees appeared within the monocular visual field.

Each observer was given a total of 50 timed acquisition trials. During each 12-second trial, the target disk appeared in one of the 45 possible target positions in random order, and there were five blank screens (trials in which no disk appeared). A target that was not reported within the 12-second search time was recorded as a missed target.

Test results were plotted on a grid to determine the search areas that had the most missed targets. All the missed targets in the binocular field of vision (a total of 18 misses) had appeared along the bottom of the visual field. There were fewer missed targets (10 misses) in the monocular field (along the extreme left and right sides of the screen) than in the binocular field.

In other words, the presence of a visual boundary can cause a pilot to concentrate the search near the center of the binocular field, or directly out the front window. The results further suggested that if no target is detected, a pilot scans the outer edges of the window structure first because crossing traffic generally presents the greatest potential threat; this scan is followed by a search below the nose. The pilot tends to scan in a relatively small area, which is one reason that other aircraft remain undetected. Because of the limitations of central vision, it is important to search all sectors, especially those around the edges of the cockpit. Aircraft maneuver in three dimensions, so visual scanning above and below the horizon is also important.

Effective Scanning Based on Sectors

To achieve the most effective coverage, the NAMRL study recommended that scanning be done by horizontal and vertical sectors. Horizontal sectors should be 90-degree segments of the horizon. Depending on the aircraft, these segments may be more easily defined along the lines of the aircraft structure, such as a wing line.

Vertical scanning should extend from 45 degrees above the horizon to the lower limit of wing-level cockpit visibility. The pilot should begin by scanning forward above the horizon and move aft. Then, scanning should continue below the horizon, moving forward. Although most civilian aircraft are not equipped with bubble canopies, it should still be possible to scan at least 45 degrees high off the nose and to the side of the aircraft. Depending on the type of aircraft, scanning the extreme upper and lower sectors may require a slight bank to look around the wing.

Enhancing Visual Skills

While scanning techniques and suggestions were designed to compensate for visual limitations, there are also ways to enhance overall visual skills. An analysis was conducted at the U.S. Air Force Aerospace Medical Research Laboratory (AMRL) to determine the effects of the pilot's visual environment on the accuracy of accommodation to a distant target. The AMRL defines accommodation as adaptation in the lens of an eye to permit retinal focus on images of objects at different distances. The results of these studies provide clues as to how visual acquisition skills can be developed.

As researchers discovered, pilots of high-performance aircraft are frequently unaware of how the cockpit environment can be "visually hostile." Dirty, scratched, or fogged windscreens are annoyances with which pilots must routinely contend. Windows should be cleaned before every flight because seemingly benign marks on the window can affect dramatically the pilot's ability to suppress saccadic eye movement, which prevents the eyes from focusing on a distant object.

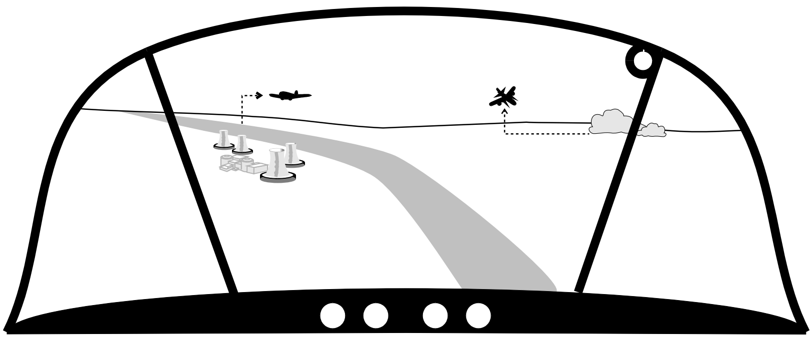
Pilots have failed to notice aircraft on collision courses because they assumed "that little black smudge on the window" was nothing more than a bug splatter. Perhaps the most insidious visual obstructions in the cockpit are those created by the curved, laminated transparencies in the windscreen itself. The symbology associated with a heads-up display can further impair the search area. As a result, a pilot may experience glare, reflections, haze, and optical distortion. These factors can hinder a pilot's ability to perceive a target by reducing the level of contrast or by producing overlapping and "phantom" (illusory) targets.

Despite these obstacles, researchers discovered that test subjects were able to look through such structured surfaces and detect distant targets. After several trials, half of the observers seemed to be able to ignore conflicting peripheral stimuli and concentrate on the target. Researchers believed that the subjects achieved this by simply disregarding nearby obstructions, while concentrating on target acquisition in the far distance. The evidence suggested that ignoring conflicting images (insect marks, scratches, windshield frames) to concentrate on target acquisition is a skill that can be developed.

In a related study, researchers found two observers with the apparent ability to focus and defocus on a target at will. The subjects were slightly younger than the participants in the earlier experiments, and each had a far acuity of 20/15 uncorrected. The target was a dark aircraft silhouette viewed against a white background. With minimal practice and no feedback during the sessions, the observers were able to change their accommodation nearly instantaneously. Each subject claimed to have focused on specific objects at various ranges to scan at that range.[9]

Figure 12-6 depicts a scan pattern in a clear and featureless (except for possible targets) sky. Note that the top of the instrument panel and the window posts can easily reduce the ability to accommodate distant targets. Learning to look through those structures makes it possible to concentrate on collision avoidance in the entire environment. Suggested practical methods for using these techniques include the following:

- Anticipate the target in the location and ranges you are searching.
- Locate a sizable, distant object (e.g., a cloud formation, mountain peak, prominent landmark, building, or pier) that is within the



The eye muscles relax and the eyes become unfocused when staring into empty space. Looking at a distant object (e.g., a cloud) immediately before searching for traffic refocuses the eyes to the range where meaningful targets will be found.

Fig. 12-6. Search technique in clear sky. Shari Stamford Krause, Ph.D.

range of the anticipated target, and focus your eyes on it as you begin each scan pattern.

- Refocus frequently on a distant point as you begin each new scan.
- Allow three to five seconds for your saccadic eye movement to suppress before shifting your search to the block of airspace around the object.
- Vary distances to ensure a thorough scan and to reduce visual fatigue.

These focusing techniques offer a significantly more effective visual-detection plan than simply seeing and then avoiding an aircraft whose course represents a threat. Using search-and-detect techniques, the pilot takes a more active role in collision avoidance, and the reward will be a greater margin of safety.

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Part IV Case Studies

Case Study IV-1: A Cessna 340 and a North American T-6

Safety issues: See-and-avoid, role of ATC

On 1 May 1987, a twin-engine Cessna 340 collided with a single-engine North American SNJ-4 (T-6) approximately 12 miles northwest of Orlando, Florida, International Airport.

Probable Cause

The NTSB determined that the probable cause of this accident was the failure of the Orlando-West controller to coordinate the handoff of traffic to the Orlando-North controller and the failure of the north controller to maintain radar-target identification. Contributing to this accident was the limitation of the see-and-avoid principle to serve as a means of collision avoidance in the circumstances of this mid-air collision.

Pilot Experience

The Cessna 340 pilot had 2,335 total flight hours, 344 in the 340. The T-6 pilot had 7,118 total flight hours, 296 in the T-6.

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Weather

The reported weather at the time of the collision was clear skies with a visibility of 7 miles.

The Flight of the Cessna 340

The Cessna pilot and his family were about to complete a cross-country that had originated in Iowa earlier that same day. At 1538 Eastern Daylight Time, the pilot contacted Orlando approach control north sector and reported he was level at 5,000 feet. The aircraft had an operating Mode-C transponder. Moments later he was cleared to "…descend and maintain three thousand." At 1545 the flight was handed off to the final controller, and the pilot reported "…with you three thousand." The controller than advised the Cessna pilot to "…present heading…maintain three thousand…straight into one eight right." The call was acknowledged, which was the last transmission of the Cessna pilot. The flight had been in the Orlando area only eight minutes before the collision with the T-6.

The Flight of the T-6

Earlier that afternoon, the pilot of the T-6 departed Orlando Executive Airport, approximately 7 miles north of Orlando International, for a skywriting flight over Disney World and Sea World. Although the aircraft had a transponder, it did not have Mode-C capability. At 1542, the pilot contacted the Orlando-West controller and requested, "…like to descend [from 10,500] out to the west…back into Exec." The controller then cleared him to "…descend and maintain six thousand…two seven zero heading." As the pilot descended through 7,700 feet the controller vectored him to 340 degrees for traffic separation.

The west controller attempted to coordinate a lower altitude for the T-6 by calling the north controller, who was busy talking to another aircraft. The west controller eventually got through to the final controller, who gave the approval for the T-6 to descend to 2,500 feet. The T-6's traffic was a Boeing 727 arriving from the northwest and landing at Orlando International. The T-6 pilot responded, "…has the traffic…" as the 727 passed on his right side going in the opposite direction.

Seconds later, the west controller advised the pilot to "…maintain visual separation…seven twenty-seven…direct to the VOR. Continue descent…to four thousand…contact approach.…" The T-6 pilot then contacted the north controller and reported, "…with you six thousand."

He was cleared to "…descend…one thousand five hundred." The transmission was acknowledged, followed by, "…proceed to the airport anytime." AT 1547 the T-6 pilot "rogered" the last clearance, and seconds later collided with the Cessna.

Impact and Wreckage Path

Both airplanes fell into the same mobile home about 7 miles northwest of Orlando Executive Airport. The majority of the wreckage was scattered over an area about 125 feet long by about 50 feet wide. All the major components from both aircraft were located within these boundaries, including may sizable pieces that were found inside the residence.

There was a 3-foot-long crater where the radial engine and forward fuselage of the T-6 had come to rest. One of the T-6's propeller blades had eight uniform gouge marks that matched the physical dimensions of the 340's right engine magneto drive gear.

ACCIDENT SURVIVABILITY

This mid-air collision was not survivable.

The Accident

Figure IV-A illustrates three views of the angle of impact. The mid-air collision occurred at 3,000 feet as the C-340 was southeastbound in level flight, and while the T-6, after just completing a right turn with a bank angle of 45

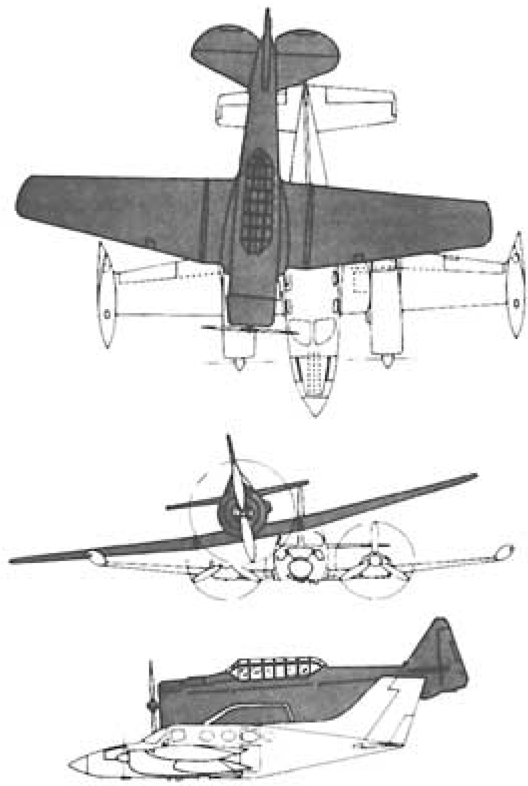

Fig. IV-A. Angle of impact: Mid-air collision of Cessna 340 and North America T-6. Adapted from NTSB.

degrees, was southeastbound descending wings level to 1,500 feet. Allowing for a descent from 6,000 to 3,000 feet, the minimum average rate of descent of the T-6 was 2,000 fpm. The ground speed of each aircraft was approximately 175 knots.

Prior to the T-6 pilot making the right turn, he was flying straight at the Cessna at a distance of a little more than 3 miles and 3,000 feet vertical. At that point, however, he would have been watching the 727 traffic as directed by ATC, and the 340 would have been below his nose. Even during the turn and after the rollout, the 340 would still have remained well below his field of view.

Because of the angle and altitude in which the T-6 was positioned to the 340, the Cessna pilot would have had to lean over and look up as much as 30 degrees in order to catch a glimpse of the T-6. Once the T-6 pilot had made his final turn, there was obviously no chance for the 340 pilot to see him because the T-6 was then directly behind him.

The Investigation

The Safety Board centered their investigation on the role of ATC in a collision-avoidance environment.

ATC PERFORMANCE

Each Orlando airport is assigned a specific letter that is entered in the data tag of individual aircraft. "T" designates Orlando Executive, and "M" represents Orlando International. Provided the final controller assigns an "M," this also means that the aircraft is at or descending to 3,000 feet.

When the west controller was unable to coordinate with the north controller for a lower altitude for the T-6, he subsequently received approval from the final controller for 2,500 feet. Because the west controller noticed the final controller had assigned an "M" tag associated with the 340, and because of the "3,000 feet" rule, he cleared the T-6 down to only 4,000 feet. Although the west controller had never gotten through to the north controller for a coordinated handoff, and because he had since diverted his attention to another aircraft, the west controller, "…assumed that the [north controller] would see the [T-6] in the turn." The west controller described his workload as moderate.

The north controller had been working the 340 for about 20 miles when the T-6 pilot came on his frequency, "…with you six thousand." He remembered seeing the "T" and a "V" (representing VFR) in the data block of the T-6. He then transferred the 340 to the final controller. Moments later the north controller cleared the T-6 down to 1,500 feet, since he believed the aircraft was on a northwesterly heading. The T-6 was actually in a right turn, not on a northwest course. This proved to be a key operational error on the part of the north controller. By this time, the two aircraft were about 2 miles from each other, and the 340 was at the T-6's two-o'clock position. The north controller then noticed the data block of the T-6 go into coast, but since the two aircraft were so close he was not surprised or concerned. He soon cleared the T-6 to proceed to the airport "anytime," based on a primary target he observed tracking northwest in the vicinity of the coasting T-6 data block. When the pilot "rogered" the clearance, the controller diverted his attention to another quadrant in his sector. He also described his workload as moderate.

When the final controller approved the west controller's request to descend the T-6, he stated that he did not see another aircraft to the northwest, nor was the 340 in handoff status to him. The final controller reported that his workload was light.

In the Safety Board's opinion, there were several ATC-related factors that either caused or contributed to this mid-air collision. First, the north controller failed to notice that the T-6 was in a steep bank, passing through a northwest (340 degree) heading. Instead, the controller had misinterpreted the aircraft's position as being on a northwest course. The T-6 was in this turn for two minutes, ample time for the controller to verify its track.

The Safety Board determined that the T-6's data tag began to coast because its antenna, which is on the bottom of the airplane, was shielded from the ARTS (Automated Radar Terminal System) IIIA antenna during the turn just before the collision. In addition, because the two aircraft were so close, the system could not discriminate between each beacon code. Even the 340's data tag was intermittently coasting.

It was later discovered that the coasting data tag the north controller was tracking was not that of the T-6. Because the primary target was heading northwest, and since he thought the T-6 was on a northwest course (not in a turn), he assumed incorrectly. This primary target ranged from 2½ to 5 miles away from the T-6's position. According to the Safety Board, the north controller should have been able to recognize that this was not the T-6.

The data tag of the T-6 was continuously coasting for 46 seconds. Investigators believed that the lack of proper radar identification techniques, a failure to maintain target identification, and an overreliance on automation on the part of controller were causal factors to this mid-air collision.

The Safety Board referred to the FAA Air Traffic Control Handbook that defines certain guidelines and responsibilities for controllers. It states that the controller must use more than one method of identification when the target goes either into coast status or there is doubt as to the proximity or position of targets. The handbook further states that the "...use of ARTS equipment does not relieve the controller of the responsibility of ensuring proper identification, maintenance of the identity, handoff of the correct target associated with the alphanumeric data, and separation of aircraft." Also, the handbook was supplemented by an Orlando International order that directs controllers: "Do not coordinate with another controller when he/she is obviously too busy to handle the distraction."

Lessons Learned and Practical Applications

1. *Say what you really mean.* The T-6 pilot reported to the north controller "...with you at six thousand." What he actually told the controller was that he was level at 6,000 feet. He was not. The T-6 pilot was descending through 6,000 feet. The phraseology should have been, "...passing through six thousand for four thousand."

2. *Don't assume anything.* The west controller assumed the north controller would see the T-6 in the turn, but instead of realizing the aircraft was in a turn, the north controller thought it was on a northwest course. How you perceive a situation doesn't mean that someone else will interpret it the same way.

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Case Study IV-2: A Cessna Citation and a Cessna 172

Safety issues: See-and-avoid, failure to turn on transponder, role of ATC

On 4 April 1998, a Cessna Citation business jet collided with a Cessna 172 over a residential area in Marietta, Georgia.

Probable Cause

The NTSB determined that the probable cause of this accident was the failure of both pilots to see and avoid conflicting traffic, and the failure of the 172 pilot to operate the transponder as required by current regulations. Factors were the controller's failure to observe the traffic conflict, the lack of radar conflict alert capability, and the training emphasis on maximum autopilot usage with the autopilot controller placed at the rear of the cockpit center-mounted pedestal.

History of Flights

The Citation pilot and three passengers departed the Dekalb-Peachtree Airport, Georgia, about 1030 Eastern Standard Time for a flight to Harrisburg, Pennsylvania. The Citation was the pilot's personal aircraft which he used for business purposes.

The pilot of the 172 departed Mathis Airfield, near Cumming, Georgia, about 1025 Eastern Standard Time reportedly to inspect power lines for the Georgia Power Company.

Pilot Experience

According to his last logbook entry a few days before the accident, the pilot of the Citation had 1,824 total flight hours, 86 hours in the Citation. He held a Citation Jet type rating with an airline transport pilot certificate that was issued four months before the accident from a Flight Safety training course.

The pilot's flight instructor since 1994 told investigators that the pilot was highly qualified, competent, and detail oriented. The instructor understood that the pilot had enrolled in the Citation Jet proficiency course which required attendance every three months.

The pilot of the 172 had just less than 14,000 total flight hours and held a commercial pilot certificate and single- and multi-engine flight instructor ratings. According to FAA records, the pilot's certificate was suspended on three occasions. In 1987, his certificate was suspended for 30 days in violation of CFR Part 91.119 regarding minimum safe altitudes. His certificate was suspended in 1990 for 45 days for violation of CFR Part 91.131 regarding an ATC clearance for operations in Class B airspace. And his certificate was suspended for 60 days in 1993 for violation of various sections of CFR Parts 23 and 91 that dealt with miscellaneous markings and placards on the airplane, airman certificate requirements, careless operation, and airworthiness of the airplane.

Weather

Reported visibility in the area was between 7 and 10 miles; scattered clouds or broken clouds between 2,600 and 2,800 feet.

The Accident

The Citation departed Dekalb-Peachtree Airport, Georgia, at about 1030 Eastern Standard Time with an instrument flight plan to Harrisburg, Pennsylvania. After takeoff, the Citation was initially assigned 3,000 feet (msl) and a heading of 280 degrees. Atlanta Terminal Radar Control (TRACON) subsequently cleared the jet from 3,000 to 14,000 feet. The pilot was acknowledging his climb clearance as he was passing through 3,400 feet, when he collided with the 172 at 1034.

The pilot of the 172 had departed Mathis Airfield around 1025 and had just initiated radio contact with Dobbins Air Force Base ATC Tower prior to entering military airspace when the collision occurred. The final transmission to Dobbins tower was, "Good morning, sir,…Cessna one seventy." The controller responded, "Seven whiskey delta you were cut out," but received no further transmissions.

Impact and Wreckage Area

Investigators believed that the nose landing gear of the 172 initially impacted at the outboard leading-edge section of the Citation's left horizontal stabilizer.

The main wreckage site of the Citation fell inverted in the backyard of a private residence in Marietta, Georgia. Pieces of wreckage were scattered over 1½ square miles of a residential area; the horizontal stabilizer, elevators, and the top one-fourth of the vertical stabilizer separated from the airplane and were located about 1 mile from the main wreckage.

Witnesses observed the 172 crashing into trees before coming to rest inverted in the yard of another private residence in the same neighborhood.

Analyses

Recorded radar data from the Atlanta TRACON tracked a primary target (a nonidentifying blip on the radar screen) that began around 1025, approximately 2 miles from the Mathis Airport. Presumably the 172, the target flew to the southwest in a curving path, intersecting the flight path of the Citation.

The Citation jet was tracking north. At the time of impact, the approximate closure rate was at 300 knots with an angular difference between both aircraft of about 52 degrees. According to a cockpit visibility study, the 172 was either behind the Citation's center windscreen post or to the right of the center windscreen post for about the final 35 seconds before impact. Further analyses indicates that the Citation was visible to the 172 pilot, based on a single eye position, in the lower left quadrant of the pilot's windscreen between 35 and 5 seconds before impact.

Under CFR Part 91.215(b), the pilot of the 172 was required to have an operating transponder while flying within 30 nm of the Atlanta-Hartsfield International Airport, Georgia. He never turned on his transponder, which was later confirmed at the crash site. The controllers involved told investigators that they did not observe the primary targets associated with the 172 and, therefore, did not provide advisories to the Citation pilot.

Lessons Learned and Practical Applications

1. *Turn on your transponder!*
2. *Scan around the perimeter of the windscreen.* As discussed in Chap. 12, many targets go undetected near the edges of the windscreen.
3. *Recognize potential distractions inherent to your cockpit.* The location of the autopilot on the Citation forced the pilot to look down and away from his normal flight duties during a critical phase of flight. While setting the autopilot is designed to alleviate such distractions, in this case, the pilot's attention may have been momentarily diverted just prior to impact.

Reference

National Transportation Safety Board. NTSB Identification: ATL98FA060A. Mid-Air Collision, Cessna Citation 525 and Cessna 172, Marietta, Georgia. April 4, 1998.

Case Study IV-3: Aeromexico Flight 498 and a Piper Cherokee

Safety issues: See-and-avoid, airspace intrusion, role of ATC

On 31 August 1986, Flight 498, a McDonnell Douglas DC-9, collided with a single-engine Piper Cherokee over Cerritos, California, in the Greater Los Angeles Basin.

Probable Cause

The NTSB determined that the probable cause of this accident was the limitations of the air traffic control system to provide collision protection. Contributing to the accident was the inadvertent and unauthorized entry of the Piper Cherokee into the Los Angeles Terminal Control Area (TCA) and the limitation of the see-and-avoid concept.

History of Flights

Flight 498 was a regularly scheduled flight between Mexico City, Mexico, and Los Angeles, California, with intermediate stops in Guadalajara, and Tijuana, Mexico. The DC-9 departed Tijuana at 1120 Pacific Daylight Time with 58 passengers and 6 crewmembers on board.

According to the flight plan of the Piper Cherokee, the pilot's proposed route was from Torrence, California, to Big Bear, California. The pilot departed Torrence at 1140 with two passengers on board.

Pilot Experience

The captain of the DC-9 had 10,641 total flight hours, 4,632 in the DC-9. The first officer had 1,463 total flight hours, 1,245 in the DC-9. The pilot of the Piper had 231 total flight hours.

Weather

Clear skies with a visibility of 15 miles.

The Accident

Flight 498 was level at 7,000 feet and setting up for an approach into Los Angeles International Airport, when at 1150 the controller advised the crew that there was "traffic, ten o'clock, 1 mile, northbound, altitude unknown." Although the crew of Flight 498 acknowledged the advisory, they never told the controller whether they had the traffic in sight. In any event, the traffic was not the Cherokee.

At 1151, Flight 498 was cleared to descend to 6,000 feet. Meanwhile, a single-engine Grumman Tiger had made an unauthorized entry into the TCA and the controller was busy vectoring him out of harm's way. Less than a minute later, the controller noticed that Flight 498 had disappeared off his radar, and he proceeded to make several unsuccessful attempts to contact it. At approximately 1152, Flight 498 and the Cherokee collided over the city of Cerritos at about 6,560 feet.

Impact and Wreckage Area

The collision occurred as Flight 498 was descending through 6,560 feet on a northwesterly heading and the Piper was on an eastbound track. Based upon collision damage on the DC-9, it appeared that the Cherokee's engine struck the main support structure of the jet's horizontal stabilizer. Refer to Fig. IV-B. The impact sheared off the top of the Cherokee's cabin, causing the DC-9's horizontal stabilizer to separate from the aircraft. Refer to Fig. IV-C.

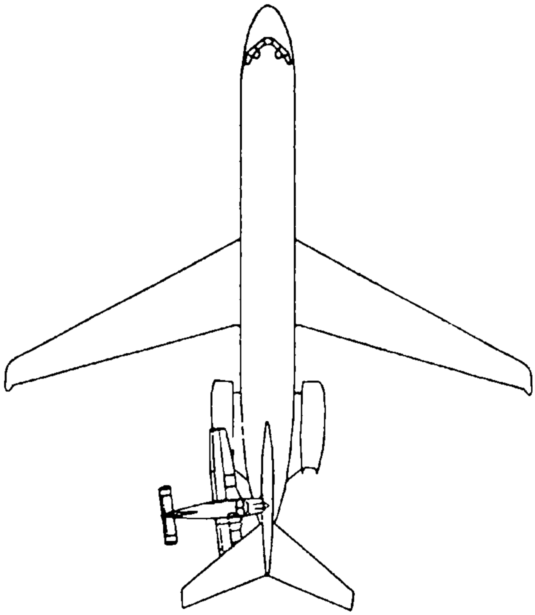


Fig. IV-B. Top view of collision geometry between Flight 498 and Piper Cherokee. Adapted from NTSB.

The best in-flight scenario that can be determined is that the Piper initially appeared 15 to 30 degrees offset to the left of the captain's windshield, and subsequently appeared in the same position through the first officer's windshield. With regard to the Piper pilot, Flight 498 was about 50 degrees to the right of the design eye reference point and, therefore, was visible out the far right-side window. Nevertheless, because the two aircraft were on a collision course, the relative motion of the Piper presumably would have been minimal, making it extremely difficult to detect.

The main wreckage sites of both airplanes were in a residential area and within 1,700 feet of each other. Except for the upper portion of the fuselage, cockpit, engine, and vertical stabilizer, the Piper remained relatively intact after the collision. The major section of wreckage fell in an open schoolyard and did not catch fire after impact.

Most of the DC-9 crashed in an area about 600 feet long by 200 feet wide. The wreckage burned to disintegration. The largest piece that was found came from the lower aft fuselage. Both engines were located near the point of impact and were noted to have been operating at a high power.

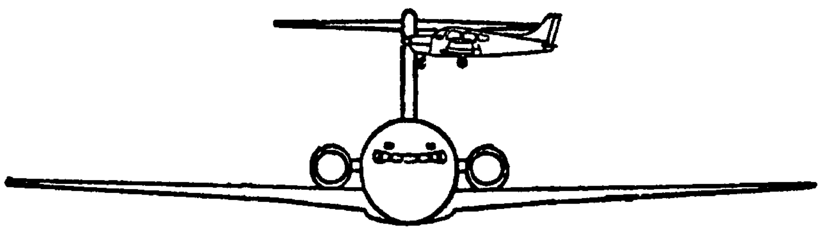


Fig. IV-C. Front view of collision geometry between Flight 498 and Piper Cherokee. Adapted from NTSB.

ACCIDENT SURVIVABILITY

This mid-air collision was not survivable.

The Investigation

The Safety Board quickly determined that the pilot of the Cherokee entered into the Los Angeles TCA without ATC clearance. There was no evidence that suggested the pilot had suffered a physiological disability or that he was unfamiliar with the TCA boundaries.

The recorded ground track of the airplane showed the pilot had proceeded almost directly to the collision point after he took off from Torrence. Based on a few simple calculations, the Safety Board determined that this average rate of climb was about 550 fpm. The aircraft maintained an almost constant heading and ground speed, as if its progress was being closely monitored and managed.

The pilot had been described as methodical in his approach to flying and had asked for advice concerning the TCA before the flight. An opened Los Angeles terminal area chart was found in the cockpit. From all accounts, the Board believed it was unlikely that he would have deliberately flown into the TCA.

RADAR RETRACK PROGRAM

Investigators sought to determine if the Piper had appeared on the controller's radar display. The recorded radar data showed that beacon returns for both airplanes were processed by the ARTS III air traffic control computer. When that data was entered into the retrack program, several "1200" VFR-coded targets, including that belonging to the Piper, were visible on the controller's display screen.

ATC PERFORMANCE

The Safety Board believed that two required ATC procedures might have influenced the controller's monitoring of traffic that day. According to the Controller's Handbook, first priority must be traffic separation service involving IFR to IFR airplanes. ATC will provide VFR traffic advisories only if a collision is imminent or "work permitting." The Handbook also specifies that an aircraft conflict-alert advisory is limited to those airplanes when the controller "is aware of another aircraft at an altitude which you believe places them in unsafe proximity." The Piper did not provide Mode-C information and therefore was not prioritized. As a result, the Safety Board concluded that the ATC procedures were causal to the accident in that they "set the stage for the controller to overlook or not see the Piper's target on his display."

Investigators noted that the controller's radio conversations with the various aircraft that he was working strongly suggested that his attention was directed toward the area east of Los Angeles International. At 1150, he advised Flight 498 of traffic at "ten o'clock" and then watched it pass behind the jet. He testified that after he observed that traffic clear, he "saw no traffic along its projected route of flight that would be a factor."

The Safety Board believed that a change in runways for Flight 498, coupled with the sudden appearance of another general aviation aircraft, caused the controller to direct his attention to one area of the screen. Since he had no expectation of additional traffic, the Safety Board concluded that this might have been why he did not see the Piper's target.

SEE-AND-AVOID

Based on cockpit visibility studies, the Safety Board determined that both airplanes were within the pilots' fields of vision for at least 1 minute and 13 seconds. However, there were several limiting factors that would have deteriorated the see-and-avoid environment. Theoretically, the Piper pilot should have been able to see the much larger DC-9 before the Aeromexico pilots saw him. But that was not the reality of the situation. The DC-9 was visible through the Piper pilot's right windscreen and near the outer portion of a side-to-side scanning pattern. The Piper was approaching the jet from the passenger side with less than a 30-degree offset to the left. The DC-9 would have subtended to 0.2 degree (12 minutes) of arc when it was about 6 nm away or 1 minute and 23 seconds before the collision. Although some eagle-eye pilots are able to pick up traffic several miles away, the probability of this being the norm is low. In this case, the DC-9 appeared near the edge of the Cherokee pilot's scanning range and had passed through the optimum visual detection area at 6 nm.

On the other hand, the Piper was visible through the center windshield of the DC-9 but in monocular view of the first officer. It appeared in the same location for the captain but had shifted within his normal binocular vision field. The Cherokee would have subtended a visual angle of 0.2 degree (12 minutes) of arc when it was a little more than 1 nm, or 15 seconds, before the collision. Remember the 12.5 second recognition and reaction rule. The Aeromexico crew most likely failed to see the Piper due to its small size and its minimal relative motion to the jet.

Lessons Learned and Practical Applications

1. *Always contact ATC when operating near airspace boundaries.* A simple radio communication is all it takes to notify ATC of your position. In this case, it would have prevented this accident.
2. *Maintain situational awareness.* This is especially true in busy traffic areas and near airspace boundaries. Be extremely diligent in monitoring your flight path if you're planning to stay out of controlled airspace. Pay particular attention to the activity on the radio. This will help you in determining the location of potentially threatening aircraft.
3. *Maintain scanning vigilance.* Never let down your guard. Remember to always use effective scanning techniques.

Reference

National Transportation Safety Board. 7 July 1987. Aircraft Accident Report: Collision of Aeronaves de Mexico, S.A., McDonnell Douglas DC-9-32, XA-JED, and a Piper PA-28-131, N4891F, Cerritos, California, August 31, 1986.

Case Study IV-4: A U.S. Army U-21 and a Piper Navajo

Safety issues: See-and-avoid, role of ATC

On 20 January 1987, a U-21 turboprop and a twin-engine Navajo collided near Independence, Missouri.

Probable Cause

The Safety Board determined that the probable cause of this accident was the failure of the radar controllers to detect the conflict and issue traffic advisories or a safety alert to the flight crew of the U-21. The deficiencies of the see-and-avoid concept as a primary means of collision avoidance were also causal factors.

Pilot Experience

The Navajo pilot had 7,418 total flight hours, 4,751 in multi-engine aircraft. His company records indicated that he had more than 596 hours in the Navajo, with 586 as pilot-in-command.

The U-21 pilot had 5,983 total flight hours, 217 in the U-21. The U-21 copilot had 6,266 hours, 1,528 in the U-21.

Weather

Reported weather at the time of the collision was: Ceiling 25,000 feet thin scattered; visibility 20 miles; wind 230 degrees at 11 knots; temperature/dewpoint 26°F/11°F.

The Flight of N60SE

At 1221 Central Standard Time, the Navajo, with a pilot and two passengers on board, departed the Kansas City Downtown Airport en route to their home base of St. Louis. The aircraft had an operating Mode-C transponder, which was squawking the 1200 VFR code. The pilot advised the local controller that he would make a left turn to the east after departure. The pilot's acknowledgment of the controller's approval of the left turn was the last known radio transmission from the Navajo.

The flight track of N60SE was reconstructed from Kansas City International Airport TRACON and Kansas City Center recorded secondary radar data from transponders. According to this evidence, the Navajo turned to an easterly heading after departing Kansas City, but remained beneath the 5,000 foot base of the TCA. Its Mode-C target was detected by the TRACON at 1222:48 when the airplane was still near the Downtown Airport at 1,600 feet. The target was tracked eastbound at a constant rate of climb to 7,000 feet until the radar return was lost at 1227:48.

The Flight of Army 18061

At 0944, the U-21 departed Calhoun Country Airport, Anniston, Alabama, en route to Sherman Army Airfield, Fort Leavenworth, Kansas, with two pilots and one passenger on board. The aircraft was equipped with an operating Mode-C transponder. The crew had filed an IFR flight plan and flew at a cruise altitude of 8,000 feet.

Around 1221, the army pilots were handed-off from Kansas City Center to the Kansas City TRACON east-radar controller. The crew was advised to expect a visual approach and was given the weather as "…sky clear, visibility 10, wind from 260 at 7 knots.…" AT 1225, Army 18061 was notified of a traffic advisory, "…twin Cessna…southwest bound." Seconds later the crew reported, "Traffic in sight." Radar contact with the flight was lost at about 1228.

Examination of the radar data confirmed that the traffic advisory to Army 18061 did not pertain to the Navajo and the U-21 was well clear of the reported traffic when the two aircraft collided. The data further proved that the crew did not alter their aircraft's heading after the last clearance, and the airplane maintained 7,000 feet until radar contact was lost.

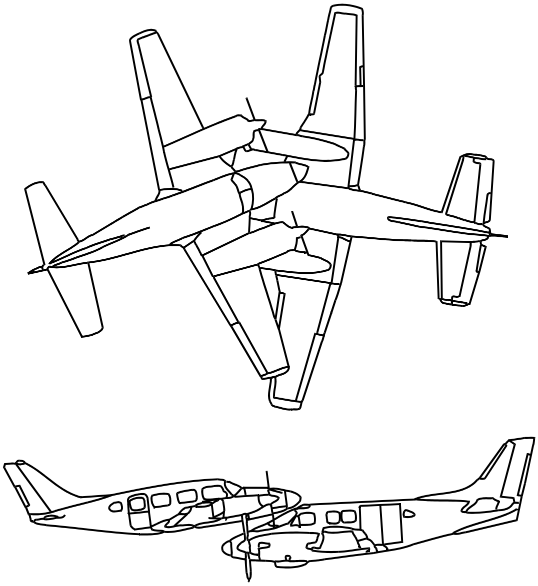
The Investigation

The Safety Board analyzed ATC and flight crew performance with regards to this accident based on the angle of impact between the U-21 and the Navajo (Fig. IV-D).

ATC PERFORMANCE

At the time of the accident, the east-radar position at the Kansas City TRACON was staffed by an area supervisor and a developmental ATC specialist. The supervisor had been monitoring Army 18061 for only seven minutes, but had provided a traffic advisory to the crew regarding the twin Cessna. The developmental controller had just sat down at the position, and so had viewed the radar screen for only a minute before the accident. Both controllers later reported not seeing any primary or secondary radar information pertaining to the Navajo.

The day after the accident, a flight inspection of the radar system and associated TRACON radio frequencies was conducted by the FAA. No discrepancies were found. The Board requested the TRACON radar data in order to study the information on their Retrack Program Computer. Although it cannot replicate the entire radar portrayal, it duplicates the alphanumerics generated by the ARTS III program and its associated logic.



Top and horizontal views of the aircraft at impact

Fig. IV-D. Angle of impact: Mid-air collision of U.S. Army U-21 and Piper Navajo. Adapted from NTSB.

An aircraft operating under an IFR flight plan is tracked on the radarscope by a full data block (FDB). A FDB includes aircraft location, identification, altitude, ground speed, and flight plan data. A limited data block (LDB) appears on the scope to represent an untracked VFR target. The aircraft's transponder code and altitude, if Mode-C is operating, readout are the only data available to the controller.

The FDB of Army 18061 appeared on the scope at 1221:40 and remained on the display until the collision. Likewise, the LDB of N60SE came into view about 1222:45 and also remained on the scope until the mid-air collision. On the last presentation that showed both airplanes, the position tracking symbols were nearly overlapped and at the same altitude.

ARTS III SAFETY FEATURES

The ARTS III has an automatic offset feature designed for these particular situations. To eliminate the possibility of data block information being unidentifiable, the computer will shift [offset] each block that is in danger of overlapping. According to the retrack presentation, the FDB of Army 18061 and the LDB of N60SE shifted the appropriate distances, which should have given the controllers an unobscured view of the data blocks.

Controllers using this system cannot suppress 1200 (VFR) transponder codes. They are depicted automatically on the radarscope with a computer-generated triangle over the primary and secondary targets for non-Mode-C targets. Mode-C transponder targets are shown by a computer-generated square over the primary and secondary targets. The system also displays the altitude in a three-digit code attached to the square by a ¼-inch leader line.

CONFLICT ALERT

Aural and visual alerts associated with the conflict-alert system are based on projected positional and velocity data for tracked Mode-C targets. A controller would not be alerted by the system if either of the involved aircraft was not tracked, even if it was equipped with an operating Mode-C transponder. Communication with a controller, or even operating a Mode-C transponder during a VFR flight, would provide collision-avoidance protection to the pilot. However, a pilot receiving VFR flight-following services would result in the radar controller tagging the target and automatically initiating the track needed by the conflict-alert system.

During this investigation, the Safety Board chose to evaluate the usefulness of the conflict-alert system with regards to potential collisions between tracked and untracked Mode-C radar targets. The Safety Board manually tagged the LDB associated with N60SE, which automatically changed it to an FDB-tracked target. This simulated FDB remained on the radarscope until it merged with Army 18061's FDB, and ultimately vanished at the moment of collision.

The Safety Board also noted that the conflict alert visual and aural alarms activated more than 40 seconds before the actual collision, and continued until the radar targets disappeared. This would have been ample time for a controller to issue a traffic or safety advisory.

COCKPIT VISIBILITY STUDY

A cockpit visibility study was conducted to determine the location of each airplane with respect to the field of vision of the pilot(s) in the other airplane. A binocular camera was used to photograph the cockpits of two airplanes with structurally identical cockpit visibility to the accident airplanes. The camera rotated about a vertical axis that is normally 3.5 inches from the lenses, approximating the distance between the front of the eye and the pivot point about which the head rotates. As a result, photographs showed the outline of the cockpit windows as seen by a crewmember rotating his head from side to side. Monocular obstructions within the window, such as the windshield or door posts, were also defined by the photographs.

Results of the study showed that the Navajo was visible through the windshields of both U-21 pilots. The aircraft would have appeared 13 degrees left and 2 degrees below the U-21 pilot eye reference points. Since the army aircraft was in level flight, the eye reference point was the horizon. Neither pilot's view would have been obstructed by the windshield, door posts, windshield wipers, or any other airplane equipment.

The U-21 would have appeared 18 degrees to the right and 3 degrees below the Navajo pilot eye reference point. Because the center windshield post of the Navajo partially obstructed the pilot's view of the U-21, his view would have been restricted temporarily to only his left eye. The copilot's view, however, was never obstructed.

THE PROBABILITY OF VISUAL DETECTION

An air-to-air visual acquisition study had been conducted previously by Lincoln Laboratory at the Massachusetts Institute of Technology. Because the circumstances surrounding the U-21 and the Navajo flights closely coincided with the model produced from this study, the Safety Board used the analyses to determine the probability of visual acquisition between the army and Navajo pilots shortly before the collision. The data given were: the speeds of both airplanes, headings, the area profile at the presentation angle, the number of pilots in each airplane engaged in the traffic search, and the visual range. The outcome indicated that the probability of target acquisition would not have been high until the last few seconds before the collision. It was determined that the Navajo pilot had only a 27 percent chance of seeing the U-21 at 12 seconds before impact. Similarly, the army pilots had only a 33 percent probability of seeing the Navajo at 12 seconds before the collision. These results, however, assumed a relatively low pilot workload and unobstructed view of the opposing aircraft. If any of the three pilots had become distracted with cockpit duties, or there were obstructions to a clear view of the other airplane, which the Navajo pilot experienced, these probabilities would have been much less.

The Safety Board's Conclusion

According to the Board, this mid-air collision could have been prevented if the Navajo pilot had requested flight-following services. He would have been assigned a discrete transponder code, giving him tracked status. If he had done so, the conflict-alert feature of the ARTS III system would have alerted the controllers of the potential conflict 40 seconds before impact. An aural alarm would have been activated and the two data blocks would have flashed.

The Safety Board believed that it was most likely that the east-radar controllers were distracted from monitoring traffic in the moments before the collision because of their position-relief briefing and associated duties. Their workload was considered light, which also might have contributed to a reduced state of vigilance on the part of both controllers. The Board believed that if the Navajo had also been tracked, the warning systems would have alerted the controllers in plenty of time to avert the accident.

Lessons Learned and Practical Applications

1. *Contact ATC when flying in a radar-controlled environment.* Because the Navajo pilot was not in communication with Kansas City TRACON, there was no opportunity for ATC to provide traffic advisories to him.
2. *When VFR, ask for flight-following services.* Even when you're operating a Mode-C transponder, the controller sees only a 1200 VFR code that could be just one of many, particularly on a busy day. Report in and ask for a discrete transponder code. Because you are VFR, ATC will provide traffic advisories only "work permitting," but at least they are aware of your presence and call sign.
3. *Don't assume anything.* The Safety Board suggested that since ATC had already notified the army pilots of traffic, and because there were very few radio calls, it seemed obvious the controllers were not busy, the U-21 pilots might have assumed that they would be alerted of any additional traffic.

Reference

National Transportation Safety Board. 3 February 1988. Aircraft Accident Report: Midair Collision of U.S. Army U-21A, Army 18061, and Sachs Electric Company Piper PA-31-350, N60SE. Independence, Missouri. January 20, 1987.

Case Study IV-5: A Mitsubishi MU-2 and a Piper Saratoga

Safety issues: See-and-avoid, distraction, uncontrolled airport traffic patterns, cockpit discipline, role of ATC

On 11 September 1992, a Mitsubishi MU-2 turboprop collided with a single-engine Piper Saratoga (PA-32) approximately 2 miles northeast of the Greenwood Municipal Airport, Indiana.

Probable Cause

The NTSB determined that the probable cause of this accident was the inherent limitations of the see-and-avoid concept for separation of aircraft operating under VFR. These factors precluded the pilots of both aircraft from recognizing a collision hazard and taking actions to avoid the mid-air collision. Contributing factors to the cause of the accident included the failure of the MU-2 pilot to use all the available ATC services by not activating his IFR flight plan before takeoff; and the failure of both pilots to follow recommended traffic pattern procedures, as detailed in the AIM, for airport arrivals and departures.

Pilot Experience

The Mitsubishi pilot had 19,743 total hours and was also an MU-2 check pilot with 9,000 hours in the airplane. The Piper pilot had a minimum of 1,224 hours, 150 in the Saratoga. The passenger in the right seat of the Piper was a pilot with 412 hours.

Weather

The reported weather at the time of the mid-air collision was: Ceiling 4,500 feet scattered, 25,000 feet scattered; visibility 15 miles; temperature 70°F; dewpoint 49°F; winds 20 degrees at 10 knots.

The Flight of the Saratoga

After taking off from the Eagle Creek Airport, outside Indianapolis, Indiana, the Piper pilot and his two passengers flew a short distance to Terry Airport. While there, the pilot spoke with a mechanic concerning the annual inspection that had been performed on the airplane, and by

1445 he and his passengers had departed Terry for Greenwood Airport, another airfield in the local area. The purpose of this leg was to take aerial photographs of the pilot's new office building.

Although the aircraft was operating under VFR, the most direct route between Terry Airport and Greenwood Airport was through the Indianapolis ARSA (Airport Radar Service Area), requiring the pilot to be in contact with ATC. At 1445:17, the pilot advised the Indianapolis Departure West/Satellite controller that he had departed Terry and was en route to Greenwood. The controller issued the pilot a discrete beacon code, radar identified the airplane, and instructed the pilot to climb and maintain 2,500 feet. Nearly six minutes later, the controller handed off the Saratoga to the Indianapolis Departure East/Satellite (DRE/Satellite) controller. Seconds later the pilot reported, "…with you at two point five [2,500 feet] going to Greenwood [Airport]." The controller replied, "…maintain VFR, I'll have on course for you in about 5 miles." The pilot acknowledged the transmission. Approximately two minutes later the controller radioed, "…proceed on course to Greenwood, advise the airport in sight." That call was answered by the pilot. At 1455:51, the controller notified the Saratoga, "…airport twelve to one o'clock…three miles." The pilot replied, "…we have the airport." The controller immediately responded with, "…squawk VFR, radar service terminated, frequency change approved." At 1456:03, the pilot made his final radio call and thanked the controller.

The Flight of the MU-2

On the morning of the accident, the pilot of the MU-2 departed from his home base at the Huntingburg, Indiana, Airport bound for the Greenwood Municipal Airport. The aircraft was owned and operated by a coal-mining company, and the purpose of the trip was to pick up four passengers at Greenwood and fly them to Columbus, Ohio.

The pilot had filed two IFR flight plans that day with the Terre Haute, Indiana, FSS. One was for the 30-minute flight from Huntingburg to Greenwood. The other was for the flight to Columbus, with a scheduled departure time of 1400. His passengers did not arrive at the airport until shortly after 1430. At 1456:41, the pilot contacted the DRE/Satellite controller to notify him that he was, "…off the ground

Greenwood [Airport] standing by for [IFR] clearance to Columbus [Airport]." Seconds later, the controller gave him a discrete beacon code and told him to, "…maintain at or below five thousand." There was no further communication with the pilot.

The Accident

According to witnesses, it was a typical day at the Greenwood Airport with little traffic. They observed the Saratoga flying southbound, while the MU-2 was climbing and turning toward the east. At approximately 1457, at an altitude of 2,100 feet, the two aircraft collided. As Fig. IV-E illustrates, the pilot of the Saratoga turned the airplane to the left seconds before it flew into the turboprop's empennage, shearing it away from the fuselage. Although the cockpit and cabin sections of the MU-2 remained intact, the airplane was uncontrollable and crashed in a residential area. Remarkably, the Saratoga did not break up in flight and the pilot-passenger was able to make a controlled landing before the airplane struck ground obstacles, including three houses.

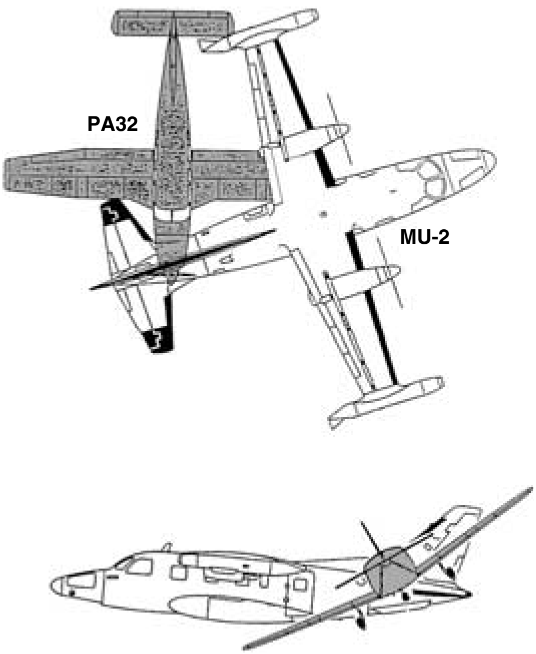


Fig. IV-E. Top and side view of collision points between MU-2 and PA-32. Adapted from NTSB.

ACCIDENT SURVIVABILITY

Because of the catastrophic damage caused by impact, the MU-2 was rendered uncontrollable. The pilot and four passengers on board received fatal injuries. The Saratoga, however, was still intact and flyable after the collision. For unknown reasons, the pilot of the Saratoga became incapacitated shortly after the mid-air collision, and later died. The pilot-passenger and the passenger in the rear seat escaped the postcrash fire with serious injuries.

The Investigation

The collision closure rate of the two airplanes was 234 knots. Radar data showed the Saratoga was on a track of 174 degrees, at a ground speed of 127 knots, with a rate of descent of 390 fpm. The MU-2 was on a course of 070 degrees, at a ground speed of 168 knots, and climbing at approximately 1,200 fpm. The collision angle at impact was close to 90 degrees because the Saratoga pilot made a 45-degree steep bank to the left seconds before contact.

COCKPIT VISIBILITY STUDY

According to the Safety Board's analysis of the cockpit visibility study, both pilots, *theoretically,* had enough time to see and avoid each other. From the tragic outcome, however, theory and reality can be quite different. Therefore, the Board determined that the inherent limitations of the see-and-avoid concept precluded these pilots from recognizing and reacting to a collision threat.

The study showed that the Saratoga might have been visible to the MU-2 pilot for 20.5 seconds—including the 12.5 second rule—prior to impact. Assuming the MU-2 pilot was sitting stationary at the design eye reference point, the Saratoga could have appeared unobstructed in the lower left corner of his left windshield for four seconds. Refer to Fig. IV-F. The Saratoga would then have shifted slightly, enough to be partially blocked by the MU-2 pilot's left windshield post. However, if the pilot had moved forward to adjust his radios or flight controls, or to scan outside, the Board suggested that he might have been able to see the Saratoga with both eyes.

The study also revealed that the MU-2 might have been in view of the Saratoga pilot for 25.5 seconds—including the 12.5 second rule—prior to impact. For about 13 seconds the MU-2 should have been positioned in the right windshield of the Saratoga. Refer to Fig. IV-G. However, due to the obstruction from the center windshield post, this view would have provided the pilot and pilot-passenger only a monocular field of vision.

UNCONTROLLED AIRPORT TRAFFIC PATTERNS

The Safety Board noted during its investigation that there is little regulation or guidance relating to arrival and departure procedures at uncontrolled airports. Since both pilots were operating under VFR, and in the vicinity of an airport, they were required to comply with

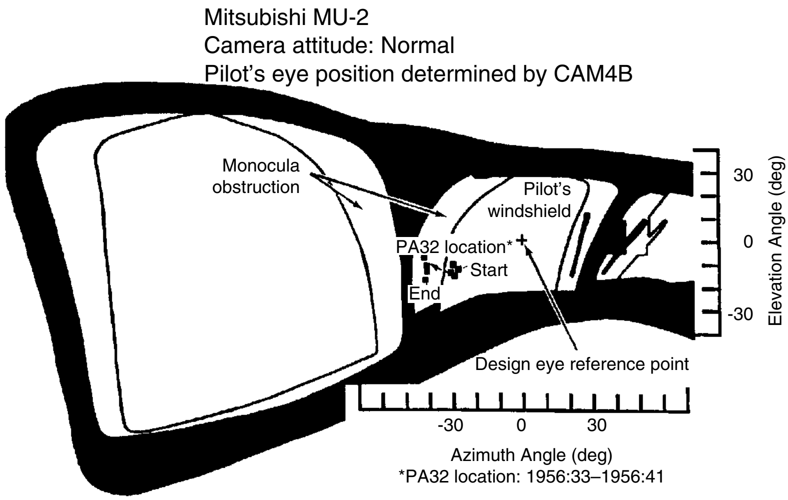


Fig. IV-F. Cockpit field of vision for MU-2 pilot. Adapted from NTSB.

FAR Part 91.127. In part, it states that: "Each person operating an aircraft to or from an airport without an operating control tower shall: (1) In the case of an airplane approaching to land, make all turns to the left, and (2) In the case of an aircraft departing the airport, comply with any traffic patterns established for that airport in Part 93."

At the time of the accident, Greenwood Municipal Airport did not have a traffic pattern established in FAR Part 93; therefore, there were no *regulatory* departure procedures. Instead, there were only *recommended* procedures published in AC 90-66 and Paragraph 4-54 of the AIM. The AC suggested a 1,000 foot agl traffic pattern, whereas, the AIM described the procedure in vague terms, including a reference to general aviation traffic patterns that can extend from 600 to 1,500 feet agl. The AIM further noted two possible departure procedures—maintain runway heading, or make a 45 degree left turn after reaching traffic pattern altitude.

Because of these discrepancies concerning uncontrolled airport traffic patterns, it was no surprise that the Board received four different answers from four local Greenwood pilots during interviews conducted as part of the investigation. Although the Airport/Facility Directory listed Greenwood Municipal as having a traffic pattern altitude of 800 feet, only one of the four pilots gave the correct answer.

Two chose 1,000 feet and the other thought it was 2,000 feet. When questioned on arrival and departure procedures at Greenwood, the four pilots came up with four different procedures, none of which resembled the recommended procedures outlined in the AIM.

According to the MU-2 backup pilot, who was one of the four local pilots interviewed, the pilot of the MU-2 had developed his own arrival and departure procedures at Greenwood. Departing on runway 36, as he did on the day of the accident, he would climb straight out 500 to 700 feet and then initiate a right turn. Since the airport is located only 2 miles from the southeast boundary of the Indianapolis ARSA, and because the MU-2 is a high-performance turboprop, the pilot devised that particular procedure to prevent an inadvertent penetration into the ARSA, and allow for a comfortable ride for his passengers.

IN-FLIGHT IFR CLEARANCE PROCEDURES

Although the weather conditions and the MU-2 pilot's altitude request (15,000 feet) did not require an IFR flight plan, the Safety Board believed his purpose in filing one was to aid in traffic separation and to prevent inadvertent entry into the ARSA. The pilot filed the flight plan for a 1400 departure time.

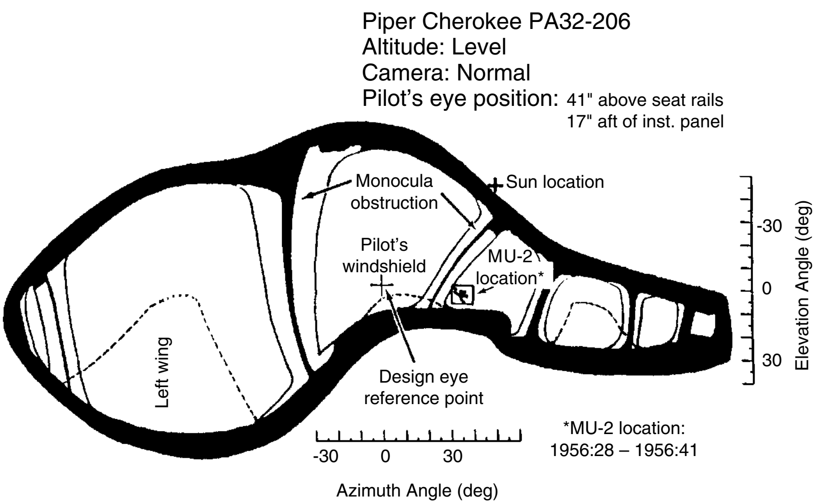


Fig. IV-G. Cockpit field of vision for PA-32 pilot. Adapted from NTSB.

According to the AIM, most centers will delete a flight plan if it has not been activated after one hour of the proposed departure time. Therefore, to ensure that a flight plan remains active, pilots should notify ATC if they encounter any delays. Otherwise, the AIM noted that due to traffic saturation, control facilities will often be unable to accept revisions to a flight plan over the radio. Revisions must then be completed by contacting the nearest FSS.

The MU-2 pilot intended to depart Greenwood at 1400 but was delayed until 1456; this suggests that he hurried to get off the ground before 1500. The Safety Board believed that because the pilot received his IFR clearance in the air, that extra responsibility increased his cockpit workload to the point of possible distraction. It also delayed the controller's ability to identify the airplane by radar before the collision. Therefore, the Safety Board concluded that the pilot should have activated his IFR flight plan before takeoff so the controller could have provided him with traffic advisories. Because the pilot failed to take full advantage of the ATC services available to him, the Board determined that this contributed to the factors that led to the accident.

PILOT WORKLOAD

In the one minute that had elapsed from the time the MU-2 pilot lifted off the ground to the point of impact, he would have performed numerous duties. These duties included: after-takeoff checklist, making radio calls to unicom and to departure control, raising the landing gear and flaps, adjusting the transponder, monitoring the engines and propellers, and flying the airplane. The Safety Board believed that in addition to those standard duties, the pilot also had concerns about inadvertently flying into the ARSA, obtaining an IFR clearance, and providing passenger comfort.

All of those physical and mental demands, jammed into one minute of flying time, produced a very high workload environment. Consequently, the Safety Board believed the pilot had a minimal amount of time available to scan for threat aircraft.

OPERATIONS NEAR AN AIRPORT

The Saratoga pilot intended to fly near his new office, so his passengers could take aerial photographs. This property was located only 3 miles from the airport, and within 1 mile of the collision point. The Safety Board believed that it was likely the pilot was looking down to facilitate the photography, thereby limiting his ability to scan for other aircraft. Likewise, the attention of both passengers might have also been distracted toward the ground.

According to the AIM, pilots flying in the vicinity of an airport should monitor and communicate on the appropriate frequency within 10 miles of that airport. The pilot and pilot-passenger were wearing headsets at the time of collision; therefore, the Board believed that they could have monitored both the Indianapolis ARSA and the Greenwood unicom. However, the Board's report did not indicate this was asked of the surviving passengers in the Saratoga.

The Safety Board further commented on the role of the radar controller. He terminated radar services and approved a frequency change for the Saratoga pilot about 3 miles from the airport. In part, the FAA Air Traffic Controller Handbook states: "Terminate ARSA service to aircraft landing at other than the primary airport at a sufficient distance from the airport to allow the pilot to change to the appropriate frequency for traffic and airport information." Since the AIM recommends pilots initiate unicom communication approximately 10 miles from the airport, the Board noted that the radar controller concluded his services too late.

THE SEE-AND-AVOID CONCEPT

The Safety Board determined that the inherent limitations of the see-and-avoid concept, especially when pilots are operating under VFR and near high density traffic areas, were directly causal to this mid-air collision. As the results of the investigation proved, both pilots had an extremely short amount of time to detect the threat and to take evasive actions against it. Although the Safety Board questioned the decisions of the MU-2 pilot to airfile his IFR flight plan, and to make a VFR right turn during departure, they concluded that the deficiencies of the see-and-avoid concept were paramount to this accident.

For background information, the Safety Board studied two other notable mid-air collisions: an Aeromexico DC-9 and a single-engine Piper (refer to Case Study IV-3); and an Army U-21 and a twin-engine Piper (refer to Case Study IV-4). In each case, "the limitations of the see-and-avoid concept to ensure traffic separation," and "the deficiencies of the see-and-avoid concept as a primary means of collision avoidance" were considered causal to the accidents. The Board further analyzed the results of laboratory and in-flight studies conducted during those investigations and concluded that there is "great difficulty of reliably seeing other airplanes when there is no warning of an impending collision and when the opposing airplane is as small as a PA-32 or an MU-2."

Safety Recommendation

Based on the commonalities between mid-air collisions in general, the Safety Board issued Safety Recommendation A93-127-132. It called for the FAA to assume a more active role in ensuring that instructor pilots are informed as to the importance of emphasizing proper scanning techniques to their students during training and biennial flight reviews. It also addressed the need for better overall pilot education concerning the many factors associated with collision avoidance.

Lessons Learned and Practical Applications

1. *Take full advantage of ATC services.* A simple phone call to ATC is all it takes to extend a flight plan. In this case, the Safety Board believed that the MU-2 pilot's decision to airfile his IFR flight plan prevented ATC from providing traffic advisories to him.
2. *Use your dual radios.* The obvious advantage of dual radios is that you can monitor two frequencies at the same time. It was unclear to the Board whether the Saratoga pilot or pilot-passenger was monitoring both the Greenwood unicom and the Indianapolis ARSA frequencies. If either one had been, the Board believed someone might have heard the MU-2 pilot's call, "…I'm off the ground at Greeenwood…" Likewise, the Saratoga pilot had announced his landing intentions at Greenwood Airport, immediately prior to the collision.
3. *Monitor frequencies early.* The AIM recommends tuning in an airport frequency when you are 10 miles away. This is also a safe

practice when on a cross-country. As part of your preflight planning, make a note of all the airports you will be flying near that "10-mile rule" and jot down the frequencies. Remember to always monitor and communicate.

4. *Maintain a vigilant scan for traffic.* This is absolutely imperative near an airport, and especially one that is uncontrolled, or in a high density traffic area.
5. *Develop safe practices that reduce pilot workload during critical phases of flight.* A suggestion: During your preflight planning, go down the list of every major task that must be accomplished for that flight. Then determine when it must be completed, and by whom. Taking those extra few minutes to *think* about your cockpit activities might be all that's needed to catch potential problems before they arise. As in this case, the Safety Board noted eight physical actions that the MU-2 pilot performed during climb out. One of those was unnecessarily rushing to airfile his IFR flight plan.
6. *Aggressively maintain situational awareness.* Don't just look, also listen for potential traffic conflicts. If you have any doubt, ask. Whether you're near an uncontrolled airport, or cruising on a cross-country, clarify those garbled or missed radio transmissions. "The Cessna that just reported inbound, please say your position." Easy.

Reference

National Transportation Safety Board. 13 September 1993. Aircraft Accident Report: Midair Collision, Mitsubishi MU-2B-60, N74FB, and Piper PA-32-301, N82419. Greenwood Municipal Airport, Greenwood, Indiana. September 11, 1992.

Historical Case Study IV-6: PSA Flight 182 and a Cessna 172

Safety issue: See-and-avoid, role of ATC, radio phraseology, cockpit discipline

On 25 September 1978, a Pacific Southwest Airlines (PSA) Boeing 727 collided with a single-engine Cessna 172 over a populated area of San Diego, California

Probable Cause

The NTSB determined that the probable cause of this accident was the failure of the flight crew of Flight 182 to comply with the provisions of a maintain-visual-separation clearance, including the requirement to inform the controller when visual contact was lost. Furthermore, air traffic control visual-separation procedures were in effect in a terminal area environment with the capability to provide lateral and vertical separation advisories to both aircraft. Contributing factors to the accident were (1) failure of the controller to advise Flight 182 of the direction of the Cessna, (2) failure of the pilot of the Cessna to maintain his assigned heading, and (3) improper resolution by the controller of the ground-radar's conflict alert.

History of Flight

PSA Flight 182 operated as a regularly scheduled flight between Sacramento, California, and San Diego, California, with an intermediate stop in Los Angeles, California. The 727 departed Los Angeles at 0834 Pacific Standard Time with 128 passengers and a crew of 7 on board.

The Cessna 172, owned by Gibbs Flite Center of San Diego, was being flown by an instrument student and his instructor.

Pilot Experience

The PSA captain had 14,382 total fight hours, 10,482 in the 727. He had been with the company since 1961 and was promoted to 727 captain six years later.

The PSA first officer had 10,049 total flight hours, 5,800 in the 727. He had held that position since 1970.

The PSA second officer had 10,800 total flight hours, 6,587 in the Boeing 727. He had been qualified in that position since 1967.

The Cessna instructor pilot had 5,137 total flight hours and had logged 347 hours in the last 90 days prior to the accident. The Cessna pilot had a commercial license and 407 total flight hours. He had flown 61 hours in the previous 90 days.

Weather

At the time of the collision, the San Diego weather was reported as clear with 10 miles visibility.

The Accident

Around 0816, the Cessna pilots departed Montgomery Field near San Diego for an instrument-instructional flight. They proceeded to Lindbergh Field to practice ILS approaches. About 45 minutes later, and after completing their second approach, the Lindbergh tower local controller cleared them to maintain VFR and contact San Diego approach control. When the 172 pilot called San Diego approach, he reported that he was at 1,500 feet and northeastbound. The controller verified that he was under radar contact. The Cessna pilot was then told to maintain VFR at or below 3,500 feet and to fly a heading of 070 degrees. The pilot acknowledged and repeated the controller's instruction.

At 0853:19 Flight 182 radioed San Diego approach and reported level at 11,000 feet. They were then cleared to descend to 7,000 feet. Moments later when the PSA pilot notified the controller that the "…airport's in sight." The flight was cleared for a visual approach. The call was acknowledged.

Shortly before 0900, the approach controller advised Flight 182 that there was "…traffic [at] twelve o'clock, 1 mile, northbound." Five seconds later (0859:33) the pilot answered, "We're looking." Again, in a matter of seconds (0859:39) the controller told Flight 182: "Additional traffic's twelve o'clock, 3 miles, just north of the field, northeastbound." The first officer responded, "Okay, we've got that other twelve."

Another report came only 25 seconds later, "…traffic's at twelve o'clock, 3 miles, out of one thousand seven hundred." This advisory was believed to have been referring to the 172. The first officer replied, "Got em," quickly followed by the captain informing ATC, "Traffic in sight."

At 0900:23, Flight 182 was then cleared to "…maintain visual separation…" and to contact Lindbergh tower. The call was acknowledged. Immediately thereafter, the controller advised the Cessna pilot that there was "…traffic at six o'clock, 2 miles, eastbound. A PSA jet inbound to Lindbergh, out of three thousand two hundred. Has you in sight." The pilot "rogered" the call.

About 11 seconds later, Flight 182 reported to Lindbergh tower that they were on the downwind leg for landing. The controller replied, "…traffic, twelve o'clock, 1 mile, a Cessna." Six seconds later the captain asked the first officer, "Is that one [we're] looking at?" The first officer answered, "Yeah, but I don't see him now." AT 0900:44, the crew informed the controller, "Okay, we had it there a minute ago." Followed shortly by, "I think he's passed off to our right." The controller responded to the call with a "yeah."

The crew continued to discuss the location of the traffic, and at 0900:52 the captain said, "He was right over there a minute ago," The first officer answered with a "yeah." Eighteen seconds later the captain told the controller they were going to extend their downwind leg 3 to 4 miles.

From the number of traffic advisories, in a relatively short period of time, it was obvious the skies near Lindbergh Field were very busy that morning. The PSA crew had been pretty successful in detecting their traffic, but there was one aircraft that kept eluding them.

At 0901:11, the first officer asked the chilling question, "Are we clear of that Cessna?" The second officer replied, "Supposed to be," followed by the captain's remark, "I guess." A deadheading PSA pilot who was riding in the jump seat answered, "I hope." Ten seconds later, the captain remembered, "Oh yeah, before we turned downwind, I saw him about one o'clock, probably behind us now." A few seconds later the first officer said, "There's one underneath." Then he added, "I was looking at that inbound there."

At 0901:47, the approach controller advised the Cessna pilot of, "…traffic in your vicinity, a PSA jet has you in sight. He's descending for Lindbergh." The sound of the mid-air collision was heard on Flight 182's cockpit voice recorder at exactly 0901:47. Eight seconds later, the captain radioed, "Tower, we're going down. This is PSA."

Impact and Wreckage Area

According to witnesses, Flight 182 was descending and overtaking the Cessna, which was climbing in a wings-level attitude. Just before impact, the jet banked to the right slightly and the Cessna pitched nose-up and collided with the right wing of the PSA. The Safety Board confirmed that scenario from the damage noted on each aircraft. Marks on the Cessna's propeller matched those on the 727's number five leading-edge flap actuator, indicating that the impact occurred on the forward and underside portion of the jet's right wing. Witnesses also testified that the Cessna broke up immediately and exploded. Parts of Flight 182's right wing and empennage were ripped off and fell to the ground.

A bright orange fire erupted near the right wing of the jet as it began a shallow right descending turn. The blaze intensified, and it was reported that the bank and pitch angles of the airplane reached about 50 degrees at impact.

The remains of both aircraft were scattered in residential areas about 3,500 feet apart and were destroyed from the force of impact and explosive fires.

ACCIDENT SURVIVABILITY

This accident was not survivable. The occupants of both aircraft sustained fatal injuries along with seven persons on the ground. An additional nine persons on the ground received minor injuries.

The Investigation

The Safety Board focused the investigation on two significant factors: the role of ATC and the responsibilities of pilots in a collision-avoidance environment.

ATC CONNECTION

At 0901:28, which was 20 seconds before the controller notified the Cessna with the traffic advisory, the data blocks of Flights 182 and 172 began to merge, triggering a conflict alert at San Diego Approach Control. Within a few seconds the data blocks were overlapping and the controller was unable to distinguish between either aircraft's altitude readout. The controller discussed the situation with his supervisor, and both elected not to manually offset the data blocks. The approach controller concluded that since Flight 182 said they had the "traffic in sight," and they confirmed the controller's request to "maintain visual separation," he did not believe any further action needed to be taken.

Although ATC was not required to notify a pilot if their aircraft was involved in a conflict-alert warning, the Safety Board believed that, in this case, it might have provided the PSA crew additional information that might have given them one more chance to avoid the collision. As the conflict alert progressed, however, the controller did advise the Cessna, "…traffic in your vicinity…," albeit too late. Flight 182 was no longer on his frequency.

The Safety Board also noted their concern over the practice of San Diego approach control issuing pilots "maintain-visual-separation" clearances when the ATC system had the capability of providing that service between IFR and participating VFR traffic. Investigators believed that aircraft, especially in the high-performance categories, flying on converging, random courses should be afforded this type of separation until they are clear of each other. In the Safety Board's opinion, if this had been done, "Flight 182 and the Cessna would not have collided."

The evidence further suggested that the approach controller seemed to have relaxed his monitoring vigilance. The PSA flight crew had reported traffic "in sight" which might have led him to believe that they had better situational awareness than he did. Even though the pilot had assumed the burden of maintaining separation, the controller should not have concluded that the pilot's ability to do so would remain unimpaired. Indeed, moments later the crew offered a few brief remarks—"Okay, we had it there a minute ago," and "I think he's passed off to our right."—to ATC concerning losing sight of the traffic. The controller's reply was, "Yeah." The Safety Board noted that he should have been prepared to update the traffic advisory and provide additional information to a crew that was obviously looking for the threat aircraft.

THE PILOT CONNECTION

The acceptance of "maintain-visual-separation" clearance requires the pilot not only to fly a safe distance from the traffic, but also to notify the controller when the traffic is no longer in sight. Although PSA's chief pilot testified that those procedures are in the company regulations, the Safety Board believed that the crew of Flight 182 might not have been aware of the requirement in its entirety. That premise was based upon the failure of the pilots to immediately advise ATC that they had lost sight of the traffic.

The investigation also found that the Cessna pilot did not remain on his assigned heading. At 0859:57, the approach controller told him to, "…maintain VFR conditions, at or below three thousand five hundred. Fly heading zero seven zero, vector for final approach course." This clearance was apparently for purposes of traffic separation since the Cessna was crossing and climbing toward the flight path of the descending 727. However, the Cessna turned to a downwind leg of 090 degrees prematurely and beneath the PSA. According to at least one dissenting Board member, if that had not occurred, the accident might not have happened.

RELATED FACTORS

At issue in this case was whether or not the PSA crew ever saw the Cessna. There was speculation that they observed another airplane that was not known by ATC, or they misidentified the Cessna with other traffic.

The two traffic advisories concerning the Cessna placed it at 1,400 to 1,700 feet northeastbound, just north of Lindbergh Field and in front of Flight 182. If the crew mistook another aircraft as the Cessna, then it was logical to assume that it was flying at the same time and at a similar course and altitude. Investigators located three possible targets; however, tower and approach controllers testified that there were no primary or beacon targets near the Cessna when the traffic advisory was issued to Flight 812. In order for a third unknown aircraft to have been misidentified as the Cessna, numerous details would have had to fall perfectly into place. All of which, according to the weight of the evidence, suggested a high improbability of such an occurrence.

Another issue to consider, although it was not causal to the accident, was the extraneous cockpit conversation between the flight crew and an off-duty PSA pilot riding in the jump seat. At various times during the approach, the crew engaged in non-flight-essential chatter that continued at critical periods, including a time when the pilots were completing a checklist. The Safety Board commented that missed traffic advisories can easily occur when this type of cockpit conversation exists in a high-workload environment.

A Final Point

In its closing statement of the accident report, the Safety Board discussed the importance of the controller-pilot team. They noted that the principle of redundancy between pilot and controller has long been recognized as one of the foundations of flight safety. However, that concept can be achieved only when both parties fully exercise their individual responsibilities, regardless of who has assumed or been assigned the procedural or regulatory burden.

Lessons Learned and Practical Applications

1. *Use clear and concise communication.* Avoid ambiguous—"We've got that other twelve."—and nondirective—"He was right over there a minute ago."—phraseology.
2. *Immediately notify ATC when you've lost sight of your traffic.* Precious seconds tick away as you hopelessly look for your traffic. Ask for help.
3. *Redirect the communication.* Controllers, if you don't get a clear and decisive response from a pilot, be directive. Reissue the advisory if there is any possibility the pilot has either misunderstood it or has lost his traffic. Don't be part of the problem.

Reference

National Transportation Safety Board. 20 April 1979. Aircraft Accident Report: Pacific Southwest Airlines, Inc., B-727, and a Gibbs Flite Center, Inc., Cessna 172, N7711G, San Diego, California, September 25, 1978.

PART V

Mechanical and Maintenance

In recent years, there have been catastrophic aircraft accidents caused by mechanical failures or lapses in maintenance and operating practices. High-profile accidents such as the uncommanded rudder upsets in B-737 aircraft, the fire on board a ValuJet DC-9, the explosion of an aging TWA B-747, and the first crash of a Concorde supersonic passenger jet are representative of the exceptional challenges facing flight crews and safety investigators. Each accident examined in this part is unique and isolated to its particular probable cause and thus stands alone in its analysis.

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Part V Case Studies

Case Study V-1: TWA Flight 800

Safety issues: Fuel tank ignition sources, fuel tank flammability, design and certification standards, maintenance and aging aircraft systems.

On 17 July 1996, TWA Flight 800, a Boeing 747, experienced a catastrophic in-flight breakup and explosion while flying off the coast of Long Island, New York.

Probable Cause

The NTSB determined that the probable cause of this accident was an explosion of the center wing fuel tank (CWT), resulting from ignition of the flammable fuel-air mixture in the tank. The source of ignition energy for the explosion could not be determined with certainty, but, of the sources evaluated by the investigation, the most likely was a short circuit outside of the CWT that allowed excessive voltage to enter it through electric wiring associated with the fuel quantity indication system.

Contributing factors to the accident were the design and certification concept that fuel tank explosions could be prevented solely by precluding all ignition sources and the design and certification of the Boeing 747 with heat sources located beneath the CWT with no

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means to reduce the heat transferred into the CWT or to render the fuel vapor in the tank nonflammable.

History of the Flight

Flight 800 operated as a regularly scheduled international flight from John F. Kennedy (JFK) International Airport, New York, to Charles DeGaulle International Airport (CDG), Paris, France. The flight departed over an hour late, at 2019 Eastern Daylight Time, with 2 pilots, 2 flight engineers, 14 flight attendants, and 212 passengers on board.

Earlier that day, the accident airplane departed Athens, Greece, and landed at JFK about 1631. That flight crew told investigators that all systems had operated normally. The airplane was refueled at the gate with the auxiliary power unit (APU) and, in accordance with TWA procedure two of the airplane's three air conditioning packs were running while the jet was parked at the gate—approximately 2½ hours before departure.

Flight 800 was scheduled to depart JFK at 1900; however, the flight was delayed because ground personnel were concerned that a checked bag did not match a passenger. At 1959, a gate agent advised the flight crew that although a passenger's bag had been pulled as a result of ground personnel's suspicion, they subsequently confirmed that "the passenger was on board the whole time."

Flight 800 pushed back from the gate at 2002, and the flight crew started the number one, two, and four engines shortly thereafter. The flight crew completed their after-start checklist and began their taxi to runway 22R—starting the number three engine and conducting the delayed engine-start and taxi checklists. Flight 800 became airborne at 2019.

At 2027, and under the control of Boston Air Route Traffic Control Center (ARTCC), Flight 800 reached its assigned altitude of 13,000 feet msl. Two minutes later the captain remarked, "Look at that crazy fuel flow indicator there on number four…see that?" There was no further discussion of the anomaly. Flight 800 was then cleared to maintain 15,000 feet, and the captain stated, "Climb thrust," and the captain/check airman acknowledged the ATC clearance. The captain repeated, "Climb thrust," and at 2030:35, the flight engineer responded, "Power's set."

The CVR recording of the next 30 seconds included the following:

- A sound similar to a mechanical movement in the cockpit (2030:42)
- An unintelligible word (2031:03)
- Sounds similar to recording tape damage noise (2031:05)
- CVR recording ended (2031:12)

Immediately before the CVR ended, a "very loud sound" was recorded for 0.117 second on all channels. Investigators later identified the sound as identical to that recorded on other aircraft that experienced in-flight breakups, including fuel tank explosions. The last recorded radar transponder return for the airplane occurred as it was climbing through 13,760 feet at 2031:12—the exact second the FDR lost power.

At 2031:50, the captain of an Eastwind Airlines Boeing 737 reported to Boston Center that he "just saw an explosion out here…we just saw an explosion up ahead of us…about 16,000 feet or something like that, it just went down into the water." Many ATC facilities in the New York/Long Island area received additional pilot reports of an explosion.

Pilot Experience

The captain had 18,800 total flight hours, including 5,490 in the 747. He flew in the left front seat position on Flight 800.

The captain/check airman had 17,000 total flight hours, including 4,700 in the 747. He flew in the right front seat position on Flight 800.

The flight engineer was a trainee on his sixth leg of initial operating experience training. He had 2,520 total flight hours, 30 hours as a flight engineer trainee in the 747. He flew in the right aft/flight engineer position on Flight 800.

The flight engineer/check airman was a TWA 747 captain until 1993, at which time he became a flight engineer on the 747 rather than accept a mandatory age retirement. He had 3,047 hours of flight engineer experience, including 2,397 as flight engineer on the 747. He flew in the left aft/cockpit jump seat on Flight 800.

Background Information on Accident Airplane Systems

TWA used a Boeing 747-100 series airplane for Flight 800, manufactured in 1971 and purchased new. According to TWA records, the airplane had 93,303 total hours of operation, including 16,869 flight cycles (one complete takeoff and landing sequence) at the time of the accident.

747-100 WING CENTER SECTION AND CENTER WING FUEL TANK

The 747-100's compartmentalized wing center section (WCS) is located aft of the forward cargo compartment and forward of the main landing gear bay in the lower fuselage. The WCS is about 21 feet wide and 20 feet long, and varies in height from about 4½ to 6 feet. It comprises the CWT and dry bay directly forward of the CWT. One of the compartments in the WCS was originally equipped with a bladder cell for water and plumbing that was used for water-injected takeoffs—an engineering design to increase engine thrust on takeoff. When the original engines were replaced with higher-thrust engines, water for water-injected takeoffs was no longer needed and that compartment was converted to a dry, empty bay.

AIR CONDITIONING SYSTEM

There are three air conditioning packs for the 747-100. They operate either from the hot bleed air from the airplane's engines, the APU, or a high-pressure power cart during ground operations. The air conditioning pack bay is located in an enclosed area under the WCS—pack number one is positioned beneath the forward left portion of the CWT; pack number two is located directly behind pack number one; and pack number three is adjacent to pack number one, beneath the forward right portion of the CWT.

The air conditioning packs remove heat from the engine bleed air through the primary and secondary heat exchangers. Excess heat exhausts into the air conditioning pack bay through a set of louvers that are flush with the lower fairings. After conditioned air leaves each of the air conditioning packs, it is routed through ductwork along the aft side of the rear spar (through the main landing gear wheel well) upward until it reaches the top of the CWT. The conditioned air is then routed forward between the upper skin of the WSC and the main cabin floor into a common assembly area located above the CWT. From there, the conditioned air branches off to vertical risers in the airplane's side walls and ascends to the air distribution and exchange system for the main cabin.

ELECTRICAL SYSTEM

During normal operation, the four engine-driven generators supply power to four main alternating current (ac) buses. The generators are synchronized and connected together by the closing bus tie (used to electrically connect two or more electric buses) and split bus breakers (a manually operated circuit breaker used to separate the ac power distribution system into two separate ac buses).

The galley power distribution system obtains primary 115/200-volt ac power from the engine-driven generators. Step-down transformers (reduce higher-voltage ac power for certain airplane systems that require lower voltages) are used to convert some of the primary 115/200-volt ac power to 28-volt ac power, which is then distributed to various instruments and most nongalley airplane lighting systems by four main ac load buses. Five separate 75-ampere transformer rectifier units (TRU), which are connected to each other through isolation relays, convert the ac power to 28-volt direct current (dc) power.

WIRING

In early production 747s, such as the accident airplane, Boeing used an alkane-imide insulated wire, known by the trade name Poly-X. In a 1970 Boeing Manufacturing Development Report, the use of Poly-X was referenced, "Employment of the new wire was designated…because its thinner insulation provided a potential weight saving of approximately 400 to 600 pounds per airplane over that achieved with the existing…wire."

Poly-X wire consists of three layers of modified alkane-imide polymer coating (0.015 inch minimum thickness) over a tin-coated copper core conductor and inner and outer layers of primary insulation (0.009 inch minimum thickness). Boeing's material specification for this type of wire states that "a coating of modified imide polymer shall be applied over the insulation. This coating shall be continuous and free from cracks, splits, blisters, and other defects when examined without the aid of magnification."

Although the original manufacturer of Poly-X stopped making the wire in 1975, the current Boeing Standard Wiring Practices Manual (SWPM) continues to specify Poly-X as an approved alternative material to use. Conversely, documentation from the FAA's Aging Non-Structural Systems Program indicated that the use of Poly-X wire was discontinued in 747 production in 1975 adding, "Airplane manufacturers typically continue to use existing stock until it is exhausted, [and as a result, some material] changeovers may have taken considerable time. Thus trying to determine the wire type installed based on the date of manufacture of an airplane is not necessarily accurate." Investigators for Flight 800 determined that "most of the wiring in the accident airplane was…Poly-X"; however, other types of wire were also recovered. The fuel quantity indication system (FQIS) wiring used in the fuel tanks was polytetrafluoroethylene, known by the trade name Teflon. According to Boeing's 747 specifications, Teflon has been used for FQIS wiring in fuel tanks and between the CWT and gauges at the flight engineer station in the cockpit.

SEPARATION OF 747 WIRE CIRCUITS

The Safety Board's review of FAA regulations revealed that the FARs do not contain specific guidance regarding separation of electric circuits and wiring. However, 14 CFR Section 25 states, "The airplane systems and associated components, considered separately and in relation to other systems, must be designed so that…the occurrence of any failure condition which would prevent the continued safe flight and landing of the airplane is extremely improbable."

A 1970 Boeing document, "Criteria for Separation of Critical Electric Circuits," provided guidelines for separation that Boeing deemed necessary for isolation of critical systems. These guidelines were applicable to "any electrical equipment or system for which the proper functioning is considered essential to safe operation" in all Boeing commercial airplanes at that time, including the 747-100. The document also stated that the "object of the circuit separation is to prevent hazardous malfunctions or simultaneous loss of redundant power supplies or redundant equipment functions due to failures such as: 1) fire or damage to any wire bundle, 2) loss of any single connector, 3) fire in a junction box, or 4) engine turbine burst."

The Boeing document listed the circuits to separate in each major airplane system—circuits designated as critical—fire warning and protection system wiring, wiring to individual fuel pumps, and individual engine installation circuits. Boeing specified separation distances of at least ¼ inch in pressurized areas and at least ½ inch in unpressurized areas. Boeing had conducted a series of tests during the design and certification of the 747 in 1969 and 1970, and again in 1980, that indicated that wire bundles separated by a minimum ¼-inch air gap from a failed bundle will not sustain damage that compromised the electrical integrity of the wire bundle. According to Boeing's Standard Wiring Practices Manual, when the necessary ¼- or ½-inch separation is not possible because of space or other constraints, insulation material or a fusible link circuit breaker is required to provide adequate separation.

Although the Boeing document on critical electric circuits and the Wiring Practices Manual specified that wiring to individual fuel pumps needed to be protected by separation, there were no special separation requirements for other FQIS and fuel system wiring, including the fuel quantity probes and interconnecting wiring and the fuel quantity gauges. However, on 747s produced after the accident airplane, Boeing incorporated an electromagnetic interference (EMI) shield on the FQIS wire bundle between the flight engineer's panel and the CWT.

FUEL SYSTEM

The 747-100's fuel system consists of seven fuel tanks—three in each wing and one in the CWT. The system includes an engine cross-feed which provides the transfer of fuel from any fuel tank to any engine; however, it does not permit the transfer of fuel from one fuel tank to another. The fueling station on the left wing, a fuel jettison system, and a surge tank in each wing tip are also part of the jet's fuel system.

According to Boeing, the capacities for the wing fuel tanks are: reserve tanks, 3,350 pounds (500 gallons) each; outboard main tanks, 29,614 pounds (4,420 gallons) each; inboard main tanks, 82,008 pounds (12,240 gallons) each; and the CWT, 86,363 pounds (12,890 gallons).

Accident Sequence—In-Flight Breakup

Investigators modified a flight simulation computer program to take into account the changes in mass and aerodynamic characteristics of Flight 800 during the seconds before and after the separation of the forward fuselage. Investigators also developed a plausible time line of events based on several scenarios, including combinations of nose-down/nose-up pitching moments, minimum/maximum drag and lift coefficients, and engine power settings.

- *2031:12.* Initial event
- *2031:15 to 2031:19.2.* Forward fuselage separation
- *2031:46.* Wing tip failure
- *2031:50.* WCS failure adjacent to left wing

The simulations indicated that the airplane climbed to above 16,000 feet msl after the forward fuselage separated, considering there was no flight control input. It was less clear, however, how to determine the lateral direction for the same scenario. Evaluation of primary radar return data from White Plains, New York; Islip, New York; and JFK Airport showed that the main portion of the airplane may have turned north after the forward fuselage separated and then turned south toward the main wreckage recovery site. However, there was considerable scatter in the radar data after the in-flight breakup resulting in differing radar tracks. The White Plains and Islip radar sites recorded a more pronounced turn to the north followed by a turn back south, while data from the JFK radar site showed a much straighter path to the wreckage site.

Witness Accounts

There were 736 documented witnesses to the in-flight breakup of Flight 800; 599 reported seeing a descending fireball; 200 of those reported seeing the main fireball split into two fireballs before hitting the water; and 258 reported observing a streak of light.

On the basis of computer simulations and witness information, the Safety Board determined that the entire breakup sequence (from the time of the CWT explosion until the time that the aft portion of the airplane impacted the water) lasted about 47 to 54 seconds. The sequencing study established that the nose portion of the airplane separated from the remainder of the airplane after the initial explosion in the CWT. Computer simulations indicated that this occurred about three to five seconds after the initial explosion. Further simulations based on radar data, trajectory calculations, and airplane performance factors indicated that after the separation of the nose portion, the remainder of the airplane (including much of the WSC, the wings, the aft fuselage, and the tail) continued in crippled flight and pitched up while rolling to the left (north), ascended from 13,800 feet to about 16,000 feet, and then rolled into a descending turn to the right (south). It is likely that, after the nose portion separated from the aft fuselage, a fuel-fed fire within the breached CWT would have been visible to witnesses from some distance and was likely the streak of light reported by many of the witnesses.

It is also likely, based on the wreckage, computer simulations, and witness documents, that shortly after the descending turn to the right, the outboard left and right wings simultaneously separated at the outboard engines in upward bending. The separation of the outboard portions of the wings probably precipitated fuel-fed fires at both outboard main wing tanks and most likely was the beginning of the developing fireball described by witnesses. This fireball probably began to develop about 34 seconds after the CWT explosion.

Shortly after the outboard portion of the wings separated, the WCS separated adjacent to the left wing, causing the left wing to separate from what remained of the airplane structure. These failures would have resulted in the continuing development of a larger fuel-fed fireball. The development of a severe fire after the separation of the burning left wing was most likely associated with portions of the WCS, the right wing, and a few pieces of attached fuselage. Investigators believed that this event is what witnesses reported as a “splitting” of the fireball.

Missile Strike Theory

For a missile to have caused the breakup sequence, it would have had to have been fired at least 41 to 49 seconds before the initial development of a fireball. This takes into consideration a 7- to 15-second missile flight plus about 34 seconds from the time of the CWT explosion to the outboard wing separations.

The majority of witnesses who reported seeing a streak of light in addition to the fireball described the phenomenon as similar to fireworks, a shooting star, or a flare. While only a small number of those witnesses remembered seeing a streak of light perhaps originate from the ground, FBI, Safety Board, and even CIA investigators analyzed the myriad of reports, radar data information, and physical evidence to determine whether or not Flight 800 was shot down with a missile. In their final analyses, investigators concluded that what the witnesses observed was not a missile attack but rather some part of the in-flight fire and breakup sequence after the CWT explosion.

A particularly credible witness was the captain of the Eastwind Airlines Boeing 737 who was the first airborne witness to report seeing the accident to the Boston Center air traffic controller. According to the radar data, the Eastwind jet was flying about 24 nm northeast of Flight 800 at an altitude of about 15,400 feet when the captain observed seeing what he thought was an off-colored landing light. According to the captain's statement the night of the accident, his initial thought was that another airplane was experiencing an engine fire, but he subsequently identified the object as a landing light and began to monitor the airplane's course. He estimated watching the airplane intermittently for two to five minutes. As the captain switched on his own landing lights to signal the other flight crew of his aircraft's location, that airplane "exploded into a very large ball of flames." The captain further stated, "Almost immediately, two flaming objects with flames trailing about 4,000 feet behind them fell out of the bottom of the ball of flame."

Investigators determined that if witnesses had observed an actual missile attack on Flight 800, they would have seen the following: (1) a light (the burning of the missile motor) ascending very rapidly and steeply for about eight seconds and visible for at least 12 nm; (2) the light disappearing (after motor burn) for up to about seven seconds, and the light would not descend like fireworks; (3) upon a missile striking the airplane and igniting the fuel-air vapor in the CWT, another light (flames) moving considerably slower and more laterally for about 30 seconds; and (4) this light descending while simultaneously developing into a fireball falling toward the ocean.

The Safety Board believed that it was noteworthy that one of the witness documents included a description of such a scenario. Therefore, the Safety Board concluded that the streak of light some witnesses observed was burning fuel from Flight 800 during some portion of the postexplosion and preimpact breakup sequence.

Fuel-Air Explosion in the Center Wing Fuel Tank

It was clear from the wreckage recovery locations that the first pieces to separate from the airplane were from the area in and around the WCS, which includes the CWT. According to investigators, the breakup sequence began as an "overpressure event"—sufficient pressure in a relatively short time that compromises the structural integrity—of the CWT. The Safety Board determined that because there was no evidence that a high-energy explosive device detonated in or through the airplane, this overpressure could only have been caused by a fuel-air explosion in the CWT.

Safety Board flight tests that re-created, to the extent possible, the conditions experienced by the accident airplane indicated that fuel vapor temperatures within the CWT at the time of the accident ranged from 101 to 127°F. A major reason for the flammability of the fuel-air vapor in the CWT on the 747 is the large amount of heat generated by the air conditioning packs located directly below the tank, which significantly elevates the temperatures in the pack bay. Heat from the pack bay can transfer to the CWT through the bottom of the tank and cause temperatures to rise above the lower flammability limit. Therefore, the 747 may operate a lengthy portion of the time with a flammable fuel-air mixture, but under these circumstances a single ignition source could cause an explosion.

Further, Safety Board–sponsored testing showed that Jet A fuel vapors under conditions simulating the pressure, altitude, and fuel mass loading of Flight 800 are flammable at these temperatures and at those as low as 96.4°F. Analysis of those results indicated that a localized ignition of the flammable vapor could have generated pressure levels that, based upon structural failure analysis, would cause the damages on Flight 800. Previous fuel-air explosions of CWTs of commercial airliners that had used Jet A fuel confirmed that a CWT explosion involving Jet A fuel can break apart the fuel tank and lead to the destruction of an airplane. Accordingly, the Safety Board concluded that a fuel-air explosion in the CWT of Flight 800 would have been capable of generating sufficient internal pressure to break apart the fuel tank.

High-Energy Explosive Device

Several factors led to speculation that the accident may have been caused by a bomb or missile strike, including numerous witnesses to the accident who reported seeing a streak of light and then a fireball, which some people believed represented a missile destroying the airplane. Due to the heightened safety and security concerns surrounding the 1996 Olympics then being held in the United States and the sudden and catastrophic nature of the in-flight breakup, the Safety Board immediately brought in the Federal Bureau of Investigation (FBI) to conduct the criminal arm of the investigation.

After an extensive investigation, the FBI found no damage to the recovered wreckage consistent with a high-energy explosive, nor did the victims' remains show any evidence of explosive injury. The FBI did, however, discover trace amounts of explosives on three separate pieces of the recovered wreckage. With assistance from the FAA's Technical Center, it was determined that residues of explosives would dissipate completely after two days of immersion in seawater. Very few pieces of airplane wreckage were recovered in that period of time, leaving investigators to believe that the source of the trace amounts of explosives was introduced after the wreckage was pulled from the water. Despite being unable to determine the exact source of the explosives, the FBI and Safety Board concluded that the most likely source came from the military personnel, ships, and ground vehicles used during the recovery operation. Trace amounts of those substances could have been transferred from the surfaces of the ships or ground vehicles, or even from military clothing onto wreckage pieces. It is also possible that the wreckage was contaminated from contact in the airplane hangar where the wreckage was later assembled and laid out.

In any event, the FBI and Safety Board determined from the lack of corroborating physical evidence associated with a high-energy explosion that the trace amounts of explosives did not result from an explosive device. Thus, the Safety Board concluded that the in-flight breakup was not caused by a bomb or a missile strike.

Ignition Source

According to the Safety Board, the only electric wiring located inside the CWT that is not separated by flame suppression passages is the wiring associated with the FQIS. Boeing design specifications state that the voltage to the FQIS wiring is limited so that it cannot discharge energy in excess of 0.02 millijoule. (A millijoule is one-thousandth of a joule, which is a measurement of electric energy—1 joule is the work done by 1 watt in 1 second.) Therefore, for the FQIS to have played a role in igniting the flammable fuel-air vapor in the CWT, the following two events must have occurred: (1) a transfer of a higher than intended voltage onto FQIS wiring from a power source outside of the fuel tank, and (2) the release of the energy from that FQIS wiring into the inside of the tank in a way that could ignite the fuel-air vapor in the tank. Investigators examined several possible ways by which energy might have been transferred to the FQIS, most plausibly through either EMI or short circuits.

EMI SOURCE

At the conclusion of extensive EMI testing, investigators discovered that the maximum energy released by FQIS wiring inside the fuel tank was 0.125 millijoule. This is significantly less than the 0.5 to 500 millijoules needed to ignite the Jet A fuel-air vapor in the CWT. Therefore, the Safety Board concluded that it was unlikely that EMI from aircraft system wiring played a role in igniting the fuel-air vapor in Flight 800's CWT.

SHORT CIRCUIT

Excess voltage from a short circuit can be transferred from wires carrying higher voltage to wires carrying lower voltage if the wires are near each other. Wires carrying high voltage can be placed near FQIS wires both in common wire bundles and at connectors in various locations. Investigators noted that Boeing design specifications permitted FQIS wiring to be bundled with, or routed next to, higher-voltage airplane system wires, some carrying as much as 350 volts. While most airplane systems carry 115 volts, the Safety Board found numerous transport-category airplanes with lighting circuits between 192 and 350 volts in bundles that also contained wiring associated with the FQIS. In addition, investigators discovered several Boeing 747s (and other transport-category airplanes) with high-voltage wires co-routed with FQIS wires in ways that do not comply with manufacturer's production illustrations (PI) or are not consistent with the guidance in Boeing's Standard Wiring Practices Manual.

The CWT FQIS wiring in the 747 terminates at common connectors with the fuel quantity indicator, the totalizer gauge, the airborne integrated data system, the volumetric shutoff, and the left wing refueling station; each of these connectors includes terminating wires from circuits that carry 115 volts. Although the Safety Board was not aware of FQIS wires sharing connectors with wires carrying more than 115 volts, Boeing specifications also permit FQIS wiring to be mixed in common connectors with airplane systems wires carrying up to 350 volts.

A short circuit can occur if the wire's internal conductors are accessible or exposed and there is either (1) direct contact between the conductors or (2) a bridge between the conductors, created by contaminants, such as metal shavings or fluid. Short circuits in connectors have caused incidents in the past, including one in 1995 when a 737 approaching Manchester, England, encountered roll and yaw oscillations that were later attributed to a short circuit in the rudder circuitry triggered from lavatory fluid bridging the pins within an electrical conductor.

Investigators for Flight 800 found that damaged or contaminated wire insulation was widespread in both old and new transport-category airplanes. Relevant to Flight 800, investigators found a sample of older airplanes that exhibited numerous mechanically damaged, chafed, cracked, and contaminated wires. Specifically, they found sharp-edged metal drill shavings, fluid stains, and other potentially hazardous material in or near critical wiring.

SHORT CIRCUIT TRANSFER ENERGY SOURCES

The Safety Board noted additional means in which a short circuit could transfer energy to Flight 800's CWT.

- In the totalizer gauge on the accident airplane, the wires attached to the connector pins for the right wing main tank FQIS and the CWT FQIS had been improperly soldered together and had subsequently cracked apart. During examination of the gauge, investigators determined that electric energy would cross the crack in the solder between the connector pins when slightly more than 270 volts was applied to one of the pins. The production illustration for the accident airplane showed right wing FQIS wires were routed through the fuselage in bundles that contained 350-volt lighting circuits.
- A higher-voltage wire in the right wing FQIS wiring could have carried excessive voltage to the CWT.
- As demonstrated during tests on an older 747, investigators found that when an electrical signal was placed on the CWT FQIS wiring, it was also detected on wiring from the left wing FQIS, indicating that if two sets of wiring are not electrically isolated, a short circuit from a higher-voltage wire to left wing FQIS wiring could result in excess energy being transferred to the CWT.

Factors Related to a Short-Circuit Event

Investigators found evidence of arcing (a luminous discharge of electricity which can elevate temperatures to several thousand degrees Celsius) on generator cables routed with wires in the leading edge of the right wing. Although this arcing damage may have been caused by the fuel-fed fire, investigators believed it was possible that it was present before the explosion. Because this wire bundle included wires leading to the right main wing tank (number four) fuel flow gauge and FQIS wiring, a short circuit in this bundle could have carried excessive energy into the CWT FQIS.

Secondly, two, non-FQIS wires, which were believed to have been co-routed in the same raceway (wire bundles grouped into a common route) as CWT FQIS wiring, were found with possible arcing damage.

The wires were located near structural repairs from a burst potable water tank and numerous other floor repairs. These repairs could have disturbed nearby wires, cracking or otherwise damaging the wire insulation, including the distribution of metal shavings. As investigators noted, metal drill shavings were found adhered to fragments of a floor beam within 2 inches of where the CWT FQIS wiring would have been routed. This area was also near galley C, which was the site of numerous reported leaks in the two weeks preceding the accident. Leakage from this area could have dripped onto electric wiring located immediately beneath the galley floor, resulting in a short circuit that affected the CWT FQIS wiring.

There had been additional repairs around the upper-deck flight attendant lighting panel. A lighting wire and pin had been repaired one month before the accident. The wire was part of a bundle that branched off from a larger bundle that contained CWT and left wing FQIS wires that led to the upper deck airborne integrated data system unit and contained high-voltage wiring for lighting; thus, manipulation of wires during the repair could have resulted in movement and cracking of these wires. As previously explained, FQIS wiring from wing tanks is not electrically isolated from the CWT FQIS wires, and, therefore, energy resulting from a short circuit to any of those FQIS wires could potentially reach the CWT.

Lastly, in addition to being bundled with FQIS wires, the lighting wires were also bundled with CVR wires and number four fuel flow wires along some portions of their path. There were several indications of anomalous electrical events occurring in the airplane just before the explosion. The captain made the comment about a "crazy" number four fuel flow indicator; the captain's CVR channel recording had two "dropouts" of background power harmonics; and the recovered CWT fuel quantity gauge displayed a gross discrepancy from ground refueling records. Evidence suggests that both electrical and mechanical gauge mechanisms read the correct amount of fuel (300 pounds) when the airplane was on the ground. The recovered gauges displayed a reading of 640 pounds. Tests revealed that applying power to a wire leading to the fuel quantity gauge can cause the digital display to change by several hundred pounds in less time than is required to trip the circuit breaker. This suggested that an electrical anomaly may have affected the reading of the cockpit gauges.

As the Safety Board noted, all the electrical anomalies were not necessarily related to the same event. However, based on the evidence, the Safety Board concluded that a short circuit producing excess voltage that was transferred to the CWT FQIS wiring was the most likely source of ignition energy for the CWT explosion.

Reference

National Transportation Safety Board. 23 August 2000. Aircraft Accident Report: In-flight Breakup over the Atlantic Ocean, Trans World Airlines Flight 800, Boeing 747-131, N93119. Near East Moriches, New York. July 17, 1996.

Case Study V-2: United Flight 585, USAir Flight 427, Eastwind Flight 517—A Compilation of Uncommanded Rudder Events in B-737 Aircraft

In 1991, United Flight 585 crashed in Colorado Springs, Colorado, following a sudden, uncommanded rudder movement. The NTSB was unable to identify conclusive evidence to determine a probable cause but offered two likely events: (1) a malfunction of the airplane's lateral or directional control system or (2) an encounter with an unusually severe atmospheric disturbance.

The 1994 crash of USAir Flight 427 in Pittsburgh, Pennsylvania, was remarkably similar to that of Flight 585. The NTSB believed that the event strongly suggested a malfunction in the rudder system, but the evidence was not definitive; and thus, the Safety Board was unable to provide a probable cause.

These accident reports were finally brought to a close after the NTSB conducted the investigation of an uncommanded yaw and roll incident for Eastwind Flight 517 in 1996. The incident paralleled the events which led to the crashes of Flights 585 and 427 and provided investigators with key physical evidence and flight crew testimony of the event.

The following case studies represent the accident sequences for Flights 585 and 427 and the account of Flight 517's recovery.

UNITED FLIGHT 585

On 3 March 1991, a United Airlines B-737 was rolling out of a right turn on the final approach for runway 35 at Colorado Springs (COS) Municipal Airport, Colorado, when it suddenly yawed and then rolled to the right, pitched nose down, and crashed short of the runway.

History of Flight

United Flight 585 was a regularly scheduled passenger flight from Denver, Colorado, to Colorado Springs. The B-737 departed Denver at 0923 Mountain Standard Time, with 20 passengers and 5 crewmembers on board.

Pilot Experience

The captain had 9,902 total flight hours, 1,732 in the B-737, including 891 as captain. The first officer had 3,903 total flight hours, 1,077 in the B-737.

Weather

Colorado Springs 0850 surface weather observation: Clear, visibility 100 miles; temperature/dewpoint 49°F/9°F; winds 330 degrees at 23 knots, gusts to 33 knots; cumulus over the mountains northwest.

The Accident Sequence

With the captain flying, the pilots prepared for the approach to COS and discussed the strong gusty winds and windshear conditions they expected to encounter, including airspeed adjustments to compensate for those conditions and missed approach procedures. At 0938:14, the first officer requested information from ATC regarding pilot reports for airspeed gains or losses. The controller replied that the pilot of a B-737 had advised him of a 15-knot loss at 500 feet; at 400 feet, plus 15 knots; and at 150 feet, plus 20 knots.

At 0940:44, with the first officer busy completing a checklist, the captain requested additional information from ATC concerning traffic. The pilots began a series of right turns toward the northbound final approach. They incrementally extended flaps, extended the landing gear, and accomplished the final descent checklist. As the pilots began to align the airplane with the final approach course, the airplane was encountering airspeed changes (±10 knots) and rapid heading changes, for which the pilots commented on the uncommanded airspeed changes. At 0943:08, the first officer said, "Wow," followed by, "We're at a thousand feet." Immediately thereafter, the first officer exclaimed, "Oh, god," and the captain called for "fifteen [degrees] flaps," as the airplane began a sharp heading change to the right and a sudden descent. The first officer responded to the flaps setting and said, "Oh," the same time the captain exclaimed, "Oh," in a loud voice. Over the period of a few seconds, the first officer and the captain made similar remarks—ending with the first officer saying, "Oh, my god…oh, my god…," and the captain saying, "Oh, no…." The sound of impact was recorded three seconds later at 0943:41.

Impact and Wreckage Area

The wreckage site was located in Widefield Park, about 3.5 miles south of runway 35. The fuselage had severe accordion-like fore and aft crushing throughout its entire length with overstress breaks. Except for two aft fuselage sections of skin and small debris, the entire fuselage was contained within the impact crater. All the major parts of the airplane were destroyed or severely burned.

ACCIDENT SURVIVABILITY

This accident was not survivable.

The Investigation and Background—B-737 Rudder System

The main rudder power control unit (PCU) is powered by hydraulic systems A and B, for a total output force of 6,000 pounds. The PCU operates by converting either a mechanical input from the rudder pedals or an electric signal from the yaw damper system into motion of the rudder by means of mechanical linkages. A servo valve directs hydraulic fluid either to extend or retract the PCU actuator rod that moves the hinged rudder surface.

The maintenance history for the airplane included two rudder-related pilot write-ups during the week before the accident: (1) "On departure got an abnormal input to rudder that went away. Pulled yaw damper circuit breaker," and (2) "Yaw damper abruptly moves rudder occasionally for no apparent reason on 'B' actuators. Problem most likely in yaw damper coupler…unintended rudder input on climbout at FL 250. [Autopilot] not in use, turned yaw damper switch OFF and pulled circuit breaker. Two inputs, one rather large deflection."

After the first write-up, maintenance replaced the yaw damper coupler and tested per the maintenance manual. Two days later, after the second write-up, maintenance replaced the main rudder PCU yaw damper transfer valve and the airplane was returned to service.

Environmental Factors

The Safety Board believed that Flight 585 encountered moderate turbulence immediately before the loss of control. The FDR information showed the aircraft in ±10-knot airspeed fluctuations and moderate vertical acceleration excursions prior to the lateral upset. Based on those indications and pilot reports, the weather conditions seemed consistent with gusty winds, rather than microburst or convective windshear activity. However, there was evidence to suggest the existence of a horizontal axis vortex near the accident site. Witnesses reported 90-mph winds east of the location and gusts of around 50 to 70 knots about the time of the upset. Another witness testified seeing a rotor microburst touch down about noon, 12 miles north of Colorado Springs.

A horizontal axis vortex strong enough to cause airplane control problems would have a core pressure several tenths of an inch of Hg lower than the ambient pressure, resulting in a transient increase in altitude of several hundred feet. If the jet penetrated the edge of a vortex, an increase in altitude would be noted on the FDR as an altitude spike, but no such event had been recorded.

Final Analysis

The Safety Board concluded that the accident sequence of Flight 585 was consistent with a rudder reversal most likely caused by a jam of the main rudder PCU servo valve secondary slide to the servo valve housing offset from its neutral position and overtravel (the ability of a device to move beyond its normal operating position or range) of the primary slide. Also, because the upset occurred when the airplane was less than 1,000 feet above the ground, the pilots had very little time to react to or recover from the event. Thus, the Safety Board concluded that the flight crew recognized the initial upset in a timely manner and took immediate action to attempt a recovery but did not successfully regain control of the airplane.

USAir FLIGHT 427

On 8 September 1994, a USAir 737 crashed outside of Pittsburgh, Pennsylvania, after it encountered an uncommanded, uncontrollable descent.

Probable Cause

The NTSB determined that the probable cause of this accident was a loss of control of the airplane resulting from the movement of the rudder surface to its blowdown limit. (The *blowdown limit* is the maximum amount of rudder travel available for an airplane at a given flight condition or configuration. It occurs when the aerodynamic forces acting on the rudder become equal to the hydraulic force available to move the rudder.) The rudder surface most likely deflected in a direction opposite to that commanded by the pilots as a result of a jam of the main rudder power control unit servo valve secondary slide to the servo valve housing offset from its neutral position and overtravel of the primary slide.

History of Flight

Flight 427 was a regularly scheduled flight from Chicago, Illinois, to Pittsburgh. The B-737 departed Chicago with 127 passengers and 5 crewmembers on board.

The Accident Sequence

The flight had been uneventful until the crew began an early evening approach into Pittsburgh. At 1902:53 Eastern Daylight Time the jet was about 7 miles from the airport when the crew began rolling out of a left bank while maintaining 190 knots at an altitude of 6,000 feet msl. Between 1902:57 and 1902:58, a sound similar to three thumps was recorded on the CVR, along with the captain exclaiming, "Sheeze." The airspeed fluctuated between 190 and 193 knots, and then decreased to 191 knots for four seconds as the airplane's left bank steepened from about 8 degrees to just over 20 degrees.

At 1902:58, the CVR recorded an additional thump, two "clickety-click" sounds, the sound of the engine's noise getting louder, and the sound of the captain inhaling and exhaling quickly one time—the FDR recorded a brief forward movement on the control column. The airplane began to briefly roll right toward a wings-level attitude when suddenly it made a rapid move back to the left. As the rudder deflected to its initial blowdown position, the rudder pedals would have moved opposite to that commanded by the first officer. As the right rudder pedal rose, the first officer made forcible attempts to depress the pedal. At 1903:03, the airplane's left bank angle increased to about 43 degrees and the airplane had begun to descend. The control column had started to move aft as the airspeed fell below 190 knots. Less than one second later, the CVR recorded the sound of the autopilot disconnect horn. The airplane increased its left roll rate and continued to lose altitude and airspeed as the pilots applied aft control column pressure.

The sounds of a stall buffet and the captain saying, "What the hell is this?" were recorded. The stickshaker activated and continued until the end of the recording. It was apparent by 1903:10 that the pilots were struggling with control of the airplane and declared an emergency. The captain told the first officer, "Pull…pull…pull." About 1903:23, Flight 427 crashed in hilly, wooded terrain 6 miles northwest of Pittsburgh.

The Investigation

FDR evidence showed that Flight 427 encountered wake vortices from a Delta Airlines 727 that was flying about 4 miles ahead. However, the results of wake-vortex flight tests and the Safety Board's computer simulations indicated that Flight 427 would not have remained in the wake long enough to have produced the heading change and bank angles that occurred after 1903.

The Safety Board conducted extensive thermal tests on the recovered rudder components of Flight 427, as well as on new rudder components, to determine if a mechanical anomaly in the rudder system was the cause of the crash. During the most severe thermal tests, the secondary slide jammed to the servo valve housing, and hydraulic fluid flow data indicated that a momentary reversal of the rudder occurred during this jam. Although Flight 427's servo valve jammed repeatedly during these extreme thermal tests, the new-production servo valve also subjected to these tests never jammed. Examination of the internal measurements of both servo valves indicated that the servo valve on Flight 427 had significantly tighter diametrical clearances between the secondary slide and the servo valve housing than the new-production servo valve. Therefore, the Safety Board considered it likely that the servo valve on Flight 427 was more susceptible to a jam because of its tighter clearances.

Furthermore, the thermal tests demonstrated that it is possible for the secondary slide of the servo valve to jam to the valve housing and leave no evidence of physical marks. Thus, with the secondary slide jammed, it is possible for the primary slide to overtravel and cause a rudder hardover in the direction opposite to that commanded without leaving any physical evidence.

FLIGHT CREW ACTIONS

The Safety Board considered that the flight crew's control wheel inputs in response to the initial wake turbulence encounter and rudder reversal were reasonable pilot reactions to the evolving situation. Therefore, the flight control inputs used in the Safety Board's computer simulation of the upset are consistent with the pilot responses that might be expected during a rudder reversal. The Safety Board added that such reversals are often fatal because few pilots (including test pilots) are able to absorb the information, analyze it, and apply inputs to correct the situation in the moments available before the airplane enters an unrecoverable attitude.

EASTWIND AIRLINES FLIGHT 517

On 9 June 1996, Flight 517 experienced a yaw and roll upset at about 4,000 feet msl, while on approach to Richmond, Virginia. The flight crew regained control of the airplane and landed without further incident.

During postaccident interviews, the captain reported that he was flying the airplane without the autopilot engaged and his feet resting lightly on the rudder pedals during the descent to land in Richmond. As the airplane descended through 5,000 feet, the captain felt a brief rudder "kick" or "bump" on the right rudder pedal, but the pedal did not move. As the airplane reached 4,000 feet, the airplane yawed abruptly to the right and then rolled to the right. The captain stated that he immediately applied "opposite rudder and stood pretty hard on the pedal," but it did not respond. He also applied left aileron, and according to the first officer the captain was "fighting, trying to regain control…standing on the left rudder." Although the flight control inputs slowed the yaw and roll event, the airplane continued trying to roll. The flight crew performed the emergency checklist and disengaged the yaw damper. The upset event stopped, and the airplane flew normally for the remainder of the flight.

Maintenance records for the airplane revealed three pilot reports for rudder-related events during the month preceding the incident. The captain of Flight 517 was flying on one of those previous flights and described a series of uncommanded "taps" on the right rudder pedal just after takeoff. He said that it felt "like someone hitting their foot on the right rudder." The captain returned to the departure airport, and the main rudder PCU was replaced that same day. The captain further reported that the rudder pedal "bumps" were identical on both flights.

When investigators examined the rudder system and the main rudder PCU after the June 9 incident, they determined that the PCU servo valve had a relatively tight clearance, similar to those measured in the USAir Flight 427 PCU servo valve. Thus, the Eastwind servo valve (as with the servo valve on Flight 427) would be more likely to jam than a servo valve with greater clearances—such as found on new-production valves.

Flight Crew Performance

The captain had adopted a personal technique of routinely disengaging the autopilot as his airplane descended through 10,000 feet msl. Consequently, when Flight 517 approached Richmond on the night of the incident, the captain was hand flying the airplane with his feet on the rudder pedals. When the captain felt the rudder pedal "bump" and the airplane immediately yaw sharply to the right and roll, he immediately applied left rudder and the appropriate control column inputs. But unlike the United and USAir flights, Flight 517 was moving throughout the event at a speed that remained well above the crossover speed—the speed in which maximum roll control can no longer counter the yaw and roll effects of a rudder deflected to its blowdown limit. Thus, the Eastwind pilots had sufficient roll control authority to overcome the effects of a full rudder deflection, and according to the Safety Board, was clearly a factor in the ability of the flight crew to recover from the event.

Conclusion—Rudder System Jam Scenarios

In its examination of the rudder systems of the USAir Flight 427, United Flight 585, and Eastwind Flight 517 airplanes, the Safety Board was unable to identify any obvious physical evidence that a jam occurred within the servo valve. Further, the investigation has not revealed how the secondary slide could jam to the servo valve housing under conditions that would normally be encountered by an airplane in air carrier operations and not leave any physical evidence that the jam occurred. However, the Safety Board demonstrated that, in servo valves with tight clearances, the secondary slide could jam to the servo valve housing and leave no physical evidence of that jam. Additionally, small particulate matter in the hydraulic fluid could reduce the already tight clearances in the servo valve, requiring less of a thermal differential for the valve to jam. It is therefore possible for a large amount of small particles to provide the jamming potential of a larger, stronger piece of metal without leaving a mark.

Testing showed that when the secondary slide was jammed to the servo valve housing and sufficiently high-rate force was applied on the input crank, the rudder system could allow the primary slide to overtravel and result in a reverse rudder command. Therefore, the Safety Board concluded the servo valve secondary slide could jam to the servo valve housing at a position offset from its neutral position without leaving any obvious physical evidence and that, combined with a rudder pedal input, could have caused the rudder to move in the opposite direction.

Block Maneuvering Speeds

The recommended maneuvering speeds for each flap configuration that provide adequate airspeed for maneuvering in at least a 40-degree bank without activation of the stickshaker are referred to as the *block maneuvering speeds*. The *block* term simplified the concept so that a single airspeed was specified for all airplane weights less than 117,000 pounds; thus, airplanes operating at weights lighter than 117,000 pounds (such as USAir Flight 427) had a greater maneuvering margin.

The Safety Board actively promoted the practice of adding 10 knots to the B-737 block maneuvering speeds. This allows a safer margin of controllability in the event of a rudder hardover.

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Case Study V-3: ValuJet 592

Safety issues: In-flight fire, hazardous cargo

On 11 May 1996, a ValuJet Airlines DC-9-32 caught fire in-flight and crashed in the Everglades about 10 minutes after takeoff from Miami, Florida, International Airport.

Probable Cause

The NTSB determined that the probable cause of this accident was a fire in the airplane's class D cargo compartment that was initiated by the actuation of one or more oxygen generators being improperly carried as cargo. The Safety Board noted that the fire was the result of (1) the failure of SabreTech (the contract maintenance facility) to properly prepare, package, and identify unexpended chemical oxygen generators before presenting them to ValuJet for carriage; (2) the failure of ValuJet to properly oversee its contract maintenance program to ensure compliance with maintenance, training, and hazardous materials requirements and practices; and (3) the failure of the FAA to require smoke detection and fire suppression systems in Class D cargo compartments.

The NTSB concluded that contributing to the accident was (1) the failure of the FAA to adequately monitor ValuJet's heavy maintenance programs and responsibilities, including ValuJet's oversight of its contractors, and SabreTech's repair station certificate; (2) the failure of the FAA to adequately respond to prior chemical oxygen generator fires with programs to address the potential hazards; and (3) ValuJet's failure to ensure that both ValuJet and contract maintenance facility employees were aware of the carrier's "no-carry" hazardous materials policy and had received appropriate hazardous materials training.

History of Flight

ValuJet Flight 592 was a regularly scheduled flight from Miami to Atlanta, Georgia. The DC-9 departed Miami at 1403 Eastern Daylight Time with 105 passengers and 5 crewmembers on board.

Pilot Experience

The captain had 8,928 total flight hours, 2,116 in the DC-9. She had been a DC-9 captain with ValuJet since 1 May 1994 and had accumulated 1,784 hours in that position.

The first officer had 6,448 total flight hours, 2,148 in the DC-9. He completed DC-9 training on 2 December 1995. According to his ValuJet employment application, the first officer had an additional 5,400 hours as a military and civilian flight engineer and had accumulated 400 hours as an MD-80 international relief captain for a Part 121 supplemental air carrier.

Weather

Weather was not a factor in this accident.

The Accident

Note the speed with which the fire spread. The airplane was approaching 10,000 feet at 1410:03 when an unidentified sound was recorded on Flight 592's CVR, after which the captain remarked, "What was that?" The captain added, "We got some electrical problem…we're losing everything." Immediately thereafter, the captain told the first officer, "…we need to go back to Miami." Seconds later, shouts in the background of "Fire, fire, fire, fire," and a male voice saying, "We're on fire, we're on fire," were heard on the CVR.

At 1410:31, the first officer radioed to Miami Center that the flight needed an immediate return to Miami. The sounds of shouting subsided five seconds later followed by the controller asking the flight about the nature of the problem. The captain said "fire," and the first officer replied to the controller, "…smoke in the cockp…smoke in the cabin." The controller gave the flight a descent clearance to maintain 5,000 feet. At 1411:12, a flight attendant was heard shouting, "completely on fire."

For the next 34 seconds the first officer and controller periodically engaged in communication concerning the emergency descent and the determination of the nearest airport. At 1412:45, the controller attempted to raise Flight 592 on the radio, but there was no response. According to the FDR, the airplane was at 7,200 feet and at a speed of 260 KIAS. Approximately three seconds later the FDR stopped recording data; however, the airplane's radar transponder continued to function allowing ATC to track Flight 592's position and altitude data.

Impact Area

Flight 592 crashed in the Everglades at 1413:42 in a right-wing-down, nose-down attitude. The site was approximately 17 miles northwest of Miami International Airport. The force of the impact created a crater 130 feet long and 40 feet wide. Most of the wreckage debris was located south of the crater in a fan-shaped pattern, with some pieces of wreckage scattered more than 750 feet south of the crater.

According to two witnesses who were fishing from a boat in the Everglades, the aircraft hit the ground in a nearly vertical attitude. They described a great explosion, vibration, and a huge cloud of water and smoke. Two additional witnesses who were sight-seeing in a nearby private airplane provided similar accounts of the accident.

The Investigation

The Safety Board learned early in its investigation that the fire originated in the Class D (forward) cargo compartment, and that a number of chemical oxygen generators stored in cardboard boxes and loose aircraft tires were loaded into that compartment prior to departure. Due to the explosive nature of unexpended oxygen generators and their close proximity to combustible tires, the Board pursued the theory that those items were a likely source of the fire.

Oxygen generators, together with oxygen masks, are mounted behind panels above passenger seats. During cabin decompression, the generators activate, the panel and mask assemblies drop, and emergency oxygen is provided to the passengers. Each mask is connected to its generator in two places. A plastic tube through which the oxygen will flow is connected from the mask assembly reservoir bag to an outlet fitting on one end of the oxygen generator. A lanyard, or slim cord, connects each mask to a retaining pin that restrains the spring-loaded initiation mechanism. The lanyard and retaining pin are designed such that a 1 to 4 pound pull on the lanyard will remove the pin.

When the retaining pin is removed, the spring-loaded initiation mechanism strikes a percussion cap containing a small explosive charge mounted in the end of the oxygen generator. The percussion cap, when struck, provides the energy necessary to start a chemical reaction in the generator oxidizer core, releasing breathable oxygen. A protective-shipping cap that prevents mechanical activation of the percussion cap is installed on new generators. The shipping cap is removed when the oxygen generator has been installed in the airplane and the final mask drop has been completed.

Chemical oxygen generators are stainless-steel cylinders. Those carried on Flight 592 were approximately 2.5 inches in diameter and

9 inches in height, and weighed about 1.5 pounds. When full, each generator has the capacity to produce oxygen for between 15 and 20 minutes.

FIRE TESTS

A series of five tests involving oxygen generators was conducted at the FAA's fire test facility near Atlantic City, New Jersey, under the direction of the Safety Board. Investigators placed 24 to 28 generators in cardboard boxes, covered the top row of generators with about 2 inches of "bubble wrap," and pulled the retaining pin for one of the generators before sealing the boxes. The first test resulted in minor smoke generation, but when the test was repeated, the temperature in the top of one of the boxes rose to 2,000°F only 10 minutes after ignition. The temperature about 1 foot above the box (approximate distance to the ceiling of Flight 592's cargo compartment) exceeded 2,000°F within 15 minutes after ignition.

In the third test, five boxes of generators were stacked on the floor similarly to how they were actually stowed on Flight 592. Investigators ended the test after 13 minutes when only minor smoke was observed. The fourth test resulted in a fire with the temperature above one of the boxes reaching 2,000°F about 13 minutes after the retaining pin was pulled. About three minutes later the temperature rose to 3,000°F.

For the final test, investigators stacked two boxes of generators on top of a main gear tire. The other three boxes of generators were placed around the tire, and luggage was positioned around the tires and boxes. About 10 minutes after ignition, the ceiling of the test cargo compartment reached 2,000°F; after 11 minutes, the temperature rose to 2,800°F. Seconds later, the temperature exceeded the temperature measuring device's limit of 3,200°F. A couple of minutes later, the tire ruptured.

THE FINAL DESCENT

Immediately upon recognizing the loss of electric power, the captain made the decision to descend and return to Miami. For the next 80 seconds, however, Flight 592 continued on a northwesterly heading away from Miami. Meanwhile, the controller vectored the aircraft for a wide circle to the left and a gradual descent back toward Miami. Because of the speed and severity with which the fire engulfed the cabin, the extra time spent flying away from Miami was inconsequential to the outcome of the flight.

Investigators evaluated the electrical system, engine, and flight control malfunctions that occurred during those 80 seconds and determined that the problems the flight crew faced were the result of insulation burning on wires in the cargo compartment. Therefore, the flight crew's comments about the electrical problems indicate that the fire had probably already burned through the cargo compartment by 1410:12.

At 1411:20, events recorded on the FDR indicate that the flight crew was confronted with a disruption in pitch control and was attempting to maintain partial control of the airplane. The persistence of malfunctions from the electrical system, engine thrust controls, and flight controls illustrates the progressive nature of the degradation in the structural integrity and flight controls of the airplane.

Investigators believe from radar data that the flight crew remained in at least partial control of the jet for a little over three minutes, shortly before impact. The data shows that at 1412:58, when the airplane was at 7,400 feet, it began a steep left turn toward Miami and a rapid descent. For the next 32 seconds, the descent rate averaged 12,000 feet per minute, and the airplane turned from a southwesterly heading toward the east. The left turn stopped and descent rate was reduced when the airplane was heading toward Miami at 900 feet. The control of these inputs show that at least one pilot was conscious until 1413:34.

FAA INSPECTIONS OF VALUJET

In the 3½-year period between ValuJet's initial certification and the accident, the FAA conducted 1,471 maintenance-related inspections. At no time, however, did any ValuJet principle maintenance inspector (PMI) inspect the SabreTech facility. According to the PMI at the time of the accident, he was in the middle of an on-site inspection of SabreTech in January 1996 when he was called away to address an unrelated problem at another contractor.

The PMI requested additional inspectors in operations and airworthiness for the oversight of ValuJet. The division manager for the Atlanta Flight Standards District Office (FSDO) denied his request because the "staffing model that flight standards used to make a determination about additional staffing did not account for factors such as rapidly growing air carrier."

The principle operations inspector (POI) testified that starting in August 1995, "...ValuJet was running about 40 pilots through their training program each month...with one assistant...I had him tied up almost totally doing flight checks, all hours of the day and night. I had to borrow from other units...."

FAA SUMMARY MAINTENANCE REPORT ON VALUJET

An Aircraft Maintenance Division (AFS-300) of the FAA's Office of Aviation Flight Standards prepared a report summary dated 14 February 1996. The report addressed, "...ValuJet Airline's accident/incidents, enforcement history, NASIP inspections, and the FAA's surveillance activity." Airworthiness concerns followed two ValuJet accidents and a DOT Office of Inspector General audit of the air carrier. The four occurrences cited in the FAA's letter included (1) "Landing in Atlanta with '0' fuel in the left fuel tank and 1,400 pounds in the right fuel tank instead of landing at the nearest suitable airport" (May 8, 1995); (2) "Continuing to Nashville with a gear problem, which resulted in an accident, instead of returning to Atlanta where maintenance was available" (January 7, 1996); (3) "Runway excursion in Atlanta while landing on a wet runway beyond the landing touchdown zone" (January 26, 1996): and (4) "Runway excursion in Savannah" (February 28, 1996).

The report further revealed that "in all areas analyzed [records and procedures, airworthiness surveillance, and aircraft records], ValuJet was at the advisory and or alert threshold in the majority of the months studied." The report concluded, "The data reviewed, clearly show some weakness in the FAA's surveillance of ValuJet...some critical surveillance activities did not receive much attention." Specifically, the report noted that for 1994 and 1995, only six inspections of manuals and procedures, five inspections of shop and facilities, and no inspections of the carrier's structural inspection program were conducted.

Discrepancies of testimony arose between the deputy director of flight standards, Atlanta FSDO, and the manager of the Aircraft Maintenance Division (AFS-300) who produced the summary report. According to investigators, the Atlanta FSDO "confirmed" during a follow-up interview "that pertinent issues of concern had been passed on by a summary report staff member." The FSDO added that they had not received the report, itself, until after the accident. At the Board's public hearing, the deputy director of flight standards testified that he had "no knowledge of the [summary report] before the accident." Opposing that assertion was the manager of AFS-300 who testified that he "personally delivered a copy of the report to the deputy director and a copy of the report was also forwarded to him as part of a congressional hearing preparation package." Officials from both ValuJet and the Atlanta FSDO stated that they had no knowledge of the existence of the report before the accident.

On 22 February 1996, the FAA began a 120-day intensive surveillance of ValuJet. The manager of the Atlanta FSDO provided testimony at the Board's public hearing as to why the inspection was necessary. In part, he noted,

> We were quite concerned about some indicators, certainly the accident/incident rate.…We were concerned about…ValuJet's rapid growth. We were concerned about the amount of vendors. They were a non-traditional carrier, which proved rather difficult for us to survey…When you have a carrier that contracts…all over the United States to do [maintenance], it's rather difficult to get out there to see it…So it caused further problems.

A letter dated 29 February 1996 to ValuJet's president and chief operating officer signed jointly by ValuJet's POI, PMI, and principal avionics inspector stated in part:

> ValuJet Airlines has recently experienced four occurrences. These occurrences coupled with the preliminary findings of the [FAA's] Special Emphasis Review completed on February 28, 1996, give us concern that ValuJet is not meeting its duty to provide service with the highest possible degree of safety in the public interest. It appears that ValuJet does not have a structure in place to handle your rapid growth, and that you may have an organizational culture that is in conflict with operating to the highest possible degree of safety.

ValuJet's rapid growth was indeed taking a maintenance and safety toll. On 1 May 1996 (11 days before the accident), the FAA released an interim report detailing the findings of inspectors who were conducting the 120-day maintenance inspection of the airline. According to the report, during the first week of their inspection program, ValuJet experienced 132 maintenance delays. This was in comparison to 44 maintenance delays per week during January 1996. The report also stated that of six airplanes inspected by the FAA immediately after having undergone contract maintenance checks, five had maintenance discrepancies. Although the most "notable discrepancies were concerning flight attendant seats, loose or missing hardware," it showed a pattern of sloppy work.

TRANSPORTING HAZARDOUS MATERIALS

At the time of the accident, ValuJet's company operations manual stated in two separate chapters that, "ValuJet will not engage in transportation of hazardous materials." The manual cited the appropriate section of the federal regulation (49 CFR 175.10) concerning hazardous materials exempted from that classification and allowed to be transported on commercial aircraft. The list includes items such as properly packed small-arms ammunition in checked baggage, aviation fuel and oil in properly installed tanks, and tire assemblies provided the tire pressure does not exceed a certain level. Chemical oxygen generators do not appear on the list of approved items and, therefore, are classified as hazardous materials.

Numerous references to ValuJet's hazardous materials policy were found in the operations manual. In part, they included

> Prompt recognition and refusal of such materials is essential to the safety of our passengers and employees because these materials can cause harm to employees handling them or to the aircraft.
>
> No packages are accepted containing hazardous material.
>
> It is important that all customer contact personnel, ramp personnel, flight crews, and dispatchers have awareness to identify Hazardous Materials.
>
> Cargo may be declared under a general description that may have hazards, which are not apparent, and the shipper may not be aware of this. You must be conscious of the fact that these items have

> caused serious incidents, and in fact, endangered the safety of the aircraft and personnel involved.
>
> Your responsibility in recognizing hazardous materials is dependent on your ability to 1. Be Alert! 2. Take the time to ask questions! Look for labels! Ramp agents should be alert whenever handling luggage or boxes.
>
> [*Printed in Capital Letters*] REMEMBER: SAFETY OF CUSTOMERS AND FELLOW EMPLOYEES DEPENDS ON YOU!

PRIOR HAZARDOUS MATERIALS INCIDENT

According to an FAA "enforcement investigative report," on 15 February 1995, a passenger on a ValuJet flight asked a ticket counter representative if she could take her oxygen cylinder on the airplane. The ticket agent was unfamiliar with the procedures for handling oxygen and asked another agent for assistance. However, after the airport security personnel refused to let the passenger through the security checkpoint with the cylinder, a ticket agent examined the cylinder, determined it to be empty, and accepted it as checked baggage.

Meanwhile, airport security had notified an employee at the FAA Civil Aviation Security office, who sent someone to the ticket counter to examine the cylinder. Pressure tests revealed that the cylinder had 1600 pounds per square inch gage of gas, and, therefore, the cylinder was not loaded on the airplane. According to the FAA report, ValuJet violated seven sections of the hazardous materials regulations. As a result of this incident, the FAA issued ValuJet a letter of warning.

VALUJET MAINTENANCE AND SABRETECH TRAINING

SabreTech of Miami, Florida, was an FAA-certificated Part 145 domestic repair station. ValuJet provided SabreTech with the documentation necessary to perform repetitive heavy-check maintenance services, including master copies of all ValuJet routine work cards.

At the time of the accident, ValuJet had six full-time instructors to train its own maintenance personnel. The SabreTech manager of maintenance training was trained at the Miami facility by a ValuJet employee who briefed him on the airlines' policies and procedures. The SabreTech manager subsequently trained SabreTech employees on ValuJet's airworthiness release procedures. The two-hour course focused on ValuJet's policies, procedures, paperwork, and the General Maintenance Manual (GMM). According to the SabreTech manager, the Miami facility did not provide a hazardous materials training program to its employees regarding the recognition or shipping of hazardous materials nor was such a program conducted by ValuJet.

The director of logistics at SabreTech told investigators that personnel relied on prior training to recognize hazardous materials because the facility had no previous experience handling oxygen generators. The president of SabreTech testified that his company did not know what was acceptable to ValuJet regarding carriage of hazardous materials aboard its airplanes.

According to the Board, chemical oxygen generators should not have been aboard Flight 592 because the airline was not authorized to carry hazardous materials.

ROUTINE WORK CARD

To confirm the completion of each step in the removal and installation of chemical oxygen generators, the maintenance work card had to be signed by the mechanic who did the work and by his or her supervisor. At issue is that the signatures meant the work was complete, *not* inspected. Furthermore, a warning was noted on the work card concerning the high temperatures produced by an activated generator, but it did not mention that unexpended generators required special handling for storage or disposal. The Board concluded that had warning labels been attached to the generators, ground personnel would most likely have handled or shipped the generators in an appropriate manner and "the accident would not likely have occurred."

LACK OF SAFETY CAPS

Based on a maintenance agreement between ValuJet and SabreTech, it was ValuJet's responsibility to provide supplies or parts that SabreTech would not normally carry in stock. Items such as generator safety caps were considered "peculiar expendables," and because SabreTech did not routinely handle oxygen generators, ValuJet was required to ensure that the safety caps were obtained and installed.

The installation of safety caps on generators was clearly specified on the maintenance work cards. Investigators noted that some SabreTech supervisors were advised by mechanics of the need for safety caps, but they took no action to acquire them, and no one followed up on the matter. A ValuJet technical representative assigned to the SabreTech facility told investigators that he observed generators without safety caps installed on other aircraft and had expressed concern to SabreTech mechanics that the generators were "hazardous when set off." Although he ensured the removal of those generators, he did not follow up on how the generators were disposed of or on the lack of safety caps.

The Safety Board was "alarmed at the apparent willingness of mechanics and inspectors at the SabreTech facility to sign off on work cards indicating that the maintenance task had been completed, knowing that the required safety caps had not been installed, and at the willingness of those individuals and other maintenance personnel (including supervisors) to ignore the fact that the required safety caps had not been installed."

LACK OF COMMUNICATION

Personnel in the shipping and receiving department were not informed about the generators when they were placed in the ValuJet customer hold area. According to the stock clerk, the boxes were already in the hold area one morning when he arrived at work. SabreTech had no formal procedure in place that required an individual leaving items in the shipping and receiving area to indicate what the items were or that they were hazardous. The stock clerk said that no one told him anything about the generators or the hazardous nature of the generators. Had SabreTech had a system requiring that items delivered to the shipping department be properly identified and classified as hazardous, and if that system had included procedures for tracking the handling and disposition of hazardous material, it is likely that the hazardous nature of the generators would not have been overlooked.

The stock clerk was told to clean up the shipping department because a prospective customer was coming to inspect the area. With boxes sitting on the floor, the stock clerk said that he asked the director of logistics if he could “close up the boxes and prepare them for shipping to Atlanta,” and heard “Okay” as the reply. The clerk believed that he had been given permission to ship the boxes, and that nobody had asked him what to do with the boxes. The director of logistics told investigators that he did not intend to have any of the ValuJet property shipped until after a disposition decision was made by the airline.

The Board determined that the lack of a formal system in SabreTech’s shipping and receiving department, including procedures for tracking the handling and disposition of hazardous material, contributed to the improper transportation of the generators aboard Flight 592.

Reference

National Transportation Safety Board. 19 August 1997. Aircraft Accident Report: In-flight Fire and Impact with Terrain. ValuJet Airlines Flight 592, DC-9-32, N904VJ, Everglades, near Miami, Florida. May 11, 1996.

Case Study V-4: Atlantic Southeast Airlines Flight 2311

Safety issues: Excessive wear in propeller control unit

On 5 April 1991, an Atlantic Southeast Airlines (ASA) Embraer Brasilia commuter crashed near the Brunswick, Georgia, Airport, after it went into an uncommanded and unrecoverable left roll.

Probable Cause

The NTSB determined that the probable cause of this accident was an in-flight loss of control as a result of a malfunction of the left engine propeller control unit (PCU) that allowed the propeller blade angles to go below the flight idle position. A contributing factor was the deficient design of the PCU by Hamilton Standard, and the approval of the design by the FAA. The design did not correctly evaluate the failure mode that occurred during this flight, which caused an uncommanded and uncorrectable movement of the blades of the airplane’s left propeller below the flight idle position.

History of Flight

Flight 2311 operated as a regularly scheduled, Part 135 commuter flight from Atlanta, Georgia, to Brunswick, Georgia. The Embraer (EMB-120RT) Brasilia departed Atlanta at 1347 Eastern Standard Time with 20 passengers and 3 crewmembers on board. Former U.S. Senator John Tower of Texas and NASA astronaut Manley Lanier Carter, Jr., were among the passengers.

Pilot Experience

The captain had 11,724 total flight hours, 5,720 in the EMB-120. He had been a pilot with ASA since 1981 and was considered an outstanding aviator. Four years after joining the airline, the captain became actively involved with the acceptance of the Brazilian-made EMB-120 into U.S. service. He received his training from the manufacturer at the same time as the FAA project pilot who subsequently gave him his type rating flight check. Written comments made by the flight examiner after the captain's check ride included, "Excellent flight check and oral test, has extensive knowledge of aircraft and systems. Excellent pilot techniques." The captain's last proficiency check was successfully completed less than two months before the accident.

The first officer had 3,925 total flight hours, 2,795 in the EMB-120. He began his flight training with ASA in July of 1988 and passed his initial proficiency check the same month. His most recent proficiency check was 11 months before the accident, and his last recurrent training was about five months later.

Weather

At the time of the accident (1451 Eastern Standard Time), the reported surface weather at Brunswick was as follows: Ceiling 2,500 feet scattered, estimated 10,000 feet broken, 20,000 feet broken; wind 160 degrees at 10 knots; visibility 7 miles; temperature/dewpoint 78°F/69°F; moderate rain was reported between 1303 and 1410.

The Accident

About 17 minutes before the scheduled departure time of Flight 2311, ASA made an airplane change because of mechanical problems with the airplane that was originally scheduled for the flight. The replacement airplane had already flown on four flights that day with no maintenance write-ups. Flight 2311 finally took off at 1347. *Note:* The aircraft was not equipped with either a CVR or DFDR.

The flight arrived in the Brunswick area around 1444, and four minutes later the crew told Jacksonville Center that the airport was in sight. They accepted their clearance for a visual approach and notified ASA at 1448:21 that the flight was "in range." That was the last known transmission from Flight 2311. The crew never made any indication to either ATC or the airline's station manager of any mechanical problems.

Among the witnesses who watched Flight 2311's approach was a person who held an airline transport pilot certificate. He was only 2 or 3 miles southwest of the airport when he saw the airplane on a left downwind to runway 07. According to his statement, the Brasilia was in a normal flight configuration when it turned the 180 degrees toward the final approach path in about a 20-degree bank and a gradual descent. The airplane suddenly pitched up about 5 degrees, rolled left until the wings were vertical with the horizon, and nose-dived into the ground. He reported that there was no visible fire or smoke during the flight and that he believed both propellers were rotating.

Many other witnesses also observed the horrific descent, and some commented that they heard loud engine noises described as a squeal, whine, or an overspeeding engine during the last seconds of the flight. They further stated that those noises diminished or ceased before impact.

IMPACT AND WRECKAGE PATH

The accident site was located about 1½ miles from the threshold of runway 07 at a bearing of 100 degrees. The terrain was flat and densely wooded. The wreckage path was around 250 feet, and damage to the trees indicated that the aircraft was in a steep left 90-degree angle of descent at impact.

The interior of the passenger cabin was destroyed by fire, and most of the fuselage between the cockpit and the aft cargo compartment was burned to ground level. Both wings were in their relative positions to the fuselage, but severely burned and distorted.

ACCIDENT SURVIVABILITY

According to the Safety Board, this accident was not survivable due to the high impact forces. The cause of death for the 20 passengers and 3 crewmembers was blunt force impact trauma.

The Investigation

The Safety Board conducted extensive examinations of aircraft and airframe components at the crash site. As a result they were able to rule out many possibilities as they began the grueling investigative work that awaited them.

Although most of the fuselage was destroyed by the postimpact fire, investigators found corroborating physical evidence at the scene that suggested the aircraft was operating normally just prior to the accident. The electrical, hydraulic, and fuel systems were functioning, flaps were set at 25 degrees, and the landing gear was extended. Both engines appeared to have been working as the Board noted an area of burned and shredded vegetation along the wreckage path. That type of related damage usually means that normal airflow and combustion in the engines existed at the time of impact.

Invaluable information was obtained from these on-site inspections, but the heart of this investigation centered on intensive tests and research conducted in airplanes, flight simulators, and laboratories across two continents.

FLIGHT SIMULATOR TESTS

Through a series of simulator and wind-tunnel tests, investigators were able to eliminate numerous in-flight failures. Asymmetric flap settings, hardover (an uncommanded position of a flight control surface due to a malfunction) aileron, hardover rudder, oscillating propeller blade angels, and an accidental power setting from flight idle to ground idle were all eventually ruled out.

AIRPLANE SYSTEMS

Selected components from the airplane were examined at the Safety Board's laboratory and at the respective manufacturers' facilities. The cockpit multiple alarm panel (MAP), the overhead panel, engine instruments, flap annunciator panel, engine control pedestal, autopilot control panels, and the engine flight idle lockout stops from the engine nacelles were studied in detail.

All 40 lightbulb capsules from the MAP and overhead panel were analyzed to see if any warning lights had been illuminated prior to impact. No problems were discovered in any specific system.

Following extensive tear-down inspections, the Board noted that there were no malfunctions with the hydraulic system, rudder power control unit and its two actuators, or the autopilot unit and its servo spools. Due to the damage of the engine flight-idle lockout stops and brackets, investigators were unable to determine the preimpact position of the engine controls.

ENGINE AND PROPELLER

The remainder of the investigation focused on the engine and propeller systems and the evidence that pointed to a failure in one of those units. The Pratt and Whitney PW-118 turbopropeller engine consists of a turbomachinery module and a reduction gearbox module that are joined to form a single unit. The turbomachinery includes two independent, coaxially mounted, centrifugal compressors that are each driven by a single-stage turbine. A two-stage power turbine drives the reduction gearbox by means of a coaxial shaft that passes through the compressor shaft. The gearbox, itself, drives a flanged propeller shaft.

The Hamilton Standard 14RF-9 propeller is a flange-mounted, controllable pitch, dual acting, full feathering, reversible, four composite-blade propeller. The propeller and PCU are mounted on a common centerline and are connected through the propeller shaft by the oil transfer tube. High-pressure oil from the main oil pump flows to the propeller hub through this tube. The PCU governor provides metered oil pressure to operate a ballscrew drive that gives a rotary motion to the transfer tube by means of a splined quill. The tube then turns an acme screw which positions the pitch change selector valve to either the increase pitch or decrease pitch side of the piston.

In this case, the splines in the PCU had been coated with a newer-designed titanium-nitrided surface, instead of the originally certified nitrided finish. As a result, the splines had a rough surface.

Through a series of tests, investigators determined that the blade angle on the right propeller was 22.6 degrees and the left propeller was 3 degrees. Those findings were based upon the position of the pitchlock acme screw. The left PCU ballscrew position revealed that the PCU had commanded a blade angle of 79.2 degrees. According to the Safety Board, the discrepancy between the positions of the ballscrew and the pitchlock acme screw was a strong indication that a disconnect of those two components occurred prior to impact. The left propeller had moved into an uncommanded blade angle below the normal flight range.

The position of the PCU ballscrew on each engine proved significant. When a propeller off-speed condition is sensed by the governor, oil pressure from the transfer tube is directed to one side or the other of the ballscrew to move the servo valve, thereby commanding an appropriate blade-angle change. However, if the speed change does not occur, the ballscrew will continue to move. Because the left PCU ballscrew was found in a position corresponding to a feather-blade angle and the left propeller actuator was at a low-blade angle position, it was apparent to investigators that the PCU was attempting to slow the propeller speed by increasing the blade angle.

In a related discovery, it was noted that the quills from both PCUs had severely worn internal splines. The spline teeth on the left quill were almost entirely worn away, and the wear pattern was slightly off the axial centerline. The right quill-spline showed a heavy wear pattern on one side but relatively little wear on the opposite teeth. The Safety Board believed that this was caused, in part, by the rough surface of the titanium-nitrided coating on the transfer tube spline sliding against the smoother nitrided quill-spline teeth.

Therefore, the Safety Board determined that the blade angle failed to change because the PCU was unable to adequately position the servo valve due to the worn quill spline. Think of it as having worn gears on a bicycle. As you try to change gears, the mechanism won't catch and engage the gear you've selected. Instead, the gear just keeps moving.

LOSS OF CONTROL

The Safety Board believed that the worn quill on the left engine PCU became disengaged from the transfer tube prior to the loss of control of the airplane. The propeller blades shifted to a low angle, resulting in an asymmetric lift and drag condition that exceeded the capability of the pilots to counteract. Without quill engagement, the pilot would have been unable to feather the propeller or have any control of the blade angle. He would have experienced limited control of engine speed, even if he had shut the engine down. The blade angle probably continued to decrease due to a centrifugal twisting moment caused by the distribution of mass along the propeller blade chord line. Consequently, a state of high asymmetric drag would have existed along the wing section aft of the propeller disk, resulting in a substantial loss of lift.

FLIGHT CREW ACTIONS

According to the Board, the pilots of Flight 2311 could not have prevented this accident. From statements made by test pilots who took part in the investigation, there was a consensus that when a propeller blade angle on an EMB-120 was between 24 and 26 degrees, the airplane would begin to mishandle. Once the propeller reached the 22-degree stop position, the aircraft would became "very difficult to control." The Board believed that the flight crew might not have noticed a problem with the airplane until the propeller began to overspeed. Since they considered it too dangerous to attempt actual flight scenarios, investigators were unable to duplicate the probable sequence of events. As a result, the Safety Board has suggested that the severity of the asymmetric lift and drag factor might have been significantly greater than any of their simulated tests.

FAULTY TESTING

Representatives and engineers from Hamilton Standard told investigators that during the FAA certification process, they conducted numerous tests, failure analyses, and computer-simulation models of the propeller system. The manufacturer believed that because of the fail-safe design of the propeller, a disengagement of the quill from the transfer tube would cause the blade angle to either remain in place or move into a feathered position. Since neither situation would be considered unsafe, the company did not propose any periodic inspection or in-service time limits on the PCU.

Hamilton Standard reported that the surface finish on the transfer-tube spline was changed in order to improve the ability of the company to manufacture the part. In following FAR 21.93, they were allowed to initiate a minor-type design change without prior FAA approval. As part of the certification paperwork submitted to the FAA, Hamilton Standard showed they had considerable experience in using titanium-nitrided coatings on similar materials—but not the specific PCU in question—with various surface finishes without any problems. They also included test reports that confirmed the propeller system was reliable to at least 500 feather cycles and 750 reverse cycles. Their documentation further proved that the wear rate for the new coating was up to four times less than the original nitrided finish. After review of the data, the FAA approved the design change and type certificate.

In light of the investigation, the Safety Board noted that Hamilton Standard conducted tests based on two critical oversights. First, they used a different engine than that certificated for the EMB-120, and as a result were unable to accurately simulate in-flight loads and vibration. Second, instead of also using a rough-surfaced, titanium-nitrided transfer tube for their propeller tests, they used ones with a smooth surface, exclusively. Consequently, the test data did not show a typical range of surfaces that would be found operationally.

In January 1991, a PCU for the model 14RF-9 propeller was returned to the company for a routine service repair. During the inspection, it was noted that the splines on the quill were extremely worn. The quill had been in service for nearly 4,000 hours. In the following four months, three other worn PCU quills were discovered. All the units had been sent in for repair after the operators found a problem with the feather/unfeather modes. The time in service ranged from 726 hours to almost 2,000 hours. Hamilton Standard engineers also reported that those faulty PCUs were originally equipped with a transfer tube that had the titanium-nitrided splines rather than the nitrided finished splines.

Investigators were told by the company that there had never before been a problem with this type of quill-spline wear, even though many PCUs had already accumulated several thousand hours in service.

Therefore, the Board determined that the accelerated wear was a result of the recent addition of titanium nitride–coated spline teeth.

A REVISITED RESPONSE

Based upon the number of worn quills, including those from Flight 2311, Hamilton Standard issued an Alert Service Bulletin on 7 May 1991 advising all operators to inspect PCUs for damaged quills. The manufacturer also began a fleet campaign to remove the titanium-nitrided transfer tubes from service and replace them with the original nitrided tubes.

Two days later, the FAA issued an emergency Airworthiness Directive (AD) that required the periodic inspection of the PCU ballscrew quills on those units with a titanium-nitrided transfer tube. At the time, a maximum of 500 in-service hours was considered an appropriate schedule. A few days later, there was a report of a quill that passed inspection but failed when it was reinstalled in the PCU. As a result, another AD was issued on 19 May that reduced the inspection time to a maximum of 200 in-service hours.

Once the transfer tube replacement program was completed by August 1991, the FAA terminated the AD status on the PCU. However, about seven months later an EMB-120 experienced a loss of propeller control after takeoff from Rome, Italy. Fortunately, the damage was not catastrophic and the crew was able to successfully land the airplane. An inspection of the PCU revealed that the outer-diameter splines of the servo ballscrew were extremely worn, which prevented the quill from engaging. Based on those findings, Hamilton Standard again issued a service bulletin that called for periodic inspections for wear of the internal splines on the 14RF-9 propeller model. One month later, on 10 April 1992, the FAA issued an AD that required operators to comply with the manufacturer's service bulletin.

Final Analysis

According to the Safety Board, the pilots of Flight 2311 "could not have prevented this accident." Without the benefit of a CVR and FDR, specific analysis of flight crew performance was unobtainable.

Reference

National Transportation Safety Board. 28 April 1992. Aircraft Accident Report: Atlantic Southeast Airlines, Inc., Flight 2311. Uncontrolled Collision with Terrain. An Embraer EMB2D120, N270AS. Brunswick, Georgia. April 5, 1991.

Case Study V-5: United Airlines Flight 232

Safety issues: Catastrophic engine failure in cruise flight, CRM, cockpit discipline, ADM

On 19 July 1989, a United Airlines DC-10 experienced a catastrophic engine failure at cruise altitude. The crew struggled with the airplane that no longer responded to flight control inputs. More than 30 minutes later, Flight 232 crashed while attepting to land at Sioux City, Iowa.

Probable Cause

The NTSB determined that the probable cause of this accident was the inadequate consideration given to human factor limitations in the inspection and quality-control procedures used by United Airlines' engine overhaul facility. This resulted in the failure to detect a fatigue crack originating from a previously undetected metallurgical defect located in the stage 1 fan disk. The subsequent catastrophic and forceful disintegration of the disk caused debris to penetrate the hydraulic systems that operated the DC-10's flight controls.

History of Flight

Flight 232 operated as a regularly scheduled flight from Denver, Colorado, to Philadelphia, Pennsylvania, with an intermediate stop in Chicago, Illinois. The DC-10 departed Denver's Stapleton Airport at 1309 Mountain Daylight Time with 285 passengers and 11 crewmembers on board.

Pilot Experience

The captain had 29,967 total flight hours, 7,190 in the DC-10. He had been with United since 1956 and was requalified as a DC-10 captain in 1987 after serving as a 727 captain for the previous two years. His most recent proficiency check in the airplane was three months before the accident.

The first officer had approximately 20,000 total flight hours, 665 in the DC-10 right seat. He was hired by United in 1985 after flying for National Airlines and Pan Am. He successfully passed his last proficiency check 11 months before the accident.

The second officer had an estimated 15,000 total flight hours, 33 in the DC-10. He had been with United since 1986 and had just completed his DC-10 transition training a little more than a month prior to the accident. His last check ride was at the same time.

An off-duty training/check captain assisted the crew during the emergency. A pilot with United since 1968, he had 23,000 total flight hours. He had logged 2,987 hours in the DC-10, of which 79 were as captain.

Weather

At the time of the accident, the surface weather observation at Sioux City Airport was an estimated ceiling of 4,000 feet with broken clouds and 15 miles visibility. There were towering cumulus clouds in all quadrants. The wind was shifting between 010 degrees at 11 knots to 360 degrees at 14 knots.

The Accident

Note: The following account of the accident is a combination of the Safety Board report and the captain's personal recollection of the events.

About one hour and seven minutes (1516:10 Central Daylight Time) after Flight 232 departed Denver, and at a cruise altitude of FL 370, the flight crew heard a loud bang followed by a vibration and shudder of the airframe. The first officer immediately grabbed the yoke as the captain and second officer evaluated the siutation. After checking the engine instruments, the crew determined that the number two aft (tail-mounted) engine had failed. To the crew's surprise, they were unable to shut down the engine. The number two throttle and fuel lever had frozen in position. The crew quickly actuated the firewall shutoff valve, and the fuel supply to that engine was finally cut off. It was in those few seconds that the crew realized that they weren't dealing with a simple engine failure. About that time, too, the scond officer noticed that the airplane's normal systems hydraulic pressure and quantity gauges were at zero.

Seconds later, the first officer told the captain that he could not control the aircraft. According to the captain, the first officer was applying full left aileron, the control column was laying in his lap, and he was calling for full-up elevator, yet the airplane was in a descending right turn with an increasing bank angle. The captain immediately confirmed the lack of response to flight control inputs and reduced power in the number one engine. The airplane began to roll back to a wings-level attitude. The crew also tried to restore hydraulic power by activating the air-driven generator, which operates the number one auxiliary hydraulic pump. With the pump selector on, the hydraulic system was still dead.

At 1520, the crew radioed Minneapolis center and requested emergency assistance and vectors to the nearest airport. The Sioux City Gateway Airport was about 50 miles away. Because Flight 232 was already heading in that direction, the captain decided to accept Sioux City as the emergency airfield.

Passengers were informed of the situation shortly after the engine failure, and the senior flight attendant was called to the cockpit. She was told to prepare the cabin for an emergency landing. Another flight attendant advised the captain that an off-duty United DC-10 training/check pilot was on board and had volunteered his services. He was immediately invited to the cockpit and briefed of the problem. Shortly thereafter, the captain directed him to try and determine the damage as seen through the aft cabin windows.

In the meantime, the crew confirmed the state of the hydraulic pressure had not changed and around 1531 the captain said, "We're not gonna make the runway, fellas." The check pilot soon returned and reported that, "Both your inboard ailerons are sticking up. That's as far as I can tell." With the check pilot eager to help, the captain drafted him to operate the throttles. For about 15 minutes, the captain and the first officer had struggled with handling the yoke and power adjustments. Alternating opening and closing the number one and three engines was the only way they could maintain some flight control. The captain told the check pilot to move the throttles in response to their commands, hoping that by one person concentrating on the necessary series of adjustments they would experience a smoother ride and a little extra control.

By that time, the crew had already dumped fuel and was about 35 miles northeast of the Sioux City airport. Concerned that the cabin was not yet prepared for landing, the captain explained to the senior flight attendant the seriousness of the emergency and that they were heading for Sioux City. He told her that it would be a difficult landing and that he had doubts as to the outcome. He concluded by telling her that when the flight attendants hear the warning, "brace, brace, brace," over the public address system, that would be their signal to prepare the passengers for landing.

As the crew continued to wrestle for control of the airplane, they had to compensate for the phugoids, each lasting between 40 and 60 seconds. A phugoid is a longitudinal oscillaton caused when an aircraft is displaced along the longitudinal axis. Provided an airplane is trimmed and the power setting is constant, phugoids are supposed to dampen themselves out after a few nose-up and nose-down cycles. However, as the captain recalled, the crew was never able to eliminate the phugoids altogether because of the inherent flight characteristics of the DC-10 and the inability of the damaged aircraft to maintain constant, level flight.

The captain explained that the DC-10 is designed to stay trimmed to level flight. Because Flight 232 was trimmed to a 270-knot cruise speed before the engine failed, that is what the aircraft attempted to maintain. The crew was often adding large amounts of thrust which raised the nose, causing the airplane to retrim, and enter into another phugoid. According to the captain, the technique to stop phugoids is the opposite of what pilots might normally think. For example, when the nose pitches down and the airspeed increases, the pilot must add power in order for the nose to come up. This is due to the pitch-up characteristics created by the two underwing-mounted engines. Once the nose strats to pitch-up, and the airspeed falls off, the pilot must then close the throttles. In the case of Flight 232, this maneuvering was especially difficult because each time the crew needed to add or decrease the power for phugoid control, it was necessary for them to increase or take away power on either side. Otherwise, the airplane would have rolled over.

The crew faced additional problems of the precise timing required to arrive at the airport at the correct heading and altitude. Because they were unable to maintain a constant rate of descent, they used a basic DC-10 formula as a guide. For every 1,000 feet of descent, the aircraft should travel 3 miles.

Since the crew had to contend with an airplane that wanted to turn only to the right, they compensated by making a series of right turns until they reached the vicinity of the airport. Refer to Fig. V-A. When Flight 232 reached 21 miles north of the field, the approach controller requested they widen their turn slightly to the left in order to get aligned with the runway, and to stay away from the city. The captain emphasized, "Whatever you do, keep us away from the city." Around 1551, the controller gave the crew a heading of 180 degrees, quickly followed by a warning that a 3,400 foot tower was located 5 miles to their right.

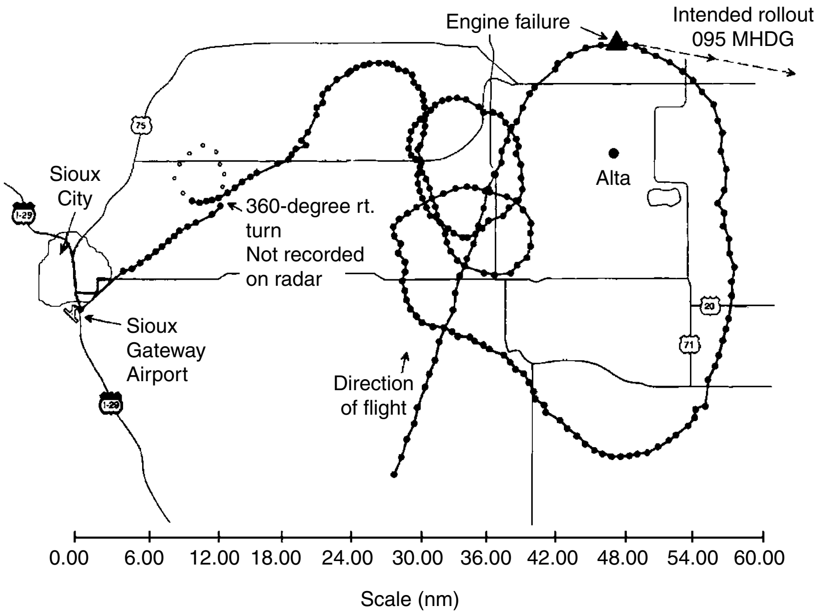


Fig. V-A. Ground track of flight 232. Adapted from NTSB.

Although the crew tried to increase the aircraft's bank angle to 30 degrees, the airplane did not respond normally, so they elected to fly straight ahead. At 1555, the controller advised the crew that if they could hold their altitude, their right turn to 180 degrees would put them 10 miles east of the airport. The captain answered, "That's what we're tryin' to do," and added that he wanted to get as close to the airport as possible.

The crew was able to maintain a heading of 180 degrees, and at 1557 the controller told them that the airport was, "twelve o'clock and one three miles." One minute later, the captain reported the runway in sight and thanked the controller for his help. The captain later noted that when they got down to 3,500 feet and actually saw a runway off their nose, they were in shock. They had found the runway, but now it was time to safely land on it.

Flight 232 was aligned with runway 22, which had been closed to accommodate the fire equipment. The controller had been trying to vector the aircraft to runway 31, and that's where the focus of the rescus centered. Nevertheless, the controller quickly cleared runway 22 as the DC-10 approached the threshold. He and the captain discussed the runway length, 6,600 feet compared to runway 31's 9,000 feet, and the open field at the end of the runway.

At 1559:29, the "brace" call was announced in the cabin, followed 30 seconds later by a series of ground proximity warning system alerts. From the captain's account, just as the aircraft came over the trees near the threshold, the airplane entered into yet another phugoid. They were at 300 feet, when the DC-10 started to pitch nosedown. On the CVR tape, at 1600:01, the captain said, "Close the throttles." The check pilot responded, "I can't pull 'em off or we'll lose it. That's what's turnin' ya." Four seconds later, the first officer repeated, "left throttle" serveral times. The captain remembered that as the nose lowered, the rate of descent and airspeed increased. At 1600:16 the aircraft struck the ground.

Impact and Wreckage Path

The airplane's right wing tip, right main landing gear, and the number three engine nacelle hit the ground nearly simultaneously. As the captain recalls, the nosewheel came down instantly, followed by the left main gear. The tail and right wing tip broke off, spilling fuel along the wreckage path. With no weight in the empennage, the aft section of the airplane came up causing the nose to bounce three times. For a matter of seconds the aircraft became airborne, but slammed back down, ripping the cockpit compartment away from the fuselage.

At the initial point of impact, an 18-inch hole was bored into the foot-thick concrete of the runway. The cause of such explosive damage was attributed to the final phugoid and a quartering tailwind that forced the airplane to touch down at 215 knots, 75 knots faster than a normal landing. The rate of descent was also recorded at an abnormally high 1,854 fpm, instead of the usual 300 fpm.

Although most of the pieces of aircraft were found in a localized area, parts of the number two engine were found scattered in farm fields as long as nine months after the accident. The center fuselage was heavily damaged by the ground impact, as was the forward cabin section. The postimpact fire consumed various portions of the airplane, including both wings.

ACCIDENT SURVIVABILITY

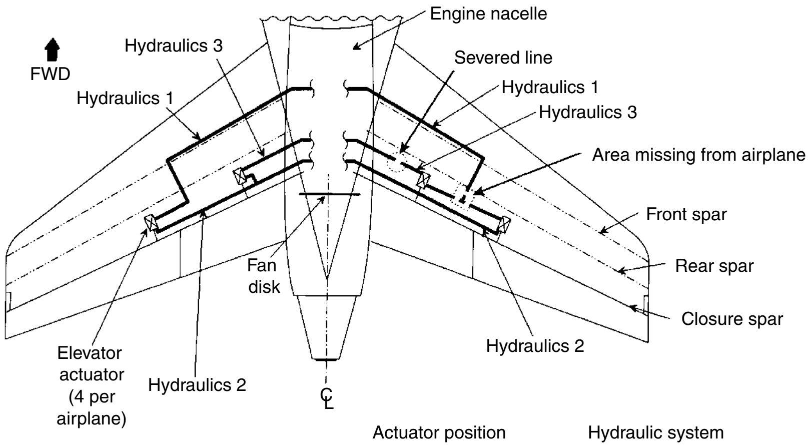
Of the 296 persons aboard, 110 passengers and 1 flight attendant sustained fatal injuries. When the cockpit separated from the forward cabin, the first-class section became unprotected and exposed to the brunt of the crash. Seventeen of those passengers died, and the remaining eight received serious injuries.

The largest intact section of the airplane was the center portion of the fuselage that contained seat rows 9 to 30. This section came to rest inverted in a cornfield and was destroyed by the postcrash fire. With the exception of two elderly passengers who died of asphyxia from smoke inhalation, all occupants in rows 9 to 21 were able to evacuate. Although the ceiling structure collapsed throughout the fuselage, the greatest amount of damage was found on the left side of the cabin near seats 22 to 30. Consequently, 33 passengers in that section died from either smoke inhalation or blunt trauma injuries. However, most of the passengers in the same numbered seats on the right side of the cabin were able to escape because there was less crushing damage in that area.

There were four infants and small children on board. The flight attendants instructed the parents of each to place them on the floor and hold them there when the “brace” command was issued. The mother of a two-year-old stated that her son “flew up in the air” upon impact, but that she was able to grab and hold on to him. Two of the other children were thrown into the wreckage, but sustained only minor injuries. One infant died of smoke inhalation.

The Investigation

The Safety Board determined that the accident sequence was initiated by a catastrophic separation of the stage 1 fan disk from the number two engine during cruise flight. The separation, fragmentation, and forceful discharge of uncontained stage 1 fan-rotor-assembly parts led to the loss of the three hydraulic systems that powered the airplane’s flight controls. Refer to Fig. V-B.



Actuator position	Hydraulic system
RH inbd elev	1&3
LH inbd elev	2&3
RH outbd elev	1&2
LH outbd elev	1&2

Not to scale

Fig. V-B. Damage to horizontal stabilizer and hydraulic systems. Adapted from NTSB.

STAGE 1 FAN DISK

As Fig. V-C illustrates, the General Electric CF6-6 engine fan rotor assembly consists of the large stage 1 disk and its attached fan blades and retainers. A smaller stage 2 disk and its attached blades and various mounting and balancing hardware also comprise this major assembly.

The stage 1 fan disk weighs 370 pounds and is made of machined titanium alloy forging about 32 inches in diameter. The rim is about 5 inches thick and is the outboard portion of the disk. The rim contains the axial "dovetail" slots that hold the fan blades. The bore is 3 inches thick and is the enlarged section of the disk adjacent to the 11-inch-diameter center hole. A disk web extends between the rim and the bore. The stage 2 fan disk is bolted to the aft face of the rim.

The primary, radial loads imposed on the stage 1 fan disk are in the dovetail slots. These loads come from the disk holding the fan blades against centrifugal forces during rotation of the assembly. The radial stress generally decreases toward the bore and are replaced by cimcumferential stresses. The forward-most corner of the bore is exposed to the maximum level of circumferential stress.

ANALYSIS OF THE FAN DISK

Examination of the fracture surfaces of the fan disk showed a region of fatigue on the inside diameter of the bore, which was believed to have begun in the early life of the disk. Investigators noted that the defected area cracked when the disk was exposed to the stresses associated with full engine power. Due to the particular geometry of the fan disk and the load paths within the disk, the frracture created a bending moment in the disk arm and web. This overstressed the disk, leading to the rupture of a blade segment. As soon as that

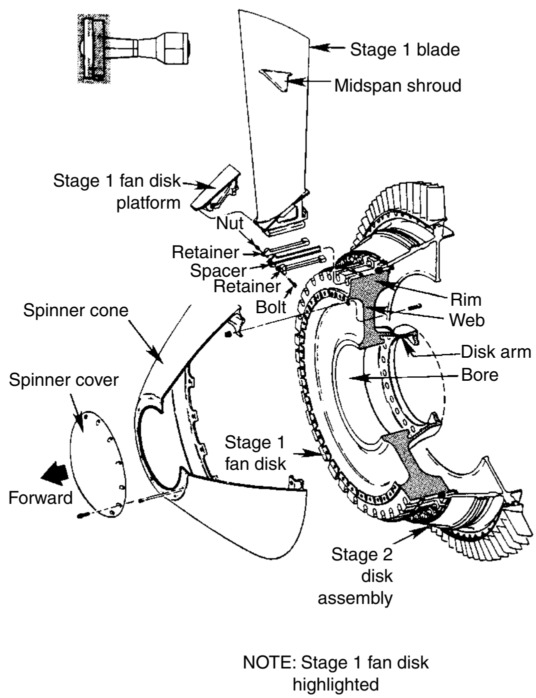


Fig. V-C. DC-10 fan rotor assembly. Adapted from NTSB.

occurred, the remainder of the disk was out of balance, causing other blades and fragments to blow outward. The right horizontal stabilizer and the aft lower fuselage area were subjected to the primary damage from this violent reaction.

MANUFACTURING DEFECT

There are three primary steps in the manufacturing of titanium alloy fan disks: Material processing, forging, and final machining. In the first step, raw materials are melted and processed into a titanium alloy ingot (a casting mold for metal). The ingot is then shaped while in a molten furnace and re-formed into a billet (an ingot after it's mechanically elongated and reduced in diameter) for further processing. The second step involves cutting the billet into smaller pieces that are then forged into geometric shapes. The last step is the machining of the forged shape into an actual part.

The Safety Board determined that the ½-inch-long fatigue crack was formed in the titanium alloy material during the manufacture of the ingot from which the disk was forged. General Electric conducted many types of nondestructive inspections, including a macroetch process that indicates material-related defects. The process that was used in 1989 was similar to that used in 1971 and was performed on the machine-forged shape. According to the Board, the flaw would have been apparent if the part had been macroetched in its final part shape.

HYDRAULIC SYSTEM

Douglas Aircraft Company considered a complete hydraulic failure on a DC-10 virtually impossible. Because of the triple redundancy of the system, the aircraft was not designed for the pilot to manaually operate the flight controls. The concept of a backup for a backup had worked so well that the airplane could still fly with only one functioning hydraulic control system. But in this case, the hydraulic lines to all three systems were severed or ruptured by the exploding shrapnel. As a result, the crew was at FL 370 with no ailerons, rudders, elevators, leading-edge devices, trailing-edge devices, wing spoilers, nosewheel steering, or brakes.

Two months after the accident, the FAA mandated Douglas Aircraft to enhance the design of the DC-10 hydraulic system that would preserve satisfactory flight control if a similar catastrophic failure were to occur. Although these enhancements appeared to have had the capability to protect the airplane, the Safety Board noted that it would not provide an additional margin of safety for certain failures; and the vulnerability of the DC-10 in such an event is still not fully known.

FLIGHT CREW PERFORMANCE

The Safety Board believed that under the cirumstances, the "flight crew's performance was highly commendable and greatly exceeded reasonable expectation." They added that the interaction between the pilots during the emergency was "indicative of the value of cockpit [crew] resource management."

The captain is a tremendous supporter of CRM and has said: "I am fairly convinced that CRM played a very important part in our landing at Sioux City with any chance of survival. I also believe that its principles apply to no matter how many crewmembers are in the cockpit." The captain continued to address the subject for those who fly single-pilot aircraft: "…CRM does not imply just the use of…sources only in the cockpit—it is an 'everybody resource'—[there are] all sorts of resources available to them." He believed that although there were 103 years of cumulative flying experience in the cockpit, the crew would not have been able to get to the airport without the steady guidance of one controller from Sioux City approach. As the captain concluded: "Use them [your crew and ATC] as team members—you are not alone up there."

Lessons Learned and Practical Applications

No better lessons can be learned from this accident than those described by the captain himself. Use all your available resources:

1. *Work as a team.* Tap into your fellow pilots' knowledge, skill, expertise—and hands. As noted in CRM research, by allowing the first officer to fly the airplane in an emergency situation, the captain then has the opportunity to evaluate the problem and make sound decisions.
2. *Be open to suggestions.* The captain viewed each crewmember's ideas as instrumental to the safe outcome of the flight.

3. *Communicate clearly and directly.* This applies to the entire flight crew. If you get a chance, read the CVR transcripts from this accident, and those from less successful flights. You will immediately notice that every crewmember from Flight 232 communciated in a clear manner. There were no disjointed comments, confusing statements, or domineering attitudes.
4. *Maintain cockpit discipline.* The crew did not allow themselves to become distracted. They remained vigilant of the situation throughout the flight.
5. *Keep ATC in the loop.* The captain had commented that tensions were high, but hearing the steady voice of the approach controller provided a tremendous calming influence to the crew.
6. *Brief flight attendants.* Don't keep an emergency situation a secret. Passenger survival depends on a prepared cabin crew.

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International Case Study V-6: Air France Flight 4590

Safety issues: Debris on the runway

On 25 July 2000, an Air France Concorde crashed shortly after takeoff from Paris-Charles de Gaulle Airport, France.

Probable Cause

The Bureau Enquetes-Accidents (BEA) determined that the probable causes of this accident were (1) the high-speed passage of a tire over a part lost by an aircraft that had taken off five minutes earlier and the destruction of that tire; (2) the ripping out of a large piece of the tank in a complex process of transmission of the energy produced by the impact of a piece of tire at another point on the tank (this transmission was associated with deformation of the tank skin and the movement of the fuel, with perhaps the contributory effect of other more minor shocks and/or a hydrodynamic pressure surge); and (3) ignition of the leaking fuel by an electric arc in the landing gear bay or through contact with the hot parts of the engine with forward propagation of the flame causing a very large fire under the aircraft wing and severe loss of thrust on the number two engine, and then the number one engine.

History of Flight

Flight 4590 was an hour late in departing Paris-Charles de Gaulle Airport for John F. Kennedy International Airport, New York. The Concorde had 100 passengers and 9 crewmembers on board.

At 14:42 (local time) the captain began his takeoff roll on runway 26R. As the airplane reached 100 knots on the runway, the right front tire on the left main landing gear struck a strip of metal that had fallen off a Continental Airlines DC-10, which had departed five minutes earlier. The shredded tire on the Concorde resulted in large pieces of rubber pelting the underside of the left wing, rupturing part of the number five fuel tank. Fire erupted under the left wing at the same time the flight crew experienced a loss of thrust from the number one and two engines. As the captain rotated seconds later, the controller informed the flight crew that flames were visible behind the aircraft. The first officer acknowledged the controller when the flight engineer notified the crew that the number two engine had just failed. The captain called for "engine fire" procedures, but the fire soon engulfed the airplane. At 1443:30, the captain told the first officer to retract the landing gear when the controller announced that large flames could now be seen behind the airplane. With the landing gear not retracting and engine fire alarms resuming, the first officer told the controller that they were trying for nearby Le Bourget Airport. The flight crew immediately lost power to the number one engine and the aircraft turned to the left and crashed into a hotel, killing four people on the ground.

Reference

http://aviation-safety.net/database/2000/000725-0.htm

Historical Case Study V-7: American Airlines Flight 191

Safety issues: Maintenance-induced aircraft damage, asymmetrical configuration

On 25 May 1979, the left engine and pylon assembly separated from an American DC-10 during rotation from runway 32R at Chicago-O'Hare International Airport, Illinois.

Probable Cause

The NTSB determined that the probable cause of this accident was the asymmetrical stall and the ensuing roll of the aircraft as a result of the uncommanded retraction of the left-wing outboard leading-edge slats. Maintenance-induced damage caused the separation of the number one engine and pylon assembly at a critical point during takeoff. Improper maintenance procedures led to the failure of the pylon structure.

Contributing factors to the accident were (1) the vulnerability of the pylon attach points design to maintenance damage; (2) the vulnerability of the leading-edge slat system design to maintenance damage; (3) the deficiencies in FAA surveillance and reporting systems that failed to detect and prevent the use of improper maintenance procedures; (4) deficiencies in the practices and communication among the DC-10 operators, manufacturer, and the FAA, which failed to determine and disseminate the particulars regarding previous maintenance damage incidents; and (5) the tolerance of prescribed operational procedures to this unique emergency.

History of Flight

Flight 191 was a regularly scheduled passenger flight from Chicago to Los Angeles, California. The DC-10-10 departed at 1502 Central Daylight Time with 258 passengers and 13 crewmembers on board.

Pilot Experience

The captain had 22,500 total flight hours, 3,000 of which were in the left seat of the DC-10. He had been with American since 1950 and had passed his last line check eight months before the accident.

The first officer had 9,275 total flight hours, 1,080 in the DC-10. He had been with the airline since 1966 and had completed his last recurrent training nine months prior to the accident.

The second officer had 15,000 total flight hours, 750 in the DC-10. He had been a flight engineer with American since 1955 and had flown other aircraft until 1978 when he requalified in the DC-10.

Weather

The weather conditions were VMC and not a factor in the accident.

The Accident

Based on the evidence, Flight 191's takeoff roll was normal until just before liftoff. According to the FDR, the takeoff thrust was stabilized at 80 KIAS and the left rudder and right aileron were used to compensate for a right crosswind. The captain called V1 (139 KIAS) and VR (145 KIAS) as the first officer eased the yoke back to rotate. The aircraft rose upward at a rate of 1.5 degrees per second and accelerated through V2 (153 KIAS). About two seconds later, one of the pilots yelled an expletive, and the CVR stopped. Witnesses told investigators that they saw white smoke or vapor coming from the vicinity of the number one engine pylon just before it separated from the aircraft and flew over the top of the wing.

Data obtained from the FDR indicated that the jet maintained a steady climb of about 1,150 fpm at a 14-degree nose-up pitch attitude. About nine seconds after liftoff, the aircraft accelerated to 172 KIAS but quickly slowed to an average rate of 1 knot per second. At 325 feet agl, the jet began an increasing roll to the left, even though the crew had applied the appropriate counter-control aileron and rudder deflections. Just before the FDR ended, the aircraft was in a 112-degree left roll and a 21-degree nose-down pitch attitude. At the time, the crew was applying full right aileron and rudder and nearly full up elevator controls. Flight 191 was airborne for only 31 seconds before impact.

Impact and Wreckage Path

Debris from the engine and pylon assembly fell onto the runway shortly after the components separated from the jet. The airplane's primary point of impact was 14,450 feet beyond the southeast end of runway 32R and 1,100 feet left of its extended centerline. Flight 191 struck the ground in a left-wing-down and nose-down attitude. The left wing tip hit first, and the aircraft exploded. The wreckage scattered onto an open field and a trailer park.

ACCIDENT SURVIVABILITY

This accident was not survivable because impact forces exceeded human tolerances. Two persons were also killed on the ground; two others sustained severe burns.

The Investigation

The investigation and analysis were concentrated primarily in two major areas. First, the Safety Board sought to identify the structural failure that led to the engine pylon separation. Second, they attempted to determine the effects the structural failure had on the aircraft's performance and essential systems; and the operational difficulties that resulted in a loss of control.

PYLON STRUCTURAL FAILURE

The pylon is attached to the wing by spherical ball joints in three different structural elements. Two of the joints are aligned vertically in a forward bulkhead which is attached to the wing, forward of the front spar. Another joint, behind the forward bulkhead, transmits thrust loads from the pylon structure into a thrust link which, in turn, is connected through a second joint to the lower surface of the wing. The third attachment point is a joint in the pylon aft bulkhead, which attaches to a clevis mounted on the underside of the wing.

The recovered pylon structure from Flight 191 was examined at the Board's metallurgical laboratory. Fractures and deformations at the separation points in the forward bulkhead and thrust link were all characteristic of overload. The separation sequence of the pylon assembly, and its direction of movement before it broke free, were found to be consistent with the loads imposed on it during rotation.

Investigators also noted evidence of a crescent-shaped deformation on the fracture surface that strongly suggested that the overstress crack in the flange was caused by pylon removal and installation maintenance procedures, not from ground impact. It was discovered that eight weeks before the accident, the number one pylon and engine had been removed in the American maintenance facility to replace the spherical bearings. This procedure was in compliance with a McDonnell Douglas Service Bulletin that was issued because six air carrier DC-10s were found to have cracks in the aft bulkhead's upper flange. Investigators learned from mechanics who worked on Continental Airlines' DC-10s that on two occasions maintenance personnel had damaged the upper flange on the aft bulkhead when the pylons were being removed or reinstalled. American and Continental used the same procedures. Therefore, the Board conducted a close examination of the those maintenance procedures.

Investigators found that because the pylon and associated wing attachments had a minimal clearance between the structural elements, maintenance personnel had to be "extraordinarily cautious" while they detached and attached the pylon. Mechanics who worked on the accident aircraft testified that those procedures were difficult and that even a minor mistake by the forklift operator could easily damage the aft bulkhead and its upper flange.

The Board noted that except for the 10-inch fracture found on the aircraft, the longest maintenance-induced crack discovered on other upper flanges was 6 inches. This particular airplane had shims installed between the bulkhead flange and the attaching spar caps and spar web. Investigators believed that the shims might have had a stiffening effect on the flanges. A load applied to the flange through a spar-web attachment bolt by the wing clevis could be spread out through the shims and, therefore, might have a tendency to produce a longer crack. This was confirmed by tests conducted by McDonnell Douglas that showed repeated load applications could produce a 10-inch crack in the upper flange. This could imply that the upper flange on Flight 191 might have made contact with the clevis more than once during the maintenance procedure.

Based upon all the evidence, the Safety Board concluded that the structural separation of the pylon was a result of a complete failure of the forward flange of the aft bulkhead. Its residual strength had been critically reduced by a maintenance-induced crack, which had been lengthened by service loads.

AIRCRAFT PERFORMANCE

The Board noted that the loss of thrust from the number one engine and the asymmetric drag caused by the leading-edge damage would not normally put the aircraft out of control. Therefore, they sought to determine the effects of the engine separation on the jet's flight control, hydraulic, electrical, instrumentation, and warning systems.

As the engine separated from the airplane, those accessories that were driven by the engine were lost. This included the number one hydraulic system and the ac generator that provided electric power to the number one ac generator bus. During a routine emergency, wherein the number one engine shuts down, all the services provided by these accessories will remain operable. This occurs because they derive their respective hydraulic pressure and electric power from redundant sources driven by one or both of the running engines. However, when the engine separates from the aircraft, the hydraulic pressure and supply lines connecting the pumps with the system are severed and the system loses all its fluid, and thus hydraulic pressure is not recoverable.

The separation cut the electric wire bundles inside the pylon. These included the main feeder circuits between the generator and the number one ac-generator bus. Although this would remove the normal source of power from the bus, it could have still operated through the ac-tie bus. The Board noted that the loss of the CVR and certain parameters on the FDR proved that the number one tie-bus relay opened when the engine separated, probably as a result of transient short circuits during the separation. Consequently, the power to the number one generator bus, including the number one dc bus and the left emergency ac and dc buses, was lost.

FLIGHT CREW PERFORMANCE

However, investigators believed that the flight crew might have been able to restore the number one generator bus and all its services by activating the guarded tie-bus relay switch on the electrical and generator reset panel. Evidence also suggested that the left emergency ac and dc buses, and the number one dc bus, could have been restored separately, by activation of the emergency power switch and the number one dc tie switch in the cockpit.

The Board believed that the crew probably did not try these procedures due to the criticality of the emergency or because they had so little time to react. In any event, the Safety Board did not criticize the crew's inaction. However, since the electric power was not restored, the captain's flight director instrument, several sets of engine instruments, and, most importantly, the stall-warning and slat-disagree warning light systems remained inoperative.

As with all normal takeoffs, the crew had extended the leading-edge slats to provide increased aerodynamic lift on the wings. When the hydraulic lines were severed, air loads forced the left outboard slats to retract. This proved to have a profound effect on the controllability of the aircraft. Because the slats were retracted only on one side, the lift of the left wing was reduced. This caused the airspeed, at which that wing would stall, to significantly increase. Simulator tests showed that the stall speed for the left wing was 159 KIAS.

Evidence was conclusive that the aircraft was being flown in accordance with the carrier's prescribed engine-failure procedures. The pilots, however, would have had no indication of the asymmetric slat position because the warning system was inoperative. The airplane's configuration was such that there was little or no warning of the impending stall. Since the inboard slats were extended, the airflow separation from the stall would have been limited to the outboard segment of the left wing. As a result, the condition would not have been felt by the left horizontal stabilizer or have created a stall buffet. The FDR indicated that the jet encountered some turbulence, which could have masked any aerodynamic buffeting. Since the roll to the left began at V2 + 6 knots (165 KIAS), which was well above the aircraft's stall speed, the crew probably did not suspect that the roll indicated a stall. Remember, the airspeed was dropping at about 1 knot per second. The Board believed that the pilots were most likely confused as to the cause of the roll, especially since the stickshaker had not activated.

Simulator tests revealed that the airplane could have been successfully flown at speeds above 159 KIAS or if the roll onset has been recognized as a stall. The crew would have simply lowered the nose, causing the jet to have accelerated out of the stall regime. However, all the participating pilots in the test, as well as the Board, believed it was not reasonable to expect the crew of Flight 191 to have recognized the roll as a stall.

The test results also indicated that the aircraft could have been landed safely in its asymmetric configuration. The Board noted that had the pilot maintained excess airspeed, or even V2 + 10 knots (163 KIAS), the accident might not have occurred.

Final Analysis

The Board concluded that the loss of control was caused by the combination of three events: (1) the retraction of the left wing's outboard leading-edge slats, (2) the loss of the slat-disagreement warning systems, and (3) the loss of the stall-warning system, all which were caused by the separation of the engine pylon assembly. Each by itself would not have put the airplane out of control. Together, especially during a critical phase of flight, they created a situation that provided an inadequate opportunity for the crew to recognize and prevent the ensuing stall of the aircraft.

The Board determined that, given the nature of the emergency and the critical time element, the crew performed the best they could with the available information. Without the benefit of the CVR, specific flight crew performance was unobtainable.

Reference

National Transportation Safety Board. 21 December 1979. Aircraft Accident Report: American Airlines, Inc., DC-10-10, N110AA. Chicago-O'Hare International Airport, Illinois. May 25, 1979.

Index

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