RTCA, Inc.
1150 18th Street, NW, Suite 910
Washington, DC 20036-4001
USA

Minimum Operational Performance Standards (MOPS) For Airborne Weather Radar Systems

RTCA DO-220A Change 1
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Prepared by: SC-230

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RTCA, Inc.

Telephone: 202-833-9339
Facsimile: 202-833-9434
Internet: www.rtca.org

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FOREWORD

This document was prepared by Special Committee 230 (SC-230) and approved by the RTCA Program Management Committee (PMC) on March 17, 2016. It supersedes RTCA DO-173, dated November 19, 1980; RTCA DO-220 dated September 21, 1993; and Change 1 to DO-220 dated June 23, 1995. Change 1 to DO-220A was also prepared by Special Committee 230 (SC-230). It was approved by the RTCA Program Management Committee (PMC) on August 17, 2018.

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- coalescing aviation system user and provider technical requirements in a manner that helps government and industry meet their mutual objectives and responsibilities;
- analyzing and recommending solutions to the system technical issues that aviation faces as it continues to pursue increased safety, system capacity and efficiency;
- developing consensus on the application of pertinent technology to fulfill user and provider requirements, including development of minimum operational performance standards for electronic systems and equipment that support aviation; and
- assisting in developing the appropriate technical material upon which positions for the International Civil Aviation Organization and the International Telecommunication Union and other appropriate international organizations can be based.

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EXECUTIVE SUMMARY

Since the last revision to DO-220, there have been many technological advances in the field of airborne weather radar. DO-220A incorporates updates and corrections to the previous version. In addition to modernizing the requirements and test procedures for the weather, ground mapping, and predictive windshear functions set out in its predecessors, SC-230 has added specifications for radar detection of turbulence and atmospheric threat awareness. Any of these functions may be implemented individually or in combination with any others. DO-220A has been designed such that the requirements and test procedures for each function are grouped into distinct sections to facilitate testing and showing of compliance.

Change 1 of this document implements the following changes:

Page	Section or Item	Description of Change
5	1.8 References	Updated instructions on where to find PWS and Turbulence datasets.
20 21	2.2.3.14 Windshear Alert Levels 2.2.3.15 Windshear Alerts and Icons	Clarified that PWS advisory alerts are optional.
22	2.2.3.16 Windshear Alert Inhibits	Approach inhibit region requirements are now different for warning vs. caution alerts. Allow the use of automatic range scaling for caution alerts. Updated associated test procedure.
23 47 59	2.2.3.20 Windshear Detection Flight Evaluation 2.4.3.3.20 Windshear Penetration Flight Evaluation 3.3.3.3.2 Penetration Flight Evaluation	Changed paragraph titles to Windshear Detection Flight Evaluation. Also changed references to penetration flights to windshear detection flights throughout (2.4.3.3.3, 2.4.4.1, 3.3.3.3.2.) Added Notes under 2.4.3.3.20 & 3.3.3.3.2, to explain nomenclature.
29	Table 2-5: Performance Test Requirements for Environmental Tests	Removed note 2 associated with humidity testing. The STC performance test associated with the Temperature Variation environment is now After, rather than During the condition. Performance tests during Op Shock are now After, rather than During the condition. Removed requirement for ATP after crash safety test. Performance tests during ESD are now After, rather than During the condition. Added a note (7) associated with ESD testing.

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1 PURPOSE AND SCOPE

1.1 Introduction

This document contains Minimum Operational Performance Standards for Airborne Radar Systems that may include any combination of the following functions: weather detection, ground mapping, forward-looking windshear detection, forward-looking turbulence detection, or atmospheric threat awareness capability.

These standards specify system characteristics that should be useful to designers, manufacturers, installers, and users of the equipment. The requirements defined in Subsection 2.1 and Paragraphs 2.2.1, 2.2.2, and 2.2.5 of this MOPS are applicable to both rotorcraft and fixed-wing aircraft. Paragraph 2.2.5 can be used to address the indication of turbulent conditions or microburst events ahead of the aircraft for rotorcraft. This document does not define the MOPS for forward-looking windshear or turbulence detection capability for rotorcraft.

Compliance with these standards is one means of assuring that the equipment will perform its intended function(s) satisfactorily under all conditions normally encountered in routine aeronautical operation. Any regulatory application of this document is the sole responsibility of appropriate governmental agencies.

Section 1 of this document provides information needed to understand the rationale for equipment characteristics and requirements stated in the remaining sections. It describes typical equipment operations and operational goals, as envisioned by the members of Special Committee 230, and establishes the basis for the standards stated in Sections 2 and 3. This section also contains definitions and assumptions essential to proper understanding of this document.

Section 2 contains the Minimum Performance Standards for the equipment. These standards specify the required performance under standard environmental conditions. Also included are recommended test procedures necessary to demonstrate equipment compliance with the stated minimum requirements.

Section 3 describes the performance required of installed equipment. Tests for the installed equipment are included when performance cannot be adequately determined otherwise.

Section 4 describes the operational performance characteristics for equipment installations and defines conditions that will assure the equipment user that the expected operational environment will allow safe and reliable operation of the equipment.

Appendix A, a normative appendix, describes the windshear database developed for the certification testing of airborne forward-looking windshear detection systems, and defines the test scenarios used for this testing. It also includes considerations associated with the use of the windshear test set-up

Appendix B, an informative appendix, includes plots associated with the windshear data sets.

Appendix C, a normative appendix, describes the analytical technique for evaluation of windshear missed events and nuisance alerts.

Appendix D, an informative appendix, contains historical information and derivations that may be useful to the radar designer.

The word “equipment” as used herein includes all components or units necessary (as determined by the equipment manufacturer or installer) for the equipment to properly perform its function. For example, the airborne radar "equipment" may include a radome, an antenna, antenna mounting, transmission line, a receiver/transmitter unit, a control/display unit, shock mounts, etc. In this illustrative example, all these components or units comprise the "equipment." It should not be inferred from the example that every equipment configuration will necessarily include (or be limited to) all these components or units. This will depend on the design chosen by the equipment manufacturer and the techniques of the installer.

Throughout this document, refer to the latest available revision of all reference material unless otherwise specified.

1.2 System Overview

A weather radar system is equipment that actively senses both meteorological and non-meteorological targets, depending on the operational mode. A weather radar system can be a valuable tool to help the flight crew make informed decisions and potentially avoid hazardous situations due to heavy/extreme precipitation, windshear, turbulence, or other atmospheric threats. The radar system may include various combinations of components such as a control panel, antenna mounting, antenna, display, receiver/transmitter, and associated software. Note that either the equipment manufacturer or another entity (e.g., integrator) may provide the controller.

Radar installations may include a dedicated display or may share a display with other aircraft systems. Most radar installations will share a multipurpose display such as an Electronic Flight Instrument System. For airborne radar systems with this architecture, the display requirements set forth in this document apply to the shared display device when used for displaying radar information.

1.3 Intended Function

The intended functions of the weather radar system described in this document fall into five general categories.

- Weather Detection
- Ground Mapping
- Forward Looking Windshear Detection
- Forward Looking Turbulence Detection
- Atmospheric Threat Awareness

The radar system manufacturer may choose to implement equipment providing these capabilities in any combination. If the system provides multiple functions simultaneously, for instance weather detection and windshear detection, then the minimum performance standards for each function should be met at all times.

The standards prescribed in this MOPS are thus grouped according to the corresponding intended function such that they can be applied to the functions implemented in the equipment.

Title 14 Code of Federal Regulations (14 CFR) or European Aviation Safety Agency (EASA) Certification Specification (CS) Sections 23.1309, 25.1309, 27.1309, and 29.1309 specify design requirements based on functional hazard categorizations. The latest revisions of Advisory Circulars AC 23.1309-1, 25.1309-1, AC 27-1, and AC 29-2 provide a basis for evaluation of the effects of the loss or malfunction of these functions.

Note: The effect of loss or malfunction should be considered at the aircraft level and at the equipment level as it may contribute to the aircraft level effect.

1.4 Operational Applications and Goals

These applications pertain to both transport aircraft and general aviation aircraft. These requirements may also provide guidance for Unmanned Aircraft Systems (UAS). The applications and goals of the Airborne Radar System include one or more of the following:

- Provide timely indications of weather conditions to aid in avoiding hazardous weather and to help with in-flight route planning.
- Provide the capability to maintain contact with geographic features such as international shoreline boundaries as a supplement to navigational orientation.
- Provide timely windshear alerts to assist in avoiding a windshear event.
- Provide timely indications of potential turbulent weather conditions to assist in navigation in the vicinity of turbulence.
- Provide timely indications of atmospheric threats.

1.4.1 Weather Detection

For weather detection, the airborne radar equipment should detect and display echoes from precipitation in a way that will allow flight crew analysis of weather. In this regard, the radar equipment should provide the following performance features:

- System Detection Range: The sensed and displayed radar range should provide sufficient indication to the flight crew consistent with the speed and maneuver performance of the aircraft in which it is installed, to allow for safe avoidance maneuvers.
- System Display Interpretation: Display features should allow for rapid pilot interpretation of weather characteristics over a wide dynamic range. These levels should be sufficient to allow interpretation of high precipitation gradients associated with turbulence.

1.4.2 Ground Mapping

In the case of ground mapping, the airborne radar equipment should be able to detect and display echoes from the surface of the earth to allow for in-flight analysis.

1.4.3 Windshear Detection

For windshear detection on fixed-wing aircraft, the airborne radar equipment detects areas containing windshear activity that is detectable by radar.

- It will be capable of correlating and generating appropriate alerts based on F-factor. This output should be clear, automatic, concise, and distinct to allow for rapid pilot interpretation.
- Selection of the windshear detection mode should occur automatically during takeoff and landing phases of flight without pilot action.

1.4.4 Turbulence Detection

For turbulence detection on fixed-wing aircraft, the airborne radar equipment detects areas containing convective turbulence activity.

- The intended function is to provide the flight crew with a situation display of regions ahead of the aircraft that present potential hazards to the aircraft under weather conditions that permit radar detection of turbulence.

- The operational goal of such equipment is to display areas of significant turbulence in such a manner as to allow the flight crew the ability to make operational decisions on how to prepare for and if possible, avoid high-risk areas of turbulence. This will place a requirement on the timeliness and location accuracy of the indications on the display.

1.4.5 Atmospheric Threat Awareness

Airborne weather radar equipment may process atmospheric information such as reflectivity, velocity, spectral width, or other information available to the radar, either individually or in combination, to provide atmospheric threat information.

- The resulting cockpit display provides valid, timely, and current advisory information to the flight crew to enhance their situational awareness of atmospheric activity and assist with atmospheric threat avoidance decisions.
- This function should not adversely impact flight crew workload.

1.5 Assumptions

For radar functions that rely on specified accuracies of other aircraft systems, see Paragraph 2.1.8. Any other assumptions are stated in the corresponding requirements section for each function.

1.6 Test Procedures

The test procedures specified in this document demonstrate compliance with the performance requirements defined in Subsection 2.2. Users of this document should not infer performance requirements based on Test Procedures.

The order of tests specified suggests that the equipment be subjected to a succession of tests as it moves from design, and design qualification, into operational use. For example, it is expected that compliance with the requirements of Section 2 have been demonstrated as a precondition to satisfactory completion of the installed system tests of Section 3.

Environmental Tests

Subsection 2.3 defines the environmental test requirements. The procedures and their associated limits provide a laboratory means of determining the electrical and mechanical performance of the equipment under environmental conditions expected to be encountered in actual operations.

Unless otherwise specified, the environmental conditions and test procedures contained in the latest revision of RTCA\DO-160, *Environmental Conditions and Test Procedures for Airborne Equipment* will be used to demonstrate equipment compliance. You may use RTCA/DO-160E or later revision. In this document, the requirements of European Organization for Civil Aviation Equipment (EUROCAE) ED-14E (or later revision) corresponding to the specified requirements of RTCA/DO-160E (or later revision) also apply.

Bench Tests and Engineering Flight Evaluations

Subsection 2.4 specifies bench test and engineering flight evaluation procedures. The bench tests detailed in Paragraph 2.4.3 provide a laboratory means of demonstrating compliance with the requirements of Subsection 2.2. The engineering flight evaluations in Paragraph 2.4.4 serve to verify the intended function(s) of the radar system. Equipment manufacturers may use test results as design guidance, for monitoring manufacturing compliance and, in certain cases, for obtaining formal approval of equipment design. Installers may use data from the engineering flight evaluations to support installation approval activities.

Installed Equipment Considerations

Tests for the installed equipment are included when performance cannot be adequately determined through bench testing or engineering flight evaluations.

Section 3 specifies the installed equipment test procedures and their associated limits. Although bench and environmental test procedures are not included with the installed equipment tests, their successful completion is a precondition to completion of the installed tests. In certain instances, however, installed equipment tests may be used in lieu of bench test simulation of such factors as power supply characteristics, interference from or to other equipment installed on the aircraft, etc. Installed tests are normally performed under two conditions:

- With the aircraft on the ground, using simulated or operational system inputs.
- With the aircraft in flight, using radar targets of opportunity.

Test results may be used to demonstrate functional performance in the intended operational environment. In addition, the procedures may be used as an operational check of equipment performance following corrective maintenance.

Operational Tests

Operational tests are specified in Section 4. This section provides considerations for operational characteristics that may be useful in conjunction with other systems on the final aircraft installation or unique to the final aircraft installation.

1.7 Definition of Terms

SHALL: A mandatory requirement. An approved design must comply with every applicable requirement. This can be assured by inspection, test, analysis, or demonstration.

SHOULD: A recommendation that would typically improve the system/equipment, but does not constitute a requirement.

MAY: A permission that would likely improve the system/equipment, but does not constitute a requirement.

1.8 References

Items marked with an asterisk (*) may be found in the RTCA Store, associated with DO-220A Change 1, or requested by emailing info@rtca.org.

1.8.1 General

Unless otherwise indicated, the latest revisions of the listed documents apply.

[G-1] RTCA/DO-155, *Minimum Performance Standards for Airborne Low-Range Radar Altimeters*

[G-2] RTCA/DO-213, *Minimum Operational Performance Standards for Nose-Mounted Radomes*.

[G-3] AC 20-68, *Recommended Radiation Safety Precautions for Ground Operation of Airborne Weather Radar*

[G-4] AC 20-115, *Airborne Software Assurance*

[G-5] AC 20-152, *RTCA, Inc., Document RTCA/DO-254, Design Assurance Guidance for Airborne Electronic Hardware*

[G-6] AC 20-182, *Airworthiness Approval for Aircraft Weather Radar Systems*

[G-7] AC 25-11, *Electronic Flight Deck Displays*

[G-8] AC 23.1309-1, *System Safety Analysis and Assessment for Part 23 Airplanes*

[G-9] AC 25.1309-1, *System Design and Analysis*

[G-10] AC 27-1, *Certification of Normal Category Rotorcraft*

[G-11] AC 29-2, *Certification of Transport Category Rotorcraft*

[G-12] AC 25.1322-1, *Flightcrew Alerting*

[G-13] ARINC 708A, *Airborne Weather Radar with Forward Looking Windshear Detection Capability*

[G-14] TSO-C63, *Airborne Weather Radar Equipment*

[G-15] DOT/FAA/CT-96/01, *Human Factors Design Guide Update (Report Number DOT/FAA/CT-96/01): A Revision to Chapter 8 - Human Interface Guidelines.* This document can be accessed on the Internet at http:\\www.hf.faa.gov.

[G-16] Federal Communications Commission OET Bulletin 65, *Evaluating Compliance with FCC Guidelines for Human Exposure to Radiofrequency Electromagnetic Fields*

[G-17] IEEE standard C95.1, *IEEE Standard for Safety Levels with respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz*

[G-18] Skolnik, M. I., *Introduction to Radar Systems*, McGraw Hill, 1962

[G-19] Skolnik, M.I. (ed), Radar Handbook, 1970

1.8.2 Windshear Detection

[W-1] Arbuckle, P. Douglas, Michael S. Lewis, and David A. Hinton, *Airborne Systems Technology Application to the Windshear Threat*. Proceedings of the 20th Congress of the International Council of the Aeronautical Sciences, Sorrento, Italy, 1996. Paper Number ICAS-96-5.7.1

[W-2] Bowles, Roland L., *Reducing Windshear Risk through Airborne Systems Technology*, Proceedings of the 17th Congress of the International Council of the Aeronautical Sciences, Stockholm, Sweden, 1990. Paper Number ICAS-90-1.9.3.

[W-3] *Britt, C. L., *Detection and False Alert Probabilities for the NASA Airborne Pulsed Doppler Windshear Radar*, NASA Contract NAS1-18925, Task Assignment No. 24, March 1993

[W-4] Doviak, R. J. and D. S Zrnic, Doppler Radar and Weather Observations, 2nd ed. Academic Press, Inc., New York. 1993

[W-5] Proctor, Fred H., David A. Hinton, and Roland L. Bowles, *A Windshear Hazard Index*; AMS 9th Conference on Aviation, Range and Aerospace Meteorology, Paper: 7.7, pages 482-487, 11-15 September 2000, Orlando, Florida

[W-6] *Switzer, G. F., F. H. Proctor, D. A. Hinton, and J. V. Aanstoos, *Windshear Database for Forward-Looking Systems Certification*, NASA Contract NAS1-18925, Task Assignment No. 26, NASA Technical Memorandum 109012, November 1993

[W-7] Vicroy, Dan D., *Microburst vertical wind estimation from horizontal wind measurements*, 1994, NASA Technical Paper 3460, December 1994. Errata NASA Technical Paper 3460, issued June 1999

[W-8] Wonnacott, T. H. and R. J. Wonnacott, Introductory Statistics, John Wiley & Sons, New York, 1969

[W-9] *NASA Windshear Database Models, NASA Langley Research Center

[W-10] *ADWRS, Airborne Doppler Weather Radar Simulation program, NASA Langley Research Center.[1]

1.8.3 Turbulence Detection

[T-1] *Bowles, Roland L. and Bill K. Buck, *A Methodology for Determining Statistical Performance Compliance for Airborne Doppler Radar with Forward-Looking Turbulence Detection Capability*, NASA/CR-2009-215769 "Corrected Copy", 2009

[T-2] *NASA Turbulence Event Scenarios, NASA Langley Research Center

[1] NASA developed the initial version of ADWRS in FORTRAN. They continue to refine and develop this simulation, including versions in other computer languages. Submit any requests for this software in computer languages other than FORTRAN directly to NASA. NASA will provide source code in the requested computer language if it has already been developed and is available for release. Contact NASA directly at Software Release Authority, NASA Langley Research Center, Hampton, VA 23681-2199

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2 EQUIPMENT PERFORMANCE REQUIREMENTS AND TEST PROCEDURES

2.1 General Requirements

The following general requirements apply to the airborne equipment. General equipment requirements need not be tested in the test procedure subsection.

2.1.1 Airworthiness

In the design and manufacturer of the equipment, the equipment manufacturer **shall** provide for installation so as not to impair the airworthiness of the aircraft.

2.1.2 Intended Function

The equipment **shall** perform its intended function(s), as defined by the radar system manufacturer, and its proper use **shall not** create a hazard to other users of the National Airspace System. See Subsections 1.3 and 1.4 for descriptions.

The radar manufacturer **shall** provide a clear description of each included function.

2.1.3 Federal Communications Commission Rules

All equipment **shall** comply with the applicable rules of the Federal Communication Commission.

2.1.4 Fire Protection

All materials used **shall** be self-extinguishing except for small parts (such as knobs, fasteners, seals, grommets and small electrical parts) that would not contribute significantly to the propagation of a fire.

Note: One means of showing compliance is contained in 14 CFR Part 25, Appendix F.

2.1.5 Operation of Controls

The equipment **shall** be designed so that controls intended for use during flight cannot be operated in any position, combination, or sequence that would result in a condition detrimental to the reliability of the equipment or operation of the aircraft.

2.1.6 Accessibility of Controls

Controls that do not require adjustment during flight **shall** be protected so that they cannot be inadvertent changed by flight personnel.

2.1.7 Radome Design

RTCA/DO-213, *Minimum Operational Performance Standards for Nose-Mounted Radomes* provides minimum operational performance standards for the Radome. The radar manufacturer **shall** specify the minimum DO-213 radome transmission efficiency class required for their system to meet the requirements of this MOPS.

To provide margin for potential radome degradation between radome maintenance cycles, the radar manufacturer **shall** test the windshear function to one class poorer than the specified minimum radome transmission efficiency class.

2.1.8 Equipment Interface Tolerances

The radar manufacturer **shall** specify any required accuracy or tolerance limitations for equipment that interfaces with the radar system.

2.1.9 Heading vs. Track frame of reference discussion

For several optional features in this document, the angular display extent requirements are defined with reference to the longitudinal axis. However, unless otherwise specified, track may be used as a frame of reference instead of longitudinal axis. The frame of reference used should be clear and unambiguous. If track is used the feature should be tested with a minimum drift angle of ± 15 degrees.

2.1.10 Effects of Test

The equipment **shall** be designed so that the application of the specified test procedures is not detrimental to equipment performance following the application of the tests, except as specifically allowed.

2.1.11 Design Assurance

The Design Assurance Levels (DAL) should be adequate to mitigate the failure classification appropriate to the contribution of the equipment to the aircraft level failure in the aircraft in which it is to be installed. The latest revisions of Advisory Circulars AC 23.1309-1 [G-8], AC 25.1309-1 [G-9], AC 27-1 [G-10], and AC 29-2 [G-11] provide a basis for the safety assessment to be performed to evaluate the effects of the loss or malfunction of these functions.

For the equipment computer software package, follow the guidelines contained in AC 20-115C, *Airborne Software Assurance* [G-3].

Guidelines for certification of Airborne Electronic Hardware (AEH) are contained in AC 20-152, *RTCA, Inc., Document RTCA/Do-254, Design Assurance Guidance for Airborne Electronic Hardware* [G-5].

2.1.12 Understandability of Displayed Information

The systems described in this document can include multiple functions and capabilities. In all cases, the information provided on the display should be clear to the flight crew. This applies to both automatic and manual operation. Clarity can be accomplished through display annunciations, control panel selections, training materials, aircraft flight crew operations manuals, or other means.

2.2 Equipment Performance – Standard Conditions

2.2.1 General Equipment Characteristics

2.2.1.1 Radar Characteristics

2.2.1.1.1 Antenna Control Accuracy

The antenna control equipment **shall** provide sufficient accuracy to perform the intended function over the following aircraft attitude envelope.

The minimum aircraft attitude envelope is specified as:

- Pitch and roll extent ±15 degrees
- Pitch and roll rates of at least ±10 degrees per second

If a manually controlled tilt value is displayed, the value displayed should be accurate within ± one quarter of the three-dB beam width or one degree, whichever is greater.

In all cases, the antenna position accuracy should be sufficient to support the Display Bearing Accuracy Requirement in Subparagraph 2.2.1.1.2.

2.2.1.1.2 Display Bearing Accuracy

With zero pitch and roll signals applied to the system, the displayed position of the target **shall** be within ± three degrees of its actual position.

2.2.1.1.3 Indicated Range Error

The error in the indicated target range **shall** be no more than five percent of the selected range or one-half nautical mile whichever is greater.

2.2.1.1.4 Minimum Displayed Target Range

When the minimum selectable range setting is selected, the system **shall** be capable of displaying data to a minimum of 0.5 nautical mile or 15 percent of the selected range, whichever is greater.

2.2.1.2 Antenna Characteristics

2.2.1.2.1 Antenna Beam Characteristics

The antenna beam characteristics **shall** meet the following:

Main Beam: Maximum effective beam width of 10 degrees as measured where the main beam power is down three dB from the maximum peak response.

The effective antenna radiation pattern should be at least 15 dB below the maximum peak response at angles beyond 15 degrees from the boresite position.

Note:

1. *The effects of the radome need not be considered in meeting this requirement.*
2. *For electronically scanned antennas, the above characteristics should be met over the azimuth and elevation requirements specified in Subparagraph 2.2.2.4 and 2.2.2.6 and the antenna control accuracy requirement specified in Subparagraph 2.2.1.1.1.*

2.2.1.3 Display Characteristics

Radar installations may include a dedicated display or may share a display with other aircraft systems. It is envisioned that most radar installations will share a multipurpose display such as an Electronic Flight Instrument System.

If the radar system includes a dedicated display as part of the radar system, then these requirements apply to that display, and it is the responsibility of the radar system manufacturer to show compliance to these requirements.

For airborne radar systems that share a multipurpose display, the display requirements set forth in this document apply to the shared display device when used for displaying radar information.

In general, the progression from green to amber/yellow to red represents an increasing degree of threat, potential hazard, or need of flight crew awareness or response. AC 25-11 [G-7] contains information on color-coding for weather radar.

If the display system is part of the aircraft systems, the display manufacturer and aircraft integrator should adhere to the following requirements.

2.2.1.3.1 Azimuth Display Coverage

The displayed azimuth coverage **shall** be at least as required by Subparagraph 2.2.2.4.

2.2.1.3.2 Vertical Display Coverage

If the system includes vertical display capability, the vertical coverage **shall** be clearly stated and identified on the display.

2.2.1.3.3 Indicator Range Scale

The display **shall** provide range scales commensurate with the maximum radar system design range to aid in long-range weather analysis. It should also allow for reduced range scales for shorter-range weather analysis.

2.2.1.3.4 Range Markers

Range indicators **shall** be provided to aid in assessing the range to displayed targets.

2.2.1.3.5 Predictive Windshear Display Considerations

If applicable, the display **shall** support the windshear icon display and symbology requirements as detailed in the following:

Subparagraph 2.2.3.18, Windshear Icon Minimum Size,

Subparagraph 2.2.3.19, Windshear Icon Symbology,

Subparagraph 2.2.3.15, Windshear Alerts and Icons.

2.2.1.3.6 Turbulence Detection Display Considerations

If applicable, the display **shall** support the turbulence detection display and symbology requirements as detailed in the following:

Subparagraph 2.2.4.2, Angular Display Extent,

Subparagraph 2.2.4.3, Multiple Turbulence Levels,

Subparagraph 2.2.4.4, Multiple Turbulence Detection Severity Non-Interference.

2.2.1.3.7 Atmospheric Threat Awareness Display Considerations

If applicable, the display **shall** support the atmospheric threat awareness display and symbology requirements as detailed in the following:

Subparagraph 2.2.5.3, Atmospheric Threat Awareness Display.

2.2.2 Airborne Weather and Ground Mapping Radar Requirements

The following requirements are applicable to both weather and ground mapping functions unless otherwise noted.

2.2.2.1 Data Freshness

The primary data used for display within 25 nm and within ± 40 degrees azimuth **shall** have been illuminated by the antenna within 60 seconds.

Note: Primary weather data is that data intended to portray the conditions at the aircraft altitude. In the case of manually controlled tilt, primary weather data is all data displayed. In the case of vertical scanning or sector scanning, primary data is the data along the vertical scan or in the sector.

2.2.2.2 Display Data Update

Reflectivity data used for display **shall** be updated on the display at least twice every 20 seconds.

Note: This requirement refers to the refresh rate for data that is provided to the display, not to the antenna scan that acquires the data. The display refresh may include compensation for aircraft motion to ensure the data is correctly positioned on the display.

2.2.2.3 Range Resolution

The range resolution of the reflectivity data used for display **shall** be finer than 5% of displayed range or three nm whichever is coarser.

2.2.2.4 Azimuth Coverage

The equipment **shall** be capable of detecting and providing data to the display that corresponds to at least that azimuth sector which is within ±40 degrees of the longitudinal axis of the aircraft when at zero degrees pitch and roll.

2.2.2.5 Range Coverage

The equipment **shall** be capable of detecting and providing data to the display from the minimum range specified in Subparagraph 2.2.1.1.4 out to the maximum design range specified in Subparagraph 2.2.2.9.

2.2.2.6 Elevation Coverage

Antenna tilt adjustment **shall** be provided such that the axis of the beam may be set to positions from at least 10 degrees below to at least 10 degrees above a plane that is perpendicular to the antenna azimuth rotation axis. This adjustment may be manual and/or automatic.

2.2.2.7 Receiver Gain Control

The equipment **shall** incorporate provision for the manual and/or automatic adjustment of the receiver gain.

2.2.2.8 Sensitivity Time Control (STC)

The equipment **shall** provide a means for automatically adjusting the receiver sensitivity to maintain a relatively uniform displayed target intensity as the range to the target varies.

Note: The purpose of STC is to display approximately the same intensity for rainstorm cells having similar size and reflectivity characteristics for ranges up to beam filling or where the radar sensitivity limits the range, whichever is shorter. The optimum rate of receiver gain change is therefore a function of the size of targets under consideration. When the target size is large enough to intercept all of the energy within half-power boundaries of the transmitted antenna beam, the strength of the return signal varies approximately as the inverse of the second power of distance from the radar to the target. When the target intercepts only a small portion of the transmitted energy, the strength of the signal varies approximately as the inverse of the fourth power of distance. The above assumes no intervening rain attenuation at the carrier frequency in use. Since intervening rain can exist between the radar and the target, the designer may employ other STC rates to compensate for variations in intervening attenuation. During ground mapping, where the half-power of the antenna beam intercepts the ground and the pulse width intercepts less than the half-power of the vertical beam, the STC function may follow the inverse third law.

2.2.2.9 Weather Performance Index

The weather performance of the radar system is defined in terms of the weather performance index. The required weather performance is determined by the category of aircraft in which the equipment is to be installed. The radar **shall** meet the minimum performance index specified in Table 2-2 for the aircraft speed class or classes for which the equipment is designed.

The manufacturer should specify the speed class or classes for which the equipment is designed.

The performance index of the equipment is calculated by the following equation:

Performance Index = $P_t + 2G + K + T - P_r$

Where:

P_t = 10 log10 of the transmitter peak power in watts at the transmitter/receiver waveguide connection.

G = the antenna gain in dB, referenced to an isotropic radiator.

K = Frequency factor. This factor considers the effect of the transmission frequency on radar reflection characteristics and includes an allowance for precipitation attenuation. (The effect of frequency on antenna gain is included in the G term.)

Table 2-1 lists the K Factors for the indicated frequency bands.

Table 2-1: K Factors and Two-way Attenuation Values

Transmitted Frequency (GHz)	K Factor		L_a (dB/nm)
	Penetration	Avoidance	
5.35 to 5.47	0 dB	+3 dB	0.02
9.3 to 9.5	-6 dB	+6 dB	0.024
15.5 to 15.7	-60 dB	+10 dB	0.056

T = 10 $\log_{10}$ of the actual transmitted pulse length in microseconds between the three dB points.

P_r = minimum discernible signal (MDS) power at the antenna port in dBm.

For digital displays, MDS is measured with a maximum probability of false alarm of 10^{-3} and a probability of detection of 30 percent.

The Minimum Performance Index values for each range contained in Table 2-2 were calculated using the following equation:

Performance Index = $113 + L_aR + 40 \log_{10} R$

Where:

R = Maximum system range (nm),

L_a =Two-way free air attenuation in dB/nm from Table 2-1

Table 2-2 lists some calculated Performance Index values for various ranges and frequency bands.

Table 2-2: Minimum Performance Index vs. Maximum System Range

	Minimum Performance Index (dB)					
	Class 1	**Class 2**	**Class 3**	**Class 4**	**Class 5**	**Class 6**
	Cruise to 100 kts	**Cruise to 200 kts**	**Cruise to 350 kts**	**Cruise to 500 kts**	**Cruise to 650 kts**	**Cruise over 650 kts**
Frequency (GHz)	**Range 25 nm**	**Range 50 nm**	**Range 75 nm**	**Range 100 nm**	**Range 125 nm**	**Range 150 nm**
5.35 to 5.47	169	182	190	195	199	203
9.3 to 9.5	170	182	190	195	200	204
15.5 to 15.7	170	184	192	199	204	208

Note:

1. *The above table allows for a radome loss of three dB and a transmission line loss of four dB. When the total two-way loss from these sources is other than seven dB, modify the above figures accordingly. Use the Performance Index equation to calculate the Performance Index for maximum ranges other than those given in the table.*

2. *The maximum ranges were chosen as being generally suitable for aircraft having cruising speeds as indicated.*

3. *For any radar function that utilizes frequencies other than those defined in the above tables, the applicant should define performance index requirements for that function.*

4. *The distinction between the two types of radar in Table 2-1, i.e., penetration and avoidance, results from the allowance made for intervening precipitation when assessing the range performance. In some cases, this may permit a radar system to have two maximum system ranges, one appropriate to the avoidance case.*
   The derivation of the attenuation allowance for the above two categories is based on an approximate attenuation for the following rainfall rates multiplied by the distance.

   Penetration: 300 millimeters per hour nautical miles

   Avoidance: 60 millimeters per hour nautical miles

5. *For historical reference, a derivation of the Performance Index equations is contained in Appendix D.*

2.2.3 Forward Looking Windshear Requirements

Definition of Terms

F-FACTOR: The computed severity of a windshear threat. The F-factor considers both the horizontal and vertical wind components as defined by the equation below. NASA developed the theoretical basis for this aviation-hazard assessment and the underlying measurement process in 1991-1993. See [Arbuckle, et. al. 1996] [W-1]; [Bowles 1990] [W-2]; [Proctor, et. al. 2000] [W-5].

$$F = \frac{\dot{w}_x}{g} - \frac{w_z}{v}$$

Where:

w_x = the horizontal component of the wind velocity in m/s relative to the aircraft horizontal flight path.

$\dot{w}_x$ = The shear term – the time rate of change of w_x in m/s^2 experienced by the aircraft

w_z = the vertical component of the wind velocity in m/s

Typically, the vertical component w_z is not directly measurable by radar. A methodology used successfully in previous implementations is discussed in [Vicroy 1994] [W-7].

g = Gravity in m/s^2

v = Aircraft true airspeed in m/s = fixed at 150 knots (77.2 m/s) for calculation of F-factor. (Although this is more representative of a heavyweight aircraft, this value can be used for all aircraft types. In general, it will tend to yield slightly higher, and thus more conservative, F-factor values than would result from lower approach speeds.)

FBAR: F-factor averaged over one-kilometer radial distance. A central F-factor is used to compute FBAR, i.e., compute the value of FBAR at a point using a spatial interval beginning 500 meters prior to the point and ending 500 meters beyond the point.

FALSE ALERT: An alert that occurs when windshear conditions do not exist

NUISANCE ALERT: An alert that occurs when a windshear phenomenon is encountered which does not exceed the defined windshear alert criteria.

MISSED EVENT: An event is encountered that exceeds the windshear Must-Alert criteria, but is not detected and/or the system does not issue a Windshear Warning Alert for such an event.

WINDSHEAR ADVISORY ALERT: An alert of a detected windshear threat that requires flight crew awareness and may require subsequent flight crew response

WINDSHEAR CAUTION ALERT: An alert of a detected windshear threat that requires immediate flight crew awareness and subsequent flight crew response.

WINDSHEAR WARNING ALERT: An alert of a detected windshear threat that requires immediate flight crew awareness and immediate flight crew response.

Windshear Detection Equipment Interface Tolerances

During development of the windshear detection performance algorithms, it was assumed that the following are available to the radar:

- Height above ground with an accuracy of ± five percent or ± three feet whichever is greater (typically provided by a radar altimeter meeting the requirements of RTCA/DO-155, *Minimum Performance Standards for Airborne Low-Range Radar Altimeters* [G-1])
- Pitch and roll with an accuracy of ± one-fourth of a degree used for stabilization
- Heading with an accuracy of ± one-fourth of a degree
- True Airspeed with an accuracy of ± two percent
- Ground Speed with an accuracy of ± two percent.

Note: *The radar manufacturer may specify alternate interfaces or interface tolerances, or may provide internal means for providing these interfaces as needed, provided that all requirements associated with the predictive windshear function are met.*

Forward Looking Windshear Performance

Windshear performance for fixed wing aircraft is established by the following criteria.

2.2.3.1 Automatic Beam Tilting – Windshear Detection Mode

Automatic beam tilting **shall** be provided in the windshear detection mode.

2.2.3.2 Azimuth Coverage – Windshear Detection Mode

For the windshear detection mode, the sector scan **shall** be at least ± 25 degrees of the longitudinal axis of the aircraft.

2.2.3.3 Windshear Must-Alert Range

The windshear system **shall** issue a warning alert of a windshear threat existing 25 degrees either side of the nose of the airplane, at least 3378 feet before the phenomenon is encountered. This must-alert range corresponds to 10 seconds x 200 KTAS, where 200 KTAS is a typical maximum speed for heavyweight minimum flap operation at high altitude airports on a hot day.

2.2.3.4 Windshear Must-Alert Events

The probability of detecting a windshear must-alert event **shall** be 0.99999 or better, per windshear event. A Must-Alert event is a windshear event with the following characteristics:

- The outflow reflectivity is between 0 dBZ and 60 dBZ, and
- The one-kilometer (radial) averaged F-factor equals or exceeds 0.13.

2.2.3.5 Windshear Must-Not-Alert (Nuisance)

The probability of a windshear nuisance warning alert **shall** be 4 x 10^{-3} or less, per windshear event. A windshear nuisance warning alert is a windshear event with the following characteristics:

- The outflow reflectivity is between 0 dBZ and 60 dBZ in the windshear warning alert region, and
- The one-kilometer (radial) averaged F-factor is less than or equal to 0.085.

Note: See Subparagraph 2.2.3.14 for warning alert level specifications.

2.2.3.6 False Windshear Alerts

The probability of a false alert **shall** be 10^{-4} or less, per takeoff, approach, or go-around. A false alert is an alert that occurs when windshear conditions do not exist.

2.2.3.7 Mutual Interference - Windshear Detection Mode

Transmission from an identical-type radar, operating on an aircraft flying a parallel approach to an adjacent runway or following the equipped aircraft as closely as two nautical miles **shall not** cause false alerts, missed detections or other observable interference.

2.2.3.8 Unannunciated Failure of the Windshear Detection Function

The probability of an unannunciated failure of the windshear detection capability **shall** be on the order of 10^{-5} or less, per flight hour of system operation.

2.2.3.9 Windshear System Fault Detection Indication

Means **shall** be provided for an indication of a failure of the windshear detection system.

2.2.3.10 Windshear System Manual Activation

The windshear system **shall** be capable of manual activation prior to the start of the takeoff roll.

2.2.3.11 Windshear System Automatic Activation

The windshear system **shall** be capable of automatic activation as follows:

- Prior to takeoff, in time to ensure that timely takeoff alerts will be provided prior to achieving the takeoff inhibit speed (see Subparagraph 2.2.3.16).

Note: The logic used for automatic activation prior to takeoff is traditionally referred to as "qualifier logic". When the qualifiers are satisfied, the windshear function will automatically activate. The aircraft manufacturer and/or the radar manufacturer choose qualifiers that are appropriate for the intended installation. These qualifiers are typically selected such that the windshear function will automatically activate at any time after leaving the ramp or gate (once it is safe to operate the radar), but no later than the start of the takeoff roll.

- During descent to approach, in time to ensure that alerts will be provided as specified in Subparagraph 2.2.3.12. The radar manufacturer will determine the appropriate altitude for automatic activation.

When qualifiers are no longer satisfied, the automatic activation should be canceled.

2.2.3.12 Windshear Alert Altitudes

The windshear system **shall** provide aural and visual textual windshear alert outputs from ground level to a minimum of 1200 feet AGL, unless inhibited per Subparagraph 2.2.3.16.

2.2.3.13 Windshear Flight Phase Transitioning

The windshear system **shall** transition to the appropriate windshear flight phase (landing or takeoff) in the event of a missed approach, go-around, or touch and go.

2.2.3.14 Windshear Alert Levels

Windshear alert levels **shall** be determined as follows:

- Warning alerts: For windshear events located within 0.25 nm of either the longitudinal axis or the aircraft track at radial ranges as great as 3.0 nm on takeoff roll or 1.5 nm when airborne after takeoff.
- Caution alerts: For windshear events located within (but not impinging on the Warning alert region) ±25 degrees of either the longitudinal axis or the aircraft track at ranges as great as 3.0 nm.
- Advisory alerts (optional): For windshear events located within ±25° of either the longitudinal axis or the aircraft track at ranges between 3.0 and 5.0 nm.

Note: The windshear alert regions and associated test scenarios were originally developed using aircraft longitudinal axis as the reference. The rationale for use of longitudinal axis is that microbursts move along with the general air mass. If the alert region is defined based on the aircraft longitudinal axis, a microburst detected within this region will drift with the aircraft and retain relevance as the aircraft approaches.

If an applicant chooses to use aircraft track or another axis for defining the alert region, at minimum the applicant should demonstrate that the windshear scenarios defined in Appendix A.3 are adequate to ensure equivalent level of safety. Modifications to the existing test cases or generation of new test cases may be necessary.

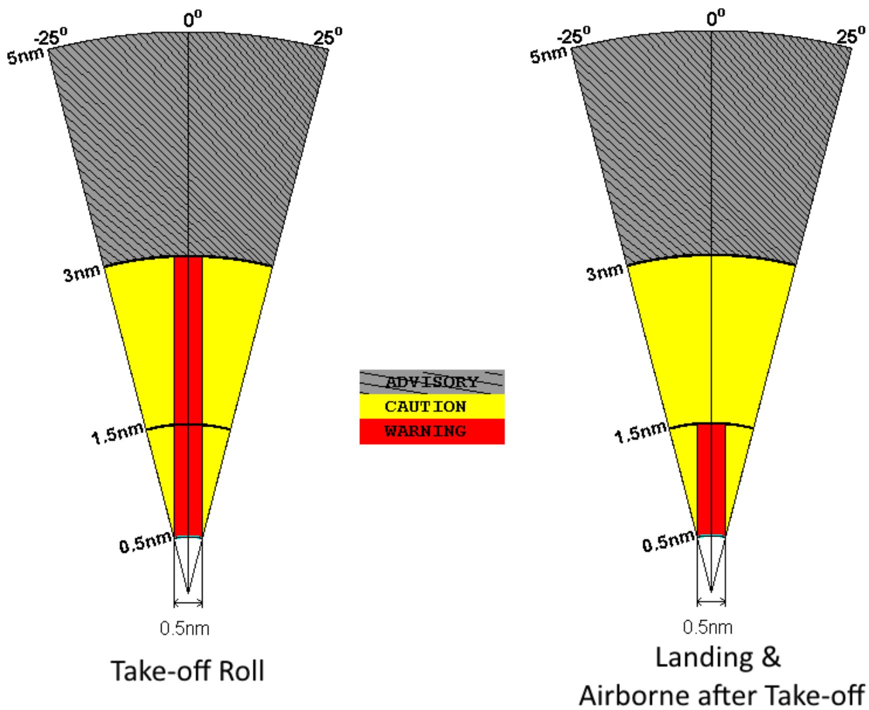

Figure 2-1: Windshear Alert Regions

2.2.3.15 Windshear Alerts and Icons

The system **shall** issue visual textual alerts, aural alerts, and icons as described in Table 2-3.

Table 2-3: Windshear Alerts

Alert Level	Advisory	Caution	Warning
Visual Textual Alert	None	Amber/Yellow Visual Textual Annunciation (or lamp): “Windshear” or “Windshear Ahead” or “W/S Ahead”	Red Visual Textual Annunciation (or lamp): “Windshear” or “Windshear Ahead” or “W/S Ahead”
Aural Alert	None	Distinctive Aural Alert: Chime or message; not containing the word windshear. Example: Tone “Whoop” or “Monitor Radar Display”	Voice Alert: Takeoff: “Windshear Ahead, Windshear Ahead” Approach or Go-around: “Go Around, Windshear Ahead”
Icon	(Optional) Icon symbology as defined in Subparagraph 2.2.3.19	Icon symbology as defined in Subparagraph 2.2.3.19	Icon symbology as defined in Subparagraph 2.2.3.19

Visual textual annunciations should follow basic cockpit alerting philosophy. Other alert phrases or wording may be used provided the applicant uses human factors technology to demonstrate that a clear and substantial benefit can be derived.

Note: The alerts should be automatically canceled following the longer of: the aural message completion; when the measured threat dissipates below threshold; or when the threat exits the area protected by the system.

2.2.3.16 Windshear Alert Inhibits

Windshear aural and visual textual alerts **shall** be inhibited under the following conditions.

- Inhibit all new aural and visual textual alerts above 1200 feet AGL.
- At takeoff, inhibit all new aural and visual textual alerts late in the takeoff roll and re-enable after lift-off. This inhibit region is generally determined by aircraft speed, which should be specified by the manufacturer as appropriate for the intended aircraft installation. The intent of this requirement is to avoid a high-speed rejected takeoff.
- During final approach, inhibit all new aural and visual textual Warning alerts from 50 feet AGL until touchdown.
- During final approach, inhibit all new aural and visual textual Caution alerts from no less than 50 feet AGL, but no greater than 400 AGL, until touchdown. This inhibit altitude should be determined as appropriate for the intended aircraft installation, considering the tradeoff between crew distraction and expanded Caution alert coverage. The intent of this requirement is to reduce potential nuisance Caution alerts during approach.
- During final approach, provide automatic range scaling to prevent the annunciation of windshear Warning alerts beyond the touchdown zone, per the following equation.

  $R = 3.14 * 10^{-3} h + 0.337$ where

  R = range in nm, and h = Feet AGL

  It is optional to provide automatic range scaling for Caution alerts.

It is permissible to display windshear icons at any altitude at which the system is armed in the windshear mode.

2.2.3.17 Windshear Icon Area

The windshear icon **shall** enclose the entire microburst area that contains FBAR values exceeding 0.13.

2.2.3.18 Windshear Icon Minimum Size

The icon **shall** be scaled to no less than a minimum size that depicts a region of 1.8 km ± 0.2 km in azimuth extent and 1.8 km ± 0.2 km in range extent, as measured from the center of the icon.

2.2.3.19 Windshear Icon Symbology

The windshear icon **shall** be depicted as follows:

- The windshear icon consists of alternating red and black bars, oriented such that they are circular arcs centered on the aircraft. The depth of each bar should make the icon conspicuous from other displayed information.

- If the selected display range is greater than five nautical miles, amber/yellow radial lines will extend from the left and right radial boundaries of the icon to the upper edge of the display. This will assist the flight crew in recognizing the event when long display ranges are selected.

In the case of multiple icons, it is permissible to provide radial lines corresponding to the outer-most edges of the combined icons, rather than for each individual icon.

To accommodate icons (or groups of icons) with wide azimuth extent, it is permissible to limit the width between the radial lines. As such, the radial lines may extend along azimuth lines that are inside the left and right radial boundaries of the icon(s).

See Figure 2-2 for some examples of icon symbology.

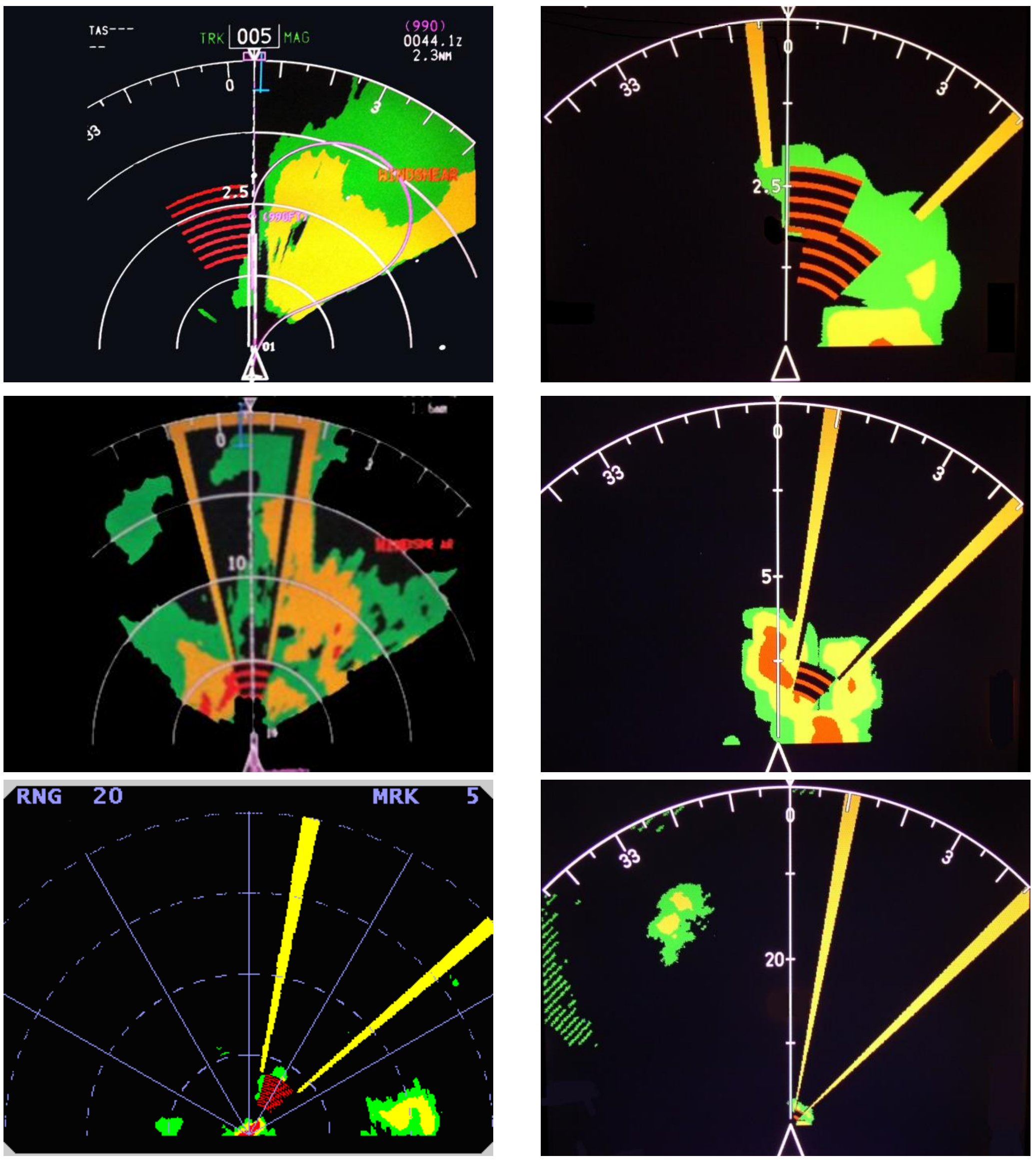

Figure 2-2: Windshear System Icon Examples

2.2.3.20 Windshear Detection Flight Evaluation

The detection capability of the forward-looking windshear system **shall be** verified by flying in areas of convective activity.

2.2.4 Forward Looking Turbulence Detection Requirements

This section establishes the minimum operational performance requirements for the forward-looking turbulence detection function of radar systems for use on a fixed wing airplane.

2.2.4.1 Performance Levels

The radar manufacturer **shall** show compliance with at least the minimum performance level for the expected type of aircraft the radar will be installed on per the paragraph below. Throughout this section $\sigma_{\Delta n}$ is used to refer to the RMS vertical load from a one-g reference, which is consistent with the terminology used in [Bowles and Buck 2009] [T-1]. The unit of $\sigma_{\Delta n}$ is g.

In Table 2-4, the performance levels described in Subparagraph 2.2.4.1.1 through Subparagraph 2.2.4.1.3 are applied as minimum performance levels for radar systems installed on different classes of aircraft. Aircraft classes are differentiated by wing loading throughout the entire flight regime under typical operating conditions. They are intended to span the range of aircraft on which turbulence detecting radar would be installed. For example, aircraft class 1 is defined as aircraft with a range of 80 to 135 lbs/ft^2 wing loading under various flight conditions as shown in Table 2-4 below. Aircraft classes 2 and 3 cover a variety of other aircraft types, wing loading, and configurations. It is necessary to determine a relationship between radar observables and $\sigma_{\Delta n}$ for each aircraft class for which the radar system is to be installed. One method to determine this relationship is documented in [Bowles and Buck 2009] [T-1]; however, other validated relationships may be used. The performance level $\sigma_{\Delta n}$ conditions are based on empirical data found in Figure 2 of [Bowles and Buck 2009] [T-1].

Table 2-4: Aircraft Class and Minimum Performance Level

Aircraft Class	Wing Loading (lbs/ft^2)	Minimum Performance Level
Class 1	80 to 135	1
Class 2	60 to 100	2
Class 3	30 to 70	3

Note: The wing loading range of a given aircraft may not be exactly described by a specific aircraft class. In that case, use the class that most closely represents the aircraft.

2.2.4.1.1 Performance Level 1

If performance level 1 is provided, the radar satisfies the following must-indicate and must-not-indicate specifications:

- Must-indicate turbulence for performance level 1 is that which corresponds to 0.3 $\sigma_{\Delta n}$ with reflectivity greater than or equal to 20 dBZ at a minimum of 12 nm with a probability of 0.85.

- Must-not-indicate turbulence for performance level 1 is that which corresponds to 0.1 $\sigma_{\Delta n}$ with reflectivity greater than or equal to 20 dBZ at a minimum of 12 nm with a probability of 0.8 or greater.

2.2.4.1.2 Performance Level 2

If performance level 2 is provided, the radar satisfies the following must-indicate and must-not-indicate specifications:

- Must-indicate turbulence for performance level 2 is that which corresponds to 0.34 $\sigma_{\Delta n}$ with reflectivity greater than or equal to 25 dBZ at a minimum of 12 nm with a probability of 0.85.
- Must-not-indicate turbulence for performance level 2 is that which corresponds to 0.1 $\sigma_{\Delta n}$ with reflectivity greater than or equal to 25 dBZ at a minimum of 12 nm with a probability of 0.8 or greater.

2.2.4.1.3 Performance Level 3

If performance level 3 is provided, the radar satisfies the following must-indicate and must-not-indicate specifications:

- Must-indicate turbulence for performance level 3 is that which corresponds to 0.38 $\sigma_{\Delta n}$ with reflectivity greater than or equal to 25 dBZ at a minimum of 12 nm with a probability of 0.85.
- Must-not-indicate turbulence for performance level 3 is that which corresponds to 0.1 $\sigma_{\Delta n}$ with reflectivity greater than or equal to 25 dBZ at a minimum of 12 nm with a probability of 0.8 or greater.

2.2.4.2 Angular Display Extent

At a minimum, the radar system **shall** provide for a graphical output of regions ahead of the aircraft, ±25 degrees of either the longitudinal axis or the aircraft track, that present a hazard to the aircraft, under weather conditions that permit radar detection of turbulence.

2.2.4.3 Multiple Turbulence Levels

If the radar manufacturer chooses to display multiple levels of turbulence, the display of those levels **shall** be sufficiently distinct from each other.

2.2.4.4 Multiple Turbulence Detection Severity Non-Interference

If the radar manufacturer chooses to display multiple levels of turbulence, the detection and display of less severe turbulence **shall** not interfere with the minimum detection and display requirements of Subparagraph 2.2.4.1 and Subparagraph 2.2.4.2.

2.2.5 Atmospheric Threat Awareness

This section provides requirements for optional atmospheric threat awareness functionality that may be included with airborne weather radar systems. This awareness capability will provide the flight crew with information of the potential for atmospheric threats ahead of the aircraft. This section applies to atmospheric threats that may be detectable by weather radar, such as, but not limited to, lightning, hail, convective vertical drafts, or volcanic ash. This section can also apply to the indication on rotorcraft of turbulent conditions and/or microburst events ahead of the aircraft. This section does not apply to the basic weather radar, ground mapping, fixed-wing forward-looking windshear, or fixed-wing turbulence detection functions. This section does not include requirements for air-to-air or surface surveillance radars or advanced ground mapping radar applications. Implementation of this functionality is optional. However, if atmospheric threat awareness functions are included, the requirements in this section apply. In this section, "detection" refers to the direct measurement, inference, or prediction of atmospheric threat awareness features using processed weather radar information.

2.2.5.1 Atmospheric Threat Awareness Non-Interference

The optional atmospheric threat awareness function **shall not** interfere with the radar's capability to meet the minimum performance requirements for weather detection, forward-looking windshear detection, forward-looking turbulence detection, and ground mapping.

2.2.5.2 Atmospheric Threat Awareness Performance

2.2.5.2.1 Must-Detect

The atmospheric threat awareness function **shall** provide the flight crew with information on the threat conditions that could affect the safe operation of the aircraft. The acceptable must-detect criteria may vary between different detection features. For example, the acceptable must-detect criteria for lightning could be different from the acceptable must-detect criteria for hail.

2.2.5.2.2 Must-Not-Detect

The atmospheric threat awareness function **shall not** indicate threat conditions that are unlikely to affect the safe operation of the aircraft. Unacceptable nuisance detection criteria exist where nuisance indications outweigh the benefit of the threat awareness detection. The criteria may vary between different atmospheric threat awareness detection features.

2.2.5.2.3 Range

The cockpit display indications **shall** be provided and depicted at a distance and altitude band that provide the flight crew with timely information to aid in making decisions and taking corrective action, if appropriate.

2.2.5.2.4 Azimuth

At a minimum, the radar system **shall** provide for a graphical output of regions for potential atmospheric threats ahead of the aircraft, ±25 degrees of the longitudinal axis or the aircraft track.

2.2.5.3 Atmospheric Threat Awareness Display

2.2.5.3.1 Symbology

The symbology or other display indications used to depict the potential threat **shall** be understandable and not misleading, distracting, or confusing.

2.2.5.3.2 Display Clutter

The atmospheric threat awareness feature's symbology and display indications **shall not** adversely impact the ability to view, read, and interpret the weather, ground mapping, turbulence, and predictive windshear display. Automatic decluttering, such as during specific phases of flight, or during certain alerts, may be appropriate.

2.2.5.3.3 Multiple Performance Levels or Intensity Levels

If multiple performance levels or intensity levels (e.g. light, moderate, or heavy) of atmospheric threat awareness depiction are provided, the equipment manufacturer **shall** make the multiple levels of the atmospheric threat awareness indications sufficiently distinct such that severe levels can be distinguished from less severe levels.

2.2.5.3.4 Mode Annunciation

The modes in use **shall** be obvious to the pilot. Consider both manual and automatic activation.

2.3 Equipment Performance – Environmental Conditions

The environmental tests and performance requirements described in this section provide a laboratory means of determining the overall performance characteristics of the equipment under conditions representative of those that may be encountered in actual aeronautical operations.

Some of the environmental tests contained in this section need not be performed unless the radar system manufacturer wishes to qualify the equipment for that particular environmental condition. These tests are identified by the phrase “When required.” If the radar system manufacturer wishes to qualify the equipment to these additional environmental conditions, then these “When required” tests **shall** be performed.

The test set-up procedures applicable to a determination of equipment performance under environmental test conditions are contained in RTCA Document DO-160G, Environmental Conditions and Test Procedures for Airborne Equipment, December 8, 2010. However, you may use RTCA/DO-160E, dated December 20, 2005, or later revision.

Some of the performance requirements in Subsection 2.2 are not tested by the test procedures herein. Moreover, not all performance tests are required during each of the environmental conditions in RTCA/DO-160G. Judgment and experience have indicated that these particular performance parameters are not susceptible to certain environmental conditions and that the level of performance specified in Subsection 2.2 will not be measurably degraded by exposure to these environmental conditions.

Additional tests may have to be performed in order to determine performance of particular design requirements that are not specified in this document. It is the responsibility of the system radar manufacturer to determine appropriate tests for these functions.

Note: During the following environmental tests, the requirements for measurement of Performance Index will be deemed to have been met if the Performance Index measured under standard test conditions is corrected by the change in receiver Minimum Discernible Signal (MDS) and by the change in mean transmitted power occurring as a result of environmental stress.

2.3.1 Environmental Test Conditions

Table 2-5 lists all of the environmental conditions and test procedures (hereafter referred to as environmental procedures) that are documented in RTCA/DO-160G. These are cross-referenced with the performance tests specified in detail in this section, which should be run subject to the various environmental procedures of RTCA/DO-160G. The performance tests are run (D)uring and/or (A)fter each environmental test as specified in the table. If the entry is grayed-out, performance testing is not required in conjunction with that environmental test.

Table 2-5: Performance Test Requirements for Environmental Tests

ENVIRONMENTAL TESTS	DO-160G Section	ATP (Note 1)	2.2.1.1.1 Antenna Control Accuracy	2.2.2.1 Data Freshness	2.2.2.8 Sensitivity Time Control (STC)	2.2.2.9 Weather Performance Index	2.2.1.1.2 Display Bearing Accuracy	2.2.1.1.3 Indicated Range Error	REMARKS
Temperature / Altitude	4.0								
Temperature Tests									
Ground Survival Low Temperature Test and Short-Time Operating Low Temperature Test	4.5.1		D	D	D	D			
Operating Low Temperature Test	4.5.2		D	D	D	D		D	
Ground Survival High Temperature Test and Short-Time Operating High Temperature Test	4.5.3		D	D	D	D			
Operating High Temperature Test	4.5.4		D	D	D	D		D	
In-Flight Loss of Cooling Test	4.5.5		D	D	D	D			
Altitude Tests									
Altitude Test	4.6.1		D	D	D	D		D	
Decompression Test	4.6.2	A							When Required
Overpressure	4.6.3	A							When Required
Temperature Variation	5.0		D	D	A	D		D	
Humidity	6.0				A	A			
Shock	7.0								
Operational Shock			A	A		A	A		
Crash Safety Shocks									
Vibration	8.0		D/A			D/A		D	Note 2
Explosion	9.0								When Required
Waterproofness									
Condensing Water Drip Proof Test	10.3.1		A			A			When Required
Drip Proof Test	10.3.2		A			A			When Required
Spray Proof Test	10.3.3		A			A			When Required
Continuous Stream Proof Test	10.3.4		A			A			When Required
Fluids Susceptibility									
Spray Test	11.4.1		A			A			When Required
Immersion Test	11.4.2		A			A			When Required
Sand and Dust	12.0		A			A			When Required
Fungus Resistance	13.0		A			A			When Required
Salt Fog	14.0		A			A	A		When Required
Magnetic Effect	15.0								When Required

ENVIRONMENTAL TESTS	DO-160G Section	ATP (Note 1)	2.2.1.1.1 Antenna Control Accuracy	2.2.2.1 Data Freshness	2.2.2.8 Sensitivity Time Control (STC)	2.2.2.9 Weather Performance Index	2.2.1.1.2 Display Bearing Accuracy	2.2.1.1.3 Indicated Range Error	REMARKS
Power Input									Note 3
Normal Operating Conditions	16.5.1 16.6.1					D	D	D	Note 4
Abnormal Operating Conditions	16.5.2 16.6.2	A							
Current Harmonics Tests	16.7.1								When Required
Allowable Phase Unbalance	16.7.2								When Required
DC Current Content in Steady-State Operation	16.7.3								When Required
Regenerated Energy	16.7.4								When Required
Inrush Current Requirements	16.7.5								When Required
Current Modulation in Steady-State Operation	16.7.6								When Required
DC Current Ripple Tests	16.7.7								When Required
Power Factor	16.7.8								When Required
Voltage Spike	17.0	A							When Required
Audio Freq. Conducted Susceptibility	18.0					D	D	D	When Required
Induced Signal Susceptibility	19.0					D/A	D/A	D/A	
RF Susceptibility	20.0					D	D	D	Note 5
Emission of RF Energy	21.0								
Lightning Induced Transient Susceptibility	22.0		D	D		D			When Required. Note 6
Lightning Direct Effects	23.0		D	D		D			When Required
Icing	24.0		D	D					When Required
Electrostatic Discharge	25.0		A	A		A			When Required Note 7
Fire / Flammability	26.0								

Note:

1. *An Acceptance Test Procedure (ATP) is a procedure used to determine if a UUT is functioning properly. It is up to the equipment manufacture to define an appropriate ATP for the UUT.*
2. *Endurance testing only requires performance tests (A)fter completing tests.*
3. *If the UUT receives conditioned power, then this section may not apply.*
4. *During power interrupts, it is not necessary to verify performance requirements, but it is necessary to verify the equipment's operation as specified by the radar system manufacturer.*
5. *The frequencies for local oscillators and intermediate frequencies should not be excluded based on DO-160( ) §20.3.d.*
6. *Pin Injection testing only requires performance tests (A)fter completing tests.*
7. *Ensure that the UUT is functional during the test, and that it appropriately handles any resets that may occur.*

2.4 Equipment Test Procedures

2.4.1 Definitions of Terms and Conditions of Test

The following are definitions of terms and the conditions under which the tests described in this section should be conducted.

- Power Input Voltage – Unless otherwise specified, conduct all tests with the power input voltage adjusted to design voltage, ± 2%. Measure the input voltage at the input terminals of the equipment under test.
- Power Input Frequency - In the case of equipment designed for operation from an AC source of essentially constant frequency (e.g., 400 Hz); adjust the input frequency to design frequency, ± 2%.

  In the case of equipment designed for operation from an AC source of variable frequency (e.g., 300 to 1,000 Hz), unless otherwise specified, conduct the tests with the input frequency adjusted to within 5% of a selected frequency and within the range for which the equipment is designed.
- Adjustment of Equipment – Ensure that the circuits of the equipment under test are properly aligned and otherwise adjusted in accordance with the equipment manufacturer's recommended practices prior to application of the specified tests.
- Test Equipment – Identify all equipment used in the performance of the tests by make, model, and serial number where appropriate, including the latest calibration dates. When appropriate, all test equipment calibration standards should be traceable to national and/or international standards. If nonstandard test equipment is required, provide essential characteristics.
- Test Instrument Precautions – Take adequate precautions during the performance of the test to prevent the introduction of errors resulting from the connection of voltmeters, oscilloscopes and other test instruments across the input and output impedances of the equipment under test.
- Ambient Conditions – Refer to DO-160G, section 3. Unless otherwise specified, perform all tests within the following ambient conditions:
  - Temperature: +15 to +35 degrees C (+59 to +95 degrees F).
  - Relative Humidity: Not greater than 85%.
  - Ambient Pressure: 84 to 1-7 kPa (equivalent to +5,000 ft to –1,500 ft) (+1,525m to –460m).
- Connected Loads – Unless otherwise specified, perform all tests with the equipment connected to loads having the impedance values for which it is designed.
- Conduct all tests after an appropriate warm-up time as specified by the radar system manufacturer.

2.4.2 Required Test Equipment

The measurement/generating/recording equipment used for each test is to be determined and justified by the radar system manufacturer. Proof of calibration, accuracy, standards applied, and capabilities or essential characteristics required should be provided as part of the test report.

2.4.3 Detailed Test Procedures

NOTE:

WHILE THE POTENTIAL FOR MICROWAVE RADIATION HAZARD IS RECOGNIZED, THIS HAZARD IS NOT ADDRESSED ON AN INDIVIDUAL TEST BASIS. THE TESTING ORGANIZATION SHOULD TAKE ALL NECESSARY PRECAUTIONS TO PROTECT PERSONNEL FROM HAZARDOUS MICROWAVE RADIATION.

The test procedures set forth below constitute a satisfactory method of determining required performance. Although specific test procedures are cited, it is recognized that other methods may be preferred. Such alternate methods may be used if the radar system manufacturer can show that they provide at least equivalent information. Therefore, the procedures cited herein should be used as one criterion in evaluating the acceptability of the alternate procedures. Ultimately, it is up to the equipment manufacturer to assess that their test procedures to ensure requirements are adequately tested.

2.4.3.1 General Equipment Characteristics

2.4.3.1.1 Radar Characteristics (Subparagraph 2.2.1.1)

2.4.3.1.1.1 Antenna Control Accuracy (Subparagraph 2.2.1.1.1)

<u>Equipment Required</u>

As determined by the radar system manufacturer in accordance with Paragraph 2.4.2.

<u>Measurement Procedures</u>

Discussion: The test procedure is broken down into two types of functionality: automated antenna operation and manual antenna operation. Perform tests for all applicable configurations of the radar under test.

Automated antenna operation:

1. Determine limits for positional accuracy
    a. These limits may be specified by the radar system manufacturer based on an analysis showing the required antenna pointing accuracy necessary to meet the functional requirements of the automatic mode (ground clutter elimination, hazard detection etc.)
    b. Include this analysis as part of the test results. These pointing accuracy requirements need to be in the form of actual position of the antenna relative to antenna pointing control signals or theoretical calculation of antenna position.
    c. Include a reasonable number of test cases that address normal azimuth and elevation operation in conjunction with pitch and roll variations as required in Antenna Control Accuracy (Subparagraph 2.2.1.1.1).
2. Evaluate accuracy
    a. Compare actual antenna position (azimuth and elevation) to calculated position (azimuth and elevation) for each test case and compare to limits determined from analysis.
3. Verify performance
    a. Verify that the actual position of the antenna (azimuth and elevation) is within the parameters specified by Subparagraph 2.2.1.1.1.

Manual antenna operation:

1. Evaluate accuracy
   a. Test a reasonable number of test cases that address normal azimuth and elevation operation in conjunction with pitch and roll variations as required in Antenna Control Accuracy (Subparagraph 2.2.1.1.1).
2. Verify performance
   a. Verify that the actual position of the antenna (azimuth and elevation) is within the parameters specified by Subparagraph 2.2.1.1.1.

2.4.3.1.1.2 Display Bearing Accuracy (Subparagraph 2.2.1.1.2)

Equipment Required

As determined by the radar system manufacturer in accordance with Paragraph 2.4.2.

Measurement Procedures

Discussion: This test procedure tests the combined accuracy of the antenna positioning system, signal processing of radar returns, and output processing circuitry that generates the display of radar returns.

1. Set up
   a. Set up the Radar system under test in a suitable ground station installation that has ground targets that can be detected and displayed. Suitable ground targets should be point type targets such as buildings or towers.
2. Calculate bearing
   a. Position the radar at a known bearing. Calculate the bearing from the radar installation to the target.
3. Verify performance
   a. Verify that the center of the target is displayed at the correct bearing per the display bearing accuracy requirement (Subparagraph 2.2.1.1.2).

Alternate procedure

1. Set up
   a. Using a signal generator tuned to the transmit frequency of the radar being tested, synchronize the generator with the antenna positioning system such that a response that is no greater than two degrees in width (azimuth) can be sent at a position of 30 degrees left of boresite.
2. Verify performance
   a. Verify that the center of the displayed return is at 30 degrees left of boresite per the Display Bearing Accuracy requirement (Subparagraph 2.2.1.1.2).
3. Repeat the test with the target azimuth being 30 degrees right of boresite.

2.4.3.1.1.3 Indicated Range Error (Subparagraph 2.2.1.1.3)

Note: The following procedure assumes a pulsed radar waveform. For CW radars, define a similar test to accomplish verification.

Equipment Required

As determined by the radar system manufacturer in accordance with Paragraph 2.4.2.

Recommended

Microwave Signal Generator

- Pulse capability with programmable delay from trigger
- Delay adjustment range from 3 µs to 2 ms
- Delay error no greater than 300 ns

Oscilloscope

Directional Coupler or similar means to inject and monitor pulse into radar receiver

Envelope Detector

Measurement Procedures

1. Configure Test Equipment
   a. Configure and connect the test equipment and the Unit Under Test (UUT). See Figure 2-3 for a suggested method.

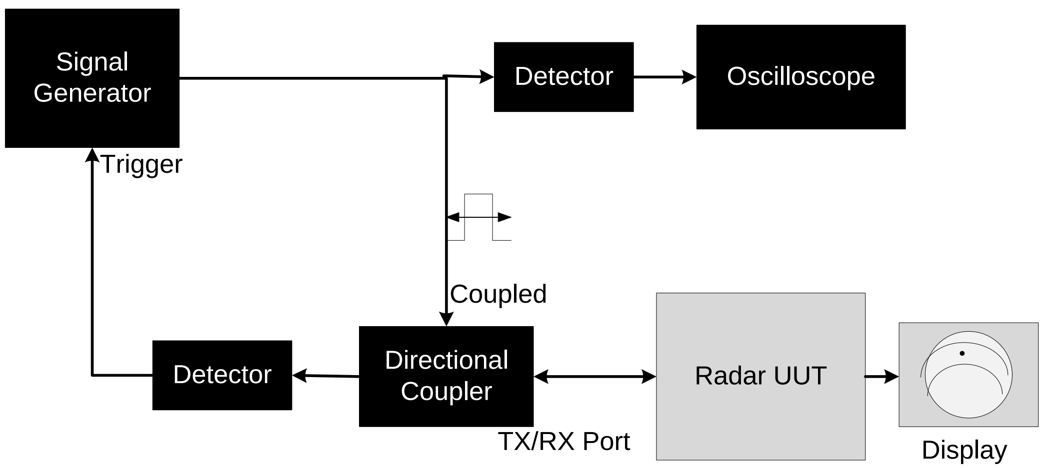

Figure 2-3: Indicated Range Error Test Configuration

2. Calibrate Pulse Input Delay
   a. Calibrate the Signal Generator delay setting to provide the correct delay for each range at the UUT RX input port.
3. Set Initial Delays
   a. Set the pulse delay on the Signal Generator for the minimum range of the UUT using the calibration offset found in step 2.
4. Measure Displayed Range
   a. Read the displayed range to the target from the system display or from the UUT display output bus.
5. Calculate Displayed Range Error
   a. Calculate the difference between the displayed range and the range setting corresponding to the delay set in step 3.
6. Verify Performance
   a. Verify that the error calculated in step 5 meets the requirements of Subparagraph 2.2.1.1.3.
7. Repeat for All Range Settings (not required during the DO-160 test)

a. Repeat steps 4 through 6 for all UUT range settings with the appropriate pulse delay set in the signal generator.

2.4.3.1.1.4 Minimum Displayed Target Range (Subparagraph 2.2.1.1.4)

Equipment Required

As determined by the radar system manufacturer in accordance with Paragraph 2.4.2.

Recommended

Oscilloscope

Signal Generator

- Pulse capability with programmable delay from trigger
- Programmable pulse amplitude capability
- Delay error no greater than 300 ns
- Amplitude error no greater than 0.2 dB

Directional Coupler

Envelope Detector

Measurement Procedures

1. Configure Test Equipment
   a. Connect the equipment as shown in Figure 2-4.

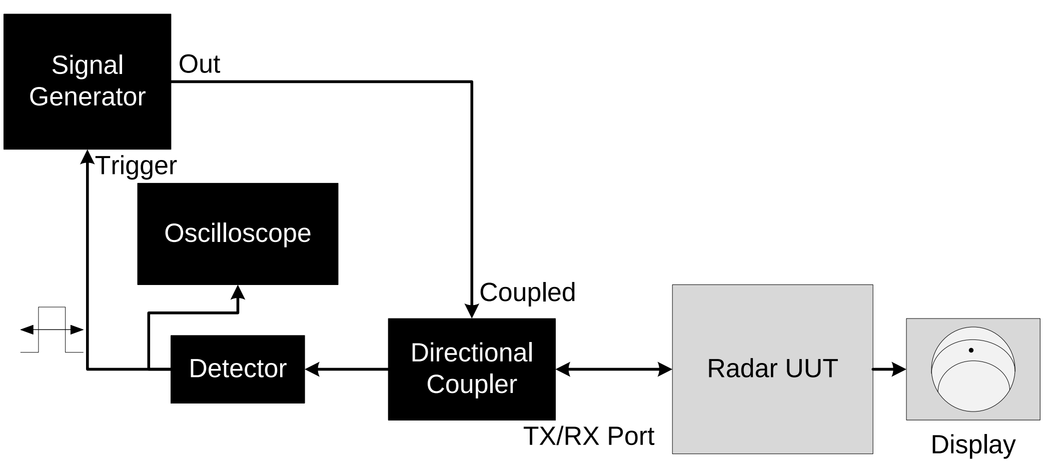

Figure 2-4: Minimum Displayed Target Range Test Configuration

2. Measure the Minimum Target Range
   a. Select weather mode for the radar.
   b. Select the minimum range of the radar
   c. Connect the directional coupler to the waveguide output of the transmitter/receiver.
   d. Adjust the microwave signal generator to produce a pulse with a width of 15 microseconds ± 5 microseconds, and synchronize the signal generator pulse to the transmitted RF pulse.
   e. Adjust the pulse delay and the signal decay level to display the target at the lowest level, starting at 2 miles.
   f. Increase the signal by 20 dB.

g. Decrease the signal generator pulse delay until the leading edge of the pulse is displayed at the lowest level. Note the range of the leading edge of the target on the display.

3. Verify Performance

a. Verify that the minimum range calculated in step 2 meets the requirements of subparagraph 2.2.1.1.4.

2.4.3.1.2 Antenna Characteristics (Subparagraph 2.2.1.2)

2.4.3.1.2.1 Antenna Beam Characteristics (Subparagraph 2.2.1.2.1)

Equipment Required

As determined by the radar system manufacturer in accordance with Paragraph 2.4.2.

Signal source antenna producing a uniform field across the aperture of the antenna under test.

An antenna mounting, by means of which the orientation of the antenna under test may be varied in bearing and elevation in increments of 1 degree or less and having a calibrated accuracy within 0.5 degree.

Note: An antenna mounting which automatically changes the antenna orientation through a predetermined cycle and a Rectangular Coordinate Recording System may be used.

Measurement Procedures

1. Equipment Setup

a. Locate the signal source antenna and the antenna under test at a height which minimizes undesired reflections, and separate the antennas by a distance of at least:

$$\frac{2D^2}{\lambda}$$

Where: D = illuminated effective diameter of the larger of the two antennas

λ= wavelength of the transmitted signal

2. Measurement Process

a. Apply a signal to the signal source antenna and orient the antenna so that its beam is directed toward the antenna under test. Change the orientation of the antenna under test in increments of one (1) degree in both bearing and elevation and note the output of the antenna under test. Conduct this test over the horizontal and vertical angles required to determine the antenna beam pattern. Reverse transmission may be used from the antenna under test to the signal source antenna

3. Verify Performance

a. Verify that the antenna beam pattern meets the requirements of subparagraph 2.2.1.2.1.

Note: For an Electronically Scanned Antenna (ESA), repeat Step 2 with the ESA focused at different azimuth and/or elevation angles to the extent necessary to characterize the antenna performance.

2.4.3.1.3 Display Characteristics (Subparagraph 2.2.1.3)

Note: During testing of display characteristics, the display used for verification may be actual or simulated. The display must be sufficient to allow verification of the radar display output requirements. If the display is a dedicated part of the radar system, then that display should be used as part of these test procedures.

2.4.3.1.3.1 Azimuth Display Coverage (Subparagraph 2.2.1.3.1)

Measurement Procedures

1. Measure the Arc
   a. With the radar on and a test pattern displayed, measure the angular coverage to the left and right of the center line of the display.
2. Verify performance
   a. Verify that the angular coverage satisfies the requirements of Subparagraph 2.2.1.3.1.

2.4.3.1.3.2 Vertical Display Coverage (Subparagraph 2.2.1.3.2)

If equipped with a vertical display, verify that vertical coverage is identified on the display and is clearly stated.

2.4.3.1.3.3 Indicator Range Scale (Subparagraph 2.2.1.3.3)

Measurement Procedures

1. Display of radar range scale
   a. Demonstrate per the requirement and document the result.
2. Verify performance
   a. Verify that the angular coverage satisfies the requirements of Subparagraph 2.2.1.3.3.

Note: This generally applies to the display system. Demonstrate compliance, if possible, by using actual aircraft displays or by reviewing the requirements of the aircraft display system.

2.4.3.1.3.4 Range Markers (Subparagraph 2.2.1.3.4)

Measurement Procedures

1. Display of Range Markers
   a. Demonstrate per the requirement and document the result.
2. Verify performance
   a. Verify that the angular coverage satisfies the requirements of Subparagraph 2.2.1.3.4.

Note: This generally applies to the display system. Demonstrate compliance, if possible, by using actual aircraft displays or by reviewing the requirements of the aircraft display system.

2.4.3.1.3.5 Predictive Windshear Display Considerations (Subparagraph 2.2.1.3.5)

Follow the test procedures defined for the requirements referenced in Subparagraph 2.2.1.3.5.

2.4.3.1.3.6 Turbulence Detection Display Considerations (Subparagraph 2.2.1.3.6)

Follow the test procedures defined for the requirements referenced in Subparagraph 2.2.1.3.6. For Turbulence Detection test procedures see Subparagraph 2.4.3.4.

2.4.3.1.3.7 Atmospheric Threat Awareness Display Considerations (Subparagraph 2.2.1.3.7)

Follow the test procedures defined for the requirements referenced in Subparagraph 2.2.1.3.7. For Atmospheric Threat Awareness test procedures see Subparagraph 2.4.3.5.

2.4.3.2 Airborne Weather and Ground Mapping Radar Requirements (Paragraph 2.2.2)

2.4.3.2.1 Data Freshness (Subparagraph 2.2.2.1)

Equipment Required

As determined by the radar system manufacturer in accordance with Paragraph 2.4.2.

Measurement Procedures

1. Set-up
   a. Turn the radar on and set to weather mode and the worst-case operational mode.
2. Timing Verification
   a. Verify that the primary data used for display is updated within the prescribed time. This can be by measurement or analysis.

2.4.3.2.2 Display Data Update (Subparagraph 2.2.2.2)

Equipment Required

As determined by the radar system manufacturer in accordance with Paragraph 2.4.2.

Measurement Procedures

1. Set-up
   a. Turn the radar on and set to weather mode and the worst-case display bus update mode.
2. Timing Measurement
   a. Verify that the display image is updated within the prescribed time.

2.4.3.2.3 Range Resolution (Subparagraph 2.2.2.3)

Procedures

1. Verify this requirement by either analysis or test/measurement.
   a. If analysis, analyze over all pulse combinations of the radar system.
   b. If using test/measurement use all pulse combinations of the radar as applicable to verify the requirement.

2.4.3.2.4 Azimuth Coverage (Subparagraph 2.2.2.4)

Equipment Required

As determined by the radar system manufacturer in accordance with Paragraph 2.4.2.

Measurement/Verification Procedures

1. Measurement of Azimuth Angle of the Antenna
   a. Measure and verify that the scan angle satisfies the requirement in Subparagraph 2.2.2.4.
2. Verification of Azimuth Angle from the radar processor
   a. Verify that the radar processor is outputting azimuth information per the requirement in Subparagraph 2.2.2.4.

2.4.3.2.5 Range Coverage (Subparagraph 2.2.2.5)

Equipment Required

As determined by the radar system manufacturer in accordance with Paragraph 2.4.2.

Measurement Procedures Minimum Target Range

1. Establish a target (either real or simulated) at a known distance through the RF path and at the minimum range specified in the requirement.
2. Verify that the target is detected and that data from that target is provided to the display per the requirement.

Measurement Procedures Maximum Target Range

1. Establish a target (either real or simulated) at a known distance through the RF path and at the maximum range specified in the requirement.
2. Verify that the target is detected and that data from that target is provided to the display per the requirement.

2.4.3.2.6 Elevation Coverage (Subparagraph 2.2.2.6)

Equipment Required

As determined by the radar system manufacturer in accordance with Paragraph 2.4.2.

Sensor for measuring the relative angular position of the antenna feed and reflector with an accuracy of a tenth of a degree

Measurement Procedures for mechanically steerable antennas

1. Test Setup
   a. Mount the antenna and attach the angular measurement sensor to the antenna feed or flat plate radiator when this type of antenna is used.
2. Compare Commanded Tilt with measured Elevation Angle
   a. Set Pitch and Roll inputs to zero. Command the tilt to zero degrees.
3. Verify performance
   a. Verify that the difference between the angular measurement sensor tilt and the commanded tilt are within specified levels across the azimuth scan.
4. Repeat for Tilt Extremes
   a. Repeat at the positive and negative tilt extremes.

Measurement Procedures for electronically steerable antennas

1. Test Setup - Calibration
   a. For electronically tilt-able antennas, measure the antenna on a range to determine that the pointing angles coincide with the beam steering angles per design specifications. Note the relationship between the beam steering signals and the antenna pointing angle.
2. Validate Beam Steering Signal Integrity when Exposed to Environmental Conditions
   a. During environmental tests required in Subsection 2.3, Equipment Performance – Environmental Conditions, measure the beam steering signals to ensure that the antenna is pointing to the specified angle.
3. Measure at Different Commanded Tilts
   a. Command the antenna to a zero-tilt angle and note the beam steering signals. Repeat with the commanded tilt set in one of its extreme positions and note the beam steering signals. Repeat again with the commanded tilt set in the other extreme position and note the beam steering signals. Determine the corresponding number of degrees change in antenna pointing angle.

4. Verify that the requirement in Subparagraph 2.2.2.6 is satisfied.

2.4.3.2.7 Receiver Gain Control (Subparagraph 2.2.2.7)

Procedures

1. For manual receiver gain adjustment: Verify that the output to the display system reflects the value of the gain setting.
2. For Automatic receiver gain adjustment: Verify that the function is working per the radar system manufacture's specification/requirements for the function.

2.4.3.2.8 Sensitivity Time Control (STC) (Subparagraph 2.2.2.8)

Equipment Required

As determined by the radar system manufacturer in accordance with Paragraph 2.4.2.

Measurement Procedures

1. Set up
   a. Determine for each pulse delay time the input signal level required to produce an equivalent output.
2. Run Test
   a. Vary the pulse delay time in at least six (6) equally spaced increments over the maximum range for which the STC function is designed.
3. Verify
   a. Verify the requirements of 2.2.2.8.

2.4.3.2.9 Weather Performance Index (Subparagraph 2.2.2.9)

Equipment Required

As determined by the radar system manufacturer in accordance with Paragraph 2.4.2.

Recommended

Signal Generator

Power Meter

Ancillary devices necessary:

- To couple the radar transmitter into a power meter in order to make a peak power measurement
- To inject known signal levels into the radar receiver

Measurement Procedures

1. Peak Power output
   a. Use the power meter and appropriate devices to measure and or calculate the peak power

Note: *It may be possible to measure peak power directly with the chosen test set up but then convert it into dBW for use in Subparagraph 2.2.2.9.*

2. Antenna Gain
   a. Determine the far field main lobe antenna gain in dB.

Note: *Antenna gain may be determined by many methods. One method of measuring antenna gain is by comparison to a calibrated antenna. If this method is used, document how it was accomplished so it can be reproduced if necessary. It is permissible to use an industry standard method and accepted tools to calculate the gain of the antenna. This should be well documented, so it can be reproduced. It is also recommended that the calculation method be verified by industry-accepted means and documented.*

3. Minimum Discernible Signal Power (MDS)
    a. Adjust the signal generator to produce a 37 μs pulse length.
    b. Adjust the receiver gain so the radar system display output would display a maximum false alarm rate of 10-3.
    c. Adjust the pulse delay time to value outside the STC function.
    d. Adjust the signal generator output until the signal band output to the display has 30% of its output active. This is the MDS region.
    e. Determine the signal level at the receiver input in dBm.
4. Weather Performance Index
    a. Calculate the index as described in 2.2.2.9 from the parameters determined in the previous steps.
5. Verify that the calculated weather performance index satisfies the requirements in Table 2-2 of Subparagraph 2.2.2.9 for the speed class or classes for which the equipment is designed.

2.4.3.3 Forward Looking Windshear Test Procedures

General Commentary: Minimum acceptable windshear performance is established by verification of compliance with criteria that include detection range; probability of missed event (must-alert); probability of nuisance (must-not) alert; probability of false alert; the probability of unannunciated failure; and more. Both simulation and analytic means are required. Simulation provides the means to measure compliance with a finite number of test cases/models. It also provides some corroborative evidence to support the analytic processes. These test cases (models) include a spectrum of hazardous and non-hazardous microburst windshears and other weather phenomena along with the test scenarios. Each weather case is defined by a modeled database, for example, a numerically generated database of reflectivity and velocity vector on a fine three-dimensional grid. This data is superimposed on radar system manufacturer recorded urban airport flight clutter and then provided to the algorithmic processes of the candidate windshear system by means of a modified NASA ADWRS or comparable simulation. Advance Warning range is measured relative to an in situ "truth", derived for each test case/model.

Extension of the measured performance to establish estimates of the probabilities of missed (must-alert) events, nuisance (must-not-alert) events, false alerts, and unannunciated failures are largely accomplished by analysis.

2.4.3.3.1 Automatic Beam Tilting – Windshear Detection Mode (Subparagraph 2.2.3.1)

Set the radar to windshear mode. Verify that the antenna automatically tilts as expected for windshear mode.

2.4.3.3.2 Azimuth Coverage – Windshear Detection Mode (Subparagraph 2.2.3.2)

Equipment Required

As determined by the radar system manufacturer in accordance with Paragraph 2.4.2.

Measurement/Verification Procedures

1. Measurement of Azimuth Angle of the Antenna
    a. Measure and verify that the scan angle satisfies the requirement in Subparagraph 2.2.3.2.
2. Verification of Azimuth Angle from the radar processor
    a. Verify that the radar processor is outputting azimuth information per the requirement in Subparagraph 2.2.3.2.

2.4.3.3.3 Windshear Must-Alert Range (Subparagraph 2.2.3.3)

Equipment Required

High capacity storage devices containing the following data sources:

- NASA database models [W-9].
- Flight recorded urban airport takeoff and/or landing flight clutter database.

Radar system manufacturer's unique digital processes or emulator of the windshear event

High speed Computer

Measurement Procedure

Windshear hazard detection range performance is derived from exercise of the test set-up shown in Figure 2-5. It combines, by superposition, emulations of radar sensor signals as input to the radar system manufacturer's unique digital windshear processes and produces estimates of the windshear system's advance alert range. These estimates are referenced to an in-situ truth (generated independently from the radar signals) using INS data for true inertial geometry.

Appendix A lists the scenario information for all test cases. Initial conditions are selected, and the set-up is exercised for each test case (combination of flight scenario and wind field model) identified in Appendix A. Runs with a must-alert encountered in-situ truth are to exhibit an alert range equal to or greater than the requirements of Subparagraph 2.2.3.3.

Radar installation losses including a radome and transmission line will be less than the loss parameter used for the Windshear must-alert range calculations (Subparagraph 2.2.3.3).

Refer to Subsection A.2 for a discussion of the development of the clutter data base, NASA microburst model database [W-9], the modified NASA Airborne Doppler Weather Radar Simulation (ADWRS) [W-10], and constraints upon their use for windshear performance evaluation. Refer to Appendix A for plots pertaining to the NASA microburst model data sets.

The NASA windshear database models [W-9] and ADWRS [W-10] may be found in the RTCA Store, associated with DO-220A Change 1, or requested by emailing info@rtca.org.

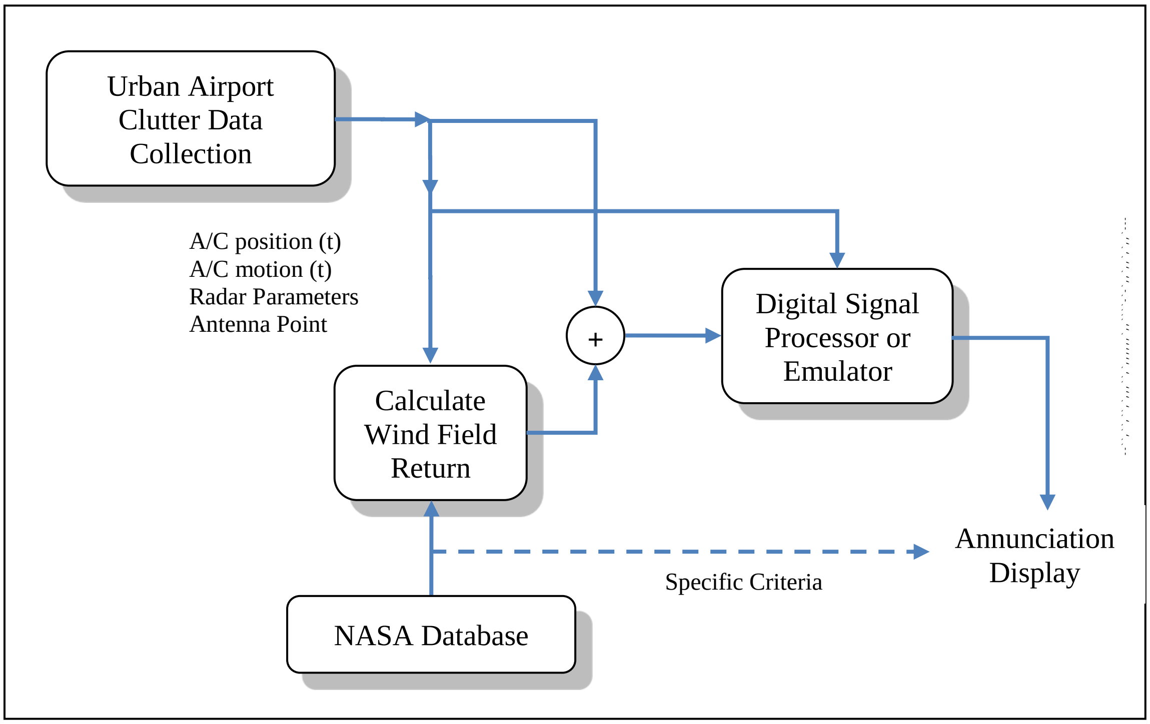

Figure 2-5: Windshear Test Configuration

See Subparagraph 2.4.4.1 for information on windshear detection flight evaluation.

2.4.3.3.4 Windshear Must-Alert Events (Subparagraph 2.2.3.4)

Establish compliance with this requirement by analysis conducted in accordance with the techniques of Appendix C or equivalent procedure, for events with reflectivity between 0 dBZ and 60 dBZ. The test runs of Subparagraph 2.2.3.3 may be used to supplement this analysis.

2.4.3.3.5 Windshear Must-Not-Alert (Nuisance) (Subparagraph 2.2.3.5)

Establish compliance with this requirement by analysis conducted in accordance with the techniques of Appendix C or equivalent procedure, for events with reflectivity between 0 dBZ and 60 dBZ. The test runs of Subparagraph 2.2.3.3 may be used to supplement this analysis.

2.4.3.3.6 False Windshear Alerts (Subparagraph 2.2.3.6)

Exhibit false alert compliance by demonstrating that clutter data collected at stressing airport environments produce no false alerts. Demonstrate compliance with the windshear false alert criteria by providing evidence of the use of good clutter suppression techniques in the system design. Suggested methods include field history for existing systems, or Monte-Carlo simulation.

Stressing airport environments have the following characteristics:

- Expressways and high-volume surface streets within approximately 1 nm of the runway;
- Nearby taxiing aircraft; and
- Concentrated urban clutter. The clutter should occupy a minimum area of approximately one nm surrounding the airport.

2.4.3.3.7 Mutual Interference - Windshear Detection Mode (Subparagraph 2.2.3.7)

Use analysis to show compliance with the requirements of mutual interference of the windshear detection function.

2.4.3.3.8 Unannunciated Failure of the Windshear Detection Function (Subparagraph 2.2.3.8)

Use analysis to show compliance with the requirements of unannunciated failure of the windshear function.

2.4.3.3.9 Windshear System Fault Detection Indication (Subparagraph 2.2.3.9)

Set the condition of failure of the windshear system. Verify the windshear fail indication.

2.4.3.3.10 Windshear System Manual Activation (Subparagraph 2.2.3.10)

Set altitude and ground speed inputs to zero. Manually command the activation of the windshear system. Verify that the radar became active in the windshear mode.

2.4.3.3.11 Windshear System Automatic Activation (Subparagraph 2.2.3.11)

- While in a takeoff configuration with the windshear function inactive, verify that the windshear function activates automatically once the appropriate qualifiers are met.
- While in an approach configuration with the windshear mode inactive, verify that the windshear mode activates automatically once the aircraft altitude is below the threshold value as chosen by the radar manufacturer.

2.4.3.3.12 Windshear Alert Altitudes (Subparagraph 2.2.3.12)

Using simulated windshear conditions (while not under inhibit conditions), verify that both audio and visual textual alerts are provided at the specified minimum altitude, maximum altitude, and at least three other in-between altitudes that are reasonably spaced apart.

2.4.3.3.13 Windshear Flight Phase Transitioning (Subparagraph 2.2.3.13)

The windshear system flight phase is used for automatic activation, alert level determination, aural alert selection, and alert inhibit determination. Test the windshear system flight phase transitioning as follows:

- Simulate a missed approach and verify that the windshear system flight phase properly transitions from landing to takeoff.
- Simulate a go-around and verify that the windshear system flight phase properly transitions from landing to takeoff.
- Simulate a touch-and-go and verify that the windshear system flight phase properly transitions from landing to takeoff.

2.4.3.3.14 Windshear Alert Levels (Subparagraph 2.2.3.14)

Set up simulated windshear conditions in regions corresponding to warning, caution and advisory alerts as specified in Subparagraph 2.2.3.14. Verify that the alerts and icons satisfy requirements specified in Subparagraph 2.2.3.15. Perform this test for all relevant phases of flight.

Note: The alert level requirement is tested together with the alerts and icons requirement.

2.4.3.3.15 Windshear Alerts and Icons (Subparagraph 2.2.3.15)

Set up simulated windshear conditions in regions corresponding to warning, caution and advisory alerts as specified in Subparagraph 2.2.3.14. Verify that the alerts and icons satisfy requirements specified in Subparagraph 2.2.3.15. Perform this test for all relevant phases of flight.

Note: The alerts and icons requirement is tested together with the alert level requirement.

2.4.3.3.16 Windshear Alert Inhibits (Subparagraph 2.2.3.16)

- Set the aircraft altitude to a value greater than 1200 feet but less than the altitude that was selected for automatic activation per Subparagraph 2.2.3.11, to ensure that the windshear mode is still operational. Set up a windshear condition and verify that the aural and visual textual alerts are inhibited. Repeat for both warning and caution alerts.
- While in a take-off configuration, set the aircraft speed to a value that is greater than the inhibit speed. Set up a windshear condition and verify that the aural and visual textual alerts are inhibited. Confirm that the alerts are re-enabled after lift-off. Repeat for both warning and caution alerts.
- While in approach configuration, set the aircraft altitude to less than 50 feet AGL. Set up a windshear warning condition and verify that the warning aural and visual textual alerts are inhibited.
- While in approach configuration, set the aircraft altitude to less than 50 feet AGL. Set up a windshear caution condition and verify that the caution aural and visual textual alerts are inhibited. If the windshear system uses a caution alert approach inhibit altitude greater than 50 feet AGL (refer to Subparagraph 2.2.3.16), repeat this test for an aircraft altitude that is greater than 50 feet AGL and less than the selected approach inhibit altitude.
- While in approach configuration, set up a windshear warning condition beyond the touchdown zone (per equation specified in Subparagraph 2.2.3.16). Verify that the warning aural and visual textual alerts are inhibited.

- If the windshear system provides automatic range scaling for caution alerts, while in approach configuration, set up a windshear caution condition beyond the touchdown zone (per equation specified in Subparagraph 2.2.3.16). Verify that the caution aural and visual textual alerts are inhibited.

Note: It is permissible to display windshear icons at any altitude at which the system is armed in the windshear mode.

2.4.3.3.17 Windshear Icon Area (Subparagraph 2.2.3.17)

Simulate at least two windshear events. Verify that the windshear icon encloses all FBAR values greater than 0.13.

2.4.3.3.18 Windshear Icon Minimum Size (Subparagraph 2.2.3.18)

Simulate at least one windshear event with a windshear region smaller than 1.6 km in the azimuth dimension. Verify that the icon depicts a region that has an azimuth extent of 1.8 ± 0.2 km, as measured from the center of the icon.

Simulate at least one windshear event with a windshear region smaller than 1.6 km in the range dimension. Verify that the icon depicts a region that has a range extent of 1.8 ± 0.2 km, as measured from the center of the icon.

Simulate at least one windshear event with a windshear region smaller than 1.6 km in both the azimuth and range dimensions. Verify that the icon depicts a region that has a range extent and an azimuth extent of 1.8 ± 0.2 km, as measured from the center of the icon.

2.4.3.3.19 Windshear Icon Symbology (Subparagraph 2.2.3.19)

Simulate at least one windshear event and select a range of five nm or less. Verify the windshear icon symbology is as expected, and that the icon is conspicuous from other displayed information.

Simulate at least one windshear event and select a range that is greater than five nm. Verify the windshear icon symbology including the radial lines is as expected, and that the icon is conspicuous from other displayed information.

2.4.3.3.20 Windshear Detection Flight Evaluation (Subparagraph 2.2.3.20)

Verify the detection capability of the forward-looking windshear system by flying in areas of convective activity that can be verified by in-situ measurements, appropriate ground based radar systems, or equivalent. If the forward-looking windshear detection capability has been previously demonstrated and it can be shown that the data are still applicable after modification to the system, then these flights need not be repeated.

Note:

1. *Flying in or near storm cells can be extremely hazardous. Flight crews should exercise good judgment for safe flight based on knowledge of their own abilities and of the capability of the aircraft when considering approaching or penetrating any storm cell or turbulent area.*
2. *"Windshear detection flight evaluations" are sometimes referred to as "windshear penetration flights" in previous versions of DO-220 and FAA Advisory Circular 20-182. This nomenclature is not meant to imply any preference for the means used to verify the windshear detection functionality of the radar.*

2.4.3.4 Forward Looking Turbulence Test Procedures

The following section provides guidance on how to verify the forward-looking turbulence detection requirements in Paragraph 2.2.3.20.

2.4.3.4.1 Performance Levels (Subparagraph 2.2.4.1)

Use a combination of statistical analysis and simulation to demonstrate compliance with the performance level requirements of 2.2.4.1. This evidence will, at a minimum, consist of the following:

- Statistical evaluation of the turbulence detection performance algorithm
- Simulation showing the capability of the radar to properly detect and indicate turbulence.

2.4.3.4.1.1 Statistical Evaluation of Performance

Provide a probabilistic and statistical analysis comparing the design characteristics of the radar system, variability in aircraft wing loading, and atmospheric disturbance to the turbulence measurement performance required by 2.2.4.1. This may be accomplished by using accepted analytical or Monte-Carlo simulation techniques. Bowles and Buck 2009 [T-1] or other validated methods may be used for these purposes.

Provide results of evaluations of the turbulence detection performance of the radar system that show the capability of the system to satisfy 2.2.4.1. There are a wide range of methods by which these evaluations can be performed.

Clearly describe the method by which the evaluations are performed, including descriptions of any simplifying assumptions used in the analysis.

In the performance evaluation for compliance with 2.2.4.1, indicate how the evaluation of the errors in the turbulence measurement process has been accounted for.

Implement the performance evaluation in a manner that reflects the actual turbulence measurement or estimation processing that is implemented onboard the radar system processor.

In the evaluation of performance, include the effect of variation in aircraft type and weight for the aircraft on which the radar system will be installed. Aircraft properties affect the relationship between the turbulence threat (RMS-g) and the wind variance.

2.4.3.4.1.2 Simulated Performance

Demonstrate system performance, defined in Table 2-4, by simulating radar signals returned from specific weather models as described below.

2.4.3.4.1.2.1 Simulation Method Description

Starting with the turbulence event scenarios described in 2.4.3.4.1.2.3 compare the following two fields:

- The radar observable turbulence truth field based on the turbulence event scenario data
- The radar indicated turbulence field based on simulated radar returns from the turbulence event scenario data

To calculate the radar observable turbulence truth field, use the turbulence event scenario's reflectivity, velocity, and flight-test conditions to create a turbulence truth field. The turbulence truth field should not have the effects of noise, sidelobes from pulse compression, or sidelobes from the antenna beam. It should take into account the measurable wind field vectors due to aircraft location and may use either a reasonable pulse volume based on radar system parameters or a 1 km^2 area as used in [Bowles and Buck 2009] [T-1].

Likewise, calculate the radar indicated turbulence field based on simulated radar returns using the turbulence event scenario's reflectivity, velocity, and flight test conditions. Use a validated radar system simulation such as the Airborne Doppler Weather Radar Simulation (ADWRS) [W-10] to simulate realistic radar returns, taking into account radar parameters such as pulse length, antenna beamwidth, noise figure, etc. Use the simulated in-phase and quadrature (I/Q) data as inputs to the actual turbulence detection and indication algorithms. Actual hardware or a validated emulation of the hardware function may be used to verify the algorithm. An actual or emulated display may be used to display turbulence for evaluation and verification purposes.

Compare the radar indicated turbulence field and radar observable turbulence truth field per Subparagraph 2.4.3.4.1.2.7.

A graphical depiction of the process used to simulate, display, and evaluate radar system performance is shown in Figure 2-6.

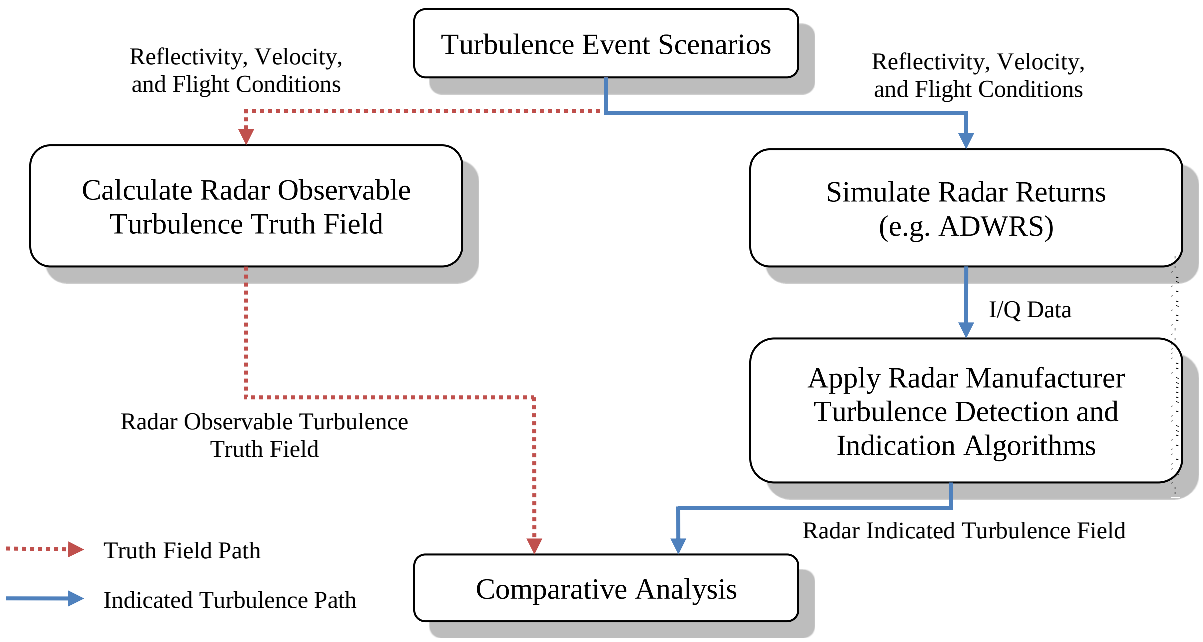

Figure 2-6: System Simulation Methodology

The radar system simulator used to generate the radar-indicated turbulence field for analysis in 2.4.3.4.1.2.7 may be ADWRS [W-10]. ADWRS and the data sets used in 2.4.3.4.1.2.3 may be found in the RTCA Store, associated with DO-220A Change 1, or requested by emailing info@rtca.org.

2.4.3.4.1.2.2 Validation of Radar System Simulator

If using a modified version of ADWRS [W-10], or if using a different radar system simulator, then verify the following:

- The geometry of the flight conditions of the plane relative to the weather's location is used correctly.
- The interpretation of the reflectivity and velocity of the event scenarios is accurate.
- The radar characteristics (pulse length, beamwidth, noise figure, etc.) are used to modify the weather returns in a realistic manner.

2.4.3.4.1.2.3 Turbulence Event Scenarios

Use the following data sets and flight conditions as turbulence event scenarios per 2.4.3.4.1.2. Radar returns may be simulated using ADWRS or other validated radar system simulators per 2.4.3.4.1.2.2.

2.4.3.4.1.2.4 191-06 – Must-Indicate Scenario

For the "191-06" data set, use the following input values:

- Altitude 30,000 ft. AGL/MSL
- Airspeed = 290 knots (indicated)/450 knots (true)
- Ground Speed = 491 knots
- Scenario is initialized at X = -2 km flying parallel to Y axis toward positive Y

2.4.3.4.1.2.5 MCY (Miles City) – Must-Not-Indicate Scenario

For the "MCY" data set, use the following input values:

- Altitude = 22,000 ft. AGL, 25,000 ft. MSL
- Airspeed = 290 knots (indicated)/418 knots (true)
- Ground Speed = 418 knots
- Scenario is initialized at Y = -15.5 km flying parallel to X axis toward positive X

2.4.3.4.1.2.6 MCY Modification for Aircraft Classes 2 and 3

For the must-not-indicate scenario for aircraft classes 2 and 3, multiply the wind velocity vectors by the following factors:

- 0.825 for aircraft class 2
- 0.515 for aircraft class 3

Note: The above factors are based on the ratio of PDF conversion factor means between class 1 and either class 2 or 3 from [Bowles and Buck 2009] [T-1]. Other factors may be used with appropriate justification.

2.4.3.4.1.2.7 Simulation Analysis

2.4.3.4.1.2.8 Must-Indicate Simulation Verification

In the case of display output for the simulation of dataset "191-06", demonstrate the display of turbulence at a minimum of 12 nm from the aircraft position, and within 2 km of the peak of the aircraft radar observable truth field as defined in Subparagraph 2.4.3.4.1.2. Since radar detection of turbulence is statistical in nature, multiple sweeps may be used to demonstrate compliance for this requirement.

2.4.3.4.1.2.9 Must-Not-Indicate Simulation Verification

In the case of display output for the simulation of dataset "MCY", demonstrate that the radar does not display persistent turbulence indications at 12 nm from the aircraft position.

Note: Persistent indications imply that the turbulence indications are spatially correlated from sweep to sweep.

2.4.3.4.2 Angular Display Extent (Subparagraph 2.2.4.2)

Test the radar with actual or simulated atmospheric conditions to demonstrate, at a minimum, that the radar system provides a graphical output of turbulence threats ahead of the aircraft, ±25 degrees of either the longitudinal axis or the aircraft track.

2.4.3.4.3 Multiple Turbulence Levels (Subparagraph 2.2.4.3)

If multiple levels of turbulence severity are depicted, demonstrate that multiple intensity levels of turbulence are depicted as sufficiently distinct from one another by evaluation or analysis.

2.4.3.4.4 Multiple Turbulence Detection Severity Non-Interference (Subparagraph 2.2.4.4)

If multiple levels of turbulence severity are provided, ensure that the less severe turbulence indication does not adversely impact the detection performance of the severe turbulence detection. This may be accomplished by ensuring testing of the severe turbulence detection function includes representative atmospheric conditions which also trigger the less severe turbulence detection function. [Bowles and Buck 2009] [T-1]

2.4.3.5 Atmospheric Threat Awareness Test Procedures

2.4.3.5.1 Atmospheric Threat Awareness (Subparagraph 2.2.5.1)

Verify that the atmospheric threat awareness function(s) do not adversely impact the performance and display of the weather, ground mapping, turbulence detection, or predictive windshear functions. This may be accomplished by ensuring that testing of the weather, ground mapping, turbulence detection, and/or predictive windshear functions includes representative atmospheric conditions that also trigger the atmospheric threat awareness function(s).

2.4.3.5.2 Atmospheric Threat Awareness Performance (Subparagraph 2.2.5.2)

Validate that the following are appropriate: detection level(s), must-detect criteria, must-not-detect criteria, range, and azimuth requirements for the atmospheric threat awareness function in Subparagraph 2.2.5.2.

Test the system with actual atmospheric events representative of actual threat conditions. Select a sufficient number of actual atmospheric events to demonstrate functionality across a variety of realistic atmospheric conditions and applicable phases of flight for the atmospheric threat. Data to support these threat occurrences may be collected by in-situ measurements, ground based radar systems, simulated historical atmospheric events, or other applicable means.

Test the system with simulated or actual atmospheric events which represent the boundary conditions for the must-detect and must-not-detect requirements.

2.4.3.5.2.1 Must-Detect (Subparagraph 2.2.5.2.1)

Accomplish testing for the must-detect criteria requirements of the atmospheric threat awareness function(s) against a variety of simulated or actual atmospheric events, as defined in Subparagraph 2.4.3.5.2. Verify that the system complies with the defined must-detect requirements.

2.4.3.5.2.2 Must-Not-Detect (Subparagraph 2.2.5.2.2

Accomplish testing for the nuisance detection criteria of the atmospheric threat awareness function(s) against a variety of simulated or actual atmospheric events, as defined in Subparagraph 2.4.3.5.2. Verify that the system complies with the defined must-not-detect requirements.

2.4.3.5.2.3 Range (Subparagraph 2.2.5.2.3)

Test the system with actual or simulated atmospheric conditions and demonstrate the atmospheric threats are detected at the minimum and maximum specified range for that atmospheric threat.

2.4.3.5.2.4 Azimuth (Subparagraph 2.2.5.2.4)

Test the system with actual or simulated atmospheric conditions to demonstrate, at a minimum, that the radar system provides a graphical output of atmospheric threat regions ahead of the aircraft, ±25 degrees of the longitudinal axis or the aircraft track.

2.4.3.5.3 Atmospheric Threat Awareness Display (Subparagraph 2.2.5.3)

2.4.3.5.3.1 Symbology (Subparagraph 2.2.5.3.1)

Verify that the symbology and other display indications used to depict the atmospheric threat are understandable and is not misleading, distracting, or confusing.

Use human factors or other assessment as part of the verification. Human factors guidelines for flight crew alerting may be found in AC 25-11 [G-7], AC 25.1322-1 [G-12], or in the FAA report *Human Factors Design Guide Update (Report Number DOT/FAA/CT-96/01): A Revision to Chapter 8 - Human Interface Guidelines* [G-15].

2.4.3.5.3.2 Display Clutter (Subparagraph 2.2.5.3.2)

Evaluate the atmospheric threat awareness feature symbology and display indications to verify that they do not adversely impact the ability to view, read, and interpret the weather, ground mapping, turbulence, and predictive windshear display. Automatic de-cluttering, such as during specific phases of flight, or during certain alerts, may also be appropriate.

2.4.3.5.3.3 Multiple Performance Levels or Intensity Levels (Subparagraph 2.2.5.3.3)

Demonstrate that multiple intensity levels of atmospheric threat awareness depictions are sufficiently distinct from one another by evaluation or analysis.

2.4.3.5.3.4 Mode Annunciation (Subparagraph 2.2.5.3.4)

Verify that the mode(s) in use are obvious to the pilot. Use of mode annunciation via the controller is an acceptable means of compliance provided the radar operation is clearly stated in the operator's guide.

2.4.4 Flight Evaluation Activities

The radar manufacturer should conduct flight evaluations to verify the intended functions of weather detection, ground mapping, windshear detection, turbulence detection, and/or atmospheric threat awareness functions as provided by the radar.

Note: Flying in or near storm cells can be extremely hazardous. Flight crews should exercise good judgment for safe flight based on knowledge of their own abilities and of the capability of the aircraft when considering approaching or penetrating any storm cell or turbulent area.

2.4.4.1 Forward-Looking Windshear Detection

The test procedure for accomplishing the windshear detection flight evaluation is detailed in Subparagraph 2.4.3.3.20.

2.4.4.2 Turbulence Detection

If the turbulence detection capability has not been previously demonstrated, then the radar manufacturer should evaluate the performance of the turbulence detection capability against operationally significant weather without placing the aircraft in the hazardous weather. This performance evaluation should ensure that the depiction of turbulence is consistent with the actual weather phenomenon. In addition, the radar manufacturer should evaluate turbulence performance in the presence of non-turbulent weather and in a variety of relevant operational scenarios, including turns, climbs, and descents, to ensure that the turbulence detection function is not prone to nuisance or false turbulence indications.

2.4.4.3 Atmospheric Threat Awareness

If the Atmospheric Threat Awareness capability has not been previously demonstrated, then the radar manufacturer should evaluate the performance of the atmospheric threat awareness detection capability against operationally significant atmospheric threats without placing the aircraft in a hazardous situation. This performance evaluation should ensure that the depiction of atmospheric threats is consistent with the actual atmospheric phenomenon. In addition, the radar manufacturer should evaluate the atmospheric threat awareness function in the presence of non-threatening atmospheric conditions and in a variety of relevant operational scenarios including turns, climbs, and descents to ensure that the atmospheric threat awareness function is not prone to nuisance or false indications.

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3 MANUFACTURER CONSIDERATIONS FOR INSTALLED EQUIPMENT

Equipment designed to meet these MOPS require separate approval for installation and use on an aircraft. This section provides some aircraft installation-related considerations that the radar system manufacturer may want to consider in the design such that approvals may be obtained when correctly installed in an aircraft.

One acceptable means of accomplishing airworthiness approval for the installation of airborne weather radar equipment is provided in Advisory Circular AC 20-182, *Airworthiness Approval for Aircraft Weather Radar Systems* [G-6]. In the event of conflict between AC 20-182 and Section 3 of this document, AC 20-182 will take precedence.

3.1 Equipment Installation

3.1.1 Accessibility

Controls and monitors provided for in-flight operations should be readily accessible from the operator/crew member's normal seated position.

3.1.2 Aircraft Environment (Subsection 2.3)

Equipment should be compatible with the environmental conditions present in the specific location in the aircraft where the equipment is installed.

3.1.3 Failure Protection

The equipment should be designed to ensure that any probable failure of the equipment will not degrade the normal operation of equipment or systems connected to it, and the failure of interfaced equipment or systems will not degrade normal operation of this equipment.

3.1.4 Interference Effects

The equipment should be designed to ensure that it will not be the source of conducted or radiated interference causing degradation of normal equipment operation nor be adversely affected by conducted or radiated interference from other equipment or systems installed in the aircraft.

Note: Electromagnetic compatibility problems noted after installation of this equipment may result from such factors as the design characteristics of previously installed systems or equipment and the physical installation itself. It is not intended that the equipment manufacturer design for all installation environments. The installing facility will be responsible for resolving any incompatibility between this equipment and previously installed equipment in the aircraft. Consider the various factors contributing to the incompatibility.

3.1.5 Inadvertent Turnoff

Appropriate protection should be provided to avert the inadvertent turnoff of the equipment.

3.1.6 Aircraft Power Source

Unless otherwise specified, tests should be conducted with the radar equipment powered by the aircraft's electrical power generating system.

3.1.7 Safety Precautions

Before energizing the equipment, be sure microwave radiation safety precautions, including both fuel and personnel safety considerations, have been observed. These include clearing all personnel to an area beyond the maximum permissible exposure level boundary as computed by the equipment manufacturer or other approved source.

Note: There are many sources available to aid in the determination of a safe distance for fuel and personnel from a radiating antenna. Acceptable sources (but not the only sources) available are as follows:

AC 20-68B *[G-3]*

IEEE Standard C95.1 [G-17]

FCC OET Bulletin 65 [G-16]

3.1.8 Adjustment of Equipment (Paragraph 2.1.8)

The equipment under test should be properly aligned and otherwise adjusted in accordance with ARINC 708A [G-13] or the radar system manufacturer's recommended practices prior to the application of the specified tests. In addition, interfacing equipment should provide acceptable accuracy in accordance with paragraph 2.1.8 or as specified by the radar manufacturer.

3.1.9 Warm-up Period

The equipment under test should be provided any necessary warm up time as required by the equipment manufacturer before the following tests.

3.2 Installed Equipment Performance Considerations

The radar equipment **shall** be tested to demonstrate compliance with the minimum requirements specified in Section 2. In order to meet this requirement, test results supplied by the equipment manufacturer and accepted as part of the supplier’s TSO application may be accepted in lieu of tests performed by the equipment installer. Similar considerations may be made for non-TSO functions.

3.2.1 Weather Radar Transmission Loss

Where a radome and/or transmission line is included as part of the radar system installation, all minimum installed system performance requirements will be met with radar signals transmitted and received with an equivalent or higher transmission loss than that of the final aircraft installation. ARINC 708A-3 [G-13] provides maximum expected transmission loss values if the final aircraft installation is unknown. The higher of the two estimates should be used to remain conservative.

3.2.2 System Performance (Subparagraphs 2.2.2.9 and 2.2.3.3)

Radar installation losses including a radome and transmission line should be less than the system loss parameter used for the performance index calculations (Subparagraph 2.2.2.9) and less than the loss parameter used for windshear must-alert range calculations (Subparagraph 2.2.3.3).

3.2.3 Aperture Blockage

Physical and engineering analyses should demonstrate that there is no antenna blockage within the area of ±10 degrees in elevation and ±40 degrees in azimuth. Outside of this area, the blockage may be no more than 10 percent.

3.3 Test Procedures for Installed Equipment Performance

Test Procedures for installed equipment are provided below. In addition to the procedures listed in this subsection, Advisory Circular AC 20-182 [G-3] provides guidance for the initial and follow-on airworthiness approval of aircraft weather radar systems.

3.3.1 Conformity Inspection

Visually inspect the installed equipment to determine that acceptable workmanship and engineering practices were used in the installation. Verify that all mechanical and electrical connections have been properly assembled and that the equipment has been installed and located according to the equipment manufacturer's recommendations.

3.3.2 Ground Test Procedure

3.3.2.1 Equipment Function (Subparagraph 2.2.1.2)

Vary all equipment controls individually through their full range of operation and verify that the system is operating according to the equipment manufacturer's instructions and that each control performs its intended function. It will be necessary to operate ancillary equipment to comply with this requirement.

3.3.2.2 Display Integration (Subparagraph 2.2.1.3)

Vary all equipment controls individually through their full range of operation. Verify that the display responds appropriately in each mode selection. Use the self-test test pattern and/or targets of opportunity to verify that display artifacts are correctly depicted. Alternatively, an equivalent test may be conducted during flight-testing.

3.3.2.3 Interference Effects

With the radar system energized, individually operate each of the other electrically operated aircraft electrical and electronic systems. Evaluate all reasonable combinations of control settings and operating modes of the equipment. Operate communications and navigation equipment on an operationally significant range of frequencies. Make note of systems or modes of operation that will also be checked during the flight tests. Verify that no harmful interference occurs throughout the test.

3.3.2.4 Bearing Alignment Tests (Subparagraph 2.2.1.1.2)

Position the aircraft on the ground so that an identifiable target is displayed. Align the aircraft's centerline with the actual target. Verify that the indicated azimuth of the target is within three degrees of the zero (center) azimuth marker on the radar indicator. Alternatively, an equivalent test may be conducted during flight-testing.

3.3.2.5 Power Supply Fluctuation

Under normal aircraft conditions, cycle the aircraft engine(s) through all normal power settings and verify proper operation of the radar equipment. Verify that proper radar equipment operation is restored within approximately 10 seconds of a total power interruption lasting longer than 200 ms.

3.3.2.6 Equipment accessibility

Verify that all controls and displays for radar equipment are readily accessible and easily interpreted.

3.3.2.7 Alerts

Verify that all alerts work properly in self-test. Verify failure annunciation. Verify prioritization of alerts.

3.3.3 Flight Test Procedures

3.3.3.1 General Flight Test Procedures

3.3.3.1.1 Normal Flight Operations Performance

Verify that the radar equipment operates per specifications during aircraft maneuvering and changes in attitude encountered in normal flight conditions.

3.3.3.1.2 Interference Effects

For those aircraft systems that can only be checked in flight, verify that no harmful interference exists between the radar system equipment and other electrically operated aircraft systems.

3.3.3.2 Airborne Weather and Ground Map Flight Test Procedures

For all steps that require the flight crew to verify proper display of weather or ground map information, if deemed necessary the weather presentation can be compared to other weather sources (either in-flight or post-flight). However, differences between the detection system characteristics (operating frequency, antenna size/type, viewing angle, transmit power, etc.) should be carefully noted and understood.

3.3.3.2.1 Antenna Control Accuracy (Subparagraph 2.2.1.1.1)

Fly a heading such that the target is at least 30 degrees to the left or right of the aircraft. Slowly maneuver the aircraft through a pitch angle of ± 15 degrees at a rate of approximately 10 degrees per second. Verify that the target remains in view. Return to level flight, then roll the aircraft to ± 15 degrees at a rate of approximately 10 degrees per second. Verify that the target is not blurred and that it appears at the proper position on the display. Repeat this test with a target at 0 degrees.

3.3.3.2.2 Range Resolution (Subparagraph 2.2.2.3)

Verify that the known target can be acquired and identified at a specific range. Fly the course to the known target to a specific range point and determine that the target is displayed as specified by subparagraph 2.2.2.3. Alternate test procedures may be used if the aircraft has a method of displaying known target locations overlaid on the radar display.

3.3.3.2.3 Weather Detection (Paragraph 2.4.4)

When airborne, verify the operation of the system in all available modes of operation.

When testing the weather detection function of the weather radar system, attempt to evaluate the performance of this function against operationally significant weather when weather is reasonably available, and you can do so without placing the aircraft in hazardous weather conditions. This performance evaluation should verify that the depiction of the weather hazards displayed by the radar system is consistent with the actual weather phenomenon. If operationally significant weather is not available during the flight test, data provided by the radar system manufacturer may be used to support verification of the feature(s) in question.

3.3.3.3 Windshear Flight Test Procedures

3.3.3.3.1 Windshear Mode Clutter Rejection (Subparagraph 2.2.3.6)

Evaluate the system's ability to reject spurious conditions (for example, clutter suppression, bi/multi-static signal interference, range ambiguous returns, and radome effects). The flight tests may be conducted under visual meteorological conditions. Conduct this evaluation at one or more stressing airports, as defined in Subparagraph 2.4.3.3.6.

3.3.3.3.2 Windshear Detection Flight Evaluation (Subparagraph 2.2.3.20)

Windshear detection evaluation flights will be accomplished by the radar manufacturer per Subparagraph 2.2.3.20. If the flight evaluation data and analysis collected as part of Subparagraph 2.2.3.20 is available and is determined to be applicable to the final aircraft installation, the installer or aircraft manufacturer does not need to conduct independent windshear detection evaluation flight tests.

Note: "Windshear detection flight evaluations" are sometimes referred to as "windshear penetration flights" in previous versions of DO-220 and FAA Advisory Circular 20-182. This nomenclature is not meant to imply any preference for the means used to verify the windshear detection functionality of the radar.

3.3.3.3.3 Windshear Detection Mode Activation (Subparagraph 2.2.3.11)

Verify that the radar will become active in the windshear mode automatically when the windshear take-off qualifiers are satisfied. Verify its operation in the windshear mode from the time the windshear take-off qualifiers are satisfied to a minimum of 1,200 feet. Upon exiting the windshear detection mode region, verify the radar automatically switches to the mode selected by the crew.

Verify windshear mode operation during the landing phase. Verify that the windshear mode has been automatically activated when the landing phase qualifiers (as specified by the radar manufacturer) are satisfied. Verify automatic cancelation of the automatic windshear mode activation when windshear qualifiers are no longer satisfied.

3.3.3.4 Turbulence Detection Flight Test Procedures

3.3.3.4.1 Turbulence Detection (Subparagraph 2.4.4.2)

When airborne, verify the operation of the system in all available modes of operation.

When testing the turbulence detection function of the radar system, attempt to evaluate the performance of this function against operationally significant weather when weather is reasonably available, and you can do so without placing the aircraft in hazardous weather conditions. This performance evaluation should ensure that the depiction of turbulence displayed by the radar system is consistent with the actual phenomenon. If operationally significant weather is not available during the flight test, data provided by the radar system manufacturer may be used to support verification of the feature(s) in question.

3.3.3.5 Atmospheric Threat Awareness Flight Test Procedures

3.3.3.5.1 Atmospheric Threat Awareness (Subparagraph 2.4.4.3)

When airborne, verify the operation of the system in all available modes of operation.

When testing the atmospheric threat awareness function(s) of the radar system, one should attempt to evaluate the performance of each such function against the specified atmospheric conditions when such conditions are available, and you can do so without placing the aircraft in hazardous conditions. This performance evaluation should ensure that the depiction of each condition displayed by the radar system is consistent with the actual phenomenon. If the specified atmospheric conditions are not available during the flight test, data provided by the radar system manufacturer may be used to support verification of the feature(s) in question.

4 AIRCRAFT OPERATIONAL PERFORMANCE CHARACTERISTICS

When equipment is designed and manufactured to meet these MOPS, and it is properly installed in an aircraft in accordance with applicable installation and operational approval guidance and regulations, it is expected that all aircraft level functional and operational performance criteria will be met.

The equipment when installed contributes to the operation and performance of the MOPS functions at the aircraft level. Other aircraft-level contributions such as redundant or additional equipment may also be required. The equipment design should consider the types and characteristics of aircraft for which installation of this equipment is intended as well as the MOPS function at an aircraft level. The equipment should be designed such that the equipment's contribution to aircraft-level operational and functional requirements is adequate. This section provides considerations for operational characteristics that may be useful in conjunction with other systems on the final aircraft installation or that may be unique to the final aircraft installation.

One acceptable means of accomplishing airworthiness approval for the installation of airborne weather radar equipment is provided in Advisory Circular AC 20-182, *Airworthiness Approval for Aircraft Weather Radar Systems* [G-6]. In the event of conflict between AC 20-182 and Section 4 of this document, AC 20-182 will take precedence.

4.1 Radome Maintenance Requirements

For radar systems that include the Forward Looking Windshear Detection function, the radar manufacturer will specify the minimum DO-213 radome transmission efficiency class required for their system to meet the requirements of this MOPS (Paragraph 2.1.7). The aircraft manufacturer should provide instruction to operators to maintain the radome to at least the radome transmission efficiency class specified by the radar manufacturer.

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5 MEMBERSHIP

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Minimum Operational Performance Standards (MOPS) For Airborne Weather Radar Systems

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APPENDIX A FORWARD-LOOKING WINDSHEAR TEST CASES

A.1 General Windshear Scenario Test Information

These testing scenarios are chosen to evaluate the system's detection capability in a variety of situations. Each is different enough from each other in terms of airplane configuration, altitude, pitch angle, and windshear location that it would be difficult to infer acceptable system performance by a more limited testing matrix. The testing matrix distributes the possible combination of conditions, e.g. wind field models, airspeeds, intervening rain, etc., to critical flight phases in lieu of applying all combinations to all flight phases.

- Radar system manufacturers are expected to certify the windshear system detection performance using a radome one level below the lowest in-service radome level. This is to account for expected degradation of the radome during normal operation.
- All tests should include considerations for the worse case transmissivity loss (within the total loss budget) and representative sidelobe magnitude and directivity characteristics associated with the class and category of radome desired for certification approval (see RTCA/DO-213, [G-2]).
- If the atmosphere outside of the local environment of these models affects the detection schemes, take this into account when demonstrating windshear detection, e.g. temperature lapse rate history during approach.
- Microbursts are static during each simulation run.
- Paths are specified by direction of takeoff or approach, X or Y coordinate of flight path, and runway threshold coordinates.
- Scenario FBARs, reflectivities and velocities are along the aircraft's three-dimensional flight path. For example, for straight-in approach scenarios they are along the -3-degree glide slope.
- Coordinates are specified with respect to the microburst data set. Positive X is true east; positive Y is true north; positive Z is altitude above ground. All coordinates are expressed in metric units.

The NASA windshear database models [W-9] and ADWRS [W-10] may be found in the RTCA Store, associated with DO-220A Change 1, or requested by emailing info@rtca.org.

A.2 Considerations Associated with the Use of The Windshear Test Set-Up

A.2.1 Test Set-up

The test set-up recommended for use in determination of windshear performance is developed around an adaptation of the NASA Langley Research Center's Airborne Doppler Weather Radar Simulation (ADWRS) program.

A.2.2 ADWRS

The ADWRS program calculates the range-Doppler return for system parameters of a coherent airborne radar. The simulation consists of a number of fine steps-in-time corresponding to coherent processing intervals (CPI). For each CPI, the aircraft position and antenna scan position are updated and then held constant for subsequent pulses within the CPI. The amplitude and phase of the resultant signal for each range gate (receiver matched time sample in inter-pulse time respective of transmit time) are the vectoral (phase and amplitude) sum of the scattered radar signal for incremental volume and area scatterers.

Effectively, the signal in a range gate is computed by the super-position of the returns from a bunch of smaller cells.

Each such increment is small relative to the radar resolution cell and is described mathematically by the radar range equation with the appropriate antenna gain for the aircraft geometry and the increment cell's line-of-sight orientation. For distributed returns, like volumetric weather and areal clutter, a random phase is determined for the increment and held constant for all subsequent pulses of the CPI/antenna position. In effect, the program enforces a phase stability on the increments and simulates Rayleigh-like CPI-to-CPI amplitude fluctuation statistics by allowing a large number of scatterers to contribute with randomized phases stable over the CPI. The program assumes re-randomization CPI to CPI. The program generates a distribution of velocities for the weather increments, simulating small-scale turbulence eddies, by adding small random velocity components to the line-of-sight wind field velocities extracted via linear interpolation from the three-dimensional spatial weather database (e.g. NASA model). The standard deviation of the random velocity components is controlled by the user-defined input STANDARD DEVIATION OF RAIN (σ_{Rain}). In effect, the user supplies an estimate of weather related small-scale eddy turbulence for the calculation.

The ADWRS program was designed to simulate the performance expected from various types of signal processing, and therefore includes models of varying fidelity of certain receiver signal processes, including down-conversion, clutter positioning, receiver gain adjustment and analog-to-digital conversion. In general, like many other such range-Doppler calculation programs, the ADWRS calculation does not address phase noise aspects of the radar geometry and assumes a pure sinusoidal carrier. For this test, those receive process models serve no useful purpose and are commented out to expedite calculation.

The ADWRS program anticipates interface with relocatable three-dimensional spatial databases (e.g. NASA microburst model data) of weather-microburst phenomena reflectivity and velocity. It also includes analytic models of representative radome-antenna gain patterns, measured radome-antenna gain patterns, or interfaces for including other equipment specific antenna-radome modeling. In its basic form, the ADWRS program outer loops are served by analytic/model calculation to initiate and step through its processes.

A.2.3 ADWRS Modified for Windshear Performance Tests

Windshear performance is demonstrated by superposition of the radar system manufacturers' recorded urban airport clutter radar signal data with calculated weather radar signal data as the input to the windshear systems digital processes. This may be accomplished as shown in Figure A-1, an adaptation of the NASA ADWRS program. In general, as the diagram indicates, the ADWRS program for weather signal return (I-Q) calculation remains intact. The major changes to ADWRS to achieve this test configuration include:

- The outer loops are now served in terms of aircraft recorded data (e.g. time history of position, velocity, antenna pointing, AGC) rather than analytic model calculation.
- Changes that reflect the radar system manufacturers' unique equipment characteristics.
- Replacement of the computations of signal processing effects by use of the measurement process (recorded clutter, windfield database).

The time history data required to drive the test set-up is recorded during the urban airport clutter recording flights using profiles. Calculation of the weather (NASA windfield model data block) may be derived off line, as shown in Figure A-2, or as one process which is part the of emulation (Figure A-1 that forms the combined clutter and microburst radar 1-Q data).

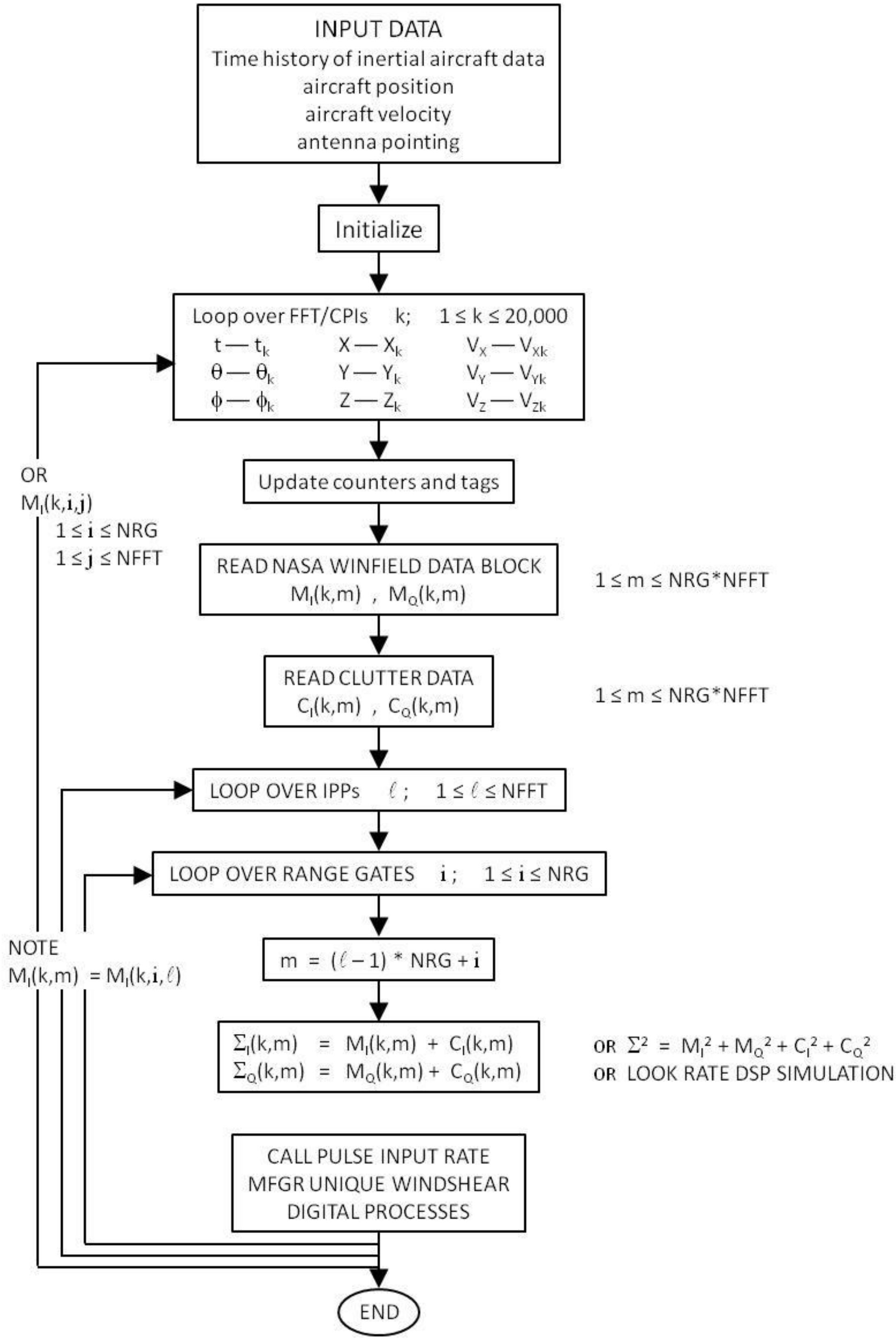

Figure A-1: Formation of Combined Clutter and Rain Return

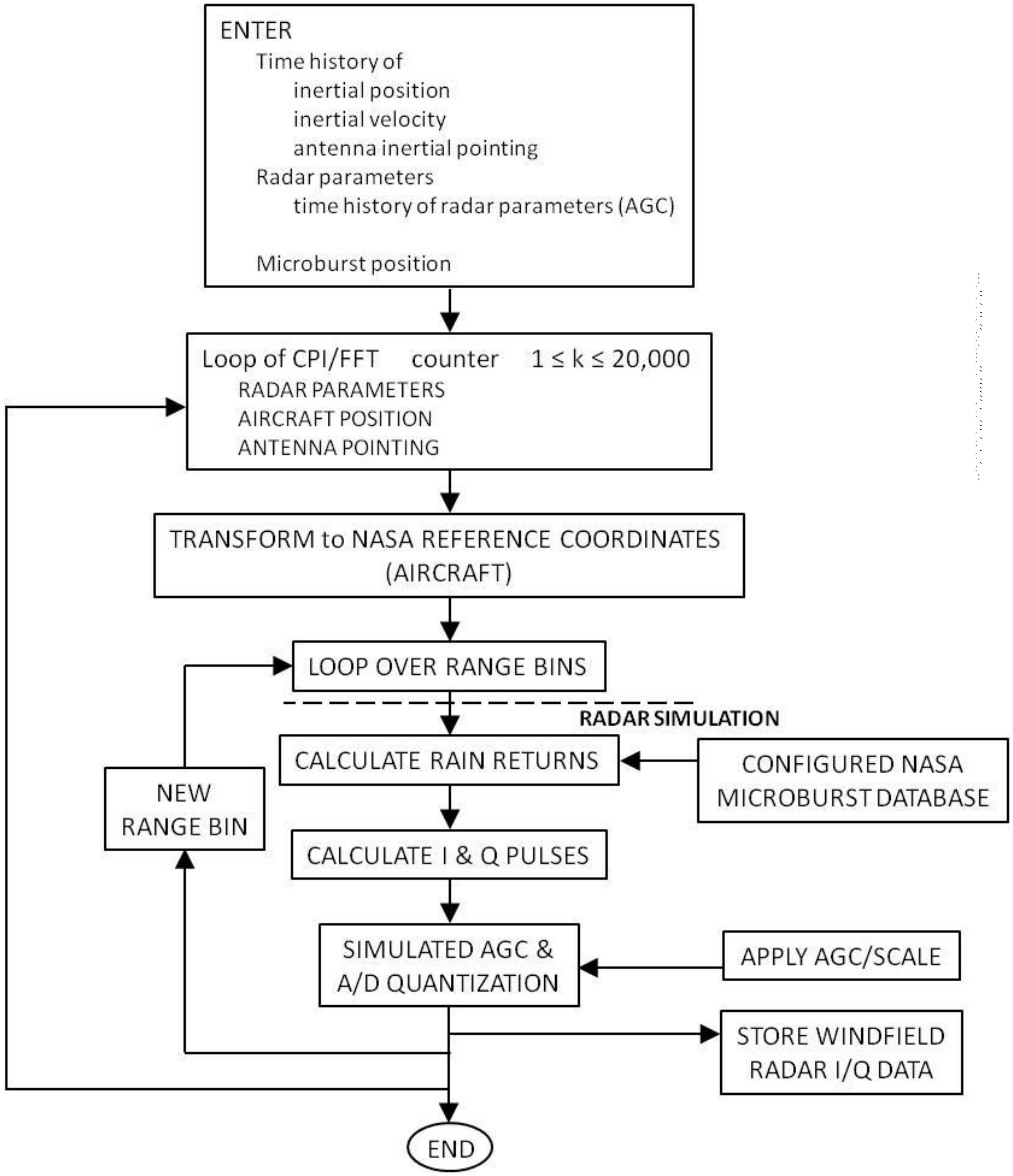

Figure A-2: Generation of Microburst Radar Return Data

A.2.4 Recording of Urban Airport Clutter Data

The general recording procedure is to execute a set of flight test data collection runs with the windshear radar installed and operated in a representative airborne environment while recording radar A/D or FFT data for post-flight simulation merging and replay with NASA model data.

The selected data collection flight paths should be representative of the ground clutter, aircraft maneuvers, and radar control expected during typical landing and takeoff operations. This radar clutter signal collection should be conducted at stressing urban airports during times of significant ground moving traffic activity where feasible. It should be conducted under VFR conditions.

The necessary clutter characteristics include:

- At least one airport with expressways and/or high-volume surface streets, nearby taxiing aircraft, and concentrated urban clutter. This clutter should occupy a minimum area of approximately one nm surrounding the airport. A portion of at least one expressway should (a) be situated in the general region near the airport and within 0.5 nm before the runway threshold, and (b) run approximately parallel to the runway. Newark airport was traditionally used to satisfy these criteria, but other airports with comparable characteristics may be used.
- At least one airport in an urban clutter environment that allows curved approaches onto a runway. The clutter should occupy a minimum area of approximately one nm surrounding the airport. Washington National airport was traditionally used to satisfy these criteria, but other airports with comparable characteristics may be used.
- At least one airport allowing curved approaches onto a runway that is aligned perpendicular to mountains located at distances that produce range ambiguous returns. Denver Stapleton airport was traditionally used to satisfy these criteria, but other airports with comparable characteristics may be used.

Note: *The term "curved approach" used here does not necessarily refer to a curved instrument approach.*

The radar instrumentation system should record all necessary ancillary data to support calibrated interpretation of the recorded radar clutter A/D or FFT data. This ancillary data should include internal and external radar signals as required, e.g. antenna pointing, receiver gain control, noise figure calibration factors, A/D calibration factors, intermediate processing results, timer tags, own-ship roll, pitch and yaw, aircraft velocities, and altitude.

The radar clutter data should be collected using a radome/antenna configuration with mainbeam/sidelobe performance that is representative of intended commercial revenue service installations. The equivalent radome insertion loss and sidelobe degradation levels for the radar being certified should be as defined in RTCA document DO-213, *Minimum Operational Performance Standards for Nose- Mounted Radomes* [G-1].

A sufficient number of clutter data runs should be collected for each landing and takeoff scenario to ensure that the representative worst-case clutter data can be selected for merging with the NASA windshear model database.

A.2.5 Calculation of Weather Signal Return for Superposition Testing

There are three issues of some concern relative to the use of the configured NASA microburst model data and superposition of that data with recorded clutter:

- Number of NASA model data base points used.
- The total standard deviation of rain velocities calculated by ADWRS.
- Radar system manufacturer arguments supporting applicability of superposition testing.

A.2.5.1 Number of Database Points

The NASA microburst data is provided with a fine grid structure. The equipment manufacturer need not use every data base point for each iteration of the weather signal computation, but use enough to show sufficient (i.e. convergent) database representation. If some data points are not used, describe how the NASA database is used in the calculation, including the number of database points accessed in computation, and inaccuracies that may be apparent from any approximations.

A.2.5.2 Standard Deviation of Rain Velocities Calculated by ADWRS

To be consistent with nature, a lower limit on the calculated rain standard deviation is required. A reasonable value of 3 m/s is given in Appendix C.

A.2.5.3 Radar System Manufacturer Arguments in Support of Superposition

In general, it is good design practice that pulse Doppler radars exhibit linear, stable, and spurious-free operation in performance of their function as a measurement system. Such a radar system would be a very nearly perfect linear radar sensor and would include all effects of platform motion and/or near departure from linearity. The effects of any non-linearity will be included in the recorded clutter data.

The use of the NASA weather wind database allows a calculation of intercepted power, as calculated from first principles of the radar range equation. Superposition of the windfield data with recorded clutter raises some issues that need to be satisfactorily addressed by the applicant using the prescribed test method. These issues include the potential generation of spurious signals when a large windfield signal is superimposed with clutter and an accounting of the appearance of the windfield signal in the digital processes.

In general, mainbeam clutter would be expected as the largest signal in the system and the recording of it and any products excited by it would be sufficient. However, it remains to account for the target signal if the weather signal is also very large. The radar system manufacturer is expected to furnish an analytical and experimental account of linearity, etc. sufficient to show that weather signals may be calculated from first principles (i.e. radar range equation).

Superposition of a calculated weather signal return with a recorded clutter (moving clutter such as cars and stationary clutter such as buildings) or interference signal requires an account of how the weather signal parameters (Doppler and reflectivity spatial distribution) will be used to represent the amplitude and phase of that computed signal with reference to the equipment under test. It is necessary to state what the Doppler offset and the amplitude conversion scales are for such signals in the presence of the recorded signals (i.e. an accounting of the effects of aircraft motion).

The use of the NASA weather-wind database allows a calculation of intercepted power, as calculated from the first principles of the radar range equation. Describe the (scaling) conversion of that intercepted power into machine quantized (sampled data) input word values, for example, at the digital word converter or the spectrum analyzer filter bank, in the presence of large or saturating signal levels.

The calculated weather/hazard return signal is summed with the recorded clutter data prior to envelope detection or other non-linearity in the digital processor. If the clutter data is not merged at the same point in the digital process that it was collected, validate any interleaving processes on it, e.g. FFT.

A.3 Windshear Scenarios

Scenario 1

NASA Windshear Data Set/Time:	111
Data Set:	1
Model Simulation Time:	11 minutes
Description:	Wet Microburst with Rain and Hail, 08/02/85 DFW Accident Case, Dallas-Fort Worth, Texas
Radar Clutter Model:	Newark 4R/22L
Flight Phase:	Aligned for takeoff
Flight Scenario Location:	Aligned for takeoff to the east. The microburst leading edge is located 3.0 nm (~5.5 km) from brake release ("far microburst" scenario).
True Airspeed:	0 knots
Windshear Penetration Path:	Takeoff toward east along Y = 0 axis Brake release at X,Y = (-6.8, 0) km Liftoff at X,Y = (-4.8, 0) km
Flight Path Assumptions:	Takeoff ground roll length = 2 km Flight path angle after takeoff = 0.10 radians (5.73 degrees) Runway length = 3 km (9840 feet)
Approximate Peak FBAR along path:	0.2
Approximate Peak Reflectivity along path:	55 dBZ
Outflow Reflectivity:	35 to 42 dBZ
Approximate Diameter of Outflow at Peak Velocity Change:	3.5 km
Growth Stage:	N/A
Intervening rain:	No
Temperature Lapse Rate:	Adiabatic
Symmetry:	Axisymmetric
Stage of Evolution for Primary Microburst:	Peak Intensity
Data Set Origin X_0, Y_0	-4000 meters, -4000 meters
Data Set Grid Cell Size ΔX x ΔY x ΔZ	50 meters x 50 meters x 50 meters
Data Set Domain Size X x Y x Z	8 km x 8 km x 2 km
Data Set Number of Grid Points IX x IY x IZ	161 x 161 x 41
General Meteorological Description:	[Note 18]
Justifications:	[Note 5], [Note 12]
Information:	[Note 1], [Note 3] This scenario is designed to demonstrate windshear detection prior to brake release. If detection is not achieved prior to brake release, the takeoff roll should be initiated and continued up to the detection point. The takeoff roll occurs outside domain of data set, with sensor looking into the data set.

Scenario 2

NASA Windshear Data Set/Time:	111
Data Set:	1
Model Simulation Time:	11 minutes
Description:	Wet Microburst with Rain and Hail, 08/02/85 DFW Accident Case, Dallas-Fort Worth, Texas
Radar Clutter Model:	Newark 4R/22L
Flight Phase:	Straight in approach
Flight Scenario Location:	-3 degree straight in approach to the east. The microburst leading edge is located 0.5 nm from runway threshold.
True Airspeed:	150 knots
Windshear Penetration Path:	Approach toward east along Y = 0 axis Place runway threshold at X,Y = (0, 0) km
Flight Path Assumptions:	Glide slope angle = 3 degrees (gamma = -0.0524) Glide path intercept point = 300 meters down runway Middle marker location = 900 meters from runway threshold Runway length = 3 km (9840 feet) The above conditions produce a glide path height of 63 meters at the middle marker.
Approximate Peak FBAR along path:	0.14
Approximate Peak Reflectivity along path:	55 dBZ
Outflow Reflectivity:	35 to 42 dBZ
Approximate Diameter of Outflow at Peak Velocity Change:	3.5 km
Growth Stage:	N/A
Intervening rain:	No
Temperature Lapse Rate:	Adiabatic
Symmetry:	Axisymmetric
Stage of Evolution for Primary Microburst:	Peak Intensity
Data Set Origin X_0, Y_0	-4000 meters, -4000 meters
Data Set Grid Cell Size ΔX x ΔY x ΔZ	50 meters x 50 meters x 50 meters
Data Set Domain Size X x Y x Z	8 km x 8 km x 2 km
Data Set Number of Grid Points IX x IY x IZ	161 x 161 x 41
General Meteorological Description:	[Note 18]
Justifications:	[Note 5], [Note 14]
Information:	[Note 1], [Note 3] The approach may begin outside the boundary of the data set due to the proximity of the microburst to the edge of the data set domain.

Scenario 3

NASA Windshear Data Set / Time:	237
Data Set:	2
Model Simulation Time:	37 minutes
Description:	Wet Microburst, 06/20/91 NASA Research Flight, Orlando, Florida
Radar Clutter Model:	Newark 4R/22L
Flight Phase:	Straight in approach
Flight Scenario Location:	-3 degree straight in approach to the south. The microburst leading edge is located 0.5 nm from runway threshold.
True Airspeed:	150 knots
Windshear Penetration Path:	Approach toward south along X = -1.8 km line Place runway threshold at X,Y = (-1.8, -1.9) km
Flight Path Assumptions:	Glide slope angle = 3 degrees (gamma = -0.0524) Glide path intercept point = 300 meters down runway Middle marker location = 900 meters from runway threshold Runway length = 3 km (9840 feet) The above conditions produce a glide path height of 63 meters at the middle marker.
Approximate Peak FBAR along path:	0.14
Approximate Peak Reflectivity along path:	50 dBZ
Outflow Reflectivity:	37 to 45 dBZ
Approximate Diameter of Outflow at Peak Velocity Change:	3.5 km
Growth Stage:	N/A
Intervening rain:	Yes
Temperature Lapse Rate:	Adiabatic
Symmetry:	Rough symmetry
Stage of Evolution for Primary Microburst:	Peak Intensity
Data Set Origin X_0, Y_0	-8834 meters, -8880 meters
Data Set Grid Cell Size ΔX x ΔY x ΔZ	100 meters x 100 meters x 50 meters
Data Set Domain Size X x Y x Z	15 km x 15 km x 2 km
Data Set Number of Grid Points IX x IY x IZ	151 x 151 x 41
General Meteorological Description:	[Note 19]
Justifications:	[Note 6], [Note 14]
Information:	[Note 1], [Note 2], [Note 3] This path produces about 4 km of intervening rain on the path prior to encountering the shear hazard. The reflectivity of the intervening rain varies from 25 to 50 dBZ.

Scenario 4

NASA Windshear Data Set / Time:	237
Data Set:	2
Model Simulation Time:	37 minutes
Description:	Wet Microburst, 06/20/91 NASA Research Flight, Orlando, Florida
Radar Clutter Model:	Newark 4R/22L
Flight Phase:	Straight in approach
Flight Scenario Location:	-3 degree straight in approach to the east. The microburst leading edge is located 0.5 nm from runway threshold.
True Airspeed:	150 knots
Windshear Penetration Path:	Approach toward east along Y = 1.1 km line Place runway threshold at X,Y = (-1.8, 1.1) km
Flight Path Assumptions:	Glide slope angle = 3 degrees (gamma = -0.0524) Glide path intercept point = 300 meters down runway Middle marker location = 900 meters from runway threshold Runway length = 3 km (9840 feet) The above conditions produce a glide path height of 63 meters at the middle marker.
Approximate Peak FBAR along path:	0.06 [Below threshold, Must-Not Alert scenario]
Approximate Peak Reflectivity along path:	50 dBZ
Outflow Reflectivity:	37 to 45 dBZ
Approximate Diameter of Outflow at Peak Velocity Change:	3.5 km
Growth Stage:	Developing
Intervening rain:	Yes
Temperature Lapse Rate:	Adiabatic
Symmetry:	Rough symmetry
Stage of Evolution for Primary Microburst:	Peak Intensity
Data Set Origin X_0, Y_0	-8834 meters, -8880 meters
Data Set Grid Cell Size ΔX x ΔY x ΔZ	100 meters x 100 meters x 50 meters
Data Set Domain Size X x Y x Z	15 km x 15 km x 2 km
Data Set Number of Grid Points IX x IY x IZ	151 x 151 x 41
General Meteorological Description:	[Note 19]
Justifications:	[Note 6], [Note 14]
Information:	[Note 1], [Note 2], [Note 3], [Note 4] Windshear event is below the MUST-NOT-ALERT boundary. The path passes through an FBAR of about 0.06 with 0.08 FBAR about 0.5 km to right of path and 0.17 FBAR about 2.5 km right of runway touchdown zone. Note that the approximate peak FBAR shown above (0.06) is along the aircraft glide slope (radar antenna tilt ~ -3.0 degrees). Depending on the actual aircraft position during the ground clutter collection flights (and corresponding radar antenna tilt), the radar detected hazard may be higher than the must-not-alert level and thus could result in an alert. It is also important to note that this scenario may produce an alert due to the presence of must-alert level hazard field in close proximity (to the right) to the actual test scenario.

Scenario 5

NASA Windshear Data Set / Time:	237
Data Set:	2
Model Simulation Time:	37 minutes
Description:	Wet Microburst, 06/20/91 NASA Research Flight, Orlando, Florida
Radar Clutter Model:	Newark 4R/22L
Flight Phase:	Go-around
Flight Scenario Location:	Go-Around at 100 ft AGL to the west. The microburst leading edge is located 1.8 nm (3.3 km) from the 100 ft point, initiation of missed approach, at the far end of the runway.
True Airspeed:	150 knots
Windshear Penetration Path:	Approach toward west along Y = -1.4 km line Place runway threshold at X,Y = (2.2, -1.4) km Go-around point is X,Y = (2.5, -1.4) km
Flight Path Assumptions:	Go around maneuvers are begun at an altitude of 30 meters, at a position 300 meters from runway threshold. Glide slope angle = 3 degrees (gamma = -0.0524) Glide path intercept point = 300 meters down runway Flight path angle after go-around = 0.10 radians (5.73 degrees) Middle marker location = 900 meters from runway threshold Runway length = 3 km (9840 feet) The above conditions produce a glide path height of 63 meters at the middle marker.
Approximate Peak FBAR along path:	0.19
Approximate Peak Reflectivity along path:	50 dBZ
Outflow Reflectivity:	37 to 45 dBZ
Approximate Diameter of Outflow at Peak Velocity Change:	3.5 km
Growth Stage:	N/A
Intervening rain:	Yes
Temperature Lapse Rate:	Adiabatic
Symmetry:	Rough symmetry
Stage of Evolution for Primary Microburst:	Peak Intensity
Data Set Origin X_0, Y_0	-8834 meters, -8880 meters
Data Set Grid Cell Size ΔX x ΔY x ΔZ	100 meters x 100 meters x 50 meters
Data Set Domain Size X x Y x Z	15 km x 15 km x 2 km
Data Set Number of Grid Points IX x IY x IZ	151 x 151 x 41
General Meteorological Description:	[Note 19]
Justifications:	[Note 6], [Note 17]
Information:	[Note 1], [Note 2], [Note 3] The path places the runway touchdown zone in clear air with the microburst and 50-dBZ precipitation at the far end of the runway.

Scenario 6

NASA Windshear Data Set / Time:	349
Data Set:	3
Model Simulation Time:	49 minutes
Description:	Multiple Microburst, 07/11/88 Incident Case, Denver, Colorado
Radar Clutter Model:	Newark 4R/22L
Flight Phase:	Straight in approach
Flight Scenario Location:	-3 degree straight in approach to the east. The microburst leading edge is located 0.5 nm from runway threshold.
True Airspeed:	150 knots
Windshear Penetration Path:	Approach toward east along Y = -4.5 km line Place runway threshold at X,Y = (8.6, -4.5) km
Flight Path Assumptions:	Glide slope angle = 3 degrees (gamma = -0.0524) Glide path intercept point = 300 meters down runway Middle marker location = 900 meters from runway threshold Runway length = 3 km (9840 feet) The above conditions produce a glide path height of 63 meters at the middle marker.
Approximate Peak FBAR along path:	0.083 [Below threshold, Must-Not Alert scenario]
Approximate Peak Reflectivity along path:	35 dBZ
Outflow Reflectivity:	10 to 16 dBZ
Approximate Diameter of Outflow at Peak Velocity Change:	3.0 km
Growth Stage:	Developing
Intervening rain:	Light
Temperature Lapse Rate:	Adiabatic
Symmetry:	Varies between microbursts
Stage of Evolution for Primary Microburst:	Developing
Data Set Origin X_0, Y_0	1190 meters, -10500 meters
Data Set Grid Cell Size ΔX x ΔY x ΔZ	100 meters x 100 meters x 50 meters
Data Set Domain Size X x Y x Z	18 km x 12 km x 2 km
Data Set Number of Grid Points IX x IY x IZ	181 x 121 x 41
General Meteorological Description:	[Note 20]
Justifications:	[Note 7], [Note 14]
Information:	[Note 1], [Note 2], [Note 3], [Note 4] Windshear event is below the MUST-NOT-ALERT boundary.

Scenario 7

NASA Windshear Data Set / Time:	349
Data Set:	3
Model Simulation Time:	49 minutes
Description:	Multiple Microburst, 07/11/88 Incident Case, Denver, Colorado
Radar Clutter Model:	Newark 4R/22L
Flight Phase:	Straight in approach
Flight Scenario Location:	-3 degree straight in approach to the north. The microburst leading edge is located 0.5 nm from runway threshold.
True Airspeed:	150 knots
Windshear Penetration Path:	Approach toward north along X = 8.5 km line Place runway threshold at X,Y = (8.5, 1.9) km
Flight Path Assumptions:	Glide slope angle = 3 degrees (gamma = -0.0524) Glide path intercept point = 300 meters down runway Middle marker location = 900 meters from runway threshold Runway length = 3 km (9840 feet) The above conditions produce a glide path height of 63 meters at the middle marker.
Approximate Peak FBAR along path:	0.13
Approximate Peak Reflectivity along path:	37 dBZ
Outflow Reflectivity:	10 to 16 dBZ
Approximate Diameter of Outflow at Peak Velocity Change:	3.0 km
Growth Stage:	Developing
Intervening rain:	Yes
Temperature Lapse Rate:	Adiabatic
Symmetry:	Varies between microbursts
Stage of Evolution for Primary Microburst:	Developing
Data Set Origin X_0, Y_0	1190 meters, -10500 meters
Data Set Grid Cell Size ΔX x ΔY x ΔZ	100 meters x 100 meters x 50 meters
Data Set Domain Size X x Y x Z	18 km x 12 km x 2 km
Data Set Number of Grid Points IX x IY x IZ	181 x 121 x 41
General Meteorological Description:	[Note 20]
Justifications:	[Note 7], [Note 14]
Information:	[Note 1], [Note 2], [Note 3], [Note 4] This path encounters light precipitation about 2 km from the event, with moderate to heavy precipitation occurring about 1 km to the right of the maximum shear. This is a developing microburst with strength approximating the MUST-ALERT boundary.

Scenario 8

NASA Windshear Data Set / Time:	351
Data Set:	3
Model Simulation Time:	51 minutes
Description:	Multiple Microburst, 07/11/88 Incident Case, Denver, Colorado
Radar Clutter Model:	Newark 4R/22L
Flight Phase:	Aligned for takeoff
Flight Scenario Location:	Aligned for takeoff to the north. The microburst leading edge is located 2 km from brake release, near the liftoff point, such that the airplane is in the headwind conditions of the outflow (“near microburst” scenario).
True Airspeed:	0 knots
Windshear Penetration Path:	Takeoff toward north along X= 16.2 km line Brake release at X,Y = (16.2, -7.6) km Liftoff at X,Y = (16.2, -5.6) km
Flight Path Assumptions:	Takeoff ground roll length = 2 km Flight path angle after takeoff = 0.10 radians (5.73 degrees) Runway length = 3 km (9840 feet)
Approximate Peak FBAR along path:	0.17
Approximate Peak Reflectivity along path:	24 dBZ
Outflow Reflectivity:	13 to 27 dBZ
Approximate Diameter of Outflow at Peak Velocity Change:	1.5 – 3.0 km
Growth Stage:	Developing
Intervening rain:	Yes
Temperature Lapse Rate:	Adiabatic
Symmetry:	Varies between microbursts
Stage of Evolution for Primary Microburst:	Near Peak
Data Set Origin X_0, Y_0	2232 meters, -10570 meters
Data Set Grid Cell Size ΔX x ΔY x ΔZ	100 meters x 100 meters x 50 meters
Data Set Domain Size X x Y x Z	18 km x 12 km x 2 km
Data Set Number of Grid Points IX x IY x IZ	181 x 121 x 41
General Meteorological Description:	[Note 20]
Justifications:	[Note 7], [Note 12]
Information:	[Note 1], [Note 2], [Note 3] This scenario is designed to demonstrate windshear detection prior to brake release. If detection is not achieved prior to brake release, the takeoff roll should be initiated and continued up to the detection point.

Scenario 9

NASA Windshear Data Set / Time:	351
Data Set:	3
Model Simulation Time:	51 minutes
Description:	Multiple Microburst, 07/11/88 Incident Case, Denver, Colorado
Radar Clutter Model:	Newark 4R/22L
Flight Phase:	Aligned for takeoff
Flight Scenario Location:	Aligned for takeoff to the east. The microburst leading edge is located 3.0 nm (~5.5 km) from brake release ("far microburst" scenario).
True Airspeed:	0 knots
Windshear Penetration Path:	Takeoff toward east along Y = -5.0 km line Brake release at X,Y = (8.5, -5.0) km Liftoff at X,Y = (10.5, -5.0) km
Flight Path Assumptions:	Takeoff ground roll length = 2 km Flight path angle after takeoff = 0.10 radians (5.73 degrees) Runway length = 3 km (9840 feet)
Approximate Peak FBAR along path:	0.19
Approximate Peak Reflectivity along path:	25 dBZ
Outflow Reflectivity:	13 to 27 dBZ
Approximate Diameter of Outflow at Peak Velocity Change:	1.5 – 3.0 km
Growth Stage:	N/A
Intervening rain:	Yes
Temperature Lapse Rate:	Adiabatic
Symmetry:	Varies between microbursts
Stage of Evolution for Primary Microburst:	Near Peak
Data Set Origin X_0, Y_0	2232 meters, -10570 meters
Data Set Grid Cell Size ΔX x ΔY x ΔZ	100 meters x 100 meters x 50 meters
Data Set Domain Size X x Y x Z	18 km x 12 km x 2 km
Data Set Number of Grid Points IX x IY x IZ	181 x 121 x 41
General Meteorological Description:	[Note 20]
Justifications:	[Note 7], [Note 12]
Information:	[Note 1], [Note 2], [Note 3] This scenario is designed to demonstrate windshear detection prior to brake release. If detection is not achieved prior to brake release, the takeoff roll should be initiated and continued up to the detection point. Takeoff is in very weak shear with 20 to 35-dBZ precipitation, followed by about 1 km of clear air before encountering a 0.19-FBAR shear in 25-dBZ precipitation.

Scenario 10

NASA Windshear Data Set / Time:	351
Data Set:	3
Model Simulation Time:	51 minutes
Description:	Multiple Microburst, 07/11/88 Incident Case, Denver, Colorado
Radar Clutter Model:	Newark 4R/22L
Flight Phase:	Takeoff – Gear up height
Flight Scenario Location:	Takeoff at gear-up height to the east. The microburst leading edge is located 3.0 nm (~5.5 km) from brake release ("far microburst" scenario).
True Airspeed:	150 knots
Windshear Penetration Path:	Takeoff toward east along Y = -5.0 km line Brake release at X,Y = (8.5, -5.0) km Liftoff at X,Y = (10.5, -5.0) km
Flight Path Assumptions:	Takeoff ground roll length = 2 km Flight path angle after takeoff = 0.10 radians (5.73 degrees) Runway length = 3 km (9840 feet)
Approximate Peak FBAR along path:	0.19
Approximate Peak Reflectivity along path:	25 dBZ
Outflow Reflectivity:	13 to 27 dBZ
Approximate Diameter of Outflow at Peak Velocity Change:	1.5 – 3.0 km
Growth Stage:	N/A
Intervening rain:	Yes
Temperature Lapse Rate:	Adiabatic
Symmetry:	Varies between microbursts
Stage of Evolution for Primary Microburst:	Near Peak
Data Set Origin X_0, Y_0	2232 meters, -10570 meters
Data Set Grid Cell Size ΔX x ΔY x ΔZ	100 meters x 100 meters x 50 meters
Data Set Domain Size X x Y x Z	18 km x 12 km x 2 km
Data Set Number of Grid Points IX x IY x IZ	181 x 121 x 41
General Meteorological Description:	[Note 20]
Justifications:	[Note 7], [Note 13]
Information:	[Note 1], [Note 2], [Note 3] The simulation run may begin at the takeoff gear up height > 50 feet AGL. Takeoff is in very weak shear with 20 to 35-dBZ precipitation, followed by about 1 km of clear air before encountering a 0.19-FBAR shear in-25 dBZ precipitation.

Scenario 11

NASA Windshear Data Set / Time:	351
Data Set:	3
Model Simulation Time:	51 minutes
Description:	Multiple Microburst, 07/11/88 Incident Case, Denver, Colorado
Radar Clutter Model:	Newark 4R/22L
Flight Phase:	Straight in approach
Flight Scenario Location:	-3 degree straight in approach to the north at a 360-degree heading. The microburst leading edge is located 0.5 nm from runway threshold.
True Airspeed:	150 knots
Windshear Penetration Path:	Place runway threshold at X,Y = (12.2, -3.0) km Orient runway on true heading of 360
Flight Path Assumptions:	Glide slope angle = 3 degrees (gamma = -0.0524) Glide path intercept point = 300 meters down runway Middle marker location = 900 meters from runway threshold Runway length = 3 km (9840 feet) The above conditions produce a glide path height of 63 meters at the middle marker.
Approximate Peak FBAR along path:	0.15
Approximate Peak Reflectivity along path:	40 dBZ
Outflow Reflectivity:	13 to 27 dBZ
Approximate Diameter of Outflow at Peak Velocity Change:	1.5 – 3.0 km
Growth Stage:	N/A
Intervening rain:	Yes
Temperature Lapse Rate:	Adiabatic
Symmetry:	Varies between microbursts
Stage of Evolution for Primary Microburst:	Near Peak
Data Set Origin X_0, Y_0	2232 meters, -10570 meters
Data Set Grid Cell Size ΔX x ΔY x ΔZ	100 meters x 100 meters x 50 meters
Data Set Domain Size X x Y x Z	18 km x 12 km x 2 km
Data Set Number of Grid Points IX x IY x IZ	181 x 121 x 41
General Meteorological Description:	[Note 20]
Justifications:	[Note 7], [Note 14]
Information:	[Note 1], [Note 2], [Note 3] This path has a mostly clear view of threat, with rain on each side of path.

Scenario 12

NASA Windshear Data Set / Time:	351
Data Set:	3
Model Simulation Time:	51 minutes
Description:	Multiple Microburst, 07/11/88 Incident Case, Denver, Colorado
Radar Clutter Model:	Newark 4R/22L
Flight Phase:	Straight in approach
Flight Scenario Location:	-3 degree straight in approach to the northeast at a 45-degree heading. The microburst leading edge is located 0.5 nm from runway threshold.
True Airspeed:	150 knots
Windshear Penetration Path:	Place runway threshold at X,Y = (12.2, -3.0) km Orient runway on true heading of 045
Flight Path Assumptions:	Glide slope angle = 3 degrees (gamma = -0.0524) Glide path intercept point = 300 meters down runway Middle marker location = 900 meters from runway threshold Runway length = 3 km (9840 feet) The above conditions produce a glide path height of 63 meters at the middle marker.
Approximate Peak FBAR along path:	0.18
Approximate Peak Reflectivity along path:	40 dBZ
Outflow Reflectivity:	13 to 27 dBZ
Approximate Diameter of Outflow at Peak Velocity Change:	1.5 – 3.0 km
Growth Stage:	N/A
Intervening rain:	Yes
Temperature Lapse Rate:	Adiabatic
Symmetry:	Varies between microbursts
Stage of Evolution for Primary Microburst:	Near Peak
Data Set Origin X_0, Y_0	2232 meters, -10570 meters
Data Set Grid Cell Size ΔX x ΔY x ΔZ	100 meters x 100 meters x 50 meters
Data Set Domain Size X x Y x Z	18 km x 12 km x 2 km
Data Set Number of Grid Points IX x IY x IZ	181 x 121 x 41
General Meteorological Description:	[Note 20]
Justifications:	[Note 7], [Note 14]
Information:	[Note 1], [Note 2], [Note 3] This path is between two small rain cells (30 to 35 dBZ) about 3 km short of runway.

Scenario 13

NASA Windshear Data Set / Time:	351
Data Set:	3
Model Simulation Time:	51 minutes
Description:	Multiple Microburst, 07/11/88 Incident Case, Denver, Colorado
Radar Clutter Model:	Newark 4R/22L
Flight Phase:	Straight in approach
Flight Scenario Location:	-3 degree straight in approach to the east at a 90-degree heading. The microburst leading edge is located 0.5 nm from runway threshold.
True Airspeed:	150 knots
Windshear Penetration Path:	Place runway threshold at X,Y = (12.2, -3.0) km Orient runway on true heading of 090
Flight Path Assumptions:	Glide slope angle = 3 degrees (gamma = -0.0524) Glide path intercept point = 300 meters down runway Middle marker location = 900 meters from runway threshold Runway length = 3 km (9840 feet) The above conditions produce a glide path height of 63 meters at the middle marker.
Approximate Peak FBAR along path:	0.17
Approximate Peak Reflectivity along path:	40 dBZ
Outflow Reflectivity:	13 to 27 dBZ
Approximate Diameter of Outflow at Peak Velocity Change:	1.5 – 3.0 km
Growth Stage:	N/A
Intervening rain:	Yes
Temperature Lapse Rate:	Adiabatic
Symmetry:	Varies between microbursts
Stage of Evolution for Primary Microburst:	Near Peak
Data Set Origin X_0, Y_0	2232 meters, -10570 meters
Data Set Grid Cell Size ΔX x ΔY x ΔZ	100 meters x 100 meters x 50 meters
Data Set Domain Size X x Y x Z	18 km x 12 km x 2 km
Data Set Number of Grid Points IX x IY x IZ	181 x 121 x 41
General Meteorological Description:	[Note 20]
Justifications:	[Note 7], [Note 14]
Information:	[Note 1], [Note 2], [Note 3] The path passes through an intervening cell for the last 4 km of the approach to the primary threat. This intervening cell contains reflectivity of about 20 to 30 dBZ and shear of about 0.08 FBAR along path. The primary shear produces an FBAR of about 0.17. This scenario will test both the ability to detect through intervening rain and the ability to reject weak shears.

Scenario 14

NASA Windshear Data Set / Time:	351
Data Set:	3
Model Simulation Time:	51 minutes
Description:	Multiple Microburst, 07/11/88 Incident Case, Denver, Colorado
Radar Clutter Model:	Newark 4R/22L
Flight Phase:	Straight in approach
Flight Scenario Location:	-3 degree straight in approach to the southeast at a 135-degree heading. The microburst leading edge is located 0.5 nm from runway threshold.
True Airspeed:	150 knots
Windshear Penetration Path:	Place runway threshold at X,Y = (12.2, -3.0) km Orient runway on true heading of 135
Flight Path Assumptions:	Glide slope angle = 3 degrees (gamma = -0.0524) Glide path intercept point = 300 meters down runway Middle marker location = 900 meters from runway threshold Runway length = 3 km (9840 feet) The above conditions produce a glide path height of 63 meters at the middle marker.
Approximate Peak FBAR along path:	0.13
Approximate Peak Reflectivity along path:	40 dBZ
Outflow Reflectivity:	13 to 27 dBZ
Approximate Diameter of Outflow at Peak Velocity Change:	1.5 – 3.0 km
Growth Stage:	N/A
Intervening rain:	Yes
Temperature Lapse Rate:	Adiabatic
Symmetry:	Varies between microbursts
Stage of Evolution for Primary Microburst:	Near Peak
Data Set Origin X_0, Y_0	2232 meters, -10570 meters
Data Set Grid Cell Size ΔX x ΔY x ΔZ	100 meters x 100 meters x 50 meters
Data Set Domain Size X x Y x Z	18 km x 12 km x 2 km
Data Set Number of Grid Points IX x IY x IZ	181 x 121 x 41
General Meteorological Description:	[Note 20]
Justifications:	[Note 7], [Note 14]
Information:	[Note 1], [Note 2], [Note 3], [Note 4] This path passes along the edge of an adjacent precipitation cell before primary threat. A strong shear exists at the far end of the runway.

Scenario 15

NASA Windshear Data Set / Time:	351
Data Set:	3
Model Simulation Time:	51 minutes
Description:	Multiple Microburst, 07/11/88 Incident Case, Denver, Colorado
Radar Clutter Model:	Newark 4R/22L
Flight Phase:	Straight in approach
Flight Scenario Location:	-3 degree straight in approach to the west at a 270-degree heading. The microburst leading edge is located 0.5 nm from runway threshold.
True Airspeed:	150 knots
Windshear Penetration Path:	Place runway threshold at X,Y = (12.2, -3.0) km Orient runway on true heading of 270
Flight Path Assumptions:	Glide slope angle = 3 degrees (gamma = -0.0524) Glide path intercept point = 300 meters down runway Middle marker location = 900 meters from runway threshold Runway length = 3 km (9840 feet) The above conditions produce a glide path height of 63 meters at the middle marker.
Approximate Peak FBAR along path:	0.17
Approximate Peak Reflectivity along path:	40 dBZ
Outflow Reflectivity:	13 to 27 dBZ
Approximate Diameter of Outflow at Peak Velocity Change:	1.5 – 3.0 km
Growth Stage:	N/A
Intervening rain:	Yes
Temperature Lapse Rate:	Adiabatic
Symmetry:	Varies between microbursts
Stage of Evolution for Primary Microburst:	Near Peak
Data Set Origin X_0, Y_0	2232 meters, -10570 meters
Data Set Grid Cell Size ΔX x ΔY x ΔZ	100 meters x 100 meters x 50 meters
Data Set Domain Size X x Y x Z	18 km x 12 km x 2 km
Data Set Number of Grid Points IX x IY x IZ	181 x 121 x 41
General Meteorological Description:	[Note 20]
Justifications:	[Note 7], [Note 14]
Information:	[Note 1], [Note 2], [Note 3] About 3 km from the runway, the path touches the edge of a strong shear to the south of the path, which produces a very weak shear and about 5 to 10 dBZ reflectivity on the path, with stronger shear and reflectivity to the left of the path.

Scenario 16

NASA Windshear Data Set / Time:	351
Data Set:	3
Model Simulation Time:	51 minutes
Description:	Multiple Microburst, 07/11/88 Incident Case, Denver, Colorado
Radar Clutter Model:	Newark 4R/22L
Flight Phase:	Straight in approach
Flight Scenario Location:	-3 degree straight in approach to the northwest at a 315-degree heading. The microburst leading edge is located 0.5 nm from runway threshold.
True Airspeed:	150 knots
Windshear Penetration Path:	Place runway threshold at X,Y = (12.2, -3.0) km Orient runway on true heading of 315
Flight Path Assumptions:	Glide slope angle = 3 degrees (gamma = -0.0524) Glide path intercept point = 300 meters down runway Middle marker location = 900 meters from runway threshold Runway length = 3 km (9840 feet) The above conditions produce a glide path height of 63 meters at the middle marker.
Approximate Peak FBAR along path:	0.13
Approximate Peak Reflectivity along path:	40 dBZ
Outflow Reflectivity:	13 to 27 dBZ
Approximate Diameter of Outflow at Peak Velocity Change:	1.5 – 3.0 km
Growth Stage:	N/A
Intervening rain:	Yes
Temperature Lapse Rate:	Adiabatic
Symmetry:	Varies between microbursts
Stage of Evolution for Primary Microburst:	Near Peak
Data Set Origin X_0, Y_0	2232 meters, -10570 meters
Data Set Grid Cell Size ΔX x ΔY x ΔZ	100 meters x 100 meters x 50 meters
Data Set Domain Size X x Y x Z	18 km x 12 km x 2 km
Data Set Number of Grid Points IX x IY x IZ	181 x 121 x 41
General Meteorological Description:	[Note 20]
Justifications:	[Note 7], [Note 14]
Information:	[Note 1], [Note 2], [Note 3], [Note 4] Detect both windshears on this path: (1) the shear with peak FBAR of 0.2 and precipitation of 25 dBZ that is 3-4 km short of runway, and (2) the primary shear that has peak FBAR of 0.13 and precipitation of 40 dBZ that is along the path.

Scenario 17

NASA Windshear Data Set / Time:	351
Data Set:	3
Model Simulation Time:	51 minutes
Description:	Multiple Microburst, 07/11/88 Incident Case, Denver, Colorado
Radar Clutter Model:	Denver 26L
Flight Phase:	Curved approach
Flight Scenario Location:	1000 ft AGL level flight standard rate 90-degree turn to the localizer, as limited by 25 degrees of bank. The microburst leading edge is located at the localizer intercept point such that it is directly in front of the aircraft when localizer is captured.
True Airspeed:	200 knots
Windshear Penetration Path:	Right Turn: Localizer course eastward on Y = -3.1 km line Center of turn at X,Y = (11.5, -5.42) km Fly north along X= 9.18 km line to X,Y = (9.18, -5.42) km Then turn right to intercept localizer at X,Y = (11.5, -3.1) km or, Left Turn: Localizer course eastward on Y = -3.1 km line Center of turn at X,Y = (11.5, -0.78) km Fly south along X= 9.18 km line to X,Y = (9.18, -0.78) km Then turn left to intercept localizer at X,Y = (11.5, -3.1) km
Flight Path Assumptions:	Radius of turn, 25 degree bank, at 200 knots (103 m/s) = 2.32 km Glide slope angle = 3 degrees (gamma = -0.0524) Glide path intercept point = 300 meters down runway
Approximate Peak FBAR along path:	0.15
Approximate Peak Reflectivity along path:	40 dBZ
Outflow Reflectivity:	13 to 27 dBZ
Approximate Diameter of Outflow at Peak Velocity Change:	1.5 – 3.0 km
Growth Stage:	N/A
Intervening rain:	Yes
Temperature Lapse Rate:	Adiabatic
Symmetry:	Varies between microbursts
Stage of Evolution for Primary Microburst:	Near Peak
Data Set Origin X_0, Y_0	2232 meters, -10570 meters
Data Set Grid Cell Size ΔX x ΔY x ΔZ	100 meters x 100 meters x 50 meters
Data Set Domain Size X x Y x Z	18 km x 12 km x 2 km
Data Set Number of Grid Points IX x IY x IZ	181 x 121 x 41
General Meteorological Description:	[Note 20]
Justifications:	[Note 7], [Note 15]
Information:	[Note 1], [Note 2], [Note 3] Flight tests for clutter data should attempt to duplicate the specified ground track by adjusting bank angle, but bank angle should be at least 20 degrees. The path encounters precipitation about 1 km prior to beginning the turn, and completes turn in moderate to heavy precipitation. The turn goes through FBAR of 0.12 prior to primary threat.

Scenario 18

NASA Windshear Data Set / Time:	436
Data Set:	4
Model Simulation Time:	36 minutes
Description:	Warm Microburst, 07/14/82 Sounding Stable Layer, Denver, Colorado
Radar Clutter Model:	Newark 4R/22L
Flight Phase:	Aligned for takeoff
Flight Scenario Location:	Aligned for takeoff to the east. The microburst leading edge is located 2 km from brake release, near the liftoff point, such that the airplane is in the headwind conditions of the outflow (“near microburst” scenario).
True Airspeed:	0 knots
Windshear Penetration Path:	Takeoff toward east along Y = 0 axis Brake release at X,Y = (-2.7, 0) km Liftoff at X,Y = (-0.7, 0) km
Flight Path Assumptions:	Takeoff ground roll length = 2 km Flight path angle after takeoff = 0.10 radians (5.73 degrees) Runway length = 3 km (9840 feet)
Approximate Peak FBAR along path:	0.23
Approximate Peak Reflectivity along path:	27 dBZ
Outflow Reflectivity:	0 to 10 dBZ
Approximate Diameter of Outflow at Peak Velocity Change:	1.0 km
Growth Stage:	N/A
Intervening rain:	No
Temperature Lapse Rate:	Stable Layer
Symmetry:	Axisymmetric
Stage of Evolution for Primary Microburst:	Past Peak but Quasi-Steady
Data Set Origin X_0, Y_0	-5000 meters, -5000 meters
Data Set Grid Cell Size ΔX x ΔY x ΔZ	50 meters x 50 meters x 50 meters
Data Set Domain Size X x Y x Z	10 km x 10 km x 2 km
Data Set Number of Grid Points IX x IY x IZ	201 x 201 x 41
Adjustment:	The NASA Windshear Simulation Data Sets were intended to represent the minimum reflectivity of 0 dBZ at the outflow region. Data set 436 has an outflow region that is less than 0 dBZ and represents the extreme case. As a result the following adjustments may be made to Data Set 436 to better represent a minimum reflectivity of 0 dBZ: In order to qualify for this adjustment this case should first be run as originally delivered, but without radar ground clutter model. Then add 15 dBZ with 28-dBZ limit and run with specified radar ground clutter model.
General Meteorological Description:	[Note 21]
Justifications:	[Note 8], [Note 12]
Information:	[Note 1], [Note 3] This scenario is designed to demonstrate windshear detection prior to brake release. If detection is not achieved prior to brake release, the takeoff roll should be initiated and continued up to the detection point. This microburst has a very small rain shaft: the diameter of the 5-dBZ precipitation contour is slightly less than 1 km at 50 meters altitude.

Scenario 19

NASA Windshear Data Set / Time:	436
Data Set:	4
Model Simulation Time:	36 minutes
Description:	Warm Microburst, 07/14/82 Sounding Stable Layer, Denver, Colorado
Radar Clutter Model:	Newark 4R/22L
Flight Phase:	Straight in approach
Flight Scenario Location:	-3 degree straight in approach to the east. The microburst leading edge is located 0.5 nm from runway threshold.
True Airspeed:	150 knots
Windshear Penetration Path:	Approach toward east along Y = 0 axis Place runway threshold at X,Y = (0.2, 0) km
Flight Path Assumptions:	Glide slope angle = 3 degrees (gamma = -0.0524) Glide path intercept point = 300 meters down runway Middle marker location = 900 meters from runway threshold Runway length = 3 km (9840 feet) The above conditions produce a glide path height of 63 meters at the middle marker.
Approximate Peak FBAR along path:	0.24
Approximate Peak Reflectivity along path:	27 dBZ
Outflow Reflectivity:	0 to 10 dBZ
Approximate Diameter of Outflow at Peak Velocity Change:	1.0 km
Growth Stage:	N/A
Intervening rain:	No
Temperature Lapse Rate:	Stable Layer
Symmetry:	Axisymmetric
Stage of Evolution for Primary Microburst:	Past Peak but Quasi-Steady
Data Set Origin X_0, Y_0	-5000 meters, -5000 meters
Data Set Grid Cell Size ΔX x ΔY x ΔZ	50 meters x 50 meters x 50 meters
Data Set Domain Size X x Y x Z	10 km x 10 km x 2 km
Data Set Number of Grid Points IX x IY x IZ	201 x 201 x 41
Adjustment:	The NASA Windshear Simulation Data Sets were intended to represent the minimum reflectivity of 0 dBZ at the outflow region. Data set 436 has an outflow region that is less than 0 dBZ and represents the extreme case. As a result, the following adjustments may be made to Data Set 436 to better represent a minimum reflectivity of 0 dBZ: In order to qualify for this adjustment this case should first be run as originally delivered, but without radar ground clutter model. Then add 15 dBZ with 28-dBZ limit and run with specified radar ground clutter model.
General Meteorological Description:	[Note 21]
Justifications:	[Note 8], [Note 14]
Information:	[Note 1], [Note 3]

Scenario 20

NASA Windshear Data Set / Time:	436
Data Set:	4
Model Simulation Time:	36 minutes
Description:	Warm Microburst, 07/14/82 Sounding Stable Layer, Denver, Colorado
Radar Clutter Model:	Newark 4R/22L
Flight Phase:	Drift angle approach
Flight Scenario Location:	-3 degree straight in approach to the east with a 25 degree drift angle. The microburst leading edge is located at the runway threshold.
True Airspeed:	120 knots
Windshear Penetration Path:	Approach toward east along Y = 0 axis Place runway threshold at X,Y = (-0.7, 0) km
Flight Path Assumptions:	Glide slope angle = 3 degrees (gamma = -0.0524) Glide path intercept point = 300 meters down runway Middle marker location = 900 meters from runway threshold Runway length = 3 km (9840 feet) The above conditions produce a glide path height of 63 meters at the middle marker.
Approximate Peak FBAR along path:	0.24
Approximate Peak Reflectivity along path:	27 dBZ
Outflow Reflectivity:	0 to 10 dBZ
Approximate Diameter of Outflow at Peak Velocity Change:	1.0 km
Growth Stage:	N/A
Intervening rain:	No
Temperature Lapse Rate:	Stable Layer
Symmetry:	Axisymmetric
Stage of Evolution for Primary Microburst:	Past Peak but Quasi-Steady
Data Set Origin X_0, Y_0	-5000 meters, -5000 meters
Data Set Grid Cell Size ΔX x ΔY x ΔZ	50 meters x 50 meters x 50 meters
Data Set Domain Size X x Y x Z	10 km x 10 km x 2 km
Data Set Number of Grid Points IX x IY x IZ	201 x 201 x 41
Adjustment:	The NASA Windshear Simulation Data Sets were intended to represent the minimum reflectivity of 0 dBZ at the outflow region. Data set 436 has an outflow region that is less than 0 dBZ and represents the extreme case. As a result, the following adjustments may be made to Data Set 436 to better represent a minimum reflectivity of 0 dBZ: In order to qualify for this adjustment this case should first be run as originally delivered, but without radar ground clutter model. Then add 15 dBZ with 28-dBZ limit and run with specified radar ground clutter model.
General Meteorological Description:	[Note 21]
Justifications:	[Note 8], [Note 16]
Information:	[Note 1], [Note 3] This path is a worst-case drift approach at 120 Knots. Ground clutter collection flights should be conducted with the aircraft at its maximum safe sideslip angle in an attempt to simulate a 25-degree drift angle on approach. Any shortfall of 25 degrees should be made up by an acceptable adjustment means.

Scenario 21

NASA Windshear Data Set / Time:	540
Data Set:	5
Model Simulation Time:	40 minutes
Description:	Very Dry Microburst, 07/08/89 Sounding, Denver, Colorado
Radar Clutter Model:	Newark 4R/22L
Flight Phase:	Takeoff – Gear up height
Flight Scenario Location:	Takeoff at gear up height to the west. The microburst leading edge is located 3.0 nm (~5.5 km) from brake release ("far microburst" scenario).
True Airspeed:	150 knots
Windshear Penetration Path:	Takeoff toward west along Y = 10.6 km line Brake release at X,Y = (10.1, 10.6) km Liftoff at X,Y = (8.1, 10.6) km
Flight Path Assumptions:	Takeoff ground roll length = 2 km Flight path angle after takeoff = 0.10 radians (5.73 degrees) Runway length = 3 km (9840 feet)
Approximate Peak FBAR along path:	0.18
Approximate Peak Reflectivity along path:	17 to 20 dBZ
Outflow Reflectivity:	-10 to -4 dBZ
Approximate Diameter of Outflow at Peak Velocity Change:	3.0 km
Growth Stage:	N/A
Intervening rain:	No
Temperature Lapse Rate:	Adiabatic
Symmetry:	Rough symmetry
Stage of Evolution for Primary Microburst:	Near Peak
Data Set Origin X_0, Y_0	-4210 meters, 2275 meters
Data Set Grid Cell Size ΔX x ΔY x ΔZ	100 meters x 100 meters x 50 meters
Data Set Domain Size X x Y x Z	16 km x 16 km x 2 km
Data Set Number of Grid Points IX x IY x IZ	161 x 161 x 41
Adjustment:	The NASA Windshear Simulation Data Sets were intended to represent the minimum reflectivity of 0 dBZ at the outflow region. Data set 540 has an outflow region that is less than 0 dBZ and represents the extreme case. As a result, the following adjustments may be made to Data Set 540 to better represent a minimum reflectivity of 0 dBZ: Add 10 dBZ with a 23-dBZ limit and run with specified radar ground clutter model.
General Meteorological Description:	[Note 22]
Justifications:	[Note 9], [Note 13]

Information:	[Note 1], [Note 3] The simulation run may begin at the takeoff gear up height > 50 feet AGL. Events drier than a core reflectivity of 5 dBZ are rare. A 5-dBZ reflectivity corresponds to 0.001 inches of water/hour at the surface. The diameter of the 5-dBZ precipitation contour is ~1.6 km. About 1 km to each side of the primary shear is a shear of about 0.12 to 0.15 FBAR, in reflectivity regions of less than 0 dBZ.

Scenario 22

NASA Windshear Data Set / Time:	540
Data Set:	5
Model Simulation Time:	40 minutes
Description:	Very Dry Microburst, 07/08/89 Sounding, Denver, Colorado
Radar Clutter Model:	Newark 4R/22L
Flight Phase:	Straight in approach
Flight Scenario Location:	-3 degree straight in approach to the north. The microburst leading edge is located 0.5 nm from runway threshold.
True Airspeed:	150 knots
Windshear Penetration Path:	Approach toward north along X = 3.8 km line Place runway threshold at X,Y = (3.8, 10.9) km
Flight Path Assumptions:	Glide slope angle = 3 degrees (gamma = -0.0524) Glide path intercept point = 300 meters down runway Middle marker location = 900 meters from runway threshold Runway length = 3 km (9840 feet) The above conditions produce a glide path height of 63 meters at the middle marker.
Approximate Peak FBAR along path:	0.16
Approximate Peak Reflectivity along path:	17 to 20 dBZ
Outflow Reflectivity:	-10 to -4 dBZ
Approximate Diameter of Outflow at Peak Velocity Change:	3.0 km
Growth Stage:	N/A
Intervening rain:	No
Temperature Lapse Rate:	Adiabatic
Symmetry:	Rough symmetry
Stage of Evolution for Primary Microburst:	Near Peak
Data Set Origin X_0, Y_0	-4210 meters, 2275 meters
Data Set Grid Cell Size ΔX x ΔY x ΔZ	100 meters x 100 meters x 50 meters
Data Set Domain Size X x Y x Z	16 km x 16 km x 2 km
Data Set Number of Grid Points IX x IY x IZ	161 x 161 x 41
Adjustment:	The NASA Windshear Simulation Data Sets were intended to represent the minimum reflectivity of 0 dBZ at the outflow region. Data set 540 has an outflow region that is less than 0 dBZ and represents the extreme case. As a result, the following adjustments may be made to Data Set 540 to better represent a minimum reflectivity of 0 dBZ: Add 10 dBZ with a 23-dBZ limit and run with specified radar ground clutter model.
General Meteorological Description:	[Note 22]
Justifications:	[Note 9], [Note 14]
Information:	[Note 1], [Note 3] Events drier than a core reflectivity of 5 dBZ are rare. A 5-dBZ reflectivity corresponds to 0.001 inches of water/hour at the surface.

Scenario 23

NASA Windshear Data Set / Time:	540
Data Set:	5
Model Simulation Time:	40 minutes
Description:	Very Dry Microburst, 07/08/89 Sounding, Denver, Colorado
Radar Clutter Model:	Newark 4R/22L
Flight Phase:	Drift angle approach
Flight Scenario Location:	-3 degree straight in approach to the north with a 25 degree drift angle. The microburst leading edge is located at the runway threshold.
True Airspeed:	120 knots
Windshear Penetration Path:	Approach toward north along X = 3.8 km line Place runway threshold at X,Y = (3.8, 10.0) km
Flight Path Assumptions:	Glide slope angle = 3 degrees (gamma = -0.0524) Glide path intercept point = 300 meters down runway Middle marker location = 900 meters from runway threshold Runway length = 3 km (9840 feet) These conditions produce a glide path height of 63 meters at the middle marker.
Approximate Peak FBAR along path:	0.12
Approximate Peak Reflectivity along path:	17 to 20 dBZ
Outflow Reflectivity:	-10 to -4 dBZ
Approximate Diameter of Outflow at Peak Velocity Change:	3.0 km
Growth Stage:	N/A
Intervening rain:	No
Temperature Lapse Rate:	Adiabatic
Symmetry:	Rough symmetry
Stage of Evolution for Primary Microburst:	Near Peak
Data Set Origin X_0, Y_0	-4210 meters, 2275 meters
Data Set Grid Cell Size ΔX x ΔY x ΔZ	100 meters x 100 meters x 50 meters
Data Set Domain Size X x Y x Z	16 km x 16 km x 2 km
Data Set Number of Grid Points IX x IY x IZ	161 x 161 x 41
Adjustment:	The NASA Windshear Simulation Data Sets were intended to represent the minimum reflectivity of 0 dBZ at the outflow region. Data set 540 has an outflow region that is less than 0 dBZ, representing the extreme case. As a result, the following adjustments may be made to Data Set 540 to better represent a minimum reflectivity of 0 dBZ: Add 10 dBZ with a 23-dBZ limit and run with specified radar ground clutter model.
General Meteorological Description:	[Note 22]
Justifications:	[Note 9], [Note 16]
Information:	[Note 1], [Note 3], [Note 4] Ground clutter collection flights should be conducted with the aircraft at its maximum safe sideslip angle in an attempt to simulate a 25-degree drift angle on approach. Any shortfall of 25 degrees should be made up by an acceptable adjustment means. Events drier than a core reflectivity of 5 dBZ are rare. A 5-dBZ reflectivity corresponds to 0.001 inches of water/hour at the surface. The peak along-path FBAR occurs after landing, with little or no vertical F-factor component. During approach, the sensor would likely see the higher FBAR values above the runway.

Scenario 24

NASA Windshear Data Set / Time:	540
Data Set:	5
Model Simulation Time:	40 minutes
Description:	Very Dry Microburst, 07/08/89 Sounding, Denver, Colorado
Radar Clutter Model:	Newark 4R/22L
Flight Phase:	Go-around
Flight Scenario Location:	Go-Around at 100 ft AGL to the north. The microburst leading edge is located 1.8 nm (3.3 km) from the 100 ft point, initiation of missed approach, at the far end of the runway.
True Airspeed:	150 knots
Windshear Penetration Path:	Approach toward north along X = 3.8 km line Place runway threshold at X,Y = (3.8, 6.8) km Go-around point at X,Y = (3.8, 6.5) km
Flight Path Assumptions:	Go around maneuvers are begun at an altitude of 30 meters, at a position 300 meters from runway threshold. Glide slope angle = 3 degrees (gamma = -0.0524) Glide path intercept point = 300 meters down runway Flight path angle after go-around = 0.10 radians (5.73 degrees) Middle marker location = 900 meters from runway threshold Runway length = 3 km (9840 feet) The above conditions produce a glide path height of 63 meters at the middle marker.
Approximate Peak FBAR along path:	0.17
Approximate Peak Reflectivity along path:	17 to 20 dBZ
Outflow Reflectivity:	-10 to -4 dBZ
Approximate Diameter of Outflow at Peak Velocity Change:	3.0 km
Growth Stage:	N/A
Intervening rain:	No
Temperature Lapse Rate:	Adiabatic
Symmetry:	Rough symmetry
Stage of Evolution for Primary Microburst:	Near Peak
Data Set Origin X_0, Y_0	-4210 meters, 2275 meters
Data Set Grid Cell Size ΔX x ΔY x ΔZ	100 meters x 100 meters x 50 meters
Data Set Domain Size X x Y x Z	16 km x 16 km x 2 km
Data Set Number of Grid Points IX x IY x IZ	161 x 161 x 41
Adjustment:	The NASA Windshear Simulation Data Sets were intended to represent the minimum reflectivity of 0 dBZ at the outflow region. Data set 540 has an outflow region that is less than 0 dBZ and represents the extreme case. As a result, the following adjustments may be made to Data Set 540 to better represent a minimum reflectivity of 0 dBZ: Add 10 dBZ with a 23-dBZ limit and run with specified radar ground clutter model.
General Meteorological Description:	[Note 22]
Justifications:	[Note 9], [Note 17]
Information:	[Note 1], [Note 3] Events drier than a core reflectivity of 5 dBZ are rare. A 5-dBZ reflectivity corresponds to 0.001 inches of water/hour at the surface.

Scenario 25

NASA Windshear Data Set / Time:	540
Data Set:	5
Model Simulation Time:	40 minutes
Description:	Very Dry Microburst, 07/08/89 Sounding, Denver, Colorado
Radar Clutter Model:	Denver 26L
Flight Phase:	Curved approach
Flight Scenario Location:	1000 ft AGL level flight standard rate 90-degree turn to the localizer, as limited by 25 degrees of bank. The microburst leading edge is located at the localizer intercept point such that it is directly in front of the aircraft when localizer is captured.
True Airspeed:	200 knots
Windshear Penetration Path:	Right Turn: Localizer course westward on Y = 10.6 km Center of turn at X,Y = (4.4, 12.92) km Fly south along X = 6.72 km line to X,Y = (6.72, 12.92) km Then turn right to intercept localizer at X,Y = (4.4, 10.6) km or, Left Turn: Localizer course westward on Y = 10.6 km Center of turn at X,Y = (4.4, 8.28) km Fly north along X= 6.72 km line to X,Y = (6.72, 8.28) km then turn left to intercept localizer at X,Y = (4.4, 10.6) km
Flight Path Assumptions:	Radius of turn, 25-degree bank, at 200 knots (103 m/s) = 2.32 km Glide slope angle = 3 degrees (gamma = -0.0524) Glide path intercept point = 300 meters down runway
Approximate Peak FBAR along path:	0.16
Approximate Peak Reflectivity along path:	17 to 20 dBZ
Outflow Reflectivity:	-10 to -4 dBZ
Approximate Diameter of Outflow at Peak Velocity Change:	3.0 km
Growth Stage:	N/A
Intervening rain:	No
Temperature Lapse Rate:	Adiabatic
Symmetry:	Rough symmetry
Stage of Evolution for Primary Microburst:	Near Peak
Data Set Origin X_0, Y_0	-4210 meters, 2275 meters
Data Set Grid Cell Size ΔX x ΔY x ΔZ	100 meters x 100 meters x 50 meters
Data Set Domain Size X x Y x Z	16 km x 16 km x 2 km
Data Set Number of Grid Points IX x IY x IZ	161 x 161 x 41
Adjustment:	The NASA Windshear Simulation Data Sets were intended to represent the minimum reflectivity of 0 dBZ at the outflow region. Data set 540 has an outflow region that is less than 0 dBZ and represents the extreme case. As a result, the following adjustments may be made to Data Set 540 to better represent a minimum reflectivity of 0 dBZ: Add 10 dBZ with a 23-dBZ limit and run with specified radar ground clutter model.
General Meteorological Description:	[Note 22]
Justifications:	[Note 9], [Note 15]
Information:	[Note 1], [Note 3] Flight tests for clutter data should attempt to duplicate the specified ground track by adjusting bank angle, but bank angle should be at least 20 degrees. Events drier than a core reflectivity of 5 dBZ are rare. A 5-dBZ reflectivity corresponds to 0.001 inches of water/hour at the surface.

Scenario 26

NASA Windshear Data Set / Time:	545
Data Set:	5
Model Simulation Time:	45 minutes
Description:	Extremely Dry Microburst (Second Pulse), 07/08/89 Sounding, Denver, Colorado
Radar Clutter Model:	Newark 4R/22L
Flight Phase:	Straight in approach
Flight Scenario Location:	-3 degree straight in approach to the north. The microburst leading edge is located 0.5 nm from runway threshold.
True Airspeed:	150 knots
Windshear Penetration Path:	Approach toward north along X = 4.67 km line Place runway threshold at X,Y = (4.67, 12.2) km
Flight Path Assumptions:	Glide slope angle = 3 degrees (gamma = -0.0524) Glide path intercept point = 300 meters down runway Middle marker location = 900 meters from runway threshold Runway length = 3 km (9840 feet) The above conditions produce a glide path height of 63 meters at the middle marker.
Approximate Peak FBAR along path:	0.15
Approximate Peak Reflectivity along path:	5 dBZ
Outflow Reflectivity:	-11 dBZ
Approximate Diameter of Outflow at Peak Velocity Change:	3.0 km
Growth Stage:	N/A
Intervening rain:	No
Temperature Lapse Rate:	Adiabatic
Symmetry:	Rough symmetry
Stage of Evolution for Primary Microburst:	Second Pulse
Data Set Origin X_0, Y_0	-3738 meters, 3639 meters
Data Set Grid Cell Size ΔX x ΔY x ΔZ	100 meters x 100 meters x 50 meters
Data Set Domain Size X x Y x Z	16 km x 16 km x 2 km
Data Set Number of Grid Points IX x IY x IZ	161 x 161 x 41
General Meteorological Description:	[Note 22]
Justifications:	[Note 9], [Note 14]
Information:	[Note 1], [Note 3] The NASA Windshear Simulation Data Sets were intended to represent the minimum reflectivity of 0 dBZ at the outflow region. Data set 545 has an outflow region that is less than 0 dBZ and represents the extreme case. Data set 545 should be run as a limiting case. It represents the extreme dry microburst and will not be considered in the PASS/FAIL criteria. Events drier than a core reflectivity of 5 dBZ are rare. A 5-dBZ reflectivity corresponds to 0.001 inches of water/hour at the surface. This second microburst pulse is extremely dry. The contour of 0-dBZ reflectivity is less than 1 km in diameter. The given runway placement will provide a core penetration altitude of about 100 meters.

Scenario 27

NASA Windshear Data Set / Time:	614
Data Set:	6
Model Simulation Time:	14 minutes
Description:	Highly Asymmetric Microburst, Derived Sounding, Florida
Radar Clutter Model:	Washington National 18
Flight Phase:	Curved approach
Flight Scenario Location:	1000 ft AGL level flight standard rate 90-degree turn to the localizer, as limited by 25 degrees of bank. The microburst leading edge is located at the localizer intercept point such that it is directly in front of the aircraft when localizer is captured.
True Airspeed:	200 knots
Windshear Penetration Path:	Right Turn: Localizer course southward on X = 14.33 km line Center of turn at X,Y = (12.01, 1.08) km Fly east along Y = 3.4 km line to X,Y = (12.01, 3.4) km Then turn right to intercept localizer at X,Y = (14.33, 1.08) km or, Left Turn: Localizer course southward on X = 14.33 km line Center of turn at X,Y = (16.65, 1.08) km Fly west along Y = 3.4 km line to X,Y = (16.65, 3.4) km Then turn left to intercept localizer at X,Y = (14.33, 1.08) km
Flight Path Assumptions:	Radius of turn, 25-degree bank, at 200 knots (103 m/s) = 2.32 km Glide slope angle = 3 degrees (gamma = -0.0524) Glide path intercept point = 300 meters down runway
Approximate Peak FBAR along path:	0.11
Approximate Peak Reflectivity along path:	50 dBZ
Outflow Reflectivity:	40 to 47 dBZ
Approximate Diameter of Outflow at Peak Velocity Change:	1.0 km
Growth Stage:	N/A
Intervening rain:	Light
Temperature Lapse Rate:	Adiabatic
Symmetry:	Asymmetric
Stage of Evolution for Primary Microburst:	Decaying
Data Set Origin X_0, Y_0	8071 meters, -3500 meters
Data Set Grid Cell Size ΔX x ΔY x ΔZ	100 meters x 100 meters x 50 meters
Data Set Domain Size X x Y x Z	10 km x 10 km x 2 km
Data Set Number of Grid Points IX x IY x IZ	101 x 101 x 41
General Meteorological Description:	[Note 23]
Justifications:	[Note 10], [Note 15]
Information:	[Note 1], [Note 2], [Note 3], [Note 4] Flight tests for clutter data should attempt to duplicate the specified ground track by adjusting bank angle, but bank angle should be at least 20 degrees. A higher FBAR (0.15) region exists 200 meters to the left of the localizer. The localizer is offset slightly from the microburst core to bring the core into 25-degree minimum field of view early in the turn.

Scenario 28

NASA Windshear Data Set / Time:	614
Data Set:	6
Model Simulation Time:	14 minutes
Description:	Highly Asymmetric Microburst, Derived Sounding, Florida
Radar Clutter Model:	Newark 4R/22L
Flight Phase:	Straight in approach
Flight Scenario Location:	-3 degree straight in approach to the north at a 360-degree heading. The microburst leading edge is located 0.5 nm from runway threshold.
True Airspeed:	150 knots
Windshear Penetration Path:	Localizer on X = 14.6 km line. Runway threshold at X,Y = (14.6, 4.9) km Orient runway on true heading of 360
Flight Path Assumptions:	Glide slope angle = 3 degrees (gamma = -0.0524) Glide path intercept point = 300 meters down runway Middle marker location = 900 meters from runway threshold Runway length = 3 km (9840 feet) The above conditions produce a glide path height of 63 meters at the middle marker.
Approximate Peak FBAR along path:	0.15
Approximate Peak Reflectivity along path:	50 dBZ
Outflow Reflectivity:	40 to 47 dBZ
Approximate Diameter of Outflow at Peak Velocity Change:	1.0 km
Growth Stage:	N/A
Intervening rain:	Light
Temperature Lapse Rate:	Adiabatic
Symmetry:	Asymmetric
Stage of Evolution for Primary Microburst:	Decaying
Data Set Origin X_0, Y_0	8071 meters, -3500 meters
Data Set Grid Cell Size ΔX x ΔY x ΔZ	100 meters x 100 meters x 50 meters
Data Set Domain Size X x Y x Z	10 km x 10 km x 2 km
Data Set Number of Grid Points IX x IY x IZ	101 x 101 x 41
General Meteorological Description:	[Note 23]
Justifications:	[Note 10], [Note 14]
Information:	[Note 1], [Note 2], [Note 3] The sensor has a clear view of the windshear during the approach. The microburst core is near X, Y = (14.2, 0.5).

Scenario 29

NASA Windshear Data Set / Time:	614
Data Set:	6
Model Simulation Time:	14 minutes
Description:	Highly Asymmetric Microburst, Derived Sounding, Florida
Radar Clutter Model:	Newark 4R/22L
Flight Phase:	Straight in approach
Flight Scenario Location:	-3 degree straight in approach to the northeast at a 45-degree heading. The microburst leading edge is located 0.5 nm from runway threshold.
True Airspeed:	150 knots
Windshear Penetration Path:	Localizer on Y = (X-13.9) km line. Runway threshold at X,Y = (17.2, 3.3) km Orient runway on true heading of 045
Flight Path Assumptions:	Glide slope angle = 3 degrees (gamma = -0.0524) Glide path intercept point = 300 meters down runway Middle marker location = 900 meters from runway threshold Runway length = 3 km (9840 feet) The above conditions produce a glide path height of 63 meters at the middle marker.
Approximate Peak FBAR along path:	0.17
Approximate Peak Reflectivity along path:	50 dBZ
Outflow Reflectivity:	40 to 47 dBZ
Approximate Diameter of Outflow at Peak Velocity Change:	1.0 km
Growth Stage:	N/A
Intervening rain:	Light
Temperature Lapse Rate:	Adiabatic
Symmetry:	Asymmetric
Stage of Evolution for Primary Microburst:	Decaying
Data Set Origin X_0, Y_0	8071 meters, -3500 meters
Data Set Grid Cell Size ΔX x ΔY x ΔZ	100 meters x 100 meters x 50 meters
Data Set Domain Size X x Y x Z	10 km x 10 km x 2 km
Data Set Number of Grid Points IX x IY x IZ	101 x 101 x 41
General Meteorological Description:	[Note 23]
Justifications:	[Note 10], [Note 14]
Information:	[Note 1], [Note 2], [Note 3] The microburst core is near X,Y = (14.2, 0.5).

Scenario 30

NASA Windshear Data Set / Time:	614
Data Set:	6
Model Simulation Time:	14 minutes
Description:	Highly Asymmetric Microburst, Derived Sounding, Florida
Radar Clutter Model:	Newark 4R/22L
Flight Phase:	Straight in approach
Flight Scenario Location:	-3 degree straight in approach to the east at a 90-degree heading. The microburst leading edge is located 0.5 nm from runway threshold.
True Airspeed:	150 knots
Windshear Penetration Path:	Localizer on Y = 0.5 km line. Runway threshold at X,Y = (15.1, 0.5) km Orient runway on true heading of 090
Flight Path Assumptions:	Glide slope angle = 3 degrees (gamma = -0.0524) Glide path intercept point = 300 meters down runway Middle marker location = 900 meters from runway threshold Runway length = 3 km (9840 feet) The above conditions produce a glide path height of 63 meters at the middle marker.
Approximate Peak FBAR along path:	0.10
Approximate Peak Reflectivity along path:	50 dBZ
Outflow Reflectivity:	40 to 47 dBZ
Approximate Diameter of Outflow at Peak Velocity Change:	1.0 km
Growth Stage:	N/A
Intervening rain:	Light
Temperature Lapse Rate:	Adiabatic
Symmetry:	Asymmetric
Stage of Evolution for Primary Microburst:	Decaying
Data Set Origin X_0, Y_0	8071 meters, -3500 meters
Data Set Grid Cell Size ΔX x ΔY x ΔZ	100 meters x 100 meters x 50 meters
Data Set Domain Size X x Y x Z	10 km x 10 km x 2 km
Data Set Number of Grid Points IX x IY x IZ	101 x 101 x 41
General Meteorological Description:	[Note 23]
Justifications:	[Note 10], [Note 14]
Information:	[Note 1], [Note 2], [Note 3], [Note 4] FBAR of 0.12 exists near path. The path encounters an area of intervening rain about 2.5 km prior to the peak shear. The microburst core is near X, Y = (14.2, 0.5).

Scenario 31

NASA Windshear Data Set / Time:	614
Data Set:	6
Model Simulation Time:	14 minutes
Description:	Highly Asymmetric Microburst, Derived Sounding, Florida
Radar Clutter Model:	Newark 4R/22L
Flight Phase:	Straight in approach
Flight Scenario Location:	-3 degree straight in approach to the south at a 180-degree heading. The microburst leading edge is located 0.5 nm from runway threshold.
True Airspeed:	150 knots
Windshear Penetration Path:	Localizer on X= 14.5 km line. Runway threshold at X,Y = (14.5, -3.5) km Orient runway on true heading of 180
Flight Path Assumptions:	Glide slope angle = 3 degrees (gamma = -0.0524) Glide path intercept point = 300 meters down runway Middle marker location = 900 meters from runway threshold Runway length = 3 km (9840 feet) The above conditions produce a glide path height of 63 meters at the middle marker.
Approximate Peak FBAR along path:	0.15
Approximate Peak Reflectivity along path:	50 dBZ
Outflow Reflectivity:	40 to 47 dBZ
Approximate Diameter of Outflow at Peak Velocity Change:	1.0 km
Growth Stage:	N/A
Intervening rain:	Light
Temperature Lapse Rate:	Adiabatic
Symmetry:	Asymmetric
Stage of Evolution for Primary Microburst:	Decaying
Data Set Origin X_0, Y_0	8071 meters, -3500 meters
Data Set Grid Cell Size ΔX x ΔY x ΔZ	100 meters x 100 meters x 50 meters
Data Set Domain Size X x Y x Z	10 km x 10 km x 2 km
Data Set Number of Grid Points IX x IY x IZ	101 x 101 x 41
General Meteorological Description:	[Note 23]
Justifications:	[Note 10], [Note 14]
Information:	[Note 1], [Note 2], [Note 3] The path encounters about 2 km of intervening rain prior to the peak shear. The microburst core is near X, Y = (14.2, 0.5).

Scenario 32

NASA Windshear Data Set / Time:	614
Data Set:	6
Model Simulation Time:	14 minutes
Description:	Highly Asymmetric Microburst, Derived Sounding, Florida
Radar Clutter Model:	Newark 4R/22L
Flight Phase:	Straight in approach
Flight Scenario Location:	-3 degree straight in approach to the southwest at a 225-degree heading. The microburst leading edge is located 0.5 nm from runway threshold.
True Airspeed:	150 knots
Windshear Penetration Path:	Localizer on Y =(X-13.9) km line. Runway threshold at X,Y = (11.6, -2.3) km Orient runway on true heading of 225
Flight Path Assumptions:	Glide slope angle = 3 degrees (gamma = -0.0524) Glide path intercept point = 300 meters down runway Middle marker location = 900 meters from runway threshold Runway length = 3 km (9840 feet) The above conditions produce a glide path height of 63 meters at the middle marker.
Approximate Peak FBAR along path:	0.19
Approximate Peak Reflectivity along path:	50 dBZ
Outflow Reflectivity:	40 to 47 dBZ
Approximate Diameter of Outflow at Peak Velocity Change:	1.0 km
Growth Stage:	N/A
Intervening rain:	Light
Temperature Lapse Rate:	Adiabatic
Symmetry:	Asymmetric
Stage of Evolution for Primary Microburst:	Decaying
Data Set Origin X_0, Y_0	8071 meters, -3500 meters
Data Set Grid Cell Size ΔX x ΔY x ΔZ	100 meters x 100 meters x 50 meters
Data Set Domain Size X x Y x Z	10 km x 10 km x 2 km
Data Set Number of Grid Points IX x IY x IZ	101 x 101 x 41
General Meteorological Description:	[Note 23]
Justifications:	[Note 10], [Note 14]
Information:	[Note 1], [Note 2], [Note 3] The sensor has a clear view of the windshear during the approach. The microburst core is near X, Y = (14.2, 0.5).

Scenario 33

NASA Windshear Data Set / Time:	614
Data Set:	6
Model Simulation Time:	14 minutes
Description:	Highly Asymmetric Microburst, Derived Sounding, Florida
Radar Clutter Model:	Newark 4R/22L
Flight Phase:	Straight in approach
Flight Scenario Location:	-3 degree straight in approach to the west at a 270-degree heading. The microburst leading edge is located 0.5 nm from runway threshold.
True Airspeed:	150 knots
Windshear Penetration Path:	Localizer on Y = 0.5 km line. Runway threshold at X,Y = (13.3, 0.5) km Orient runway on true heading of 270
Flight Path Assumptions:	Glide slope angle = 3 degrees (gamma = -0.0524) Glide path intercept point = 300 meters down runway Middle marker location = 900 meters from runway threshold Runway length = 3 km (9840 feet) The above conditions produce a glide path height of 63 meters at the middle marker.
Approximate Peak FBAR along path:	0.13
Approximate Peak Reflectivity along path:	50 dBZ
Outflow Reflectivity:	40 to 47 dBZ
Approximate Diameter of Outflow at Peak Velocity Change:	1.0 km
Growth Stage:	N/A
Intervening rain:	Light
Temperature Lapse Rate:	Adiabatic
Symmetry:	Asymmetric
Stage of Evolution for Primary Microburst:	Decaying
Data Set Origin X_0, Y_0	8071 meters, -3500 meters
Data Set Grid Cell Size ΔX x ΔY x ΔZ	100 meters x 100 meters x 50 meters
Data Set Domain Size X x Y x Z	10 km x 10 km x 2 km
Data Set Number of Grid Points IX x IY x IZ	101 x 101 x 41
General Meteorological Description:	[Note 23]
Justifications:	[Note 10], [Note 14]
Information:	[Note 1], [Note 2], [Note 3], [Note 4] The sensor has a clear view of the windshear during the approach. The microburst core is near X, Y = (14.2, 0.5).

Scenario 34

NASA Windshear Data Set / Time:	614
Data Set:	6
Model Simulation Time:	14 minutes
Description:	Highly Asymmetric Microburst, Derived Sounding, Florida
Radar Clutter Model:	Newark 4R/22L
Flight Phase:	Straight in approach
Flight Scenario Location:	-3 degree straight in approach to the northwest at a 315-degree heading. The microburst leading edge is located 0.5 nm from runway threshold.
True Airspeed:	150 knots
Windshear Penetration Path:	Localizer on Y = -(X-14.67) km line. Runway threshold at X,Y = (12.87, 1.80) km Orient runway on true heading of 315
Flight Path Assumptions:	Glide slope angle = 3 degrees (gamma = -0.0524) Glide path intercept point = 300 meters down runway Middle marker location = 900 meters from runway threshold Runway length = 3 km (9840 feet) The above conditions produce a glide path height of 63 meters at the middle marker.
Approximate Peak FBAR along path:	0.13
Approximate Peak Reflectivity along path:	50 dBZ
Outflow Reflectivity:	40 to 47 dBZ
Approximate Diameter of Outflow at Peak Velocity Change:	1.0 km
Growth Stage:	N/A
Intervening rain:	Light
Temperature Lapse Rate:	Adiabatic
Symmetry:	Asymmetric
Stage of Evolution for Primary Microburst:	Decaying
Data Set Origin X_0, Y_0	8071 meters, -3500 meters
Data Set Grid Cell Size ΔX x ΔY x ΔZ	100 meters x 100 meters x 50 meters
Data Set Domain Size X x Y x Z	10 km x 10 km x 2 km
Data Set Number of Grid Points IX x IY x IZ	101 x 101 x 41
General Meteorological Description:	[Note 23]
Justifications:	[Note 10], [Note 14]
Information:	[Note 1], [Note 2], [Note 3], [Note 4] The sensor has a clear view of the windshear during the approach. The microburst core is near X, Y = (14.2, 0.5).

Scenario 35

NASA Windshear Data Set / Time:	727
Data Set:	7
Model Simulation Time:	27 minutes
Description:	Gust Front, 08/02/81 Adjusted Knowlton Sounding, Montana
Radar Clutter Model:	Newark 4R/22L
Flight Phase:	Aligned for takeoff
Flight Scenario Location:	Aligned for takeoff to the west. The microburst leading edge is located 2 km from brake release, near the liftoff point, such that the airplane is in the headwind conditions of the outflow (“near microburst” scenario).
True Airspeed:	0 knots
Windshear Penetration Path:	Takeoff toward west along Y = 1.0 km line Brake release at X,Y = (25.5, 1.0) km Liftoff at X,Y = (23.5, 1.0) km
Flight Path Assumptions:	Takeoff ground roll length = 2 km Flight path angle after takeoff = 0.10 radians (5.73 degrees) Runway length = 3 km (9840 feet)
Approximate Peak FBAR along path:	0.12
Approximate Peak Reflectivity along path:	20 dBZ in area of largest FBAR
Outflow Reflectivity:	18 to 20 dBZ
Approximate Diameter of Outflow at Peak Velocity Change:	N/A
Growth Stage:	N/A
Intervening rain:	No
Temperature Lapse Rate:	Adiabatic
Symmetry:	Asymmetric
Stage of Evolution for Primary Microburst:	N/A
Data Set Origin X_0, Y_0	18510 meters, -1500 meters
Data Set Grid Cell Size ΔX x ΔY x ΔZ	100 meters x 100 meters x 50 meters
Data Set Domain Size X x Y x Z	14 km x 5 km x 2 km
Data Set Number of Grid Points IX x IY x IZ	141 x 51 x 41
General Meteorological Description:	[Note 24]
Justifications:	[Note 11], [Note 12]
Information:	[Note 1], [Note 3] This scenario is designed to demonstrate windshear detection prior to brake release. If detection is not achieved prior to brake release, the takeoff roll should be initiated and continued up to the detection point. Peak FBAR along the path (0.12) occurs at about X = 22.3 km. The reflectivity along the path in the region of shear is about 20 dBZ.

Scenario 36

NASA Windshear Data Set / Time:	727
Data Set:	7
Model Simulation Time:	27 minutes
Description:	Gust Front, 08/02/81 Adjusted Knowlton Sounding, Montana
Radar Clutter Model:	Newark 4R/22L
Flight Phase:	Straight in approach
Flight Scenario Location:	-3 degree straight in approach to the west. The microburst leading edge is located 0.5 nm from runway threshold.
True Airspeed:	150 knots
Windshear Penetration Path:	Approach toward west along Y = 1.0 km line Place runway threshold at X,Y = (21.5, 1.0) km
Flight Path Assumptions:	Glide slope angle = 3 degrees (gamma = -0.0524) Glide path intercept point = 300 meters down runway Middle marker location = 900 meters from runway threshold Runway length = 3 km (9840 feet) The above conditions produce a glide path height of 63 meters at the middle marker.
Approximate Peak FBAR along path:	0.13
Approximate Peak Reflectivity along path:	20 dBZ in area of largest FBAR
Outflow Reflectivity:	18 to 20 dBZ
Approximate Diameter of Outflow at Peak Velocity Change:	N/A
Growth Stage:	N/A
Intervening rain:	No
Temperature Lapse Rate:	Adiabatic
Symmetry:	Asymmetric
Stage of Evolution for Primary Microburst:	N/A
Data Set Origin X_0, Y_0	18510 meters, -1500 meters
Data Set Grid Cell Size ΔX x ΔY x ΔZ	100 meters x 100 meters x 50 meters
Data Set Domain Size X x Y x Z	14 km x 5 km x 2 km
Data Set Number of Grid Points IX x IY x IZ	141 x 51 x 41
General Meteorological Description:	[Note 24]
Justifications:	[Note 11], [Note 14]
Information:	[Note 1], [Note 3]

Notes

1. True Airspeed:
F-factors will differ in the data sets developed for airspeeds of 120, 150, and 200 KTAS. Since the calculation of F-factor is weakly dependent on the true airspeed (TAS) of the airplane, a typical airspeed of 150 knots has been chosen to standardize the evaluation of these systems. However, the windshear system algorithms may be sensitive to true airspeed, and high airspeed is critical for system update rate evaluation relative to minimum detection time and low airspeed should be evaluated simply to show that the system will in fact actually work at low airspeeds. Therefore, a limited number of runs are to be evaluated at 120 KTAS and 200 KTAS. The 120 KTAS chosen is a typical minimum for lightweight maximum flap takeoffs and landings at sea level standard day, and the 200 KTAS is a typical maximum for heavyweight minimum flap operation at high altitude airports on a hot day.

2. Intervening Rain:
Intervening rain may adversely affect system performance. The system should be able to detect a hazardous windshear with sufficient advance warning to be classified as a forward-looking system. Since windshears can be contained in an environment with heavy rain, they should be detectable in these conditions. Therefore, for testing sensor performance in intervening rain, some flight paths have been oriented such that they pass through significant areas of rain prior to reaching the microburst hazard.

3. Pitch Angle:
The windshear detection system may have vertical look strategies that are fixed or variable. Since the airplane's pitch angle is a function of excess thrust, configuration, and flight mode, the system should perform satisfactorily over all expected circumstances. Radar ground clutter collection flights should be conducted using the flight phases and characteristics specified in this section. All flight tests should be conducted using sensor/airplane pitch angles critical for system performance.

4. F-factors at MUST-ALERT, below MUST-NOT-ALERT, or within MAY-ALERT:
Flight paths and NASA Windshear Data Sets have been chosen to provide FBAR events close to the MUST-ALERT and MUST-NOT-ALERT boundary and within the MAY-ALERT criteria for several microburst events. These events have been chosen to depict characteristics of the developing, peak and decaying growth stages of these microbursts. The reflectivity, attenuation, relative strengths of the vertical and horizontal windfield, symmetry (Data Sets 237, 349, and 614), etc., can change relatively as a microburst develops and decays. These tests are to show that the system is insensitive to specific modeled relationships. The F-factors for several of these cases are chosen to approximate the MUST-ALERT F-factor. However, depending upon the threshold chosen for alert, the events located within the MAY-ALERT criteria may not produce an alert. Also, several of these cases are to show that the system is free from nuisance alerts when the windshear event is below the MUST-NOT-ALERT boundary.

5. Justification for NASA Windshear Data Set 111:
This is the best-documented accident case with data from a multichannel flight data recorder on the Delta L-1011, which crashed in Dallas Texas August 2, 1985. It is probably one of the most studied and debated atmospheric events in aviation history. Therefore, it is sensible that it be demonstrated that a detection system will give advance warning of this event. This event represents the most severe, very wet microburst likely to be encountered in service incorporating rain and hail. The event produced a pronounced temperature drop.

6. Justification for NASA Windshear Data Set 237:
This event's characteristics have been well documented from its penetration by the NASA 737 airplane. This airplane incorporated radar and IR forward-looking sensors, a reactive windshear detection system, and the event was correlated by a ground-based research Terminal Doppler Weather Radar (TDWR). It is of moderate to strong intensity incorporating a wet core along with some

intervening rain. Evaluation of the system's performance against this model will provide a traceable link between airborne and ground TDWR measurements.

7. Justification for NASA Windshear Data Set 349 and 351:
This event is a well-studied incident case and represents a multiple microburst event. The model includes low to moderate reflectivity microbursts, a severe low reflectivity microburst, wide and narrow downdrafts with asymmetry. It expands into a macroburst with embedded microbursts with multiple downdraft centers within one of the microburst cores. This model is included in order to stress the detection system to determine if stronger events may be hidden by closer weak wet microbursts. Also, the asymmetry will stress the algorithm calculating the F-factor. This is to be shown by penetrating the model using several headings.

8. Justification for NASA Windshear Data Set 436:
Microbursts can penetrate a temperature inversion stable layer causing a non-typical temperature signature. This case also produces a high F-factor in a small area with a shallow outflow. These characteristics will stress the detection system's assessment of hazard in terms of range-bin size and azimuth averaging or other nuisance rejection schemes.

9. Justification for NASA Windshear Data Set 540 and 545:
This model will determine the system's ability to detect "dry" microbursts. The second pulse very dry 5 dBZ core event was chosen as a compromise between wet and extremely dry (less than 0 dBZ core) but of low probability, and the technology needed to not miss such events at the 10^{-5} probability level.

10. Justification for NASA Windshear Data Set 614:
Microbursts are not necessarily symmetric; therefore, the assumption that along track radial outflow is directly related to downflow is only an approximation. This windfield model will stress the system's ability to assign a proper F-factor to microbursts that are highly asymmetric when penetrated every 45 degrees of azimuth.

11. Justification for NASA Windshear Data Set 727:
Convection activity gust fronts can produce hazardous windshears. Even though gust fronts can be safely penetrated while in flight, since the tailwind energy loss is preceded by a headwind energy gain, if they occur during the takeoff roll they can be considerably more hazardous. This occurs if the headwind increase is encountered during the takeoff roll before VR. As soon as the airplane is airborne, the rapid loss of the headwind shear of the gust front can then pose serious performance shortfalls that have not been offset by the earlier headwind increase. This model is to determine that the system can also detect these events if their F-factor is above the hazard threshold.

12. Justification for Aligned for Takeoff Flight Scenario:
The takeoff scenario is to evaluate conditions similar to those existing in the Continental accident in Denver on August 7, 1975 and the Pan Am accident in New Orleans on July 9, 1982. This evaluation will also determine the system's ability to scan ahead using update rates high enough to provide the crew with timely information on hazardous windshear conditions prior to brake release.
Data Set 1 was selected since it would pose considerable hazard to the airplane even at the most nose down direction relative to the airplane. The specific microbursts of Data Set 3 and Data Set 4 were selected because if not detected, the pilot may mistakenly take off into the windshear because of its benign appearance due to being dry. Additionally, Data Set 4 was selected as being critical for detection at close range because its shallow outflow and small diameter would not necessarily pose much of a threat during later stages of the takeoff; to require its detection at 3.0 nm from brake release was considered unnecessarily severe in evaluation of the system. Data Set 7 (gust front) was selected since the takeoff is the critical flight phase for hazardous effects from this event.
Takeoff – "near microburst" scenarios: This windshear hazard located such that the airplane is in the headwind outflow closely matches the reference accident cases and would reduce the system's capability to determine the relative velocity change or relative temperature difference across the outflow. This is because the airplane is essentially located in a portion of the increased headwind to

start with.

Takeoff – “far microburst” scenarios: This windshear hazard located such that its leading edge is at 3.0 nm is to show that the system will issue a windshear warning prior to takeoff.

13. Justification for Takeoff Gear-Up Height Flight Scenario:

    This scenario represents the next stabilized phase of flight and is significantly different from brake release. This case will evaluate the system’s capability to scan in the most nose-down direction relative to the airplane.

    Data Set 3 was selected because if the microburst is not detected, the pilot may mistakenly take off into the windshear because of its benign appearance due to being dry. Data Set 5 is large enough to be a threat. Due to its benign appearance and due to being dry, it would be a challenge for the crew to detect without a windshear detection system.

    Takeoff Gear-Up Height – “far microburst” scenarios: The windshear hazard leading edge at 3 nm from brake release puts the event at approximately 1.5 nm from the gear up point. This is the distance recommended for the crew to be given a windshear warning in flight.

14. Justification for Straight-In Approach Flight Scenario:

    This scenario represents the typical nominal operational approach condition. The leading edge of the hazard is chosen at the middle marker. This assures that when the system alerts are enabled at 1200 feet AGL that approximately four miles to the hazard are available for system detection and display evaluation. In this case, the hazard is located only about 10 seconds from the runway threshold. It was considered sensible for evaluation to be able to compare the system’s performance for windshear detection over a range of windshear events while holding other variables more or less fixed. The straight-in approach provides the longest stabilized flight phase for this evaluation, and therefore has been chosen to evaluate all windfield models.

15. Justification for Curved Approach Flight Scenario:

    This scenario assesses the system performance during an approach in which the airplane, initially with its flight path offset from the windshear turns into it while lining up on the localizer. Having the leading edge of the windshear hazard located at the point where the airplane intercepts the localizer represents the worst case for advanced warning. The system should have enough azimuth scan to give at least 10 seconds advanced warning as the airplane turns into the hazard.

    Since this evaluation is only to assess the system’s ability to detect windshears as the airplane turns into them, only a limited number of windfield models need to be evaluated. Data Sets 3, 5, and 6 have been chosen as representing a reasonable sample with F-factor values close to the system MUST-ALERT boundary. During the Data Set 3 event, one of the airplanes that actually encountered this windshear made a turning approach into it. This then forms a historical basis for demonstration. Data Set 5 is a small microburst that will stress the system’s ability to detect the windshear’s outflow in a timely manner since the airplane is initially approaching offset from it. Data Set 6, being highly asymmetric, will stress the system’s ability to accurately calculate the event’s F-factor since the microburst’s perspective will be constantly changing as the airplane turns into it.

    Since it is assumed that a higher initial lateral offset from the windshear is the critical condition, only the 200 KTAS case has been picked. This will produce an initial lateral offset of 7600 feet for a standard rate (3 degrees / second as limited by 25 degrees bank angle) turn to intercept.

    The altitude of 1000 feet was chosen to assure that the windshear detection system alerts are active.

16. Justification for Drift Angle Approach Flight Scenario:

    It has been determined that microbursts are driven along the ground by upper winds. Their downflows penetrate the lower air mass, which contains the airplane, and can therefore have relative motion within the local air mass. Relative drift obtained from data during TDWR testing shows that windshear events either side of a fixed narrow beam (± 5 degrees) sensor, that just looks along the airplane’s projected longitudinal axis or ground track, could be missed. However, with the alert boundary extended to 0.25 nautical miles either side of the airplane projected longitudinal axis, adequate warning will be given. An event approaching along the outer edge of the display, due to a 25-degree drift angle, should generate a warning alert 10 seconds prior to the encounter with the

airplane flying at 200 KTAS.
The 25-degree drift angle specification was established by determining the demonstrated crosswind values for a number of current large transport airplanes from their airplane flight manuals. Thirty knots at 50 feet AGL represented a reasonable consensus, with none higher than 31 knots. This value was extrapolated to 1200 feet AGL using the standard correction method of the height ratio to the one-seventh power. The 47.2-knot crosswind at 1200 feet AGL will produce a 23.2 drift angle for a 120 KTAS approach speed. The 25-degree requirement will provide margin to allow some variation in actual conditions.
The windshear event has been located at the threshold to give the longest possible time from the system alerts enabling altitude (1200 feet AGL minimum) to evaluate the detection and displays.
Since this evaluation is only to assess the system's ability to detect windshears with the worst-case drift angle, it is sensible that only a limited number of windfield models need to be evaluated. Data Sets 4 and 5 were selected as they have small diameter outflows, and being on the edge of the system's scan, they will stress the system's ability to detect, display, and issue timely alerts.
Since for a given value of crosswind low airspeed will give a higher drift angle than high airspeed, only the 120 KTAS case has been picked for evaluation.

17. Justification for Go-Around Flight Scenario:
This scenario is to evaluate the system mode transition from approach to go-around. Alerting ranges, logic changes, system gains and biases, antenna scan elevation, etc., are possible effects that need to be evaluated. The leading edge of the hazard is located 1.8 nm from the go-around point as this provides a reasonably low altitude encounter which could be hazardous.
Data Sets 2 and 5 were selected because of their benign appearance (5 especially being dry) and the pilot may mistakenly assume they are safe to penetrate.

18. General Meteorological Description for DFW Microburst, Data Set 1:
The 2 August 1985, Dallas – Fort Worth (DFW) microburst was a high-reflectivity microburst that resulted in the crash of a commercial jetliner. This event is simulated with the 2-D axisymmetric Terminal Area Simulation System (TASS) model by assuming an environmental sounding interpolated from observed data. The simulated microburst is associated with high reflectivity due to rain and hail, moderate rainfall rates, pronounced temperature drop, and hazardous wind shear with strong outflow winds. The data set is taken near the time of peak intensity, at 11 minutes simulation time. Although the numerical simulation is 2-D, there is reasonable comparison with observed data taken from aircraft flight data recorders.

19. General Meteorological Description for Orlando Microburst, Data Set 2:
The 20 June 1991, Orlando microburst, was encountered by a NASA aircraft instrumented with in-situ and forward-look windshear sensors. It was also measured within the Terminal Doppler Weather Radar (TDWR) test bed. The parent storm and ensuing microbursts are simulated with 3-D TASS. Comparisons of the simulation with observed data indicate a reasonable agreement. The simulation, as verified from measurements, indicates a high-reflectivity microburst with hazardous shear and heavy rainfall rates. Although the area covered by the outflow is roughly symmetrical, complex regions of windshear hazard are embedded within the outflow. The data set is taken at a simulation time of 37 minutes, when the microburst is near peak intensity. This time corresponds to observed measurements at approximately 2046 Universal Coordinated Time (UTC). The microburst contains multiple downdraft cores and regions of up-flow embedded within the outflow. The strongest hazard is located near the southern end of the outflow and has a peak FBAR of about 0.19. An approach from the north would encounter intervening rain, as well as pockets of both performance increase and decrease, before entering the area of primary hazard. The outflow near ground level is associated with a pronounced temperature change, with the maximum drop being about 6º C.

20. General Meteorological Description for Denver Multiple Microburst Event, Data Set 3:
The 11 July 1988, Denver, storm is simulated by initializing 3-D TASS with the 2000 UTC observed special sounding. This storm is of special interest, since it produced a severe low- to moderate-

reflectivity microburst of unusual intensity that was inadvertently encountered by four commercial jetliners trying to land at Denver Stapleton. An in-depth study of this incident, including comparisons with TDWR, surface measurements, and flight data recorder (from the four aircraft) data was done. Very good agreement with observed measurements was obtained. Model results show that multiple microbursts (with FBAR of up to 0.2) formed downstream of the main precipitation shaft, which itself was characterized by a weak microburst. The microbursts (all produced by one storm) grow and interact, eventually coalescing into a large macroburst outflow. Some of the microbursts display large asymmetry. The most eastern of these microbursts is the one that was encountered by the four aircraft. Data sets are given at two simulation times: 49 and 51 min. The first is near the time of initial ground contact for the downstream eastern microburst. Several minutes later, it grows into a hazardous microburst, which is captured in the second data set. At 51 minutes, the eastern microburst is near peak intensity. It is near this time that the first two encounters take place. Low-level outflow from this microburst has peak ΔV (velocity change) of up to 40 m/s. The western-most microburst, which is associated with the storm's primary rain shaft, remains weak although associated with moderate values of radar reflectivity. Temperature drops in the microburst outflows are only a few degrees C.

21. General Meteorological Description for Denver Warm Microburst, Data Set 4:
Data for this case is from a 2-D axisymmetric simulation of a narrow, low reflectivity, microburst occurring in an environment characterized by a low-level stable layer. This simulation does not attempt to model a particular observed event, but uses an input sounding (14 July 1982) measured during the Joint Airport Weather Studies (JAWS). The temperature profile from the sounding has been modified for an isothermal temperature profile between the ground and 500 m, resulting in a ground-based stable layer. Relative to the size and intensity of other microbursts, this event contains a strong narrow-core downdraft, shallow outflow, and very large FBAR. However, the region occupied by the hazardous shear is small in horizontal scale compared to most other events. This simulated microburst also is characterized by warm outflow (positive temperature change from ambient). The time-freeze used for this case is when the microburst is in a quasi-steady state, at 36 minutes, some 13 minutes after peak intensity. Similar microbursts that were characterized by downward-protruding, stalactite-appearing radar echoes were observed during JAWS. Numerous warm microbursts were measured by ground-based instruments during JAWS.

22. General Meteorological Description for Denver Dry Microburst, Data Set 5:
On 8 July 1989, a very strong microburst was detected by LLWAS, within the approach corridor just north of Denver Stapleton Airport. The microburst was encountered by a Boeing 737-200 in a "go around" configuration and was reported to have lost considerable air speed and altitude during penetration. LLWAS data revealed a pulsating microburst with peak strength associated with the first pulse. Interviews indicated that the microburst was accompanied by no apparent visible clues such as rain or virga, although blowing dust was reported. A National Center for Atmospheric Research (NCAR) research Doppler radar was operating, although poorly sited for low-level wind shear detection at Stapleton. Meaningful velocity could not be measured at the lowest radar scan due to very low reflectivity factor. This case attracts special interest since it may represent a dangerous microburst that is difficult to detect with Doppler radar. The life cycle of the microburst-producing storm is simulated with the 3-D version of TASS. Environmental conditions are taken from a sounding observed near the time and location of the event. Results from the numerical simulation show a low-reflectivity microburst with three distinguishable pulses. Data sets are generated from the simulation at two times: (1) at 40 minutes, which is near peak intensity; and (2) 5 minutes later, which is near the time of the second microburst pulse. The first and strongest pulse (at 40 minutes) is associated with a peak velocity differential (ΔV) of 37 m/s and a peak horizontal wind speed of 26 m/s. At this time, radar reflectivity in most of the microburst outflow is less than -5 dBZ, and reflectivity exceeding 10 dBZ is confined to a 1-2 km diameter area within the core of the microburst. By the time of the second pulse (45 minutes), there is even less precipitation at low levels, yet hazardous levels of wind shear are maintained. The outflow from the first pulse has expanded into a macroburst and grown more asymmetric with time. The microburst associated with the second pulse

is embedded within this larger scale outflow. The temperature changes between the environment and outflow remain small at all times, never more than 2.5º C.

23. General Meteorological Description for Highly-Asymmetric Florida Microburst, Data Set 6:
A translating microburst with highly asymmetric outflow is simulated with the 3-D model, by allowing an isolated precipitation shaft to fall through a prescribed ambient wind with vertical shear. The same ambient temperature and humidity profile from Data Set 2 is used in this simulation. The model simulation produces a wet microburst, with a bow-shaped radar-reflectivity pattern. Strong horizontal winds are generated along the leading edge of the translating outflow. The microburst contains high values of radar reflectivity, large rainfall rates, and a pronounced temperature drop. The data set chosen for certification testing is at 14 minutes, within the period of decaying intensity. Hazardous windshear exists, but is located in a very small region. The diameter of the hazardous shear is about 1 km with a peak FBAR of about 0.16. Other regions of performance decreasing F-factor exist within the asymmetric outflow, but generally contain weak values. Movement of the microburst is to the east at 17.5 m/s.

24. General Meteorological Description for Montana Gust Front, Data Set 7:
Thunderstorm gust fronts are characterized by a region of performance-increasing shear and turbulence, but usually pose little hazard due to performance-decreasing shear. Surges and secondary discontinuities within the outflow behind gust fronts have been observed, and may be associated with hazardous windshear. The case described below is selected because it has both a strong gust front (with performance-increasing shear) and a "discontinuity" in the outflow associated with hazardous windshear. A gust front is simulated with 3-D TASS using the 2 August 1981, Knowlton special sounding with modified winds. [Modification: The observed ambient winds are rotated 270º (a wind blowing toward the south is now blowing toward the east) and the now north-south component is set to zero. This is done to allow the simulation of a gust front within a high-resolution rectangular domain.] For this case, the model assumes periodic north/south boundaries, and a gust front is generated from a north-south oriented line of precipitation. At the simulation time chosen for this data set, the gust front is well developed and is translating toward the east at about 21 m/s. The gust front is characterized by strong performance-increasing shear (negative F-factor), pronounced temperature change, very-low radar reflectivity, and upward motion. A region of hazardous windshear is located within the outflow some distance behind the gust front. It is associated with a horizontal roll-vortex that is located at the edge of the precipitation shaft.

APPENDIX B PLOTS FOR FORWARD-LOOKING WINDSHEAR DATA SETS

This appendix has been drawn from the technical report by [Switzer, et.al. 1993] [W-6].

B.1 Input Sounding Plotted on Skew T-log p Diagrams

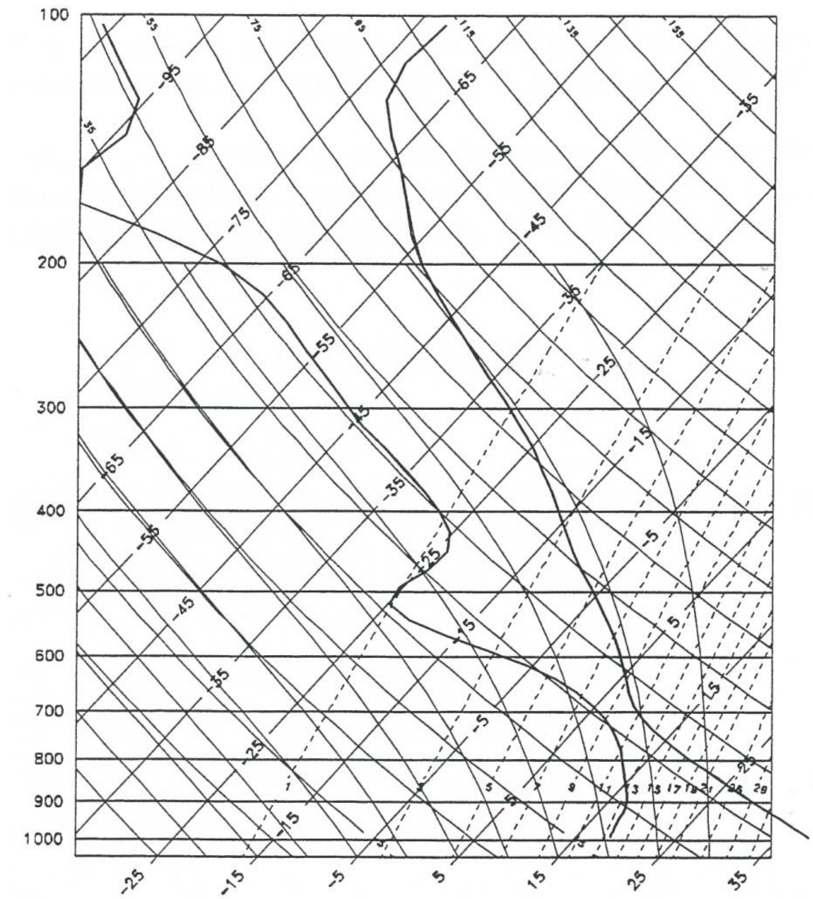

Figure B-1: Skew-T Diagram of Atmospheric Sounding for Data Set #1

Sounding interpolated from data observed at Dallas, Ft. Worth, 3 August 1985, 0000 UTC.

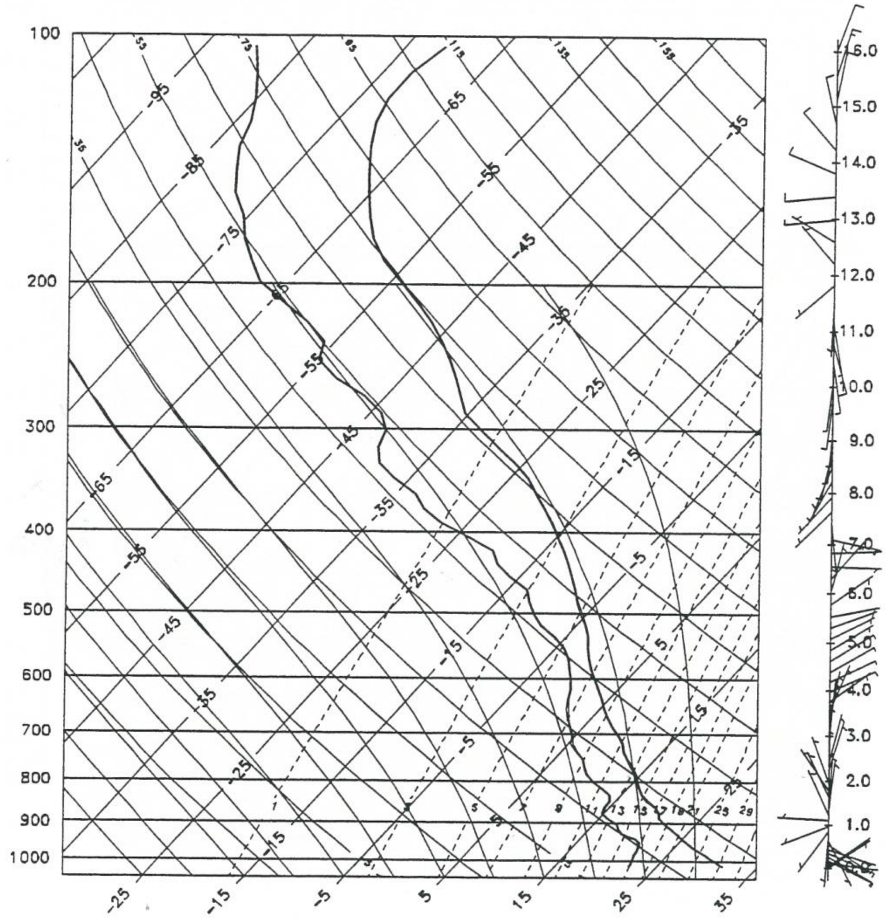

Figure B-2: Skew-T Diagram of Atmospheric Sounding for Data Set #2

Modified from special sounding observed at Orlando, Florida based, 20 June 1991, 2035 UTC. Wind barbs are pointed along the compass direction of the wind. Each full wind barb equals 5 m/s (10 knots).

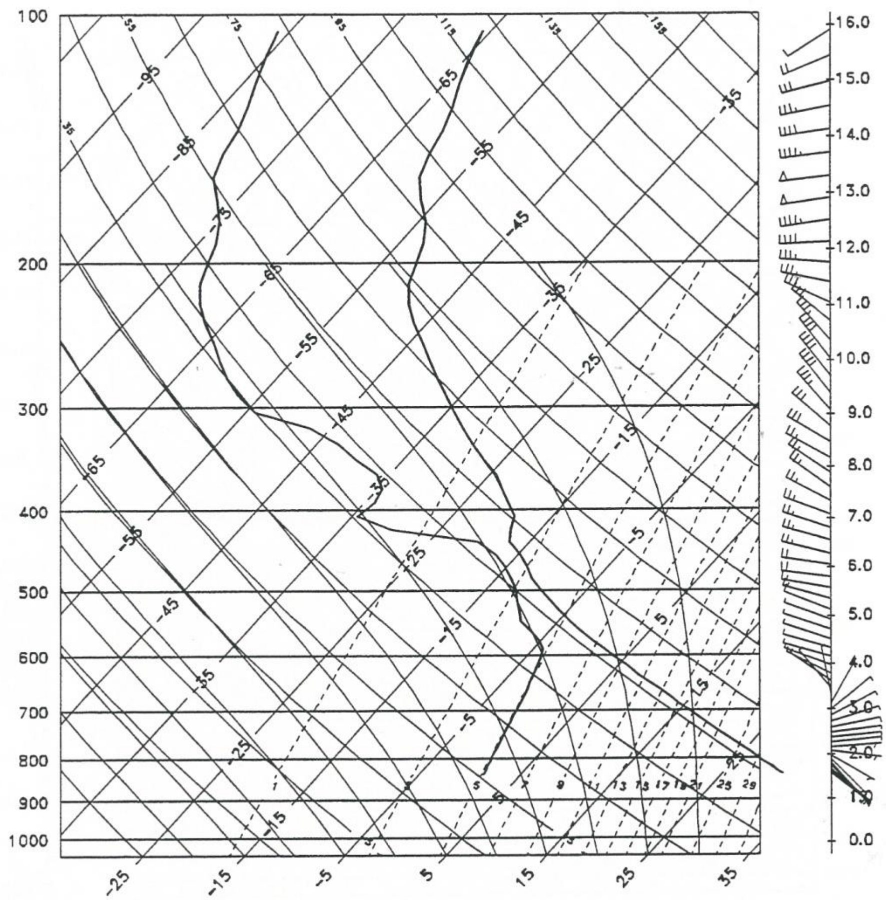

Figure B-3: Skew-T Diagram of Atmospheric Sounding for Data Set #3

Special sounding observed at Denver, Colorado, 11 July 1988, 2000 UTC, modified for latest surface observations.

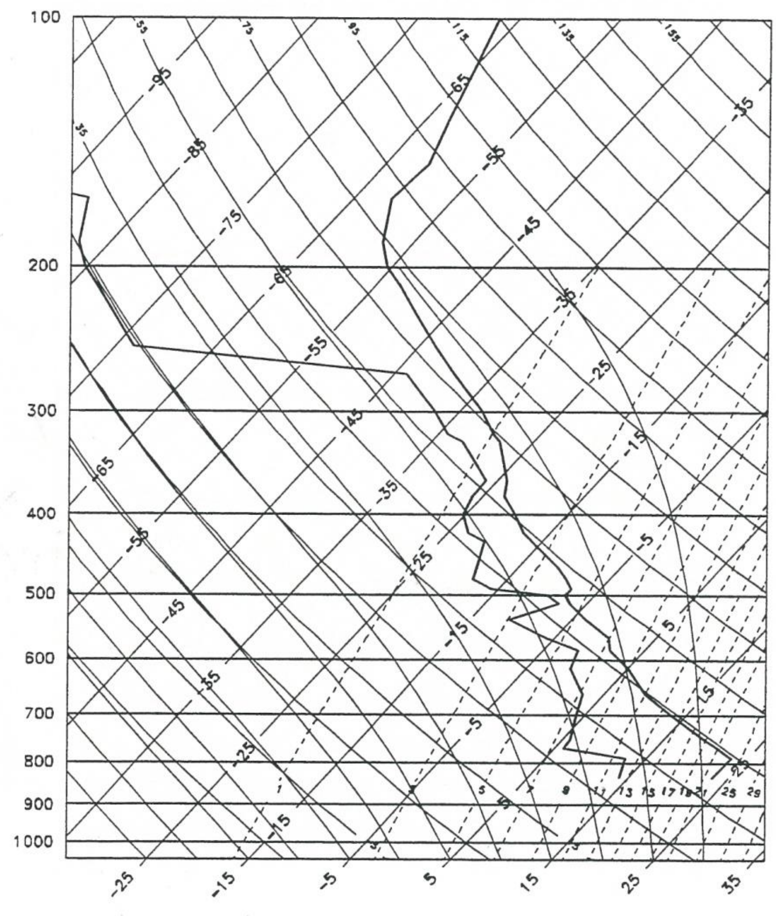

Figure B-4: Skew-T Diagram of Atmospheric Sounding for Data Set #4

From observed sounding at Denver, Colorado, 14 July 1982, 2000 UTC, but modified for a 500 m deep surface-base isothermal layer.

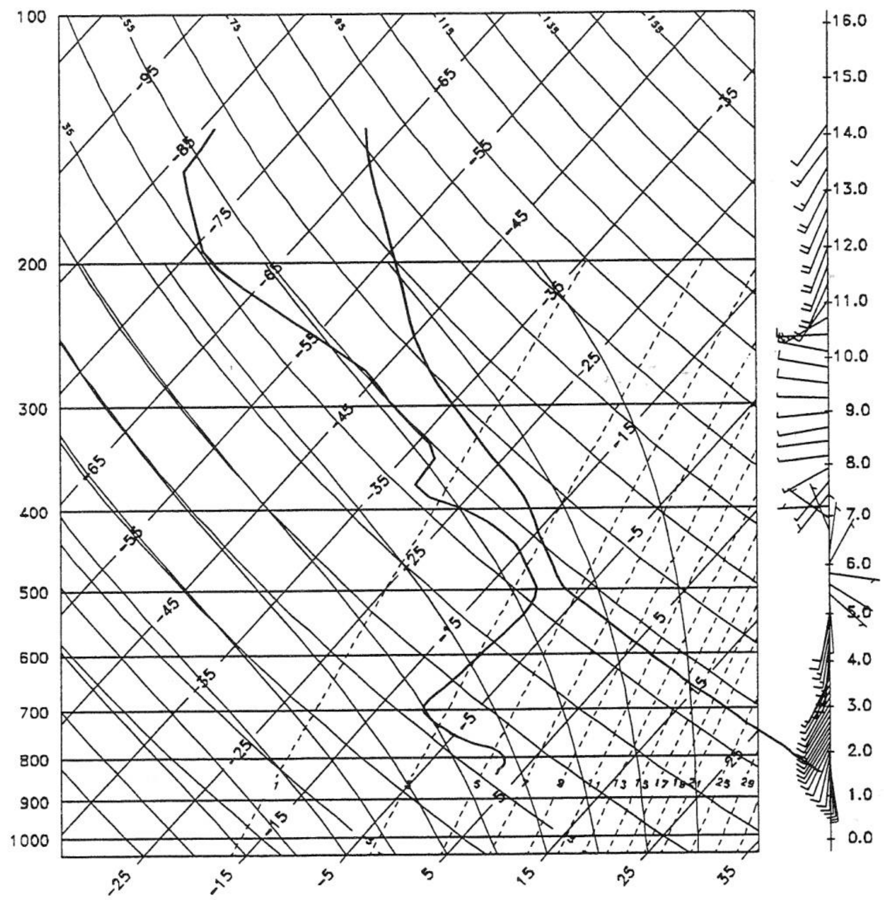

Figure B-5: Skew-T Diagram of Atmospheric Sounding for Data Set #5

Sounding observed at Denver, Colorado, 9 July 1989, 0000 UTC.

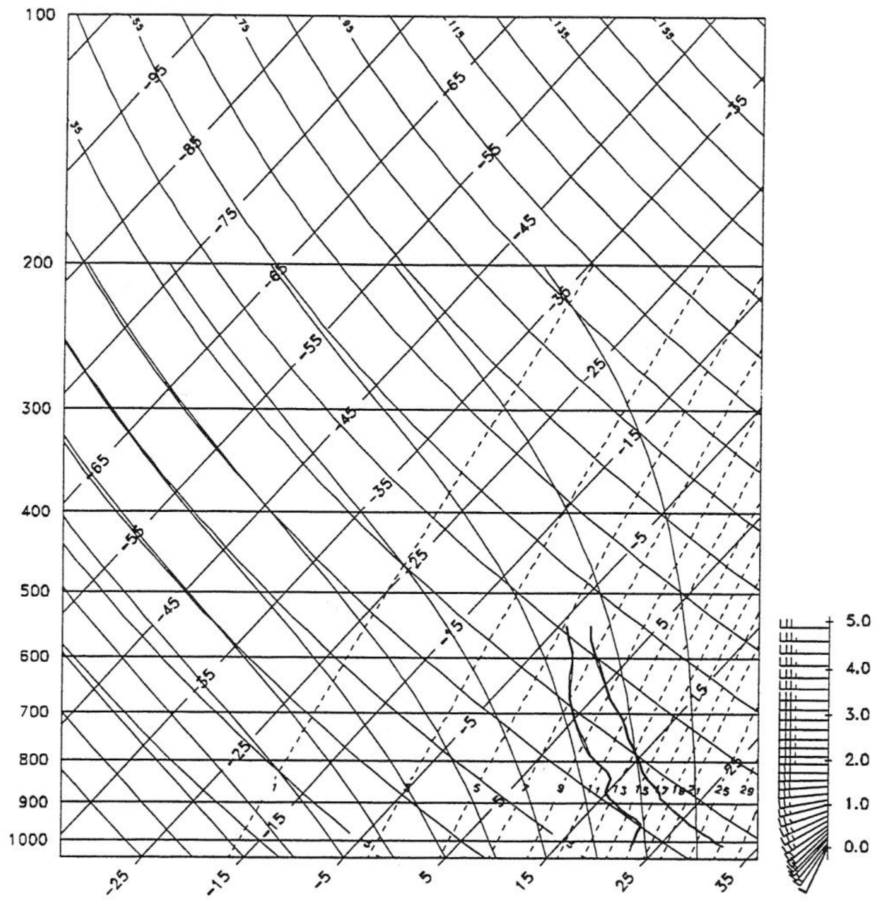

Figure B-6: Skew-T Diagram of Atmospheric Sounding for Data Set #6

Same sounding as Data Set #2, but with observed winds replaced by hypothetical winds. Environmental winds modified in order to create asymmetric microburst in Data Set #6.

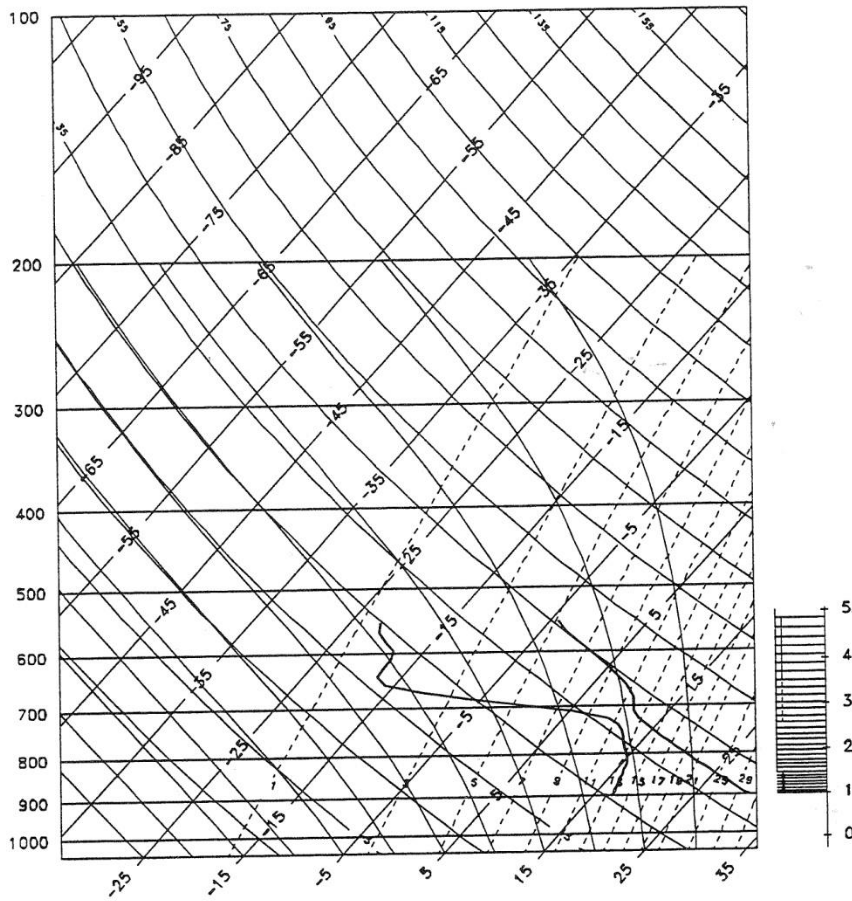

Figure B-7: Skew-T Diagram of Atmospheric Sounding for Data Set #7

Modified from special sounding observed at Knowlton, Montana, 3 August 1981, 0000 UTC. Only the northern component of the observed ambient wind is used and is shifted 90°.

B.2 North-South and East-West FBAR Contour Plots

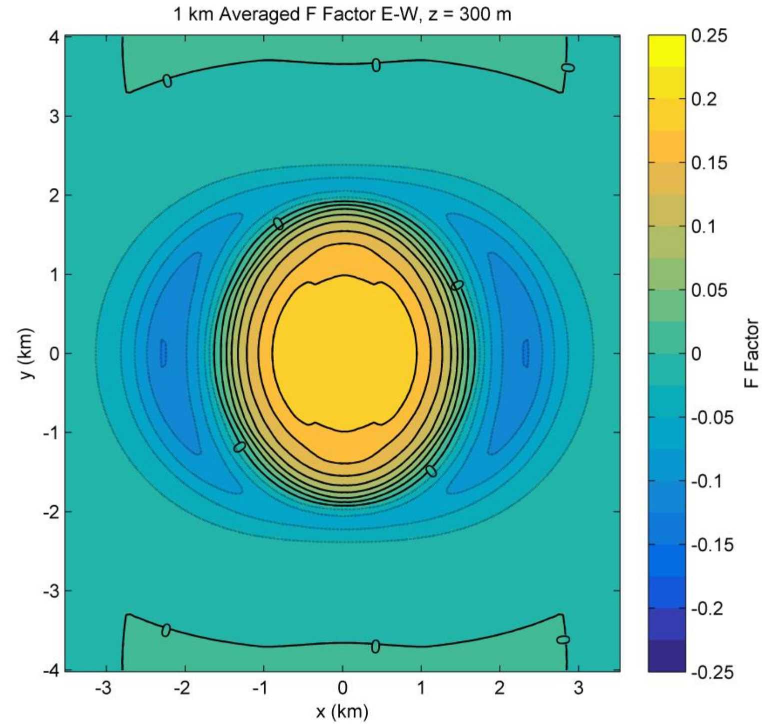

Figure B-8: Data Set/Time #111: East-West FBAR at 300 Meters Elevation

Data Set/Time #111: DFW Accident Case, Wet Microburst, East-West FBAR at 300 meters elevation. The contour interval is 0.025. Maximum value of about 0.20.

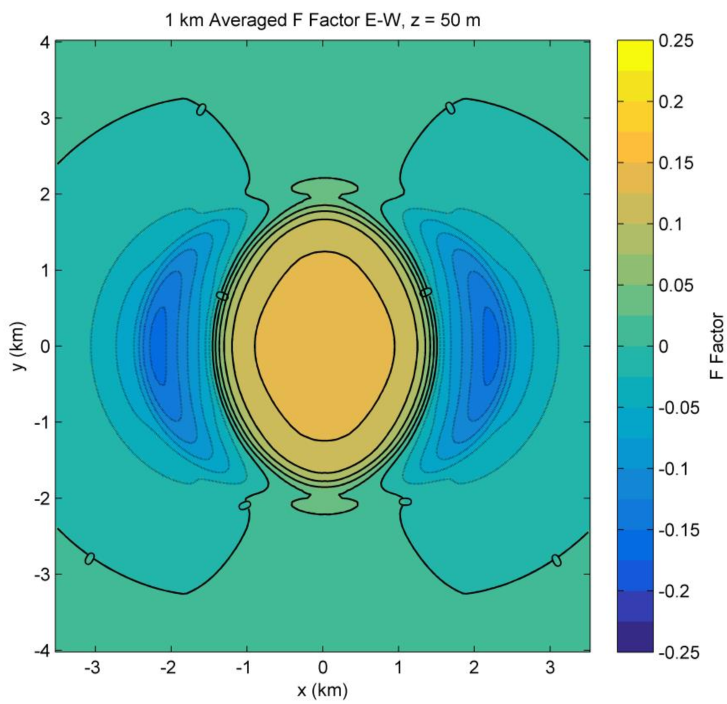

Figure B-9: Data Set/Time #111: East-West FBAR at 50 Meters Elevation

Data Set/Time #111: DFW Accident Case, Wet Microburst, East-West FBAR at 50 meters elevation. The contour interval is 0.025. Maximum value of about 0.15.

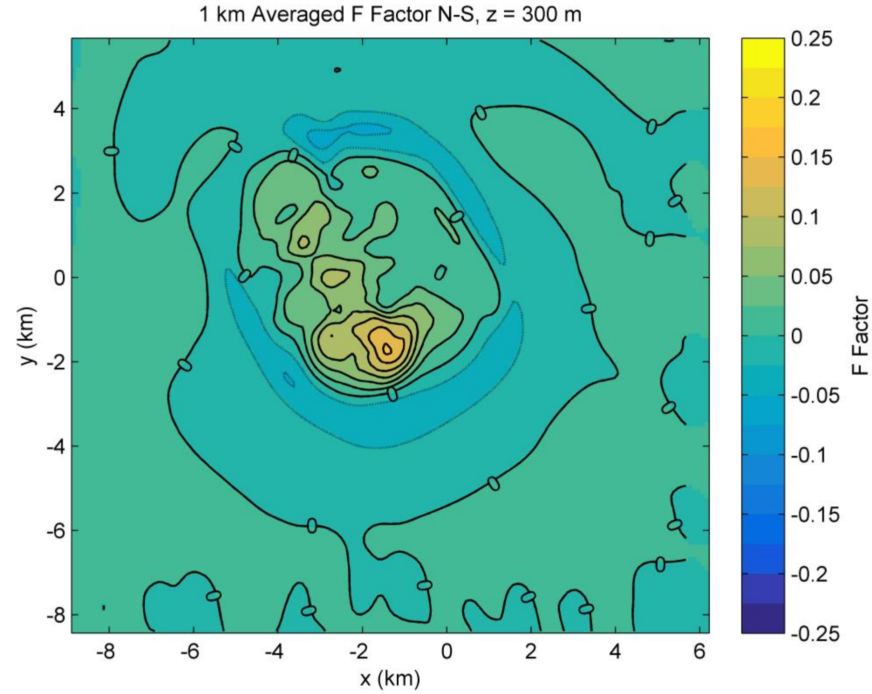

Figure B-10: Data Set/Time #237: North-South FBAR at 300 Meters Elevation

Data Set/Time #237: 06/20/91 Orlando NASA Event #143, North-South FBAR at 300 meters elevation. The contour interval is 0.025. Maximum value of about 0.17.

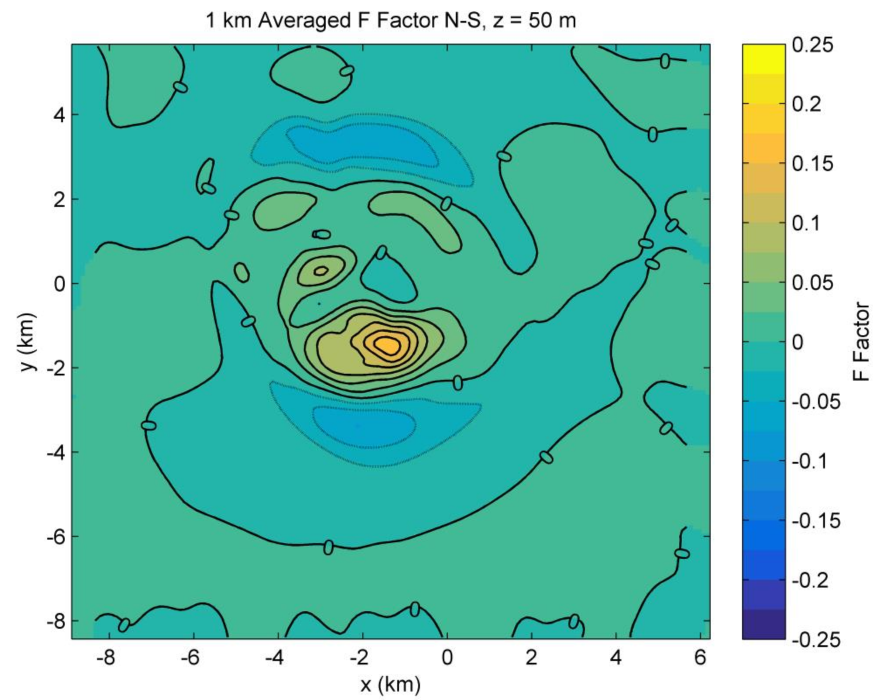

Figure B-11: Data Set/Time #237: North-South FBAR at 50 Meters Elevation

Data Set/Time #237: 06/20/91 Orlando NASA Event #143, North-South FBAR at 50 meters elevation. The contour interval is 0.025. Maximum value of about 0.17.

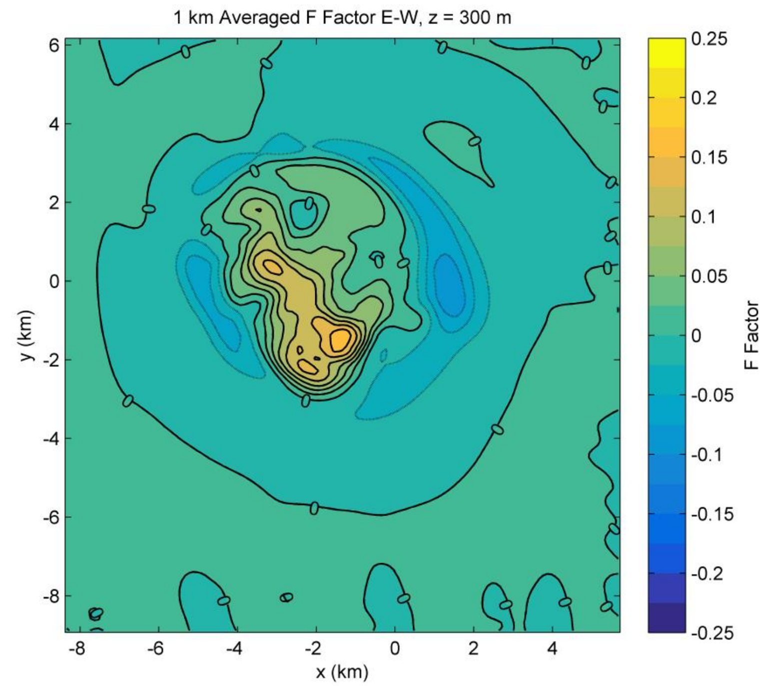

Figure B-12: Data Set/Time #237: East-West FBAR at 300 Meters Elevation

Data Set/Time #237: 06/20/91 Orlando NASA Event #143, East-West FBAR at 300 meters elevation. The contour interval is 0.025. Maximum value of about 0.18.

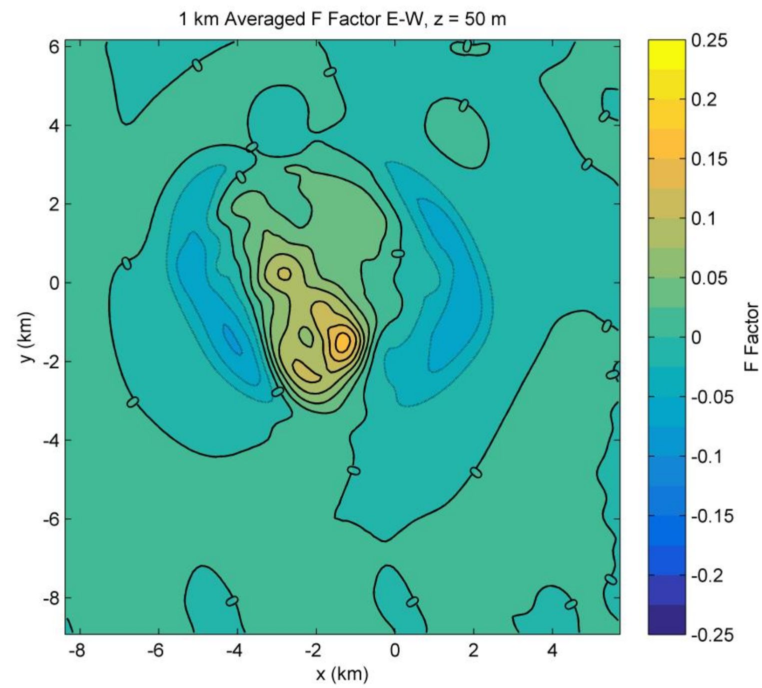

Figure B-13: Data Set/Time #237: East-West FBAR at 50 Meters Elevation

Data Set/Time #237: 06/20/91 Orlando NASA Event #143, East-West FBAR at 50 meters elevation. The contour interval is 0.025. Maximum value of about 0.17.

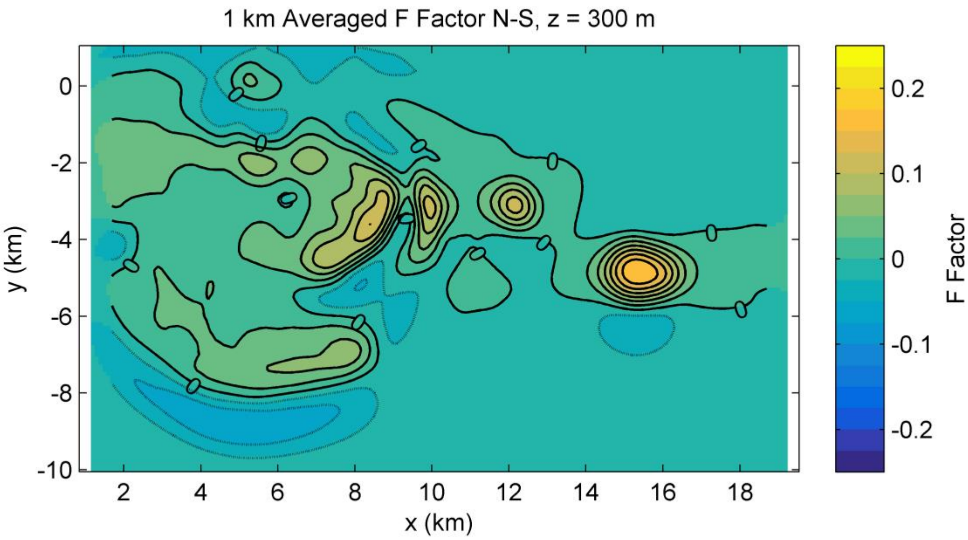

Figure B-14: Data Set/Time #349: North-South FBAR at 300 Meters Elevation

Data Set/Time #349: 07/11/88 Denver, Multiple Microburst, North-South FBAR at 300 meters elevation. The contour interval is 0.025. Maximum value of about 0.19.

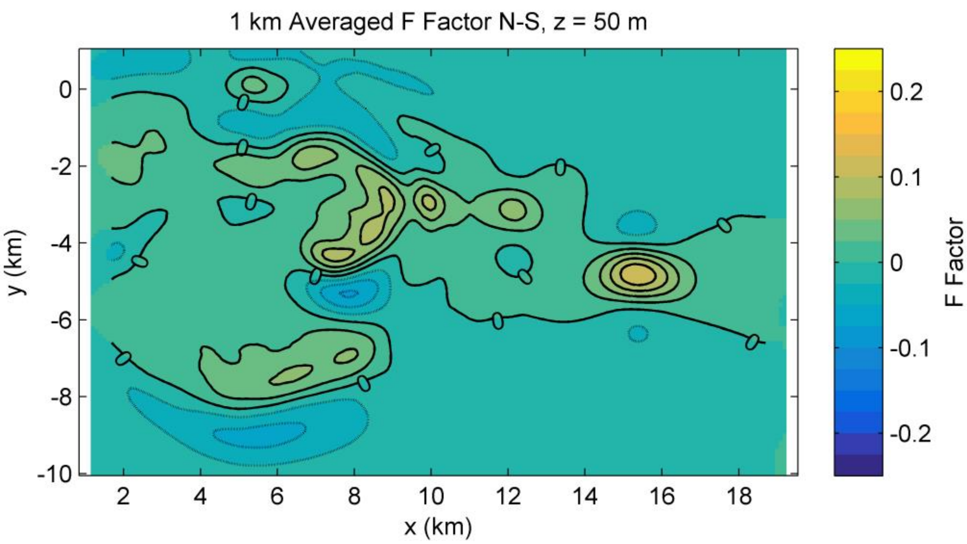

Figure B-15: Data Set/Time #349: North-South FBAR at 50 Meters Elevation

Data Set/Time #349: 07/11/88 Denver, Multiple Microburst, North-South FBAR at 50 meters elevation. The contour interval is 0.025. Maximum value of about 0.13.

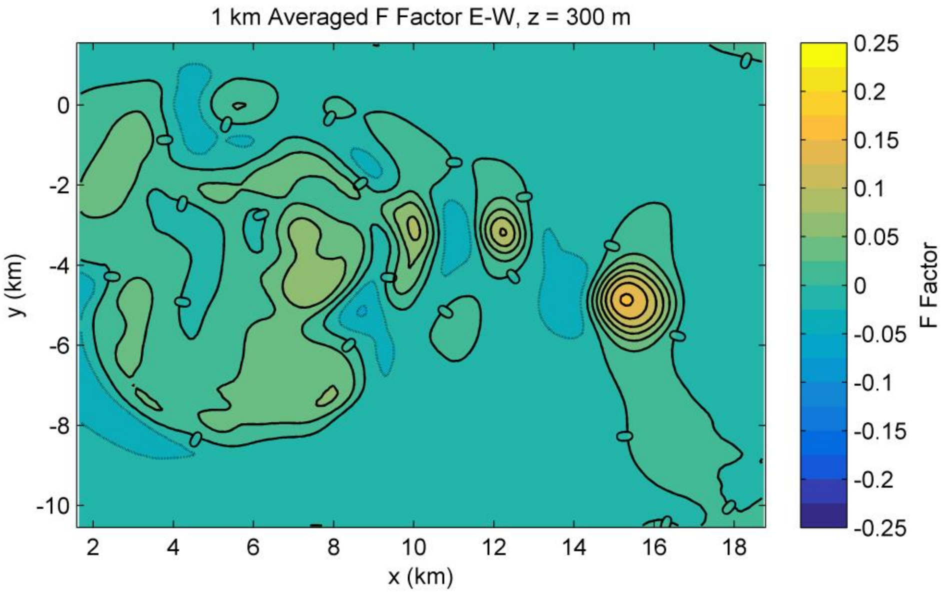

Figure B-16: Data Set/Time #349: East-West FBAR at 300 Meters Elevation

Data Set/Time #349: 07/11/88 Denver, Multiple Microburst, East-West FBAR at 300 meters elevation. The contour interval is 0.025. Maximum value of about 0.17.

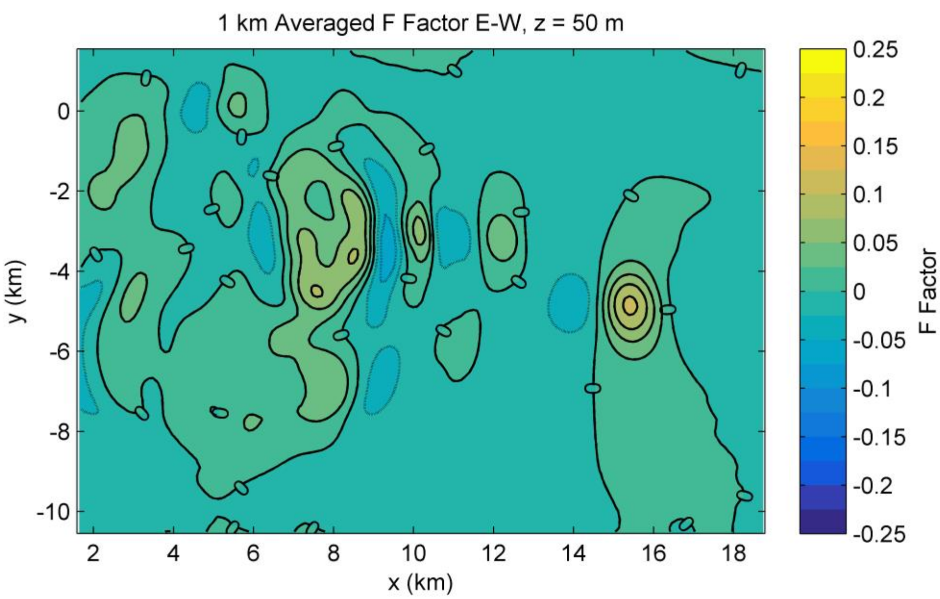

Figure B-17: Data Set/Time #349: East-West FBAR at 50 Meters Elevation

Data Set/Time #349: 07/11/88 Denver, Multiple Microburst, East-West FBAR at 50 meters elevation. The contour interval is 0.025. Maximum value of about 0.11.

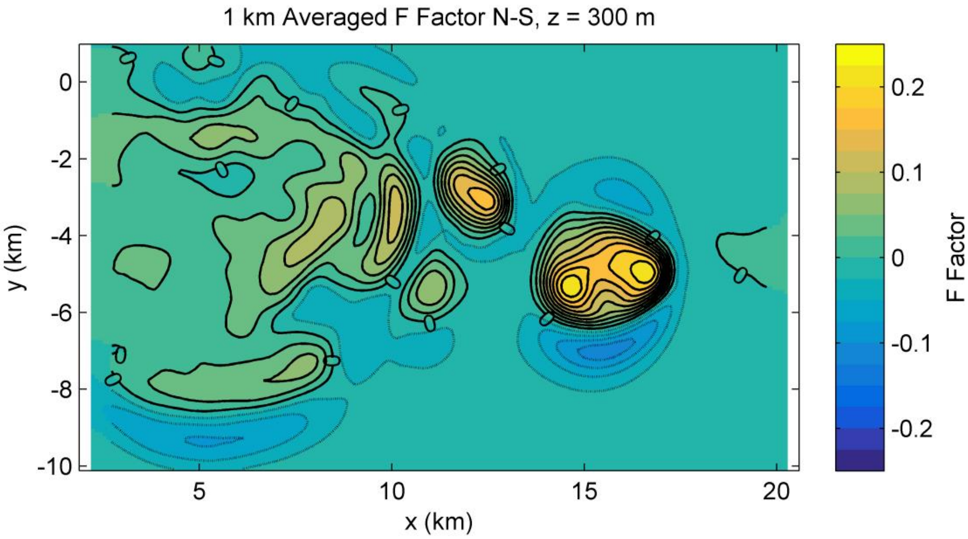

Figure B-18: Data Set/Time #351: North-South FBAR at 300 Meters Elevation

Data Set/Time #351: 07/11/88 Denver, Multiple Microburst, North-South FBAR at 300 meters elevation. The contour interval is 0.025. Maximum value of about 0.24.

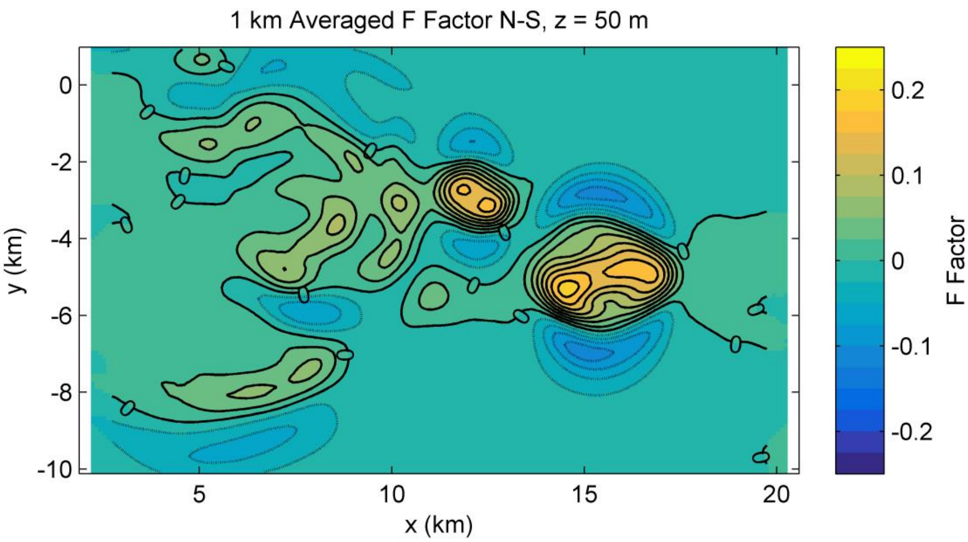

Figure B-19: Data Set/Time #351: North-South FBAR at 50 Meters Elevation

Data Set/Time #351: 07/11/88 Denver, Multiple Microburst, North-South FBAR at 50 meters elevation. The contour interval is 0.025. Maximum value of about 0.20.

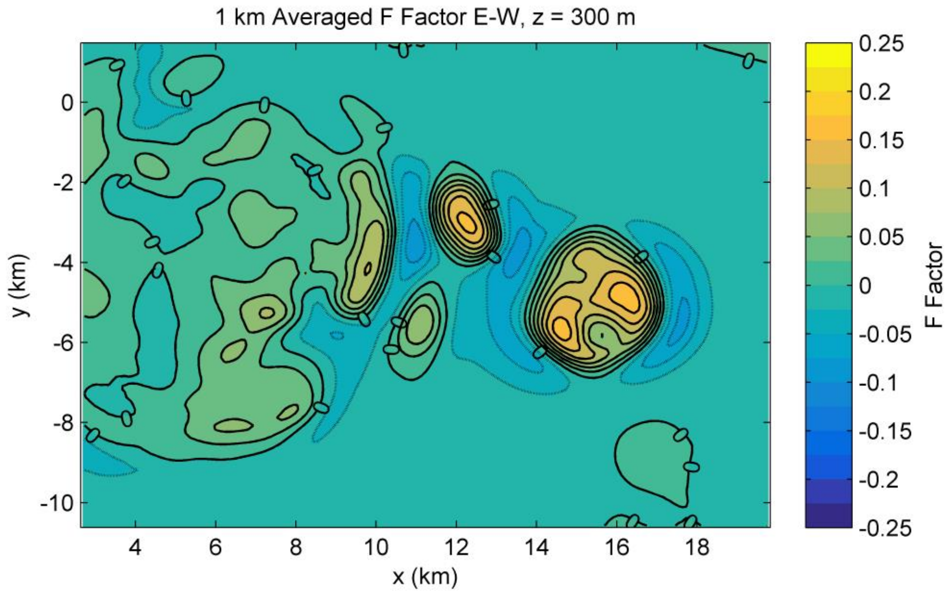

Figure B-20: Data Set/Time #351: East-West FBAR at 300 Meters Elevation

Data Set/Time #351: 07/11/88 Denver, Multiple Microburst, East-West FBAR at 300 meters elevation. The contour interval is 0.025. Maximum value of about 0.18.

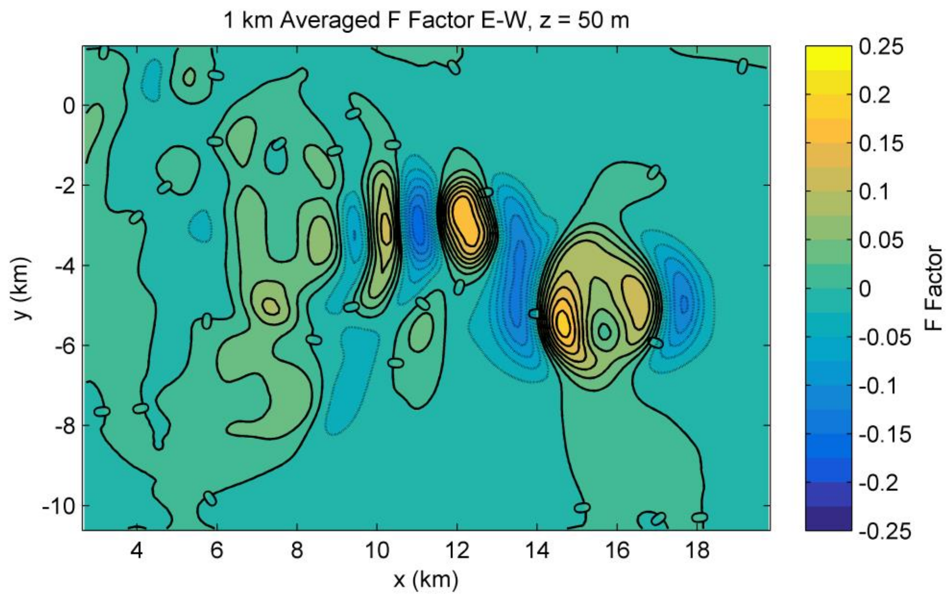

Figure B-21: Data Set/Time #351: East-West FBAR at 50 Meters Elevation

Data Set/Time #351: 07/11/88 Denver, Multiple Microburst, East-West FBAR at 50 meters elevation. The contour interval is 0.025. Maximum value of about 0.20.

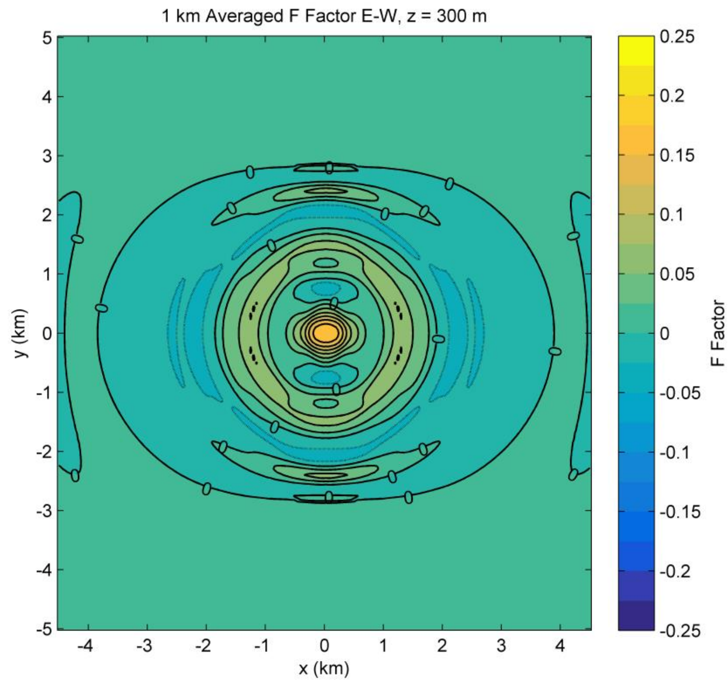

Figure B-22: Data Set/Time #436: East-West FBAR at 300 Meters Elevation

Data Set/Time #436: 07/14/82 Denver, Temperature Inversion, East-West FBAR at 300 meters elevation. The contour interval is 0.025. Maximum value of about 0.18.

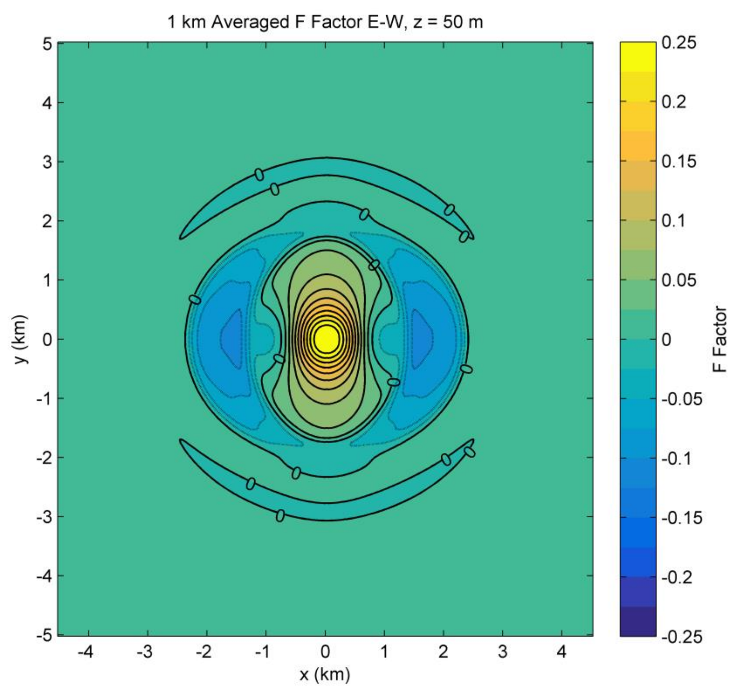

Figure B-23: Data Set/Time #436: East-West FBAR at 50 Meters Elevation

Data Set/Time #436: 07/14/82 Denver, Temperature Inversion, East-West FBAR at 50 meters elevation. The contour interval is 0.025. Maximum value of about 0.29.

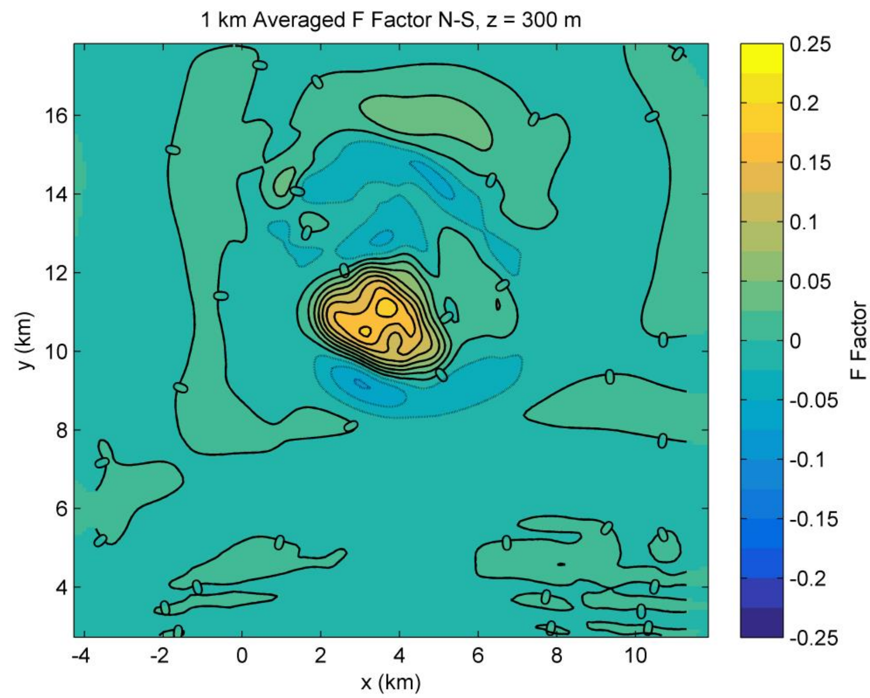

Figure B-24: Data Set/Time #540: North-South FBAR at 300 Meters Elevation

Data Set/Time #540: Very Dry Microburst NASA Derived, North-South FBAR at 300 meters elevation. The contour interval is 0.025. Maximum value of about 0.21.

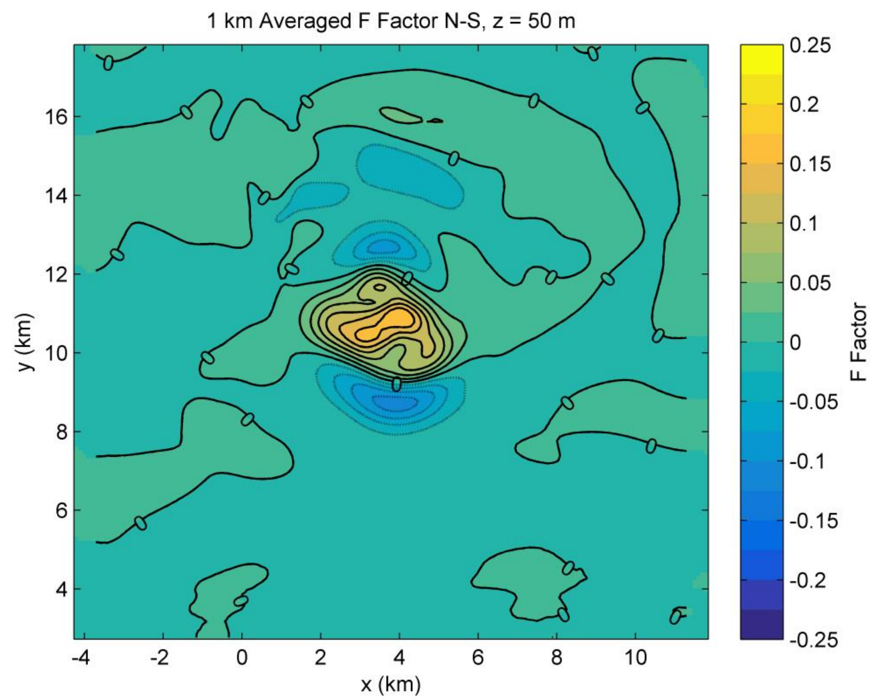

Figure B-25: Data Set/Time #540: North-South FBAR at 50 Meters Elevation

Data Set/Time #540: Very Dry Microburst NASA Derived, North-South FBAR at 50 meters elevation. The contour interval is 0.025. Maximum value of about 0.18.

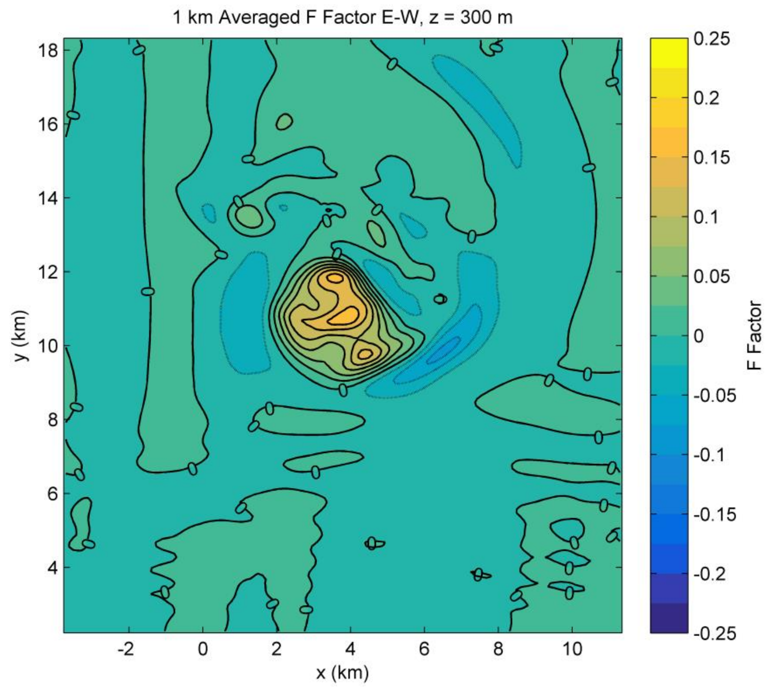

Figure B-26: Data Set/Time #540: East-West FBAR at 300 Meters Elevation

Data Set/Time #540: Very Dry Microburst NASA Derived, East-West FBAR at 300 meters elevation. The contour interval is 0.025. Maximum value of about 0.18.

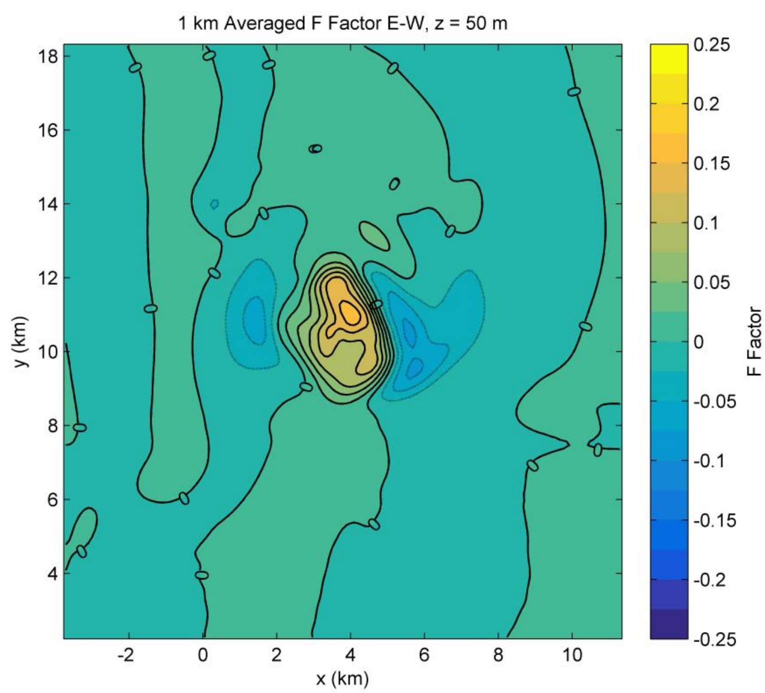

Figure B-27: Data Set/Time #540: East-West FBAR at 50 Meters Elevation

Data Set/Time #540: Very Dry Microburst NASA Derived, East-West FBAR at 50 meters elevation. The contour interval is 0.025. Maximum value of about 0.18.

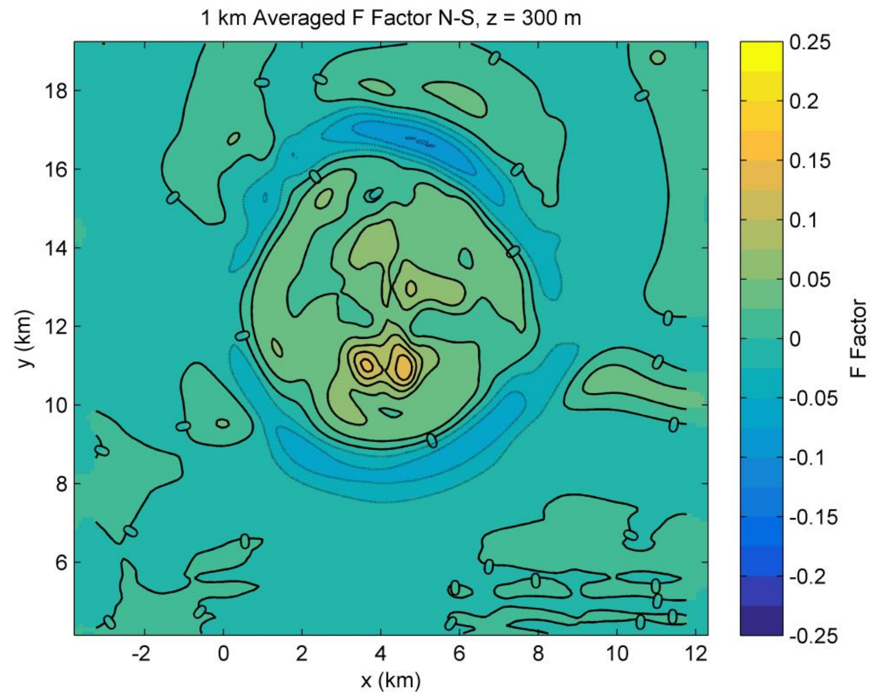

Figure B-28: Data Set/Time #545: North-South FBAR at 300 Meters Elevation

Data Set/Time #545: Extremely Dry Microburst NASA Derived, North-South FBAR at 300 meters elevation. The contour interval is 0.025. Maximum value of about 0.16.

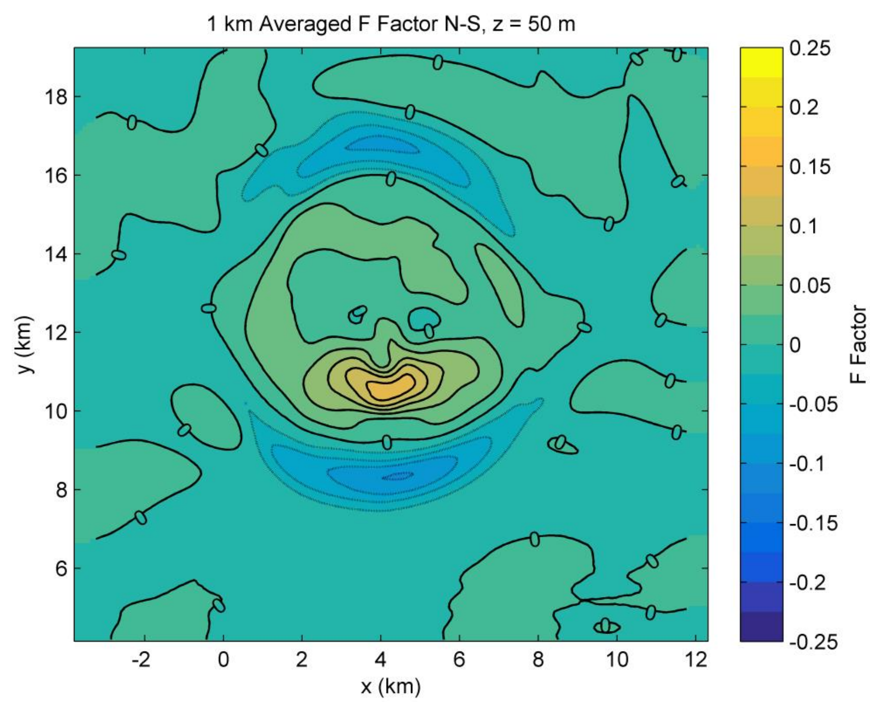

Figure B-29: Data Set/Time #545: North-South FBAR at 50 Meters Elevation

Data Set/Time #545: Extremely Dry Microburst NASA Derived, North-South FBAR at 50 meters elevation. The contour interval is 0.025. Maximum value of about 0.15.

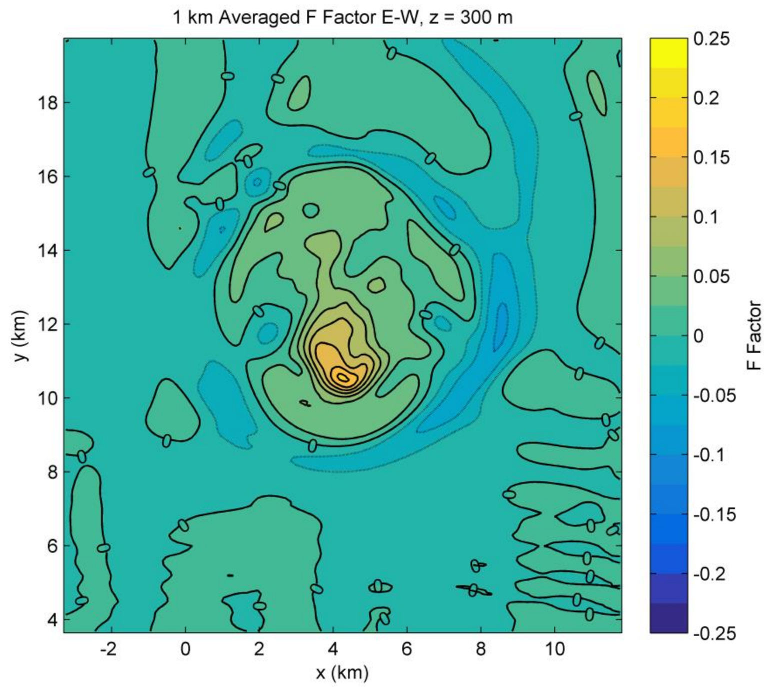

Figure B-30: Data Set/Time #545: East-West FBAR at 300 Meters Elevation

Data Set/Time #545: Extremely Dry Microburst NASA Derived, East-West FBAR at 300 meters elevation. The contour interval is 0.025. Maximum value of about 0.20.

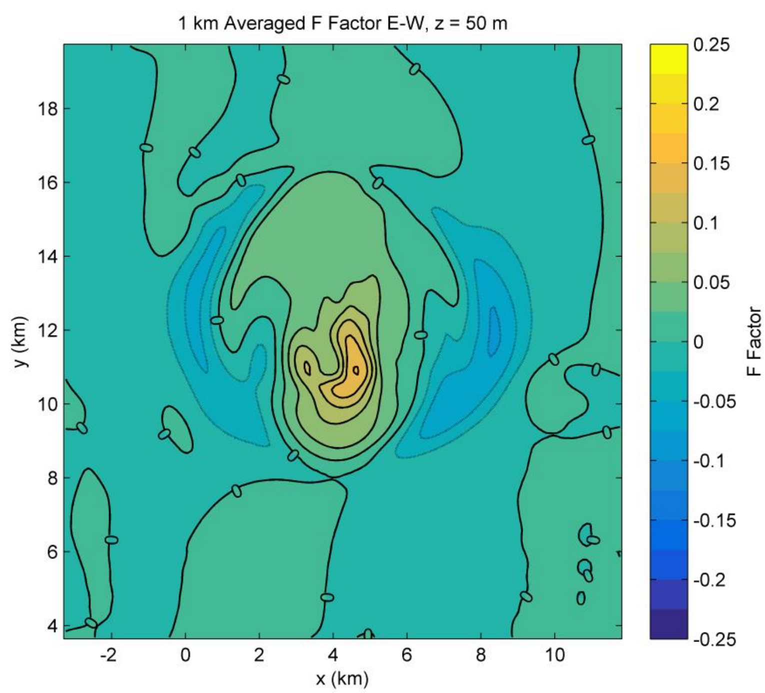

Figure B-31: Data Set/Time #545: East-West FBAR at 50 Meters Elevation

Data Set/Time #545: Extremely Dry Microburst NASA Derived, East-West FBAR at 50 meters elevation. The contour interval is 0.025. Maximum value of about 0.16.

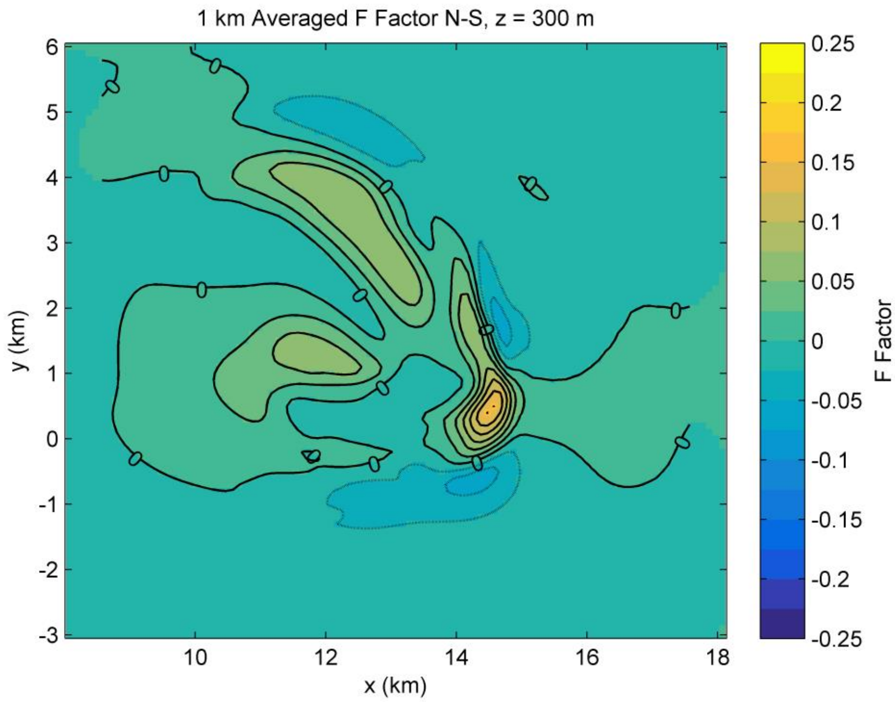

Figure B-32: Data Set/Time #614: North-South FBAR at 300 Meters Elevation

Data Set/Time #614: Highly Asymmetric Microburst, North-South FBAR at 300 meters elevation. The contour interval is 0.025. Maximum value of about 0.16.

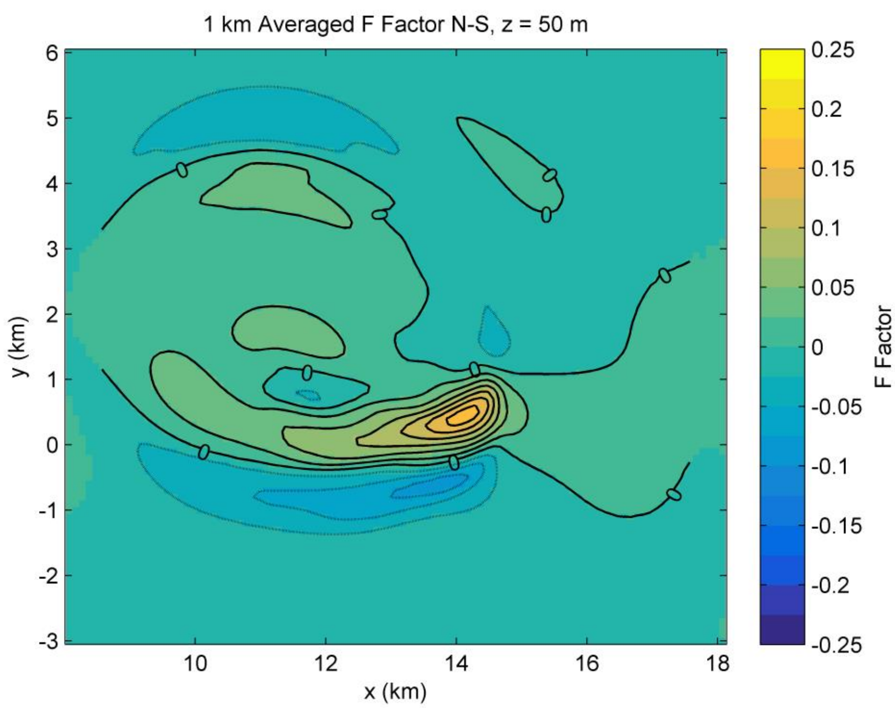

Figure B-33: Data Set/Time #614: North-South FBAR at 50 Meters Elevation

Data Set/Time #614: Highly Asymmetric Microburst, North-South FBAR at 50 meters elevation. The contour interval is 0.025. Maximum value of about 0.17.

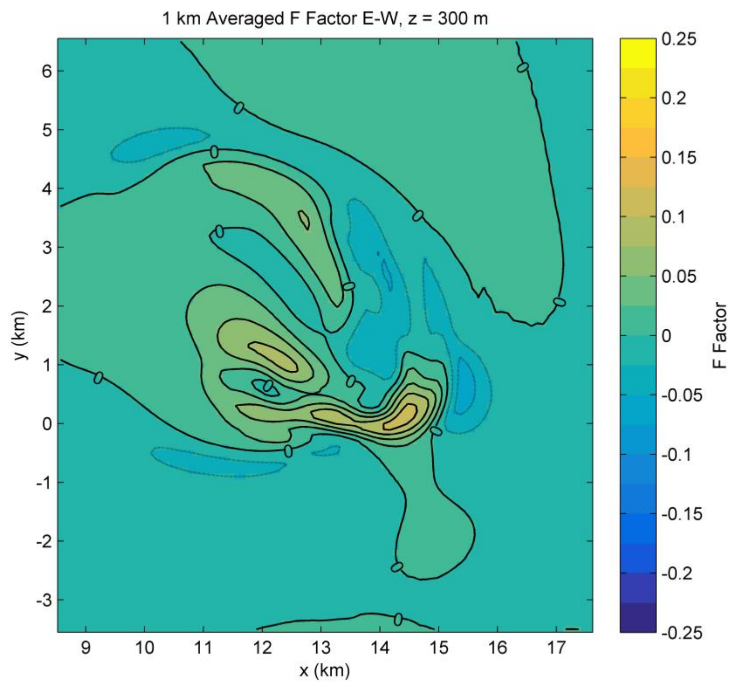

Figure B-34: Data Set/Time #614: East-West FBAR at 300 Meters Elevation

Data Set/Time #614: Highly Asymmetric Microburst, East-West FBAR at 300 meters elevation. The contour interval is 0.025. Maximum value of about 0.12.

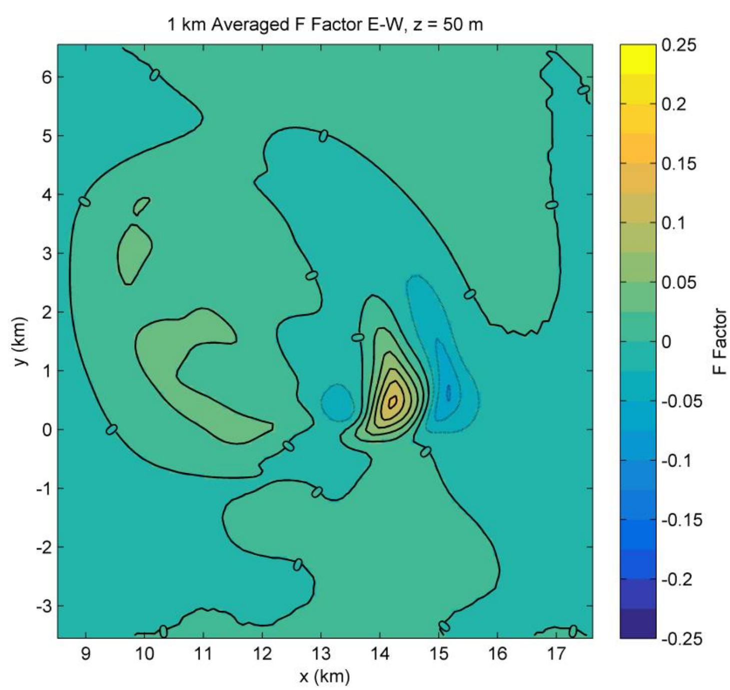

Figure B-35: Data Set/Time #614: East-West FBAR at 50 Meters Elevation

Data Set/Time #614: Highly Asymmetric Microburst, East-West FBAR at 50 meters elevation. The contour interval is 0.025. Maximum value of about 0.13.

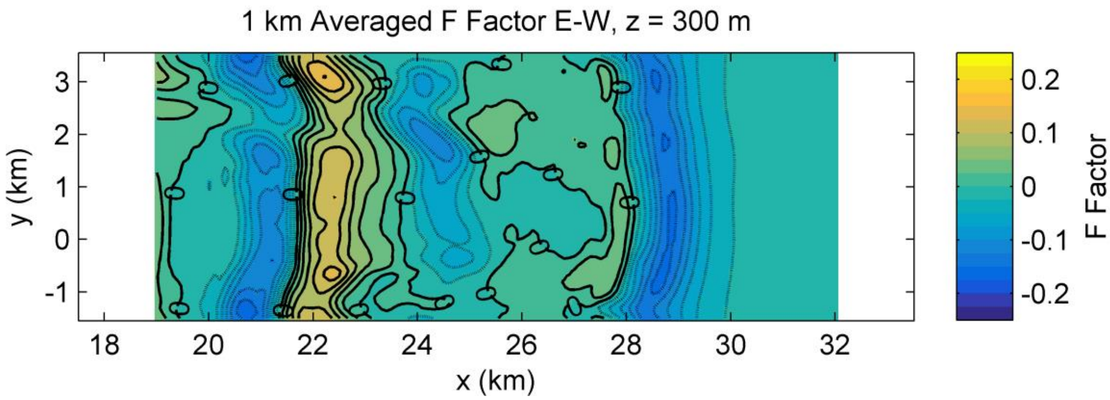

Figure B-36: Data Set/Time #727: East-West FBAR at 300 Meters Elevation

Data Set/Time #727: Gust Front, East-West FBAR at 300 meters elevation. The contour interval is 0.025. Maximum value of about 0.16.

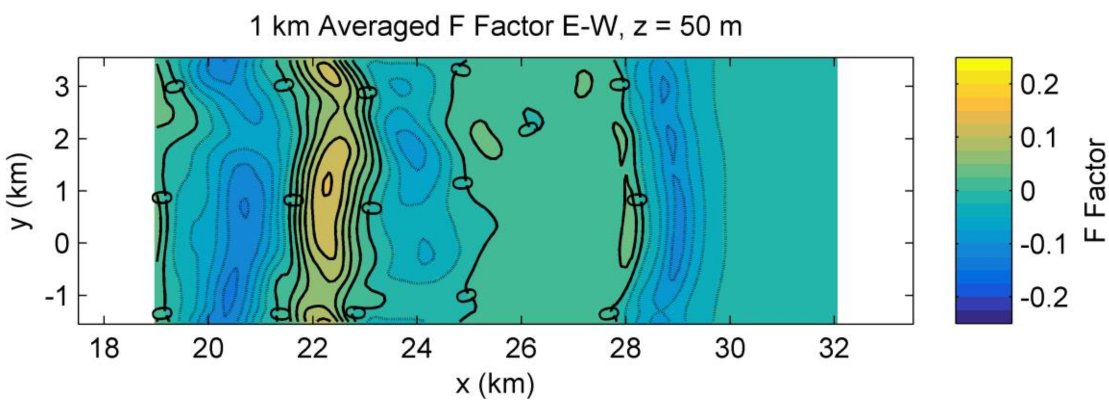

Figure B-37: Data Set/Time #727: East-West FBAR at 50 Meters Elevation

Data Set/Time #727: Gust Front, East-West FBAR at 50 meters elevation. The contour interval is 0.025. Maximum value of about 0.13.

B.3 Radar Reflectivity Contour Plots

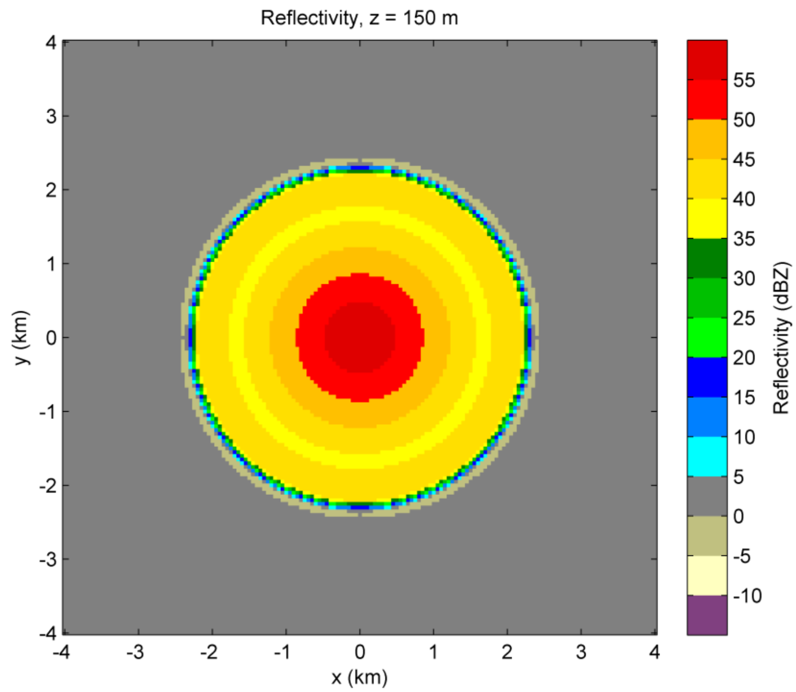

Figure B-38: Data Set/Time #111: Radar Reflectivity

Data Set/Time #111: DFW Accident Case, Wet Microburst, Radar Reflectivity (dBZ) at 150 meters elevation. Maximum value of about 56 dBZ.

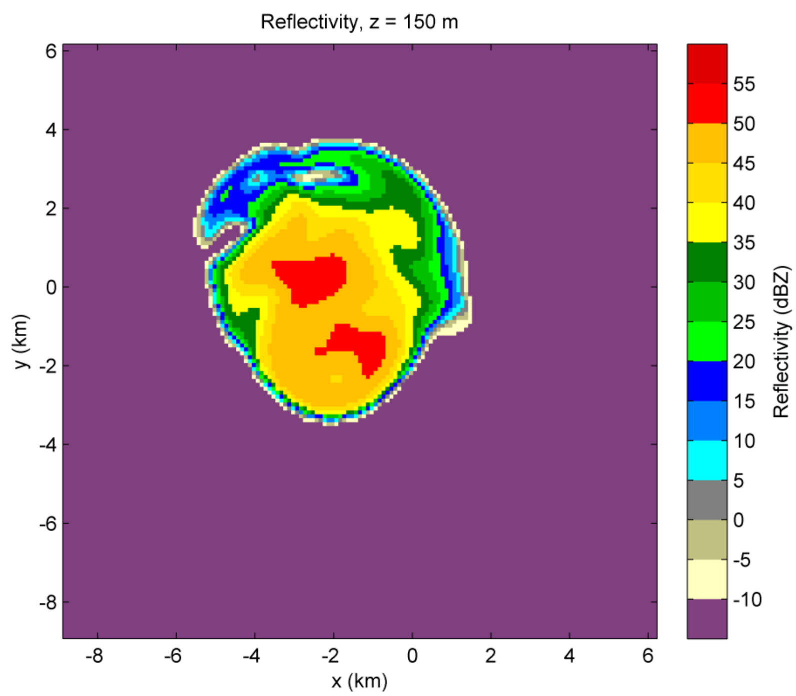

Figure B-39: Data Set/Time #237: Radar Reflectivity

Data Set/Time #237: 06/20/91 Orlando NASA Event #143, Radar Reflectivity (dBZ) at 150 meters elevation. Maximum value of about 53 dBZ.

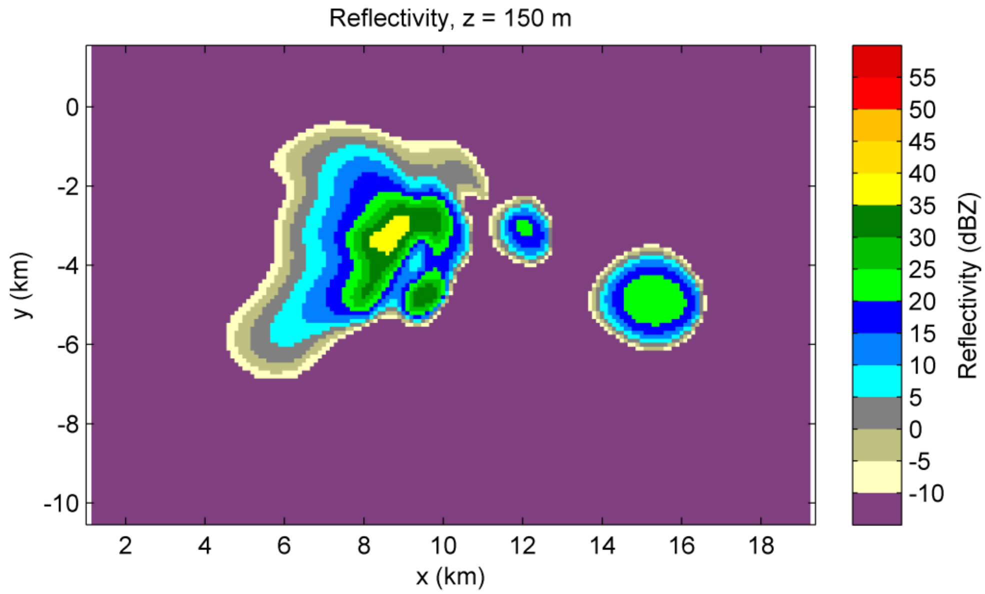

Figure B-40: Data Set/Time #349: Radar Reflectivity

Data Set/Time #349: 07/11/88 Denver, Multiple Microburst, Radar Reflectivity (dBZ) at 150 meters elevation. Maximum value of about 37 dBZ.

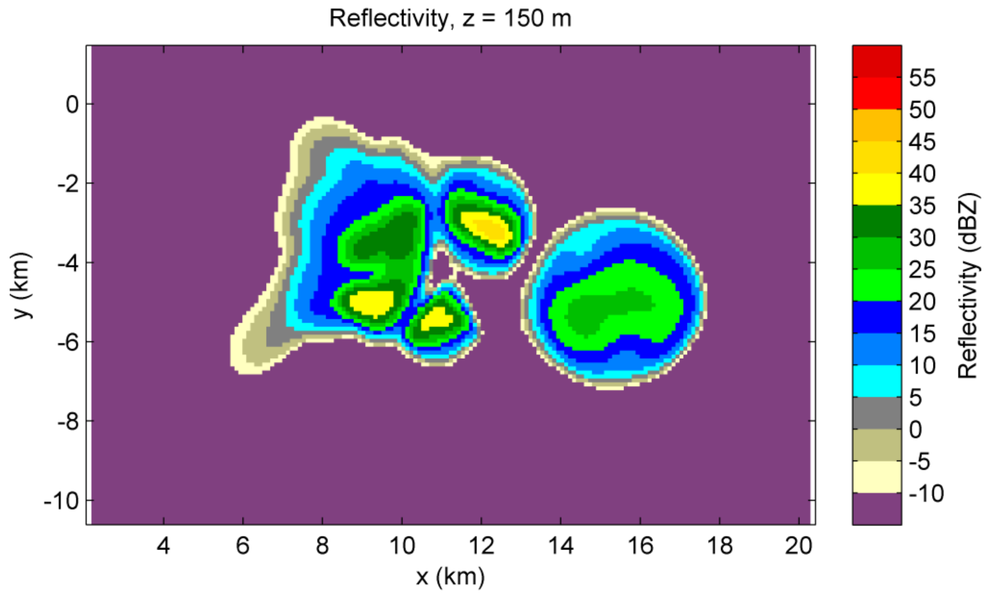

Figure B-41: Data Set/Time #351: Radar Reflectivity

Data Set/Time #351: 07/11/88 Denver, Multiple Microburst, Radar Reflectivity (dBZ) at 150 meters elevation. Maximum value of about 43 dBZ.

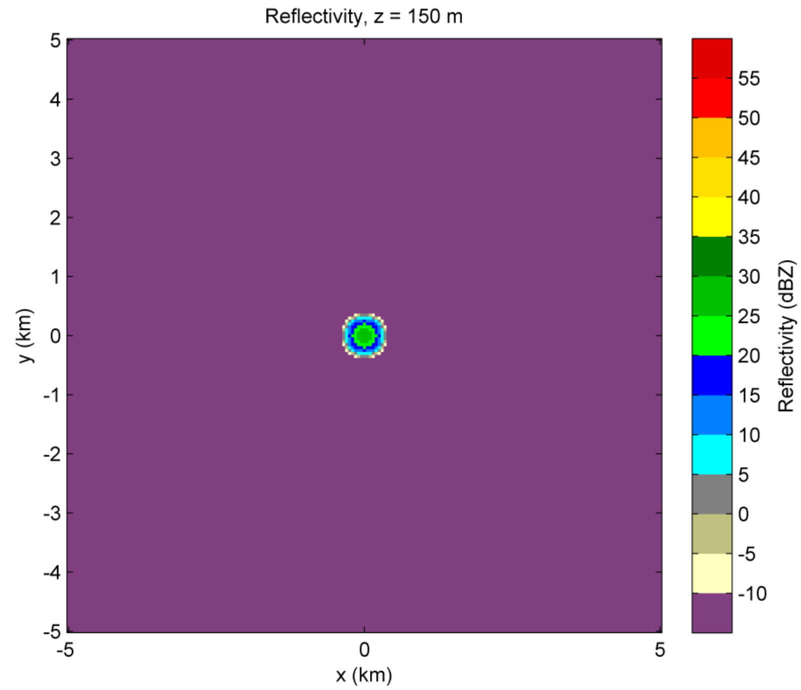

Figure B-42: Data Set/Time #436: Radar Reflectivity

Data Set/Time #436: 07/14/82 Denver, Temperature Inversion, Radar Reflectivity (dBZ) at 150 meters elevation. Maximum value of about 28 dBZ.

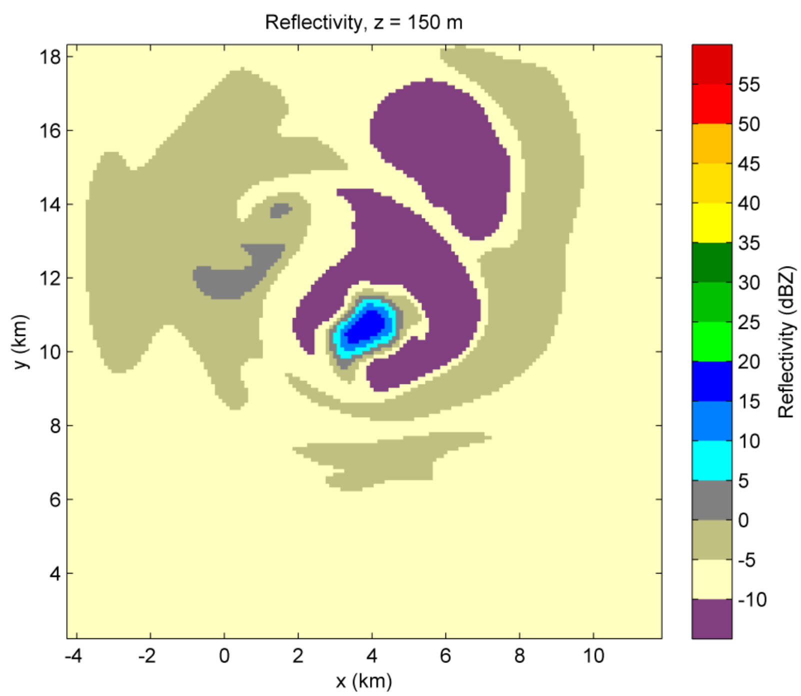

Figure B-43: Data Set/Time #540: Radar Reflectivity

Data Set/Time #540: Very Dry Microburst NASA Derived, Radar Reflectivity (dBZ) at 150 meters elevation. Maximum value of about 20 dBZ.

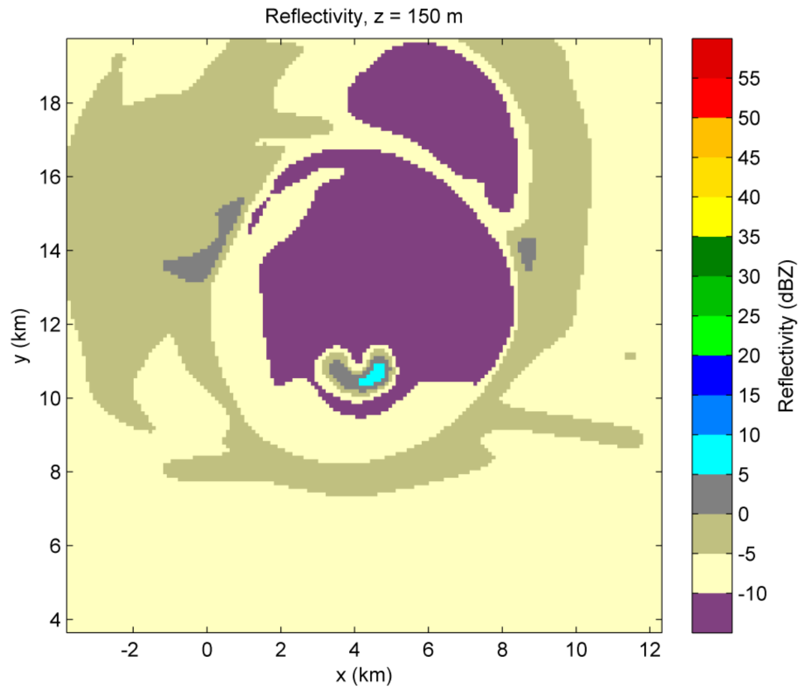

Figure B-44: Data Set/Time #545: Radar Reflectivity

Data Set/Time #545: Extremely Dry Microburst NASA Derived, Radar Reflectivity (dBZ) at 150 meters elevation. Maximum value of about 8 dBZ.

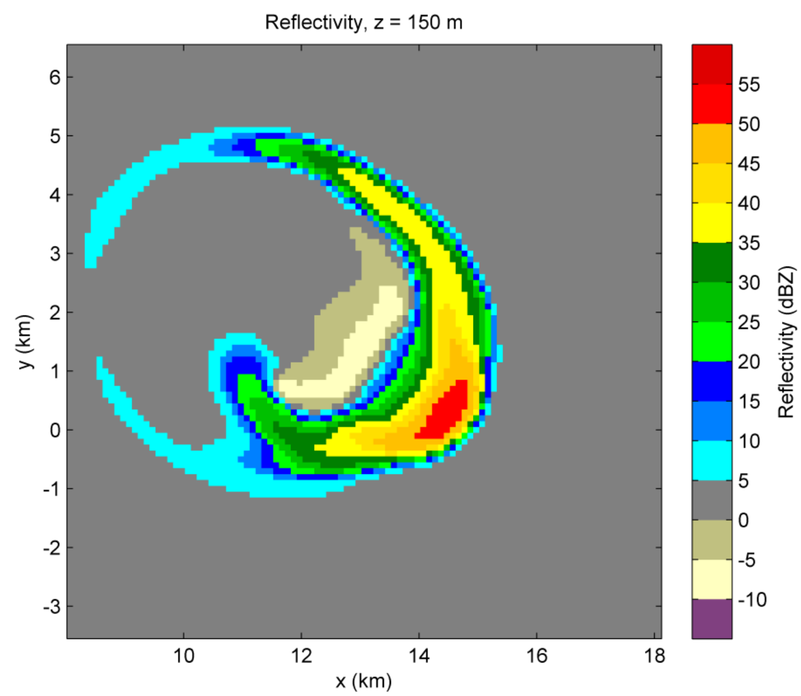

Figure B-45: Data Set/Time #614: Radar Reflectivity

Data Set/Time #614: Highly Asymmetric Microburst, Radar Reflectivity (dBZ) at 150 meters elevation. Maximum value of about 52 dBZ.

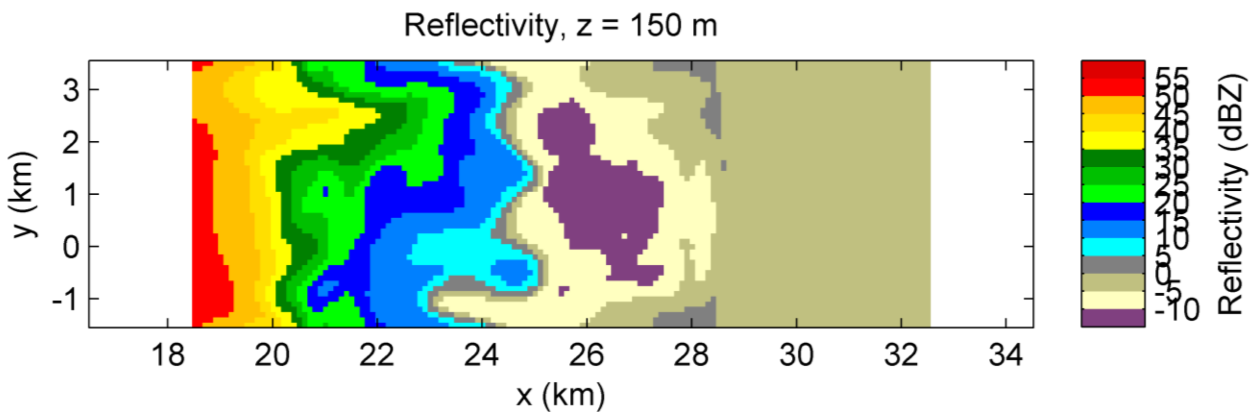

Figure B-46: Data Set/Time #727: Radar Reflectivity

Data Set/Time #727: Gust Front, Radar Reflectivity (dBZ) at 150 meters elevation. Maximum value of about 54 dBZ.

B.4 Wind Vectors

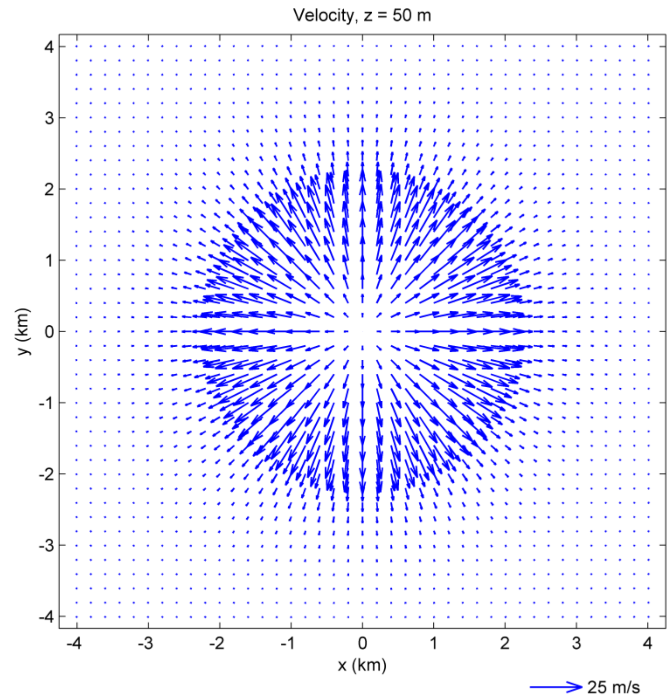

Figure B-47: Data Set/Time #111: Horizontal Wind Vectors at 50 Meters Elevation

Data Set/Time #111: DFW Accident Case, Wet Microburst, horizontal wind velocity vectors (m/s) at z = 50 m.

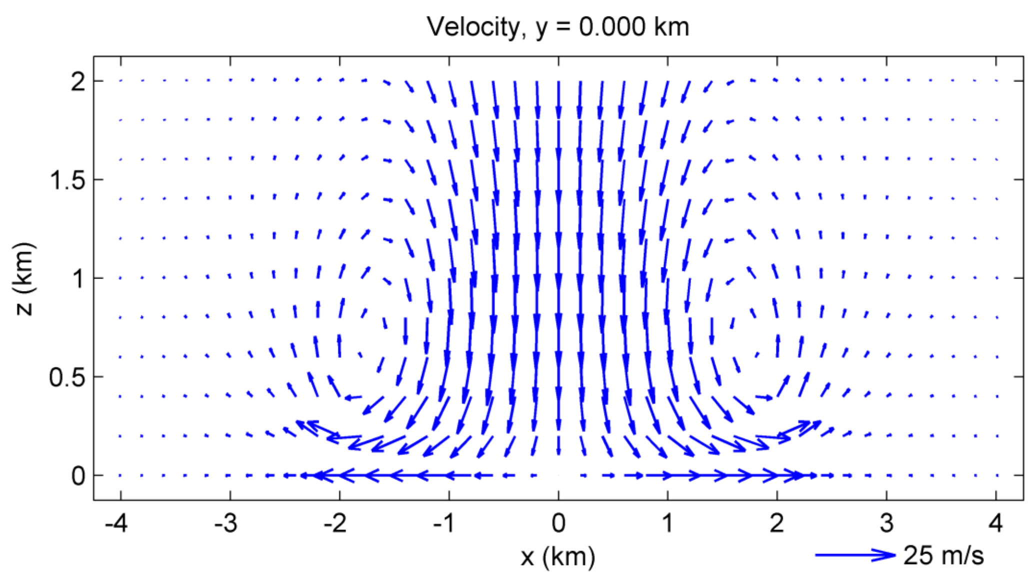

Figure B-48: Data Set/Time #111: East-West Vertical Wind Vectors at y = 0 Km

Data Set/Time #111: DFW Accident Case, Wet Microburst, East-West vertical wind velocity vectors (m/s) at y = 0 km.

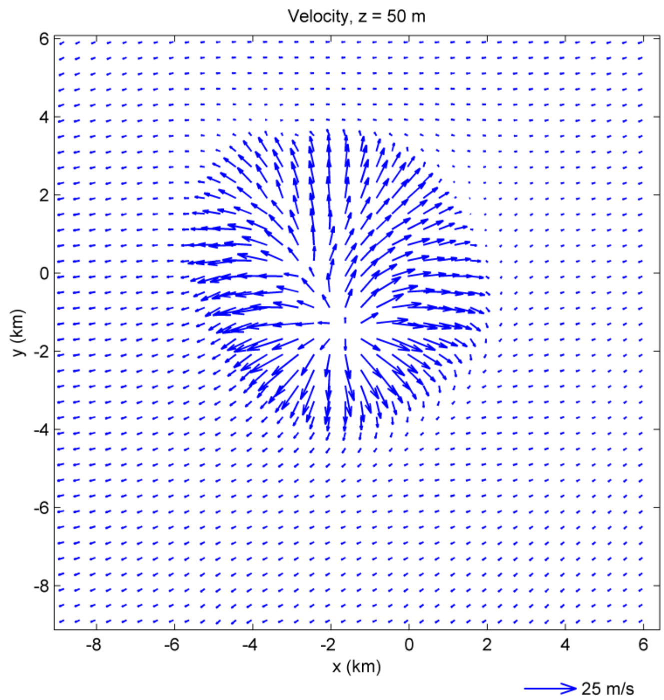

Figure B-49: Data Set/Time #237: Horizontal Wind Vectors at 50 Meters Elevation

Data Set/Time #237: 06/20/91 Orlando NASA Event #143, horizontal wind velocity vectors (m/s) at z = 50 m.

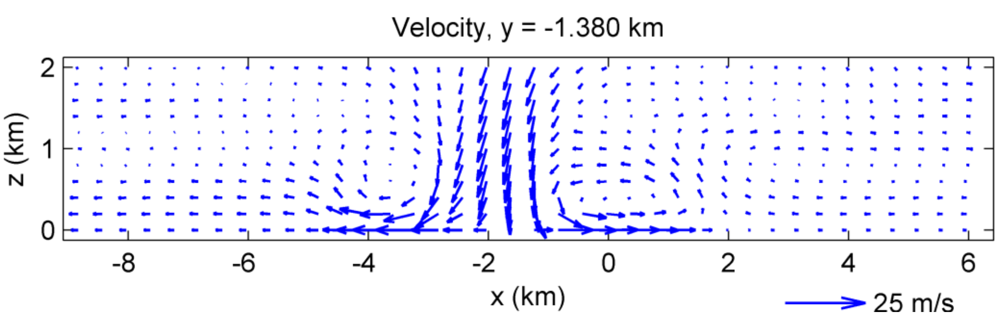

Figure B-50: Data Set/Time #237: East-West Vertical Wind Vectors at y = -1.38 Km

Data Set/Time #237: 06/20/91 Orlando NASA Event #143, East-West vertical wind velocity vectors (m/s) at y = -1.38 km.

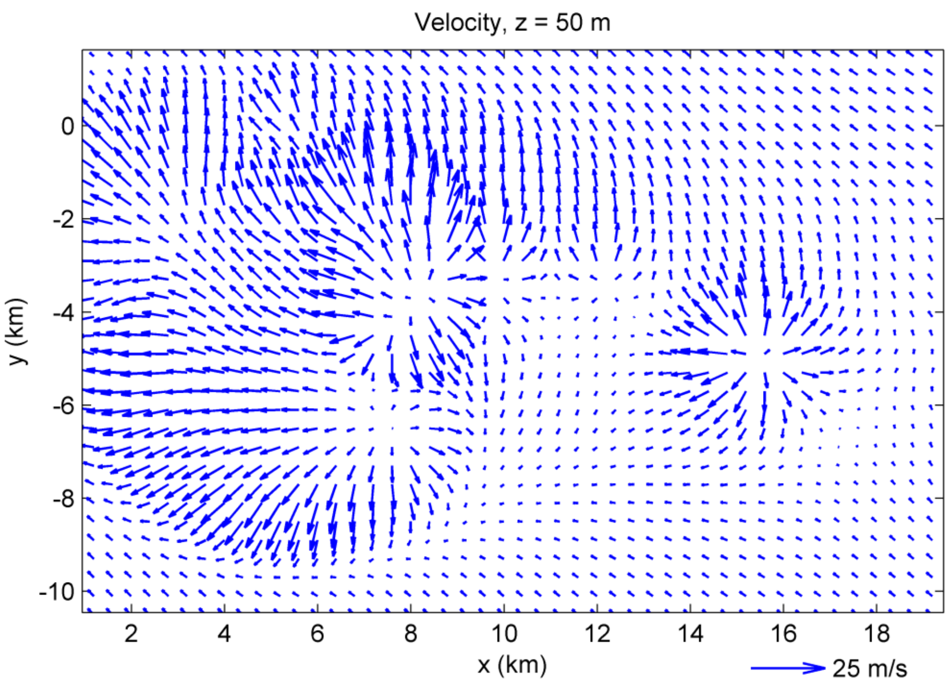

Figure B-51: Data Set/Time #349: Horizontal Wind Vectors at 50 Meters Elevation

Data Set/Time #349: 07/11/88 Denver, Multiple Microburst, horizontal wind velocity vectors (m/s) at z = 50 m.

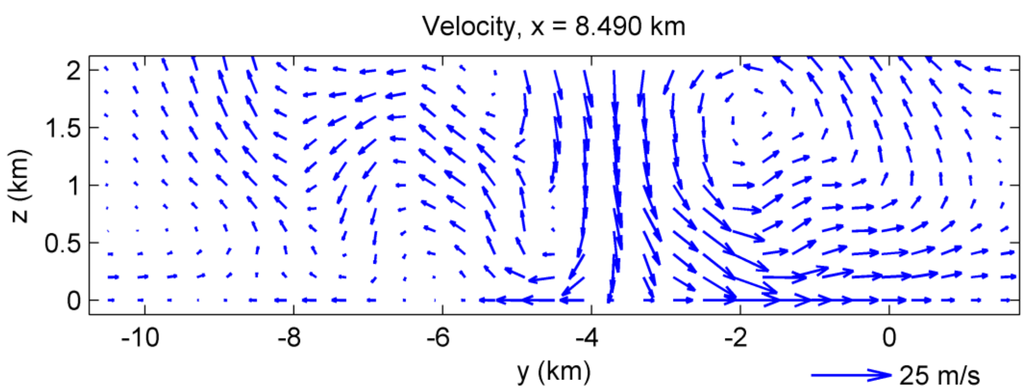

Figure B-52: Data Set/Time #349: North-South Vertical Wind Vectors at x = 8.49 Km

Data Set/Time #349: 07/11/88 Denver, Multiple Microburst, North-South vertical wind velocity vectors (m/s) at x = 8.49 km.

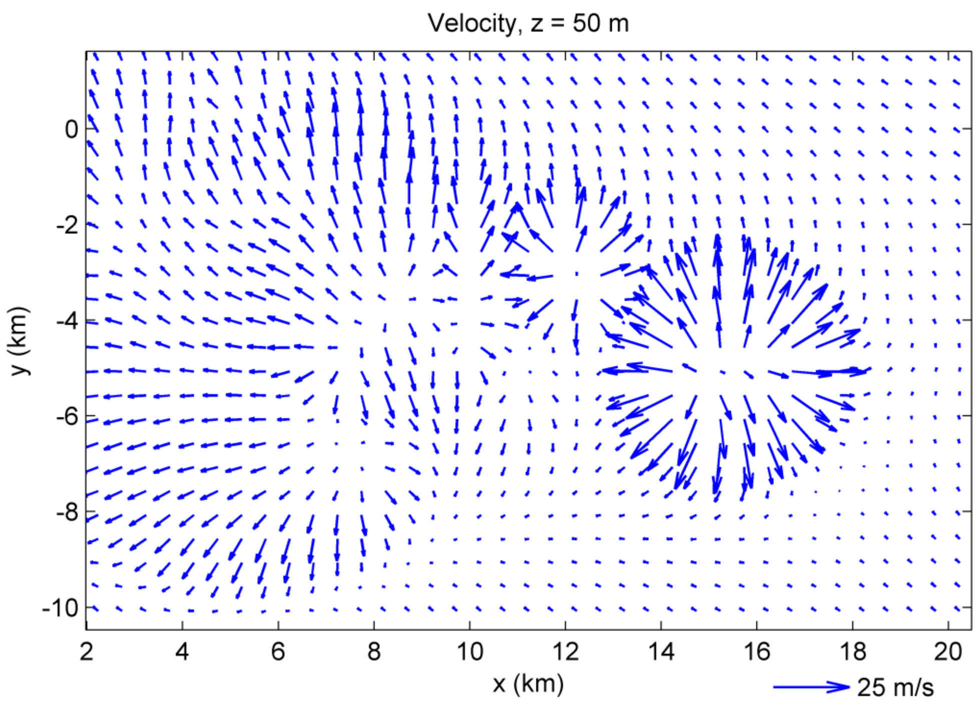

Figure B-53: Data Set/Time #351: Horizontal Wind Vectors at 50 Meters Elevation

Data Set/Time #351: 07/11/88 Denver, Multiple Microburst, horizontal wind velocity vectors (m/s) at z = 50 m.

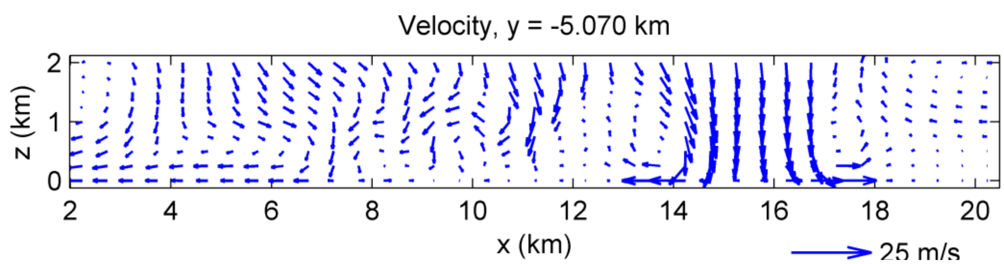

Figure B-54: Data Set/Time #351: East-West Vertical Wind Vectors at y = -5.07 Km

Data Set/Time #351: 07/11/88 Denver, Multiple Microburst, East-West vertical wind velocity vectors (m/s) at y = -5.07 km.

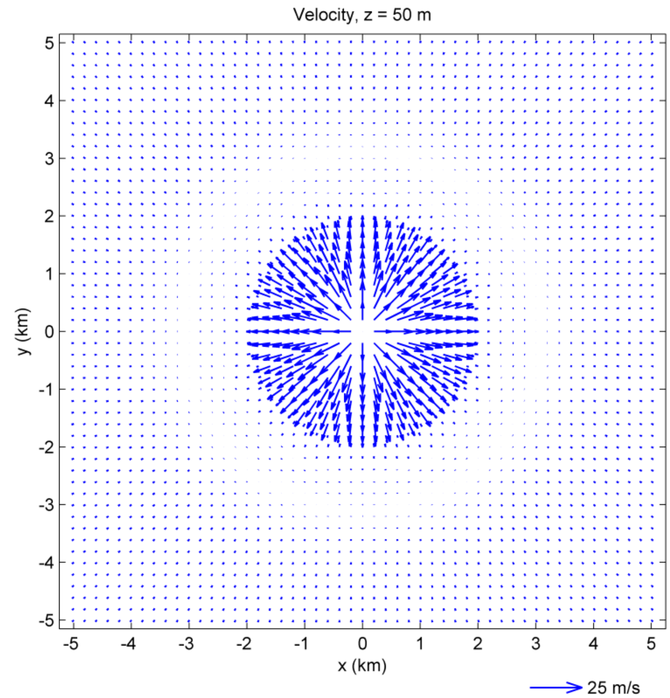

Figure B-55: Data Set/Time #436: Horizontal Wind Vectors at 50 Meters Elevation

Data Set/Time #436: 07/14/82 Denver, Temperature Inversion, horizontal wind velocity vectors (m/s) at z = 50 m.

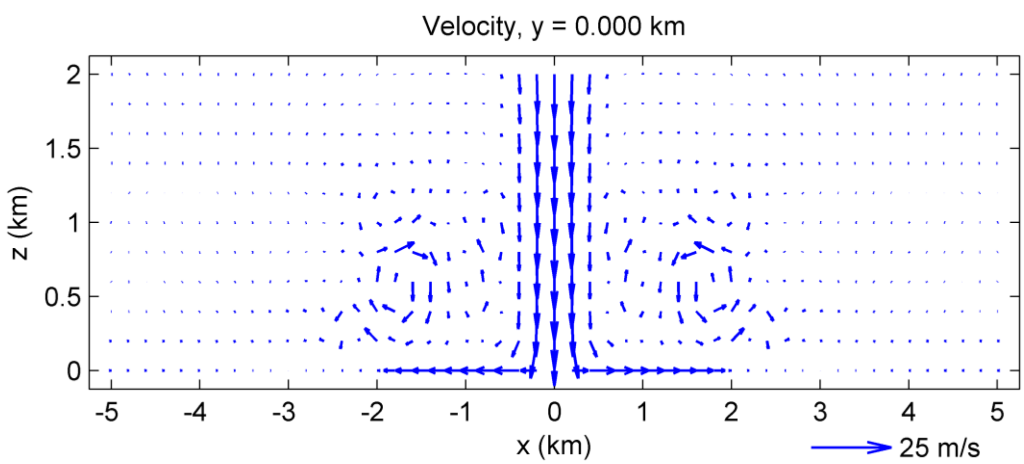

Figure B-56: Data Set/Time #436: East-West Vertical Wind Vectors at y = 0 Km

Data Set/Time #436: 07/14/82 Denver, Temperature Inversion, East-West vertical wind velocity vectors (m/s) at y = 0 km.

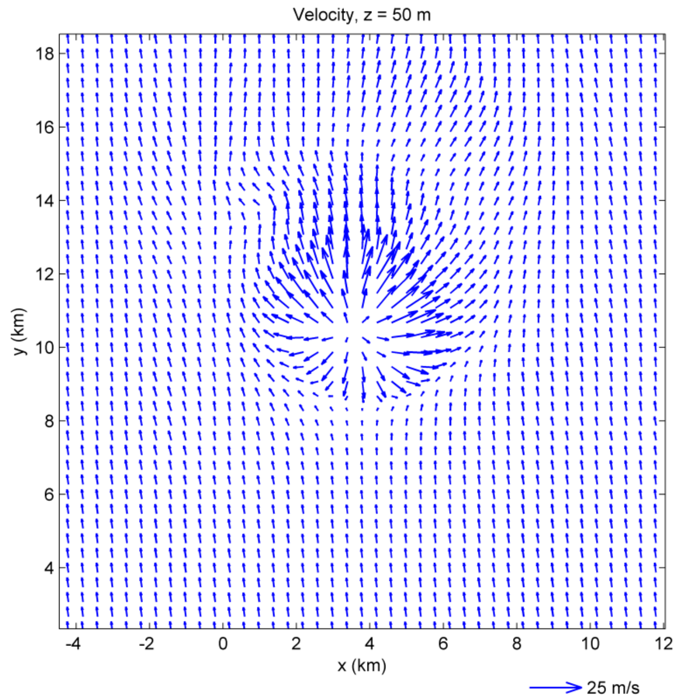

Figure B-57: Data Set/Time #540: Horizontal Wind Vectors at 50 Meters Elevation

Data Set/Time #540: Very Dry Microburst NASA Derived, horizontal wind velocity vectors (m/s) at z = 50 m.

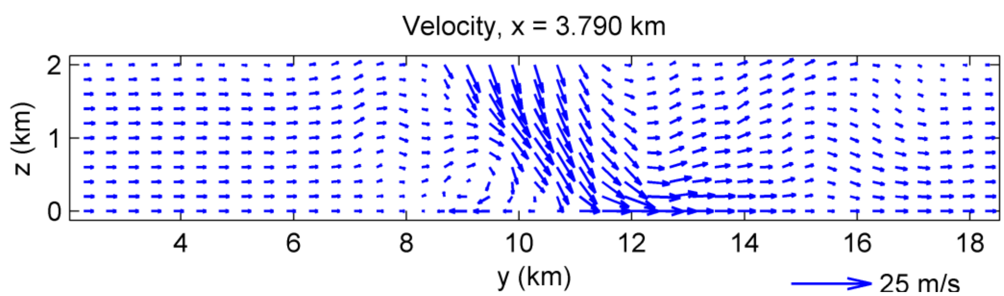

Figure B-58: Data Set/Time #540: North-South Vertical Wind Vectors at x = 3.79 Km

Data Set/Time #540: Very Dry Microburst NASA Derived, North-South vertical wind velocity vectors (m/s) at x = 3.79 km.

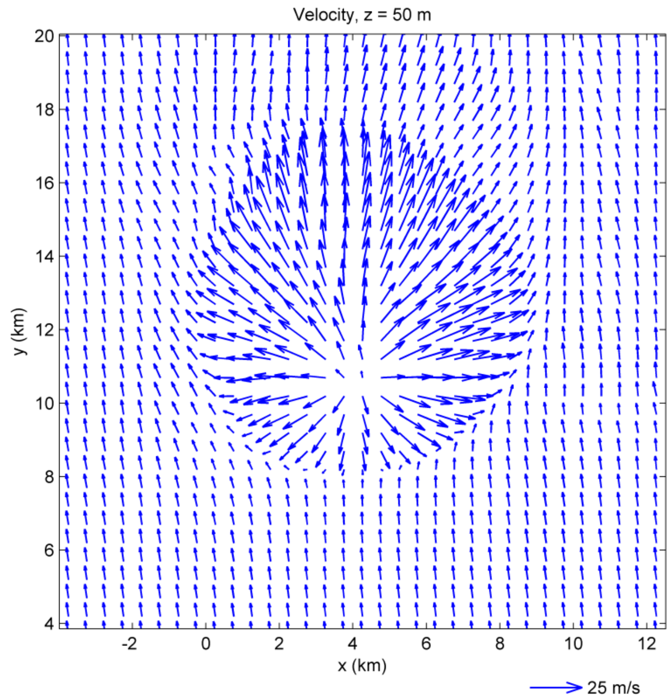

Figure B-59: Data Set/Time #545: Horizontal Wind Vectors at 50 Meters Elevation

Data Set/Time #545: Extremely Dry Microburst NASA Derived, horizontal wind velocity vectors (m/s) at z = 50 m.

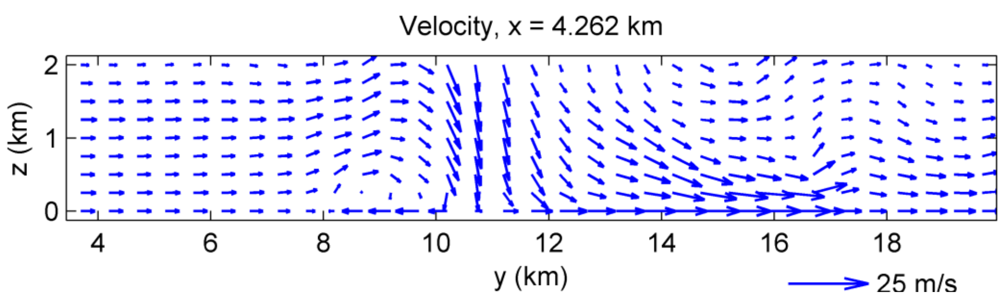

Figure B-60: Data Set/Time #545: North-South Vertical Wind Vectors at x = 4.262 Km

Data Set/Time #545: Extremely Dry Microburst NASA Derived, North-South vertical wind velocity vectors (m/s) at x = 4.262 km.

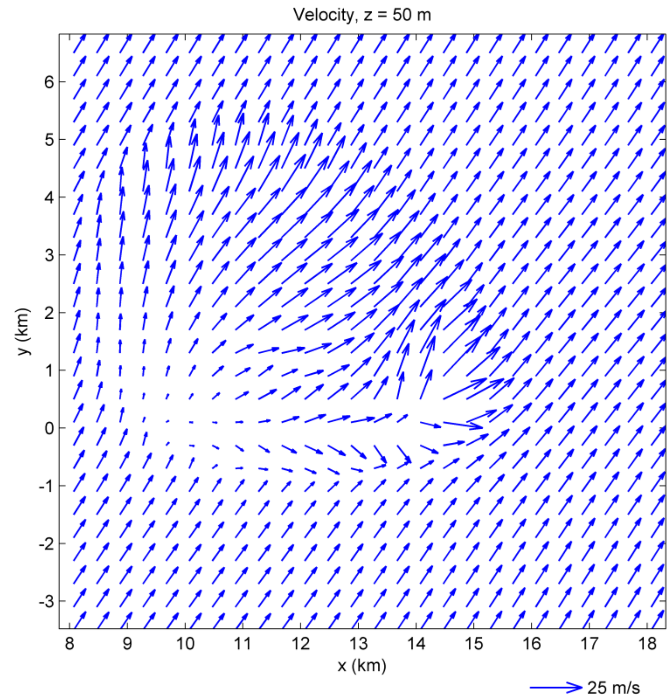

Figure B-61: Data Set/Time #614: Horizontal Wind Vectors at 50 Meters Elevation

Data Set/Time #614: Highly Asymmetric Microburst, horizontal wind velocity vectors (m/s) at z = 50 m.

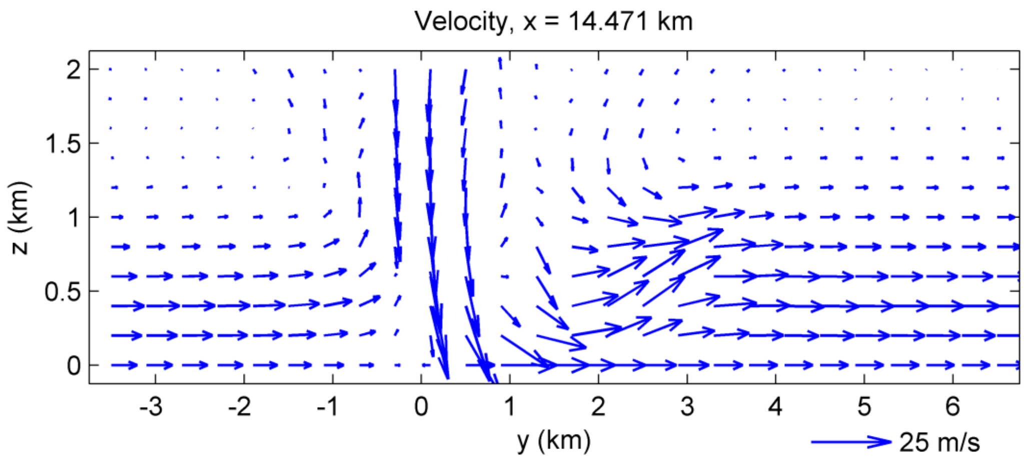

Figure B-62: Data Set/Time #614: North-South Vertical Wind Vectors at x = 14.471 Km

Data Set/Time #614: Highly Asymmetric Microburst, North-South vertical wind velocity vectors (m/s) at x = 14.471 km.

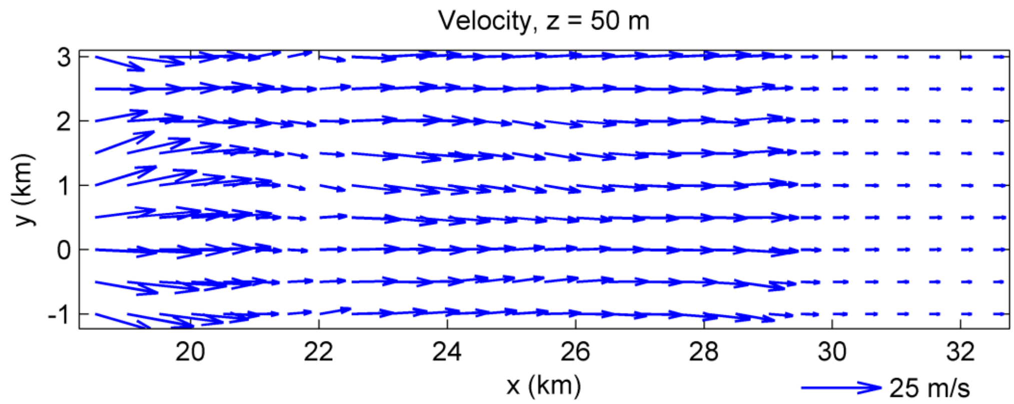

Figure B-63: Data Set/Time #727: Horizontal Wind Vectors at 50 Meters Elevation

Data Set/Time #727: Gust Front, horizontal wind velocity vectors (m/s) at z = 50 m.

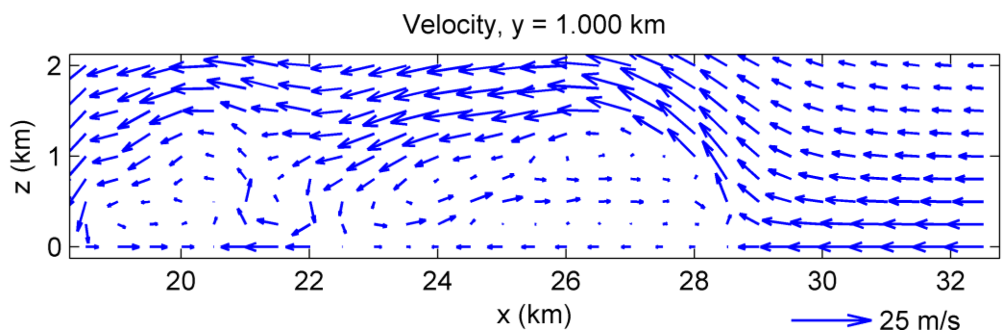

Figure B-64: Data Set/Time #727: East-West Vertical Wind Vectors at y = 1.0 Km

Data Set/Time #727: Gust Front, East-West vertical wind velocity vectors (m/s) at y = 1.0 km. U velocity is biased by 21 m/s to show winds relative to translation of gust front.

B.5 Along-Path Flight Scenario Plots

The black solid line represents the 1 Kilometer averaged F-factor or FBAR, the blue dashed line represents the reflectivity (in dBZ), the green dotted line represents the altitude of the sensor (in 10s meter, so multiply by 10 to get meters), and the red dash-dot line represents the wind velocity along the flight path (in m/s).

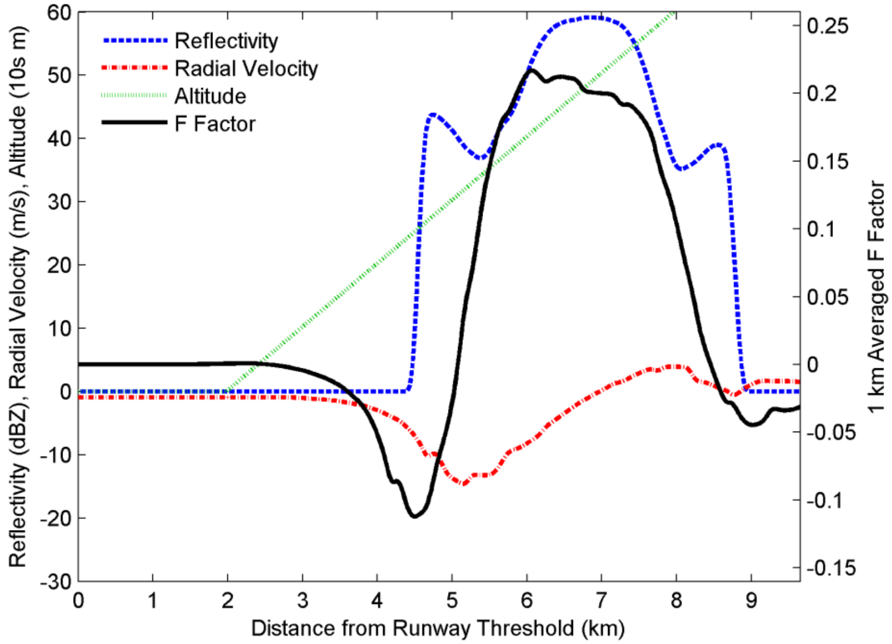

Figure B-65: PWS Scenario 1: Data Set/Time #111, Aligned for Takeoff on Track 90

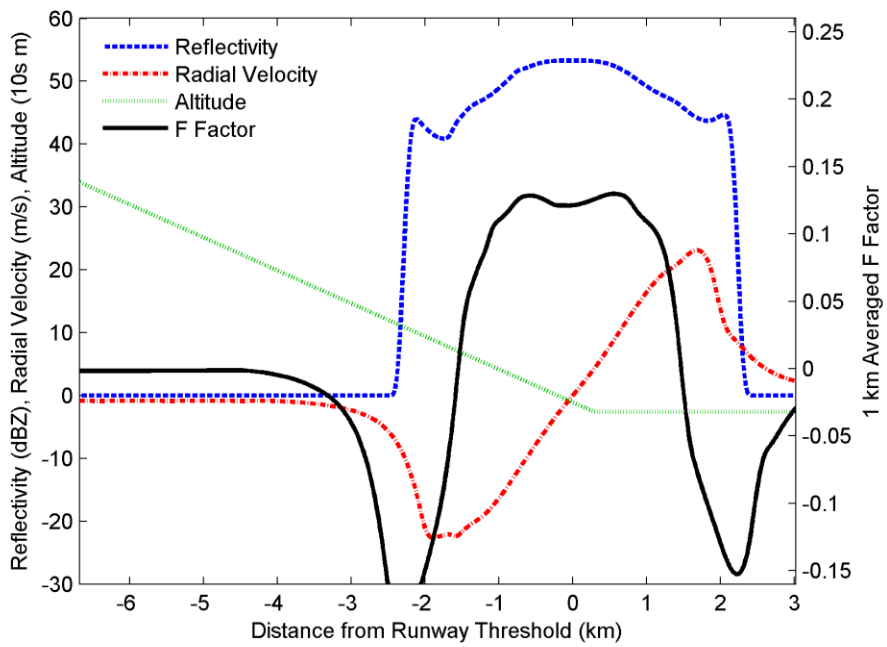

Figure B-66: PWS Scenario 2: Data Set/Time #111, Straight-In Approach on Track 90

The black solid line represents the 1 Kilometer averaged F-factor or FBAR, the blue dashed line represents the reflectivity (in dBZ), the green dotted line represents the altitude of the sensor (in 10s meter, so multiply by 10 to get meters), and the red dash-dot line represents the wind velocity along the flight path (in m/s).

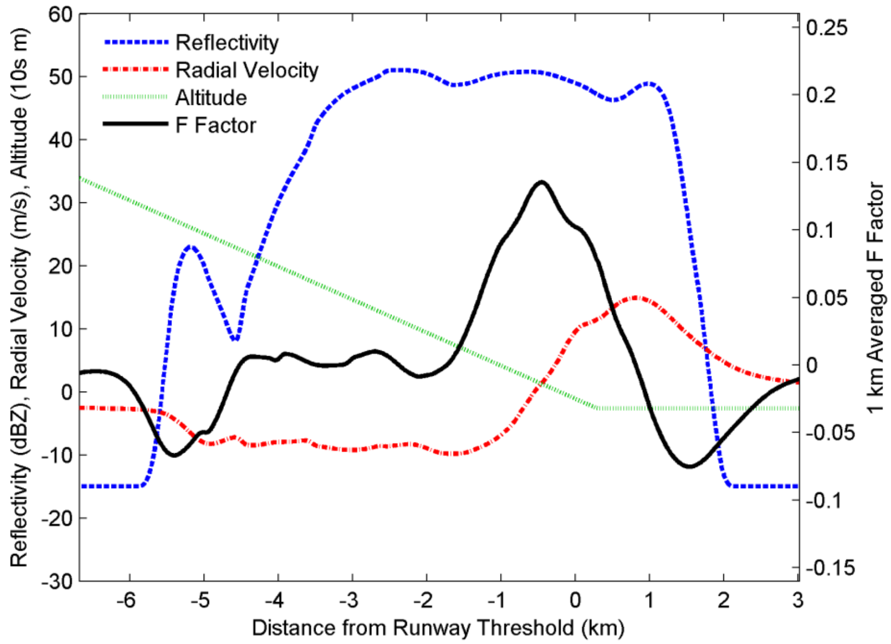

Figure B-67: PWS Scenario 3: Data Set/Time #237, Straight-In Approach on Track 180

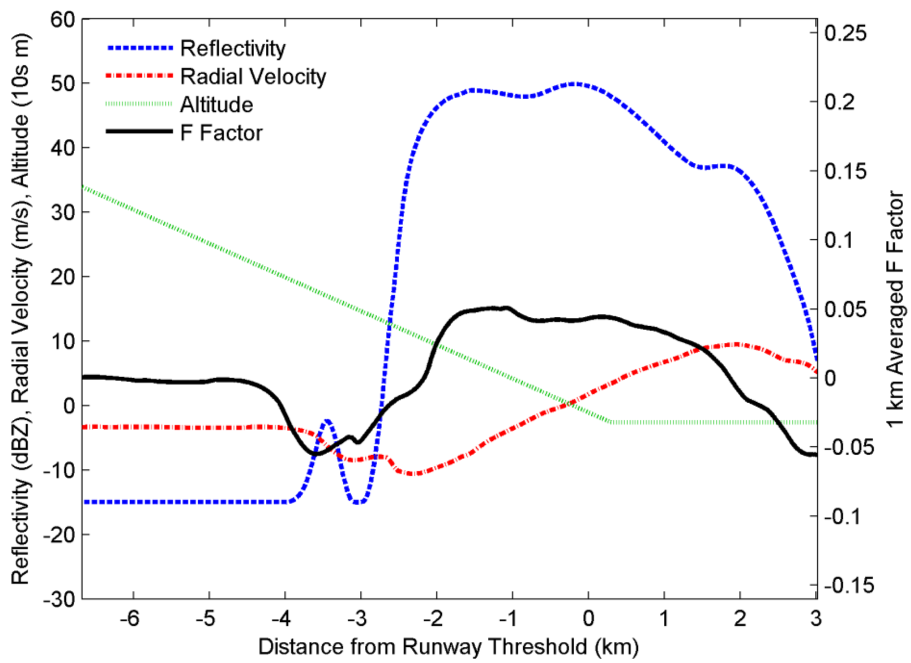

Figure B-68: PWS Scenario 4: Data Set/Time #237, Straight-In Approach on Track 90, Below Alert Threshold Shear

The black solid line represents the 1 Kilometer averaged F-factor or FBAR, the blue dashed line represents the reflectivity (in dBZ), the green dotted line represents the altitude of the sensor (in 10s meter, so multiply by 10 to get meters), and the red dash-dot line represents the wind velocity along the flight path (in m/s).

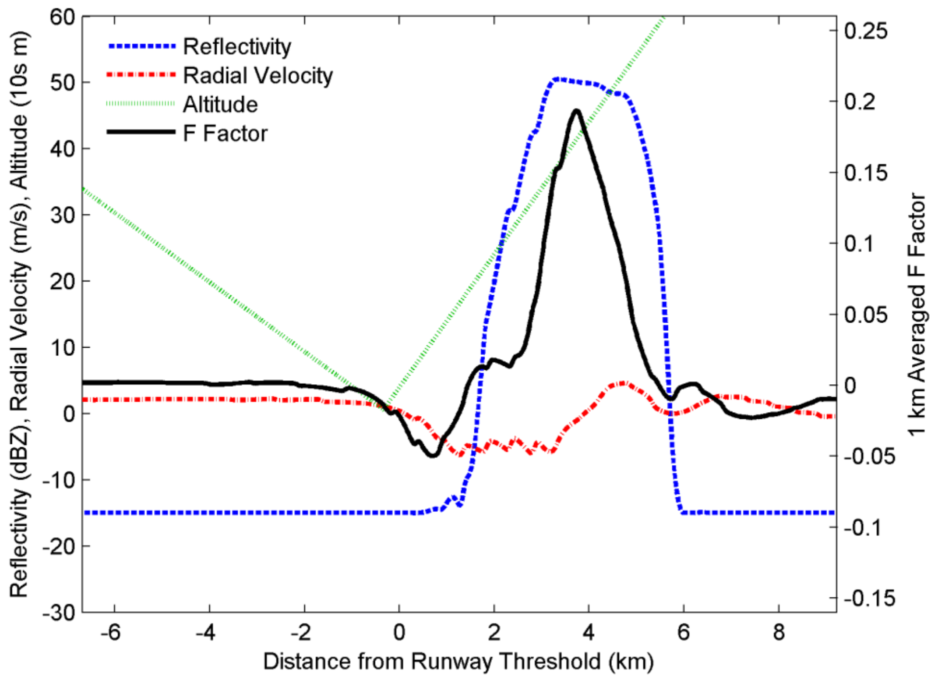

Figure B-69: PWS Scenario 5: Data Set/Time #237, Go-Around on Track 270

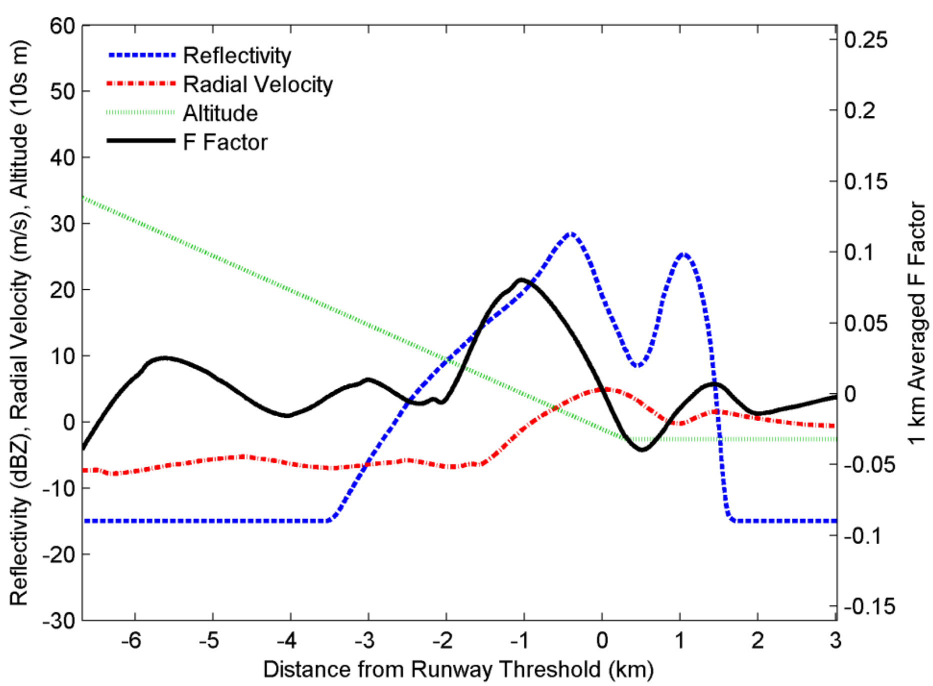

Figure B-70: PWS Scenario 6: Data Set/Time #349, Straight-In Approach on Track 90, Below Alert Threshold Shear

The black solid line represents the 1 Kilometer averaged F-factor or FBAR, the blue dashed line represents the reflectivity (in dBZ), the green dotted line represents the altitude of the sensor (in 10s meter, so multiply by 10 to get meters), and the red dash-dot line represents the wind velocity along the flight path (in m/s).

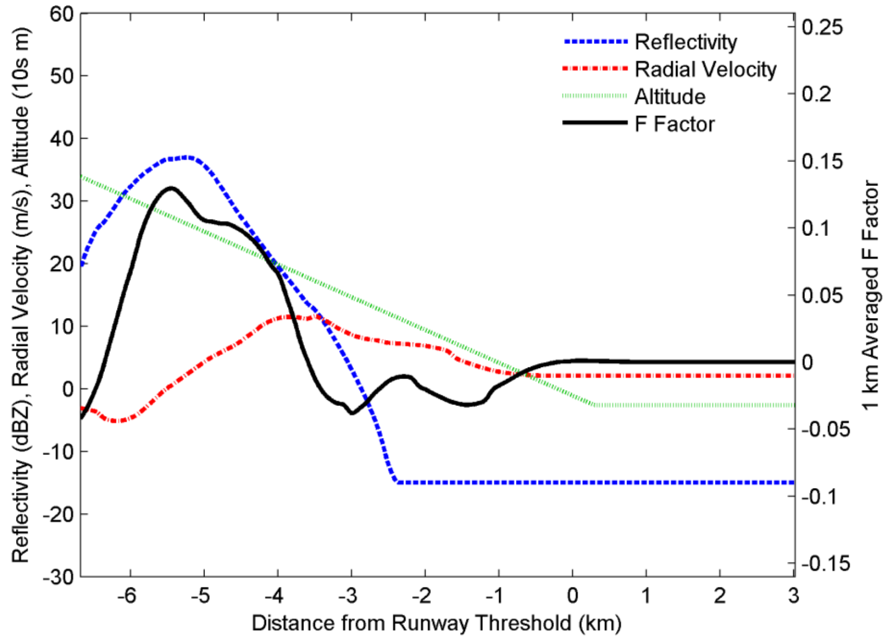

Figure B-71: PWS Scenario 7: Data Set/Time #349, Straight-In Approach on Track 360

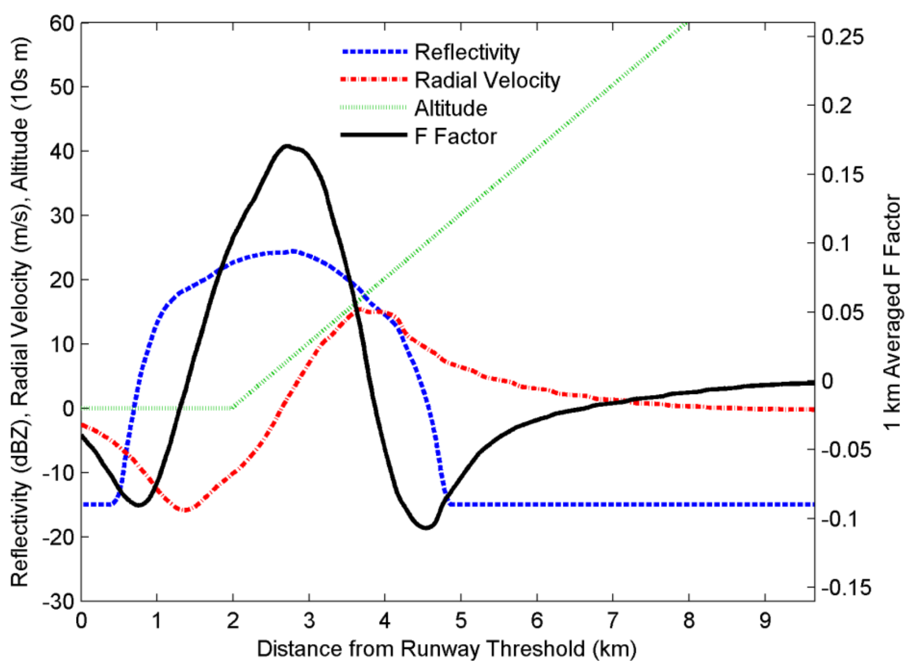

Figure B-72: PWS Scenario 8: Data Set/Time #351, Aligned for Takeoff on Track 360

The black solid line represents the 1 Kilometer averaged F-factor or FBAR, the blue dashed line represents the reflectivity (in dBZ), the green dotted line represents the altitude of the sensor (in 10s meter, so multiply by 10 to get meters), and the red dash-dot line represents the wind velocity along the flight path (in m/s).

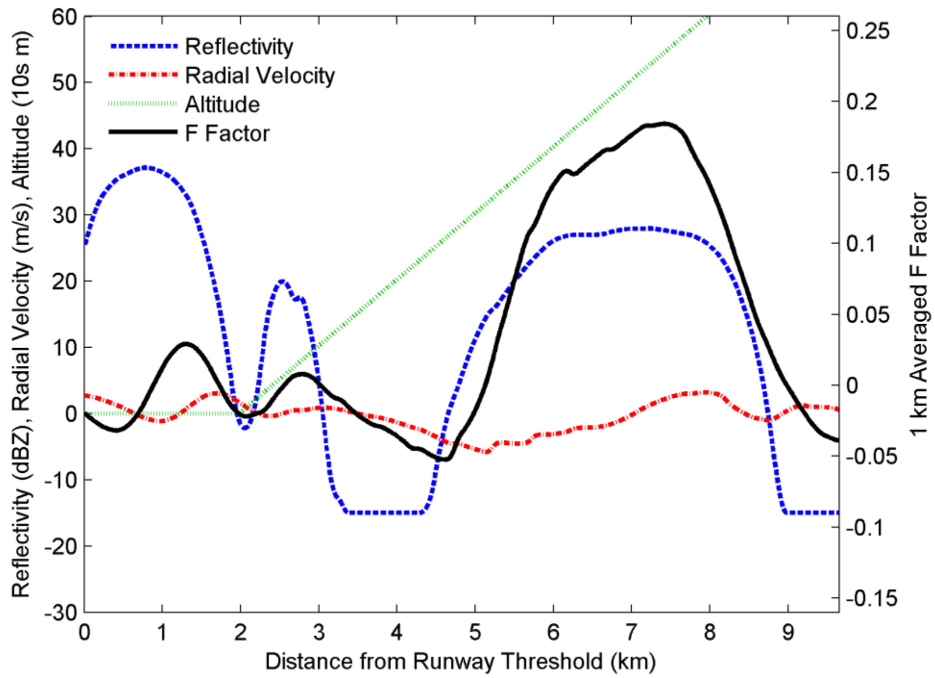

Figure B-73: PWS Scenario 9: Data Set/Time #351, Aligned for Takeoff on Track 90

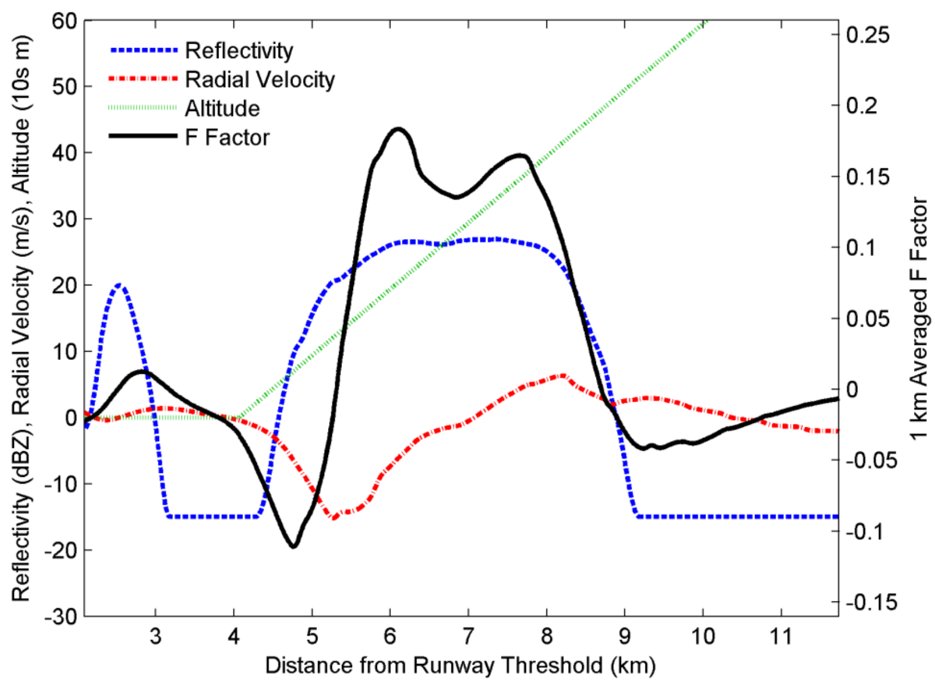

Figure B-74: PWS Scenario 10: Data Set/Time #351, Takeoff Gear-Up Height on Track 90

The black solid line represents the 1 Kilometer averaged F-factor or FBAR, the blue dashed line represents the reflectivity (in dBZ), the green dotted line represents the altitude of the sensor (in 10s meter, so multiply by 10 to get meters), and the red dash-dot line represents the wind velocity along the flight path (in m/s).

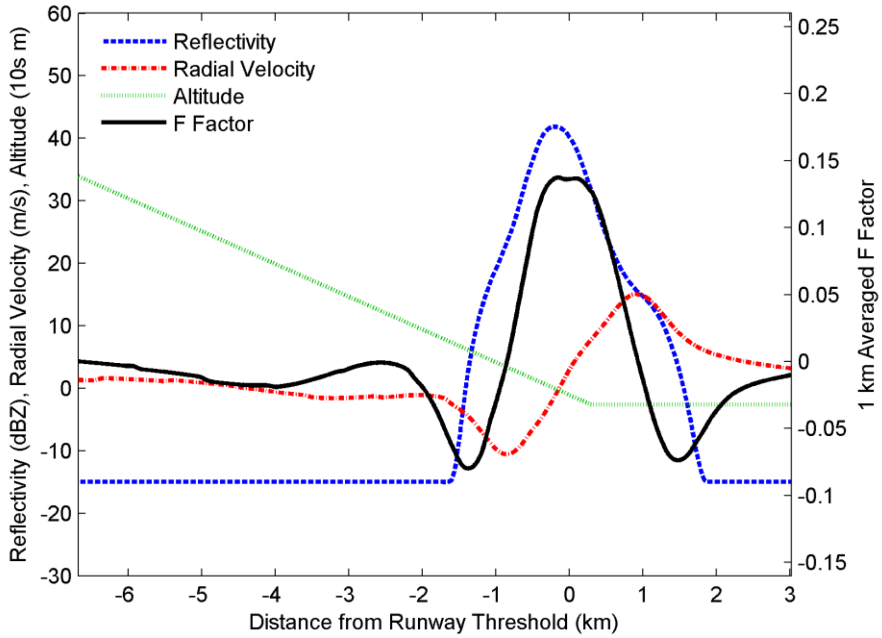

Figure B-75: PWS Scenario 11: Data Set/Time #351, Straight-In Approach on Track 360

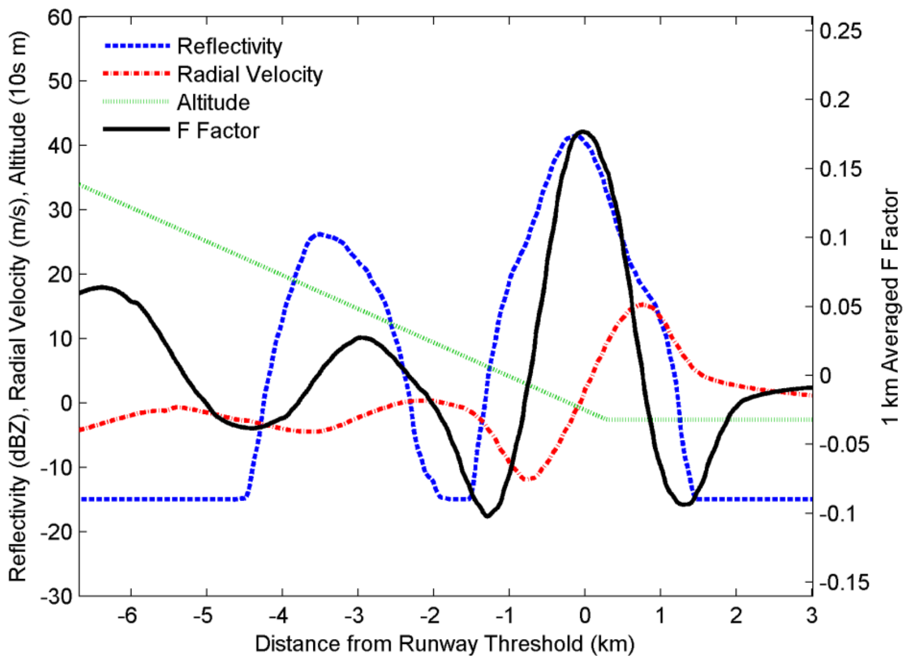

Figure B-76: PWS Scenario 12: Data Set/Time #351, Straight-In Approach on Track 45

The black solid line represents the 1 Kilometer averaged F-factor or FBAR, the blue dashed line represents the reflectivity (in dBZ), the green dotted line represents the altitude of the sensor (in 10s meter, so multiply by 10 to get meters), and the red dash-dot line represents the wind velocity along the flight path (in m/s).

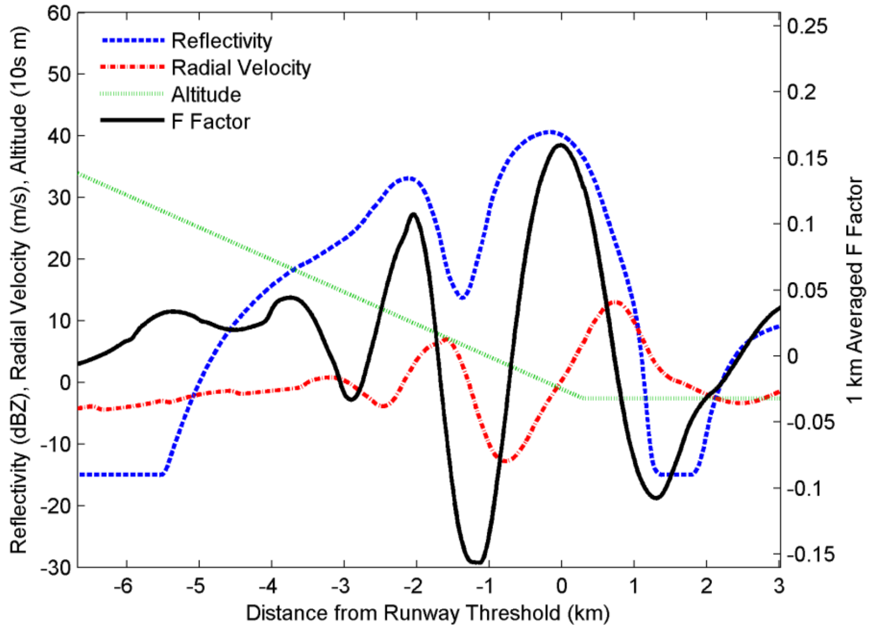

Figure B-77: PWS Scenario 13: Data Set/Time #351, Straight-In Approach on Track 90

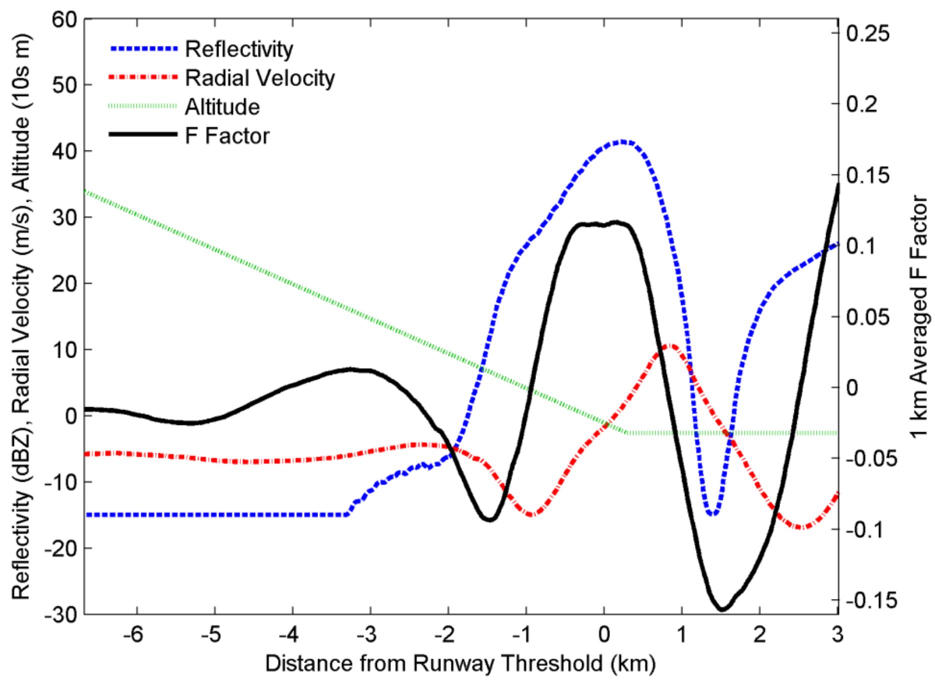

Figure B-78: PWS Scenario 14: Data Set/Time #351, Straight-In Approach on Track 135

The black solid line represents the 1 Kilometer averaged F-factor or FBAR, the blue dashed line represents the reflectivity (in dBZ), the green dotted line represents the altitude of the sensor (in 10s meter, so multiply by 10 to get meters), and the red dash-dot line represents the wind velocity along the flight path (in m/s).

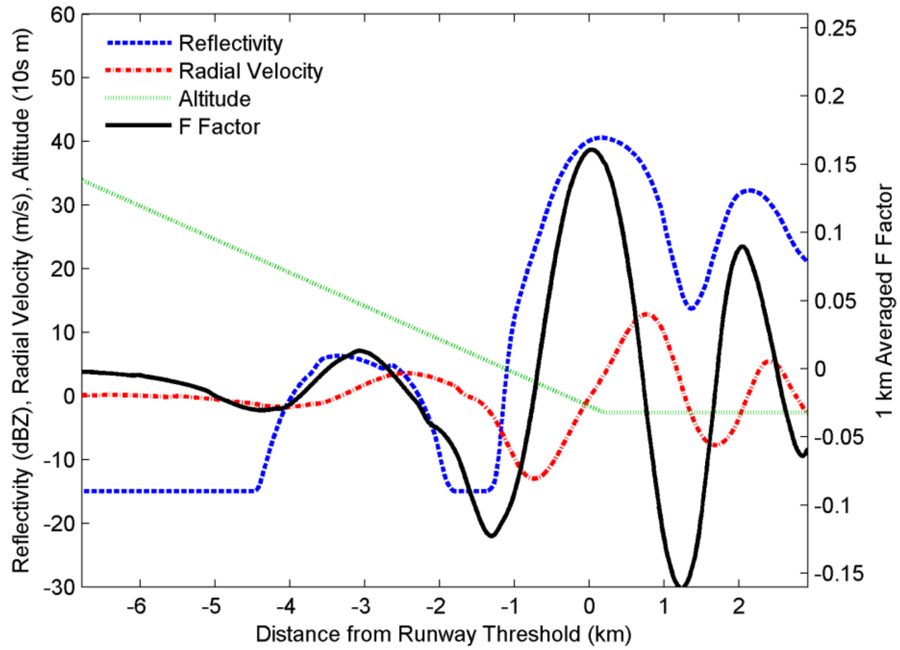

Figure B-79: PWS Scenario 15: Data Set/Time #351, Straight-In Approach on Track 270

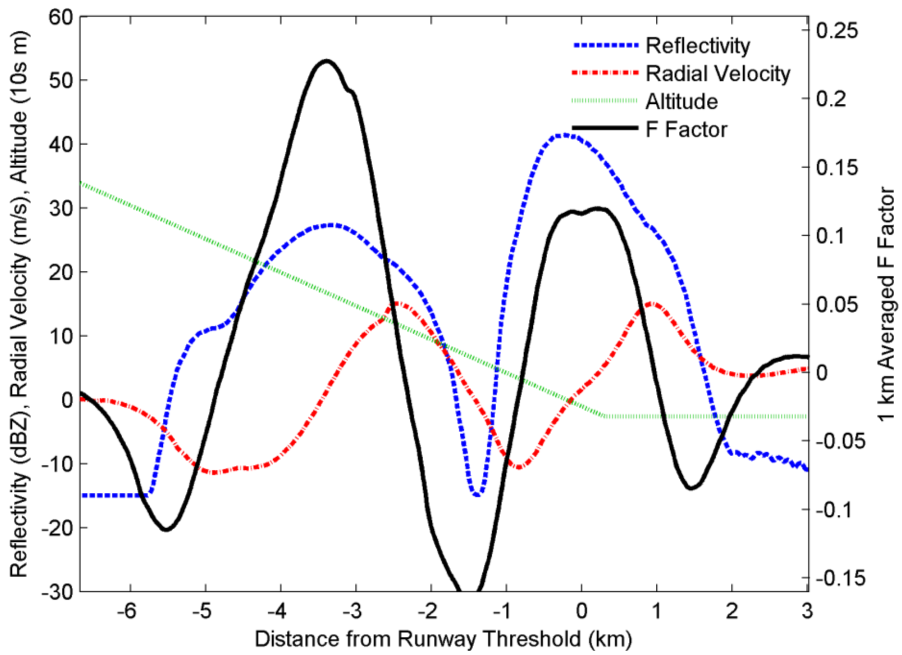

Figure B-80: PWS Scenario 16: Data Set/Time #351, Straight-In Approach on Track 315, Two Windshears on This Path

The black solid line represents the 1 Kilometer averaged F-factor or FBAR, the blue dashed line represents the reflectivity (in dBZ), the green dotted line represents the altitude of the sensor (in 10s meter, so multiply by 10 to get meters), and the red dash-dot line represents the wind velocity along the flight path (in m/s).

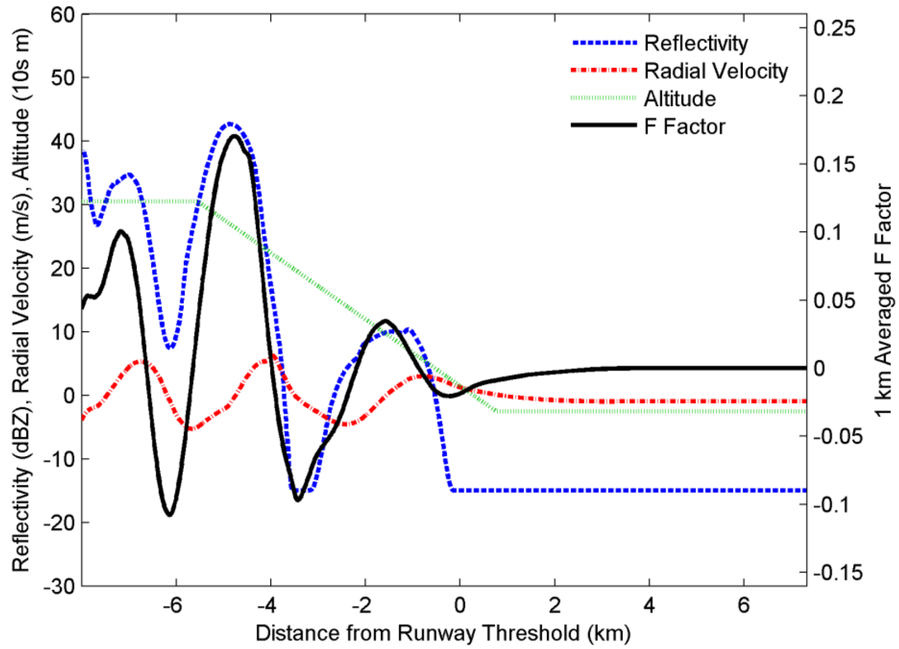

Figure B-81: PWS Scenario 17 (Right Turn): Data Set/Time #351, Curved Approach Right Turn with Localizer on Track 90

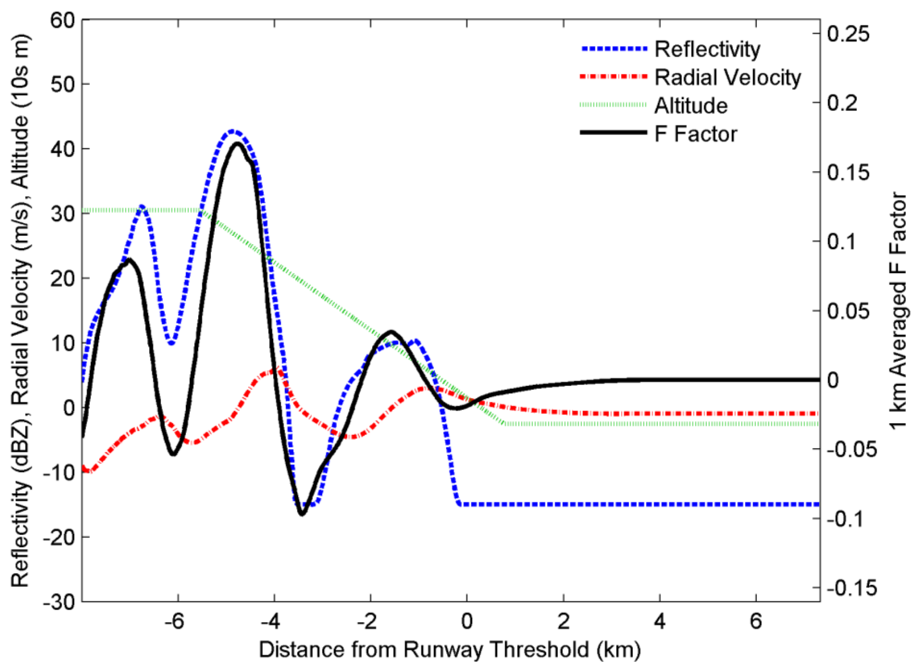

Figure B-82: PWS Scenario 17 (Left Turn): Data Set/Time #351, Curved Approach Left Turn with Localizer on Track 90

The black solid line represents the 1 Kilometer averaged F-factor or FBAR, the blue dashed line represents the reflectivity (in dBZ), the green dotted line represents the altitude of the sensor (in 10s meter, so multiply by 10 to get meters), and the red dash-dot line represents the wind velocity along the flight path (in m/s).

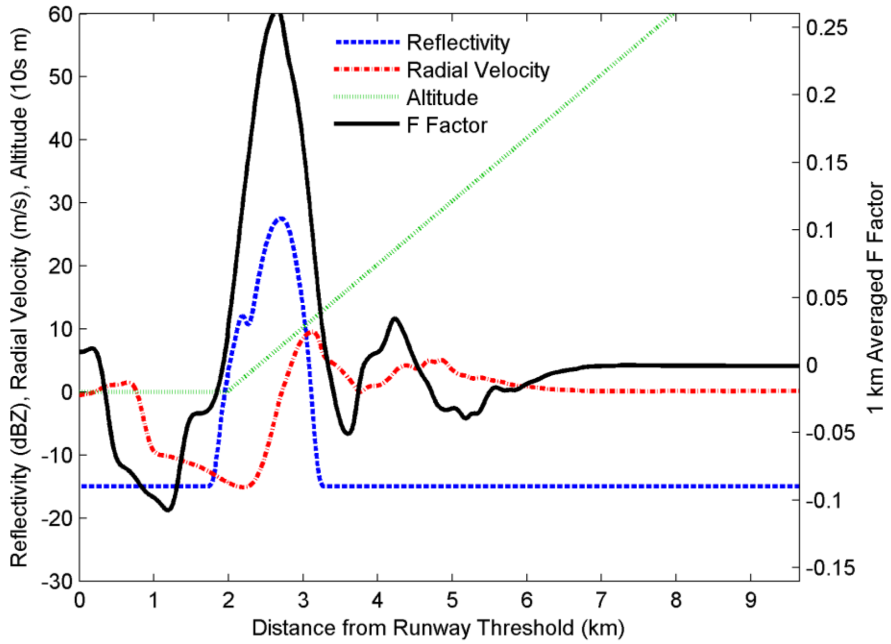

Figure B-83: PWS Scenario 18: Data Set/Time #436, Aligned for Takeoff on Track 90

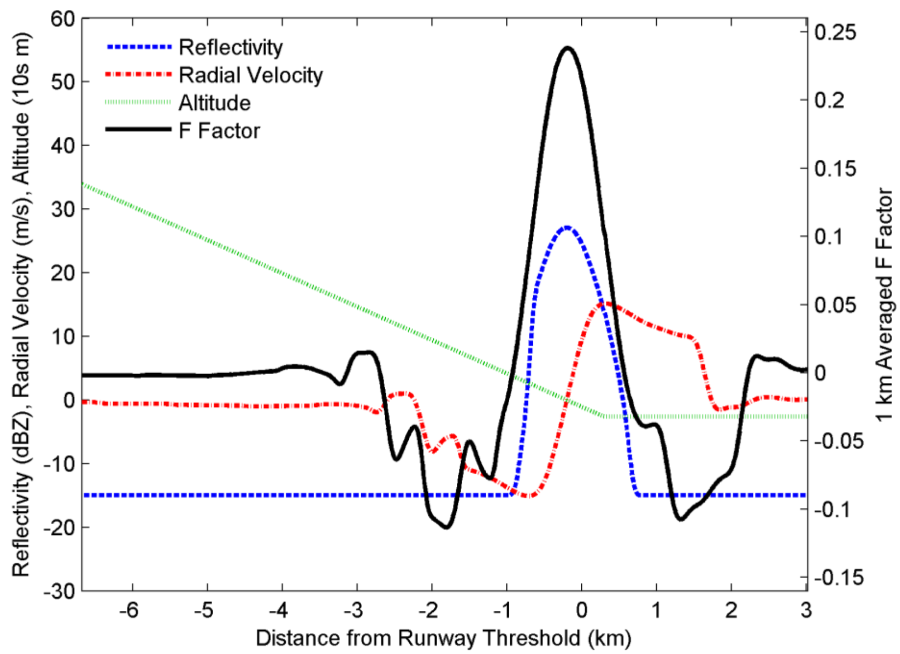

Figure B-84: PWS Scenario 19: Data Set/Time #436, Straight-In Approach on Track 90

The black solid line represents the 1 Kilometer averaged F-factor or FBAR, the blue dashed line represents the reflectivity (in dBZ), the green dotted line represents the altitude of the sensor (in 10s meter, so multiply by 10 to get meters), and the red dash-dot line represents the wind velocity along the flight path (in m/s).

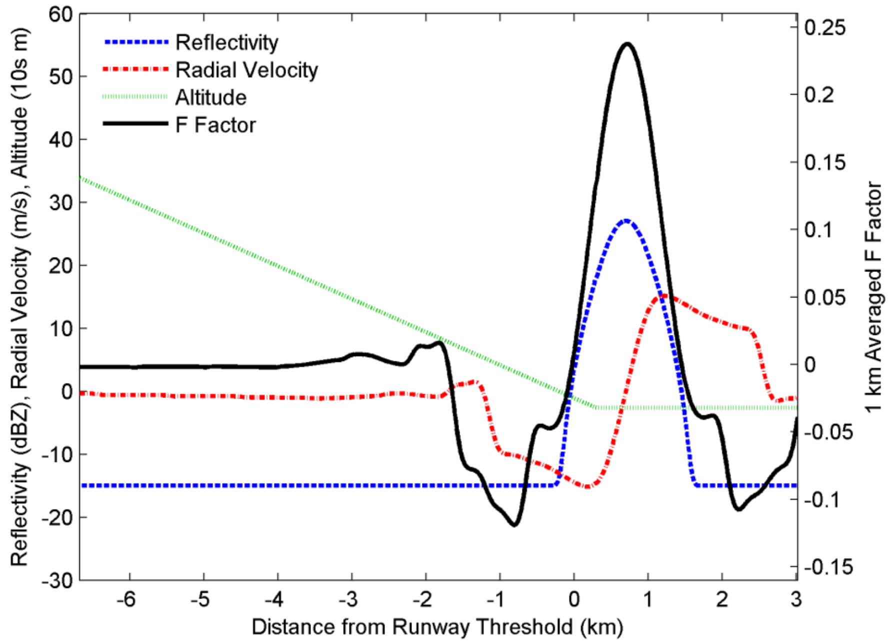

Figure B-85: PWS Scenario 20: Data Set/Time #436, Worst-Case Drift Angle Approach on Track 90

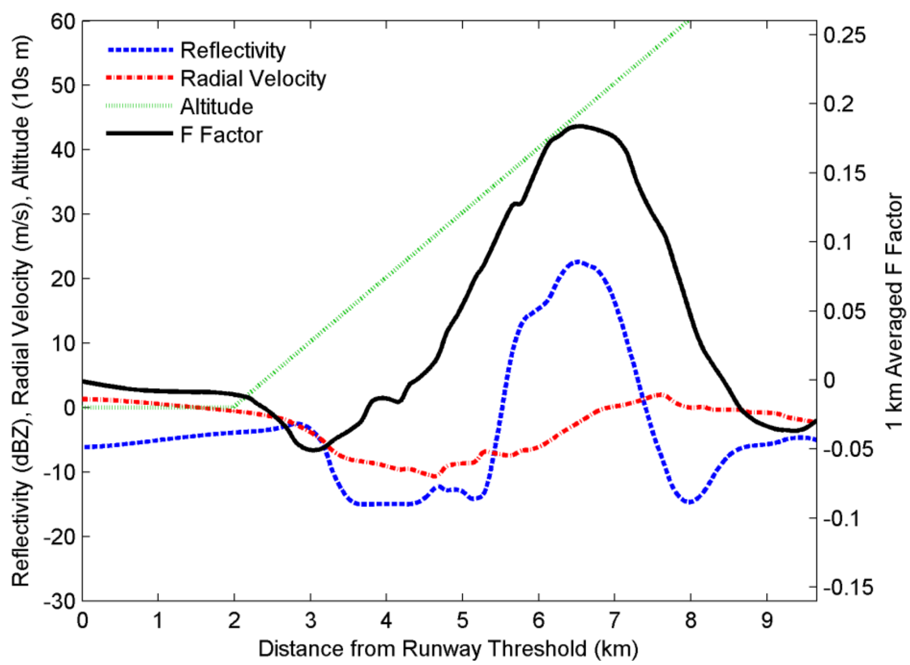

Figure B-86: PWS Scenario 21: Data Set/Time #540, Takeoff Gear-Up Height on Track 270

The black solid line represents the 1 Kilometer averaged F-factor or FBAR, the blue dashed line represents the reflectivity (in dBZ), the green dotted line represents the altitude of the sensor (in 10s meter, so multiply by 10 to get meters), and the red dash-dot line represents the wind velocity along the flight path (in m/s).

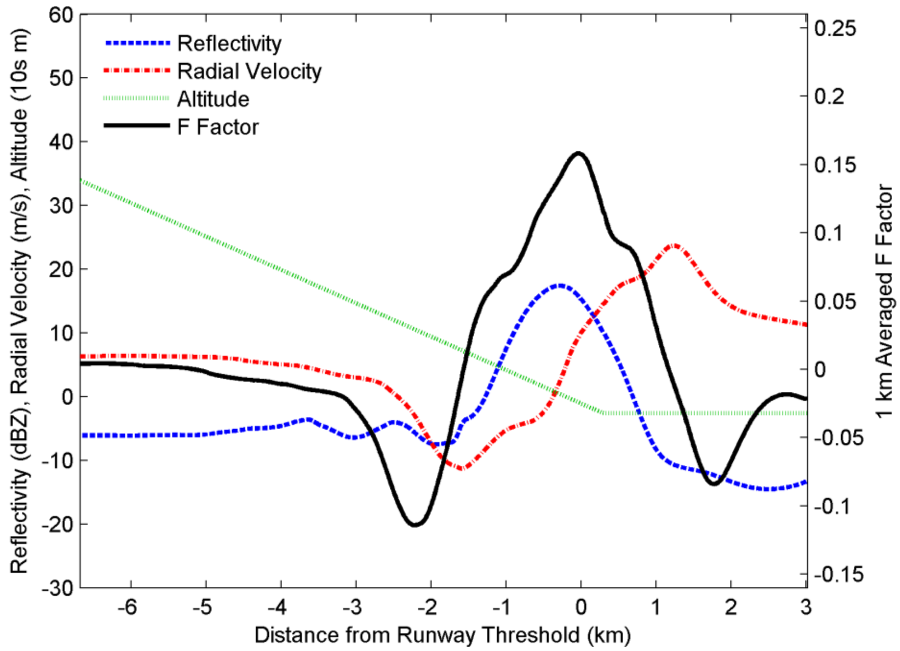

Figure B-87: PWS Scenario 22: Data Set/Time #540, Straight-In Approach on Track 360

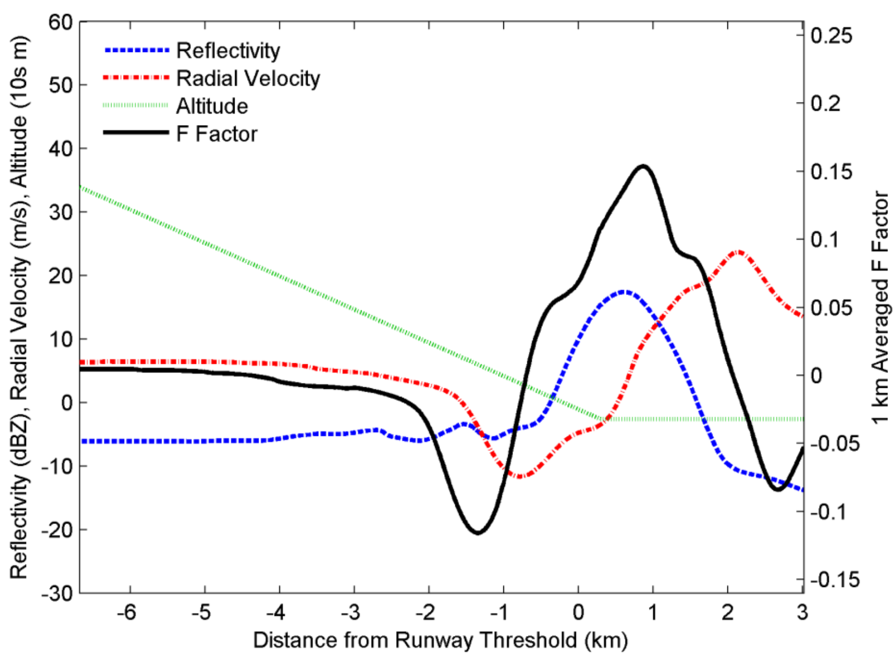

Figure B-88: PWS Scenario 23: Data Set/Time #540, Worst-Case Drift Angle Approach on Track 360

The black solid line represents the 1 Kilometer averaged F-factor or FBAR, the blue dashed line represents the reflectivity (in dBZ), the green dotted line represents the altitude of the sensor (in 10s meter, so multiply by 10 to get meters), and the red dash-dot line represents the wind velocity along the flight path (in m/s).

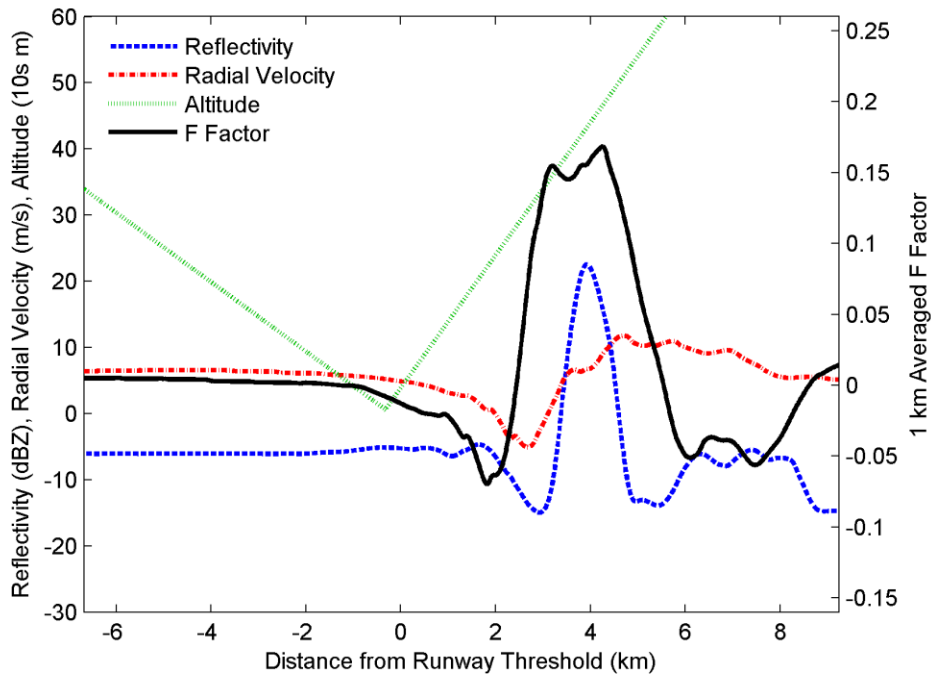

Figure B-89: PWS Scenario 24: Data Set/Time #540, Go-Around on Track 360

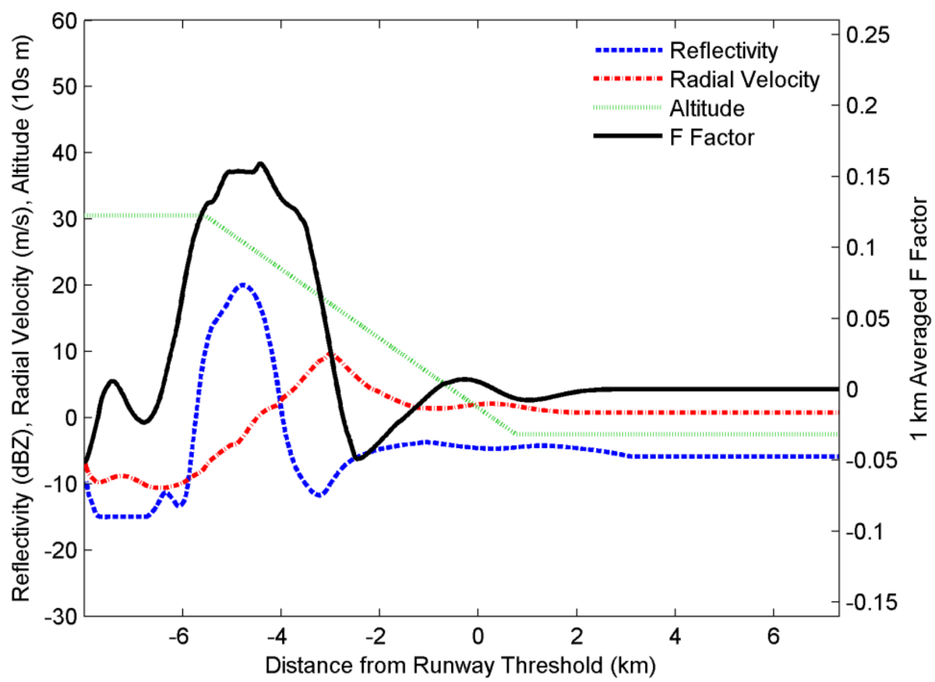

Figure B-90: PWS Scenario 25 (Right Turn): Data Set/Time #540, Curved Approach Right Turn with Localizer on Track 270

The black solid line represents the 1 Kilometer averaged F-factor or FBAR, the blue dashed line represents the reflectivity (in dBZ), the green dotted line represents the altitude of the sensor (in 10s meter, so multiply by 10 to get meters), and the red dash-dot line represents the wind velocity along the flight path (in m/s).

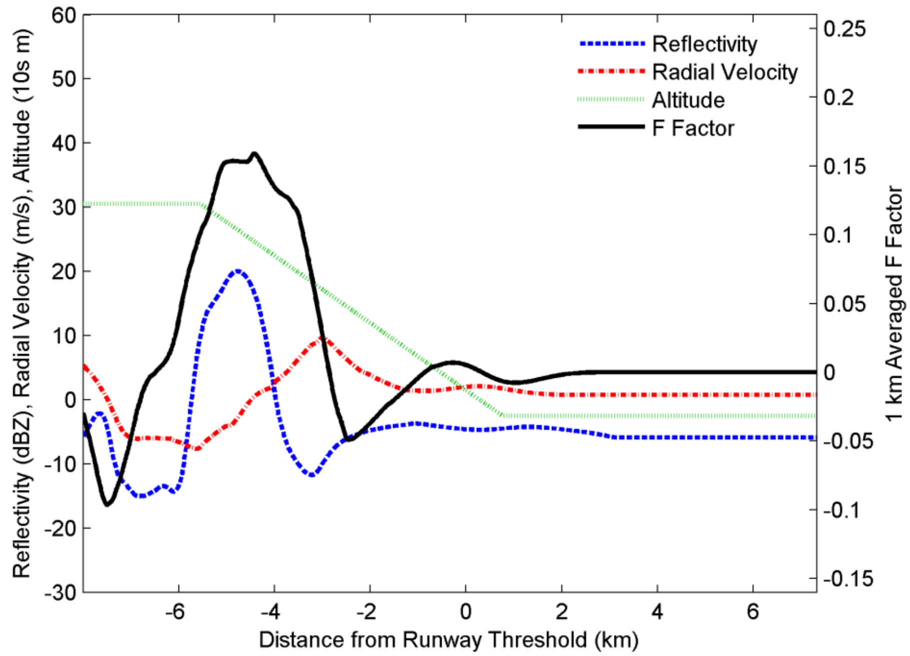

Figure B-91: PWS Scenario 25 (Left Turn): Data Set/Time #540, Curved Approach Left Turn with Localizer on Track 270

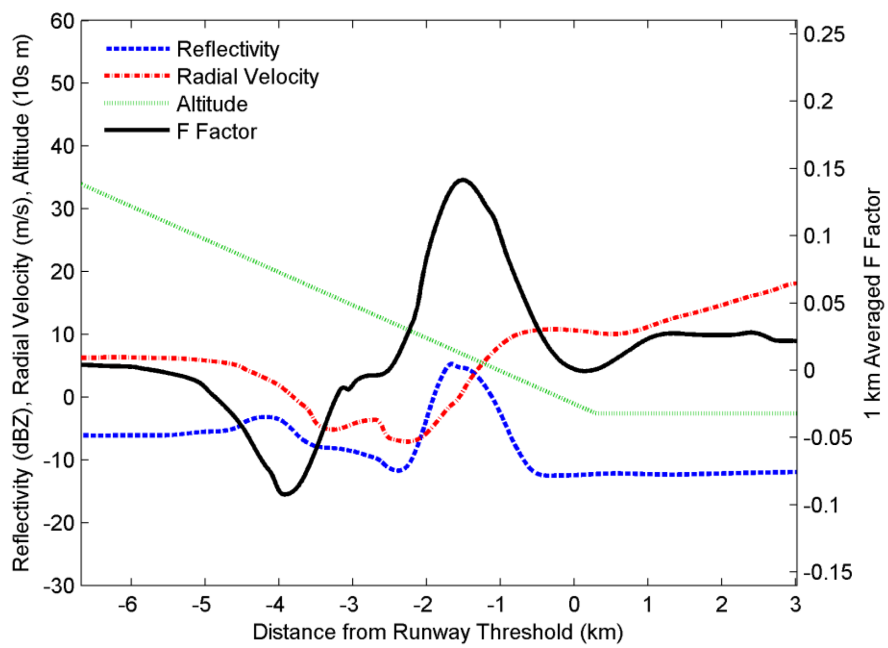

Figure B-92: PWS Scenario 26: Data Set/Time #545, Straight-In Approach on Track 360

The black solid line represents the 1 Kilometer averaged F-factor or FBAR, the blue dashed line represents the reflectivity (in dBZ), the green dotted line represents the altitude of the sensor (in 10s meter, so multiply by 10 to get meters), and the red dash-dot line represents the wind velocity along the flight path (in m/s).

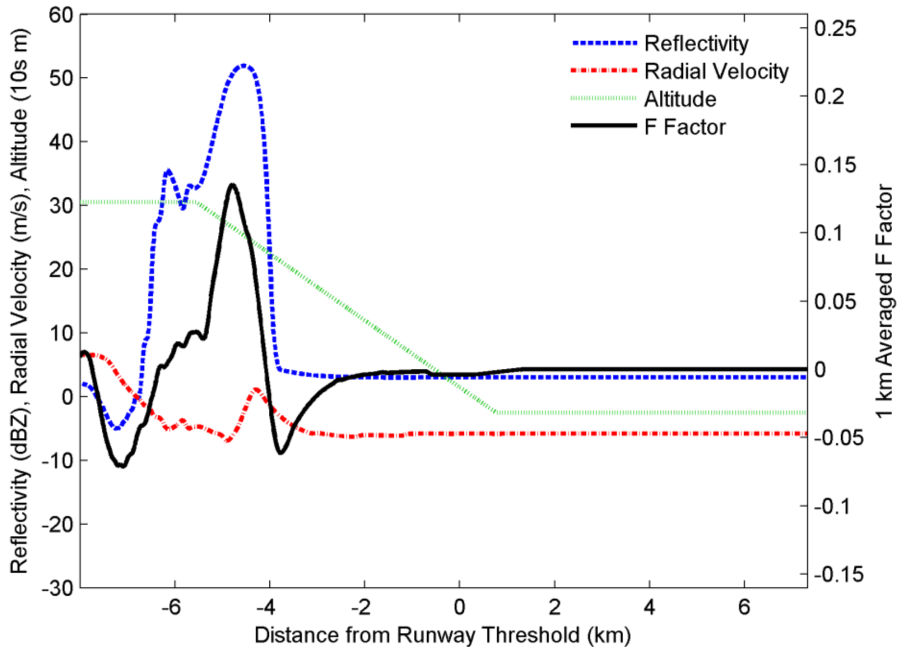

Figure B-93: PWS Scenario 27 (Right Turn): Data Set/Time #614, Curved Approach Right Turn with Localizer on Track 180

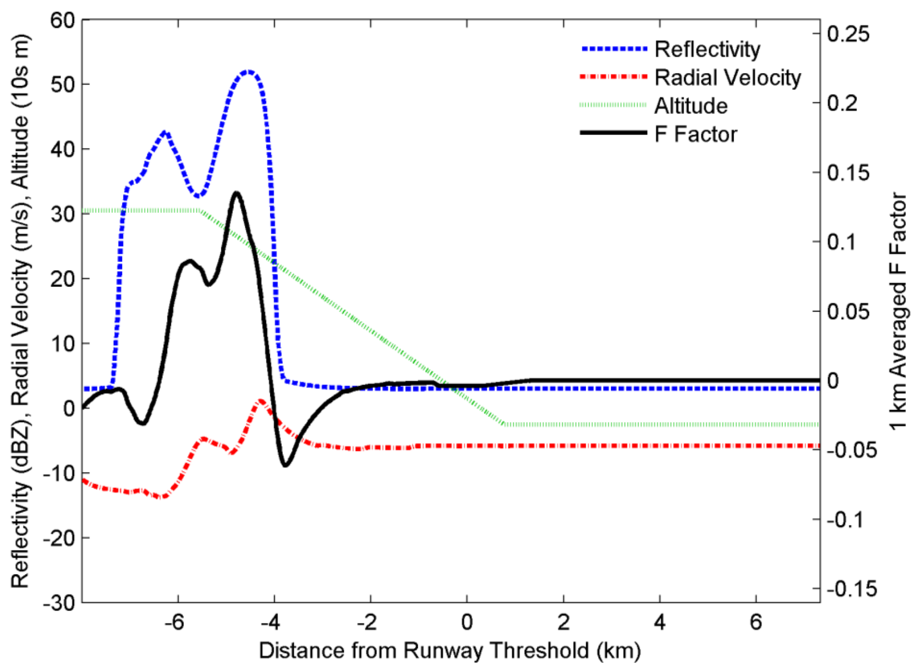

Figure B-94: PWS Scenario 27 (Left Turn): Data Set/Time #614, Curved Approach Left Turn with Localizer on Track 180

The black solid line represents the 1 Kilometer averaged F-factor or FBAR, the blue dashed line represents the reflectivity (in dBZ), the green dotted line represents the altitude of the sensor (in 10s meter, so multiply by 10 to get meters), and the red dash-dot line represents the wind velocity along the flight path (in m/s).

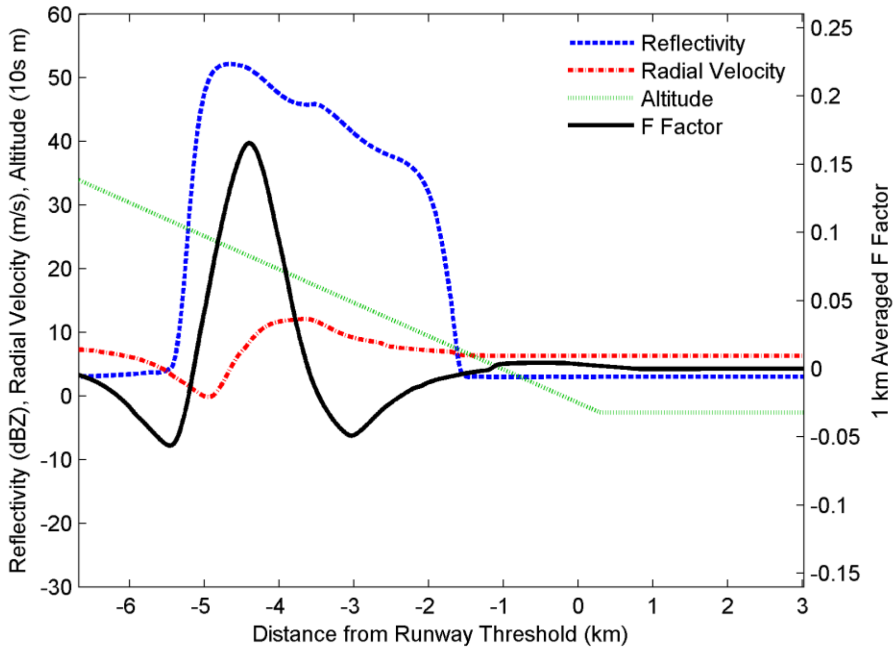

Figure B-95: PWS Scenario 28: Data Set/Time #614, Straight-In Approach on Track 360

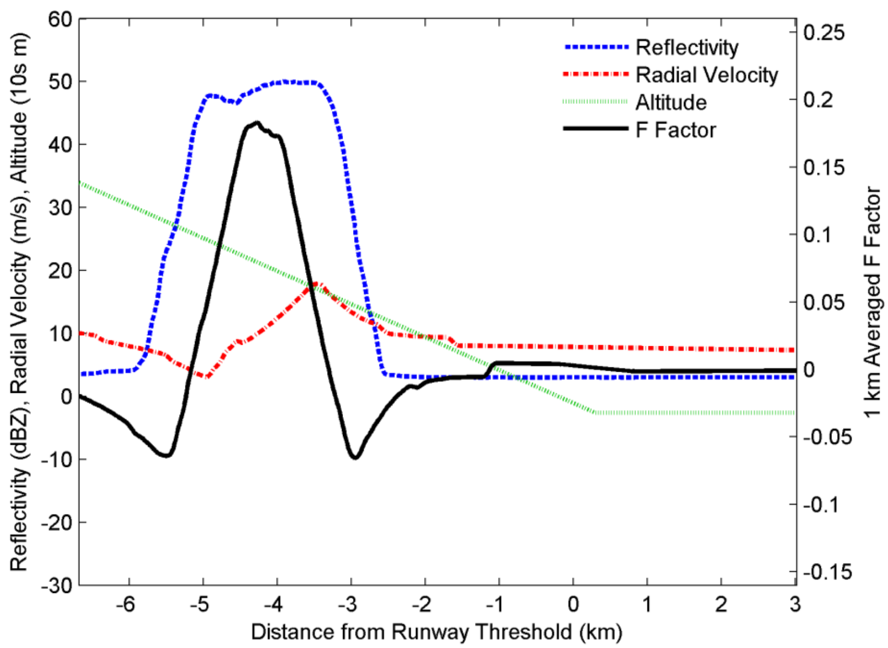

Figure B-96: PWS Scenario 29: Data Set/Time #614, Straight-In Approach on Track 45

The black solid line represents the 1 Kilometer averaged F-factor or FBAR, the blue dashed line represents the reflectivity (in dBZ), the green dotted line represents the altitude of the sensor (in 10s meter, so multiply by 10 to get meters), and the red dash-dot line represents the wind velocity along the flight path (in m/s).

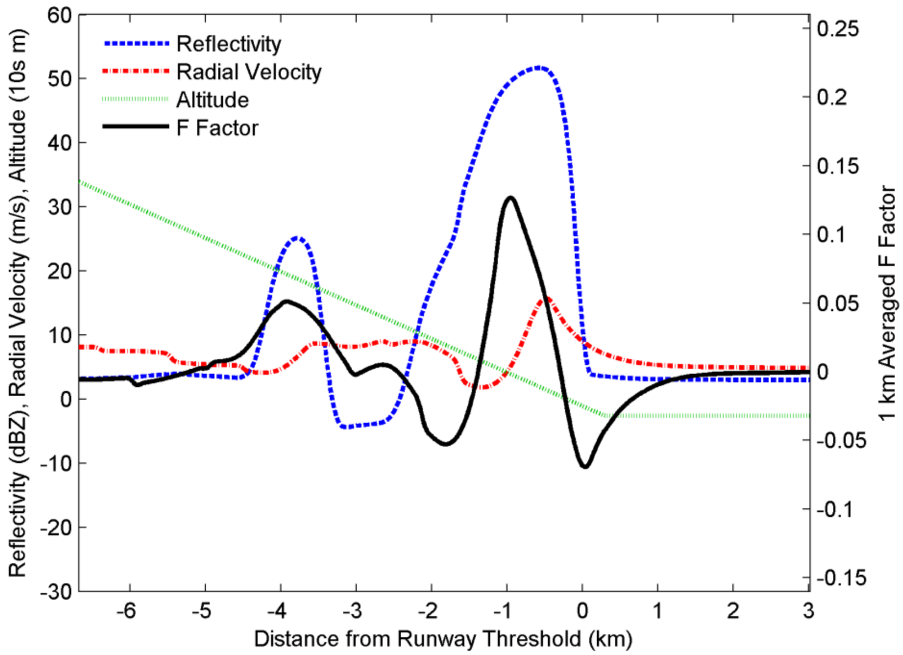

Figure B-97: PWS Scenario 30: Data Set/Time #614, Straight-In Approach on Track 90

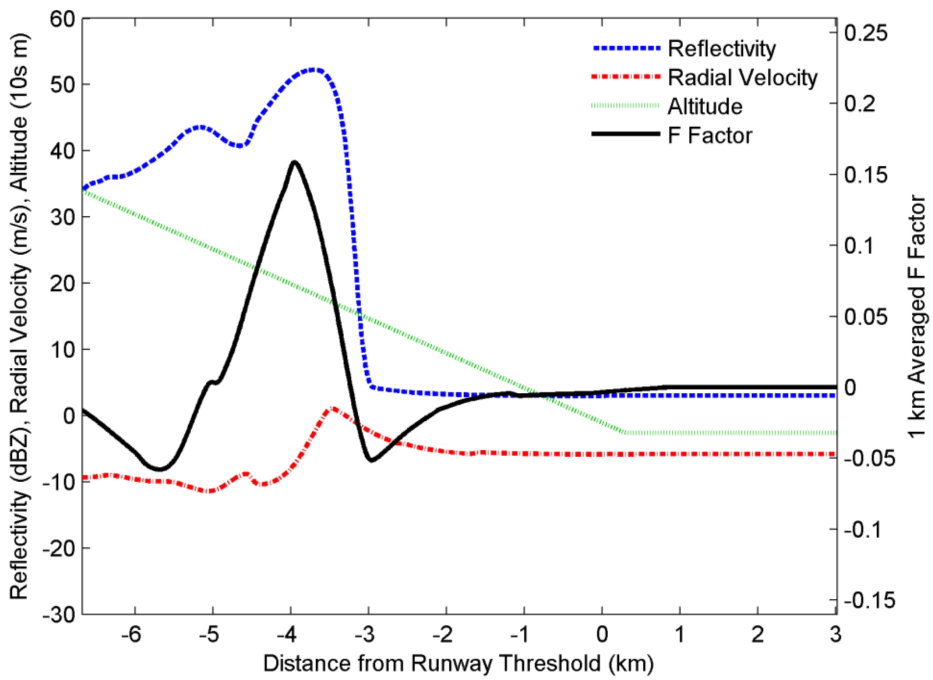

Figure B-98: PWS Scenario 31: Data Set/Time #614, Straight-In Approach on Track 180

The black solid line represents the 1 Kilometer averaged F-factor or FBAR, the blue dashed line represents the reflectivity (in dBZ), the green dotted line represents the altitude of the sensor (in 10s meter, so multiply by 10 to get meters), and the red dash-dot line represents the wind velocity along the flight path (in m/s).

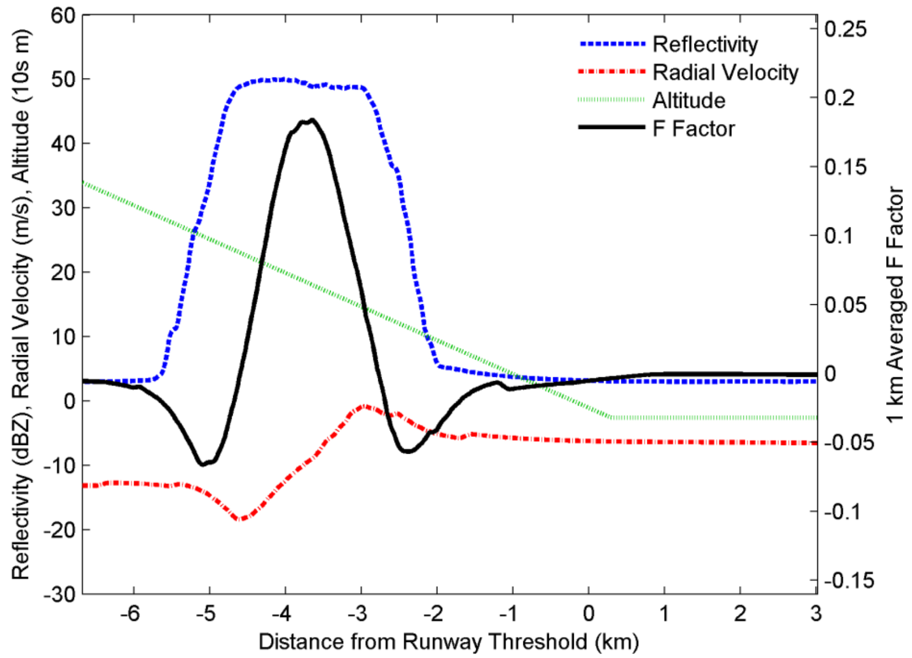

Figure B-99: PWS Scenario 32: Data Set/Time #614, Straight-In Approach on Track 225

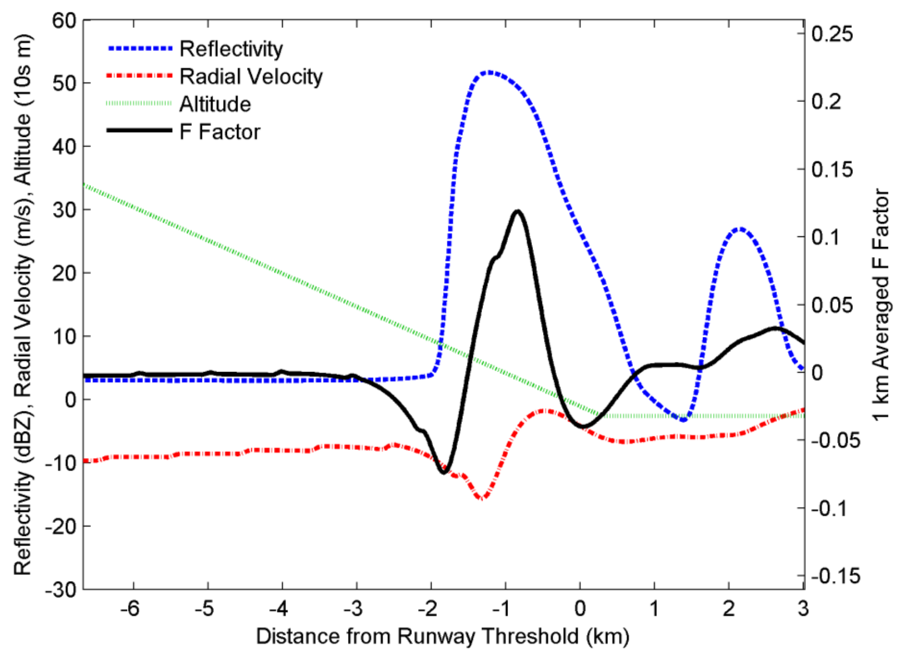

Figure B-100: PWS Scenario 33: Data Set/Time #614, Straight-In Approach on Track 270

The black solid line represents the 1 Kilometer averaged F-factor or FBAR, the blue dashed line represents the reflectivity (in dBZ), the green dotted line represents the altitude of the sensor (in 10s meter, so multiply by 10 to get meters), and the red dash-dot line represents the wind velocity along the flight path (in m/s).

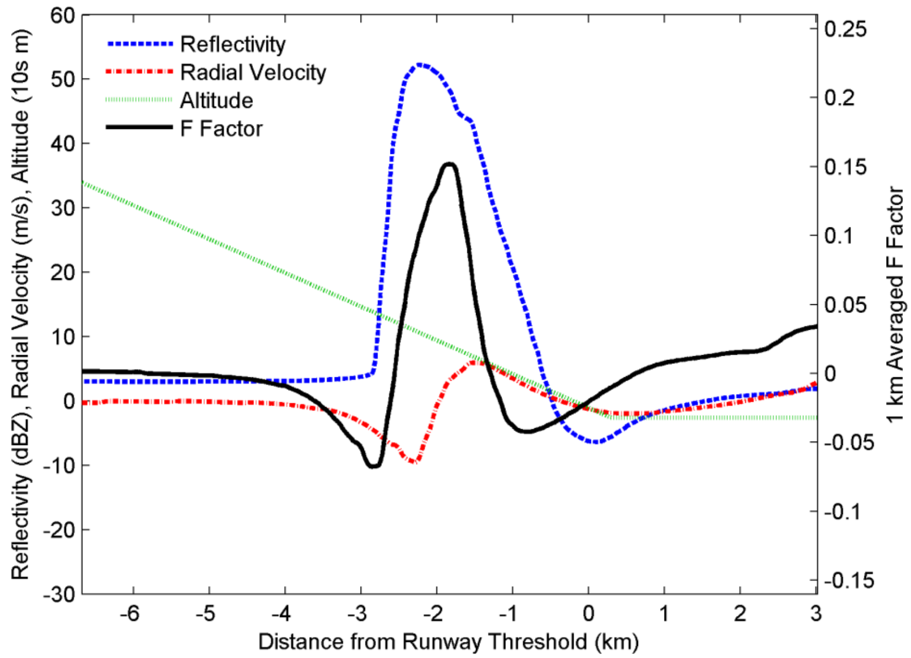

Figure B-101: PWS Scenario 34: Data Set/Time #614, Straight-In Approach on Track 315

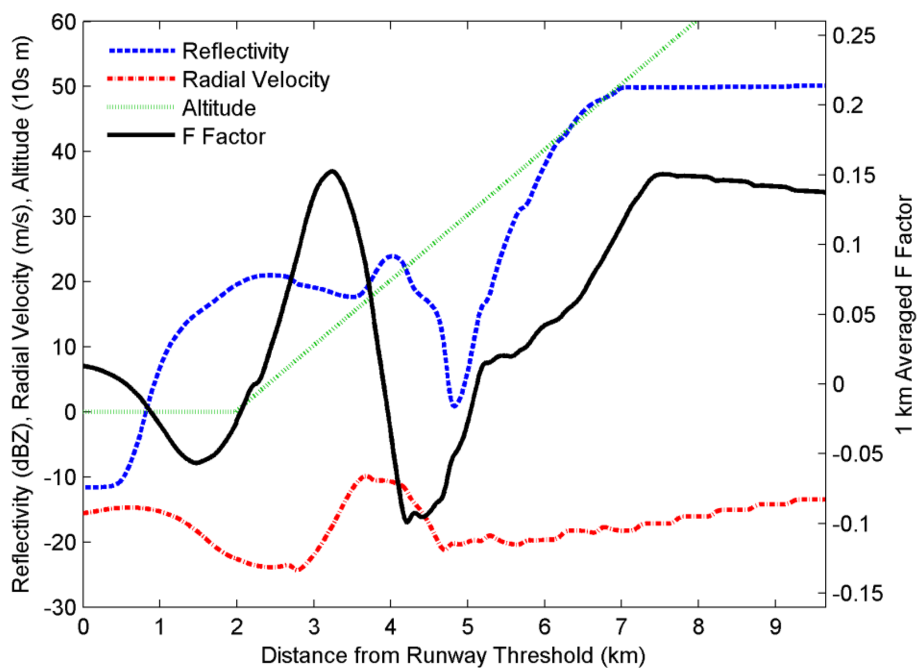

Figure B-102: PWS Scenario 35: Data Set/Time #727, Aligned for Takeoff on Track 270

The black solid line represents the 1 Kilometer averaged F-factor or FBAR, the blue dashed line represents the reflectivity (in dBZ), the green dotted line represents the altitude of the sensor (in 10s meter, so multiply by 10 to get meters), and the red dash-dot line represents the wind velocity along the flight path (in m/s).

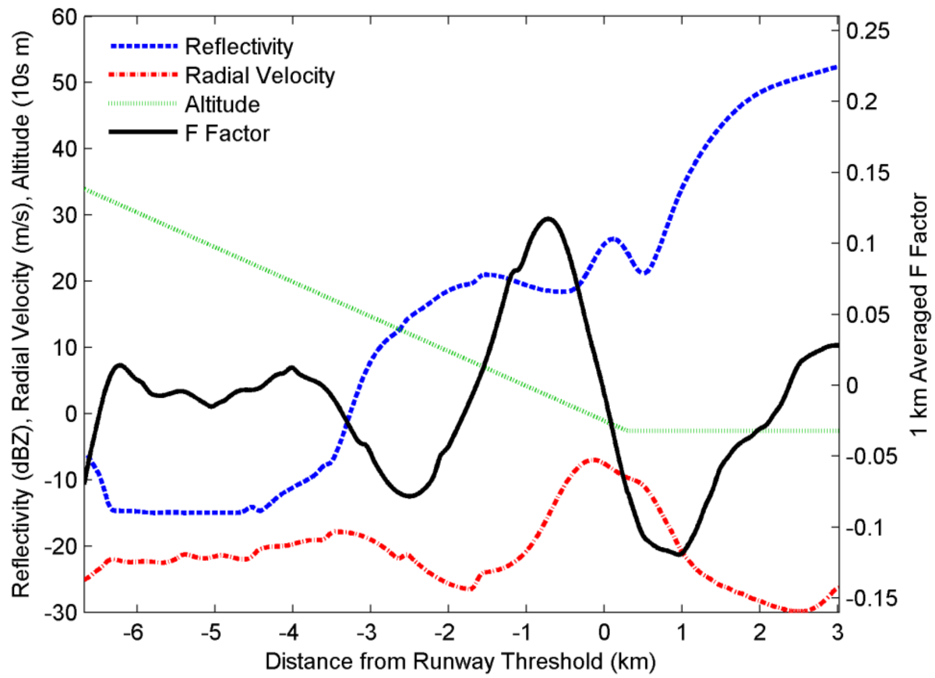

Figure B-103: PWS Scenario 36: Data Set/Time #727, Straight-In Approach on Track 270

APPENDIX C ANALYTICAL TECHNIQUE FOR EVALUATION OF MISSED EVENTS & NUISANCE ALERTS

This appendix has been drawn from the technical report by [Britt 1993] [W-3].

C.1 Introduction

This memo summarizes a method for calculation of the detection probability for the NASA windshear radar. It should be noted that the effect of ground clutter is not considered in these calculations. It is expected that in most cases, ground clutter will define the limits of system performance.

The equations used in the calculations are associated with the specific signal and data processing techniques used in the NASA experimental radar system. For calculations on radar systems using different parameters and processing techniques, modify the equations accordingly.

C.2 Single Pulse SNR

The single pulse signal-to-noise ratio as a function of the system parameters and the rain reflectivity is given by:

$$\frac{S}{N} = \frac{P_t\, G^2\, \tau\, \theta_B\, \varphi_B\, \Delta R\, \pi^6 \left|k_w\right|^2 Z_e\, 10^{-18}}{4 R^2 \lambda^2 (4\pi)^3 (k\, T_0\, F_n) L} \tag{C-1}$$

Where:

S/N = Signal-to-noise ratio, SNR (linear)

P_t = Transmitted power (watts)

G = Antenna gain (linear)

λ = Wavelength (m)

τ = Pulse width (s)

θ_B = Antenna 3 dB azimuth beamwidth (radians)

φ_B = Antenna 3 dB elevation beamwidth (radians)

ΔR = Range bin size (m)

$|k_w|^2$ = 0.92

where $k_w = (m^2 - 1) / (m^2 + 2)$ and m = complex refractive index of water

Z_e = Equivalent reflectivity factor (mm^6/m^3)

R = Range to target (m)

k = Boltzmann constant = 1.38×10^{-23} (J/K)

T_0 = 290 K

L = System losses (linear)

F_n = System noise figure (linear)

C.3 Velocity Measurement Error

The variance of a single power weighted mean velocity measurement as a function of SNR (using FFT processing) is derived in [Doviak and Zirnic 1993] [W-4] as

$$\sigma_v^2 = \frac{\lambda^2}{4MT_s^2}\left[\frac{\sigma_{wn}}{4\sqrt{\pi}} + 2\sigma_{wn}^2\frac{N}{S} + \frac{1}{12}\left(\frac{N}{S}\right)^2\right] \tag{C-2}$$

Where:

M = Number of samples used in FFT

T_s = Time between (uniform) samples (s)

σ_{wn} = Normalized spectral width of the weather signal ($2\sigma_w T_s/\lambda$)

σ_w = Spectral width (m/s)

$\frac{N}{S}$ = Single pulse noise-to-signal ratio

This equation is an approximation and assumes Gaussian signal spectra of narrow width relative to the Nyquist frequency.

C.4 Errors in Hazard Factor Estimation Using the Least-Squares Algorithm

The least-squares horizontal hazard estimator estimates the slope of the velocity measurements values along a range line. An expression for the standard deviation of the slope [Wonnacott and Wonnacott 1969] [W-8]) can then be related to the standard deviation of the total hazard factor, giving:

$$\sigma_F = \frac{3.464\ \sigma_v\left[\frac{V}{g} + \left(\frac{2h}{V}\right)\right]}{\Delta R\left[\left(N_e+1\right)\left(N_e-1\right)N_e\right]^{0.5}} \tag{C-3}$$

Where:

ΔR = Range bin size (m)

N_e = Number of points used in least-squares estimator

V = Aircraft ground speed and aircraft air speed (m/s) (assumed to be equal)

g = Acceleration due to gravity (m/s^2)

h = Altitude AGL of the center of the resolution volume (m), assumed to be 100 m

σ_v = Standard deviation of an individual velocity measurement (from eq. C-2) (m/s)

σ_F = Standard deviation of the total hazard factor

C.5 Errors in Averaging the Hazard Factor Estimates Along an Azimuth Line

The process of averaging several least-square hazard factor estimates over a range of 1000m to provide an averaged hazard factor ($\hat{F}$) can be considered as providing a weighted sum of the individual measurements of velocity over the averaging distance. An expression can be derived for the variance of $\hat{F}$ as:

$$\sigma_{\bar{F}}^2 = \frac{12\ \sigma_F^2}{\left[N_e\left(N_e+1\right)\left(N_e-1\right)\right]N_a^2}\left[\Sigma_j\left(\Sigma_i C_i\right)_j^2\right] \qquad \text{(C-4)}$$

Where:

N_e = Number of samples in least-square estimate

N_a = Number of individual F-Factor measurements averaged

σ_F^2 = Variance of individual F-Factor measurements

C = X_i / ΔR = normalized weighting factor of i^{th} measurement at a distance X_i from the measurement at i = 0.

ΔR = Distance between velocity measurements

$(\Sigma C_i)_j^2$ = Sum of weights of j^{th} velocity measurement squared

$\Sigma_j(\Sigma C_i)_j^2$ = Total of squared weights of all measurements used

$\sigma_{\bar{F}}^2$ = Variance of the averaged hazard factor or FBAR

For N_e and N_a odd ($N_a > N_e$), there will be a total of $N_a + N_e - 1$ velocity measurements used to calculate $\hat{F}$, each with a weighting factor associated with the measurement.

For example, for Ne = 5 and Na = 7, there are 11 velocity measurements involved. For an averaged $\hat{F}_j$ with index 0, the velocity measurements used will range from V-5 to V+5, and the squared normalized weights on each measurement are:

$$\left(\Sigma C_i\right)_{-5}^2 = 4 \quad \left(\Sigma C_i\right)_{-2}^2 = 4 \quad \left(\Sigma C_i\right)_{1}^2 = 0$$

$$\left(\Sigma C_i\right)_{-4}^2 = 9 \quad \left(\Sigma C_i\right)_{-1}^2 = 0 \quad \left(\Sigma C_i\right)_{2}^2 = 4 \quad \left(\Sigma C_i\right)_{4}^2 = 9$$

$$\left(\Sigma C_i\right)_{-3}^2 = 9 \quad \left(\Sigma C_i\right)_{0}^2 = 0 \quad \left(\Sigma C_i\right)_{3}^2 = 9 \quad \left(\Sigma C_i\right)_{5}^2 = 4$$

So that

$$\Sigma_j\left(\Sigma C_i\right)_j^2 = 52.$$

Thus, the calculation using eq. C-4 is:

$$\sigma_{\bar{F}}^2 = \frac{\sigma_F^2}{10}\left(\frac{52}{49}\right) = 0.106\ \sigma_F^2$$

$$\sigma_{\bar{F}} = 0.32\ \sigma_F$$

For this case, the averaging has improved the standard deviation of the least-squares measurements by a factor of 0.32.

C.6 Averaging Over Adjacent Azimuth Lines

If the measurements are taken over several adjacent azimuth lines, it will be assumed that the measurement errors are not correlated, and the variance of the averaged F will be reduced as follows:

$$\sigma_{\hat{F}} = \frac{\sigma_{\bar{F}}}{\sqrt{n_\theta}} \qquad \text{(C-5)}$$

Where:

n_θ = the number of azimuth lines over which the measurement is averaged

$\sigma^2_{\bar{F}}$ = Standard deviation of the averaged hazard factor or FBAR

$\sigma_{\hat{F}}$ = Standard deviation of measurement error

C.7 Missed Detection and Detection Probability (Single Scan)

If it is assumed that the probability density of the hazard estimate $f(\hat{F})$ is normally distributed ($\hat{F}_a, \sigma_{\hat{F}}$), then the probability of detection of a hazard of level $\hat{F}_a$ on a single scan as a function of range is (see Figure C-5)

$$PD(R/\hat{F}_a, Z) = \int_{FT}^{\infty} f(\hat{F}/\hat{F}_a, Z)\, d\hat{F} \qquad \hat{F}_a > FT \qquad \text{(C-6)}$$

Where:

$f(\hat{F}/\hat{F}_a, Z)$ = Probability density function of the 1000 m averaged F-Factor ($\hat{F}$) for given values of F-factor $\hat{F}_a$ and reflectivity value Z (conditional probability density)

$\hat{F}_a$ = Value of hazardous F-factor (must-alert level) = 0.130

FT = Hazard detection threshold

R = Range

$\sigma_{\hat{F}}(Z)$ = Standard deviation of measurement error

Z = Reflectivity

The probability of a missed detection on a single scan is therefore:

$$PM(R/\hat{F}_a, Z) = 1 - PD(R/\hat{F}_a, Z) \qquad \hat{F}_a > FT \qquad \text{(C-7)}$$

C.8 Nuisance Alert Probability

A nuisance alert will be given if the system alerts on a hazard with $\hat{F}$ less than the threshold value FT. In this case, if $f(\hat{F})$ is normal ($\hat{F}_{na}, \sigma_{\hat{F}}$), the probability of a nuisance alert in a single scan is

$$PN(R/\hat{F}_{na}, Z) = \int_{FT}^{\infty} f(\hat{F}/\hat{F}_{na}, Z)\, d\hat{F} \qquad \hat{F}_{na} < FT \qquad \text{(C-8)}$$

Where:

$\hat{F}_{na}$ = Value of non-hazardous F-factor (nuisance alert level) = 0.085

$\sigma_{\hat{F}}(Z)$ = Standard deviation of measurement error

FT = Hazard detection threshold

C.9 Multiple Pixel Detection Requirements

In the NASA system, a detection on a single pixel will not trigger an alert. Instead, an area threshold is used such that several adjacent pixels need to indicate a hazard in order to declare an alert (i.e., the sum of the areas of the individual pixels indicating a hazard will exceed the area threshold). This feature is incorporated to reduce the possibility of a false alert due to noise or ground clutter.

To take this feature into account in the detection probability calculations, it is necessary to estimate the probability of a hazard detection or nuisance detection in M pixels simultaneously. This calculation is difficult because the pixels in the range direction are highly correlated (due to the hazard averaging process). If averaging over adjacent pixels in the azimuth direction is done, correlations will also exist in this direction.

To avoid extremely complex calculations, the assumption will be made that pixels in the range direction are 100% correlated and the pixels in the azimuth direction represent independent measurements.

The probabilities of simultaneous detection and of nuisance detection in M independent pixels are:

$$PD(R) = \left[PD^{s}(R)\right]^{M} \tag{C-9}$$

$$PN(R) = \left[PN^{s}(R)\right]^{M} \tag{C-10}$$

where the nomenclature indicating the probabilities are conditional on values of $\hat{F}_a$ and Z has been omitted for simplicity in writing and:

M = Number of adjacent pixels within area threshold in the azimuth direction

$PD^s(R)$ = Probability of a detection in a single pixel

$PN^s(R)$ = Probability of a nuisance detection in a single pixel

and as an approximation,

$$M \approx INT\left(\frac{(A_T)^{1/2}}{R\Delta\theta}\right) + 1$$

Where:

A_T = Pixel area threshold (m^2)

$\Delta\theta$ = Pixel angular width (rad)

R = Range to pixel (m)

INT = Integer operator

The errors caused by the above approximation should be small since with the ranges and area threshold used (0.2 sq km), the value of M will be small (≈ 2 – 4) over the ranges of interest.

C.10 Requirement for Hazard Detection on More Than One Azimuth Scan

To reduce false alerts due to clutter, the NASA radar has a provision to require detection of a hazard on N_s consecutive scans of the radar, with N_s usually set to a value of two. This requirement has the effect of reducing both the detection and nuisance alert probabilities as compared to the single scan values.

When detection on N_s scans is required prior to declaring an alert, the probability of declaring the alert can be written as

$$[PD'(R)]_i = \prod_{k=1}^{N_s} [PD(R)]_{i-k+1} \tag{C-11}$$

and the probability of a missed alert is

$$[PM'(R)]_i = 1 - [PD'(R)]_i \tag{C-12}$$

In the above equations,

i = Scan number starting at initial scan, i = 1, 2, … N

$[PD^s(R)]_i$ = Probability of detection on scan i

k = Scan index, $1 \le k \le N_s$

Similarly, the probability of a nuisance alert on scan i is given by

$$[PN'(R)]_i = \prod_{k=1}^{N_s} [PN(R)]_{i-k+1} \tag{C-13}$$

C.11 Cumulative Probability of Detection and Nuisance Alert

With each azimuth sweep of the radar, the system has a new opportunity to detect a hazard. With multiple scans, the cumulative probability of at least one detection in N scans is:

$$[PD(R)]_i = 1 - \prod_{k=1}^{N} [PM'(R)]_{i-k+1} \tag{C-14}$$

Where $[PM'(R)]_i$ is the probability of a missed detection on scan i (from eq. C-12).

Similarly, the cumulative probability of at least one nuisance alert in N scans of a non-hazardous windshear is

$$[PN(R)]_i = 1 - \prod_{k=1}^{N} [1 - PN'(R)]_{i-k+1} \tag{C-15}$$

Where $[PN(R)]_i$ is the probability of a nuisance alert on scan i, and $[1 – PN'(R)]_i$ is the probability of no nuisance alert on scan i.

The NASA system does not start making measurements of velocity and hazard factor until the SNR of the system exceeds a threshold level SNR_T. Thus, the total number of scans observed after closing to a range R from an approaching hazard is

$$N(R) = INT\left[\frac{R_T - R}{V T_s}\right] + 1 \qquad R_M \le R \le R_T \tag{C-16}$$

Where:

INT = Integer operator

R_T = Range at which SNR > SNR_T (m)

V = Aircraft ground speed (m/s)

T_s = Scan interval (s)

R_M = Minimum radar range (m)

Equations C-14, C-15, and C-16 permit the calculation of the cumulative probabilities of detection and nuisance alarm for given values of "must-not-alert" and "must-alert" hazard, SNR threshold, weather reflectivity, and system parameters.

C.12 Calculations

C.12.1 Discussion

A program has been developed to make the calculations described above. The calculations have been made for the NASA system both with and without the special techniques used to reduce false alerts due to clutter. These techniques include the use of an area threshold (requiring hazard detection in more than one pixel) and the requirement for the detection of a hazard on two consecutive scans of the radar prior to declaring an alert.

The NASA system also uses a power level threshold such that no velocity of hazard measurements are made if the received power is less than this threshold. The value of this threshold strongly affects calculations of cumulative probabilities, since the threshold determines where the accumulation of probabilities starts. The threshold also affects the single-scan probability calculations, since the probability of a detection (or nuisance detection) is zero unless the power (or SNR) is above the threshold. To provide maximum information on the plots calculated, the power threshold is not used in single-scan probability calculations. The threshold is used for the cumulative probability calculations and the value selected is shown on the associated plot.

All hazard factor calculations are based on an aircraft ground speed of 80 m/s and an altitude of 100 m.

C.12.2 Calculation of SNR and Measurement Errors

Figure C-1 provides a list of system parameters used in the calculations. The single-pulse SNR (eq. C-1) of the system is plotted versus range in Figure C-2 for three values of rain reflectivity.

Figure C-3 plots the resulting standard deviation of velocity (eq. C-2) versus range for a weather spectral width of 3 m/s.

Figure C-4 plots the standard deviation of the averaged F-factor (eqs. C-3, C-4 and C-5). In this plot, it is assumed that no averaging over adjacent azimuth lines is used (i.e., $n_\theta = 1$).

C.12.3 Probability Calculations

A sketch showing the technique for calculation of detection and nuisance alert probability is given in Figure C-5. The mean averaged F-factor for detection of a hazard is selected as 0.130 (must-alert value) and the mean averaged F-factor for nuisance alert calculations is 0.085 (must-not alert value). The system hazard factor threshold is 0.105.

Based on the above values, the probability of a missed detection of a 0.130 microburst is plotted vs. radar range in Figure C-6 for three values of weather reflectivity. Figure C-7 shows the probability of a nuisance detection of a 0.085 microburst vs. range. Neither of these plots shows the effect of an SNR threshold. The threshold would make the plot of missed detection go to one and the plot of nuisance detection go to zero at ranges where the signal level was below the threshold value.

Figure C-8 plots the detection and nuisance alert probability vs. the single-pulse SNR level. At low SNR, both curves approach an asymptotic value of 0.5 due to the nature of the calculation (see Figure C-5).

Figure C-9 plots the ratio of the detection probability to the nuisance alert probability vs. single-pulse SNR. Figure C-10 is a similar plot except that the post-processed SNR (based on 128 pulses) is used as the ordinate. These curves permit selection of an SNR threshold that will provide a desirable single scan ratio of detection to nuisance alert. A value of log 1 for this ratio (i.e., 1 nuisance alert per 10 true alerts) will be attained using an SNR threshold of approximately -3 dB (single pulse SNR) or + 7.5 dB (processed SNR). This value is used for the following cumulative probability calculations.

Cumulative probability calculation using equations C-14 and C-15 are shown in Figure C-11, Figure C-12, and Figure C-13 for -5, 0, and +5 dBZ respectively. The detection probability rapidly goes to unity just after the SNR threshold is reached. The nuisance alert probabilities reach an asymptotic value as shown.

C.12.4 Probability Calculations with the NASA Clutter Suppression Techniques Considered

The above calculations were made assuming no hazard area threshold or multiple scan detection was used. Calculations using these features have also been made and are plotted in Figure C-14 through Figure C-18.

Figure C-14 and Figure C-15 plot the probability of missed detection and nuisance detection for the NASA system using hazard detection on two radar scans prior to declaring an alert and a hazard area threshold of 0.2 sq. km. The steps in the plots are caused by the multiple scan detection requirement and the hazard area thresholding effect.

The associated cumulative probability plots using an SNR threshold of -3 dB (single pulse) are shown in Figure C-16, Figure C-17, and Figure C-18. Notice that the probability of a nuisance alert has been reduced considerably and the probability of a missed detection has been increased somewhat at a given range.

C.13 Summary and Conclusions

The equations and calculations discussed above provide a useful exercise in determining the expected radar system performance as limited by receiver noise. They also can provide a guide to threshold settings and the effect of these thresholds on detection performance.

The threshold settings used in the calculations have not been optimized, and further calculations will be made to adjust the thresholds to provide an optimized tradeoff between detection and nuisance alert performance.

C.14 Figures

Transmitted Power (watts)	200.0
Frequency (GHz)	9.3
Pulse width (μs)	1.0
Range bin size (m)	150.0
Pulse repetition rate (Hz)	3755.0
System noise figure (dB)	4.0
System losses (dB)	1.0
Antenna 3 dB azimuth beamwidth (deg)	3.5
Antenna 3 dB elevation beamwidth (deg)	3.5
Antenna gain (dB)	34.0
Number of F-Factors averaged	7
Number of samples in least-square estimate	5
Number of azimuth lines averaged	1
Number of pulses processed (or FFT size)	128
Aircraft air speed and ground speed (m/s)	80.0
Rain reflectivity (dBz)	0
Rain spectral width (m/s)	3.0
Altitude of center of the resolution volume (m)	100.0
Hazard detection threshold or F-Factor threshold	0.105
Must-alert F-Factor	0.130
Antenna scan interval (s)	4.2
Must-not-alert F-Factor	0.085
SNR threshold for detection (dB)	-3.0
Pixel area threshold (km2)	0.2
Pixel azimuth angular width (deg)	2.0
Number of scans for detection	2

Figure C-1: List of Parameters for Calculation of Detection and Nuisance Alert Probabilities Shown in Subsequent Figures.

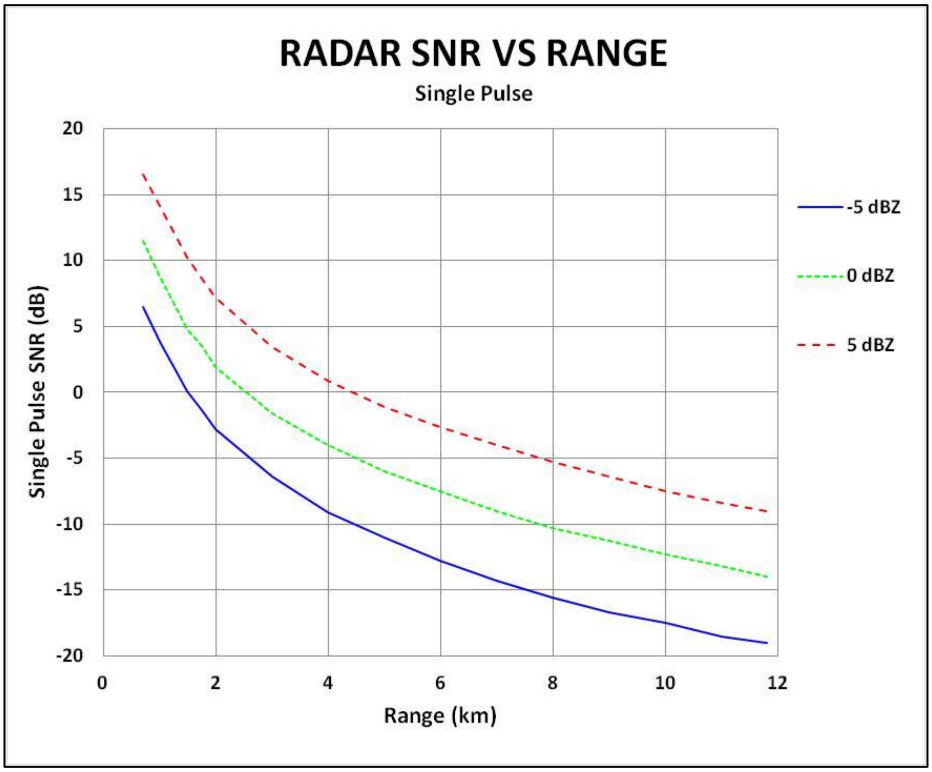

Figure C-2: Radar Single Pulse Signal-To-Noise Ratio versus Radar Range for Three Values of Rain Reflectivity.

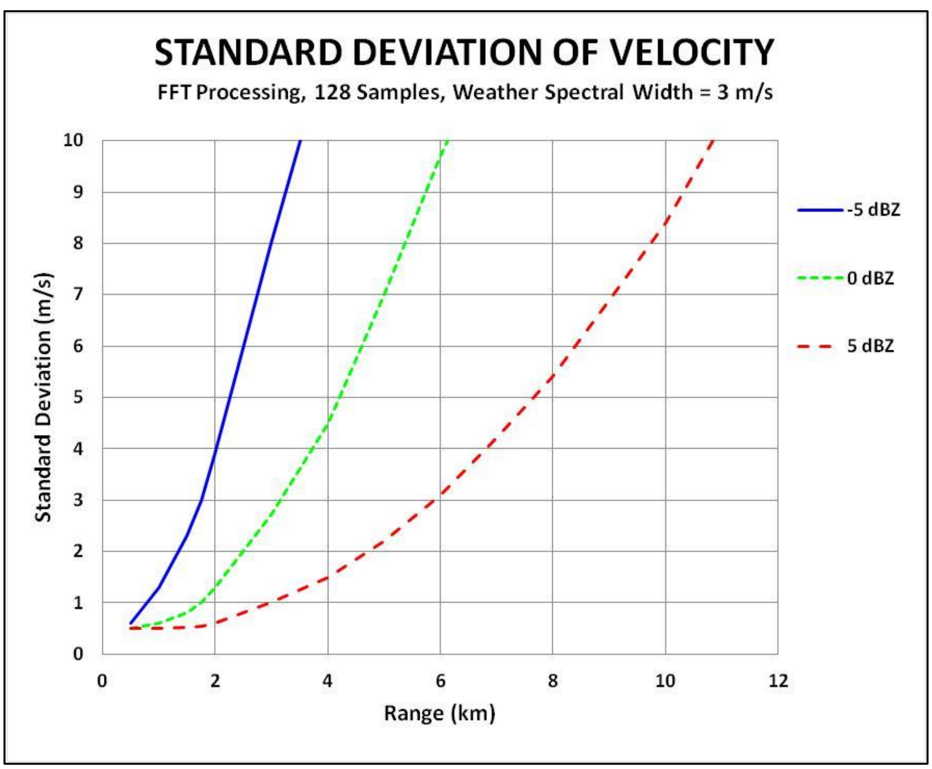

Figure C-3: Standard Deviation of a Velocity Measurement Based on FFT Processing of 128 Pulses. The Weather Spectral Width = 3 m/s.

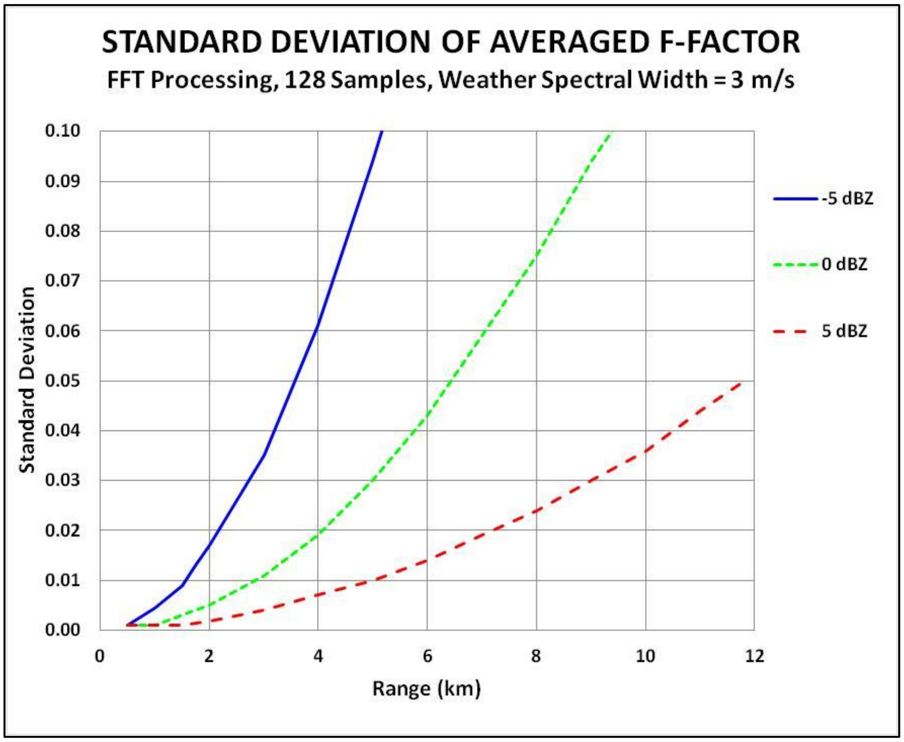

Figure C-4: Standard Deviation of 1000 Meter Averaged F-Factor (or FBAR) Using FFT Processing of 128 Samples. No Averaging Over Adjacent Azimuth Lines Is Used.

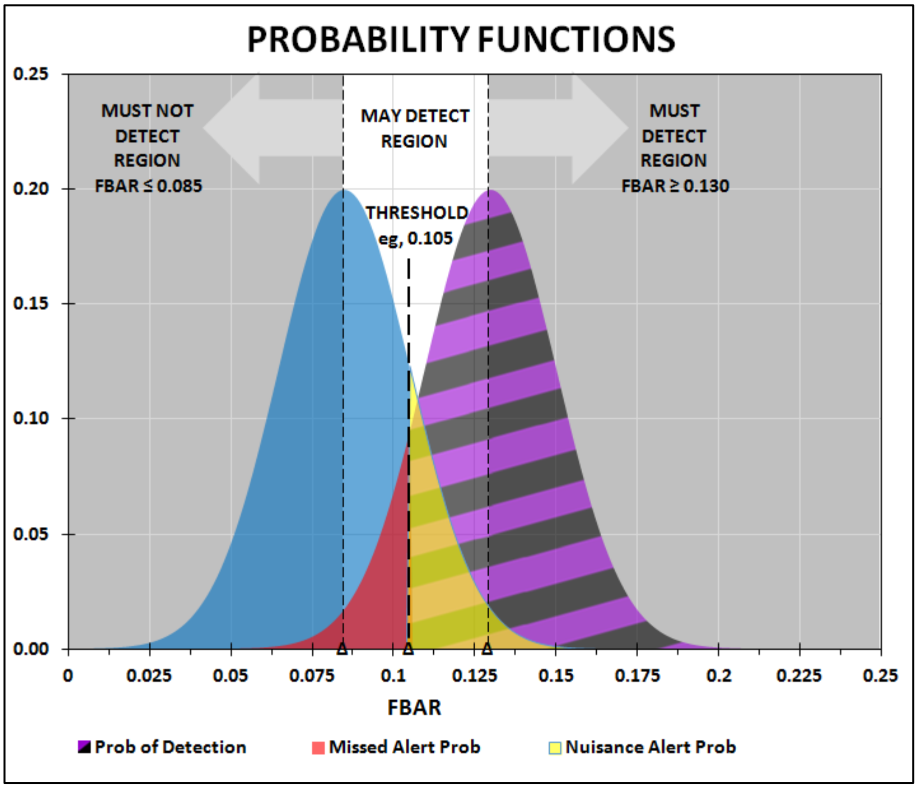

Figure C-5: Sketch Indicating the Technique for Calculation of Detection and Nuisance Alert Probability: Must-Alert F-Factor = 0.13 And Must-Not-Alert F-Factor = 0.085.

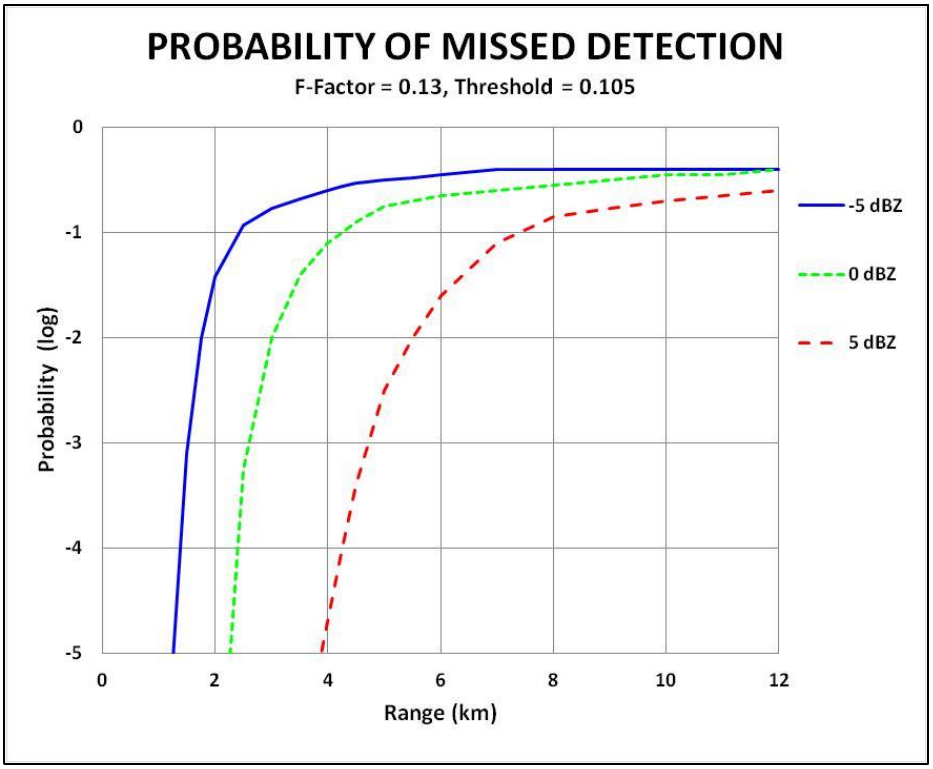

Figure C-6: The Probability of a Missed Detection of a 0.13 Averaged Hazard Plotted versus Range.

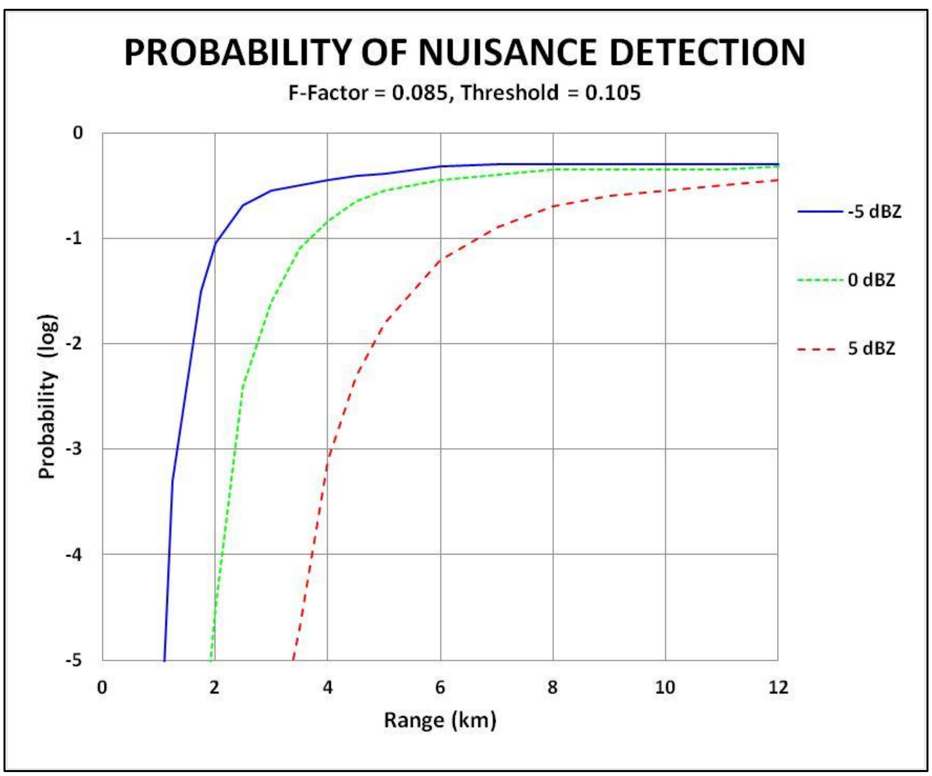

Figure C-7: The Probability of a Nuisance Detection of a 0.085 Averaged Hazard Plotted versus Range.

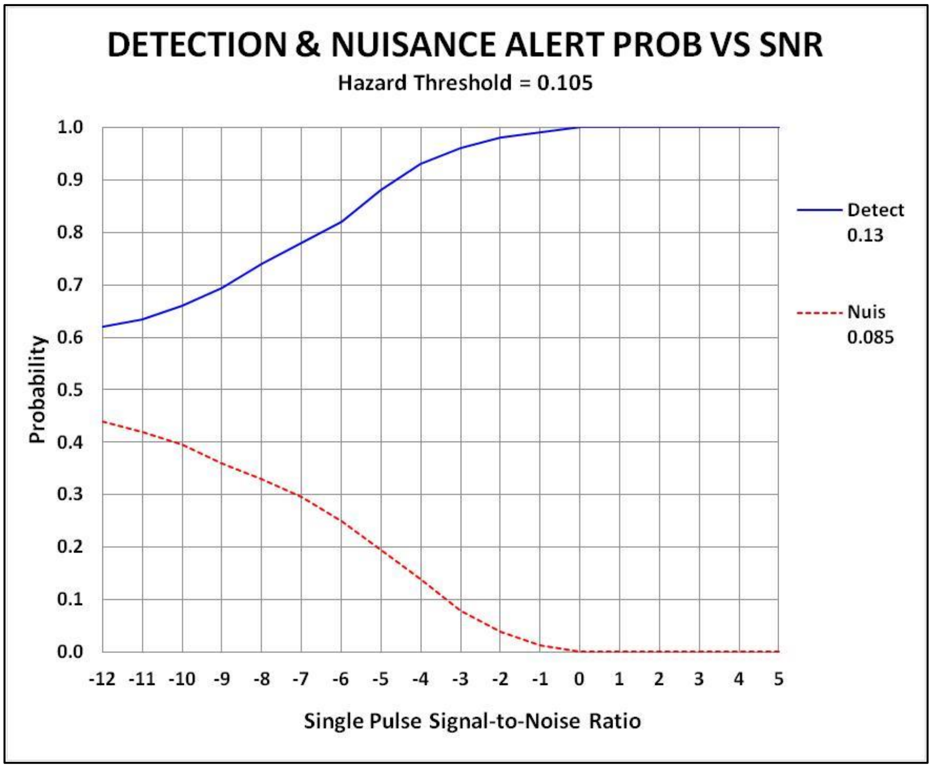

Figure C-8: Detection and Nuisance Alert Probability Plotted versus The Single Pulse Signal-To-Noise Ratio.

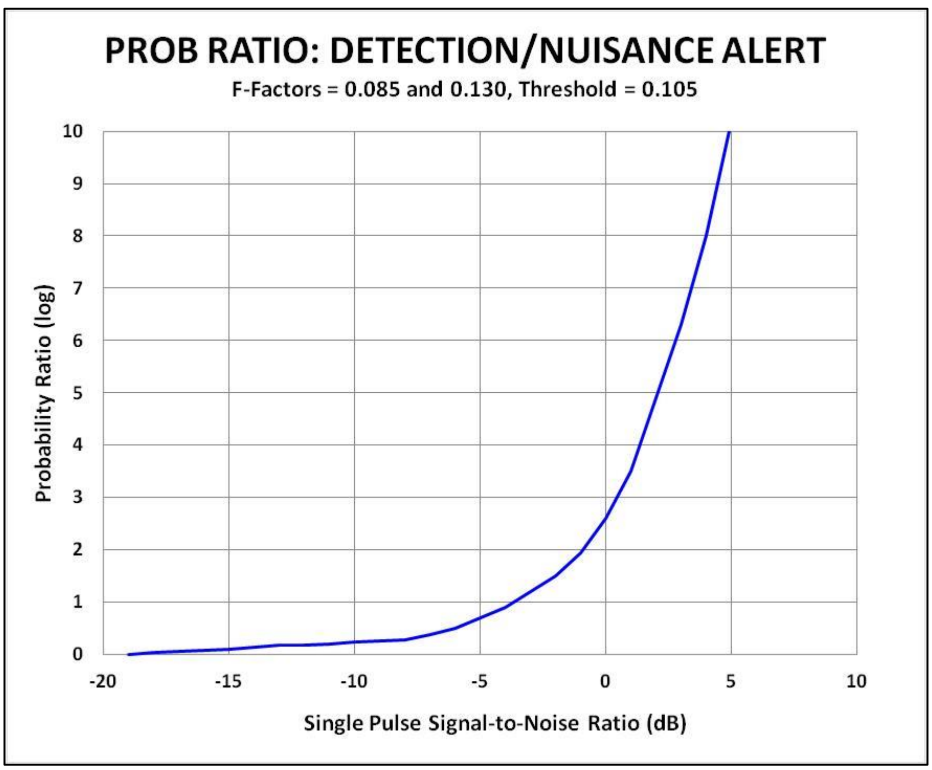

Figure C-9: Ratio of Detection to Nuisance Alert Probability Plotted versus Single Pulse Signal-To-Noise Ratio.

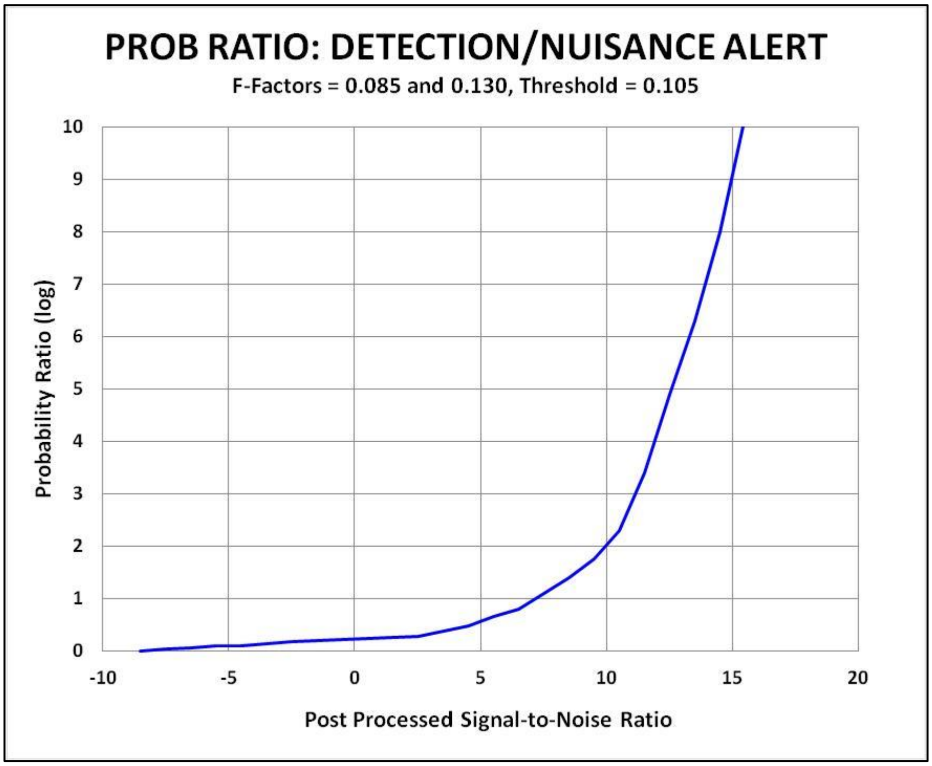

Figure C-10: Ratio Plot Similar to Figure C-9, Except That the Post-Processed Signal-To-Noise Ratio Is Used as The Ordinate. Use A Signal-To-Noise Ratio Threshold of Approximately 7.5 dB To Maintain the Ratio of One Nuisance Alert Per 10 True Alerts.

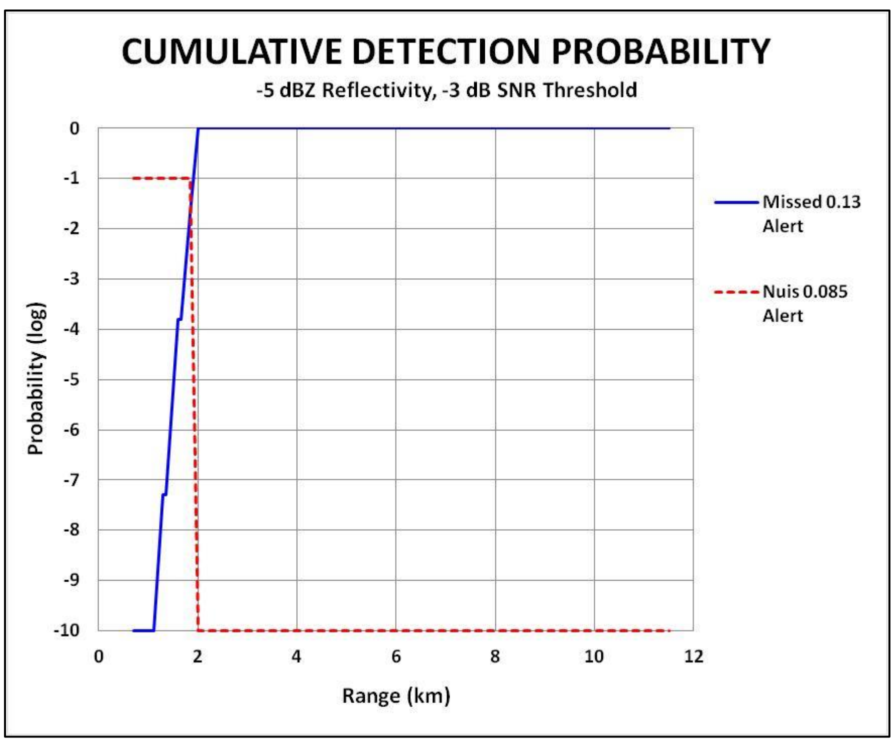

Figure C-11: Cumulative Probability of Missed and Nuisance Detection For -5 dBZ Weather Reflectivity and an SNR Threshold Of -3 dB.

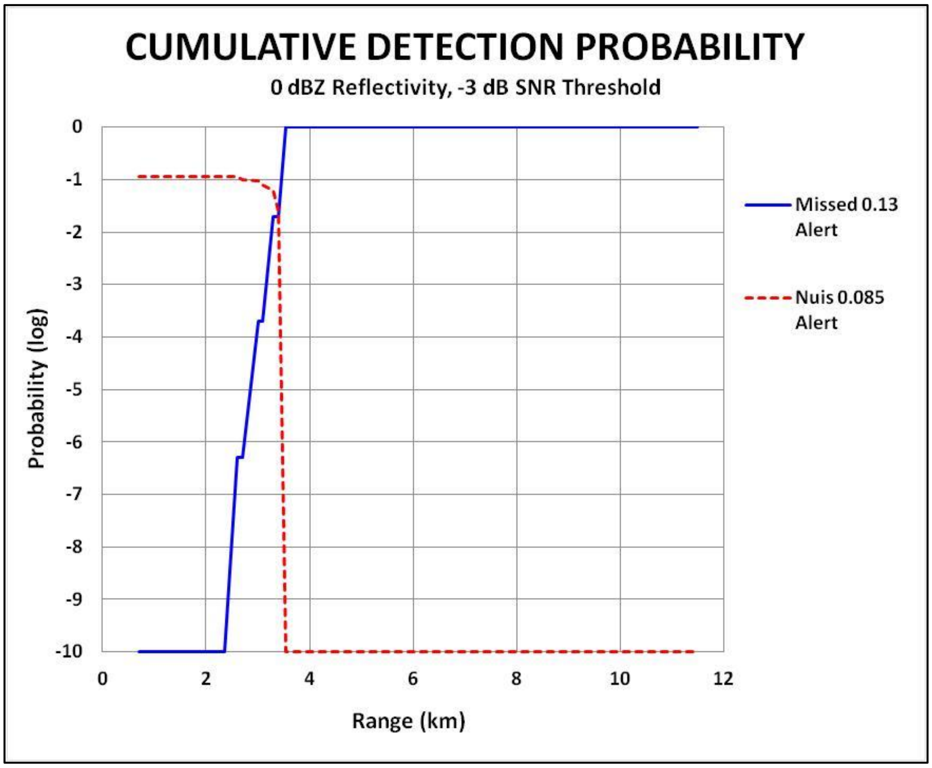

Figure C-12: Cumulative Probability of Missed and Nuisance Detection For 0 dBZ Weather Reflectivity and an SNR Threshold Of -3 dB.

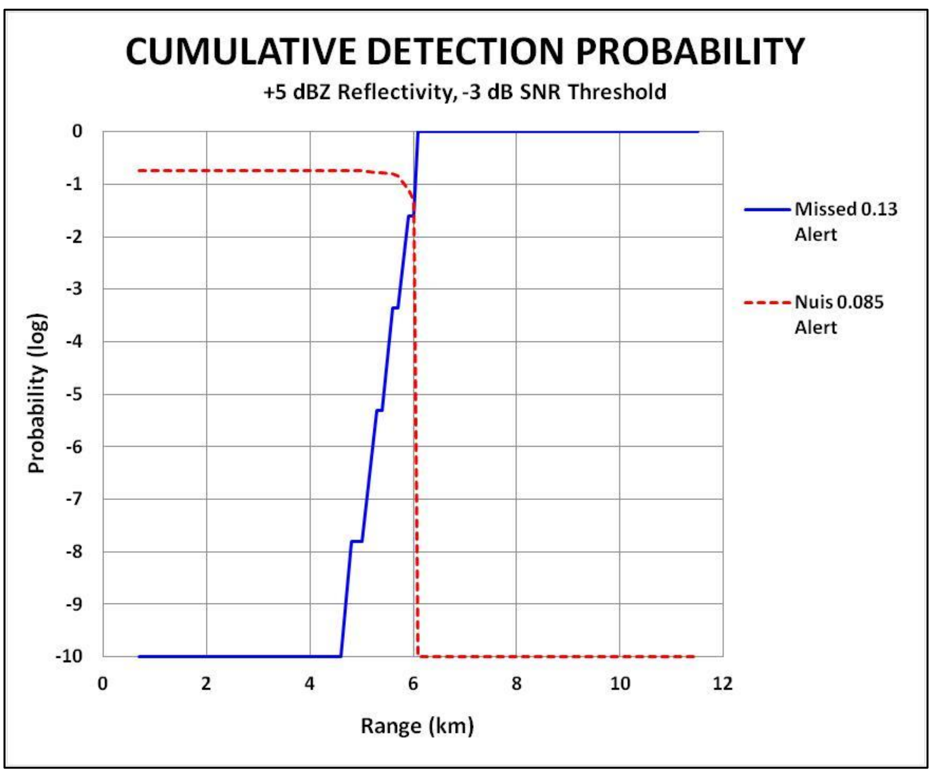

Figure C-13: Cumulative Probability of Missed and Nuisance Detection For +5 dBZ Weather Reflectivity and an SNR Threshold Of -3 dB.

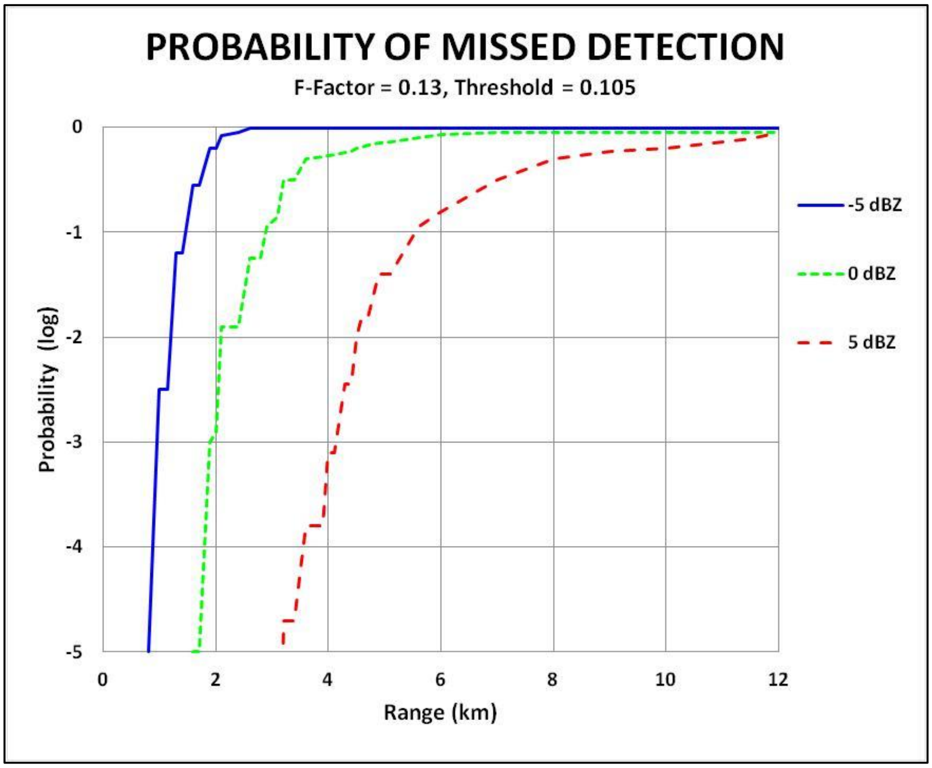

Figure C-14: Probability of a Missed Detection of a .13 Hazard for the NASA System Using a Hazard Area Threshold Of 0.2 Sq. Km. and Requiring Two Consecutive Scans Prior To Declaring an Alert.

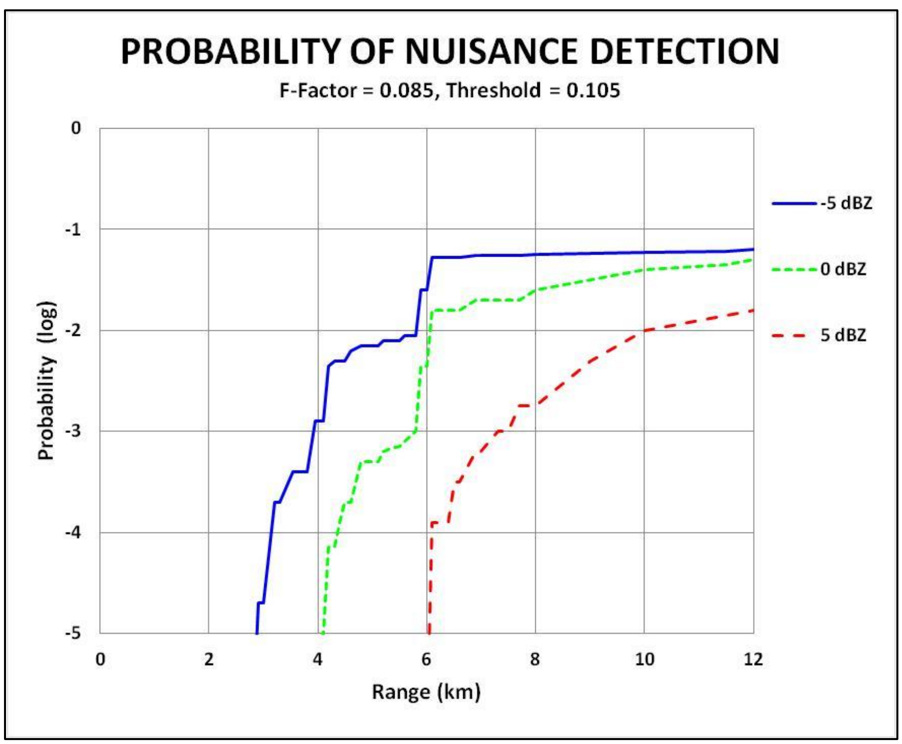

Figure C-15: Probability of a Nuisance Detection of a 0.085 Hazard for the NASA System Using a Hazard Area Threshold Of 0.2 Sq. Km. and Requiring Two Consecutive Scans Prior To Declaring an Alert.

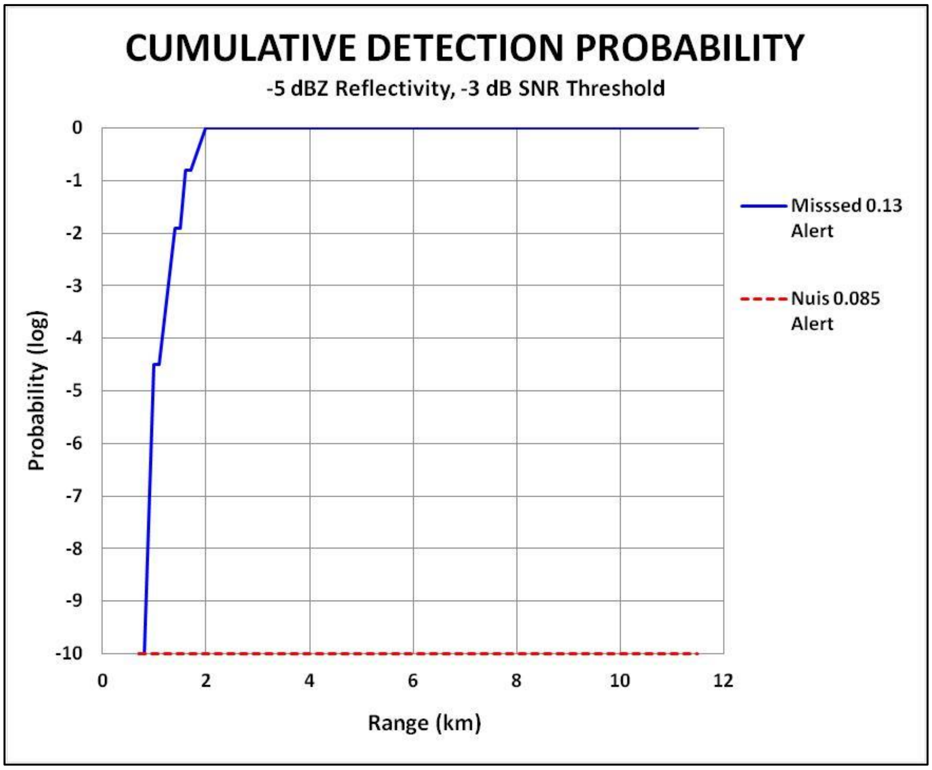

Figure C-16: Cumulative Probability of a Missed and Nuisance Detection for the NASA System with an SNR Threshold Of -3 dB and a Weather Reflectivity of -5 dBZ.

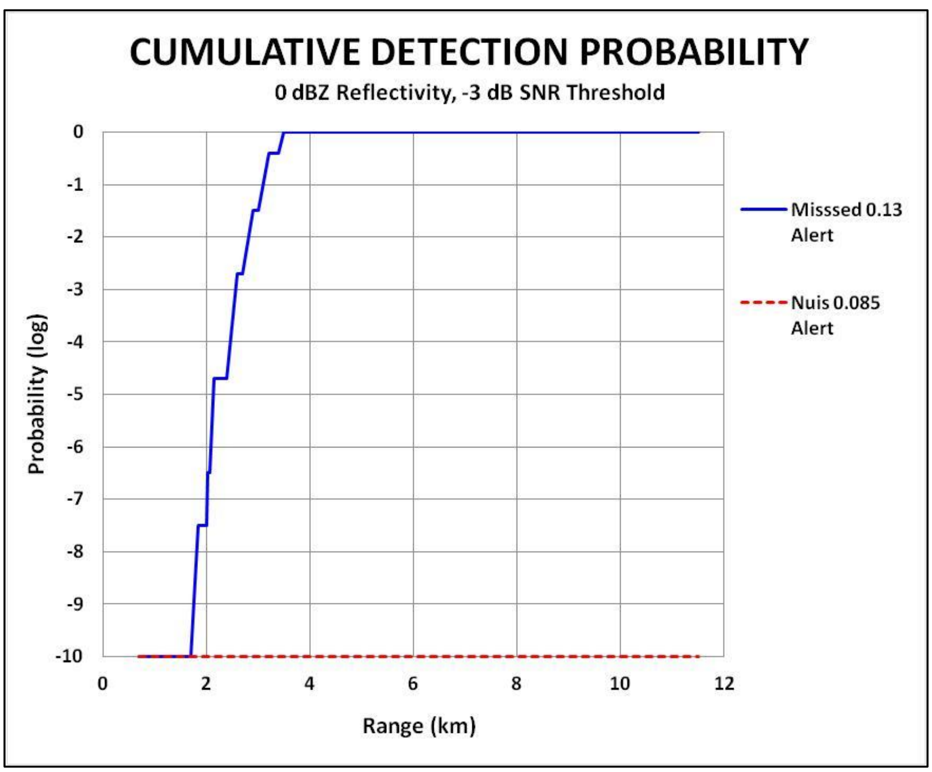

Figure C-17: Cumulative Probability of a Missed and Nuisance Detection for the NASA System with an SNR Threshold of -3 dB and a Weather Reflectivity of 0 dBZ.

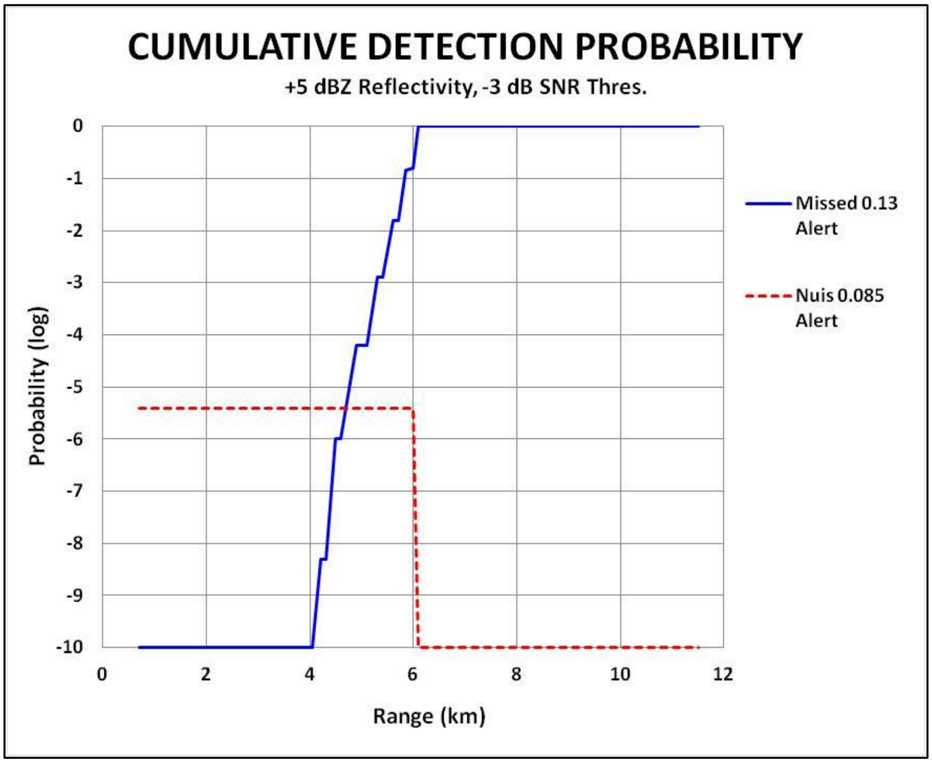

Figure C-18: Cumulative Probability of a Missed and Nuisance Detection for the NASA System with an SNR Threshold of -3 dB and a Weather Reflectivity of +5 dBZ.

APPENDIX D HISTORICAL INFORMATION AND DERIVATIONS

The following text and equations have been taken from Appendix B of RTCA/DO-173. They are captured here with slight modernization to preserve the historical derivations developed therein. These derivations do not necessarily result in the same performance indices or other values that are specified in the requirements section of this document.

D.1 Performance Index Equation Derivation

DO-173 modified the performance index equation as compared to that used in DO-134 (the precursor to DO-173). The resulting equation uses displayed Minimum Discernible Signal (MDS) as a means for establishing the radar sensitivity. The following is a derivation of this equation, which incorporates MDS:

Basic range equation:

$$R^4 = \frac{P_t g^2 \lambda^2 \sigma L}{(4\pi)^3 P_r} \qquad \text{(D-1)}$$

Where:

- P_t = Peak transmitter power (W)
- R = Range to target (nm)
- g = Antenna gain relative to isotropic (ratio)
- λ = Wavelength (nm)
- σ = Radar cross section of target $(nm)^2$
- L = Losses two way (ratio)
- P_r = MDS receiver power necessary to detect signal (W) for non-beam filling weather

$$\sigma = V_m \sum_i \sigma_i$$

$$V_m = A_w \frac{ct}{2}$$

Where:

- V_m = Volume of range cell $(nm)^3$
- c = Speed of Light (nm/μs)
- t = Pulse duration (μs)
- A_w = Physical area of weather illuminated by antenna $(nm)^2$
- $\sum_i \sigma_i$ = Summation of the σ for each object in V_m

Substituting:

$$R^4 = \frac{P_t g^2 \lambda^2 L \, ct \, A_w \sum_i \sigma_i}{2(4\pi)^3 P_r}$$

L can be divided into two factors: $L = L_a L_r$

Where:

L_a = Losses in atmosphere to and from the target ($L_a < 1$)

L_r = Losses in radar from transmitter to atmosphere and from atmosphere to receiver

Substituting:

$$R^4 = \frac{P_t g^2 \lambda^2 L_a L_r \, ct \, A_w \sum_i \sigma_i}{2(4\pi)^3 P_r}$$

Let:

$$k = \frac{c\lambda^2 A_w \sum_i \sigma_i \, L_r}{2(4\pi)^3}$$

Then:

$$R^4 = \frac{P_t g^2 \, t \, L_a \, k}{P_r}$$

Rearranging:

$$\frac{R^4}{L_a} = \frac{P_t g^2 \, tk}{P_r}$$

Expressing in dB format:

$$40\log_{10} R - 10\log_{10} L_a = 10\log_{10} P_t + 20\log_{10} g + 10\log_{10} t + 10\log_{10} k - 10\log_{10} P_r$$

Redefining terms:

$$40\log_{10} R + L_A = P_t + 2G + T + K - P_r$$

Where:

L_A = Losses in atmosphere to and from the target (dB)

Note: This term is positive since La < 1.

P_t = 10 $\log_{10}$ of the transmitter peak power in watts (dB)

G = the antenna gain in dB, referred to an isotropic radiator

T = 10 $\log_{10}$ transmitted pulse length in μs (dB)

K = Frequency factor (dB). See Weather Performance Index in Subparagraph 2.2.2.9

P_r = MDS receiver power at antenna port (dBm)

L_A is a function of R:

$$L_A(dB) = L_a \ (dB/nm) \ R\ (nm)$$

Substituting:

$$40\log_{10} R + L_a R = P_t + 2G + T + K - P_r$$

This is the form of the performance index (PI). The left side of the equation plus a constant can be used to calculate PI for a given range.

$$PI_{DO-173} = K_1 + L_a R + 40\log_{10} R$$

The K_1 term is added to keep the DO-134 method of calculating PI equivalent to this DO-173 method.

The right side of the equation is used to evaluate the particular radar system under question with the K term as per the DO-134 method of calculating PI.

$$PI_{DO-173} = P_t + 2G + T + K - P_r$$

The remaining task is to evaluate the constant K_1 such that the DO-134 method of calculating PI is equivalent to the DO-173 method.

To evaluate K_1 subtract PI_{DO-134} from PI_{DO-173}:

$$PI_{DO-173} - PI_{DO-134} = (K_1 + L_a R + 40\log_{10} R) - (10 + 40\log_{10} R)$$

Note: $PI_{DO-134} = 10 + 40\, log_{10} R$ *is the proper equation for evaluation of PI as a function of R in DO-134.*

Simplifying:

$$PI_{DO-173} - PI_{DO-134} = K_1 + L_a R - 10$$

Since the DO-134 method of calculating PI did not account for atmospheric loss we should evaluate K_1 for R = 0. As R becomes larger, the $L_a R$ term will be an added PI requirement.

For R = 0:

$$PI_{DO-173} - PI_{DO-134} = K_1 - 10$$

Rearranging:

$$K_1 = PI_{DO-173} - PI_{DO-134} + 10$$

Measurements of several radar systems by their manufacturers have resulted in an average value for $PI_{DO-173} - PI_{DO-134} = 103\, dB$.

Thus:

$$K_1 = 103 + 10 = 113\, dB$$

A separate and independently developed derivation based on target reflectivity is included below. The resulting PI equation for evaluating the radar system is identical to that in Subparagraph 2.2.2.7 of DO-173.

The Radar Range Equation has been developed in many places and usually takes the form:

$$R = \left(\frac{P_t G^2 \lambda^2 \sigma}{(4\pi)^3 P_r L}\right)^{1/4} \qquad \text{(D-2)}$$

The value of σ, which is the radar target cross-section in m^2, $miles^2$, or whatever terms are being used in the equation when used for weather detection, is defined as:

$$\sigma = \frac{\pi^5}{\lambda^4}|K|^2 Z\ (Target\ Pulse\ Volume)$$

The target pulse volume is (see Figure D-1):

Target Pulse Volume = $\left(\frac{CT}{2}\right)\left(\frac{\pi d^2}{4}\right)$

Where:

C = speed of propagation

T = transmitter pulse width

d = diameter of the storm cell

Therefore:

$$\sigma = \frac{\pi^5}{\lambda^4}|K|^2 Z \left(\frac{C\pi d^2}{8}\right) T$$

or

$$\sigma = \frac{\pi^6}{\lambda^4}|K|^2 Z \left(\frac{Cd^2}{8}\right) T \qquad \text{(D-3)}$$

When the radar target cross-section is less than antenna beam filling at the range(s) of interest, calculate the target volume using the model shown in Figure D-1 (still assuming, however, that the target depth is at least equal to the transmitted pulse width).

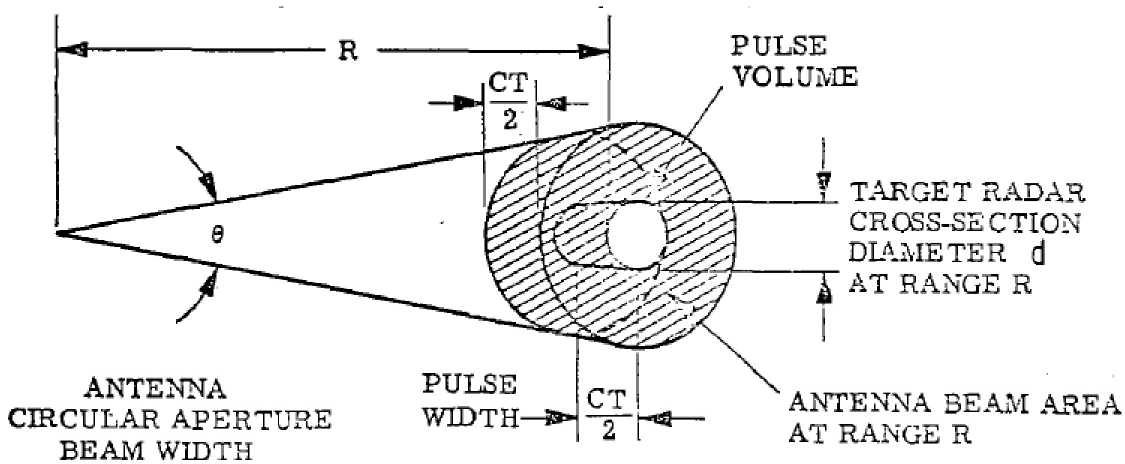

Figure D-1: Target Pulse Volume

Substituting Equation (D-3) into Equation (D-2), we obtain the meteorological radar range equation (D-4).

$$R^4 = \frac{P_t\, G^2\, T}{P_r\, L\, \lambda^2}\left[\frac{\pi^3 d^2 Z\, C\, |K|^2}{512}\right] \qquad \text{(D-4)}$$

Where:

P_t = Watts

G = Antenna gain (one way) over isotropic expressed as a ratio.

T = Transmitter pulse width in μs.

P_r = Received power at the radar R/T Waveguide Connector expressed in dBm.

L = Losses due to transmission line between R/T and antenna radiator, radome losses (these are two-way losses), system losses or gains for whatever cause which can be justified including intervening rain, and other atmospheric losses at the frequency of interest. This is a number.

d = Diameter of the storm cell in nautical miles. Three nautical miles has been the storm model in the past.

Z = Radar reflectivity factor. It has a relationship to rainfall rate. However, a reflectivity factor of $Z = 10^5$ has been used for the storm model in the past.

K = The complex index of refraction for water at the radar frequencies of interest. The absolute value of $|K|^2 = 0.93$ is commonly used.

λ = The radar carrier frequency wavelength for the particular frequency of interest. For C-Band use 5.56 cm, for X-Band use 3.2 cm and for Ku-Band use 1.9 cm as a reference.

Since the Range Equation will be expressed in nautical miles as a function of receiver sensitivity in dBm, transmitter power in watts and transmitter pulse width in microseconds, it is necessary to convert the equation terms accordingly. See Subsection D.2.

D.2 Conversion Calculations

$$C = \frac{3x10^8\, m/sec}{1852\ m/nm} = 1.61987x10^5\, nm/s$$

$$T = 10^{-6}\, s/\mu s = 10^{-6} s$$

$$d = 3\, nm$$

$$d^2 = 9\, nm^2$$

$$Z = \frac{mm^6}{m^3} \qquad 1mm = \frac{10^{-3}\ m}{1852\, m/nm} = 5.39957x10^{-7}nm$$

$$mm^6 = \left(\frac{10^{-3}m}{1852\ \ m/nm}\right)^6 = 2.4783x10^{-38}nm^6$$

$$\mathrm{m}^3 = \left(\frac{1\ \mathrm{m}}{1852\,\mathrm{m/nm}}\right)^3 = 1.5743\mathrm{x}10^{-10}\mathrm{nm}^3$$

$$Z = \frac{2.4783x10^{-38}}{1.5743x10^{-10}} = 1.5743x10^{-28}\ nm^3$$

$$Z = 10^5 = 1.5743x10^{-23}\ nm^3$$

$$\pi^3 = 31.0$$

$$|K|^2 = 0.93\ \ (for\ all\ weather\ radar\ bands)$$

$$P_r = 10^{-3}\ Watts$$

Using equation (D-4)

$$R^4 = \frac{\mathrm{P_t\ G^2\ T}}{\mathrm{P_r\ L}\,\lambda^2}\left[\frac{\pi^3\ \ \mathrm{d}^2\ \ \mathrm{Z\ \ C\ \ |K|^2\ T}}{512\ \mathrm{P_r}}\right]$$

$$R^4 = \frac{\mathrm{P_t\ G^2\ T}}{\mathrm{P_r\ L}\,\lambda^2}\left[\frac{31\ \mathrm{x}\ 9\ \mathrm{x}\ 1.5743x10^{-28}\ \mathrm{x}\ \ 1.61987x10^5\ \mathrm{x}\ \ 0.93\ x\ 10^{-6}}{512\ 10^{-3}}\right]$$

$$R^4 = \frac{\mathrm{P_t\ G^2\ T}}{\mathrm{P_r\ L}\,\lambda^2}\ (1.292308\ \mathrm{x}\ 10^{-21}) \qquad \text{(D-5)}$$

Table D-1 provides converting λ^2 to nautical miles information

Table D-1: Conversion λ2 to nautical miles

	λ (meters)	**λ^2 (nm^2)**
C-band	0.056	9.143×10^{-10}
X-band	0.032	2.98564×10^{-10}
Ku-band	0.01928	1.08376×10^{-10}

For each carrier wavelength, substitute the appropriate value of λ^2 into equation (D-5):

$$R^4 = \frac{\mathrm{P_t\ G^2\ T}}{\mathrm{P_r\ L}}\left(\frac{1.292308 \times 10^{-21}}{\lambda^2}\right) \qquad \text{(D-6)}$$

$$R_C^4 = \frac{\mathrm{P_t\ G^2\ T}}{\mathrm{P_r\ L}}\ (1.4134 \times 10^{-12}) \qquad (-118.497\ \text{dB})$$

$$R_X^4 = \frac{\mathrm{P_t\ G^2\ T}}{\mathrm{P_r\ L}}\ (4.3284 \times 10^{-12}) \qquad (-113.637\ \text{dB})$$

$$R_{Ku}^4 = \frac{\mathrm{P_t\ G^2\ T}}{\mathrm{P_r\ L}}\ (1.19242 \times 10^{-11}) \qquad (-99.2357\ \text{dB})$$

Using tables from [Skolnik 1962] [G-18] Section 12.6, and graphs prepared by the American Meteorology Society, radar attenuation as a function of rainfall rate and carrier frequency is now calculated.

For avoidance, 1 mm/hr for a range of 60 nautical miles is used, as shown in Table D-2.

For penetration, 5 mm/hr for a range of 60 nautical miles is used, as shown in Table D-2.

Table D-2: Avoidance and Penetration Calculations

	Avoidance: 1 mm/hr 2-way attenuation 60 nm	**Penetration: 5 mm/hr 2-way attenuation 60 nm**
C-band	0.0148 dB/nm x 60 nm = 0.888 dB	0.0333 dB/nm X 60 nm = 2.0 dB
X-band	0.0375 dB/nm X 60 nm = 2.25 dB	0.2408 dB/ nm X 60 nm = 14.4 dB
Ku-band	0.2222 dB/nm X 60 nm = 13.33 dB	1.1112 dB/ nm X 60 nm = 66.7 dB

A 1.6 dB antenna scanning loss normally applies for radar systems. This loss is added to the avoidance and penetration losses calculated above.

In addition, a seven-dB total radar installation loss is assumed. This loss can be apportioned as follows:

Radome loss (2-way)	2.0 dB
Transmission line joints	1.0 dB
Transmission line run	4.0 dB
Total losses	7.0 dB

If the actual installation losses differ, loss adjustments should be made according to Table D-3.

Table D-3: Actual Installation Losses Differ, Lost Adjustments

	System Losses		Avoidance		Penetration	
	Scanning	Installation	Rain	Total Losses (dB)	Rain	Total Losses (dB)
C-band	1.6	7.0	0.888	9.488	2.0	10.6
X-band	1.6	7.0	2.25	10.85	14.4	23.0
Ku-band	1.6	7.0	13.33	21.93	66.7	75.3

This material is added to Equation (D-6). Six equations will result: three for avoidance (one for each frequency band) and three for penetration (one for each band) (see Table D-4).

Table D-4: Avoidance Vs. Penetration

	Avoidance	Penetration
C-band	$R_C^4 = \frac{\mathrm{P_t\,G^2\,T}}{\mathrm{P_r}}\,(-118.497 - 9.488)\mathrm{dB}$ $= \frac{\mathrm{P_t\,G^2\,T}}{\mathrm{P_r}} - 127.985\text{ dB }(\cong -128)$	$R_C^4 = \frac{\mathrm{P_t\,G^2\,T}}{\mathrm{P_r}}\,(-118.497 - 10.6)\mathrm{dB}$ $= \frac{\mathrm{P_t\,G^2\,T}}{\mathrm{P_r}} - 129.097\text{ dB }(\cong -129)$
X-band	$R_X^4 = \frac{P_t\,G^2\,T}{P_r}\,(-113.637 - 10.85)\mathrm{dB}$ $= \frac{\mathrm{P_t\,G^2\,T}}{\mathrm{P_r}} - 124.487\,dB\ (\cong -124)$	$R_X^4 = \frac{P_t\,G^2\,T}{P_r}\,(-113.637 - 23.0)\mathrm{dB}$ $= \frac{\mathrm{P_t\,G^2\,T}}{\mathrm{P_r}} - 136.637dB\ (\cong -137)$
Ku-band	$R_{Ku}^4 = \frac{P_t\,G^2\,T}{P_r}\,(-99.2357$ $- 21.93)\mathrm{dB}$ $= \frac{\mathrm{P_t\,G^2\,T}}{\mathrm{P_r}} - 121.1657\mathrm{dB}\ (\cong -121)$	$R_{Ku}^4 = \frac{P_t\,G^2\,T}{P_r}\,(-99.2357 - 75.3)\mathrm{dB}$ $= \frac{\mathrm{P_t\,G^2\,T}}{\mathrm{P_r}} - 174.5357\,dB\ (\cong -175)$

Next convert Equation (D-6) into dB format for each carrier frequency and for both avoidance and penetration cases (see Table D-5).

Table D-5: Conversion to Db Format

	Avoidance	Penetration
C-band	$40\log R_C = 10\log P_t + 20\log \mathrm{G} + 10\log \mathrm{T} - 10\log P_r - 128\text{ dB}$	$40\log R_C = 10\log P_t + 20\log \mathrm{G} + 10\log \mathrm{T} - 10\log P_r - 129.097\text{ dB}$
X-band	$40\log R_X = 10\log P_t + 20\log \mathrm{G} + 10\log \mathrm{T} - 10\log P_r - 124\text{ dB}$	$40\log R_X = 10\log P_t + 20\log \mathrm{G} + 10\log \mathrm{T} - 10\log P_r - 137\text{ dB}$
Ku-band	$40\log R_{Ku} = 10\log P_t + 20\log \mathrm{G} + 10\log \mathrm{T} - 10\log P_r - 121\text{ dB}$	$40\log R_{Ku} = 10\log P_t + 20\log \mathrm{G} + 10\log \mathrm{T} - 10\log P_r - 175\text{ dB}$

These equations can be noted in an abbreviated form as

$$4R = \mathrm{P_t} + \ 2\mathrm{G} + \mathrm{T} - \mathrm{P_r} + \mathrm{A} + \mathrm{K}^* \qquad \text{(D-7)}$$

*K will assume various values as explained below.

$4R = \mathrm{PI} + \mathrm{A}$

Where:

$PI = \mathrm{P_t} + 2\mathrm{G} + \mathrm{T} - \mathrm{P_r} + \mathrm{K}$

$$Range = \text{Antilog}\ \frac{\mathrm{PI} + \mathrm{A}}{40} \quad \text{(D-8)}$$

Let us set A = -129 as our reference. This is the C-Band penetration case as was done in the past.

$$Range = \text{Antilog}\ \frac{\mathrm{PI} - 129}{40}$$

The value of K will be the difference between 129 dB and the avoidance or penetration numbers calculated for Equation (D-7) for the three radar carrier frequencies.

K = C-band 129 dB + calculated values listed from Equation (D-6) (Table D-6).

Table D-6: K Value Calculations

	K (Avoidance)	**K (Penetration)**
C-band	$K_C = 129\text{ dB} + (-128\text{ dB}) = +1\text{ dB}$	$K_C = 129\text{ dB} + (-129\text{ dB}) = 0\text{ dB}$
X-band	$K_X = 129\text{ dB} + (-124\text{ dB}) = +5\text{ dB}$	$K_X = 129\text{ dB} + (-137\text{ dB}) = -8\text{ dB}$
Ku-band	$K_{Ku} = 129\text{ dB} + (-121\text{ dB}) = +8\text{ dB}$	$K_{Ku} = 129\text{ dB} + (-175\text{ dB}) = -46\text{ dB}$

Therefore, a table of K factors for the frequency bands are as indicated in Table D-7:

Table D-7: K Factor

Transmitter Frequency (GHz)	**K Factor**	
	Avoidance	**Penetration**
5.35 to 5.47	+1 dB	0 dB
9.3 to 9.5	+5 dB	-8 dB
15.5 to 15.7	+8 dB	-46 dB

Radar theory has it that for a pulse type system,

$P_r = \mathrm{K\ T\ B}\ (S/\mathrm{N})\ (\mathrm{NF})$

Where:

K = Boltzmann's Constant

T = Absolute Temperature (°K)

B = Receiver Bandwidth

This assumes that the receiver input noise is K T B where K T is 4 x 10^{-21} watts/Hz of bandwidth and B is the receiver bandwidth in Hz. In order for range or the PI equation to be valid, it is necessary for the transmitter (actually receiver pulse width) to be related to the overall receiver bandwidth by a factor of approximately 1.2. That is, B T = 1.2 (T = Pulse Width). The receiver noise figure (NF) is that measured from the Receiver Transmitter (R/T) transmission line flange and somewhere in the IF amplifier following most of the amplification but prior to the final (usually 2nd) detector. The Signal-to-Noise Ratio (S/N) usually assumes a certain probability of detection (P_d) and a False Alarm Rate (P_{fa}). A good discussion on this matter, which covers Swerling cases, may be found in Section 2.4 of [Skolnik 1970] [G-19]. It is recommended that when the radar receiver threshold is properly set such that there is no STC (Sensitivity Time Control) used, that a reasonable threshold crossing occurs (False Alarms), and that the Probability of Detection (P_d) be 50%, both of these factors be as viewed on the radar indicator (Display). Normally, a P_d of 50% and a P_{fa} of 10^{-4} is acceptable. Note that the relationship between P_{fa} and the time between false alarms (or threshold crossings) T_{fa} and the overall receiver bandwidth B is:

$$T_{fa} = \frac{1}{\mathrm{B\ P_{fa}}} \text{seconds}$$

Because P_r is measured on the radar display, such factors as collapsing losses, operator losses, integration gain, and other factors may generally be ignored in this application. Using RTCA/D0-134 parameters, which relate range to PI, a PI of 90 lists a maximum range of 100 nautical miles. In order to provide equivalent PIs for this new calculation method, Table D-8 is prepared:

Table D-8: Equivalent PIs for New Calculation Method

Maximum System Range (nm)	Minimum Performance Index (dB)
25	175
50	187
75	194
100	199
125	203
150	206