CFI Notebook

Reference notes for the private, instrument, and commercial pilot candidate and instructor

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For Zoë, Sebastian, and Malcolm, who hopefully find as much inspiration from me as I do from them. I hope that they can learn to fly one day too.

Introduction

DISCLAIMER: As of this writing, the author is NOT an FAA-certified ground or flight instructor. This book must be used for reference purposes, only. For the purpose of ground or flight instruction, the reader is directed to consult a ground instructor, certificated flight instructor (CFI) or certificated flight instrument instructor (CFII).

This book represents José's draft CFI notebook. One day, I hope to use this collection of notes to help me remember everything I learned, and how I learned it, so that I might share this wisdom with my students.

There are some training materials that are directed at a motivated 17 year old. They gloss over details and speak in platitudes. They are helpful, but I would argue they are a good start. I would argue they do not assume enough of their audience.

There are some training materials that are extremely thorough, Denker [2] comes to mind. They are fantastic. They also assume a pretty rigorous grounding in physics. I love these training materials - as *references*.

So, where does this work lie? It's somewhere in between.

As an engineer, I perceive the world - including aviation - in a rigorous, quantitative fashion. Sure, when flying, I make subjective, sometimes spontaneous decisions, based on experience. But, when learning, I find that the basics are enough. I need rigor. I need quantification. The added information is most immediately useful as a memory aid, providing another mental structure (in addition to time in the aircraft) to scaffold everything we learn.

I'll take lazy eights as an example here. The author's command on this commercial pilot maneuver took a quantum leap once some key observations were made.

Join me as we take to the skies.

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Chapter 1

High Altitude Operations

In this chapter, we introduce high altitude operations.

Before we dive in, we must answer a couple of questions.

What are high altitude operations? Simply put, these are operations far outside the "normal" environment you might expect to find on a Standard Day at sea level. We're talking about altitudes that are not terribly comfortable for humans, and possibly altitudes that are so high above MSL that we won't find any terrain there at all. There are enough aeromedical factors and enough changes to aircraft performance that we need to consider these operations carefully.

Why do we care about high altitude operations? We might need to get high enough to cross some mountains and stay above terrain. But there is also the desire for speed. I'm not just talking about the speed limit of 250 knots below 10,000 feet - if we wish to go faster, we need to go higher. I'm talking about the fact that *thinner air provides less drag*, which permits us to fly through the air more efficiently.

Mother Nature, of course, exists outside the realm of aviation. The challenges of high altitudes were present well before the first powered flights - just ask anyone who tried to climb Mount Everest in the 1800s. So, first, we must have a look at the atmosphere itself.

1.1 The Atmosphere and Its Layers

Recalling the basics from aviation weather, we know that the atmosphere is divided into several layers. Starting from the ground and going on up, we have the troposphere, the stratosphere, the mesosphere, the thermosphere, and the exosphere. All weather - and most of the earth's air! - reside in the troposphere. Flight operations rarely venture into the stratosphere (even more rarely now that Concorde is no longer flying).

So, when we say "high altitude", we mean "higher than a short cross country flight but lower than Concorde". We're talking altitudes below about 45,000 feet. If you ever manage to get above that, please let me know. (I'm looking at you, astronaut friends... you know who you are!)

1.2 Density and Altitude

In order to better talk about the atmosphere, can we all agree on a make believe, consistent, common, daresay, *standard* atmosphere?

Well, apparently, we can. Aviators are all too familiar with the International Standard Atmosphere. This aviator only recently learned that when we say standard, we mean Standard, namely, International Standard (ISO) 2533 from 1975, which is identical to the ICAO Standard Atmosphere from -2 to 32 km, or up to about 100,000 feet.

Assuming you've paid the 198 CHF fee, or can otherwise access the standard, you would see an interesting thing happening. You would see the value of p, the pressure, and ρ, the density of the atmosphere, decrease as altitude increases - and rapidly at that. At sea level (zero elevation), pressure is the all too familiar 1013.25 hectopascals. At 3,000 meters or about 10,000 feet, we're down to 701.21 hectopascals - only 69% of the pressure at sea level! That means 69% as much air, 69% as much oxygen available for breathing or combustion, 69% as much drag.

Up at 10,000 meters or about 33,000 feet - typical airliner altitudes - we're down to 262 hectopascals. That's just over 25% of the pressure at sea level.

This is a huge change! It's enough that we need to pay special attention to how we are powering our airplanes, how we are providing our bodies with oxygen, and how we are constructing our airplanes. It's enough that we need to take into account certain operational considerations.

1.3 Propulsion

One of the problems with high altitude flight is that the air is so thin, there may not be enough oxygen for the (internal combustion) engine to run properly.

Recall that a normally aspirated aircraft with a piston engine has a service ceiling. That ceiling is defined as the altitude at which the airplane's climb rate slows to 100 feet per minute [3]. That exact altitude will vary based on aircraft loading and how the conditions compare to a standard day. Famously, Concorde would continue to climb while underway, going higher as it got lighter. But the fact remains: for a piston airplane, we can only go so high.

Since the limitation is oxygen, and not fuel, there are a few ways that we could gain power at a higher altitude.

What if we had an electric aircraft? That would be great - it doesn't need oxygen at all. Today, in 2022, battery technology isn't quite there, nor are solar cells, outside from a very few research aircraft.

What if we simply had supplemental oxygen on board? Certainly, if we carried oxygen tanks, we could supplement the oxygen in ambient air to gain more power. Operationally, this is not a great idea, since we now have to deal with the added weight, complexity, and risk of an oxygen system, and it will not last very long. But air-breathing rockets do exactly this, so it's not a bad idea per se, simply not the right one.

What if we could grab more air from the atmosphere, possibly by compressing the air before it gets to the engine intake manifold? Now we're on the right track.

The first approach we might take is simply inserting a compressor between the outside air intake and the engine's intake manifold. That compressor could be a piston pump, similar to the vacuum pum in the airplane. But that's not terribly efficient: it generates a fair amount of waste heat. For this application, a turbine is a better idea. We could power this compressor with the aircraft's engine, most likely with a belt or a gear drive off the engine crankshaft. Such a contraption has a name: supercharger. It requires more power from the engine, and there are some losses due to the belt or gear drive mechanism, but it is a new positive up to a point: we can shove more oxygen into the engine, and raise our service ceiling.

Some clever person (who?) looked elsewhere on the engine and found another possible source of energy for driving this compressor. They realized that the exhaust gasses coming out of the engine were quite warm and under a decent amount of pressure. What if this energy could be captured? We can add a *second* turbine in line with the exhaust pipe, and use the torque generated by that turbine to drive our intake compressor! As it turns out, this works better than a supercharger. We call this a "turbocharger". Sometimes we have more than one.

(some diagrams should go here)

Operating a supercharged or turbocharged engine has some key differences from operating a normally aspirated engine. One, we need to re-calibrate our manifold pressures. By this I mean, in normal operation, a piston engine's intake manifold would achieve a pressure no higher than ambient pressure, likely no more than 32 inches of mercury. But, a turbocharged (or supercharged) engine may be able to go above this. I say "may" because some turbos simply give sea-level pressure at higher altitudes (turbonormalized), whereas others can go well above sea level pressure. Regardless, the turbo lets the engine run harder than it could otherwise, which means increased heat and risk of engine damaged. There are often limitations on how long an engine may run on a particular power setting as a result.

The turbocharger (or supercharger) turbines are themselves metal parts that are subject to fatigue and thermal stresses. After flights, we want to give the turbines some time to cool down, lest we shut them off entirely and subject them to thermal shock.

Recall that, when we compress air, it gets quite warm. This is unfortunate, since we recall from the application of carburetor heat that warm air will lean our mixture. What if there were a way to compress the air, and then cool it to get it as dense as possible? There is: it is called an "intercooler". But, as this requires even more heat to be dissipated from the aircraft, the intercooler must be carefully placed so that it can dissipate heat effectively.

With a turbocharged engine in particular, the concept of "exhaust gas temperature" takes on a new meeting. Where are we measuring: before the exhaust turbine, or after? It makes more sense to measure before, and we call this the "turbine inlet temperature" or TIT. We need to manage this temperature carefully: we want the TIT to be as high as possible for efficient leaning of the engine, but if it is too high, it could melt the exhaust turbine.

These turbines need to spin quite fast - think 100,000 RPM - in order to be effective. It is challenging and expensive to create machinery that can operate at this speed.

All of this seems awfully complicated for a little bit of extra power. What if there was a better way?

There is. It's called the jet engine.

The jet engine is, at is simplest, a single turbine. It ingests air and compresses it. We inject fuel into the compressed air and ignite it, causing it to heat and expand. The exhaust heats and expands so much that it exerts a force on a turbine, which serves as thrust for the airplane. Much like the turbocharger, the jet engine grabs some energy from the exhaust system to power the input compression phase.

More specifically, this single arrangement is called a "turbojet". It is simple, powerful, and reliable. So long as fuel usage and noise are of no concern, this is the best powerplant. The military often doesn't care about fuel or noise so we see turbojets on plenty of military aircraft. If we care more about efficiency and noise than (potentially supersonic) speed, we can also attach a really fast-spinning propeller to this, and capture the propeller's thrust in a duct for maximum efficiency. This combination of a turbojet with a ducted fan is called a "turbofan" and is the most popular way of powering large aircraft.

Of course, the propulsion system allows the aircraft to operate at a higher altitude. But what about the pilot, flight crew, and passengers? Do we need to do anything special for them if we are flying at high altitudes?

1.4 Aeromedical Factors

Much like the airplane's engine, the human body needs a certain amount of oxygen to perform.

1.4.1 Impairment

Different symptoms for every person. Going into a hypobaric chamber is recommended experience.

1.4.2 Hypoxia

Hypoxic Hypoxia

If we want to get really specific about this, the real problem is that the "partial pressure" of the oxygen in the air is not enough to cross into the blood stream. So the problem we need to solve, one way or another, is making sure that there is enough oxygen in the air, that it has enough pressure to cross into the blood stream.

The oxygen isn't there.

Hypemic Hypoxia

The oxygen is there but we can't get it through the lungs into the blood. COVID, smoking.

Stagnant Hypoxia

The blood is oxygenated but it can't get to the destination due to poor blood flow.

Histotoxic Hypoxia

We can't pull the oxygen off the red blood cells at the destination.

1.4.3 Time of Useful Consciousness

Table in PHAK. 30 minutes at 20,000 feet. 1-2 minutes at 30,000 feet. 9-15 seconds at 45,000 feet.

1.4.4 Diving and Flight

12h if a controlled ascent was not required or up to 8k feet.

24h if controlled ascent was required or above 8k feet.

My personal minimums: 24h for all passengers.

1.4.5 Humidity

Dehydration is a secondary risk with dry air.

1.5 Oxygen Systems

At this point we are well convinced that we need more oxygen. It will keep the crew able to do their job and the passengers happy. The next natural question is, where should we get it? We have two options: do a better job of pulling it out of the air, or, carry it with us.

1.5.1 Pressurization

One way of getting more oxygen into the cabin is to grab more oxygen from the air around the airplane. At typical airliner altitudes, there is not enough oxygen to sustain human life. But, there is enough that, if we had some way of compressing air and keeping it in the airplane, we could manage.

So, to be pedantic (a theme in this book, in case you have not noticed), the problems of "getting more oxygen" and "keeping it around" are separate, but must work together to provide more oxygen to the humans and other living creatures aboard the aircraft.

We've already talked about some solutions to the "getting more oxygen" problem. They include superchargers, turbochargers, and turbine compressor sections. These are already pressurizing the air for the sake of the engine. Is getting more oxygen really as simple as siphoning off a bit of pressurized air from these compression systems, maybe filtering it, and breathing it in? In short, yes.

What if we don't have a turbo or a turbine? Do we have other options? Sure, but they are not terribly common. One is to simply use a pump. Using a combination of ram air pressure and a pump, we could compress air in much the same way a turbocharger would. To power this pump, we could use an electrical source, a belt or gear off the engine, or maybe even a ram air turbine. The author is not aware of such a system ever being built or used - prove me wrong!

We might also use an oxygen concentrator. We're just beginning to see these applied to the world of aviation. Oxygen concentrators are effectively reverse-osmosis machines for air. They grab air from the atmosphere and push it through an extremely fine filter (a porous solid). The filter is sized to allow oxygen moleculed through but nothing much larger. On the other side, we find a higher concentration of oxygen (and nitrogen!) than we might otherwise find.

But, now that we have the extra oxygen, where do we keep it? One option is to pressurize the entire aircraft, blowing it up ever so slightly like a giant aluminum (or carbon fiber) balloon. One option is to keep it in a tank. One option is to just put it in a pipe and send it directly to a human, discarding any excess.

The most popular method is pressurization. We inflate the entire aircraft. In designing the aircraft, we take great care to pressurize only as much of the airframe as necessary, and select materials, openings, and structures that will permit the airframe to withstand not only an overpressure compared to the outside world, but also repeated cycles. (The early de Havilland DH.106 Comet airliner is a famous example of a plane designed without understanding of the stresses of pressurization cycles.)

With a pressurized aircraft, there are some essential design and operational considerations.

First off, let's say we pressurize the aircraft once. Are we done? Can we simply seal off the aircraft once this is done? The answer is no: in doing so, the occupants of the aircraft would slowly, but surely, convert all the oxygen in the cabin to carbon dioxide, leading to the eventual suffocation of all on board. (Plus, depending on what everyone had for dinner, it would smell pretty awful in the cabin, if you take my meaning. I can hear my children giggling at the prospect.)

So, we need not only pressurization, but also a constant flow of fresh air through the cabin. We have a source of air, likely bleed air from a turbine or a jet. So what about exhaust air? We can lose air through a controlled leak in the aircraft. We're familiar with controlled leaks: the vertical speed indicator famously uses a controlled leak to operate.

How much should we pressurize the airplane? This is a complicated choice. We can refer to our Standard Atmosphere table as a reference. Keeping the pressurization level as close as possible to sea level will keep our passengers and crew as comfy as can be. But, this results in the highest overpressure and the most stress on the airframe. We know from the FARs that above 12,500 feet, the crew need oxygen (after 30 minutes), and above 15,000 feet, we must offer oxygen to our passengers. Presumably this is because the pilots need to be alert, whereas the passengers mostly need to stay seated and are free to doze off. So, if I had to venture a guess, I'd interpolate: take the best case (sea level) and the worst case (15,000 feet) and take the average. Pressurize to 7,500 feet? As it turns out, yes, airliners often pressurize to about 8,000 feet, so this isn't a bad guess after all.

Airframe designers aren't thinking in terms of altitude, they're thinking in terms of pressure, and specifically, differential pressure: the difference between the pressure inside the airplane and the pressure outside. They're designing for a particular pressure differential, taking the airplane's operating altitudes into consideration. A hypothetical airliner with a cabin pressure altitude of 10,000 feet flying at a ceiling of 20,000 feet, has to deal with a much lower pressure differential than another airliner with a cabin pressure altitude of 6,000 feet (hello, Dreamliner!) operating at 40,000 feet.

Now that we know what pressure we need, and how to maintain it (with a controlled leak), how do we get there? Can we just start pumping air into the cabin? Not exactly. Humans (and other animals...) have fairly sensitive respiratory systems. Pressurizing too fast can wreak havoc on ear drums and sinuses - especially if one is congested. So, pressurization systems need to have a rate control mechanism. This can be manual or automated.

With the rate considered, we can have three kinds of pressure: too much, not enough, and just right. (Terminology is my own.)

What if we have too much pressure? Well, the aircraft has a structural limitation. Too much pressure will start blowing out windows, blowing rivets, etc. If the calibrated drain of which we spoke earlier were to become clogged, this could be a possibility. This does not make for a great passenger experience. So, we need some sort of emergency pressure dump.

What if we have not enough pressure? Those FARs we talked about are regulatory. So if we don't have enough pressure - maybe the aircraft's intake was cracked, or we lost a window, or some other horrible catastrophe - we'd need to get the plane down to a lower altitude to be legal. The pilots and the passengers have supplemental oxygen in most cases (we'll talk about that in a moment...) but they only last for so long. In this case, an emergency descent down to an appropriate altitude is in order.

Those design considerations aside, pressurizing the cabin works great. Airliners do it all the time. Even Concorde did it up at 60,000 feet. Once we start getting much higher than that, it is difficult to impossible to get enough air to pressurize a large volume. Pressure suits are smaller than an entire cabin, which is why SR-71, U-2, and other high altitude pilots utilized them. True spacecraft don't have the opportunity to scavenge oxygen from the air, since there is no air!

With that said, it's high time to talk about ways that we can make our own luck, so to say, and carry oxygen with us.

1.5.2 Supplemental Oxygen Sources

Different from compressing outside air.

Oxygen tanks.

Aviator's breathing oxygen, 99.5% water free, so it doesn't freeze in lines. Mounted to aircraft or portable system.

Chemical oxygen generators - need to be stored/secured correctly.

Any source only lasts for so long.

1.5.3 Oxygen Delivery

Pressure suit?

Much of this information is straight out of the PHAK.

Mask. Fitted to face. May contain microphone. Usually oronasal - mouth and nose. Clean regularly.

Cannula. Nose only.

Diluter-demand: oxygen supplied only when user inhales. Mixes cabin air and oxygen.

Pressure-demand: similar to diluter-demand but oxygen comes in at positive pressure for higher altitudes above 40,000 feet. Requires a tight seal - no beard.

Continuous-flow: oxygen collects in a bag, which may not inflate fully, and is mixed with cabin air when inhaled.

Electrical pulse-demand: detects user breathing and only provides oxygen at start of breath, 50-85 percent more efficient.

Rebreather?

Pulse oximeter is a cheap and easy way to measure serum oxygen.

1.6 Operational Considerations

Loss of pressurization: get the mask on immediately (time of useful consciousness). Emergency dive down to 15,000 feet.

Overpressure: operation of dump valves.

Rate limitation error: manual override or no flight, see aircraft procedures.

Hyperventilation.

Chapter 2

The Commercial Pilot

So you want to become a commercial pilot? What are the privileges and limitations for such a pilot? What does that even mean?

One thing is for certain: the private pilot checkride is NOT simply a "glorified commercial pilot checkride". The expectations - and risks - for a commercial pilot are much higher.

Think of it this way. The private pilot checkride represents your first flight with a passenger (albeit a fairly picky one at that). The commercial pilot checkride is meant to simulate your first *job interview* as a pilot. It's all about professionalism, polish, and positive control.

The private pilot checkride is your change to demonstrate competence. The commercial pilot checkride demonstrates fluency, professionalism, experience, and finesse. Of course, the ATP checkride takes this to another level, but we'll talk about that another day.

The PHAK [6] is a great reference. So is the AFH [4]. It's good for commercial pilots to be familiar with hazardous attitudes [1] as well.

2.1 Maneuvers

The Commercial Pilot is held to a higher standard than the Private Pilot. Many of the maneuvers on the private pilot checkride make an appearance on the commercial pilot checkride as well. Quantitatively, the commercial pilot has less margin: tighter limits for airspeed, altitde, heading, bank, landing distance, etc. Qualitatively, the checkride examiner wants to see that the commercial pilot candidate is the clear master of the aircraft. They are looking for positive control, smoothness, rudder coordination (and cross-coordination when appropriate!), and appropriate use of trim or checklists.

With the private pilot we ask, would I trust the candidate to take my spouse or child flying? With the commercial pilot we ask, would I trust the candidate to take my entire family flying? Are they the clear master of the aircraft? Can they explain the aircraft's, as Doug De Muro would say, quirks and features? Do they make the airplane do what they want it to do, when they want it, for reasons they can clearly explain?

The Commercial Pilot ACS [5] is the bible for the Commercial Pilot checkride. We refer to it frequently in this section.

The author has, as of this writing, spent the most time in the P32T type, a T-tailed Piper Lance II. The detailed procedures here implicitly refer to the Lance, and its airspeeds and quirks. Some details will differ based upon the particular aircraft.

2.1.1 Lazy Eights

A lazy eight is a combination of a 180 degree turn, done at the same time as a shallow climb and descent. We turn one way, then turn the other. Its nearest living relative is the private pilot maneuver "S-turns across a road". The aerobatic maneuver "wingover" is a cousin.

The standard literature describes this as a "graceful" maneuver. It is supposed to be "beautiful". It is supposed to be "ballet in the air". It is supposed to demonstrate "mastery of the aircraft" or somesuch.

Such subjective descriptions are of zero use to the poor pilot who attempts this maneuver. We need some more rigor to derive and describe this maneuver.

The lazy eight is NOT a chandelle. It is a slow maneuver. The standard literature describes it as "lazy". Again, that's subjective. How slow? About 40 seconds for a Cessna 152, and about 60 seconds for the Lance. This largely comes down to how many knots of airspeed separate V_A and V_S0 on your aircraft. I suspect it has to do with the square of that since we're talking about energy that needs to be dissipated. I'll get back to that.

Before we go too much further, let's at least talk through the conventional way of teaching this maneuver. It's not a bad start, and for many student pilots more skilled at the controls than the author, it's often enough.

First, let's consider a skateboarder shredding a half pipe. If not familiar, have a look at this video: https://www.youtube.com/watch?v=FJfqcpnH6Ys. The half-pipe in this case is a U shaped channel, about twice as tall as the skateboarder and about 30 times as long as the skateboard. The skateboarder starts at the top of the pipe. They skate down the ramp, raching maximum speed at the bottom. They climb up the other side, going about as high as the top. Once they reach the top, they turn and go back down. As they go up the pipe, they convert kinetic for potential energy, slowing down as they climb. The minimum speed is at the top of the pipe, where they turn around and go back down.

Usually, to stay on the pipe, the skateboarder makes all their turns in the same direction - to the left or to the right. But, if the pipe were sufficiently long, the skateboarder could do one to the left, then one to the right, continuing on indefinitely down the half-pipe.

One thing. The half-pipe happens pretty quickly. What if the pipe were more shallow? Well, then we could slow it down, and take our time turning around at the top.

A lazy eight is similar to shredding half-pipes (in alternating directions) in the sky with the airplane, except we make it take longer to demonstrate that we can control the aircraft.

In the airplane, we start out by flying straight and level. We pitch up and start turning. The plane climbs. As the plane climbs, it slows down, and our rate of turn naturally increases. At some point about halfway through, we've reached our minimum speed. The plane noses over and starts descending. We end up flying straight and level in the opposite direction.

Seems easy enough. What's so tricky about it? A couple of things. If we do the maneuver too quickly, we risk stalling or spinning the aircraft. If we do it too slowly, it's not really a maneuver, so much as just flying the airplane. So we pick a time scale somewhere in the middle.

Another tricky thing is that it's easy to get disoriented. For this we need good visual references. Not terribly surprising since the commercial pilot certificate is a visual certificate. I'll come back to this.

Another challenge is consistency. We need to impose some order on the maneuver so we can reproduce it consistently. I group being on the correct airspeed and heading under consistency.

The final challenge for now is airspeed management and airframe protection. Too fast and we could rip the wings off the airplane. Too slow and we could stall and spin.

Once you put all those constraints together, you arrive at the following procedure, which is usually how lazy eights are taught.

The pilot selects a clear visual reference line on the ground. A major highway, river, railroad, right of way for a power line, or other sufficiently long, straight feature is suitable for this maneuver. The keys are that the reference line be visible from all angles, and be distinct enough from other things on the ground to avoid confusion, disorientation, and ultimately, maneuver failure. A short road is not great. A small road among many other small roads is not great. The edge of a field is not great. If necessary, scope this out ahead of time using a sectional chart, Google Earth, or any other available resource.

The pilot plans to enter the maneuver flying perpendicular to the ground reference line. To protect the airframe, we want to be flying no faster than V_A, the design maneuvering speed for the aircraft. We likely want to be flying slower since we're probably not at gross weight. In the Lance, we enter at 120 knots indicated.

While flying straight at the reference line, but before crossing it, the pilot selects some key reference points. One is at 45 degrees off the nose in the direction of the turn. This point will represent the one-quarter point through the turn. One is at 90 degrees. More than likely this will simply be the reference line itself. Alignment with the reference line will represent the halfway point through the turn. The last reference point is at 135 degrees, or 45 degrees behind the reference line. That point represents the three-quarter point through the turn. Since the turn in one direction will immediately be followed by a turn in the other direction, it would be a good idea to get 45 and 135 degree references on both sides. Try to pick something obvious: a quarry, a silo, a castle, a lake, a river bend. Clouds aren't the worst choice but they do move. A particular field surrounded by other similar fields is probably not a great choice.

We break the maneuver down into quarters. We begin execution once we cross the reference line. This is a constant power maneuver, so don't touch the throttle - 18" of manifold pressure and 2400 RPM in the Lance on a standard day at 4500' MSL is about perfect. We shouldn't need to touch the trim either. Let's assume calm winds for now. Here we go!

In the first quarter, we are, at the same time, entering a shallow turn of about 5 degrees, and beginning to increase our pitch. Control inputs smoothly increase. At the 45 degree point, we are at 10 degrees of pitch, representing maximum pitch, and at about 15 degrees of bank, representing half of our maximum bank. We've gained about 200 feet.

In the second quarter, we are starting to let the nose down while increasing bank to the maximum. Just before the 90 degree point - let's say ten degrees prior - an interesting thing starts to happen with the nose. We are approaching maximum turn rate and minimum speed. Our lift vector is no longer pointing straight up. The nose wants to nose over and slice through the horizon. Let it!

At the half way point, our airspeed is about 10 knots above stall speed, 80 knots in the Lance. Our pitch attitude is level since we've already let the nose start falling. Our bank momentarily reaches maximum bank of 30 degrees. We're thinking about *letting* the nose down and releasing the controls. We've gained about 200 more feet.

In the third quarter, we're rolling out from 30 degrees of bank and pitching down. Close to the three quarter point, we find that the Lance needs some nose-down help from the yoke, so we provide that. The airplane is accelerating and descending at this point. We need to manage that. At the three quarter point, we're back at 15 degrees of bank and whatever pitch is appropriate for our other goals - probably 5 or so degrees down.

In the fourth quarter, we're taking our time to make sure that we roll out on airspeed, and on heading.

We finish the maneuver at the same airspeed and altitude as our entry, but in the opposite direction, over the same reference line. Once we're there, we start a turn in the opposite direction. We can keep doing this indefinitely.

The hypothetical perfect VFR pilot can conduct this maneuver exclusively by looking at the airplane, so they say.

Simple enough, huh?

Well, the author didn't think so. Here are a few more tricks that the author found helpful.

First, watch this video: https://www.youtube.com/watch?v=3Oxbr1PuoSQ.

The video raises some important points.

First is that the lazy eight is an exercise in managing the overbanking tendencies of the aircraft. Past a few degrees of input, the airplane wants to keep turning. Or, as I see it, we tickle an unstable mode of the aircraft with this maneuver.

Second is the incredible importance of coordination. Sure, skidding or slipping is disqualifying on a checkride, but that's not the important or interesting part. The airplane has a left turning tendency, which we'll need to fight with right rudder. The Lance has a decent amount of adverse yaw that ends up helping us some here.

Third is an important reminder that this is a visual reference maneuver. In the video, the instructor has the panel covered with a sheet of paper. All he does is take a couple of quick peeks at the instruments to confirm altitude and airspeed.

Last is that we can complete the maneuver with fairly minimul control inputs. Well, at least, on a Cessna. But that's not true on the Lance. As my Navy test pilot friend points out, the Lance has *extreme* roll stability, so we have to help it along some.

In addition to the video, I'll add my own observations.

Thinking about the timing of the maneuver helped me to quantify what it means to "slow down". As someone who regularly deals with events that happen in the span of about 5 *milli*seconds at work, fifteen seconds feels like an eternity! But quantifying that helped tremendously. Each quarter should take about 15 seconds, and a complete turn should take about 60 seconds.

I also thought more carefully about what the aircraft was doing in each of the yaw, pitch, and roll axes individually, and what the aircraft's stability was doing for us.

In yaw: the airplane is turning 180 degrees. The rate of yaw increases through the first half and decreases through the second half. It's probably close to a perfect cosine. The Lance is lightly stable in yaw and doesn't need much help here.

In pitch: We're nosing up, than descending. Yoke back, let the nose fall over, yoke forward. Since we didn't touch power or trim, the airplane *wants* to find its original airspeed and altitude. Zoom up, zoom down.

In roll: We start the plane rolling. We give it a bank angle and maybe a touch of momentum. The airplane wants to keep increasing the bank to some extent. But these things are happening at time constants that end up being faster than our maneuver. So we baby the airplane into, and out of, a gentle bank, not exceeding 30 degrees.

We haven't talked about crosswinds yet. Strictly speaking, this is not a ground reference maneuver. But if we don't correct for winds, we don't stay on our line. Instead, we start drifting. So, through the maneuver, just like in a traffic pattern, we can think about gaming the turn. If we're getting blown away from our reference line, maybe we want to hurry up the first quarter and start our turn sooner. If we're getting blown toward it, maybe we want to slow down through the first quarter and slow down the last quarter.

This maneuver comes back on the CFI checkride, where we might need to teach it. So approaching it with rigor up front pays dividends later.

For anyone who picked up this maneuver more easily, without all this rigor: I envy you.

If you're still stuck, have a look at https://www.av8n.com/how/htm/maneuver.html#sec-lazy-eight. I don't degree with teaching the attitude-centric or nose-centric view of that explanation, but it provides an interesting cross-check for what I've described above.

2.1.2 Soft-Field Takeoff and Climb

The soft field takeoff and climb demonstrates that the pilot is able to operate the aircraft safely on a dirt, grass, or other similar off-pavement airstrip. The constant theme is unweighting: keeping weight off of the tires, particularly the nosewheel. A secondary theme is smoothness.

We configure the aircraft with two notches of flaps and one or two turns of nose-up trim past the neutral point. Once we begin moving the aircraft, we continue to move until we are airborne or abort the landing. Back pressure on the yoke will transfer as much weight as possible from the nose wheel to the mains. The Lance has very little elevator authority at low speeds so this effect will be minimized.

Taxi smoothly and continuously onto the runway. Apply takeoff power, at perhaps half the rate as usual (taking 6-8 seconds to advance the throttles instead of 3-4) to help prevent kicking up debris. Holding firm backpressure, accelerate down the runway.

The Lance's V_x speed with gear down is only 68 knots. The Lance usually doesn't climb until 70 knots. So, in this aircraft, it may not be necessary to accelerate in ground effect, as we might with many other aircraft. The pilot must be mindful of this.

Once we are airborne at rotation speed above V_x, we hold that to clear a 50- or 100-foot obstacle. Then, once positive rate is confirmed and the obstacle is clear, we retract the gear, lower the flaps one notch at a time, and continue accelerate to our gear up V_x of 87 knots, which just so happens to be V_y with gear down and flaps up. After that, we continue to accelerate to a clean V_y of 92 knots, and continue to climb from there.

Disqualifications might include: porpoising on the ground due to incorrect transition to ground effect flight (which we shouldn't need in the Lance), stopping once we begin the ground roll, inappropriate use of controls, incorrect airspeeds.

2.1.3 Soft-Field Approach and Landing

The soft field landing demonstrates that the pilot is able to manage the aircraft on a surface other than a paved runway. Much like the soft field take off, the goal of the maneuver is to keep as much weight off of the tires, particularly the nose tire, for as long as possible. Note that, by default, the soft field approach is NOT also a short field approach. However, the Lance's POH does not differentiate between them.

The landing begins as a typical short landing: wheels down at 75 knots, full flaps. In the Lance, a blip of throttle is needed to allow the main tires to gently set down on the ground as opposed to slamming down and potentially digging in. Then, we continue to hold back pressure and leave the flaps down to gently bring the nose down, doing so as late as able. We can lower the flaps to two notches as soon as able, and have the option of leaving them down as we taxi. We must not stop until we are clear of the active.

In the Lance, we typically do these maneuvers with half a tank of fuel and two front seat occupants pushing the station weight limit of 440 lbs. This leads to a fairly fore CG condition where the aircraft is nose heavy. When the aircraft is aft loaded, the nose becomes MUCH lighter, and it is possible to wheelie all the way down the runway unless we are very careful.

Note that the soft field landing has no aiming point specified. This is good, since a true grass strip won't have markings.

Disqualifications might include: bouncing, slamming the nose wheel, stopping on the runway.

2.1.4 Short-Field Takeoff and Maximum Performance Climb

In the short field takeoff, we are looking to use a minimum of runway, lifting off at the earliest spot possible, and to clear a 50 foot obstacle. To use the minimum runway, we position the aircraft as close to the very end of the runway as possible, using a displaced threshold to our advantage. In the Lance we use two notches of flaps. We hold the brakes, apply full power, lean if appropriate, and release the brakes. Seriously - feet off the brakes!

We recall that V_x in the Lance is a mere 68 knots in the dirty configuration. We're lucky if we are airborne at 70-75. Maintain that airspeed until clear. Then it's gear up and flaps up as we accelerate through V_x of 87 knots to V_y of 92 knots.

Disqualifications might include: forgetting to position the airplane as far as possible on the end of the runway, incorrect flap settings, forgetting to run up with brakes held, incorrect airspeeds.

2.1.5 Short-Field Approach and Landing

The Lance doesn't like to be slow as this maneuver reminds us.

The short field approach is an important practical maneuver. On a checkride, we usually have the examiner give us an aiming point, and it's usually the 1000 foot markers. In real life, that aiming point is the numbers as we're looking to truly use minimal runway.

In the Lance, we set up for a full flaps stabilized approach diung 75 knots over the numbers. The plane will want to sink quickly when we cut power so a small dose of throttle will set us up for success. However, it's imporant to be within 100 feet of the required spot, so a hard landing is better than a failed checkride. Recalling that the 1000 foot markers are 200 feet ling (source?), the goal is to be ON the markers.

Once down, retract flaps (easy in the Lance, lower the lever to the ground), apply full back pressure, and call out "maximum braking". It's not necessary to actually brake hard, we don't need to leave tire marks on the runway.

Disqualifications - and there are many for this one - might include: improper configuration, missing the aiming point, bouncing so hard that we porpoise and have to go around, forget to call out "maximum braking".

2.1.6 Power-Off 180° Accuracy Approach and Landing

This maneuver is probably responsible for more failed commercial pilot and CFI checkrides than all the others combined. It is unforgiving and requires a very high degree of precision, particularly to correct for winds. The candidate gets one shot at this one. If they land short, or land long, or have to go around, that's a disqualification. It still makes sense to continue the checkride, but if this happens to you, expect to lick your wounds, spend an hour with a CFI for an additional signoff, and to take another shot in the coming week.

For this maneuver, we fly a traffic pattern with a closer than usual downwind leg ($\frac{1}{3}$ of the way up the Lance's wing instead of just off the tip) and cut the power abeam our touchdown point, the 1000 foot markers. We immediately pitch for our best glide speed of 92 knots, turn a fairly tight pattern, put the gear down once the field is made, and execute a normal, possibly no flaps landing. This ends up being a fiarly aggressive, tight, rounded approach, with no real base leg, as downwind transitions smoothly to base and final.

DO NOT FORGET TO PUT THE GEAR DOWN. If you're less than 50' AGL and don't see three greens, GO AROUND. This isn't worth a new engine.

With respect to the aiming point, there are three possible outcomes:

- Too short. We've lost too much energy and have no hope of making the aiming point. Perhaps our pattern was too wide, we did not correct for wind, or we otherwise failed to manage energy. Identify and call out the situation, and immediately GO AROUND. Whether or not this is disqualifying, this is the correct course of action.

- On point. This is ideal. But getting it magically right by chance means we're not really in control of the aircraft. So, even though this will pass the test, it's not the best place to be.
- Too far. We have not lost enough energy. As long as we don't have *such* an excess of energy that we cannot manage the airplane and the landing, this is fine. We have some tricks to get lower: cut the airspeed (down to 75 instead of 87-92), lower the flaps, slip with flaps extended (approved in the Lance!).

You've got 200 feet from the aiming point for this one. If the aiming point is the near side of the 1000 foot markers, the limit will be the end of them. You'll know immediately when you've done this one correctly, and so will your examiner.

Assuming you do this correctly, this is arguably the hardest part of the checkride. So spend plenty of time practicing.

Disqualifications include: failing to make the aiming point (obviously), failing to go around when appropriate.

2.1.7 Slow Flight and Stalls

Nothing too special about these except the very tight commercial pilot ACS limits: ± 50 feet for altitude, $\pm 10°$ heading, $+5/-0$ for airspeed (which in the Lance is usually 70), and $\pm 5°$ angle of bank. The examiner may want to see these in the clean configuration, or an approach configuration, which could be one notch of flaps, two notches of flaps and gear down, full flaps and gear down. The may ask you to fly straight and level, to turn (usually 15 degrees is about right), to climb or descend, or to do more than one at the same time. If we're doing these power off, of course we cannot maintain altitude, so allow plenty of margin for descending just above stall speed. If we're doing these power on, correct rudder application is paramount.

Remember: pitch (and quite a lot of nose up trim in the Lance) for airspeed, power for altitude.

Give plenty of space above the ground for these. KMDD airport sits at 2805.4 feet MSL. We could be entering these maneuvers at 5500-6000 feet MSL.

For the commercial pilot, stalls may be to first indication (BEEEP!) or a full stall (BEEEP!, heavy buffet, and a very tiny nose drop and excessive sink rate in the Lance).

Disqualifications include: getting below 1,500 AGL. Make that 2000 AGL. Stall recovery can be up to 550 feet in the Lance. Call that 3000 AGL. Forgetting to make clearing turns is disqualifying. Forgetting to stay coordinated could be as well.

2.1.8 Accelerated Stalls

Fortunately, these are harder to enter than they are to exit. Also fortunately, we don't have an altitude requirement for this one. Well, except for one: DO NOT get below 3000 feet AGL. If we're especially ham fisted, we'll enter a stall, which - shocker! - is disqualifying.

Set up the airplane for V_A, configure as requested, set power appropriately, and enter a coordinated 45 degree banking turn. Don't worry about altitude as long as we're high enough.

Now: PULL. It will take a HEAVY two handed pull in the Lance to get a stall warning.

Hear the BEEEP? Wings level and go around. Done.

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