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AIRBORNE SHORT AND LONG RANGE WINDSHEAR PREDICTIVE SYSTEMS

(FORWARD LOOKING WINDSHEAR SYSTEMS)

Interim Certification Requirements

Revised by: FAA Certification Team

PREFACE

This document was drafted by the Forward Looking Windshear Working Group involved in exemption # 5256.

The requirements listed in this document utilize and reflect the thought process currently expressed or implied in; FAR 121.358, SAE document 4102: Annex 11; Windshear Detection System for Air Transport Aircraft, Advisory Circular 25.??? and the Road Map to Certification for Forward Looking Windshear Detection Systems. Where no requirements previously existed for this application, the working group has provided the necessary requirements to achieve the certification objectives.

It is anticipated that the applied technologies to this system will require on-going version of this document to reflect the requirements for a specific application.

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Section 1

Introduction

The Development and Certification of a Forward Looking Windshear system has raised new certification issues. This document was developed to help aid the FAA and industry in approaching these issues systematically. It is anticipated that the certification of these systems will greatly increase aviation safety.

1.1 Background

On April 9, 1990 FAR 121.358 "Low-altitude windshear system equipment requirements" was amended to include airborne detection and avoidance systems (predictive), as a recognized alternative to airborne windshear warning and flight guidance systems (reactive). Reactive windshear systems (RWS) recognize a windshear encounter once the airplane has encountered the event, while a predictive windshear system (PWS) recognizes a windshear before the airplane has encountered it. Because the predictive systems would provide pilots with an opportunity to avoid an encounter or increase the airplanes energy state before the encounter, the FAA amended 121.358 to allow the use of predictive systems as soon as they became available and certified.

As a result, four airlines applied to the FAA for a time extension to the compliance date listed in FAR 121.358, to complete an evaluation and certification program of predictive systems. American, Continental, Eastern, and Northwest Airlines submitted a comprehensive plan which included their stated objectives of the evaluation and a time schedule for completion. The FAA subsequently approved each of the four applications under Exemption No. 5256 on December 12, 1990. The exemption granted a two year extension to the compliance schedule under FAR121.358, and placed a series of requirements on the operators to achieve specific milestones in order to preserve their exemption status.

Representatives of the Federal Aviation Administration(FAA), National Aeronautics & Space Administration (NASA), airplane and PWS manufacturers, and the airlines named in Exemption No. 5256, were then organized as the Forward Looking Windshear Detection System Working Group. The airlines along with the FAA and NASA first conducted a series of technical meetings that established a "Road Map To Certification". As a continuation of these meetings, it was determined that this working group should create a draft of a top level systems requirement document and establish certification guidelines for Forward Looking Windshear Detection Systems.

In order to develop this criteria the group began by reviewing the certification requirements for RWS. The review showed that some of the criteria and basic methodology could be used, but because of the predictive nature of the new systems some new methods would also have to be used. RWS detection function can be demonstrated by subjecting the windshear computer to aircraft type simulations that have incorporated simple wind field data sets. These data sets were designed to exceed predetermined thresholds that were based on aircraft available energy during takeoff and approach/go-around flight scenarios. Since the detection is based on the RWS ability to sense the real time performance loss generated by the winds along the flight path, it is a simple matter to determine when a given performance loss has occurred and if an alert is given. While RWS are able to measure the winds effect directly by its reaction on the airplane a PWS must remotely measure, or infer, atmospheric conditions ahead of the airplane and estimate a predicted performance loss along the flight path. Applying the RWS type of certification methodology to a forward looking system initially seemed reasonable, but it became apparent that due to the forward looking sensors detection characteristics, an entirely new methodology for certification using simulation would be required and a new atmospheric data set would have to be developed. This data set would have to include not only wind vectors but the meteorological conditions present during a windshear event that are used, or may effect the PWS detection capability. Furthermore, since predictive systems would be looking ahead of the aircraft, a larger spatial orientation of the meteorological environment around the windshear would be required to simulate intervening conditions.

The measure of the systems required performance, in terms of missed events, was a difficult issue. Very dry events could be missed by radar, and very wet events could be missed by lidar. Events with non representative thermal signatures could be missed by a infrared sensor. However, it was agreed that even with certain shortfalls a predictive system could provide improved safety over a RWS. But at what performance levels could the PWS stand alone and at what levels would a combined system be required. Therefore, it was recognized early on that some events could be missed by a PWS. Likewise, it is not too difficult to show that even assuming a 100 percent detection rate for reactive windshear systems (which is not the case), its probability of preventing a windshear accident is on the order of 50 percent due to latency (Martin Marietta Analysis). Therefore, it was agreed that a better criteria is not whether some events can be missed but whether a particular PWS will be at least as effective in preventing windshear accidents as an RWS which is the only system which has been certified to meet FAR 121.358.

Even a simplistic approach would show that if a PWS missed 10 percent of all windshear events, it would be a more robust system than an RWS . This is because the advanced warning for 90 percent of the events will allow either safe penetration at higher available airplane energy (while executing a missed approach) or avoidance. Such a system has on the order of a 90 percent chance of preventing a windshear accident even ignoring its on the runway protection capability which most RWS lack. However the windshear team considers the windshear detection system an essential system since a missed windshear event could reduce the flight crew's ability to cope with the adverse operating conditions. Therefore, in accordance with FAR 25.1309 the probability of a missed defined windshear threat event must be 10^{-5}, or less, per windshear threat event. There is no equivalent requirement for the reactive windshear system.

However, as discussed earlier for this to be a realistic criterion (not applying to all possible events), a data set of reasonable windshear event characteristics was established by the team based on historical data. This set contains events that if detected will provide a significant windshear accident risk reduction in compliance with FAR 121.358. This set does not encompass all possible events, but certainly more than 90 percent of them overall based on data obtained from Terminal Doppler Weathe Radar (TDWR) sites at Denver, Kansas City, and Orlando (Appendix D). Those that are missed may be dealt with in a manner similar to how they are dealt with for airplanes with a RWS without flight path guidance, e.g., FAA Windshear Training Aid pilot techniques. However, using the RWS as a bench mark, a PWS meeting the criteria of this document will provide a higher accident reduction factor than the RWS. Additionally, to further enhance this accident reduction factor the PWS provides windshear protection before and during the takeoff roll. This function is not required for reactive systems, but has been offered as an option by some manufactures. However, due to the RWS design characteristics which could cause an unwanted rejected takeoff late in the takeoff roll, this option has generally not been activated by the airline operators.

In conclusion the group has developed these new requirements and a certification methodology that is based on fundamental scientific and engineering principles. The data sets included in this document are based on historical data that includes the threat intensity, shear length, and meteorological atmospherics in and around the events. As mentioned earlier the data sets are not based on detecting all known windshear events, but a reasonable set of events that will provide a level of safety that is better than that of the RWS.

1.2 System Description

A Forward Looking Windshear System provides the flight crew with an advanced warning or advisory of a windshear condition by sampling the atmosphere ahead of the airplane. Through a process of direct and inferred measurements of the air mass dynamics, these systems will identify the severe weather signature associated with a hazardous windshear phenomena and warn the flight crew.

Several technologies are involved in the research and development effort:

- o Infrared
- o Doppler radar
- o Millimeter wave radar
- o LIDAR (Light Detection and Ranging)

1.3 System Design Goals

The Forward Looking Windshear Detection System design goals represent and reflect the intent of FAR 121.358. It is recognized that forward looking windshear detection systems should not detect benign windshear conditions that are clearly no threat to transport category airplanes. The intent of the stated goals is to develop systems that ensure operational safety by alerting the flight crew so they can as appropriate avoid windshear accidents by using normal operating procedures, or perform a windshear escape maneuver earlier than would be possible with a reactive system if avoidance is impossible. This should be accomplished while minimizing false and nuisance alerts.

1.3.1 Detect the Windshear threat:

The system shall be capable of detecting the windshear threat as defined in paragraph 4.1.9 and 4.1.21.

1.3.2 Annunciate the windshear threat:

The system shall clearly annunciate to the flight crew the detected hazard and appropriate alert level.

1.3.3 Situational display of the windshear threat:

Systems capable of displaying the windshear threat shall provide:

a. A display free from ambiguity

b. A display of the hazard relative to the airplanes projected longitudinal axis.

Section 2
Certification Methodology

2.1 General

The windshear threat has been defined in measurable scientific terms of F-factor, discussed in Appendix B, along with defined mathematical wind field models and signature characteristics. Windshear field strength, size and volume parameters are described in Table 9 of Appendix A, and define both dry and wet windshears and dry and wet intervening conditions.

Systems should be analyzed and tested to demonstrate capability in detecting the windshear threat in the defined models in accordance with the requirements of this document. If an individual system is not fully capable of detecting the windshear threat, a combination of systems may be required to fully satisfy the detection requirements contained herein and envisioned by FAR 121.358.

2.2 Simulation

NASA windshear simulation data sets in Table 9 of Appendix A mathematically represent the windshear threat definition, and should be used along with models of spurious conditions, e.g. ground clutter, range ambiguous returns and radome effects, to verify the sensor set and windshear detection algorithms. These simulations should be conducted in accordance with Table 9 of Appendix A.

The Simulated windshear detection system used for these tests should be shown to perform in a manner equivalent to the actual system hardware.

The models of ground clutter should be representative of severe clutter environments. These data should be obtained using maneuvers and look angles consistent with the flight phases shown in able 10 of Appendix A. These data should be gathered at Denver Stapleton runway (26L), Newark (4R/22L), and Washington National (18) airports, or equivalent, at a time of day which maximizes returns from moving traffic. The clutter data used with the NASA windshear simulation data sets should be obtained from actual flight measurements, and properly merged with the simulated windshear detection dynamic range capabilities of the system.

2.3 Flight Test

2.3.1 Basic System Certification.

Flight tests shall be conducted by the PWS manufacturers as follows for certification of new, or modifications to, windshear detection computers, software, radar transmitter units, and radome/antenna combinations that may change the windshear detection capability.

2.3.1.1 The detection capability shown during the simulation tests shall be verified by flying in areas of convective activity that can be validated by Terminal Doppler Weather Radar (TDWR), or equivalent. In-situ measurements may be used in lieu of TDWR for verification. Provided it is shown that these measurements represent the actual (un-biased) windshear conditions.

2.3.1.2 The system fault detection and EMI/RMI effects from and to other systems shall be evaluated.

2.3.1.3 The systems ability to reject spurious conditions shall be evaluated, e.g. clutter suppression, bi/multi-static signal interference, range ambiguous returns, and radome effects. This evaluation shall be conducted at a minimum of three airports such as Washington National R/W 18, Denver Stapleton R/W 26L, and Newark R/W 4R airports or airports providing equivalent.

2.3.1.4 The system's situational displays, alerts, annunciators, and controls shall be evaluated for appropriateness in day and night lighting conditions. Night lighting evaluations may be conducted by other suitable methods in lieu of flight tests.

2.3.2 Follow-on System Certification.

Flight tests shall be conducted as follows for certification of basic windshear detection systems when installed on different airplane types.

2.3.2.1 The system shall be evaluated in accordance with paragraph's 2.3.1.2, 2.3.1.3 at one airport with a clutter-rich environment, and 2.3.1.4.

2.3.2.2 The radome/antenna performance must be maintained to a level equal to or better than that demonstrated for the basic windshear system certification.

2.4 Software Testing - DO178B Level C

2.5 Environmental Testing - DO160C

Section 3
Definitions

3.1 Systems

3.1.1 Airborne Short or Long Range Windshear Predictive Systems:

Systems which sense and identify a windshear threat before the phenomenon is encountered.

3.1.1.1 Airborne Short Range Windshear Predictive System:

A minimum system which senses and identifies a windshear alert shortly before the phenomenon is encountered such that pilot action sufficient to negate the hazard may precede the encounter.

3.1.1.2 Airborne Long Range Windshear Predictive System:

A system which senses and identifies a windshear threat sufficiently far in advance of the phenomena to significantly reduce the hazard of an encounter by providing the pilot with the opportunity to increase the airplane's energy state, reduce the airplane's drag, or in some cases to maneuver the airplane so as to avoid the windshear phenomena. A situational display to assist the flight crew with the location of the hazardous area is required.

3.1.2 AP: Auto Pilot

3.1.3 EFIS: Electronic Flight Instrument System

3.1.4 GPWS: Ground Proximity Warning System

3.1.6 MFD: Multiple Function Display

3.1.7 ND: Navigation Display

3.1.8 TASS: Terminal Area Simulation System

3.1.9 TCAS Traffic Alert and Collision Avoidance System

3.2 Alerts and Annunciators

3.2.1 Windshear Warning Alert:

An alert for a detected windshear threat requiring immediate corrective action by the crew.(Emergency Condition, Level Three, ARP4102/4).

3.2.2 Windshear Caution Alert:

An alert for a detected windshear threat requiring immediate crew awareness. Possible corrective action may be required. (Abnormal Condition, Level Two, ARP4102/4)

3.2.3 Windshear Advisory Alert:

An alert for a detected windshear threat requiring crew awareness and may require crew action.(Advisory Condition, Level One, ARP4102/4)

3.2.4 False Alert:

An alert which occurs when windshear conditions do not exist.

3.2.5 Nuisance Alert:

An alert which occurs when a windshear phenomena is encountered which does not exceed the defined windshear alert criteria.

3.2.6 Missed Event:

An event is encountered that exceeds the windshear Must Alert Warning as defined in 4.1.9 , but is not detected and/or the system does not issue a Level Three Warning Alert in accordance with paragraph 4.2.1 or 4.3.1.

3.2.7 Mode Annunciation:

The method of displaying the system's current mode.

3.2.8 Unannunciated Failure:

A failure in the windshear system, or a failure of the system to arm when required, that is not detected and/or annunciated.

3.3 Windshear Situational Displays.

3.3.1 Dedicated - A display which only shows information sent from the windshear detection system, but may also include the normal radar weather reflectivity and turbulence.

3.3.2 Time-shared - A display which shows windshear information plus additional information from other systems (e.g. an EFIS/ND/MFD).

3.3.3 Icon - A symbol used on a situational display to represent windshear threats.

Section 4
System Requirements

4.1 General

4.1.1 The system shall provide an advance warning of the windshear threat as specified in paragraphs 4.2 and 4.3.

4.1.2 The system shall be able to detect dry and wet windshear threats in both dry and wet meteorological conditions as specified in paragraphs 4.1.21, 4.2.1, 4.3.1, and 4.3.3.

4.1.3 System may be designed to interface with other systems; e.g., GPWS, TCAS, AP.

4.1.4 Systems shall not adversely affect the functioning of, or be adversely affected by, other airplane systems.

4.1.5 Systems shall not be adversely affected by systems outside the airplane, e.g. from other aircraft or ground radar systems.

4.1.6 The system shall have no emissions harmful to people or wildlife under normal or expected operational conditions.

4.1.7 The computed severity of a windshear threat shall consider both the horizontal and vertical wind components as specified in paragraph 4.1.10.

4.1.8 The system shall meet the performance requirement of this specification in terminal area clutter environments, where the effects of other RF, terrain, buildings, vehicular traffic, heat sources, etc., may be present.

4.1.9 The system shall detect and annunciate a windshear threat of an F-factor greater than or equal to 0.13 averaged over one kilometer radial distance, i.e., FBAR, throughout the Weight, Altitude and Temperature Envelope approved for takeoff and landing as specified in Table III. Alert thresholds must be placed below 0.13 in order to achieve the detection performance of 4.1.21.

4.1.10 F - factor:

$$F=\frac{w_x}{g}-\frac{w_h}{V}$$

Where:

w_x = The horizontal component of the wind velocity relative to the airplane horizontal flight path.

w_h = The vertical component of the wind velocity.

g = Gravity.

v = Airplane true airspeed. This may be assumed to be fixed at 150 knots for calculation of FBAR by the system for turbojet powered airplanes and 100 knots for propeller driven airplanes.

4.1.11 The system must operate satisfactorily with all approved takeoff, takeoff climb, approach, go-around, and landing configurations, and the respective airspeeds expected.

4.1.12 The system shall be capable of manual activation prior to the start of the takeoff roll. It shall be automatically activated no later than the start of the takeoff roll.

4.1.13 The system's aural and visual windshear alerts shall be inhibited late in the takeoff roll until after liftoff. The system's display(s) shall be inhibited at the same point unless a windshear icon is displayed. The inhibit scheme shall consider hazardous events located just beyond the liftoff point, and shall allow the system to issue a warning for those events prior to inhibition.

New technology airplanes that have the capability of programming V1 speeds should use this capability to set the inhibit point to approximately 20 kts below V1.

4.1.14 The system performance must be satisfactory within the range of normal flight path angles.

4.1.15 During the final approach, the system shall provide automatic range scaling/or suitable system capability to prevent aural and visual warning alerts of a windshear threat beyond the Touchdown Zone as .

4.1.16 The system shall reset to normal operation in the event of a go-around or touch and go.

4.1.17 The PWS manufacturers shall accomplish the quantitative probability analysis as specified in paragraphs 4.1.18 through 4.1.21.

4.1.18 The probability of an unannunciated failure shall be 10^{-5} per flight hour of system operation, or less.

4.1.19 The probability of a false warning alert for systems without a display, or the display of a false windshear icon for systems with a display, shall be 10^{-4}, or less, per takeoff, approach, or go-around.

4.1.20 The probability of a nuisance warning alert for systems without a display, or the display of a nuisance windshear icon for systems with a display, shall be 10^{-1} or less, per windshear event. This shall be determined in accordance with Appendix D, or equivalent procedure, for system critical event reflectivity of between 0 dBz and 60 dBz.

4.1.21 The probability of a missed windshear threat event shall be 10^{-5}, or less, per windshear threat event. This shall be determined in accordance with Appendix D, or equivalent procedure, for system critical event reflectivity of between 0 dBz and 60 dBz.

4.2 Airborne Short Range Windshear Predictive System

4.2.1 The 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 (10 seconds x 200 KTAS) before FBAR of paragraph 4.1.9 of the phenomenon is encountered. For the purposes of establishing alerting distance, a central F-factor average shall be 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. The warning alert shall be demonstrated as described in Table 9 of Appendix A.

4.2.2 The system shall issue visual and aural annunciation's without pilot intervention as described in Tables 1 and 2 of Appendix A .

4.2.3 The system shall be enabled automatically without pilot intervention below a minimum of 1500 feet AGL. No alerts should be given above 1200 feet AGL.

4.2.4 A windshear situational display is optional for short range windshear predictive systems.

4.3 Airborne Long Range Windshear Predictive System

4.3.1 The system shall conform to the requirements of paragraphs 4.2.1., 4.2.2., and 4.2.3.

4.3.2 The windshear situational display shall conform to the requirements of paragraph 5.5.

4.3.3 The system shall issue a caution alert of a windshear threat, existing 25 degrees either side of the extended aircraft longitudinal axis. This should occur at least 3 nautical miles before the phenomenon is encountered. This shall be demonstrated as described in Table 9 of Appendix A.

Section 5
Alerts/Annunciators/Displays

5.1 Alerts

5.1.1 Warning Alerts

5.1.1.1 A warning alert shall be indicated by a red annunciation in each pilot's primary field of view in conjunction with a voice that says "Go-around Windshear Ahead" once for approach and go-around, and "Windshear Ahead" twice for takeoff roll and climb, as described in tables 1 and 2 of Appendix A.

These annunciators should flash and then become steadily illuminated in accordance with the guidelines contained in Report DOT/FAA/RD-81/38, II, dated January 1981. However, they may be steadily illuminated if such is consistent with the alerting scheme of the basic cockpit, i.e. "dark quiet design concept." This design philosophy results in few or no irrelevant background lights illuminated in the cockpit for normal operation.

5.1.1.2 The visual alert annunciations shall not be readily cancelable by the pilots. The alerts shall be automatically canceled following the longer of the aural message completion or when the measured threat dissipates below threshold or exits the area protected by the system.

5.1.1.3 Prioritization should be provided with the aural reactive windshear warning as the first priority followed by forward looking windshear system. However, GPWS modes 2 through 4 should be available following the forward looking windshear aural alert. If simultaneous aural alerts can be given, then the words must be understandable.

5.1.2 Caution Alerts

5.1.2.1 A caution alert shall be indicated by an amber annunciation in each pilot's primary field of view in conjunction with two attenson chimes or other appropriate aural alert, as described in Tables 1 and 2 of Appendix A. The amber annunciators shall remain illuminated until the measured threat dissipates below threshold, moves into the warning region, or exits the area protected by the system.

5.1.2.2 The caution alert annunciations may be cancelable after alerting.

5.1.2.3 If a reactive windshear system is also installed its caution alert must be disabled.

5.2 Reserved

5.3 Reserved

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329 666

5.4 Windshear System Failure Annunciation

5.4.1 The annunciation of the failure of the windshear detection system shall be readily visible to the flight crew. This alert may be cancelable.

5.5 Windshear Situational Displays

5.5.1 General

5.5.1.1 Situational displays used to show the size and location of the windshear threat shall use an icon as described in paragraph 5.5.4. If the range selected by the pilot for the display is greater than 5 miles, which may not allow the pilot to recognize the event from other displayed information, amber radial lines shall extend from the left and right radial boundaries of the icon extending to the upper edge of the display.

Other symbology may be used provided the applicant uses human factors technology to demonstrate that a clear and substantial benefit can be derived by its use.

5.5.1.2 These displays shall depict the windshear threat, including position, with respect to the nose of the airplane, in an unambiguous and easily understandable manner, in accordance with the criteria contained in 3 through 8 of Appendix A.

5.5.1.3 An indication of the relative motion of the windshear threat with respect to the airplane ground track is optional.

5.5.1.4 These displays should be selectable by the pilot, e.g., before system enabling conditions during takeoff, without a windshear alert being present, or above the automatic enabling altitude. Icons only may be displayed above 1200 feet AGL. This mode should be suitably annunciated.

5.5.2 Dedicated Windshear Situational Displays

5.5.2.1 When a windshear threat is detected the display of it shall be automatically presented and should use a range scale of approximately 5 miles, overriding ranges previously selected by the pilot, if applicable. Pilot selections of other ranges may then be made available.

5.5.3 Time-shared Displays

5.5.3.1 When a windshear threat is detected, the corresponding display may be automatically presented or selected by pilot action. Pilot workload necessary for its presentation should be minimized and should not take more than one action when the cockpit is configured using the normal operating procedures.

5.5.4 Icon Characteristics

5.5.4.1 The icon consists of alternating red and black bars. The bars shall be oriented such that they are circular arcs centered on the apex. The depth of each bar shall make the icon conspicuous from other displayed information. The area displayed corresponds to the criteria contained in appendix C.

5.5.4.2 While the windshear F-factor is above the alert threshold the icon shall change in size at each update cycle to reflect changes in the detected/computed threat area.

5.5.4.3 Once an icon is displayed, and the computed windshear F-factor decays below the alert threshold value, the

Appendix A.

icon shall remain displayed in its proper position relative to the airplane, until its F-factor decays below the MUST NOT ALERT value. The size of the icon shall be maintained at the value computed just prior to decaying below the alert threshold. See Appendix C for the MUST-ALERT/MUST-NOT-ALERT criteria.

AC

TABLE 1

Visual Annunciation Takeoff Roll and Climb, Approach and Go-Around				
Alert Level	**Cockpit Presentation**	**Word**	**Color**	**Characteristics**
Advisory Level 1	Windshear display only.	None	ICON alternating Red and Black with Yellow radial lines.	ICON display only.
Caution Level II	EFIS Primary Flight Display or dedicated annunciator in both pilots primary field of view.	"Windshear" or "Windshear-Ahead" or "W/S-Ahead"	Amber	Should follow basic cockpit alerting philosophy. Can be steady, flashing, or flashing then steady. (See 5.1.1.1)
Warning Level III	EFIS Primary Flight Display or dedicated annunciator in both pilots primary field of view.	"Windshear" or "Windshear-Ahead" or "W/S-Ahead"	Red	Should follow basic cockpit alerting philosophy. Can be steady, flashing, or flashing then steady. (See 5.1.1.1)

TABLE 2

Audio Annunciation		
Alert Level	**Aircraft Operations**	**Description**
Caution Level II	Takeoff prior to brake release, takeoff-roll, climb, approach, and go-around	Distinctive Aural Alert: Chime or appropriate message, not containing the word windshear. Example: "Monitor Radar Display"
Warning Level III	Takeoff prior to brake release, takeoff-roll and climb	Voice alert said twice: "Windshear Ahead", "Windshear Ahead"
	Approach and go-around	Voice alert said once: "Go-around windshear ahead"

ALT 0176

FIGURE A
WINDSHEAR ALERT REGIONS

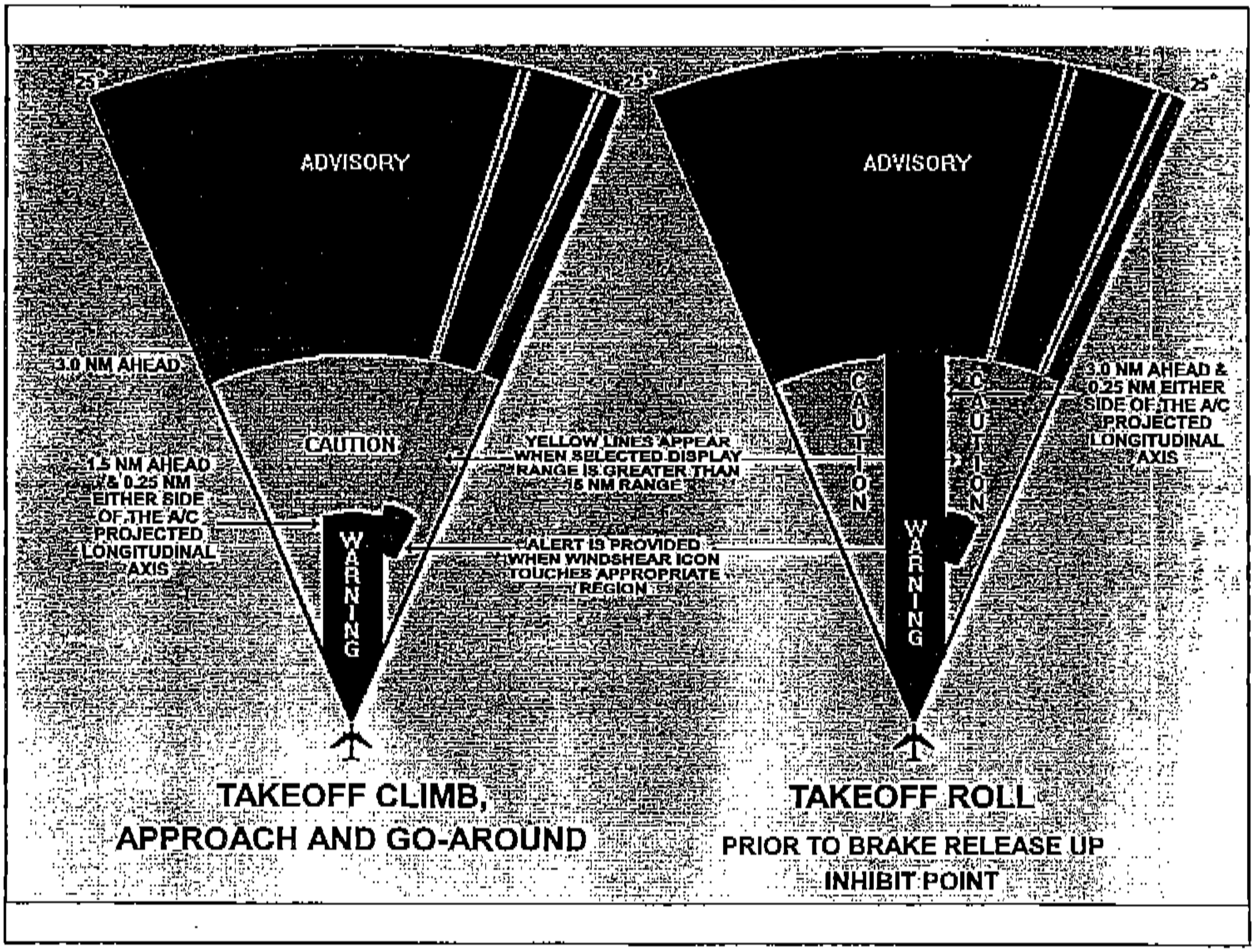


TABLE 3
Display & Alert Operational Characteristics
Normal Takeoff-roll and Climb

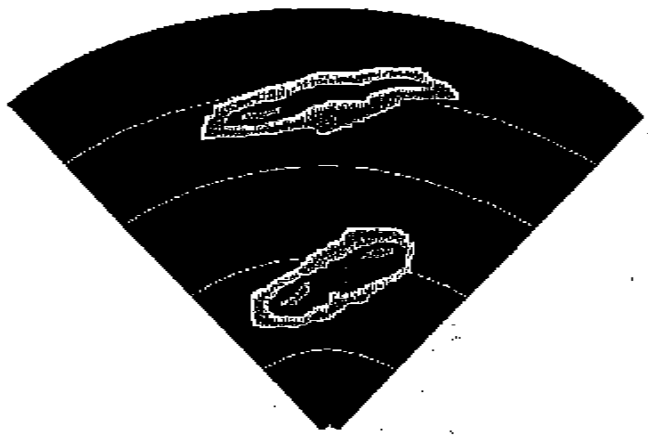
Aircraft Operation	Weather Display	Visual and Audio Annunciation (Table 1&2)
Below 1200' AGL	Normal weather display and scan, but windshear scan can delay the weather update rate up to 12 seconds. Weather remains displayed between updates. Example Display:  5NM Range Scale	None.

TABLE 4
Display & Alert Operational Characteristics
Windshear Present During Takeoff-roll and Climb

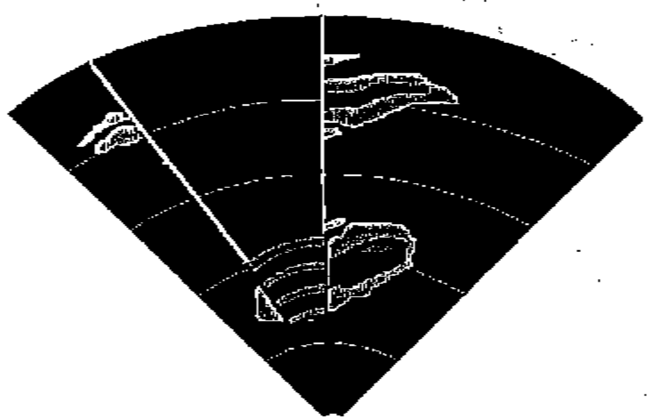
Aircraft Operation	Weather Display	Visual and Audio Annunciation (Table 1&2)
Below 1200' AGL	Normal weather display and scan, but windshear detection scan can delay weather update rate up to 12 seconds. Weather remains displayed between updates, but may be removed from the displayed ICON sector. When alert's are issued prior to the inhibit point weather display will not be required, and the takeoff should not be conducted. Example Display:  5NM Ragne Scale	<u>Advisory, Caution, and Warning Alerts:</u> Must be enabled no later than the beginning of the takeoff roll, through 1200' AGL. Should be inhibited late in the takeoff-roll and reactivated at 50' AGL. <u>ICON Display:</u> ICON must be displayed to 1200' AGL. ICON may be displayed up to 1500'. If the ICON is displayed prior to the takeoff-roll inhibit point, it should remain on the display throughout the inhibit function. ICON must track windshear. <u>Dedicated Display:</u> ICON must pop-up <u>Time-shared Display:</u> ICON may be presented with one pilot action.

TABLE 5
Display & Alert Operational Characteristics
Normal Approach and Go-Around

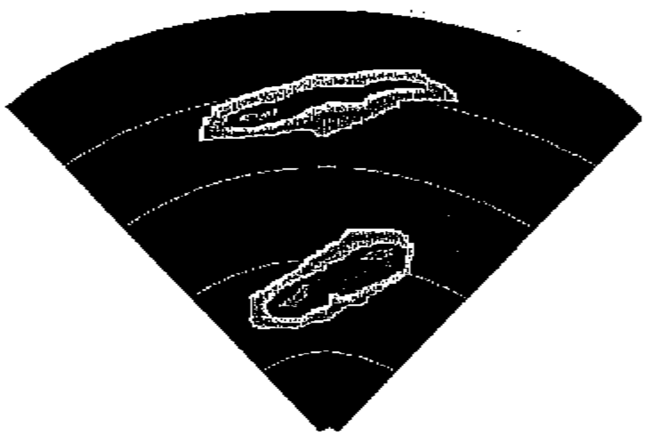
Aircraft Operation	Weather Display	Visual and Audio Annunciation (Table 1&2)
All Altitudes	Normal weather display and scan with basic system update rate down to 1500' AGL. Normal weather display and scan below 1500' AGL, but windshear scan can delay weather update up up to 12 seconds. Weather remains displayed between updates. Example Display:  5NM Range Scale	None.

TABLE 6
Display & Alert Operational Characteristics
Windshear Present During Approach and Go-Around

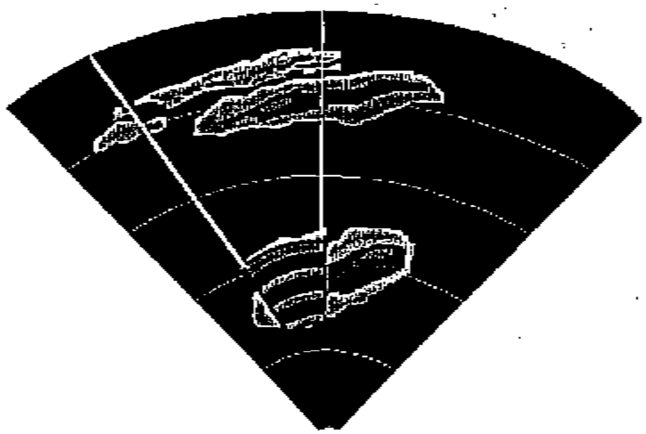
Aircraft Operation	Weather Display	Visual and Audio Annunciation (Table 1&2)
Above 1500' AGL	Normal weather display and scan with basic system update rate. Weather dispaly must not be affected. Example Display  5NM Range Scale	Advisory, Caution, and Warning Alerts: Must not be enabled above 1200' AGL. ICON display only. ICON Display: ICON display is optional above 1500' AGL. If ICON is displayed it must track the windshear. Dedicated Display: ICON may pop-up, or be presented with one pilot aciton. Time-Shared Display: ICON may be presented with one pilot aciton.

TABLE 7
Display & Alert Operational Characteristics
Windshear Present During Approach and Go-Around

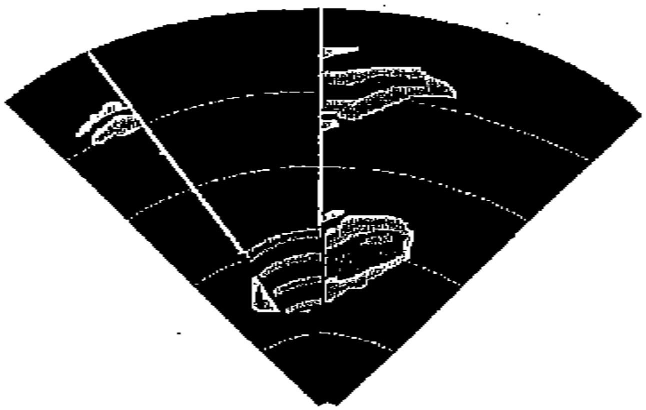
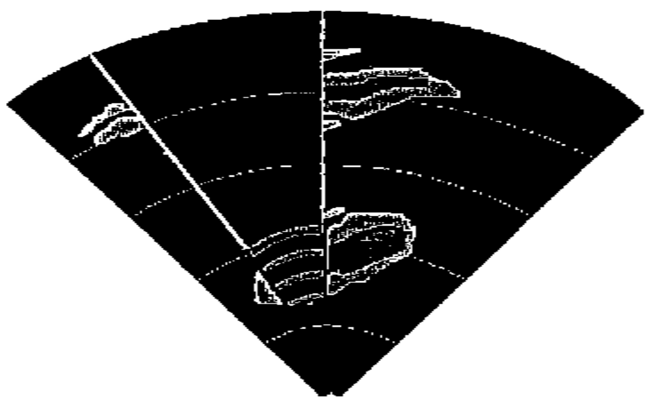
Aircraft Operation	Weather Display	Visual and Audio Annunciation (Table 1&2)
Between 1500' AGL and 1200' AGL	Normal weather display and scan, but windshear detection scan can delay weather update rate up to 12 seconds. Weather remains displayed between updates, but may be removed from the displayed ICON sector. When alert's are issued prior to the inhibit point weather display will not be required, and the takeoff should not be conducted. Example Display:  5NM Ragne Scale	<u>Advisory, Caution, and Warning Alerts:</u> Must not be enabled above 1200' AGL. ICON display only. <u>ICON Display:</u> ICON display is optional above 1200' AGL. If ICON is displayed it must track the windshear. <u>Dedicated Display:</u> ICON may pop-up, or be presented with one pilot aciton. <u>Time-Shared Display:</u> ICON may be presented with one pilot aciton.

TABLE 8
Display & Alert Operational Characteristics
Windshear Present During Approach and Go-Around

Aircraft Operation	Weather Display	Visual and Audio Annunciation (Table 1&2)
Below 1200' AGL.	Normal weather display and scan, but windshear detection scan can delay weather update rate up to 12 seconds. Weather remains displayed between updates, but may be removed from the displayed ICON sector. Example Display:  5 nm range scale	Advisory, Caution, and Warning Alerts: Must be enabled below 1200' AGL. ICON Display: ICON must be displayed. ICON must track the windshear. Dedicated Display: ICON must pop-up. Time-Shared Display: ICON may be presented with one pilot aciton.

NASA TASS Data Sets Justification

NASA TASS Data Set	Justification
DFW ACCIDENT CASE Data Set: 1 Time: 11 min.	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 advanced 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.
06/20/91 NASA RESEARCH FLIGHT ORLANDO, FLORIDA Data Set: 2 Time: 37 min.	This event's characteristics have been well documented from its penetration by the NASA 737 airplane. This airplane incorporated radar and IR forward look 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.
07/11/88 INCIDENT CASE DENVER, COLORADO Data Set: 3 Time: 49 min. 51 min.	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, and 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 as described in appendix E. Also see Table 10, Note 2.
07/14/82 TEMPERATURE INVERSION CASE DENVER, COLORADO Data Set: 4 Time: 36 min.	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.
07/8/94 WEATHER SOUNDING DENVER, COLORADO Data Set: 5 Time: 40 min. 45 min.	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. Also see Table 10, Note 4.
DERIVED WEATHER SOUNDING FLORIDA Data Set: 6 Time: 14 min.	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. Also see Table 10, Note 2.
08/2/81 ADJUSTED KNOWLTON WEATHER SOUNDING MONTANA Data Set: 7 Time: 27 min.	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 which 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.

Flight Scenario Justification

Flight Scenario	Justification
ALIGNED FOR TAKEOFF Data Set: 1,3,4,7	This 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. The specific microburst of Model 3, and Model 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, Model 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 to be unnecessarily severe in evaluation of the system. Model 7 (gust front) was selected since the takeoff is the critical flight phase for hazardous effects from this event. See discussion for NASA Data set number 727. The 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 gust front to start with. The 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. Model 1 was selected since it would pose considerable hazard to the airplane, even at the most nose down direction relative to the airplane.
TAKEOFF GEAR UP HEIGHT Data Set: 3,5	This scenario represents the next stabilized phase of flight and is significantly different than brake release. This case will evaluate the system's capability to scan in the most nose down direction relative to the airplane. Model 5 is large enough to be a threat, and due to its benign appearance due to being dry would be a challenge for the crew to detect without a windshear detection system. For justification of NASA TASS Data Set, see above discussion for Aligned for Takeoff. For justification of 150 KTAS, see Table 10, Note 3. 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. This event should have also produced a windshear warning at brake release using the minimum 3 NM range criteria in paragraph 4.3.2 for a long range predictive system.
-3 DEGREES STRAIGHT IN APPROACH Data Sets: All	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 (paragraphs 4.2.3 and 4.3.1) 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 to make this evaluation and therefore has been chosen to evaluate all windfield models. For justification of 150 KTAS, see Table 10, Note 3.

Flight Scenario Justification

Flight Scenario	Justification
1000 ' AGL LEVEL FLIGHT STANDARD RATE TURN TO THE LOCALIZER Data Sets: 3,5,6	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 must have enough azimuth scan to give at least 10 seconds advanced warning (paragraphs 4.2.1 and 4.3.1) 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. Models 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 Model 3 event, one of the airplanes that actually encountered this windshear made a turning approach into it. This model then forms a historical basis for demonstration. Model 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. Model 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. For justification of 200 KTAS, see Tables 10, Note 3. The altitude of 1000 feet AGL was chosen to assure that the windshear detection system alerts are active (1200 feet AGL per Paragraph 4.2.3 and 4.3.3).
-3 DEGREES APPROACH 25 DEGREES DRIFT ANGLE Data Sets: 4,5	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 airmass. 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 1/4 nautical mile 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. These requirements are specified in paragraphs 4.2.1, 4.3.1, and 4.3.3. 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 degree 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 per Paragraph 4.2.3 and 4.3.1) to evaluate the detection and displays. Since this evaluation is only to assess the system's ability to detect windshears with the worse case drift angle, it is sensible that only a limited number of windfield models need to be evaluated. Models 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. For justification of 120 KTAS, see discussion for Table 10, Note 3.

Flight Scenario Justification

Flight Scenario	Justification
GO-AROUND @ 100' AGL Data Sets: 2,5	This scenario is to evaluate the system mode transition from approach to go-around. Alerting ranges (Paragraph 4.1.15), logic changes, system gains and biases, antenna scan elevation, etc., are possible effects that need to be evaluated (Paragraph 4.1.16). 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. Models 2 and 5 were selected because of their benign appearance (5 especially being dry) and the pilot may mistakenly assume they are safe to fly into. For justification of 150 KTAS, see discussion for Table 10, Note 3.

TABLE 9
General Notes

These testing scenarios are chosen in general to evaluate the General system's detection capability in situations likely to be encountered in service. 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. However, as more experience is gained in the characteristics of these systems, a more simplistic testing approach may be possible.

The testing matrix distributes the possible combination of conditions, e.g., windfield models, airspeeds, intervening rain, etc., to critical flight phases in lieu of applying all combinations to all flight phases. This reduces the number of individual runs from 570 to approximately 36. The rationale for the selection is covered under the justification for each flight phase.

A. Certain detection systems may use biases, gain delays, etc., based on events not contained in these reference windfield models. If this is the case, these effects should be introduced into the simulation system to accurately demonstrate overall system performance.

If atmosphere out side of the local environment of these models affects the detection schemes it must be accounted for when demonstrating Windshear detection, e.g. Temperature lapse rate history during approach.

B. Poor radome design and maintenance can seriously degrade radar performance. Since the windshear detection is an essential system, additional considerations must be introduced, as compared to the typical weather radar system. Some current maintenance procedures have reduced the radome efficiency to as low as 60 percent due to moisture content, and thickness changes during repair, which change the radomes electrical properties.

Therefore, it is sensible to include accountability for the real world maintenance standards in assessing a given windshear system's performance. These standards are being addressed by RTCA SC-173 and will be contained in MOPS DO-213. Also, the radome lightning protection system may affect the clutter rejection and other detection characteristics; therefore, the simulation must properly assess these characteristics.

TABLE 9
General Notes (Continued)

C. The NASA TASS Windshear Simulation Data Sets were intended to represent the minimum reflectivity of 0 dBz at the outflow region. Data set cases 436, 540 and 545 have outflow regions that are less than 0 dBz and represent the extreme case.

As a result the following adjustments may be made to Data Sets 436 and 540 to better represent to minimum reflectivity of 0 dBz:

Data Set Case	Adjustment
Temperature Inversion Case: 436	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.
Weather Sounding Case: 540	Add 10 dBz with 23 dBz limit and run with specified radar ground clutter.

Data set case 545 should be run as a limiting case. It represents the extreme dry microburst and will not be considered in the pass/fail criteria.

TABLE 9
General Notes (Continued)

D. FLIGHT SCENARIO'S

Flight phase with paths as described in Appendix E (1)	NASA TASS Data Set No	Location of F-factor field leading edge	Radar clutter model	Airspeed KTAS
Aligned for Takeoff	3,4,7	Such that the airplane is in the headwind conditions of the outflow	Newark 4R/22L	0
Aligned for Takeoff	1,3	3.0 NM from brake release	Newark 4R/22L	0
Takeoff - Gear up Height	3,5	3.0 NM from brake release	Newark 4R/22L	150
-3 Degrees straight in approach (2)	All	Middle Marker (1/2 NM) from runway threshold.	Newark 4R/22L	150
1000' AGL level flight standard rate, as limited by 25 degree bank, 90 degree turn to localizer	3,5,6	At localizer intercept (1000' AGL)	3,5 Denver 26L 6 Wash. Natl.	200
-3 Degrees straight in approach 25 degree drift angle	4,5	At runway threshold	Newark 4R/22L	120
Go-around @ 100' AGL	2,5	1.8 NM from 100' point	Newark 4R/22L	150

TABLE NOTES:

(1) All tests should be conducted using sensor/airplane pitch angles critical for system performance.

(2) Windshear data sets 3 and 6 are penetrated using several headings as described in Appendix E.

TABLE 9 - Windshear Simulation Data Sets

No.	NASA Terminal Area Simulation System (TASS) Data Set	Horz. grid spacing (meters) [1]	Max reflectivity (dBz)	Outflow reflectivity (dBz)	Approx. diameter of outflow @ peak_V (km)	Growth stage	Approx. peak 1 km FBAR [2]	Intervening rain [3]	Temp. lapse rate	Symmetry	Radar clutter model	Flight Scenario Location and Airspeed [4]
1	DFW Accident DATA SET/TIME: 111 Wet Microburst with rain and hail	50	55	35 to 42	3.5	N/A	0.2	No	Adiabatic	Asym	Newark 4R/22L	Aligned for take-off to the east with the microburst leading edge 3.0 NM from brake release. Airspeed: 0 ktas [5]
2	DFW Accident DATA SET/TIME: 111 Wet Microburst with rain and hail	50	55	35 to 42	3.5	N/A	0.14	No	Adiabatic	Asym	Newark 4R/22L	-3 degree straight in approach to the east with the microburst located at the middle marker 1.2 NM from runway threshold. Airspeed: 150 ktas
3	06/20/91 NASA Research Flight Orlando Florida DATA SET/TIME: 237 Wet Microburst	100	50	37 to 45	3.5	N/A	0.14	Yes	Adiabatic	Rough	Newark 4R/22L	-3 degree straight in approach to the south with the microburst located at the middle marker 1.2 NM from runway threshold. Airspeed: 150 ktas
4	06/20/91 NASA Research Flight Orlando Florida DATA SET/TIME: 237 Wet Microburst	100	50	37 to 45	3.5	Developing Below threshold case [6]	0.06	Yes	Adiabatic	Rough	Newark 4R/22L	-3 degree straight in approach to the east with the microburst located at the middle marker 1.2 NM from runway threshold. Airspeed: 150 ktas
5	06/20/91 NASA Research Flight Orlando Florida DATA SET/TIME: 237 Wet Microburst	100	50	37 to 45	3.5	N/A	0.19	Yes	Adiabatic	Rough	Newark 4R/22L	Go-Around at 100 ft. to the west with the microburst 1.8 NM from the 100 ft. point at the end the far end of the runway. Airspeed: 150 ktas
6	7/11/88 Incident Case Denver Colorado DATA SET/TIME: 349 Multiple Microburst	100	35	10 to 16	3	Developing Below threshold case [6]	0.083	Light	Adiabatic	Varies between microburst	Newark 4R/22L	-3 degree straight in approach to the east with the microburst located at the middle marker 1/2 NM from runway threshold. Airspeed: 150 ktas

TABLE 9 - Windshear Simulation Data Sets (Continued)

No.	NASA Terminal Area Simulation System (TASS) Data Set	Horz. grid spacing (meters) [1]	Max reflectivity (dBz)	Outflow reflectivity (dBz)	Approx. diameter of outflow @ peak_V (km)	Growth stage	Approx. peak 1 km FBAR [2]	Intervening rain [3]	Temp. lapse rate	Symmetry	Radar clutter model	Flight Scenario Location and Airspeed [4]
7	7/11/88 Incident Case Denver Colorado DATA SET/TIME: 349 Multiple Microburst	100	37	10 to 16	3	Developing Below threshold case [6]	0.13	Yes	Adiabatic	Varies between microburst	Newark 4R/22L	-3 degree straight in approach to the north with the microburst located at the middle marker 1/2 NM from runway threshold. Airspeed: 150 knts
8	7/11/88 Incident Case Denver Colorado DATA SET/TIME: 351 Multiple Microburst	100	24	13 to 27	1.5 - 3.0	Developing Must Alert threshold case [6]	0.17	Yes	Adiabatic	Varies between microburst	Newark 4R/22L	Aligned for take-off to the north with the microburst leading edge placed such that the airplane is in the headwind conditions of the outflow. Airspeed: 0 knts [5]
9	7/11/88 Incident Case Denver Colorado DATA SET/TIME: 351 Multiple Microburst	100	25	13 to 27	1.5 - 3.0	N/A	0.19	Yes	Adiabatic	Varies between microburst	Newark 4R/22L	Aligned for take-off to the east with the microburst leading edge placed such that the airplane is in the headwind conditions of the outflow. Airspeed: 0 knts [5]
10	7/11/88 Incident Case Denver Colorado DATA SET/TIME: 351 Multiple Microburst	100	25	13 to 27	1.5 - 3.0	N/A	0.19	Yes	Adiabatic	Varies between microburst	Newark 4R/22L	Take-off at gear up height to the east with the microburst leading edge 3.0 NM from brake release. [5] Airspeed: 150 knts [7]
11	7/11/88 Incident Case Denver Colorado DATA SET/TIME: 351 Multiple Microburst	100	40	13 to 27	1.5 - 3.0	N/A	0.15	Yes	Adiabatic	Varies between microburst	Newark 4R/22L	-3 degree straight in approach to the north at a 360 degree heading. The microburst is located at the middle marker 1/2 NM from runway threshold. Airspeed: 150 knts
12	7/11/88 Incident Case Denver Colorado DATA SET/TIME: 351 Multiple Microburst	100	40	13 to 27	1.5 - 3.0	N/A	0.18	Yes	Adiabatic	Varies between microburst	Newark 4R/22L	-3 degree straight in approach to the northeast at a 45 degree heading. The microburst is located at the middle marker 1/2 NM from runway threshold. Airspeed: 150 knts

TABLE 9 - Windshear Simulation Data Sets (Continued)

No.	NASA Terminal Area Simulation System (TASS) Data Set	Horz. grid spacing (meters) [1]	Max reflectivity (dBz)	Outflow reflectivity (dBz)	Approx. diameter of outflow @ peak_V (km)	Growth stage	Approx. peak 1 km FBAR [2]	Intervening rain [3]	Temp. lapse rate	Symmetry	Radar clutter model	Flight Scenario Location and Airspeed [4]
13	7/11/88 Incident Case Denver Colorado DATA SET/TIME: 349 Multiple Microburst	100	40	13 to 27	1.5 - 3.0	N/A	0.17	Yes	Adiabatic	Varies between microburst	Newark 4R/22L	-3 degree straight in approach to the east at a 90 degree heading. The microburst is located at the middle marker 1/2 NM from runway threshold. Airspeed: 150 knts
14	7/11/88 Incident Case Denver Colorado DATA SET/TIME: 351 Multiple Microburst	100	40	13 to 27	1.5 - 3.0	N/A	0.13	Yes	Adiabatic	Varies between microburst	Newark 4R/22L	-3 degree straight in approach to the southeast at a 135 degree heading. The microburst is located at the middle marker 1/2 NM from runway threshold. Airspeed: 150 knts
15	7/11/88 Incident Case Denver Colorado DATA SET/TIME: 351 Multiple Microburst	100	41	13 to 27	1.5 - 3.0	N/A	0.17	Yes	Adiabatic	Varies between microburst	Newark 4R/22L	-3 degree straight in approach to the west at a 270 degree heading. The microburst is located at the middle marker 1/2 NM from runway threshold. Airspeed: 150 knts
16	7/11/88 Incident Case Denver Colorado DATA SET/TIME: 351 Multiple Microburst	100	40	13 to 27	1.5 - 3.0	N/A	0.13	Yes	Adiabatic	Varies between microburst	Newark 4R/22L	-3 degree straight in approach to the northwest at a 315 degree heading. The microburst is located at the middle marker 1/2 NM from runway threshold. Airspeed: 150 knts
17	7/11/88 Incident Case Denver Colorado DATA SET/TIME: 351 Multiple Microburst	100	40	13 to 27	1.5 - 3.0	N/A	0.15	Yes	Adiabatic	Varies between microburst	Denver 26L	1000' AGL level flight standard rate turn to the localizer, as limited by 25 degrees of bank. The microburst should be placed such that it is directly in front of the aircraft when localizer is captured. Airspeed: 200 knts [8]
18	7/14/82 Temperature Inversion Denver Colorado DATA SET/TIME: 436 Multiple Microburst	50	27	0 to 10	1.0	N/A	0.23	No	Stable Layer	Asym	Newark 4R/22L	Aligned for take-off to the east with the microburst leading edge placed such that the airplane is in the headwind conditions of the outflow. Airspeed: 150 knts

TABLE 9 - Windshear Simulation Data Sets (Continued)

No.	NASA Terminal Area Simulation System (TASS) Data Set	Horz. grid spacing (meters) [1]	Max reflectivity (dBz)	Outflow reflectivity (dBz)	Approx. diameter of outflow @ peak_V (km)	Growth stage	Approx. peak 1 km FBAR [2]	Intervening rain [3]	Temp. lapse rate	Symmetry	Radar clutter model	Flight Scenario Location and Airspeed [4]
19	7/14/82 Temperature Inversion Denver Colorado DATA SET/TIME: 436 Multiple Microburst	50	27	0 to 10	1.0	N/A	0.24	No	Stable Layer	Asym	Newark 4R/22L	-3 degree straight in approach to the east with the microburst located at the middle marker 1/2 NM from the runway threshold. Airspeed: 150 knts
20	7/14/82 Temperature Inversion Denver Colorado DATA SET/TIME: 436 Multiple Microburst	50	27	-10 to -4	3.0	N/A	0.24	No	Stable Layer	Asym	Newark 4R/22L	-3 degree straight in approach to the east with a 25 degree drift angle. The microburst leading edge is placed at the runway threshold. Airspeed: 120 knts [9]
21	7/8/89 Sounding Denver Colorado DATA SET/TIME: 540 Very Dry Microburst [10]	100	17 to 20	-10 to -4	3.0	N/A	0.18	No	Adiabatic	Rough	Newark 4R/22L	Take-off at gear up height to the west with the microburst leading edge 3.0 NM from brake release. Airspeed: 150 knts [7]
22	7/8/89 Sounding Denver Colorado DATA SET/TIME: 540 Very Dry Microburst [10]	100	17 to 20	-10 to -4	3.0	N/A	0.16	No	Adiabatic	Rough	Newark 4R/22L	-3 degree straight in approach to the north with the microburst located at the middle marker 1/2 NM from the runway threshold. Airspeed: 150 knts
23	7/8/89 Sounding Denver Colorado DATA SET/TIME: 540 Very Dry Microburst [10]	100	17 to 20	-10 to -4	3.0	N/A	0.12	No	Adiabatic	Rough	Newark 4R/22L	-3 degree straight in approach to the north with a 25 degree drift angle. The microburst leading edge is placed at the runway threshold. Airspeed: 120 knts [9]
24	7/8/89 Sounding Denver Colorado DATA SET/TIME: 540 Very Dry Microburst [10]	100	17 to 20	-10 to -4	3.0	N/A	0.17	No	Adiabatic	Rough	Newark 4R/22L	Go-around at 100 ft. to the north with the microburst 1.8 NM from the 100 ft. point at the far end of the runway. Airspeed: 150 knts

TABLE 9 - Windshear Simulation Data Sets (Continued)

No.	NASA Terminal Area Simulation System (TASS) Data Set	Horz. grid spacing (meters) [1]	Max reflectivity (dBz)	Outflow reflectivity (dBz)	Approx. diameter of outflow @ peak_V (km)	Growth stage	Approx. peak 1 km FBAR [2]	Intervening rain [3]	Temp. lapse rate	Symmetry	Radar clutter model	Flight Scenario Location and Airspeed [4]
25	7/8/89 Sounding Denver Colorado DATA SET/TIME: 540 Very Dry Microburst [10]	100	17 to 20	-10 to -4	3.0	N/A	0.16	No	Adiabatic	Rough	Denver 26L	1000' AGL level flight standard rate turn to the localizer, as limited by 25 degrees of bank. The microburst should be placed such that it is directly in front of the aircraft when localizer is captured. Airspeed: 200 kts [8]
26	7/8/89 Sounding Denver Colorado DATA SET/TIME: 545 Extremely Dry Microburst Second Pulse [10]	100	5	-11	3.0	N/A	0.15	No	Adiabatic	Rough	Newark 4R/22L	-3 degree straight in approach to the north with the microburst located at the middle marker 1/2 NM from the runway threshold. Airspeed: 150 kts
27	Derived Sounding Florida DATA SET/TIME: 614 Highly Asymmetric Microburst	100	50	40 to 47	1.0	N/A	0.11	Light	Adiabatic	Asym	Wash. National 18	1000' AGL level flight standard rate turn to the localizer, as limited by 25 degrees of bank. The microburst should be placed such that it is directly in front of the aircraft when localizer is captured. Airspeed: 200 kts [8]
28	Derived Sounding Florida DATA SET/TIME: 614 Highly Asymmetric Microburst	100	50	40 to 47	1.0	N/A	0.15	Light	Adiabatic	Asym	Newark 4R/22L	-3 degree straight in approach to the north with a 360 degree heading. The microburst is located at the middle marker 1/2 NM from the runway threshold. Airspeed: 150 kts
29	Derived Sounding Florida DATA SET/TIME: 614 Highly Asymmetric Microburst	100	50	40 to 47	1.0	N/A	0.17	Light	Adiabatic	Asym	Newark 4R/22L	-3 degree straight in approach to the northeast with a 45 degree heading. The microburst is located at the middle marker 1/2 NM from the runway threshold. Airspeed: 150 kts
30	Derived Sounding Florida DATA SET/TIME: 614 Highly Asymmetric Microburst	100	50	40 to 47	1.0	N/A	0.15	Light	Adiabatic	Asym	Newark 4R/22L	-3 degree straight in approach to the south with a 180 degree heading. The microburst is located at the middle marker 1/2 NM from the runway threshold. Airspeed: 150 kts

TABLE 9 - Windshear Simulation Data Sets (Continued)

No.	NASA Terminal Area Simulation System (TASS) Data Set	Horz. grid spacing (meters) [1]	Max reflectivity (dBz)	Outflow reflectivity (dBz)	Approx. diameter of outflow @ peak_V (km)	Growth stage	Approx. peak 1 km FBAR [2]	Intervening rain [3]	Temp. lapse rate	Symmetry	Radar clutter model	Flight Scenario Location and Airspeed [4]
31	Derived Sounding Florida DATA SET/TIME: 614 Highly Asymmetric Microburst	50	50	40 to 47	1.0	N/A	0.19	Light	Adiabatic	Asym	Newark 4R/22L	-3 degree straight in approach to the southwest with a 225 degree heading. The microburst is located at the middle marker 1/2 NM from the runway threshold. Airspeed: 150 knts
32	Derived Sounding Florida DATA SET/TIME: 614 Highly Asymmetric Microburst	50	50	40 to 47	1.0	N/A	0.13	Light	Adiabatic	Asym	Newark 4R/22L	-3 degree straight in approach to the west with a 270 degree heading. The microburst is located at the middle marker 1/2 NM from the runway threshold. Airspeed: 150 knts
33	Derived Sounding Florida DATA SET/TIME: 614 Highly Asymmetric Microburst	100	50	40 to 47	1.0	N/A	0.13	Light	Adiabatic	Asym	Newark 4R/22L	-3 degree straight in approach to the northwest with a 315 degree heading. The microburst is located at the middle marker 1/2 NM from the runway threshold. Airspeed: 150 knts
34	8/2/81 Adjusted Knowlton Sounding Montana DATA SET/TIME: 727 Gust Front	100	20 In area of largest FBAR	18 to 20	N/A	N/A	0.12	No	Adiabatic	Asym	Newark 4R/22L	Aligned for take-off to the west with the microburst leading edge placed such that the airplane is in the headwind conditions of the outflow. Airspeed: 0 knts [5]
35	8/2/81 Adjusted Knowlton Sounding Montana DATA SET/TIME: 727 Gust Front	100	20 In area of largest FBAR	18 to 20	N/A	N/A	0.13	No	Adiabatic	Asym	Newark 4R/22L	-3 degree straight in approach to the west with the microburst located at the middle marker 1/2 NM from the runway threshold. Airspeed: 150 knts

TABLE 9
[Notes]

[1] NASA TASS data sets will all be delivered with 50 meter resolution.

[2] 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. (Reference Paragraph 4.1.11)

[3] Intervening rain may adversely affect system, performance. The system should be able to detect a hazardous windshear with at least 10 seconds advance warning to be classified as a forward looking system ("short or long range"). Since windshears can be contained in an environment with heavy rain, they should be detectable in these conditions.

Analysis of TDWR data obtained at Orlando has shown that the largest difference in reflectivity seen between two microburst-producing cells within 5 kilometers of each other was 10 dBz. At Denver this number increased to a maximum of 30 dBz, which was only seen twice. Therefore, for the purpose of testing sensor performance in intervening rain, the flight paths depicted in Appendix E have been, where appropriate, oriented such that they pass through significant areas of rain prior to reaching the microburst hazard.

Flight paths as described in Appendix E have been oriented, where appropriate, to achieve areas of intervening rain prior to reaching the windshear hazard.

[4] These detection systems 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 must perform satisfactorily over all expected circumstances (Reference Paragraph 4.1.11 and 4.1.14).

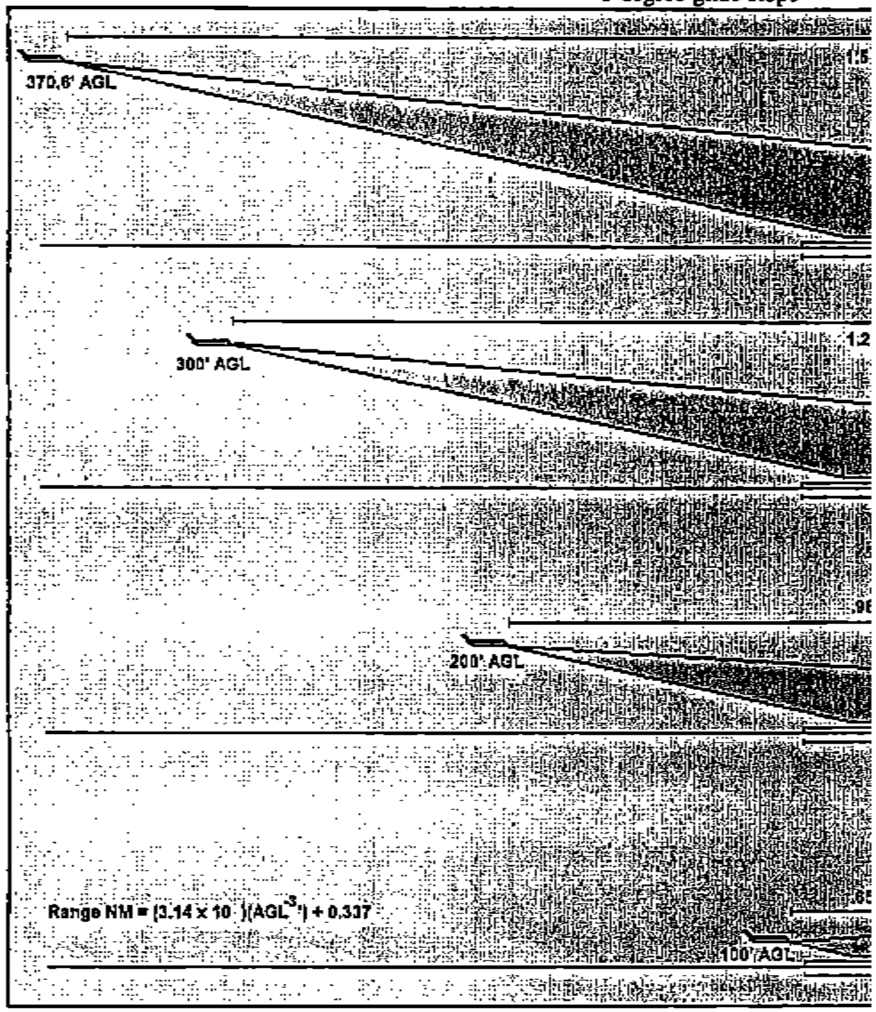
To require the entire test matrix to be evaluated for each configuration would be contentious; therefore, it is sensible for the system manufacture to determine and justify the critical conditions (relative to detection, clutter suppression, display, etc.) for their systems.

Radar ground clutter collection flights should be conducted using the flight phases and characteristics described in appendix E. All flight tests should be conducted using sensor/airplane pitch angles critical for system performance.

[5] These flight scenarios are 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.

FIGURE B
AUTOMATIC RANGE SCALIN(

Approach Mode Only
3 degree glide slope



Appendix B
Windshear Threat Definition

1. Performance-Based Threat:

The threat to be detected and avoided is an airplane performance or energy loss, expressed in terms of potential climb capability, due to flight through a sustained horizontal wind gradient and/or downdraft. The loss of potential climb angle is quantified by the F-factor equation given in 4.1.10. Events such as turbulence, which cause only passenger discomfort or short-period disturbances, are not considered a threat for the purpose of setting requirements for windshear detection and avoidance systems.

2. Threat Intensity and Shear Length:

To qualify as a threat to airplane performance, a significant level of F-factor must be sustained over a shear length sufficient to cause a critical loss of energy (airspeed and/or altitude) and for that energy change to result in a change of airplane flight path. Figure B-1 depicts the results of an energy tradeoff analysis used to determine the average F-factor required at various shear lengths to realize a specified, critical energy loss for 2, 3, and 4-engined transport category airplanes in takeoff and landing situations. The derivation of the curves assumes that the F-factor is zero both before and after the shear length under consideration, that is, performance gains that may be experienced before or after the windshear encounter are not modeled. Table B-1 shows the airplane related assumptions and specified energy losses used to produce the curves. The assumptions used represent the most critical airplane, flap settings, temperatures, and weights as selected from a set of representative airplanes. Also plotted is a turbulence curve, which shows the maximum F-factor due to turbulence that will occur over the indicated shear lengths with a probability of 10^{-4} (Reference 1). The figure shows that, over shear lengths of approximately 1000 meters or greater, the specified energy loss is caused by F-factor levels of greater than about 0.1.

Given the atmospheric and airplane assumptions used in the analysis, a hazardous windshear event could be defined as any windshear that produces an average F-factor that exceeds the applicable hazard definition curve in Figure B-1. This definition must be modified, since realizable phenomena of short shear lengths generally do not obey the assumption that F-factor is zero before and after the windshear event. These short shear length events tend to be followed by performance increasing shears before the airplane flight path can be altered, and are perceived as turbulence. Below about 600 meters shear length, phenomena can be found that exceed the hazard definition curves but do not threaten airplane performance, as evidenced by the turbulence curve merging with the hazard curves. Below about one kilometer shear length, the potential of finding a realizable windshear phenomena that does threaten the airplane rapidly diminishes as shear length decreases. In fact, reactive system certification criteria do not require those systems to detect events less than about 400 meters in shear length, regardless of F-factor intensity. At shear lengths greater than about 3000 to 4000 meters, the probability of finding an atmospheric phenomena to sustain hazardous F-factor levels (that does not also exceed the hazard curves at shorter lengths) becomes exceedingly small.

3. Threat Definition:

A working definition of the windshear threat to transport category airplanes can be described as any windshear that produces an average F-factor that exceeds the applicable hazard definition curve in Figure B-1, at shear lengths approaching one kilometer or greater.

4. Practical Considerations for Hazard Definition:

Practical windshear detection does not require determination of the average F-factor over each shear length. Although very severe shears of shear lengths near one kilometer, 900 meters for example, may exceed the hazard definition curve levels and present a risk, these phenomena will also exceed or be very close to the hazard definition curve levels over a one kilometer shear length. Likewise, nature does not produce constant shear values over long distances, and a 2000 or 3000 meter shear that exceeded the hazard definition curve would also likely have a higher one kilometer average F-factor somewhere within the event. This relationship is illustrated by figure B-2, which shows an estimate of the average F-factor for a range of shear lengths for four hazardous actual microburst encounters. The most severe shear shown represents the 1985 Dallas-Fort Worth accident microburst; the other three curves represent a research airplane penetration and two air carrier microburst encounters that resulted in very low-altitude go-around maneuvers. An average F-factor taken over a one kilometer averaging interval may therefore be used as a practical hazard measurement parameter. The rapid decrease in average F-factor with increasing scale length, for these hazardous shears, also suggests that detection systems should not use large shear length averaging schemes.

This hazard definition does not represent an alert threshold. Additional factors such as existing crew windshear training, installed reactive system thresholds (Reference 2), and other operational factors, such as uncertainty in sensor measurements and prevention of destabilized approaches, must be considered in the establishment of an alert threshold.

5. References

1. Dempster, John B.; Bell, Clarence A.: Summary of Flight Load Environment Data Taken on B-52 Fleet Aircraft, Journal of Aircraft, p.p. 398-406, Volume 2, No. 5, Sept.-Oct. 1965.

2. Federal Aviation Administration: Technical Standard Order TSO C-117, Airborne Windshear Warning and Escape Guidance Systems for Transport Airplanes, July 24, 1990.

TABLE B-1: HAZARD DEFINITION CURVE ASSUMPTIONS

	Takeoff Case	Landing Case
Assumptions		
Airplane Still Air Climb Gradient Capability (radians)	(takeoff flaps, gear up)	(landing flaps, gear down)
2-engine:	0.152	0.076
3-engine:	0.104	0.042
4-engine:	0.075	0.032
Initial Flight Path Angle (deg):	1.72	-3
Pilot Response Time to Windshear (sec):	0	5
Engine Spool Up Time (sec):	0	8
Initial Airspeed (knots true airspeed)		
2-engine:	143.1	145.9
3-engine:	147.0	138.6
4-engine:	176.5	170.1
Specified Energy Loss		
Airspeed Loss (knots true airspeed):		
2-engine:	27.8	26.9
3-engine:	32.5	29.9
4-engine:	27.4	35.2
Required Flight Path Angle (deg):	1.72	-2.5

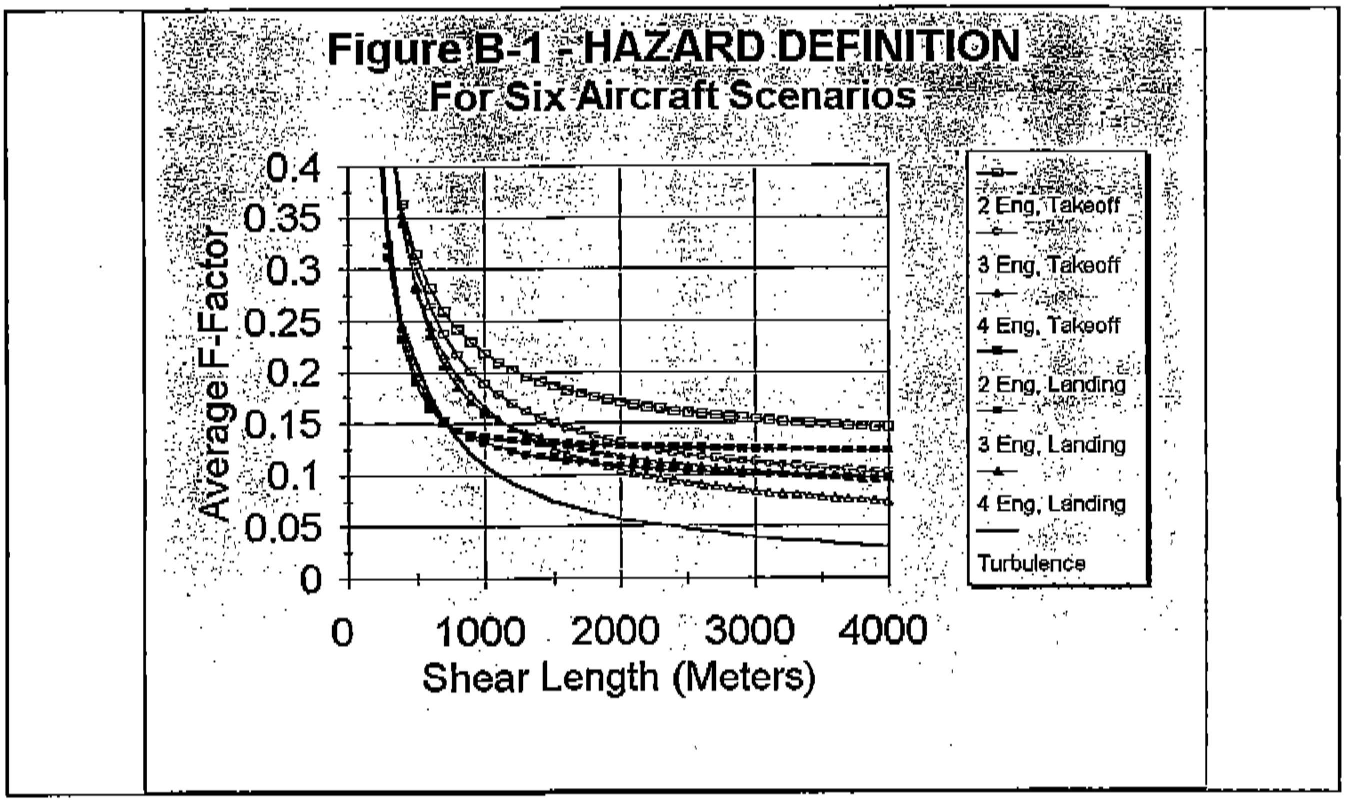


Figure B-1 - HAZARD DEFINITION
For Six Aircraft Scenarios
Average F-Factor
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
1000
2000
3000
4000
Shear Length (Meters)
2 Eng, Takeoff
3 Eng, Takeoff
4 Eng, Takeoff
2 Eng, Landing
3 Eng, Landing
4 Eng, Landing
Turbulence

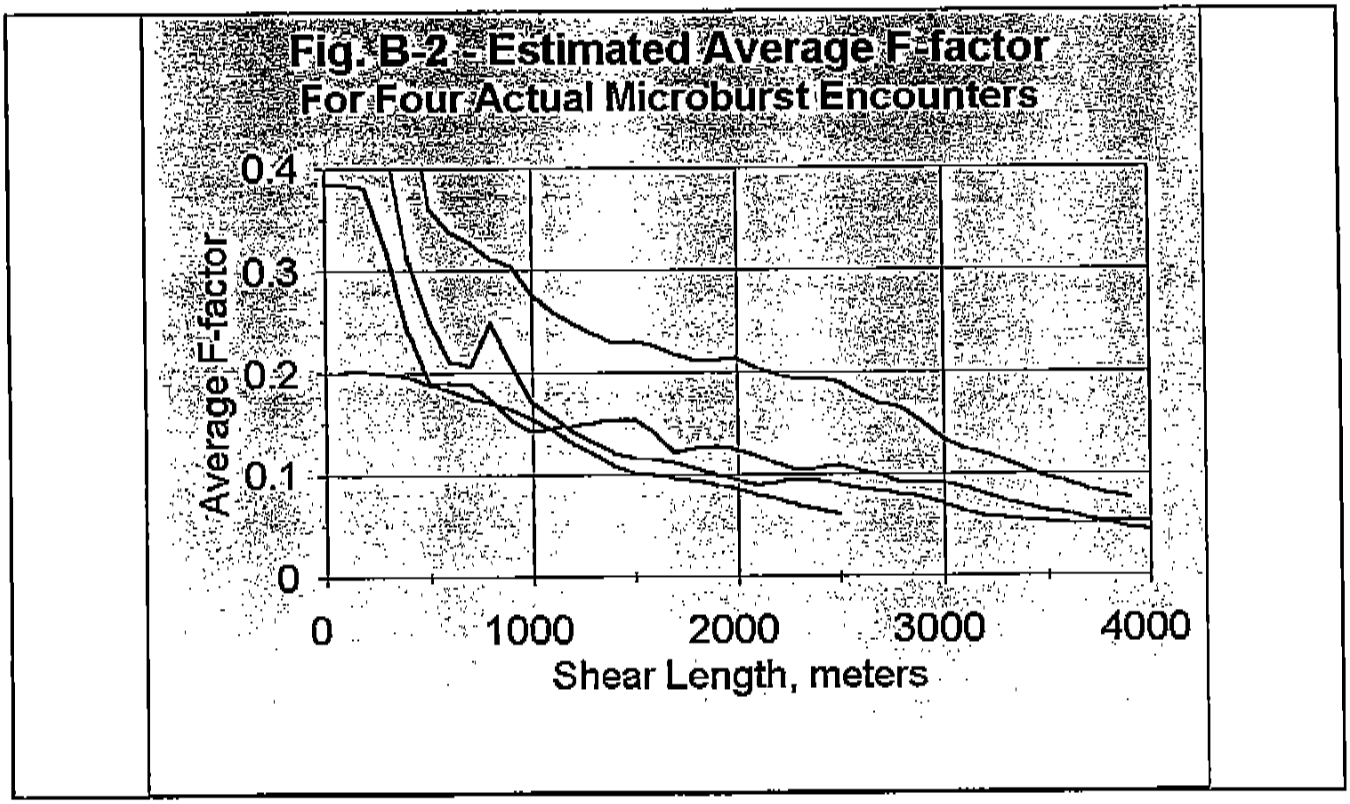


Fig. B-2 - Estimated Average F-factor
For Four Actual Microburst Encounters
Average F-factor
0.4
0.3
0.2
0.1
0
0
1000
2000
3000
4000
Shear Length, meters

Appendix C

Criteria Guidelines/Attributes

The following candidate criteria is intended to be used for comparison of the output of windshear forward-look systems undergoing certification testing, against the Terminal Area Simulation System (TASS) model certification data sets. The following guidelines or attributes were considered in the development of these criteria:

1. The criteria must accommodate both short and long range systems.
2. The output of the system under test may consist of an alert only, or an alert and icon. Range/azimuth plots of F-factor may not be available.
3. The criteria must not be dependent on the technology under test. The criteria will be stated in terms of the TASS data set "truth".
4. Practical criteria must include a "must alert", "may alert", and "must not" alert region to accommodate measurement uncertainties.
5. Definition of the must-alert region should be driven by the airplane performance hazard definition F-factor levels.
6. The size of any icon drawn on a display should be sufficient to allow the pilot to avoid the threat, provided that the pilot does not fly through any area depicted by the icon, while minimizing the size of the depicted threat region to avoid overwarning.

Note that a certification success criteria cannot be derived analytically from the physics of windshear or detection systems. Although a logical basis must be established for any criteria, by necessity some judgment must be used in the criteria development. In some cases, quantitative requirements may be reasonable estimates rather than numbers that can be supported by analysis. For this reason, the success criteria must be flexible and should be allowed to evolve as lessons continue to be learned about windshear detection and threat quantification.

Basis for Criteria

The "truth", or measurement standard, against which the output of candidate sensors will be compared will be a function of contours of one-kilometer FBAR, taken from the TASS data set in use, at the altitude that the airplane would encounter the threat if not given a forward-look alert. A one-kilometer FBAR, for this purpose, indicates an average F-factor, taken over a one-kilometer window along any radial from the sensor through the wind field. A one-kilometer FBAR at any point in space is the average F-factor over a distance of 1000 meters length, centered at the point in question, along a straight path through the shear. The NASA documentation of the TASS data sets will include one-kilometer FBAR contours along constant altitude parallel lines in the direction of flight, but the "truth" FBAR plot should be computed, by the applicant, along the sensor line of sight from the viewing position of the sensor in the data base. Contour intervals of 0.01 F should be plotted. Note that FBAR can be taken over averaging intervals other than one kilometer. The FBAR of the hazard definition curves, which will be used to establish the success criteria, are calculated over the averaging interval specified by the abscissa of the plot. An approximate technique for correlating these FBAR values to a standard one-kilometer FBAR will be suggested. If the sensor under test measures the hazard along shear lengths slightly different from one kilometer, the applicant will need to compute truth contour maps at the different shear length.

The threshold for reactive system alerting is an F-factor of 0.105. This value has been suggested as a candidate one-kilometer FBAR alerting threshold for forward-looking systems. In this case an alert would be given if the average F-factor exceeded 0.105 over any interval of one kilometer or greater. At one-kilometer shear lengths, however, considerable margin exists between the candidate threshold value and the most critical hazard definition curve. The hazard definition curve depicts the average F-factor, as a function of shear length (averaging interval) to produce a critical airplane energy loss. That hazard curve suggests that an FBAR of about 0.13 is required for a one-kilometer shear to produce the specified energy loss for the lowest performance airplane considered. As shear length increases, lower FBAR values become hazardous. Given the unavoidable errors in forward-look windshear hazard estimation, a requirement to detect any one-kilometer FBAR exceedances of 0.105 would be unnecessary and would create many nuisance alarms. The success criteria will therefore map a "must-alert" region of F-factor and shear length using the most critical hazard definition boundary. For certification testing, the term "must alert" applies only to the FBAR contour intensity. Before the system must actually alert, that microburst region must have entered the appropriate alerting region relative to airplane position. The alert is not required on each scan or sensor measurement update, but must be given prior to the microburst region reaching the specified minimum alerting range to the airplane.

The shear length over which FBAR is taken must also be related to the FBAR contours that will be produced from the TASS data sets. The TASS data set FBAR contour plots will always use a one-kilometer averaging interval to compute FBAR. If the TASS FBAR plot shows a threshold exceedance at only one point, this indicates that the average F-factor over a one kilometer distance exceeds that threshold. Likewise, if a particular contour of one-kilometer FBAR (0.11 for example) is two kilometers deep along the line of flight, and the contour does not enclose contours of lower strength, then the average F-factor over a 3 kilometer distance equals or exceeds the 0.11 F-factor value. (Since the three-kilometer averaging interval begins 500 meters prior to reaching the 0.11 contour line, and continues 500 meters beyond the far side of the contour.) Note that the opposite is not generally true. An actual FBAR of 0.11 over three-kilometers may produce a contour of one-kilometer FBAR = 0.11 that is less than two kilometers deep, depending on the value of the peak F-factor within the contour. Since significant deviations from this relationship between one-kilometer FBAR contour depth and the hazard definition curve FBAR shear lengths would require peak F-factors well above the FBAR value, and the one-kilometer FBAR contours are being plotted at intervals of 0.01 F, an FBAR shear length of X distance on the hazard definition curve may usually be approximated by a one-kilometer FBAR contour of (X-1000) meters in depth.

Must-Alert Criteria

Given that the hazard definition curves are based on the most critical airplane and conditions, a "must-alert" boundary line can be drawn at the lowest of the hazard definition curves. This boundary line is not the lowest of any of the six individual hazard definition curves, but is a new curve based on the minima of the other six curves at each shear length. At shear lengths of approximately 2000 meters and greater, the boundary curve falls below the baseline reactive system threshold of 0.105. Requiring a system to alert at F-factors below 0.1 would produce many nuisance alarms, and is not necessary given the relationship of FBAR to shear length for any given shear. As shown in figure C-1, a given microburst will generally produce lower FBAR values as the averaging interval (shear length) is increased. The events that exceed 0.105 at two to three kilometer shear lengths also exceed the 0.13 boundary at one kilometer. For the small radius microburst events, FBAR decreases so rapidly with shear length that FBAR values are below reasonable thresholds at averaging intervals of two to three kilometers. To avoid excessive nuisance and missed alert problems in actual operations, certification testing should take place only within a limited range of shear lengths, preferably within about 200 meters of one kilometer. The final must-alert boundary is a straight line approximation to the boundary line resulting from the hazard definition curves. The boundary line of lowest hazardous F-factor, the must-alert boundary, and plots of FBAR for four hazardous microburst encounters are shown in figures C-1 and C-2. Figure C-2 shows the same data and boundaries as figure C-1, but the shear length axis has been altered to emphasize the acceptable testing region. The must-alert boundary is defined by the following points.

FBAR Shear Length (meters)	FBAR at which alert must be given	TASS 1 km FBAR Contour Depth to Approximate the FBAR Shear Length (meters)
< 700	Not tested.	N/A
700	0.15	N/A (700 m FBAR contours would be required)
1000	0.13	Smallest resolution of data set
1500	0.12	500
>1500	Not tested.	N/A

Note that these numbers do not represent sensor thresholds or relate to internal algorithms. For example, this table does not suggest that a single pixel of FBAR = 0.14, as sensed by the detection system, should generate an alert. The table does indicate that a TASS data set event, that produces a single FBAR contour of 0.13, must be detected by the sensor within the time or distance required. The must-alert region also represents minimum acceptable performance. While not required, forward-look systems should warn of events with one-kilometer FBAR values of approximately 0.11 to 0.12, to avoid exposing the airplane to situations that would activate reactive windshear systems. A one-kilometer shear of 0.12, while within the performance capabilities of transport airplanes, would likely cause a pilot to execute a go-around, should activate an installed reactive system, and could lead to a hazardous situation. Below 0.11, reactive systems may or may not alert, depending on the shear length of the hazard.

Must-Not-Alert Criteria

The must-not-alert boundary is driven by the need to minimize nuisance alerts. At very small shear lengths, less than about 500 meters, the turbulence curve shown with the hazard definition indicates that very large FBAR levels may be exceeded. The nature of turbulence is such that these performance decreasing shears are followed by performance increasing shears before the airplane flight path can respond, hence no performance loss hazard is created. For this reason the must-not-alert boundary will exclude all shear lengths less than 500 meters regardless of FBAR. In terms of a maximum FBAR that may activate an alarm, an assumed standard deviation of 0.02 for forward-look F-factor estimation was subtracted from the baseline reactive system threshold of 0.105. The resulting boundary is FBAR = 0.085, regardless of shear length. The composite of these two areas is the final must-not-alert region.

May-Alert Criteria

The may-alert region is simply the area between the must-alert and must-not-alert regions. At 1000 meters shear length, a sensor may alert if the TASS data set FBAR is between 0.085 and 0.13, and must alert if FBAR exceeds 0.13. At this shear length, the margin between the must-alert and must-not-alert boundary is 0.045 F.

As described above, any given windshear event will generally contain higher FBAR levels over short shear lengths and lower FBAR levels over large shear lengths. A plot of FBAR and shear length for a given microburst may then fall into all three regions (must-not, may, and must-alert). For example, a severe microburst may have an FBAR of 0.25 over 400 meters (must-not-alert), 0.20 over 900 meters (may alert), and 0.14 over 2000 meters (must alert). For the purposes of certification testing, the highest region applies and the alert must be given. Figure C-1 shows the relationship between the alert regions, the lowest of the hazard definition curves, and average F-factor for four actual microburst penetrations.

Icon Size Criteria

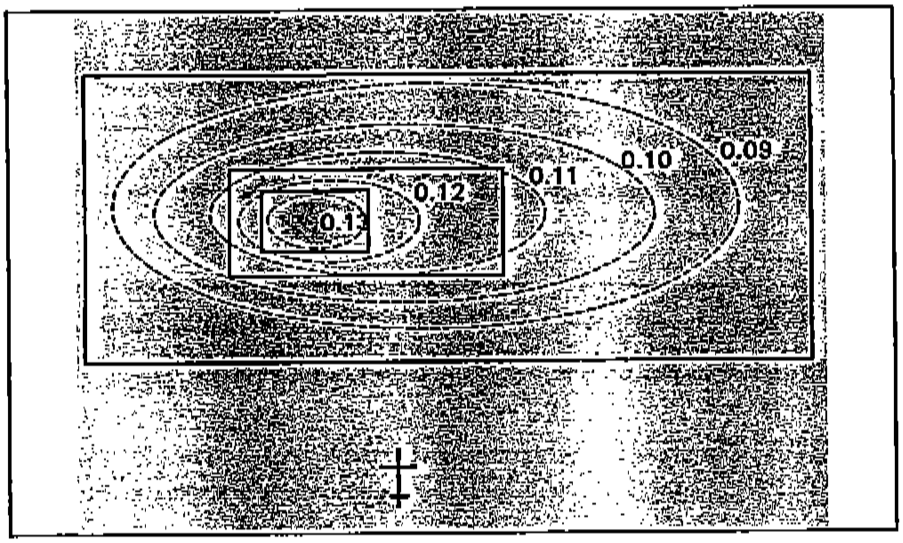
The icons should be sized to depict the shear region forward of the airplane that would cause a well-trained pilot to execute a go-around or would have a high likelihood of activating a reactive windshear system if penetrated. The icon size must also be limited to avoid unnecessary missed approaches or takeoff delays when microbursts are to the side of the intended path. Icon size requirements can be related to TASS data set one-kilometer FBAR contours. The relationship between the one-kilometer FBAR contours and the required icons will be expressed both in terms of the percent of the contour area covered by the icon and the azimuth extent of the contour, as observed from the airplane, that is depicted by the icon. The requirement for azimuth coverage should be more rigorous than the contour areal coverage, since a pilot may use the display to coordinate lateral avoidance with ATC, but would not likely use a display in an attempt to fly very close to the threat before turning. The requirements specified here do not include other practical requirements that may be superimposed, such as a minimum icon size for display legibility. The requirements described below are in terms of the TASS data set "truth" contours and not in terms of sensor estimates of the hazard.

As a minimum requirement, the icons depicted shall enclose the entire microburst area, both in range and azimuth, that contain FBAR values in the "must-alert" region. Shear lengths from 800 meters to 1200 meters may be used in this FBAR calculation.

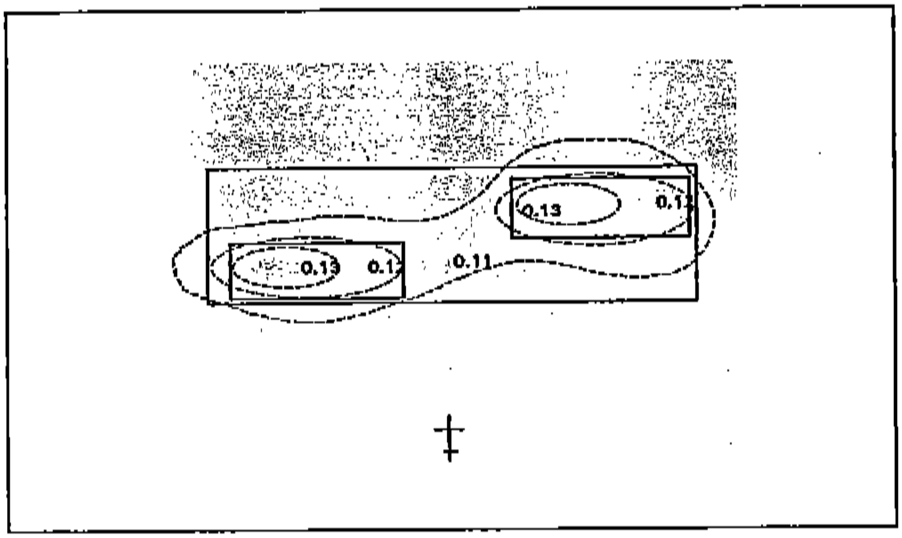
Provided that a microburst is detected, slightly larger icon shapes are desirable. For TASS one-kilometer FBAR contours of 0.12, 100 percent of the azimuth extent and at least 90 percent of the areal extent should be enclosed by the icon. This added coverage is desirable to avoid exposing the airplane to shear levels that would activate reactive systems, if the airplane just missed the shear region depicted by the icon. For 0.11 contours, the icons should enclose at least 80 percent of the contour azimuth extent and at least 70 percent of the areal extent.

In terms of the maximum size of icons, at least 80 percent of the azimuth extent of an icon shall contain a TASS one-kilometer FBAR contour of 0.09 or greater. Since FBAR contour shapes may be irregular or elongated, the areal extent is expressed in terms of range. At least 80 percent of the icon range coverage (distance from near edge of icon to far edge of icon) should be occupied by FBAR regions of 0.09 or greater. The attached sketch shows the approximate acceptable range of icon sizes for an example set of FBAR contours. The arc-shaped microburst icon shapes specified for forward-look displays have been approximated in this sketch by rectangles.

An exception to the icon size requirements should be made for shears that might produce multiple icons close together. Microbursts frequently occur in lines, and attempted flight between two closely spaced icons could produce an encounter with a developing downdraft core. Closely spaced shears that would otherwise produce icons separated in azimuth by approximately 2 to 4 kilometers or less, should be represented as one icon. This concept is depicted in an attached sketch.



Approximate minimum, desired, and maximum size of icons for given FBAR contours, arc-shaped icons approximated with rectangles in sketch.



Example of one icon used to enclose two closely-spaced shear areas, that might otherwise produce two small icons.

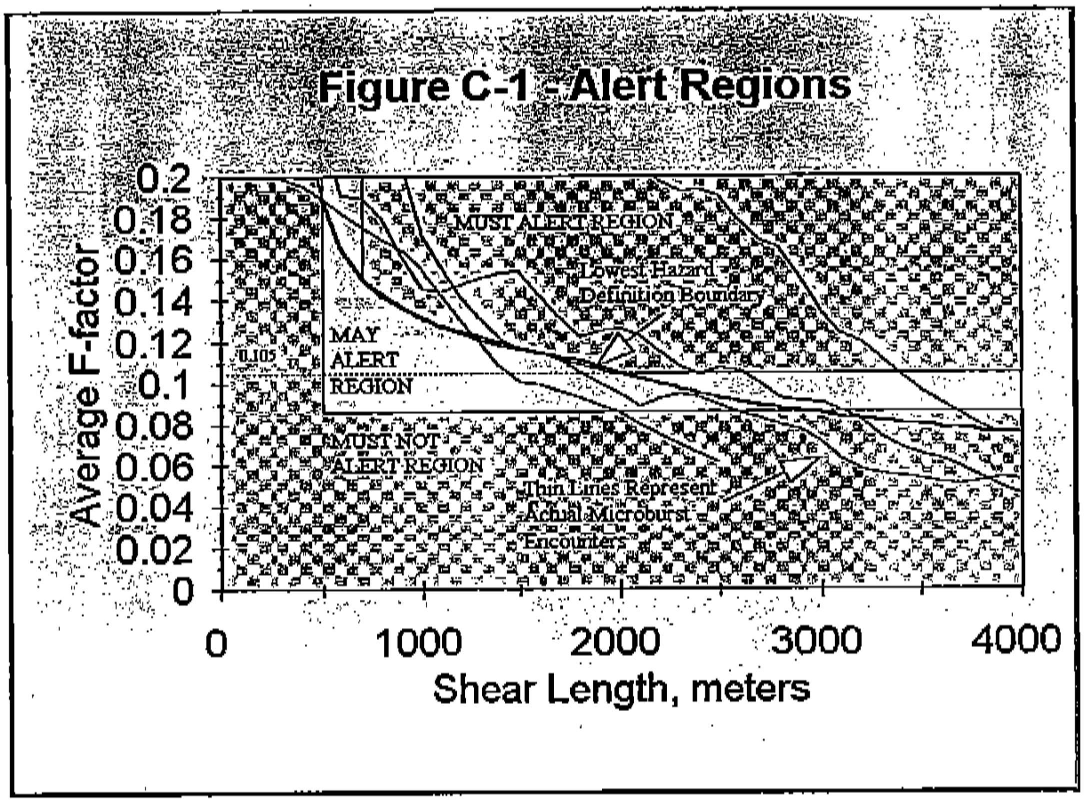
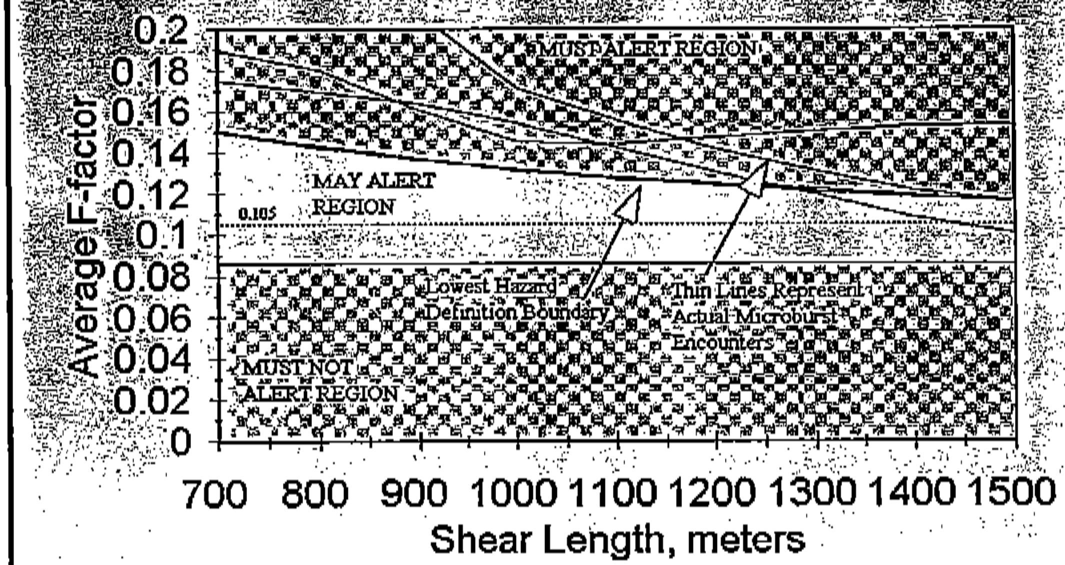


Figure C-1 - Alert Regions

Figure C-2 - Testing Alert Regions



Appendix D

Note

Appendix D is an analysis based on the NASA Windshear Detection System. The reference to "false" alert is equivalent to "nuisance" alert in Section 3.2.5 of this System Level Requirements Document.

Revision 10.2
January 1995

RTI/4500/024-01S

March 1993

DETECTION AND FALSE ALERT PROBABILITIES FOR THE NASA AIRBORNE PULSED DOPPLER WINDSHEAR RADAR

By: C. L. Britt

TECHNICAL MEMORANDUM

NASA Contract NAS1-18925
Task Assignment No. 24

Prepared for

National Aeronautics and Space Administration
Langley Research Center
Hampton, VA 23681

Prepared by

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Revision 5

Detection and False Alert Probabilities
for the NASA Airborne Pulsed Doppler Windshear Radar

I. INTRODUCTION.

This memo summarizes a method for calculation of the detection probability for the NASA windshear radar. The method follows the general procedure given in [ref.1]. However, several of the equations in [ref. 1] have been replaced by equations felt to be more applicable for the techniques used in the NASA system. 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, the equations must be modified accordingly.

II. SINGLE PULSE SNR

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

$$SNR = \frac{P_t G^2 T \theta_B \phi_B \Delta R \pi^6 |k_v|^2 Z_e 10^{-18}}{4R^2 \lambda^2 (4\pi)^3 (KT_o F_n) L} \quad (1)$$

Where:

P_t	=	Transmitted power (watts).
G	=	Antenna Gain.
λ	=	Wavelength (m).
T	=	Pulse width (s).
θ_B	=	Antenna beamwidth - azimuth.
ϕ_B	=	Antenna beamwidth - elevation.
ΔR	=	Range bin size (m).
$\lvert k_v \rvert$	=	Rain dipole moment constant = .92.
Z_e	=	Reflectivity factor (mm^6 / m^3).
R	=	Radar Range (m).
KT_o	=	4×10^{-21} (watt - secs).
L	=	System losses.
F_n	=	System noise figure.

III. VELOCITY MEASUREMENT ERROR

The variance of a single power weighted mean velocity measurement as a function of SNR (using FFT processing) is derived in [ref. 2] as

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

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).
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.

IV. 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 [ref. 3] can then be related to the standard deviation of the total hazard factor, giving:

$$\sigma_F = \frac{3.464\quad \sigma_v\ \left[\frac{V}{g} + \left(\frac{2h}{V}\right)\right]}{\Delta\left[(N_e+1)\quad (N_e-1)\quad N_e\right]^{.5}} \tag{3}$$

Where:

Δ	=	Radar range bin length (m).
N_e	=	Number of points used in l.s. estimator.
V	=	Aircraft ground speed = aircraft air speed (m/s).
g	=	Acceleration of gravity (m/s²).
h	=	Altitude of the measurement (m).
σ_v	=	Standard deviation of an individual velocity measurement (from eq. 2) (m/s).
σ_F	=	Standard deviation of the total hazard factor.

V. 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 1000 m 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:

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

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.
Δ	=	distance between velocity measurements.
$C_i = x_i/\Delta$		normalized weighting factor of i^{th} measurement at a distance x_i from the measurement at $i = 0$.
$(\Sigma C_i)_j^2$	=	Sum of weights of j^{th} velocity measurement squared.
$\Sigma_j(\Sigma C_i)_j^2$	=	Total of squared weights of all measurements used.

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 $N_e = 5$ and $N_a = 7$, 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:

$(\Sigma C_i)_{-5}^2 = 4$	$(\Sigma C_i)_{-2}^2 = 4$	$(\Sigma C_i)_1^2 = 0$	$(\Sigma C_i)_4^2 = 9$
$(\Sigma C_i)_{-4}^2 = 9$	$(\Sigma C_i)_{-1}^2 = 0$	$(\Sigma C_i)_2^2 = 4$	$(\Sigma C_i)_5^2 = 4$
$(\Sigma C_i)_{-3}^2 = 9$	$(\Sigma C_i)_0^2 = 0$	$(\Sigma C_i)_3^2 = 9$	

so that

$$\Sigma_j\,(\Sigma C_i)_j^2 = 52.$$

thus, the calculation using eq. (4) is:

$$\sigma_{\hat{F}}^2 = \frac{\sigma_F^2}{10}\left(\frac{52}{49}\right) = .106\,\sigma_F^2$$

$$\sigma_{\hat{F}} = .32\,\sigma_F$$

For this case, the averaging has improved the standard deviation of the least-squares measurements by a factor of .32.

VI. AVERAGING THE $\hat{F}$ 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 [ref. 1]

$$\sigma'_{\hat{F}} = \frac{\sigma_{\hat{F}}}{\sqrt{n_\theta}} \tag{5}$$

Where:

n_θ = is the number of lines over which the measurement is averaged.

VII: 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 5)

$$PD(R/\hat{F}_a, Z) = \int_{FT}^{\infty} f(\hat{F}/\hat{F}_a, Z)\; d\hat{F} \qquad \hat{F}_a > FT \tag{6}$$

Where:

$f(\hat{F}/\hat{F}_a, Z)$	=	Probability density function of the 1000 m averaged F-Factor ($\hat{F}$) for given values of true averaged F-factor $\hat{F}_a$ and reflectivity value Z (conditional probability density).
$\hat{F}_a$	=	True value of hazardous F-factor..
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:

$$PM(R/\hat{F}_a, Z) = 1 - PD(R/\hat{F}_a, Z) \qquad \hat{F}_a > FT \tag{7}$$

VIII. FALSE ALERT PROBABILITY

A false alert will be given if the system alerts on a hazard with a true $\hat{F}$ 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 false alert in a single scan is

$$PF(R/\hat{F}_{na}, Z) = \int_{FT}^{\infty} f(\hat{F}/\hat{F}_{na}, Z)\ d\hat{F} \qquad \hat{F}_{na} < FT \tag{8}$$

Where:

$\hat{F}_{na}$	=	True value of non-hazardous F-factor.
$\sigma_F(Z)$	=	Standard deviation of measurement error.
FT	=	Hazard detection threshold.

IX. 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 must indicate a hazard in order to declare an alert (i.e. the sum of the areas of the individual pixels indicating a hazard must 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 false 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 false detection in M independent pixels are:

$$PD(R) = [PD^{s}(R)]^{M} \tag{9}$$
$$PF(R) = [PF^{s}(R)]^{M} \tag{10}$$

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 detection in a single pixel.
$PF^s(R)$	=	Probability of a false detection in a single pixel.

and as an approximation,

$$M = INT\left(\frac{A_T^{1/2}}{R\Delta\theta}\right) + 1$$

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 (.2 sq km), the value of M will be small (≈ 2 - 4) over the ranges of interest.

X. 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 false 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

$$[PD'(R)]_i = \prod_{k=1}^{N_s} [PD(R)]_{i-k+1} \tag{11}$$

and the probability of a missed alert is

$$[PM'(R)]_i = 1-[PD'(R)]_i \tag{12}$$

In the above equations,

i	=	scan number starting at initial scan, i = 1, 2....N.
$[PD(R)]_i$	=	probability of detection on scan i.
k	=	scan index, $1 \le k \le N_s$.

Similarly, the probability of a false alert on scan i is given by

$$[PF'(R)]_i = \prod_{k=1}^{N_s} [PF(R)]_{i-k+1} \tag{13}$$

XI. CUMULATIVE PROBABILITY OF DETECTION AND FALSE 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:

$$[PD(R)]_i = 1 - \prod_{k=1}^{N} [PM'(R)]_{i-k+1} \tag{14}$$

Where:

$[PM'(R)]_i$ is the probability of a missed detection on scan i, (from eq. (12)).

Similarly, the cumulative probability of at least one false alert in N scans of a non-hazardous windshear is

$$[PF(R)]_i = 1 - \prod_{k=1}^{N} [1-PF'(R)]_{i-k+1} \tag{15}$$

Where:

$[PF(R)]_i$ is the probability of a false alert on scan i.
$[1 - PF'(R)]_i$ is the probability of no false 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

$$N(R) = INT\left[\frac{R_T-R}{VT_s}\right]+1 \qquad R_M \le R \le R_T \tag{16}$$

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 (14), (15) and (16) permit the calculation of the cumulative probabilities of detection and false alarm for given values of "must-not-alert" and "must alert" hazard, SNR threshold, weather reflectivity, and system parameters.

XII. PROBABILITIES AVERAGED OVER THE POPULATION OF MICROBURSTS.

The previous equations have been developed based on an encounter with an idealized microburst with a given averaged hazard factor ($\hat{F}$) and reflectivity (Z). Hence, the probabilities are conditional probabilities based on a given $\hat{F}$ and Z.

To develop probabilities of detection and false alert per microburst encounter, use can be made of the empirical probability functions given in [ref. 1] for microburst hazard intensity and reflectivity. From [ref. 4], the probability that a randomly encountered microburst will have a hazard value F less than a value x is given by:

$$\Pr(F < X) = 1 - \exp[-(x/.123)^2] \tag{17}$$

Because of the lack of data on averaged hazard factor, it is necessary to assume that the above probability function also applies to the 1000 m. averaged F-factor ($\hat{F}$).

The corresponding probability density function for $\hat{F}$ is:

$$f_H(\hat{F}) = \frac{2\,\hat{F}\ \exp\left[-(\hat{F}/.123)^2\right]}{(.123)^2} \tag{18}$$

In [ref. 1], expressions are also developed for the probability density functions of outflow reflectivity at three locations. The outflow reflectivity data were obtained from Steve Campbell at M.I.T. Lincoln Laboratory [ref. 5]. These density functions are, for $-20 < Z < 60$,

a. Denver

$$f^D(Z) = \frac{d_1}{\cosh^2[d_2(Z-10)]} \tag{19}$$

b. Kansas City

$$f^k(Z) = k_1(60-Z)^{1.5}\ \exp\left[-k_2(60-Z)^{2.5}\right] \tag{20}$$

c. Orlando

$$f^O(Z) = O_1(60-Z)^{1.5}\ \exp\left[-O_2(60-Z)^{2.5}\right] \tag{21}$$

Where:

$$\cosh(x) = \frac{1}{2}[\exp(x) + \exp(-x)]$$

$$d_1 = 3.4250 \times 10^{-2}$$

$$d_2 = 6.8515 \times 10^{-2}$$

$$k_1 = 3.8655 \times 10^{-4}$$

$$k_2 = 1.5462 \times 10^{-4}$$

$$o_1 = 5.7028 \times 10^{-4}$$

$$o_2 = 2.2811 \times 10^{-4}$$

and $-20 \le Z \le 60$. The assumption is made that eq. (19) to (21) characterize the microburst population and that the hazard factor and reflectivity are independent variables.

The detection probability averaged over a population of microbursts is given by

$$<PD(R)> = \frac{\int_{ZLO}^{ZHI} \int_{FDLO \times FT}^{FDHI} PD(R/\hat{F}_a, Z)\, f_H(\hat{F}_a)\, f_z(Z)\, d\hat{F}_a dZ}{\int_{ZLO}^{ZHI} \int_{FDLO \times FT}^{FDHI} f_H(\hat{F}_a)\, f_z(Z)\, d\hat{F}_a dZ} \qquad (22)$$

The probability of a missed detection on a single scan is

$$<PM(R)> = 1 - <PD(R)> \qquad (23)$$

Similarly, the averaged false alert probability is

$$<PF(R)> = \frac{\int_{ZLO}^{ZHI} \int_{FFLO}^{FFHI \times FT} PF(R/\hat{F}_a, Z)\, f_H(\hat{F}_a)\, f_z(Z)\, d\hat{F}_a dZ}{\int_{ZLO}^{ZHI} \int_{FFLO}^{FFHI \times FT} f_H(\hat{F}_a)\, f_z(Z)\, d\hat{F}_a dZ} \qquad (24)$$

The averaged cumulative probabilities can be obtained using eq. (23) and (24) with the cumulative probabilities used in the equations in place of the single scan probabilities.

The integration limits ZLO, ZHI, FDLO, FDHI, FFLO, and FFHI define the population of microbursts to be used in the averaging process. For example, to determine the averaged probability of detection of $\hat{F}_a >= .13$ microbursts with reflectivity greater than 0 dBz, the integration limits are:

ZLO = 0.	FDLO = 0.13
ZHI = 60.	FDHI = 0.30

For the averaged probability of false detection of $\hat{F}_a <= .085$ microbursts with reflectivity greater than 0 dBz, the limits are:

ZLO = 0.	FFLO = 0.0
ZHI = 60.	FFHI = 0.085

It should be noted that the conditional probabilities $PD(R/\hat{F}_a, Z)$ and $PF(R/F_a, Z)$ are calculated using a fixed F-factor detection threshold (FT) of .105.

XIII. CALCULATIONS

a) Discussion

A FORTRAN 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 or hazard measurements are made if the received power is less than this threshold. The value of this threshold strongly effects calculations of cumulative probabilities, since the threshold determines where the accumulation of probabilities starts. The threshold also effects the single-scan probability calculations, since the probability of a detection (or false 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 groundspeed of 80 m/s and an altitude of 100 m.

b) Calculation of SNR and Measurement Errors

Figure 1 provides a list of system parameters used in the calculations. The single-pulse SNR (eq. 1) of the system is plotted versus range in figure 2 for three values of rain reflectivity.

Figure 3 plots the resulting standard deviation of velocity (eq. 2) versus range for a weather spectral width of 3 m/s.

Figure 4 plots the standard deviation of the averaged F-factor (eqs. 3, 4 and 5). In this plot, it is assumed that no averaging over adjacent azimuth lines is used (i.e. $n_a = 1$).

c) Probability Calculations

A sketch showing the technique for calculation of detection and false alert probability is given in figure 5. The mean averaged F-factor for detection of a hazard is selected as .130 (must alert value) and the mean averaged F for false alert calculations is .085 (must-not alert value). The system hazard factor threshold is .105.

Based on the above values, the probability of a missed detection of a .130 microburst is plotted vs. radar range in figure 6 for three values of weather reflectivity. Figure 7 shows the probability of a false detection of a .085 microburst vs. range. Neither of these plots show the effect of an SNR threshold. The threshold would make the plot of missed detection go to one and the plot of false detection go to zero at ranges where the signal level was below the threshold value.

Figure 8 plots the detection and false alert probability vs. the single-pulse SNR level. At low SNR, both curves approach an asymptotic value of .5 due to the nature of the calculation (see figure 5).

Figure 9 plots the ratio of the detection probability to the false alert probability vs. single-pulse SNR. Figure 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 false alert. A value of log 1 for this ratio (i.e. 1 false alert per 10 true alerts) will be attained using an SNR threshold of approximately -3dB (single pulse SNR) or +7.5 dB (processed SNR). This value is used for the following cumulative probability calculations.

Cumulative probability calculation using equations 14 and 15 are shown in figures 11 to 13 for -5, 0, and +5 dBZ respectively. The detection probability rapidly goes to unity just after the SNR threshold is reached. The false alert probabilities reach an asymptotic value as shown.

d) Averaged Probabilities for Denver, Orlando and Kansas City

Using eqs. 18 to 23, the probability functions are averaged over a selected population of microbursts at three locations. These averaged probabilities may be interpreted as the probabilities of a missed or false alert on a randomly encountered microburst with a reflectivity greater than 0 dBz at the given location. It is assumed that the microburst F-factor and outflow reflectivity are independent parameters. The calculations are based on an SNR threshold of -3dB (single-pulse) and a F-factor threshold of .105. The must alert F-factor is .13 and the must-not alert F-factor is .085. Thus, the integration limits are the same as the example in section XII.

Figure 14 plots the probability density functions for reflectivity (eqs. 19, 20 & 21) used in the calculation. Figure 15 is a plot of the hazard factor probability density.

Figures 16 to 18 show the averaged probabilities of a missed and false alert on a single radar scan for Denver, Orlando, and Kansas City respectively for the selected population of microbursts.

Figures 19 to 21 are similar plots showing the averaged cumulative probabilities vs. radar range.

e) Probability Calculations with the NASA Clutter Suppression Techniques Considered

The above calculation 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 figures 22 to 32.

Figures 22 and 23 plot the probability of missed detection and false detection for the NASA system using hazard detection on two radarscans 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 figures 24 to 26. Notice that at a given range the probability of a false alert has been reduced considerably, and the probability of a missed detection has been reduced somewhat at the closer ranges.

Figures 27 to 32 plot the averaged probabilities vs. range for Denver, Orlando and Kansas City using the clutter suppression technique and the selected microburst population ($Z \geq 0$ dBz).

XIV. SUMMARY & 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 false alert performance.

The noise-limited performance of the system averaged over the selected microburst populations ($Z \geq 0$ dBz) at Denver, Kansas City and Orlando indicates that a missed alarm probability of 10^{-5} per encounter will be achieved at ranges less than 2.5 km. If the total microburst population is included in the calculation, however, ($-20 \geq Z \leq 60$ dBz), the detection performance degrades significantly, particularly at Denver where a significant percentage of microbursts have reflectivities less than 0 dBz.

It should be emphasized again that the calculations do not consider the effects of ground clutter or of bias on velocity measurements at low SNR values. For realistic prediction of system detection performance, these factors should be taken into account.

TRANSMITTED POWER (WATTS)	200.
FREQUENCY (GHZ)	9.3
PULSE WIDTH (MSECS)	1.0
PULSE REP. RATE	3755.
SYSTEM NOISE FIGURE (DB)	4.0
SYSTEM LOSSES (DB)	1.0
ANTENNA BEAMWIDTH - AZ (DEG)	3.5
ANTENNA BEAMWIDTH - EL (DEG)	3.5
ANTENNA GAIN (DB)	34.0
NO. OF F-FACTORS AVERAGED	7.0
NO. OF MEAS. IN LEAST- SQUARES EST.	5.0
NO. OF AZ LINES AVERAGED	1.0
NO. OF PULSES PROCESSED	128.
AIRSPEED/GROUNDSPEED (M/S)	80.
RAIN REFLECTIVITY (DBZ)	0.
RAIN SPECTRAL WIDTH (M/S)	3.
HEIGHT OF MEASUREMENT (M)	100.
SUM OF SQUARED WTS - AVR F-FACTOR EST.	52.
F-FACTOR THRESHOLD	.105
MUST ALERT F-FACTOR	.13
STARTING RANGE (M)	12000.
ANTENNA SCAN INTERVAL (S)	4.2
MUST-NOT ALERT F-FACTOR	.085
SNR THRESHOLD FOR DETECTION (DB)	-3.
HA ALERT AREA THRESHOLD (SQKM)	.2
AZ PIXEL ANGULAR SPACING (DEG)	2.
CITY (1=DENVER, 2=KC, 3=ORLANDO)	1.
NO. OF SCANS FOR DETECTION	2.
DO AVERAGED PROB CALC (1.=YES)	0.

Figure 1 - List of System Parameters Used in the FORTRAN Program for Calculation of Detection and False Alert Probabilities.

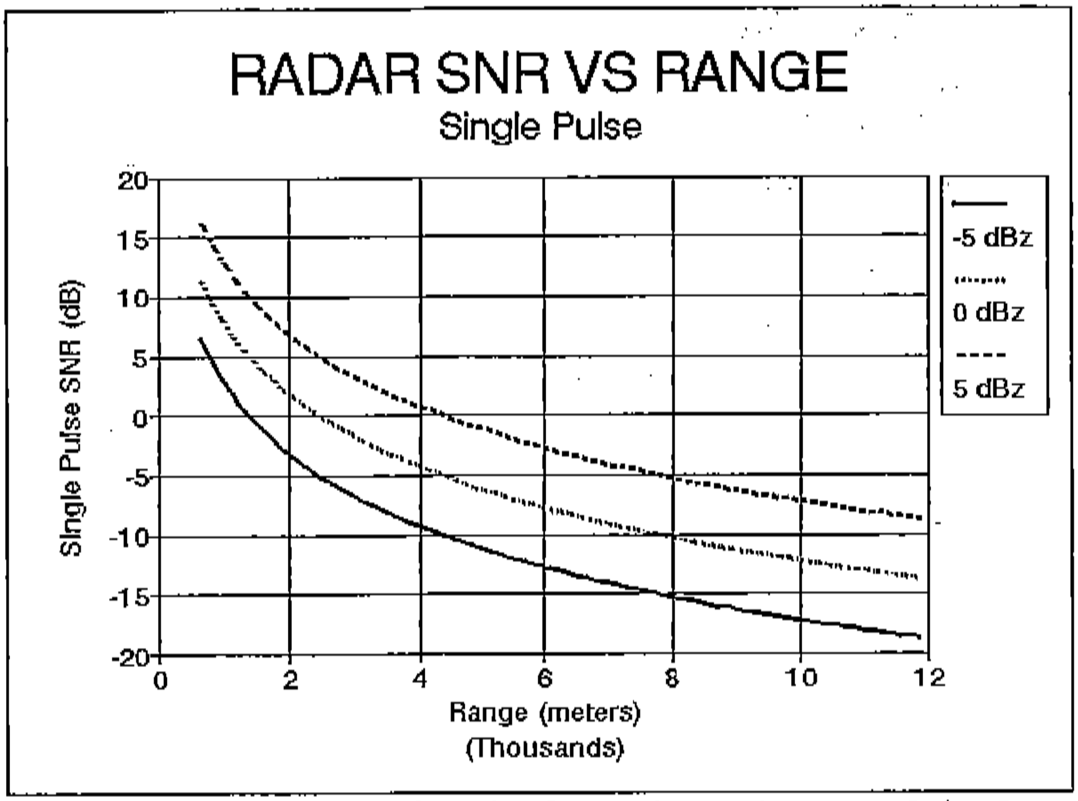

Figure 2 - Radar Single Pulse Signal-to-Noise Ratio versus Radar Range for Three Values of Rain Reflectivity.

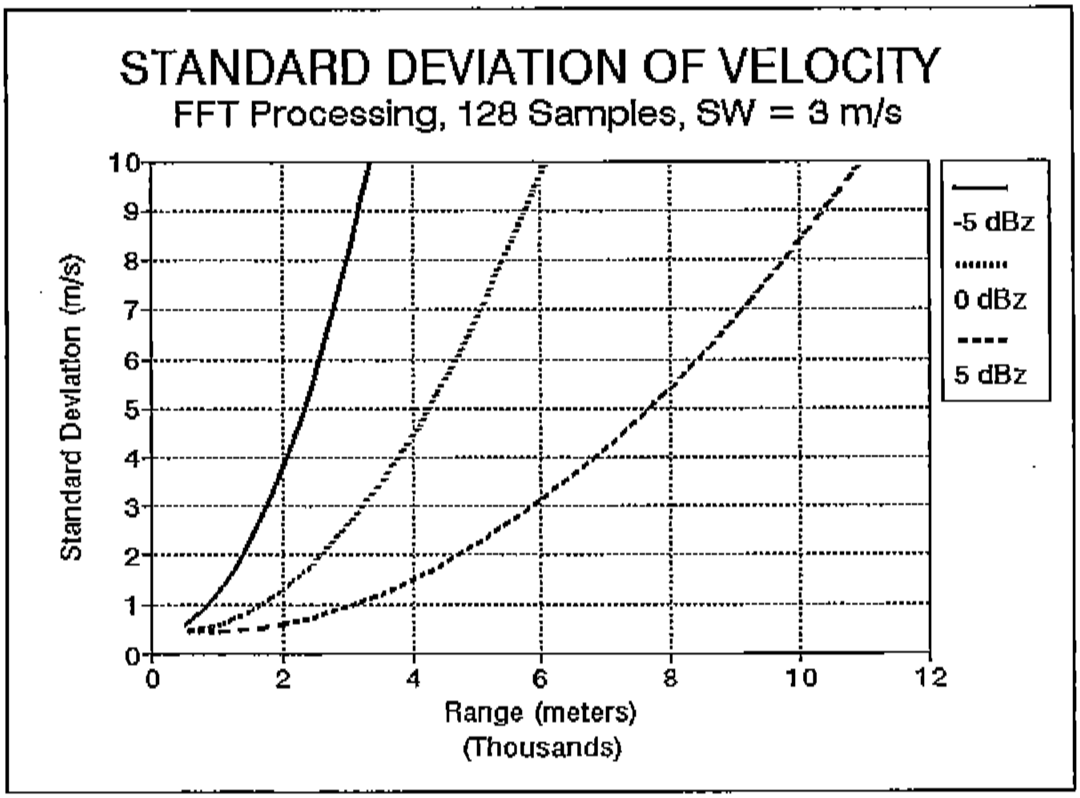

Figure 3 - Standard Deviation of a Velocity Measurement Based on FFT Processing of 128 Pulses. The weather spectral width is assumed to be 3 meters per second.

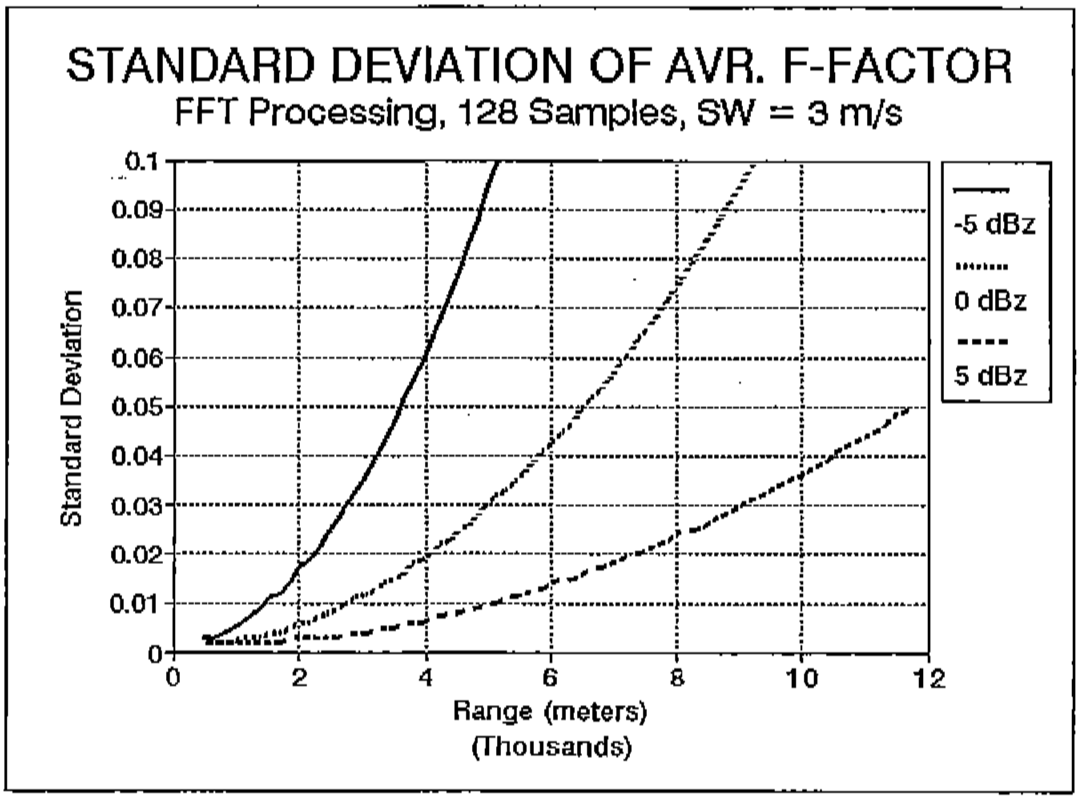

Figure 4 - Standard Deviation of 1000 meter Averaged F-Factor Using FFT Processing of 128 Samples. No averaging over adjacent azimuth lines is used.

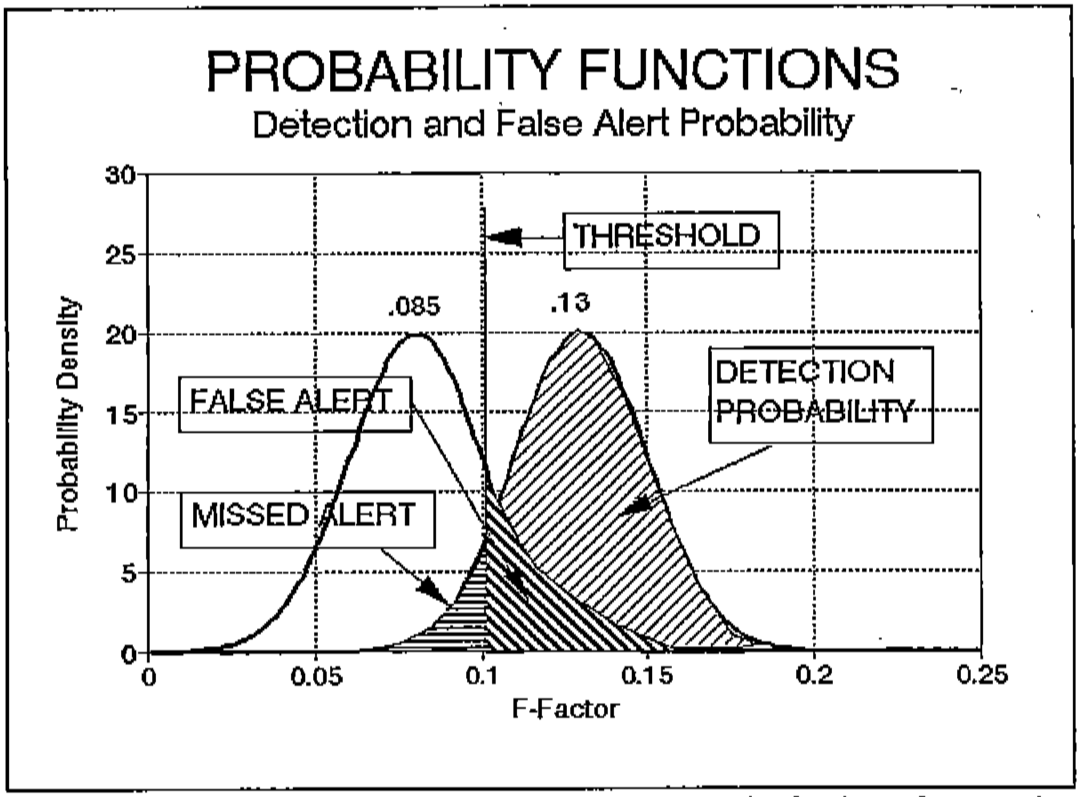

Figure 5 - Sketch Indicating the Technique for Calculation of Detection and False Alert Probability. The must alert F-Factor is assumed to be .13 and the must-not alert F-Factor is .085.

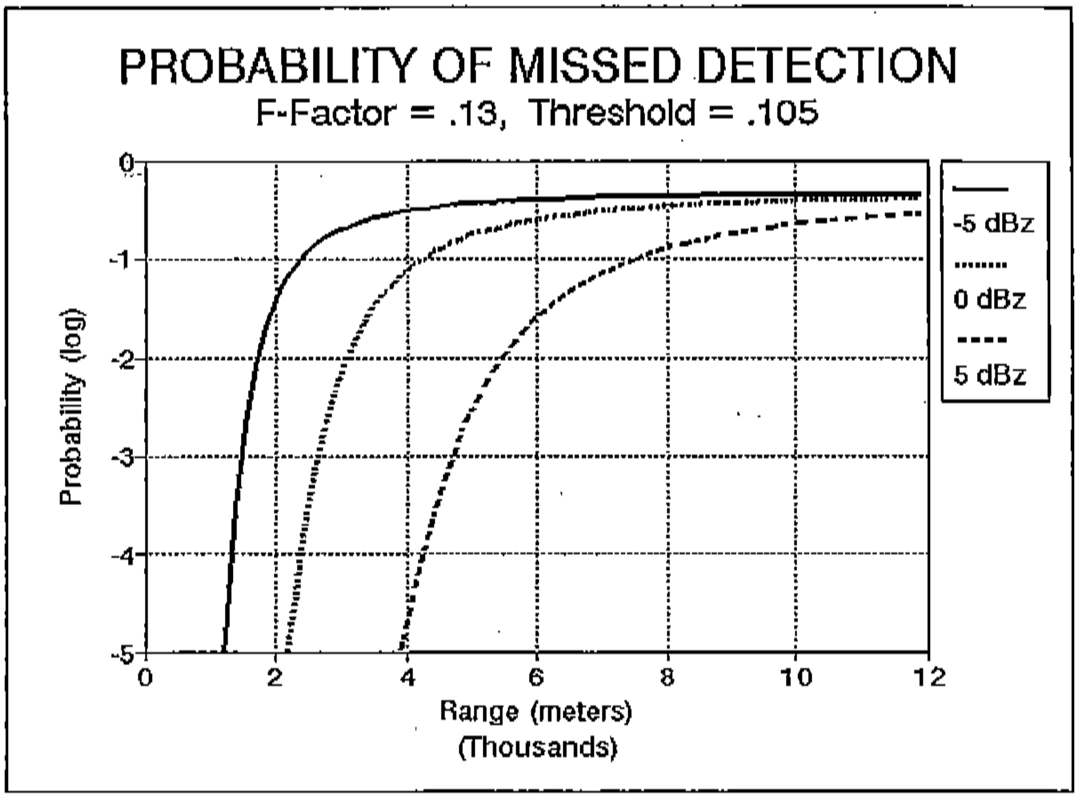

Figure 6 - The Probability of a Missed Detection of a .13 Averaged Hazard Plotted Versus Range For A Single Range/Azimuth Bin.

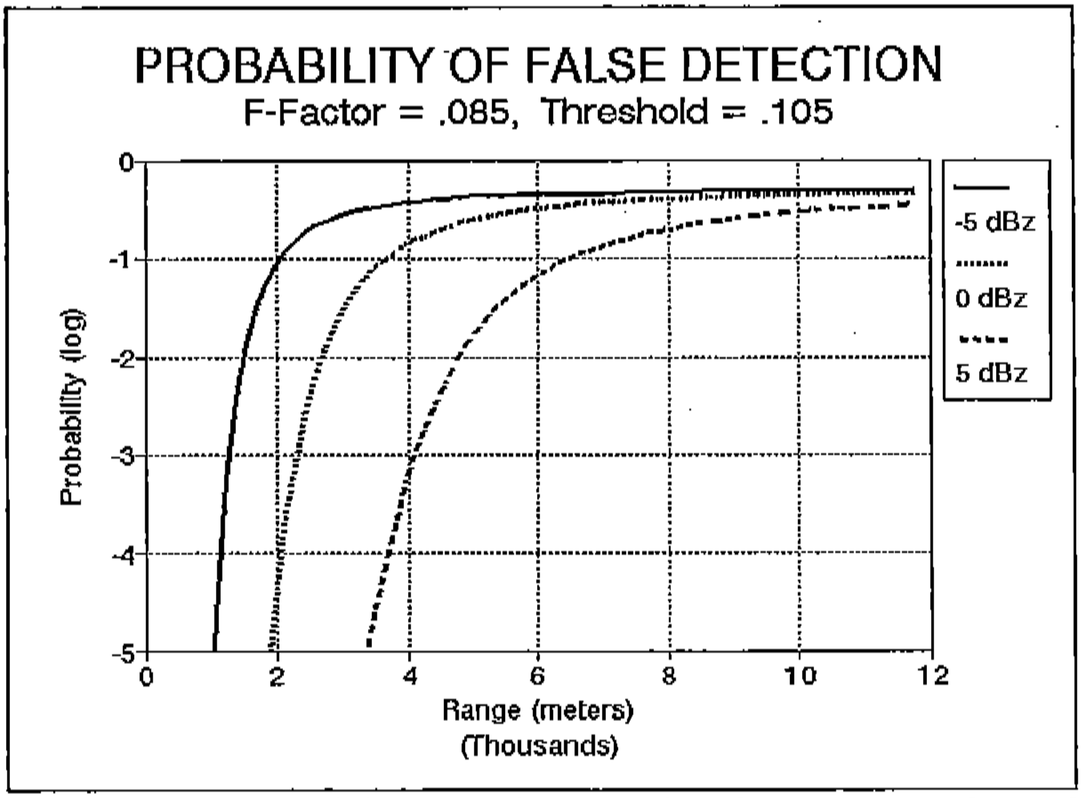

Figure 7 - The Probability of a False Detection of a .085 Averaged Hazard Plotted versus Range For A Single Range/Azimuth Bin.

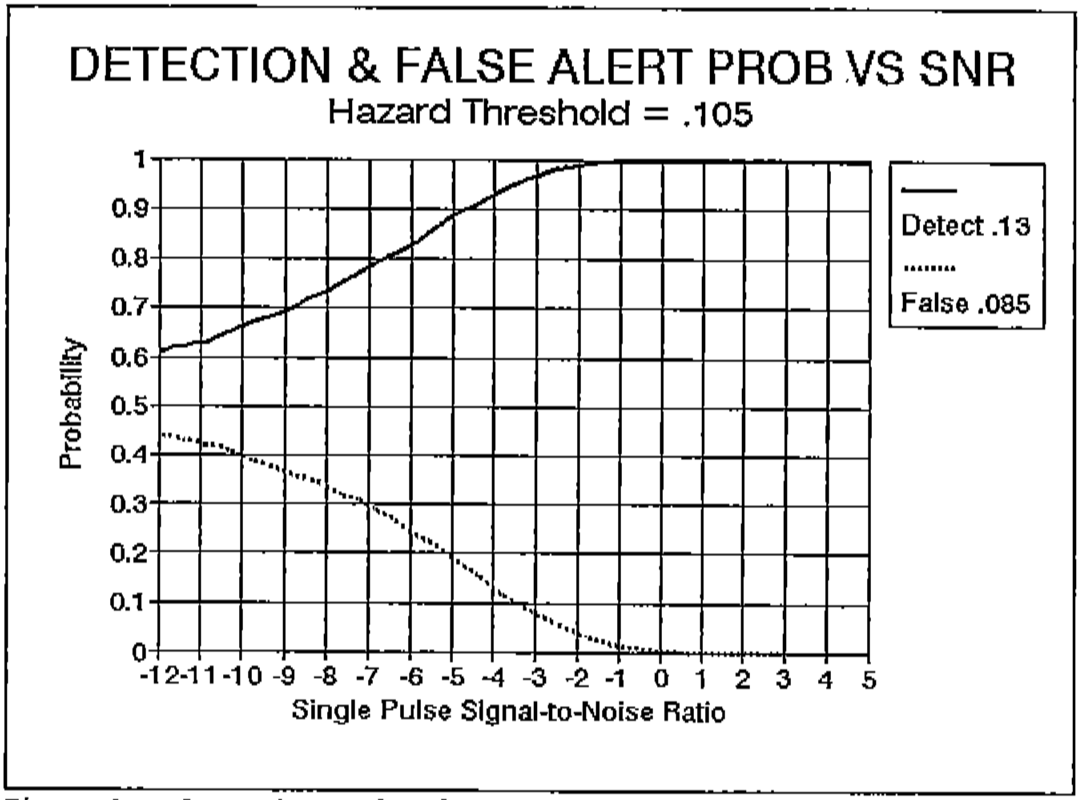

Figure 8 - Detection and False Alert Probability Plotted Versus the Single-Pulse Signal-to-Noise Ratio.

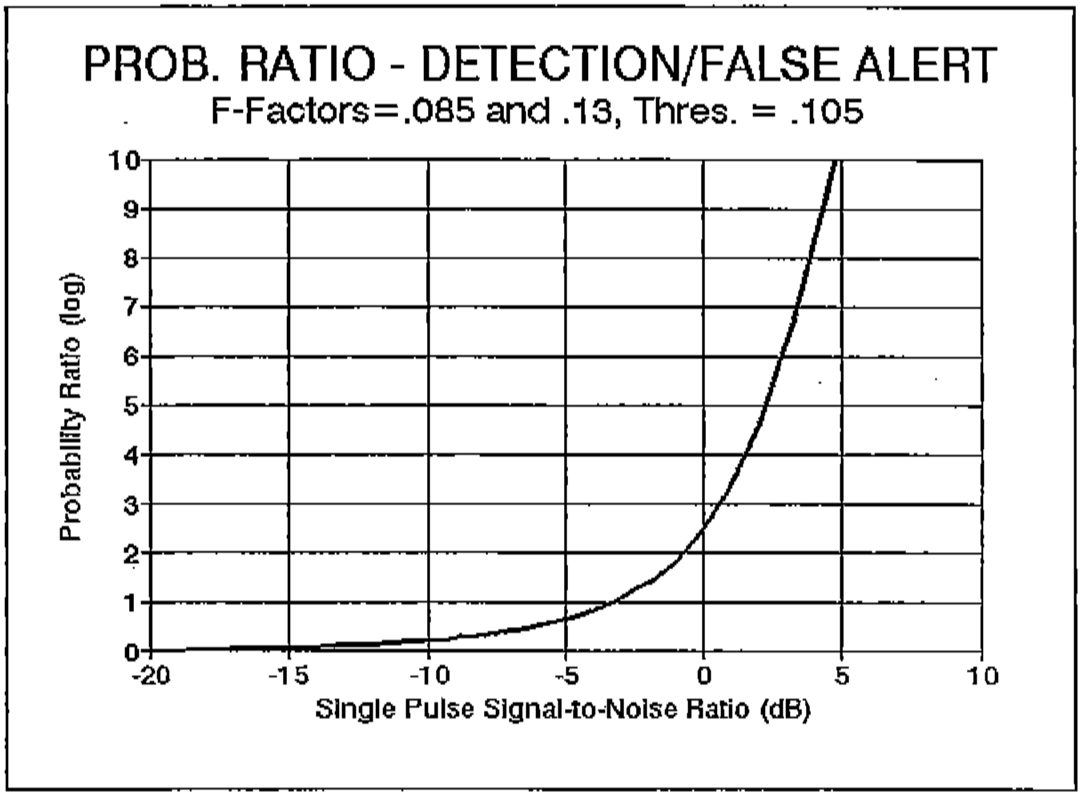

Figure 9 - Ratio of Detection to False Alert Probability Plotted Versus Single-Pulse Signal-to-Noise Ratio.

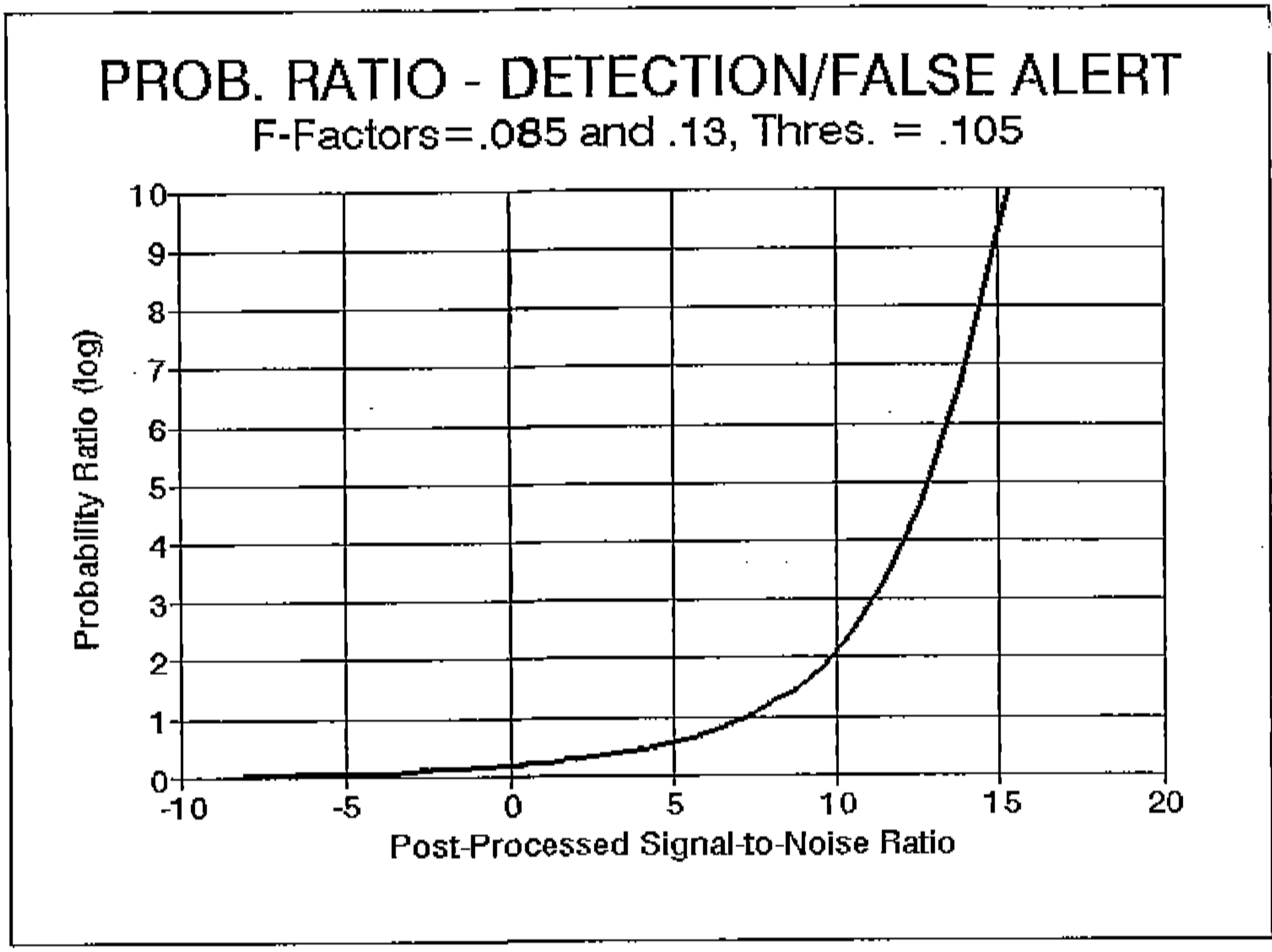

Figure 10 - Ratio Plot Similar to Figure 9 Except that the Postprocessed Signal-to-Noise Ratio is Used as the Ordinate. A signal-to-noise ratio threshold of approximately 7.5 dB must be used to maintain the ratio of one false alert per 10 true alerts.

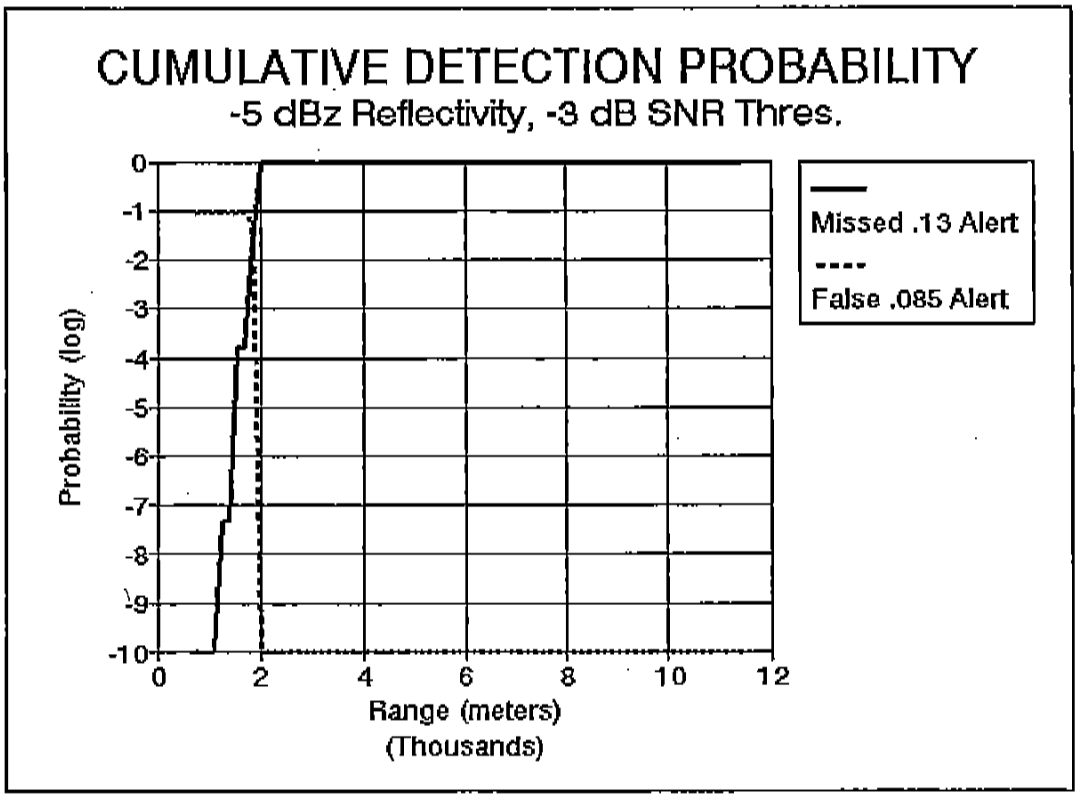

Figure 11 - Cumulative Probability of Missed and False Detection for -5 dBz Weather Reflectivity and an SNR Threshold of -3dB.

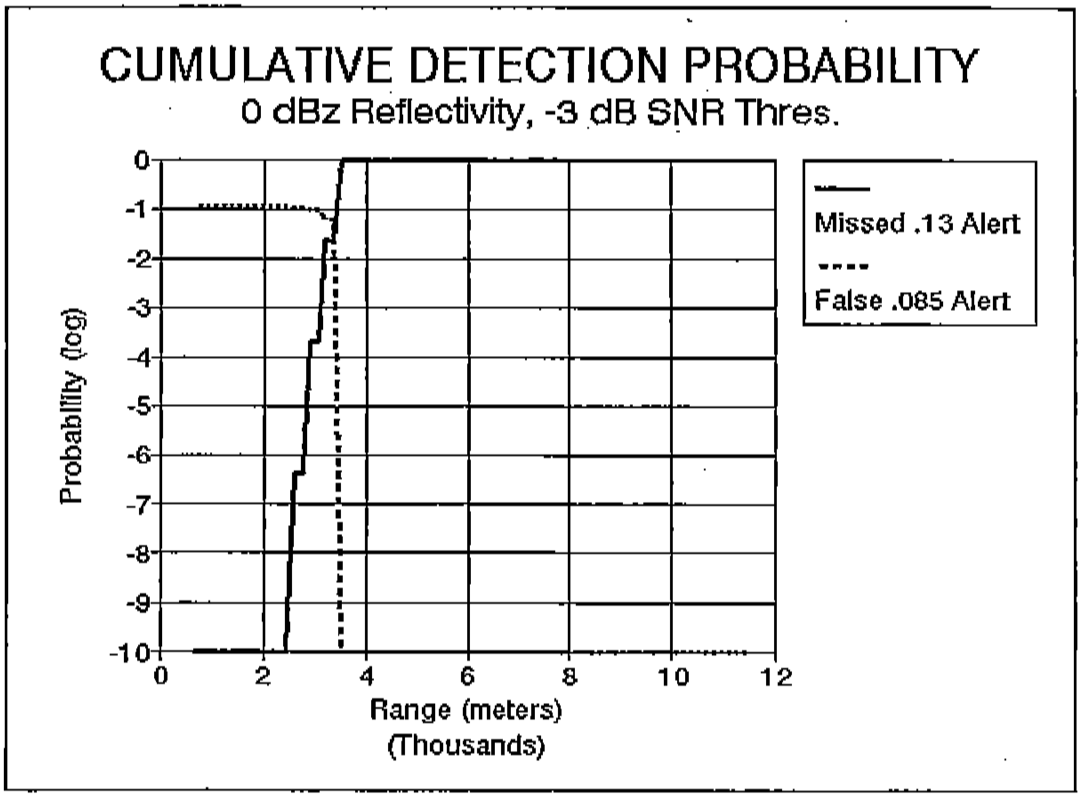

Figure 12 - Cumulative Probability of Missed and False Detection for -0 dBz Weather Reflectivity and an SNR Threshold of -3 dB.

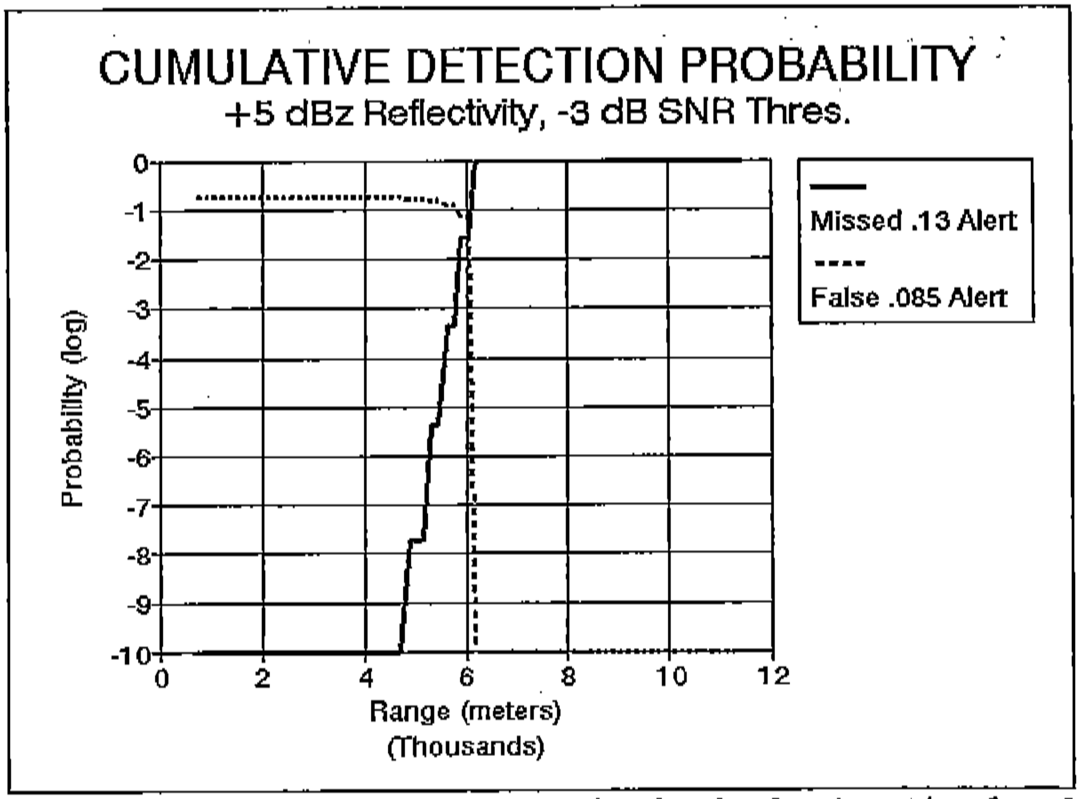

Figure 13 - Cumulative Probability of Missed and False Detection for +5 dBz Weather Reflectivity and an SNR Threshold of -3 dB.

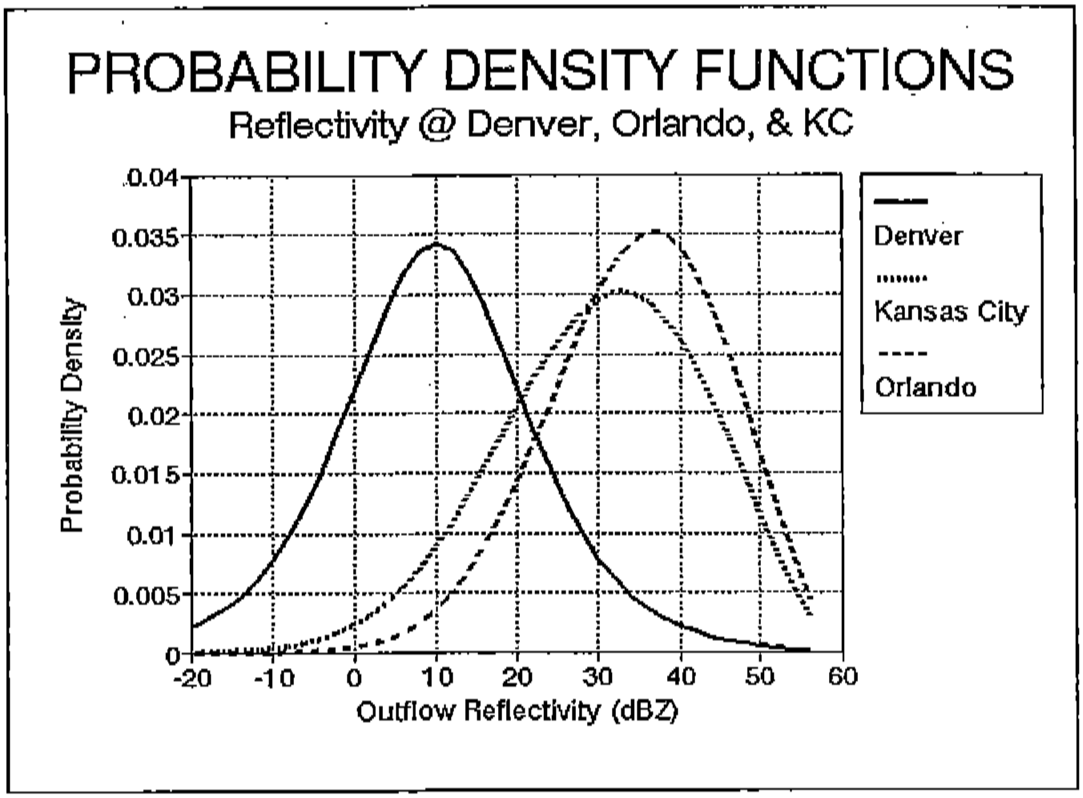

Figure 14 - Plot of the Probability Density Functions of Outflow Reflectivity from Denver, Orlando and Kansas City (from Reference 5).

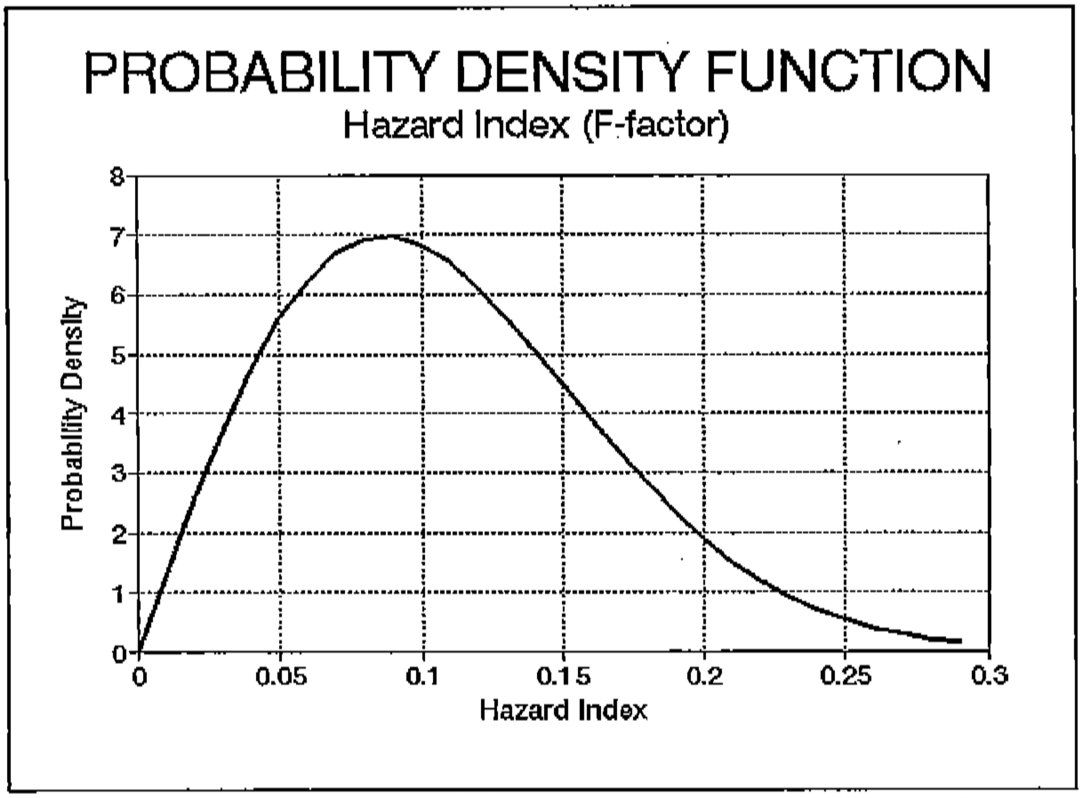

Figure 15 - Plot of the Probability Density Function of Hazard Factor (from Reference 4). It is assumed that this density function applies to the 1000 meter averaged F-Factor.

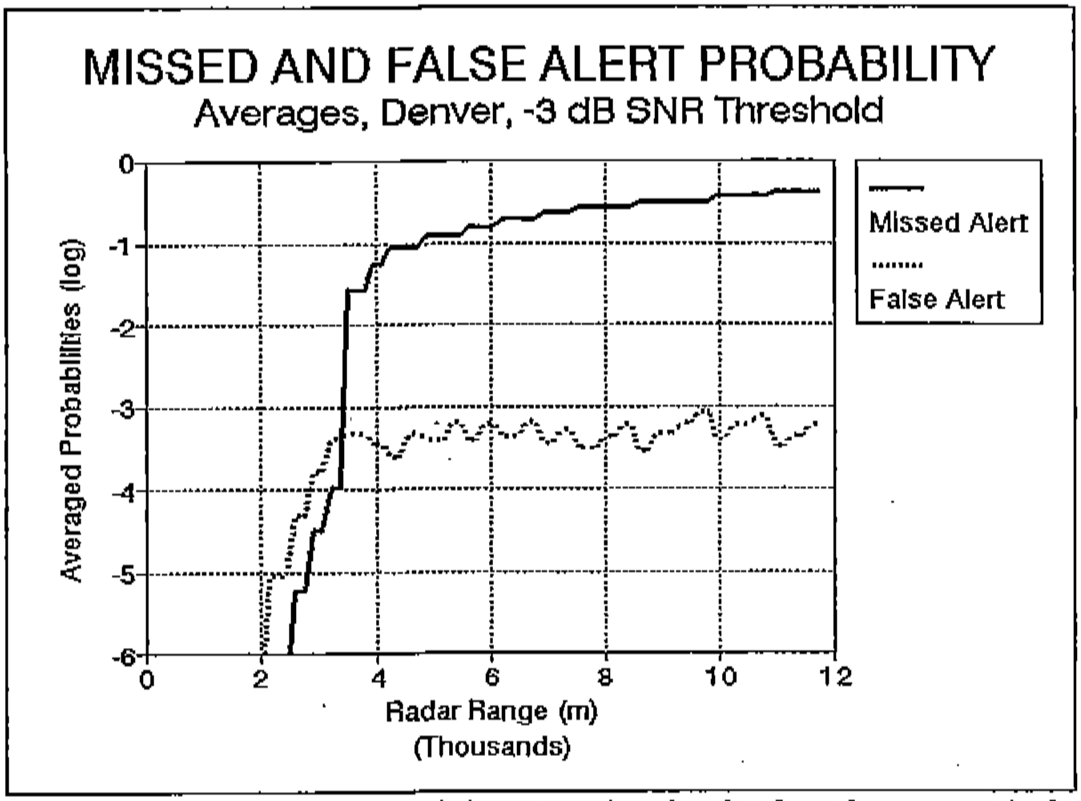

Figure 16 - Averaged Probabilities of a Missed and False Alert on a Single Scan at Denver for Microbursts Exceeding 0 dBz Reflectivity.

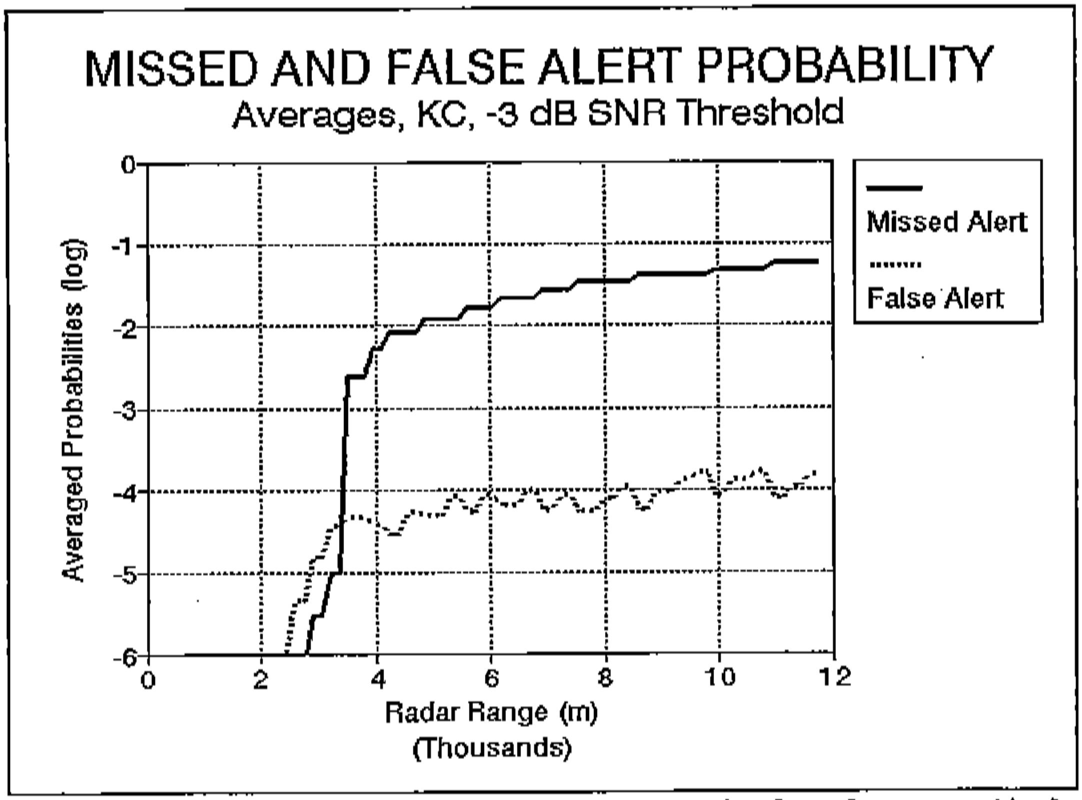

Figure 17 - Averaged Probabilities of a Missed and False Alert on a Single Scan at Kansas City for Microbursts Exceeding 0 dBz Reflectivity.

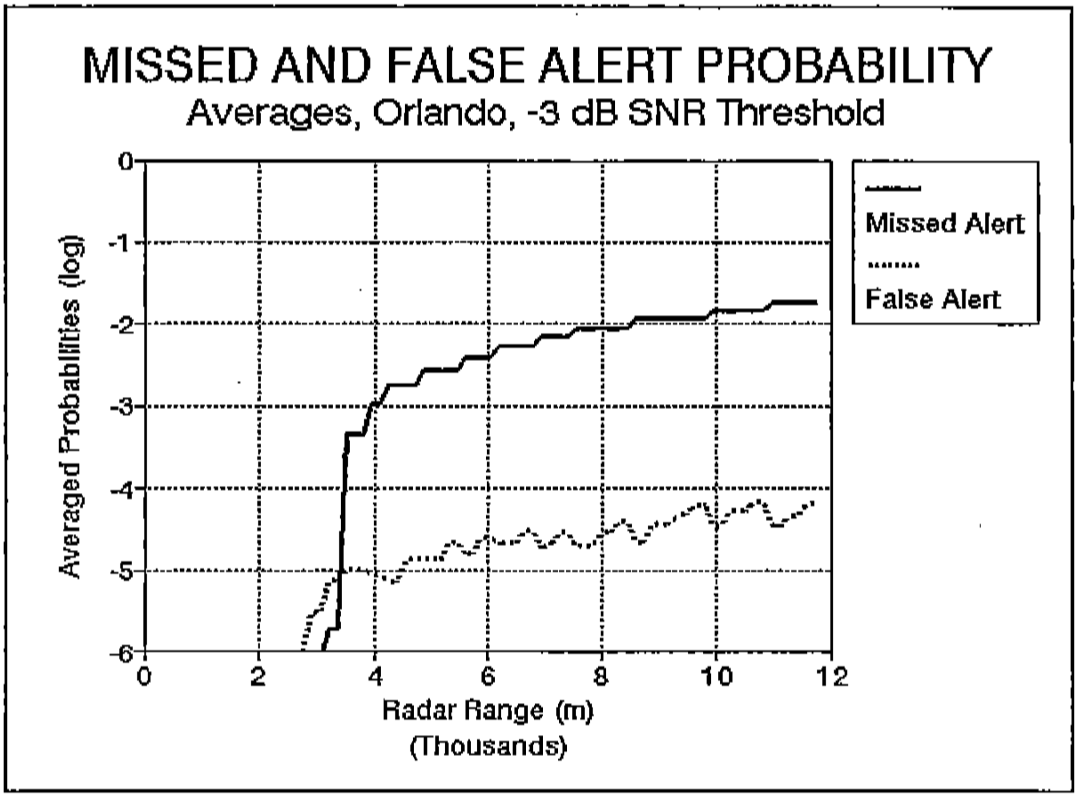

Figure 18 - Averaged Probabilities of a Missed and False Alert on a Single Scan at Orlando for Microbursts Exceeding 0 dBz Reflectivity.

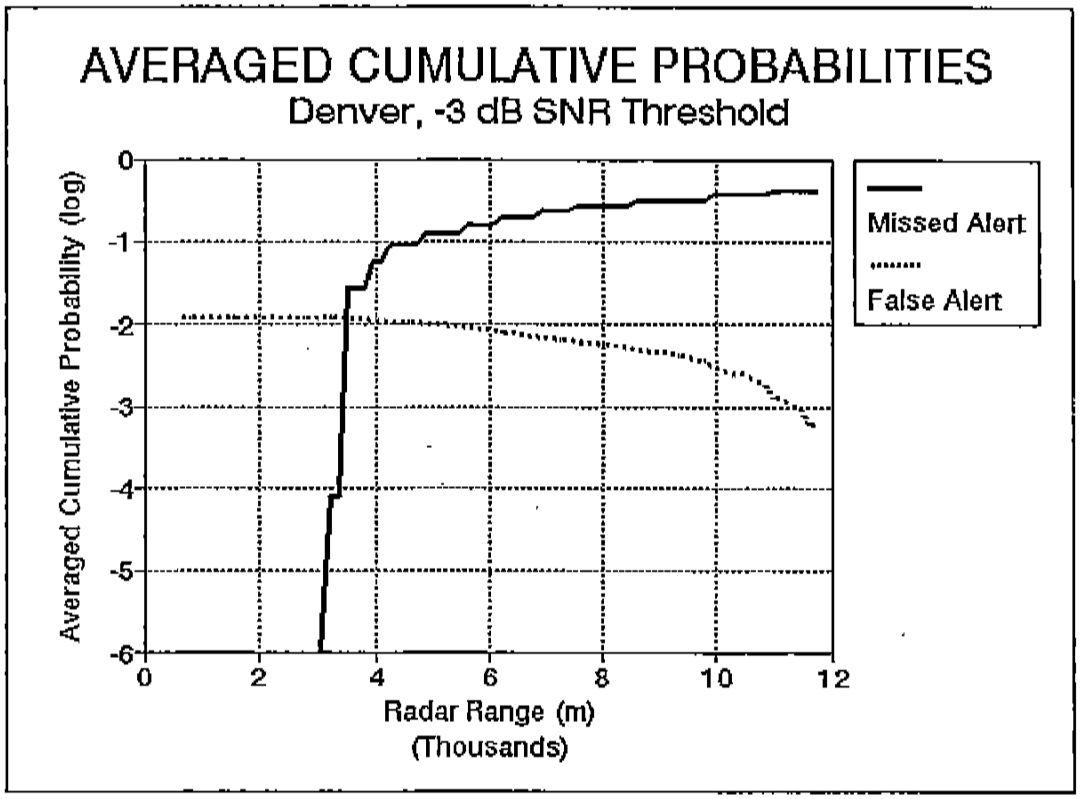

Figure 19 - Averaged Cumulative Probabilities of a Missed and False Alert at Denver Using an SNR Threshold (Single-Pulse) of -3 dB for Microbursts Exceeding 0 dBz Reflectivity.

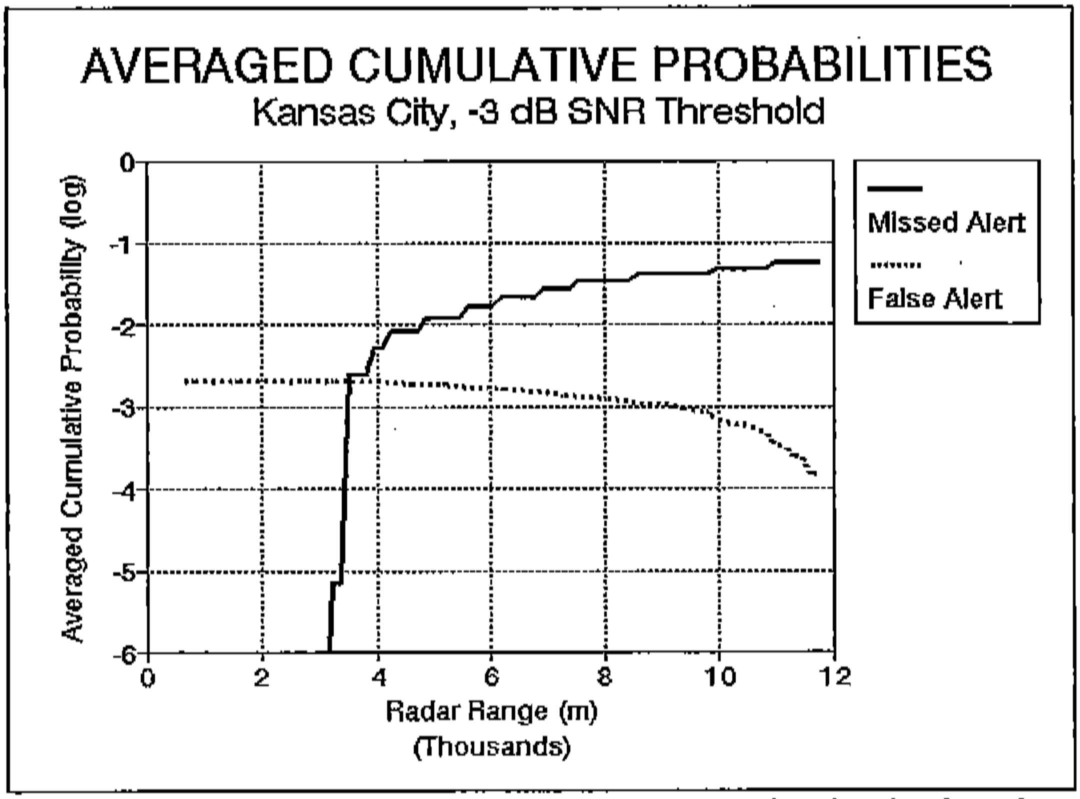

Figure 20 - Averaged Cumulative Probabilities of a Missed and False Alert at Kansas City Using an SNR Threshold (Single-Pulse) of -3 dB for Microbursts Exceeding 0 dBz Reflectivity.

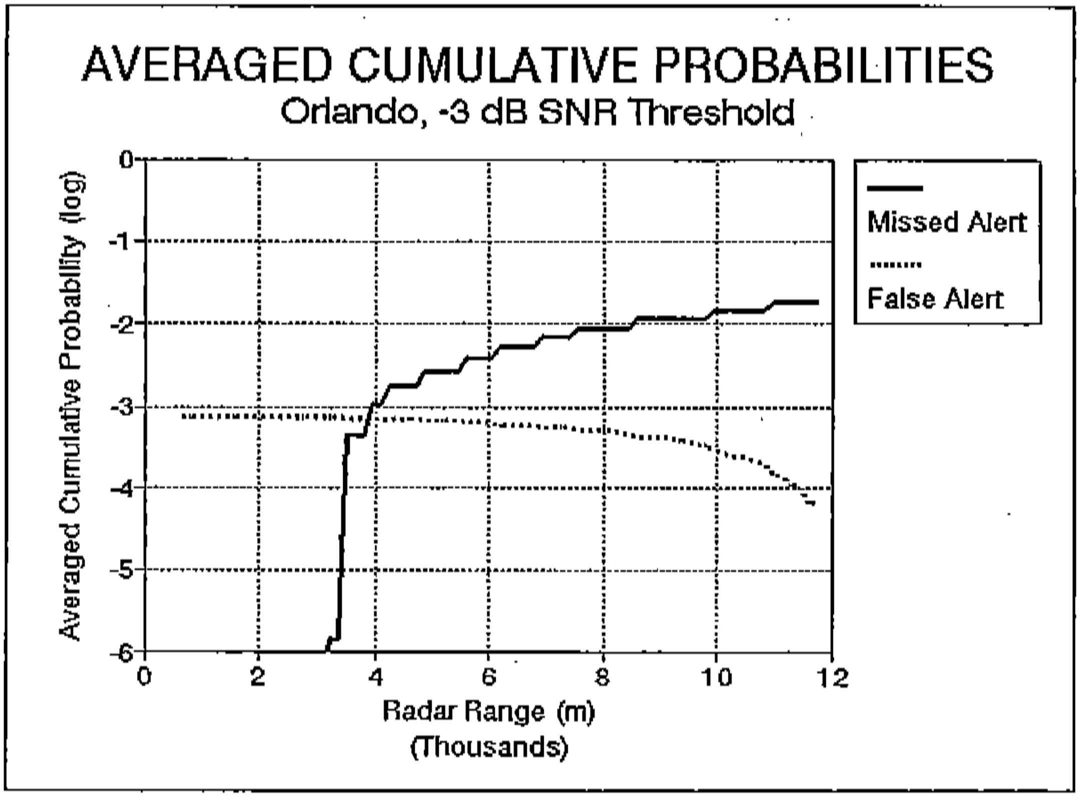

Figure 21 - Averaged Cumulative Probabilities of a Missed and False Alert at Orlando Using an SNR Threshold (Single-Pulse) of -3 dB for Microbursts Exceeding 0 dBz Reflectivity.

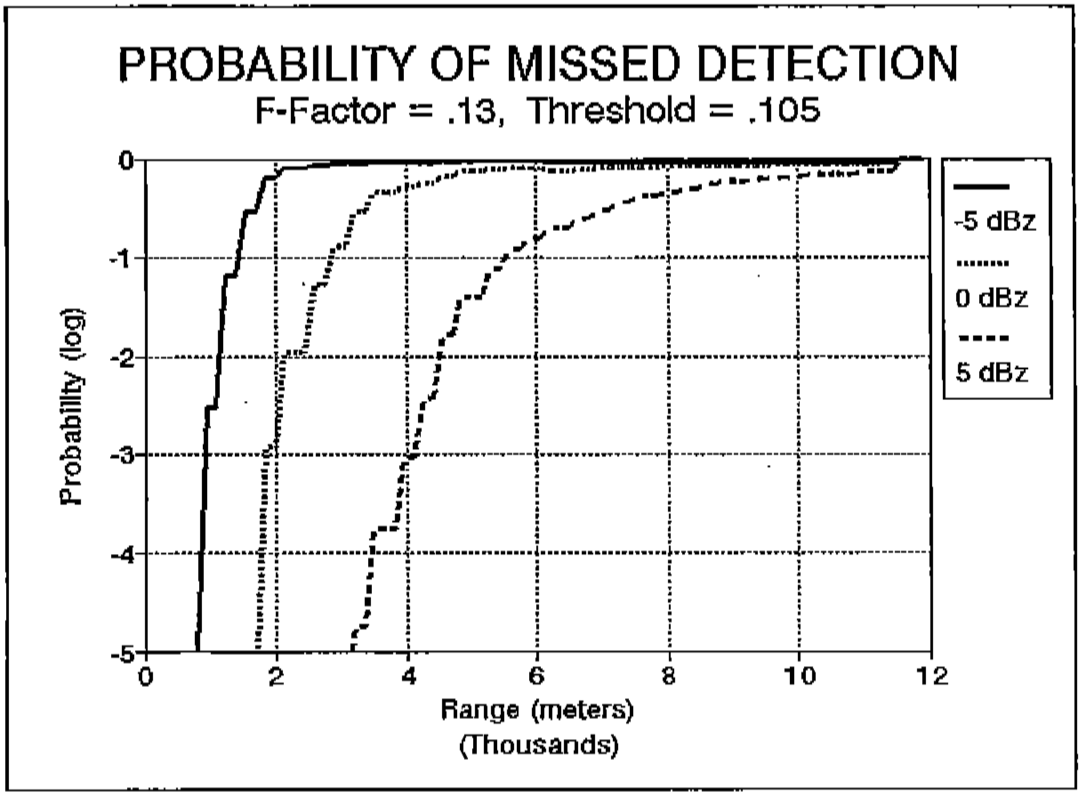

Figure 22 - Probability of a Missed Detection of a .13 Hazard for the NASA System Using a Hazard Area Threshold of .2 sq. km. and Requiring Two Consecutive Scans Prior to Declaring an Alert.

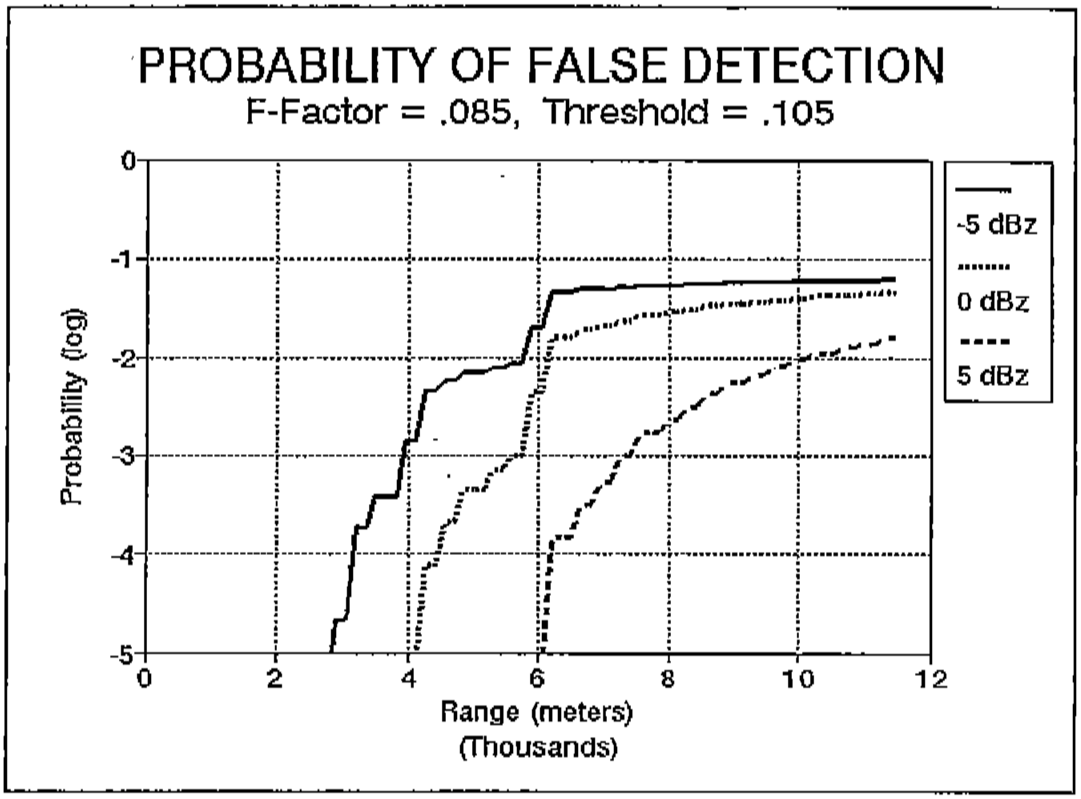

Figure 23 - Probability of a False Detection of a .085 Hazard for the NASA System Using a Hazard Area Threshold of .2 sq. km. and Requiring Two Consecutive Scans Prior to Declaring an Alert.

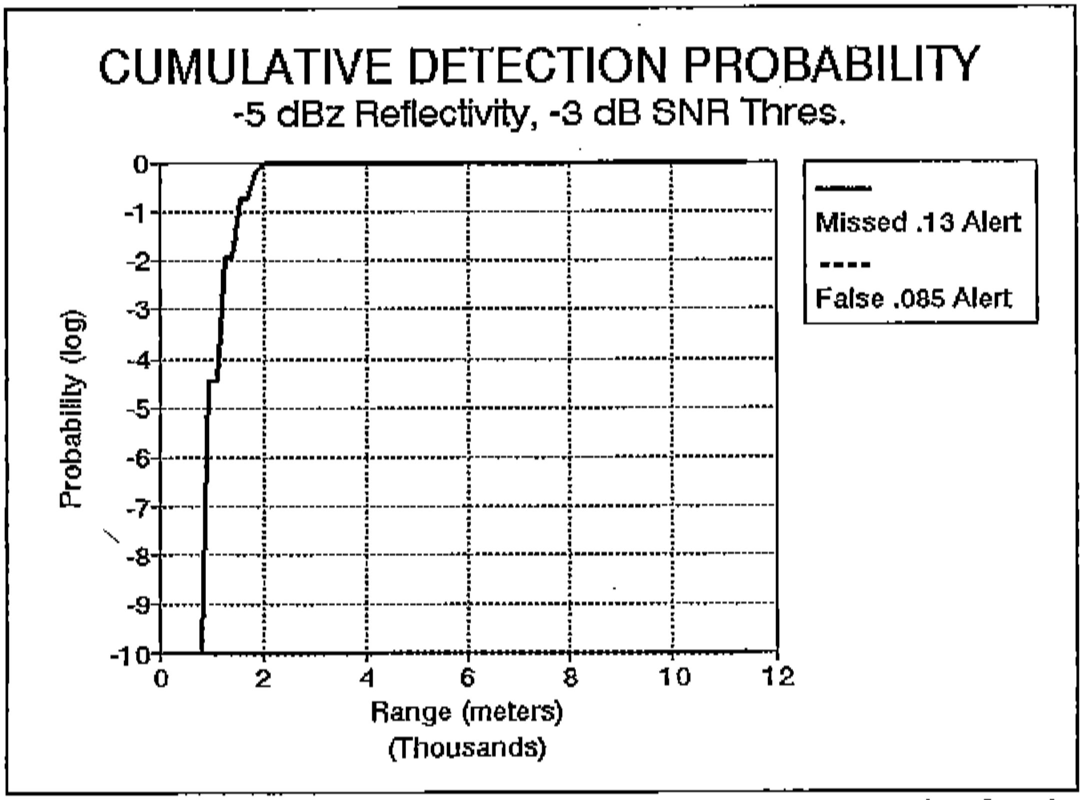

Figure 24 - Cumulative Probability of a Missed and False Detection for the NASA System with an SNR Threshold of -3 dB and a Weather Reflectivity of -5 dBz.

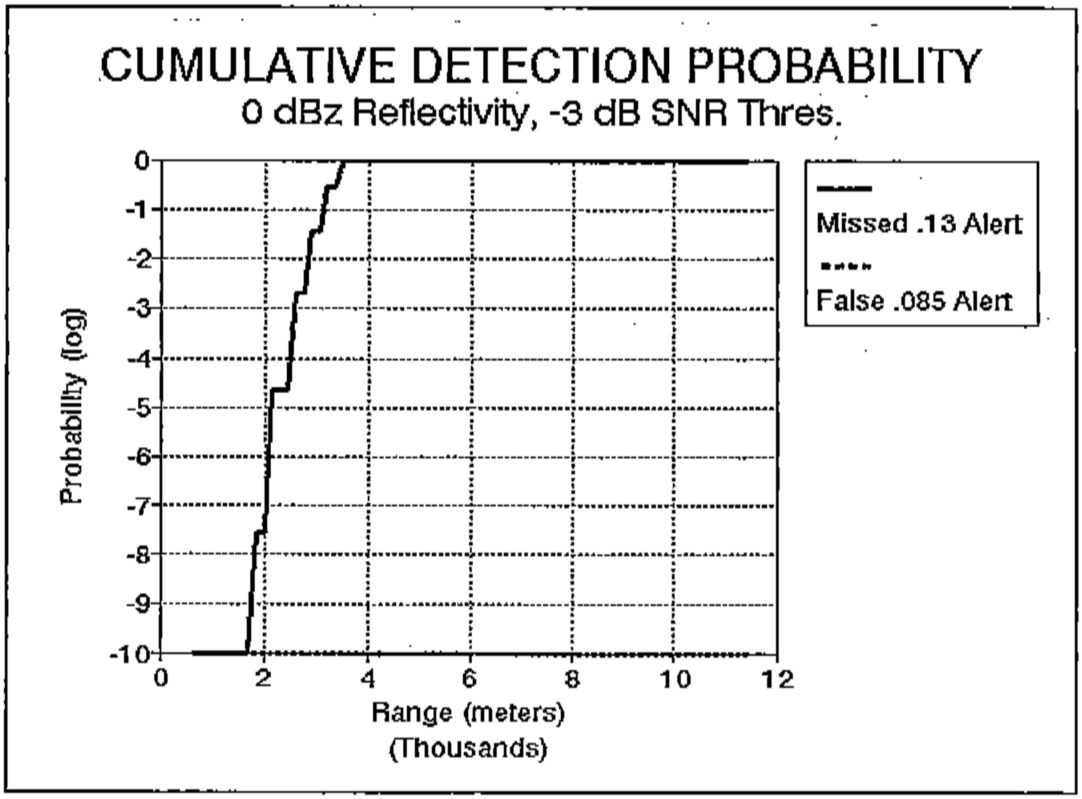

Figure 25 - Cumulative Probability of a Missed and False Detection for the NASA System with an SNR Threshold of -3 dB and a Weather Reflectivity of 0 dBz.

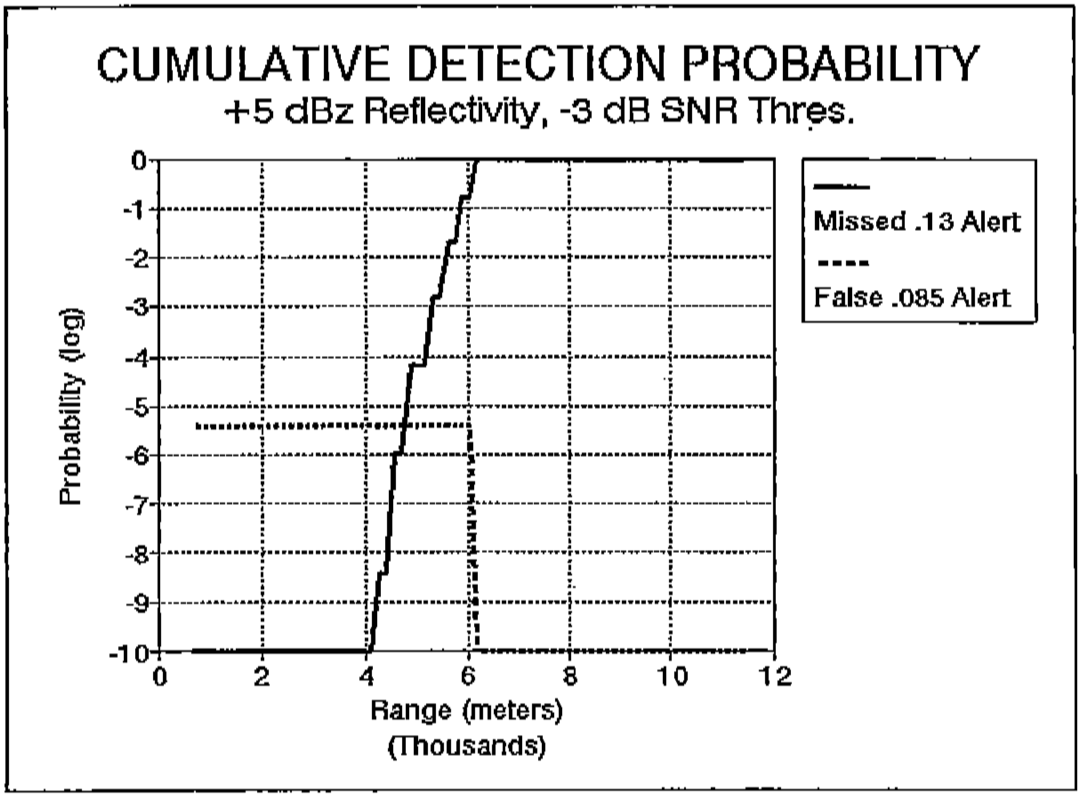

Figure 26 - Cumulative Probability of a Missed and False Detection for the NASA System with an SNR Threshold of -3 dB and a Weather Reflectivity of +5 dBz.

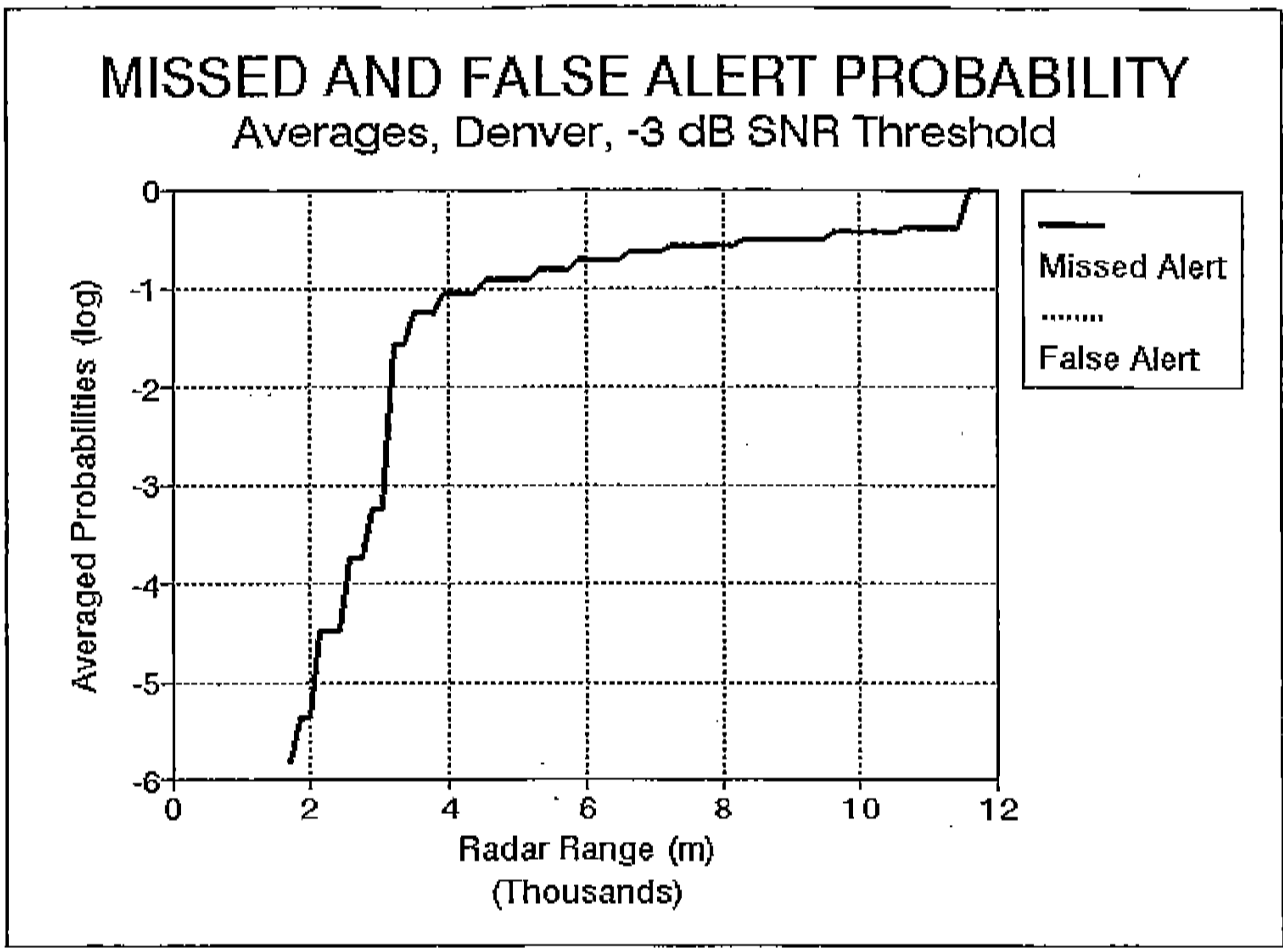

Figure 27 - Averaged Probability of Missed and False Detection at Denver for the NASA System with Hazard Area Threshold and Multiple Scan Detection for Microbursts Exceeding 0 dBz Reflectivity. The plot of false alert probability is less than 10^{-6} (off scale).

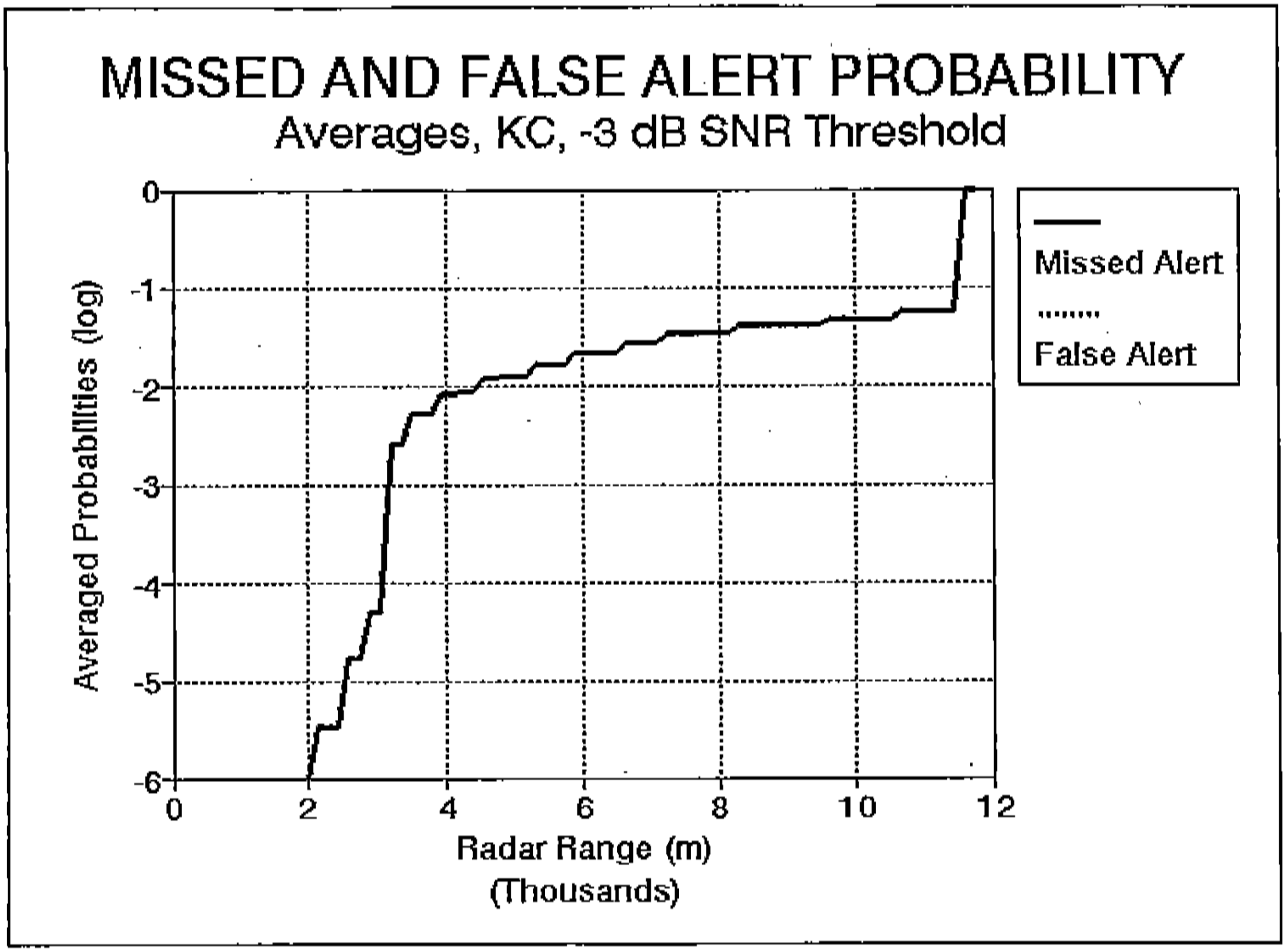

Figure 28 - Averaged Probability of Missed and False Detection at Kansas City for the NASA System with Hazard Area Threshold and Multiple Scan Detection for Microbursts Exceeding 0 dBz Reflectivity. The plot of false alert probability is less than 10^{-6} (off scale).

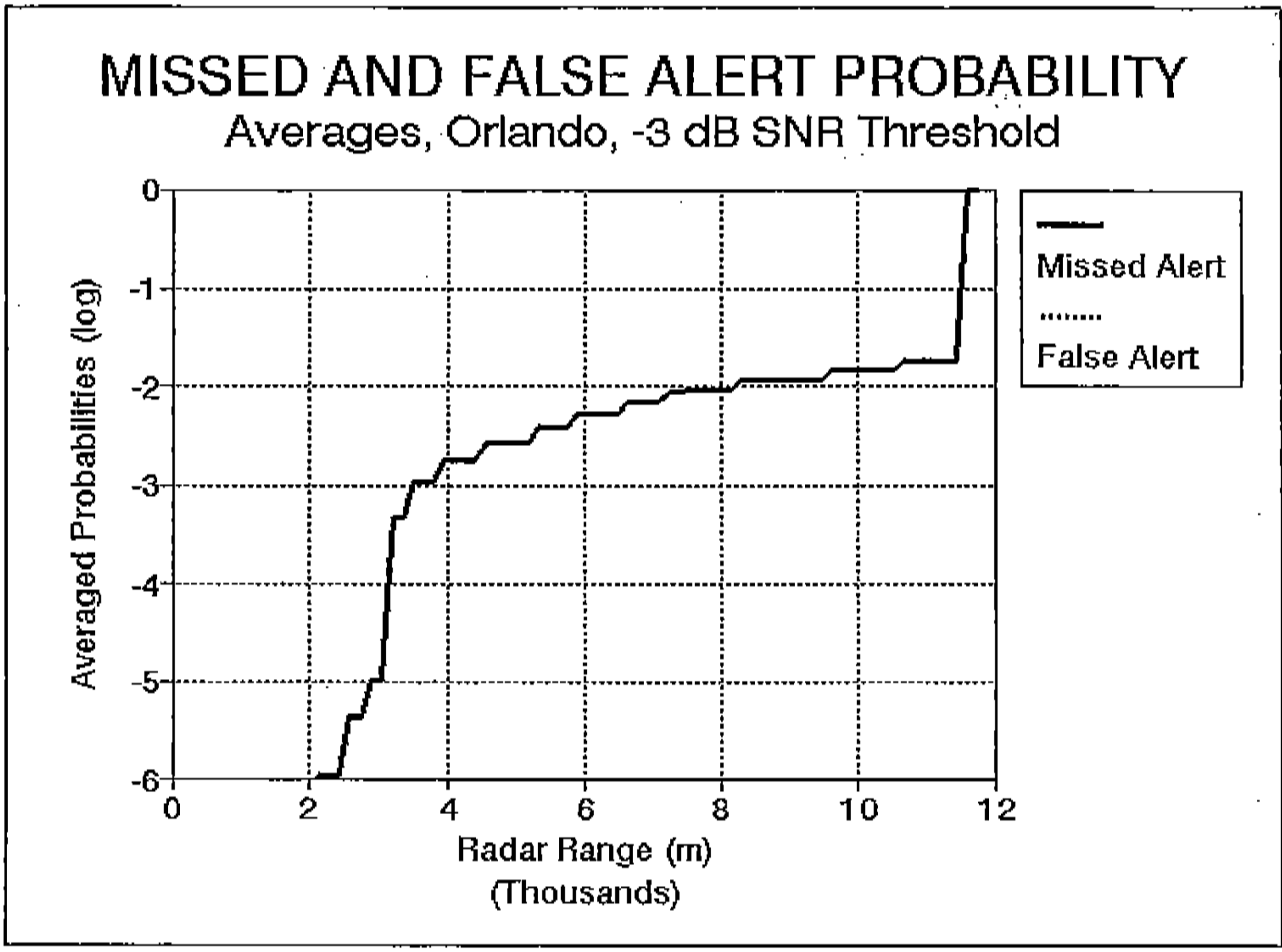

Figure 29 - Averaged Probability of Missed and False Detection at Orlando for the NASA System with Hazard Area Threshold and Multiple Scan Detection for Microbursts Exceeding 0 dBz Reflectivity. The plot of false alert probability is less than 10^{-6} (off scale).

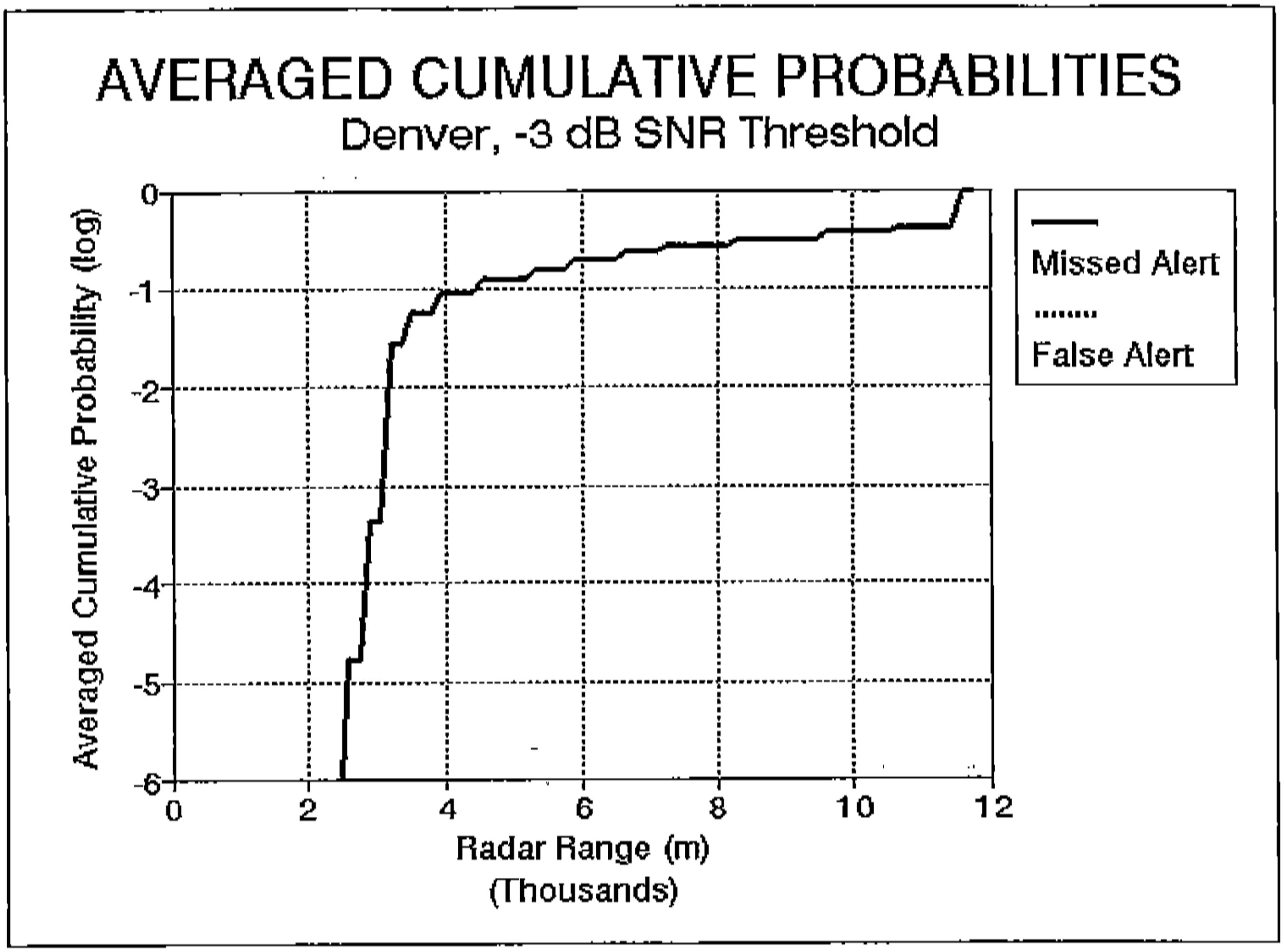

Figure 30 - Averaged Cumulative Probability of Missed and False Detection at Denver for the NASA System with Hazard Area Threshold and Multiple Scan Detection for Microbursts Exceeding 0 dBz Reflectivity. The plot of false alert probability is less than 10^{-6} (off scale).

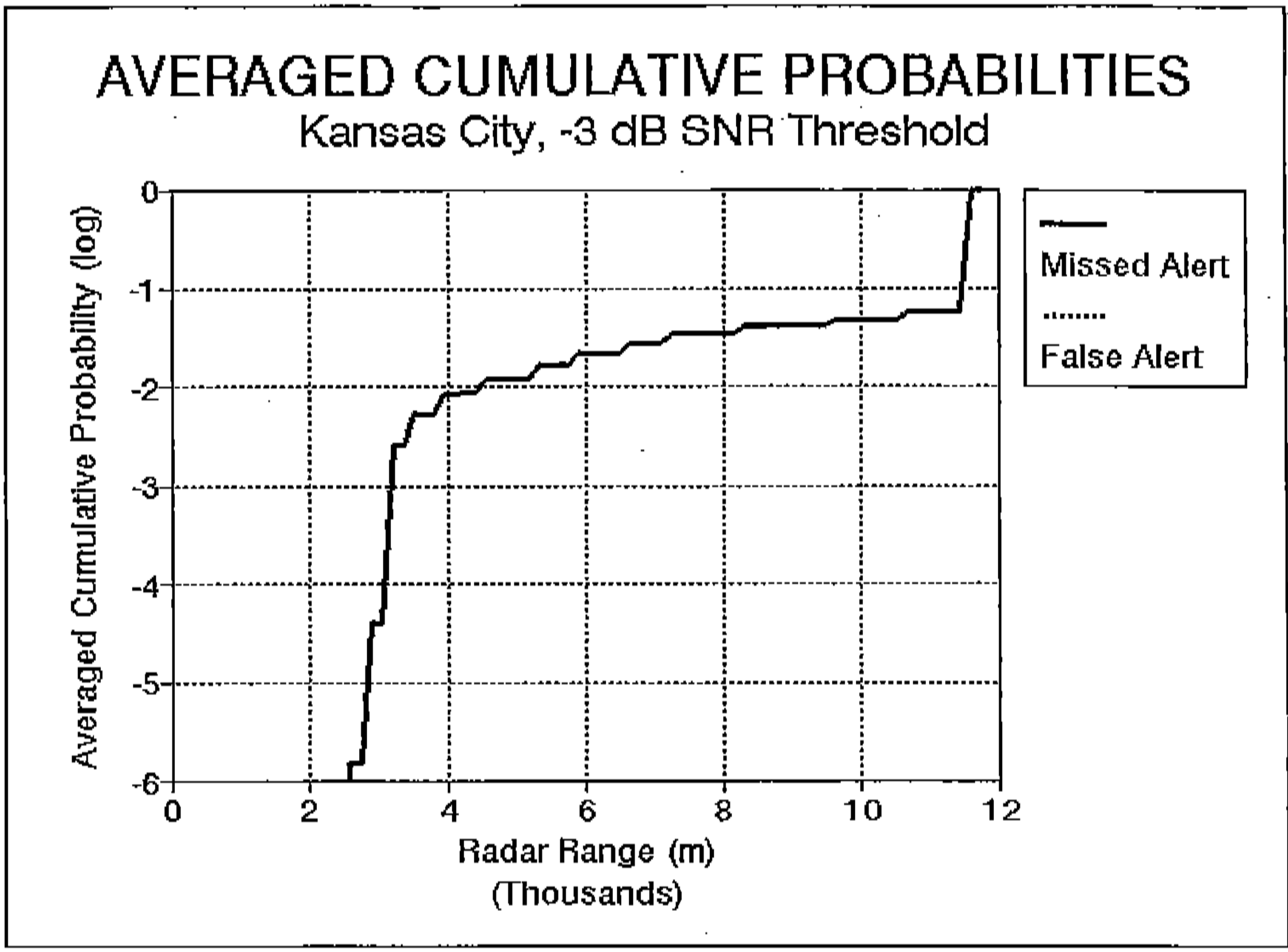

Figure 31 - Averaged Cumulative Probability of Missed and False Detection at Kansas City for the NASA System with Hazard Area Threshold and Multiple Scan Detection for Microbursts Exceeding 0 dBz Reflectivity. The plot of false alert probability is less than 10^{-6} (off scale).

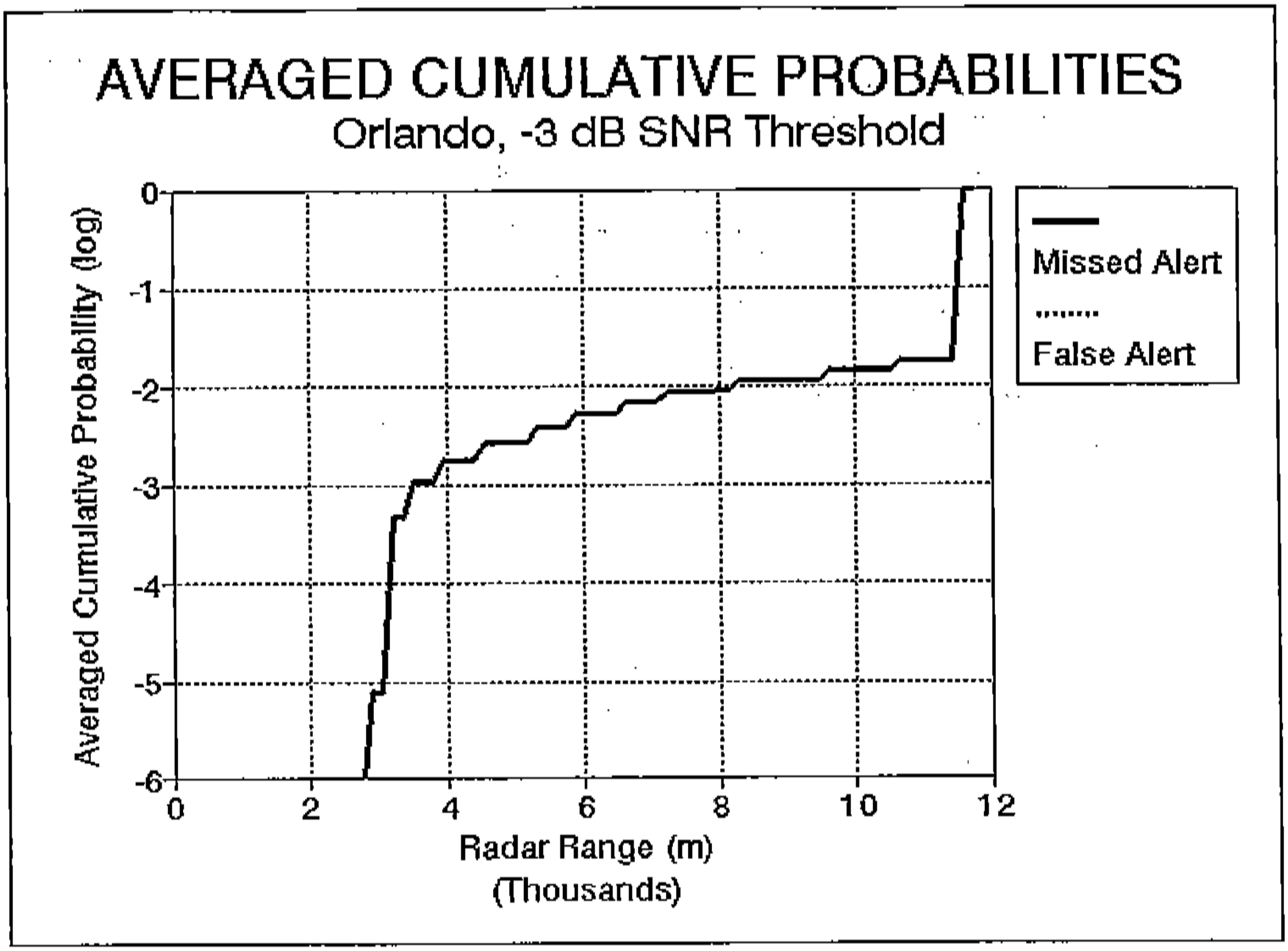

Figure 32 - Averaged Cumulative Probability of Missed and False Detection at Orlando for the NASA System with Hazard Area Threshold and Multiple Scan Detection for Microbursts Exceeding 0 dBz Reflectivity. The plot of false alert probability is less than 10^{-6} (off scale).

REFERENCES

[1] Mathews, B. D. and Fran Miller: "Principles and Computation of Microburst Windshear Hazard Factor Detection Range Performance with Airborne Pulsed Doppler Radar". Westinghouse Electric Corporation, Baltimore, Maryland (Westinghouse preliminary memo submitted to NASA).

[2] Doviak, R. J. and D. S Zrnic: Doppler Radar and Weather Observations, Academic Press, Inc., New York.

[3] Wonnacott, T. H. and R. J. Wonnacott. Introductory Statistics, John Wiley & Sons, New York.

[4] Bowles, R. L. *Windshear Detection and Avoidance: Airborne Systems Survey*, Proceedings of the 29th Conference on Decision and Control. Honolulu, Hawaii, December 1990.

[5] Campbell, S. M.I.T., Lincoln Laboratory, personal communication, and in
Biron, P. and Isaminger, B.: *Microburst Characteristics Determined from 1988-1991 TDWR Testbed Measurements*; Airborne Wind Shear Detection and Warning Systems, Fourth Combined Manufacturers' and Technologists' Conference, Williamsburg, VA. September 1992.

APPENDIX E.

TASS Data Sets: Certification Path Definition

4/20/93

Assumptions used for path definition:

1. Glide slope angle = 3 degrees (gamma = -0.0524).
2. Runway length = 3 km (9840 feet).
3. Glide path intercept point = 300 meters down runway.
4. Middle marker is 900 meters from runway threshold.
5. The above conditions produce a glide path height of 63 meters at the middle marker.
6. Go around maneuvers are begun at an altitude of 30 meters, at a position 300 meters from runway threshold.
7. Takeoff ground roll length = 2 km.
8. Flight path angle after takeoff or go around = 0.10 (5.73 degrees).
9. Radius of turn, 25 degree bank, at 200 knots (103 m/s) = 2.32 km.

1. Aligned for takeoff, near microburst: The icon leading edge is near the liftoff point (2 km from brake release).

   2. Aligned for takeoff, far microburst and Takeoff, gear up height: The icon leading edge is about 5.5 km (3 nm) from brake release.

   3. ILS approach: The icon leading edge is near the middle marker.

   4. Curved approach at 200 knots: The icon leading edge is near the localizer intercept point.

   5. Worse-case drift approach: The icon leading edge is near the runway threshold.

   6. Go-around maneuver: The icon leading edge is about 3.3 km (1.8 nm) from initiation of missed approach.

Paths are specified by direction of takeoff or approach, X or Y coordinate of flight path, and runway threshold coordinates.

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.

Microbursts are static during each simulation run. Drift angle runs are accomplished by biasing the orientation of the sensor, not through the presence of any ambient crosswind.

Paths:

Data set 1, DFW microburst, Time = 11 min., 2-D TASS simulation

Scenario: **Aligned for takeoff, far microburst, and Takeoff, gear up height.**

Takeoff toward east along Y =	0 axis.
Brake release at X,Y =	-6.8,0 km.
Liftoff at X,Y =	-4.8,0 km.
Peak FBAR along path:	about 0.2.
Peak reflectivity along path:	about 57 dBZ.

Note: The takeoff roll occurs outside the domain of the data set, with the sensor looking into the data set.

Scenario: **ILS approach.**

Approach toward east along Y =	0 axis.
Place runway threshold at X,Y =	0,0.
Peak FBAR along path:	about 0.14.
Peak reflectivity along path:	about 55 dBZ.

Note: Due to the proximity of the microburst to the edge of the data set domain, the approach may begin outside the boundary of the data set.

Data Set 2. Orlando Event 143. Time = 37 min.

Scenario: **ILS approach.**

Approach toward south along X =	-1.8 km line.
Place the runway threshold at X,Y =	-1.8, -1.9.
Peak FBAR on path:	about 0.14.
Peak reflectivity on path:	about 50 dBZ.

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: **Go-around maneuver.**

Approach toward west along Y =	-1.4 km line.
Place runway threshold at X,Y =	2.2, -1.4.
Go-around point is X,Y =	2.5, -1.4.
Peak FBAR along path:	about 0.19.

This path places the runway touchdown zone in clear air, with the microburst and 50 dBZ precipitation at the far end of the runway.

Scenario: **ILS approach through below alert threshold shear.**

Approach toward east along Y =	1.1 km line.
Place runway threshold at X,Y =	-1.8, 1.1.

The path passes through an FBAR of about 0.06 with 0.08 FBAR about 500 meters to right of path, and 0.17 FBAR about 2.5 km right of runway touchdown zone. The peak reflectivity on the path is about 50 dBZ.

Data Set 3. Denver 7/11/88 event. Time = 49 and 51 min.

Scenario: **Aligned for takeoff, near microburst.**

Use time =	51 min. data set.
Takeoff toward north along X =	16.2 km line.
Brake release at X,Y =	16.2, -7.6.
Liftoff at X,Y =	16.2, -5.6.

Peak FBAR along path:	about 0.17.
Peak reflectivity along path:	about 24 dBZ.

Scenario: **Aligned for takeoff, far microburst and Takeoff, gear-up height.**

Use time =	51 min. data set.
Takeoff toward east along Y =	-5.0 km line.
Brake release at X,Y =	8.5, -5.0.
Liftoff at X,Y =	10.5, -5.0.

The takeoff will be in a 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: **ILS approach, 6 paths, 45 degree azimuth changes.**

Use time =	51 min. data set.
Place runway threshold at X,Y =	12.2, -3.0.

At this point, FBAR is about 0.17 in the north-south direction and 0.18 in the east-west direction, with 40 dBZ precipitation. Orient the runway on true headings of 360, 045, 090, 135, 270, and 315 to achieve 6 trajectories.

Characteristics of each path:

Track 360: This path provides a mostly clear view of the threat, with rain on each side of the path. Peak FBAR = 0.15.

Track 045: The approach path is between two small rain cells (about 30 to 35 dBZ) about 3 km short of the runway. Peak FBAR = 0.18 along path.

Track 090: 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.

Track 135: The path passes along the edge of an adjacent precipitation cell before reaching the primary threat. A strong shear exists at the far end of the runway. Peak FBAR along path is about 0.13.

Track 270: 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. The primary shear produces an FBAR of about 0.17.

Track 315: The path penetrates a strong shear (FBAR about 0.2) 3 to 4 km short of the runway. The initial shear contains 25 dBZ precipitation. The primary shear has a peak FBAR of about 0.13 and reflectivity of about 40 dBZ along the path. A windshear sensor should detect both threats.

Scenario: **Curved approach at 200 knots.**

Use time =	51 min. data set.
Localizer course is toward east on Y =	-3.1 km line.
Place center of turn at X,Y =	11.5, -5.42.

Fly north on X = 9.18 km line to X,Y = 9.18, -5.42; then turn right to intercept localizer at X,Y = 11.5, -3.1.

The path encounters precipitation about 1 km prior to beginning the turn and completes the turn in moderate to heavy precipitation. The turn carries the sensor through a shear region of FBAR near 0.12, which approximates the "must-alert" level, prior to the primary threat. The primary threat has an FBAR of about 0.15.

Scenario: **ILS approach, microburst strength below alert threshold.**

Use time =	49 min. data set.
Approach toward east along Y =	-4.5 km line.
Place runway threshold at X,Y =	8.6, -4.5 km.

Peak FBAR along path:	about 0.08.
Peak reflectivity along path:	about 25 dBZ.

Scenario: **ILS approach, developing microburst with strength approximating "must-alert".**

Use time =	49 min. data set.
Approach toward north along X =	8.5 km line.
Place runway threshold at X,Y =	8.5, 1.9 km.

Peak FBAR along path:	about 0.13.
Peak reflectivity along path:	about 37 dBZ.

The 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.

Note: Other interesting above and below alert threshold encounters can be constructed from the 7/11/88 data sets, including a 0.11 to 0.12 FBAR encounter near X,Y = 15.5, -5.0 km in the time = 49 minute data set (which ideally would be detected even though below the 0.13 "must alert" level).

Data set 4: 7/14/82 Denver temperature inversion case. Time = 36 min., TASS 2-D simulation.

Scenario: **Aligned for takeoff, near microburst.**

Takeoff toward east along Y =	0 axis.
Brake release at X,Y =	-2.7, 0 km.
Liftoff point at X,Y =	-0.7, 0 km.
Peak FBAR along path:	about 0.23.
Peak reflectivity along path:	about 27 dBZ.

This microburst presents a very small rain shaft. The diameter of the 5 dBZ precipitation contour is slightly less than 1 km at 50 meters altitude.

Scenario: **ILS approach.**

Approach toward east along Y =	0 axis.
Place runway threshold at X,Y =	0.2, 0 km.
Peak FBAR along path:	about 0.24.
Peak reflectivity along path:	about 27 dBZ.

Scenario: **Worse-case drift ILS at 120 knots.**

Approach toward east along Y =	0 axis.
Place runway threshold at X,Y =	-0.7, 0 km.
Peak FBAR along path:	about 0.19.
Peak reflectivity along path:	about 27 dBZ.

Data Set 5, very dry microburst, Denver 7/8/89 sounding, Time = 40 and 45 min.

Scenario: **Aligned for takeoff, far microburst.**

Use time =	40 min. data set.
Takeoff toward west along Y =	10.6 km line.
Brake release at X,Y =	10.1, 10.6 km.
Peak FBAR along path:	about 0.18.
Peak reflectivity along path:	about 22 dBZ.
Diameter of 5 dBZ contour:	about 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: **ILS approach.**

Use time =	40 min. data set.
Approach toward north along X =	3.8 km line.
Place runway threshold at X,Y =	3.8, 10.9 km.
Peak FBAR along path:	about 0.16.
Peak reflectivity along path:	about 17 dBZ.

Scenario: **Worse-case drift ILS at 120 knots.**

Use time =	40 min. data set.
Approach toward north along X =	3.8 km line.
Place runway threshold at X,Y =	3.8, 10.0 km.
Peak FBAR along path:	about 0.12.
Peak reflectivity along path:	about 17 dBZ.

The peak along-path FBAR value occurs after landing, with little or no vertical F-factor component. A sensor scanning the shear during approach would likely see the higher FBAR values above the runway.

Scenario: **Go-around maneuver.**

Use time =	40 min. data set.
Approach toward north along X =	3.8 km line.
Place runway threshold at X,Y =	3.8, 6.8 km.
Go-around point is at X,Y =	3.8, 6.5 km.
Peak FBAR along path:	about 0.17.
Peak reflectivity along path:	about 22 dBZ.

Scenario: **Curved approach at 200 knots.**

Use time =	40 min. data set.
Localizer course is toward west on Y =	10.6 km line.

Place center of turn at X,Y = 4.4, 8.28 for a left turn or at X,Y = 4.4, 12.92 for a right turn.

Fly north or south on X = 6.72 km line until abeam turn center point; then turn to intercept localizer at X,Y = 4.4, 10.6 km.

Peak FBAR along path:	about 0.16.
Peak reflectivity along path:	about 20 dBZ.

Scenario: **ILS approach, Second Microburst Pulse, Extremely Dry.**

Use time =	45 min. data set.
Approach toward north along X =	4.67 km line.
Place runway threshold at X,Y =	4.67, 12.2 km.

Peak FBAR along path:	about 0.15.
Peak reflectivity along path:	about 7 dBZ.

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.

Data Set 6. Highly Asymmetric Microburst. Time = 14 min.

Scenario: **Curved approach at 200 knots.**

Localizer course is toward south on X = 14.33 km line.

Place center of turn at X,Y = 12.01, 1.08 for a right turn toward the south.

Fly east on Y = 3.4 km line until abeam turn center point; then turn to intercept localizer at X,Y = 14.33, 1.08 km.

Peak FBAR along path: about 0.11 with higher values (0.15) 200 meters left of localizer.

Peak reflectivity along path: about 50 dBZ.

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: **ILS approach, 7 paths, one each 45 degrees of azimuth.**

The runway will be placed such that the approximate core of the microburst (X,Y = 14.2, 0.5) is penetrated at an altitude of about 60 to 300 meters. The core position varies with altitude, which is taken into consideration in the path definitions. The lower encounter altitudes are used for the east/west paths, where the core will be placed near the middle marker location. This location is used since the east/west FBAR values are very close to likely system alert thresholds at 300 meters (about 0.11), but at lower altitudes are in the range where alerts should be given (over 0.12). Higher altitude encounters are used for other directions of flight, to stress the sensor vertical wind estimation and, in some cases, to achieve FBAR values close to the "must-alert" value. In a few cases the peak FBAR along path is about 0.12. This level presents a reasonable test, since the must-alert F-factor value of 0.13 represents a worse-case for difficult-to-detect events. Forward-look systems should alert at levels starting at about 0.11 to prevent exposing the aircraft to threats that would activate a reactive detection system or that would cause a pilot, using the FAA Windshear Training, to execute a missed approach. At the core location the peak one-kilometer F-factor varies with direction of flight and altitude approximately as:

	North/South	East/West
50 meters AGL	0.167	0.126
150 meters AGL	0.165	0.123
300 meters AGL	0.156	0.115

The runway will be oriented on true headings of 360, 045, 090, 180, 225, 270, and 315 degrees to achieve 7 trajectories. The 135 degree path is not used, as the peak FBAR in this direction is only 0.10. The reflectivity at the microburst core is about 50 dBZ. In the microburst simulation, the storm drift is towards the east at about 35 knots. A static wind field is assumed for these trajectories. In a few of these paths the runway may be outside the domain of the wind field data set. The testing in these cases will end after the sensor has completed transit of the microburst.

Definition of each path:

Track 360:
- Localizer on X = 14.6 km line.
- Runway threshold at X,Y = 14.6, 4.9 km.
- Peak FBAR = 0.15.

The sensor has a clear view of the windshear during approach.

Track 045:
Localizer on Y = (X-13.9) km line.
Runway threshold at X,Y = 17.2, 3.3 km.
Peak FBAR = 0.17.

Track 090:
Localizer on Y = 0.5 km line.
Runway threshold at X,Y = 15.1, 0.5 km.
Peak FBAR on path: about 0.10 with 0.12 near path.

The path encounters an area of intervening rain about 2.5 km prior to peak shear.

Track 180:
Localizer on X = 14.5 km line.
Runway threshold at X,Y = 14.5, -3.5 km.
Peak FBAR = 0.15.

The path encounters about 2 km of intervening rain prior to the peak shear.

Track 225:
Localizer on Y = (X-13.9) km line.
Runway threshold at X,Y = 11.6, -2.3 km.
Peak FBAR = 0.19.

The sensor has a clear view of the windshear during approach.

Track 270:
Localizer on Y = 0.5 km line.
Runway threshold at X,Y = 13.3, 0.5 km.
Peak FBAR along path: about 0.12 to 0.13.

The sensor has a clear view of the windshear during approach.

Track 315:
Localizer on Y = -(X-14.67) km line.
Runway threshold at X,Y = 12.87, 1.80 km.
Peak FBAR along path: about 0.13.

The sensor has a clear view of the windshear during approach.

Data Set 7. Gust Front, Time = 27 min.

Scenario: **Aligned for takeoff, gust front near departure end of runway.**

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.

Peak FBAR along path: about 0.12 at approximately X= 22.3 km.
Reflectivity along path in region of shear: about 20 dBZ.

Scenario: **ILS approach.**

Approach toward west along Y =	1.0 km line.
Place runway threshold at X,Y =	21.5, 1.0 km.

Peak FBAR along path:	about 0.13.
Peak reflectivity along path:	about 20 dBZ.