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Airborne Windshear Detection and Warning Systems

Fifth and Final Combined Manufacturers' and Technologists' Conference

Compiled by
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(NASA-CP-10139-Pt-1) AIRBORNE WINDSHEAR DETECTION AND WARNING SYSTEMS. FIFTH AND FINAL COMBINED MANUFACTURERS' AND TECHNOLOGISTS' CONFERENCE, PART 1 (NASA. Langley Research Center) 445 p

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Proceedings of a conference sponsored by the Federal Aviation Administration, Washington, D.C., and the National Aeronautics and Space Administration, Washington, D.C., and held in Hampton, Virginia
September 28–30, 1993

July 1994

Foreword

A dramatic improvement in the flight safety of transport aircraft worldwide has become possible through the development of sensor systems that detect hazardous wind changes miles ahead of an aircraft. This development--the result of a unique cooperation among NASA, the FAA, industry, and academia--involved fundamental breakthroughs in the understanding and measurement of commercial aviation's most lethal weather threat: microburst windshear.

One purpose of the meeting reported in these Proceedings was to spread the word: we were challenged with a need, joined forces to meet that need, and were enormously successful. U. S. avionics manufacturers small and large have capitalized on the results of our research and consulting guidance, and now have mounted independent sensor development efforts in the best entrepreneurial tradition. The technology applications include Doppler radar, lidar (laser radar), and infrared systems, each of which required groundbreaking advances in state-of-the-art design and signal processing. Many systems are now in the final stages of FAA production certification and commercial sales.

The meeting had another purpose: to open the next chapter in interagency and industry cooperation--this time for the development and application of sensors for wake vortices and for synthetic and enhanced vision systems. This too is reported in these Proceedings.

The windshear research reported here is the result of NASA and the FAA in 1986 setting a timetable for developing and demonstrating a solution to a problem then responsible for more than half the U. S. commercial aviation fatalities of the preceding decade. The success of this research, with flight tests completed two years ahead of schedule, ensures that, in the very near future, all airline passengers will travel with the threat of aviation's worst weather hazard effectively removed.

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The Fifth (and Final) Combined Manufacturers' and Technologists' Airborne Wind Shear Review Meeting

OBJECTIVES

The Fifth (and Final) Combined Manufacturers' and Technologists' Airborne Wind Shear Review Meeting, co-sponsored by the National Aeronautics and Space Administration (NASA) and the Federal Aviation Administration (FAA), provided a forum for the transfer of information from the NASA/FAA Airborne Wind Shear Sensors Program to industry. Furthermore, the meeting provided an opportunity for all participants to pose and discuss developments and problems of current interest. This was the final such meeting, marking the conclusion of the NASA/FAA Airborne Wind Shear Sensors Program.

Tremendous advances in product development and certification methodologies had occurred since the previous meeting; the final meeting covered these and other efforts throughout the breadth of windshear technology. Future sensor technology applications, in addition to wind shear detection, were also discussed.

ORGANIZATION

General Co-Chairpersons

Dr. Roland L. Bowles
NASA Langley Research Center

Mr. Robert H. Passman
Federal Aviation Administration

Technical Program Chairperson
Dr. Victor E. Delnore
Lockheed Engineering and Sciences Company

Conference Manager
Ms. Doris B. Stroup
The Bionetics Corporation

Audio Tape Transcriber
Ms. Nancy Hale
Kelly Services

FIFTH (and final)
COMBINED MANUFACTURERS'
and
TECHNOLOGISTS' AIRBORNE WIND SHEAR
REVIEW MEETING

TUESDAY, SEPTEMBER 28

0900 Logistics/Administration
R. Bowles, NASA Langley Research Center
V. Delnore, Lockheed, Engineering and Sciences Co.

0910 Welcome Address and Overview
R. Bowles, NASA Langley Research Center

SESSION 1

WINDSHEAR FLIGHT TEST OVERVIEW

0930 Chair: R. Bowles, NASA Langley Research Center

0940 Flight Test of AWAS III
B. McKissick, NASA Langley Research Center

1000 BREAK

1020 Flight Test Evaluation of a Data Link and Aircraft Integration of TDWR Windshear Information
D. Hinton, NASA Langley Research Center

1040 A Performance Evaluation of Airborne Coherent Lidar Wind Shear Sensors
P. Robinson, Lockheed Engineering and Sciences Co.

1100 Westinghouse MODAR 3000 Flight Test Results
W. Patterson and M. Eide, Westinghouse Electric Corp.

1120 NASA's Airborne Doppler Radar for Detection of Hazardous Windshear
E. Bracalente, NASA Langley Research Center

1140 LUNCH

SESSION 2

WINDSHEAR MODELING, FLIGHT MANAGEMENT, AND GROUND-BASED SYSTEMS

1250 Chair: D. Vicroy, NASA Langley Research Center

1300 Microburst Avoidance Crew Procedures for Forward-Look Sensor-Equipped

Aircraft
D. Hinton and R. Oseguera, NASA Langley Research Center

1320 Piloted Simulator Evaluation of Forward-Look Windshear Crew Procedures
R. Oseguera and D. Hinton, NASA Langley Research Center

1340 Vertical Wind Estimation from Horizontal Wind Measurements
D. Vicroy, NASA Langley Research Center

1400 BREAK

1420 Characteristics of a Dry, Pulsating Microburst at Denver Stapleton Airport
F. Proctor, NASA Langley Research Center

1440 Future Enhancements to Ground Based Microburst Detection
M. Matthews, S. Campbell, and T. Dasey, Massachusetts Institute of Technology

1500 Determining F -Factor Using Ground-Based Doppler Radar: Validation and Results
D. Elmore, D. Albo, and R. Goodrich, National Center for Atmospheric Research

1520 Evaluation of Iconic vs F-Map Microburst Displays
M. Salzberger, R. Hansman and C. Wanke, Massachusetts Institute of Technology

1540 BREAK

1610 Q & A
Chairpersons: Sessions 1 and 2

1700 ADJOURN

WEDNESDAY, SEPTEMBER 29

SESSION 3

AIRBORNE WINDSHEAR DETECTION SYSTEMS

0830 Chair: S. Harrah, NASA Langley Research Center

0840 Successful Infrared Prediction of Low Level Windshear
P. Adamson, Turbulence Prediction Systems

0900 Overview and Highlights from Superposition Testing of the MODAR 3000
B. Mathews, F. Miller, K. Rittenhouse, L. Barnett, and W. Rowe, Westinghouse Electric Corp.

0920 Wind Hazard Detection with a CO_2 Airborne Laser Radar
R. Targ, Lockheed Research and Development Co.
P. Robinson, Lockheed Engineering and Science Co.
R. Bowles and P. Brockman, NASA Langley Research Center

0940 BREAK

1000 CLASS (Coherent Lidar Airborne Shear Sensor) Windshear Detection System
P. Forney and L. Celmer, Lockheed Missiles and Space Co.
R. Calloway and P. Brockman, NASA Langley Research Center
F. Austin, Lockheed Engineering and Science Co.

1020 RDR-4B Doppler Weather Radar with Windshear Detection Capability
D. Kuntman, Bendix-Allied Signal Co.

1040 The Collins Windshear Program
R. Robertson, Rockwell-Collins Co.

1100 LUNCH

SESSION 4

CERTIFICATION OF PREDICTIVE WIND SHEAR DETECTION AND AVOIDANCE SYSTEMS

1230 Chair: D. Hinton, NASA Langley Research Center

1240 The FAA View
R. Passman and F. Rock, FAA

1300 Windshear Certification Data Base for Forward-Look Detection Systems
G. Switzer, Research Triangle Institute
D. Hinton and F. Proctor, NASA Langley Research Center

1320 Certification Methology Applied to the NASA Experimental Flight System
C. Britt and G. Switzer, Research Triangle Institute
E. Bracalente, NASA Langley Research Center

1340 Certification of Windshear Performance with RTCA Class D Radomes
B. Mathews and L. Barnett, Westinghouse Electric Corporation

1400 Airport Surveillance Using a Solid State Coherent Lidar
M. Hufaker, Coherent Technologies, Inc.

1420 BREAK

1440 Q & A
Chairpersons: Session 3 and 4

PANEL: Windshear Wrap-up
Chairperson

1630 ADJOURN

THURSDAY, SEPTEMBER 30

SESSION 5

FUTURE AERONAUTICS TECHNOLOGY RESEARCH PROGRAMS

0830 High Speed Civil Transportation Research
M. Lewis, NASA Langley Research Center

0845 Terminal Area Productivity
G. Steinmetz, NASA Langley Research Center

SESSION 6

DEVELOPMENT AND APPLICATIONS OF SENSORS FOR AIRCRAFT WAKE VORTEX DETECTION AND AVOIDANCE

0900 Chair: R. Bowles, NASA Langley Research Center

0910 Characteristics of Civil Aviation Atmospheric Hazards
R. Marshall and J. Montoya, Research Triangle Institute
M. Richards and J. Galliano, Georgia Tech Research Institute

0930 Ground-Based Wake Vortex Monitoring, Prediction, and ATC Interface
S. Campbell and J. Evans, Massachusetts Institute of Technology

0950 BREAK

1010 Aircraft Wake RCS Measurement
W. Gilson, Massachusetts Institute of Technology

1030 Wake Vortex Detection at Denver Stapleton Airport with a Pulsed 2-micron Coherent Lidar
S. Hannon and A. Thomson, Coherent Technologies, Inc.

1050 Doppler Radar Detection of Vortex Hazard Indicators
J. Nespor, E. Hudson, and R. Stegall, Government Electronic Systems, Martin Marietta
J. Freedman, Mitre Corp.

1110 Remote Sensing of Turbulence in the Clear Atmosphere with 2-micron Lidars
R. Martinson, Lightwave Atmospherics, Inc.
J. Flint, Schwartz Electro-Optics, Inc.

1130 PANEL
Chairperson

1200 LUNCH

SESSION 7

SYNTHETIC AND ENHANCED VISION SYSTEMS

1315 Chair: T. Campbell, NASA Langley Research Center

1320 ESAS (Enhanced Situation Awareness Systems)
A. Lambregts, Boeing Commercial Airplane Co.

1340 Overview of Westinghouse Enhanced Vision Technology Activities
W. Patterson, Westinghouse Electric Corp.

1400 Evaluation of Candidate Millimeter Wave Sensors for Synthetic Vision
N. Alexander, J. Echard, and B. Hudson, Georgia Tech Research Institute

1420 Passive MMW Camera for Low Visibility Landings
M. Schoucri, TRW Applications Technology Div.

1440 Synthetic Vision System Flight Test
L. Jordan, Honeywell Technical Center

1500 Enhanced Synthetic Vision Systems
C. Taylor, Lear Astronics Corp.

1520 BREAK

1545 PANEL
Chairperson

1610 Q & A
Chairpersons: Sessions 6 and 7

1630 ADJOURN

Compiler's Notes

This publication is the Conference Proceedings from the Fifth (and Final) Combined Manufacturers' and Technologists' Airborne Windshear Review Meeting. Long-timers will recall that there had been five earlier meetings, held in 1984, '87, '88, '90, and '92. Because the '92 had for some reason been called the Fourth, the next one (the one reported here) is called the Fifth. Over all six meetings, the numbers of papers given were 21, 12, 42, 39, 38, and 37, respectively. These meetings were attended by, again in order, 58, 45, 126, 186, 143, and 132 researchers, regulators, technologists, manufacturers, and aircraft operators from around the world.

This meeting is called the Final one, because it serves as a wrap-up of completed research and a transfer of the technology to the marketplace. Over the years, the tone of the meetings has shifted from tentative questioning of how we might go about measuring windshear from an airplane operating close to an airfield, through commitments of cooperation among workers from the wide range of disciplines, to, finally, here's what we've accomplished and now let's see what certification issues remain. Also, the closing day of this Final meeting anticipated the development and applications of sensors for wake vortices and for synthetic and enhanced vision systems.

Layout of these Proceedings

The printed material for each formal presentation consists here of a uniform title-and-author sheet, followed by copies furnished by the presenter of his or her transparencies. No attempt was made by the compiler to edit the material provided, other than to obtain black-and-white halftones of any color prints furnished. For several presentations the title on the furnished material differed from that given in the agenda; in these cases an explanatory note is given on the title-and-author sheet.

Following the materials from the formal presentations are the transcriptions from the audio recordings of the discussions which followed each morning or afternoon of presentations.

Acknowledgments

Doris Stroup of the Bionetics Corporation gathered nearly all of the papers at the conclusion of each session, thereby minimizing later collection problems. Also, she provided camera-ready copies of the agenda and of the list of attendees. Don Morrison of the Raytheon Company took great care in the recording of the Question & Answer and Panel discussions, as did Nancy Hale of Kelly Services in the transcribing of the resulting tapes. David Hinton, NASA, helped with the list of acronyms. Dan Vicroy, also of NASA, provided much valuable advice based on his experience as compiler for two of the previous conferences.

VED

Session 1:
WINDSHEAR FLIGHT TEST OVERVIEW.

Chair: R. Bowles,

NASA Langley Research Center

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Flight Test of AWAS III. B. McKissick, NASA Langley Research Center

Flight Test Evaluation of a Data Link and Aircraft Integration of TDWR Wind- shear Information. D. Hinton, NASA Langley Research Center

A Performance Evaluation of Airborne Coherent Lidar Wind Shear Sensors. P. Robinson, Lockheed Engineering and Sciences Co.

Westinghouse MODAR 3000 Flight Test Results. W. Patterson and M. Eide, Westinghouse Electric Corp.

NASA's Airborne Doppler Radar for Detection of Hazardous Windshear. E. Bracalente, NASA Langley Research Center

Flight Test of AWAS III.

B. McKissick,

NASA Langley Research Center

Flight Test of AWAS III

by

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5th (and Final) Combined
Manufacturers' and Technologists'
Airborne Wind Shear Review Meeting

September 28-30, 1993
Radisson Hotel
Hampton, Virginia

Flight Test of AWAS III

Outline

I. Introduction

II. 9 Strong Events

- ***A.Scatter Plots Analysis***
- ***B.Look Distances***
- ***C.Cross Correlation Analysis***

III. 21 Events

- ***A. Scatter Plot Analysis***
- ***B. Contingency Tables***
- ***C. Look Distances***

IV.Conclusions

NASA'S EFFORT WITH TPS IN INFRARED SYSTEM DEVELOPMENT

Phase I SBIR (1987) determined that a passive infrared system is feasible for windshear detection

Phase II SBIR (1989-1991)

- **Flight test of AWAS I on NASA 515 in 1989-1990**
- **Development of AWAS III**

Flight test of AWAS III on NASA 515 at Orlando and Denver in 1991 resulted in numerous changes to AWAS III

Flight test of improved AWAS III on NASA 515 at Orlando and Denver in 1992

AWAS III'S IMPROVEMENTS

TPS redesigned periscope

- ➢ *pressurized periscope*
- ➢ *periscope and reflector installation similar to others*
- ➢ *heated reflector*

New method of compensating for lapse rate effects

Filtered AWAS III hazard indices

Infrared Periscope Mounted in Side Window of 737 Aircraft

AWAS III'S DATA RESTRICTIONS

AWAS III's hazard indices are applicable for approach speeds only.

In situ f-factor was transformed to an approximation of in situ f-factor at 140 knots ground speed in order to compare to AWAS III's indices.

AWAS III does not scan.

Only events where aircraft motions were "small" (stable events) were analyzed.

STABLE FLIGHT CRITERIA

An event is defined as a "stable event" if during the time interval 40 seconds prior to a peak in situ F-factor measurement

- ***max. heading - min. heading < 15 degrees***
- ***max. pitch - min pitch. < 10 degrees and***
- ***altitude < 1400 feet AGL.***

MNEMONICS AND SYMBOLS

AWASFF- wind shear hazard index based on infrared temperature measurements,

AWASFT- wind shear hazard index based on temperature measured at the aircraft,

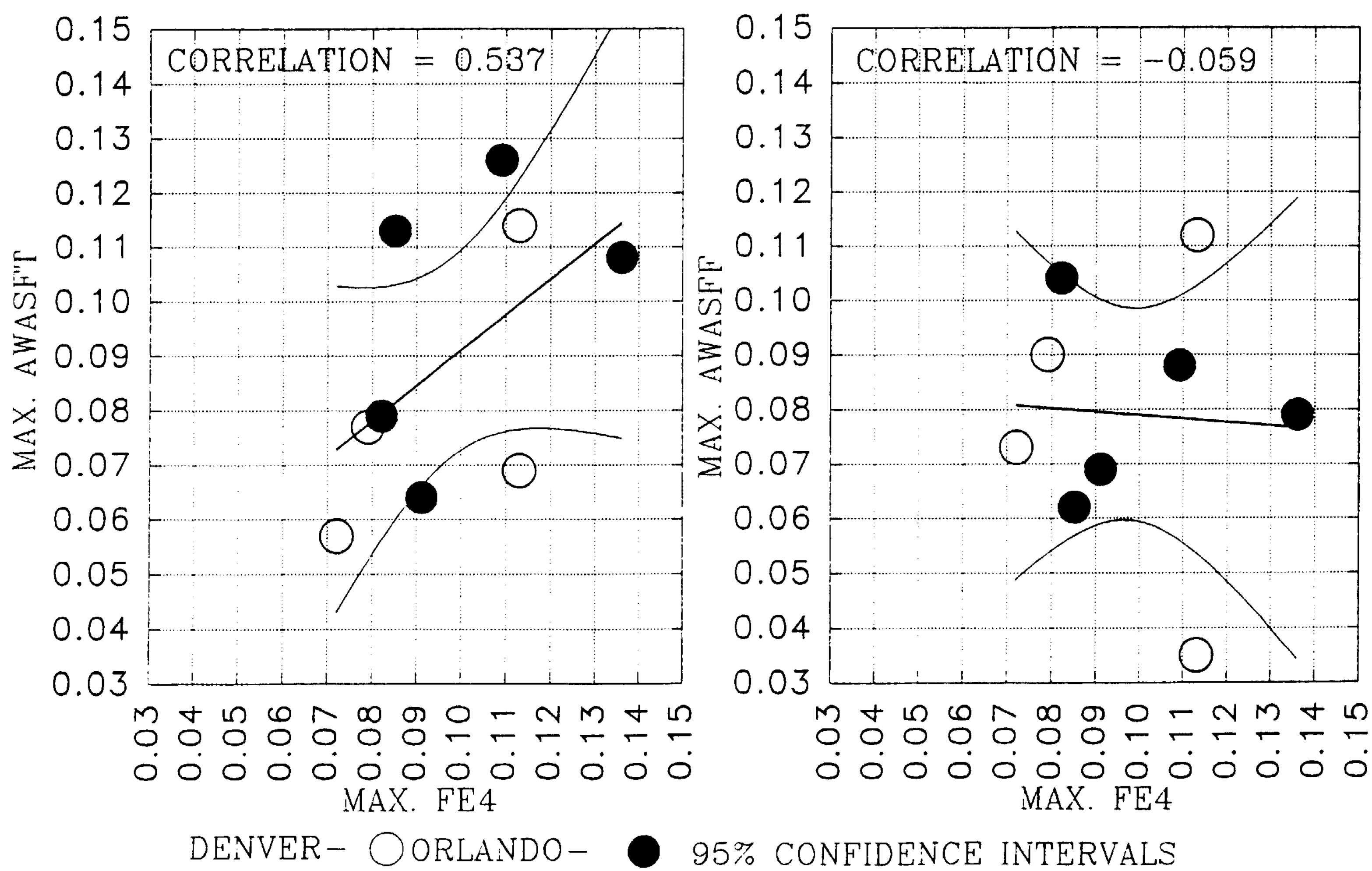
AWAS III- Advanced Warning Airborne System version III,

D2- infrared measurement of far field minus near field temperature from detector 2,

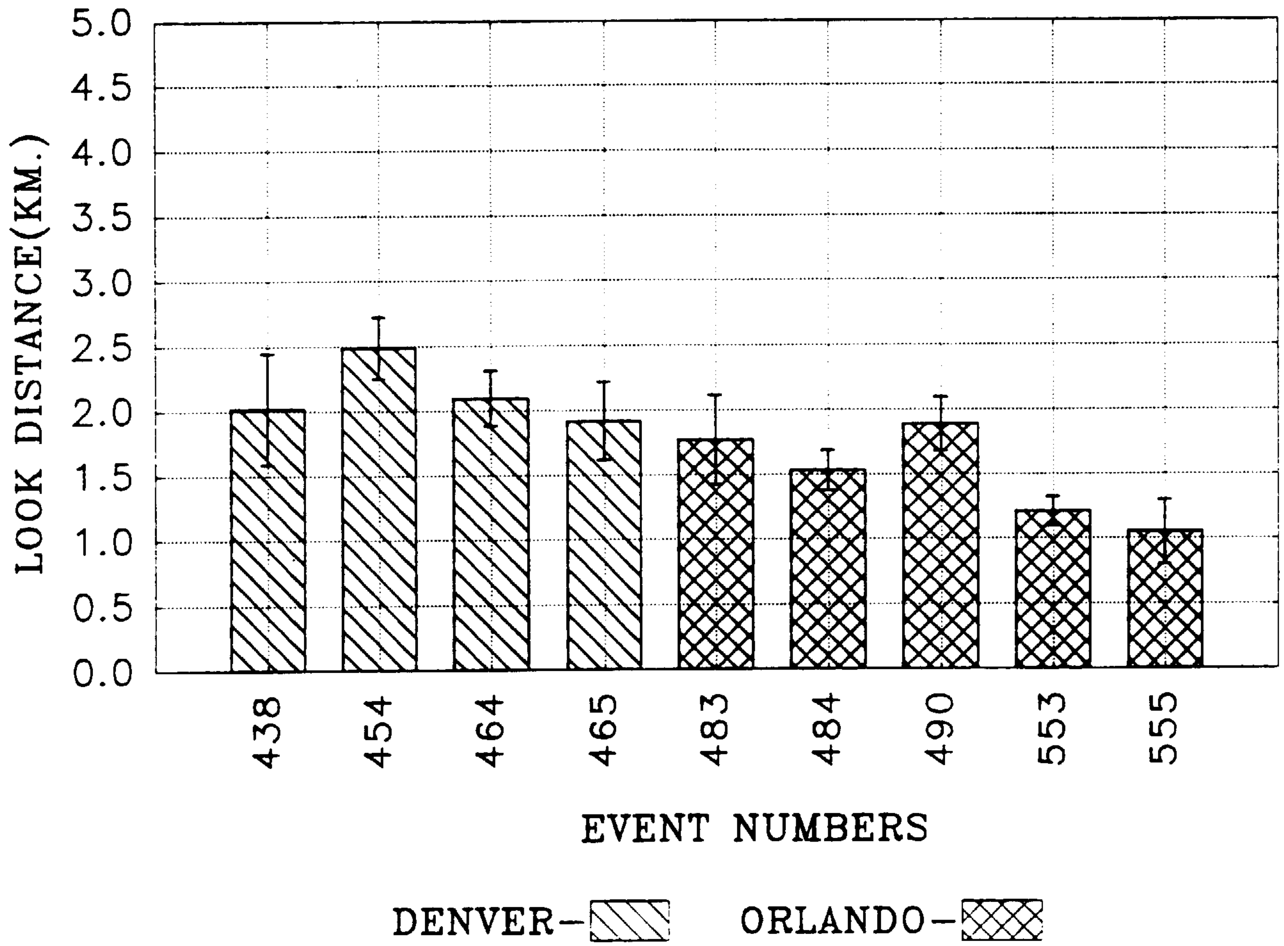
FE3- total in situ f-factor,

FE4- transformation of FE3 for ground speed of 140 knots,

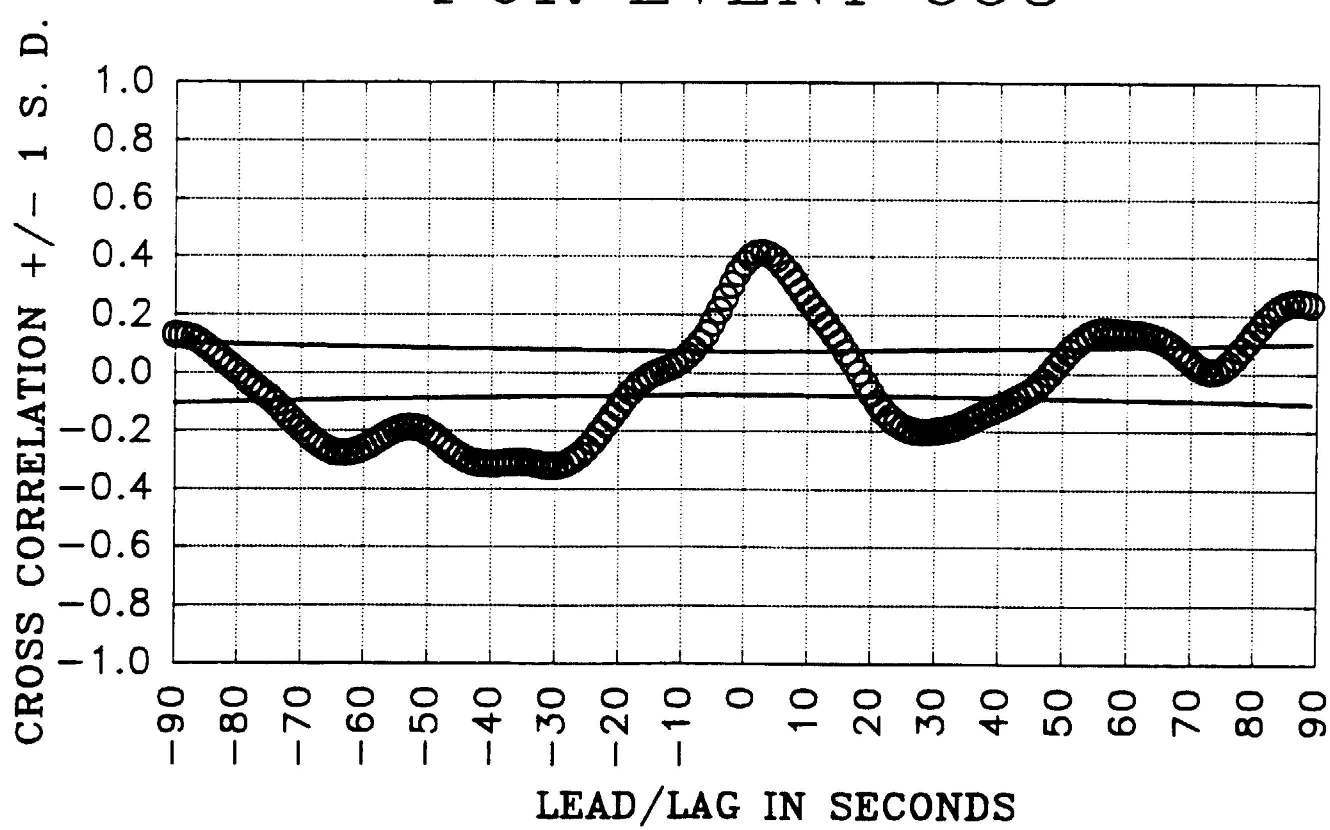
SCATTER PLOT FOR 9 EVENTS FOR 1992 DEPLOYMENTS



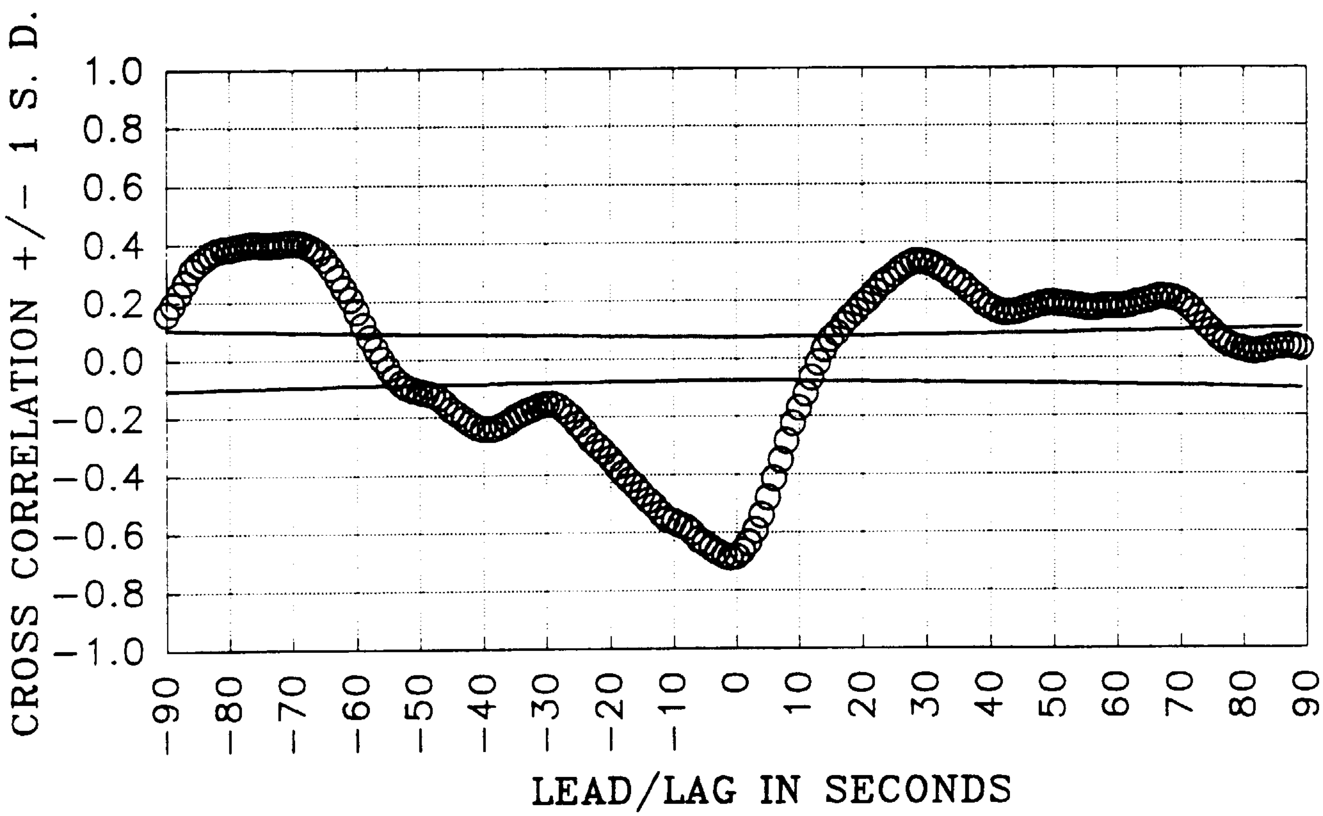
LOOK DISTANCES FOR NINE EVENTS FOR 1992 DEPLOYMENTS



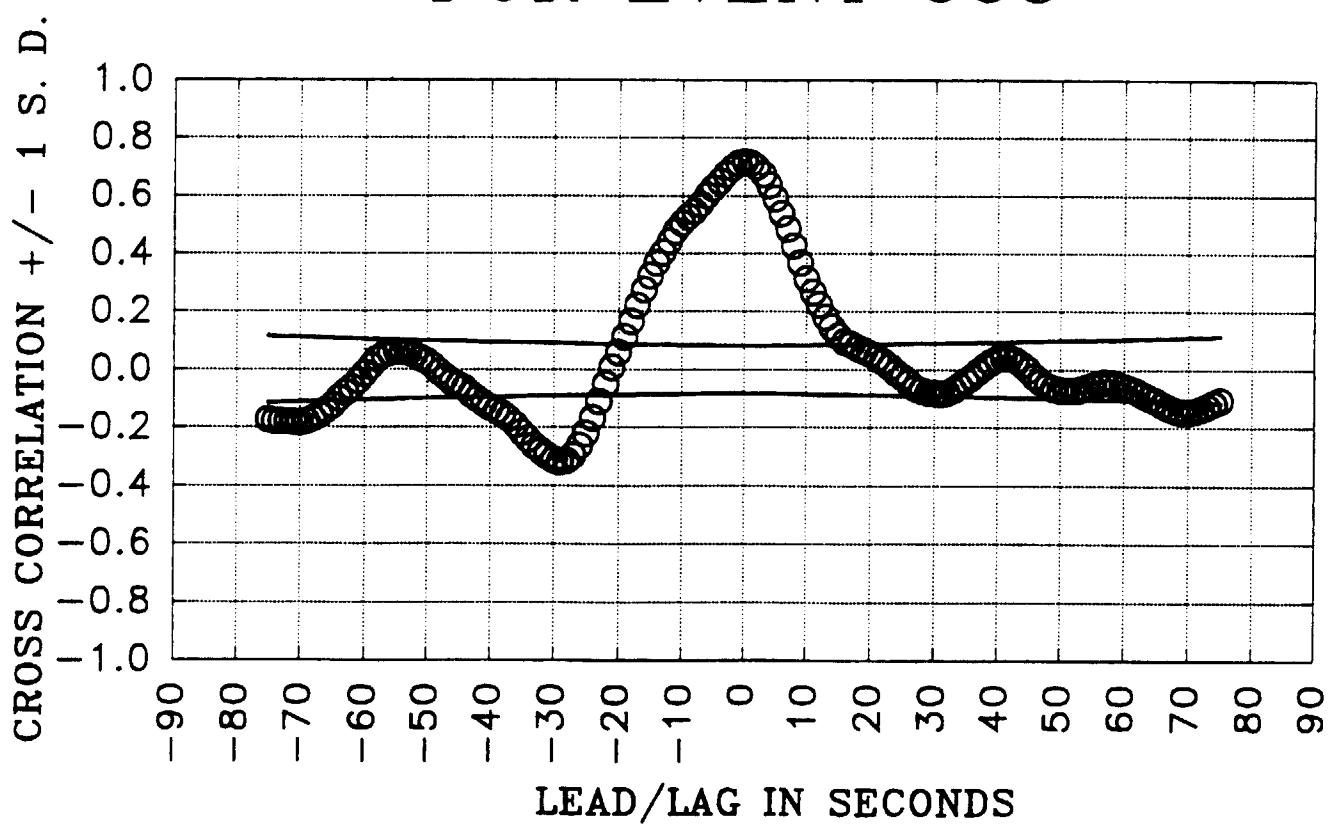
CROSS CORRELATION OF AWASFT VERSUS FE4 FOR EVENT 553



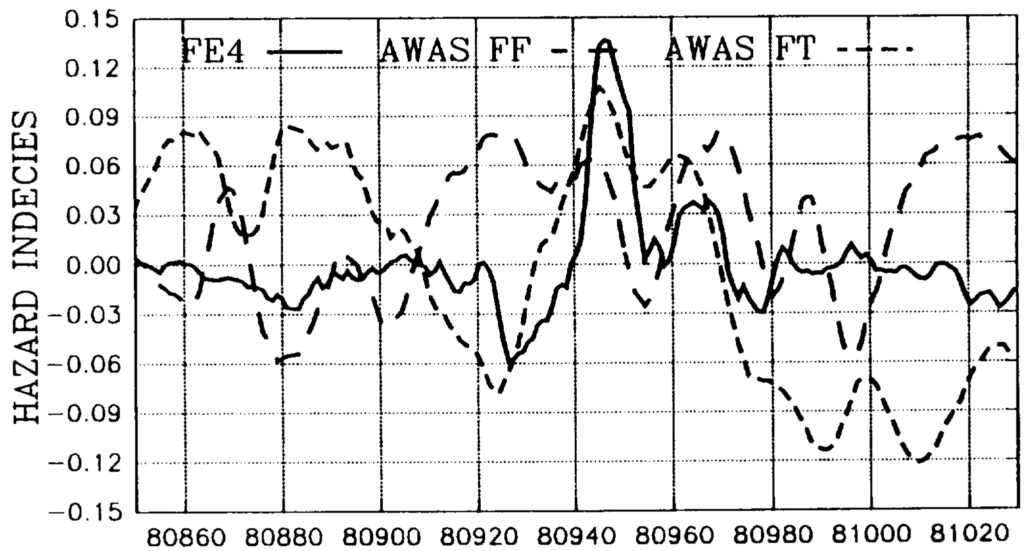
CROSS CORRELATION OF D2 VERSUS TEMP. FOR EVENT 553

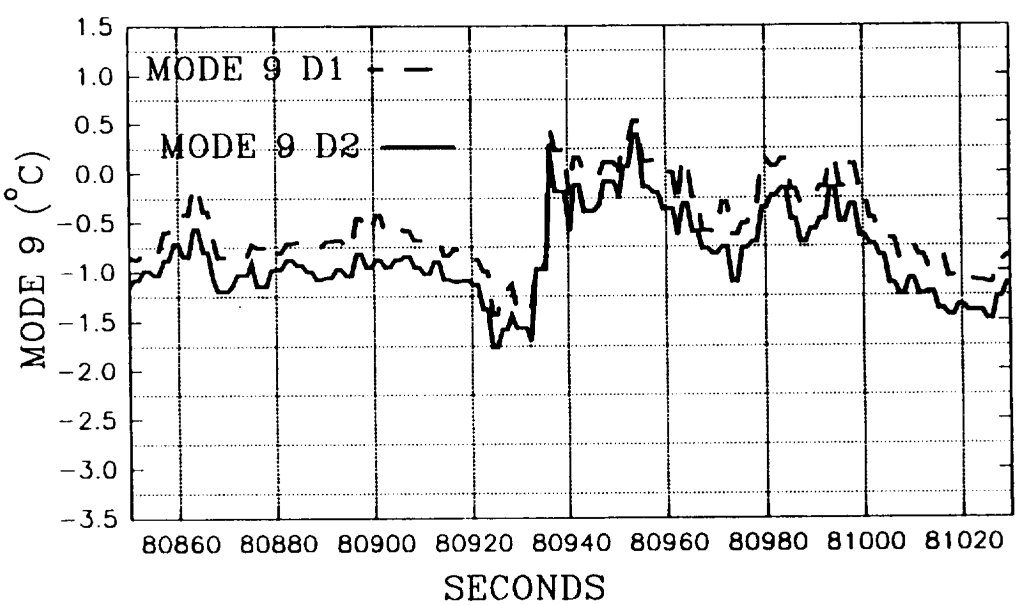


CROSS CORRELATION OF
D2 VERSUS T(t+29)−T(t−1)
FOR EVENT 553



DATA FOR #553
FLIGHT 665 ON 8/17/92 AT ORLANDO
FOR A MICROBURST PENETRATION





Advanced Detection Times for Stable Events with FE4 > 0.07*

Event Number	Advanced detection time based on AWAS III's look distance**	Advanced detection time based on correlation coefficients
438	17.064 seconds	53 seconds
454	21.044 seconds	11 seconds
464	17.714 seconds	8 seconds
465	16.202 seconds	not computable
483	14.976 seconds	not computable
484	12.956 seconds	55 seconds
490	15.948 seconds	28 seconds
553	10.226 seconds	28 seconds
555	8.883 seconds	37 seconds
Mean (Standard Error)***	15.001 (1.263)	31.428 (6.972)

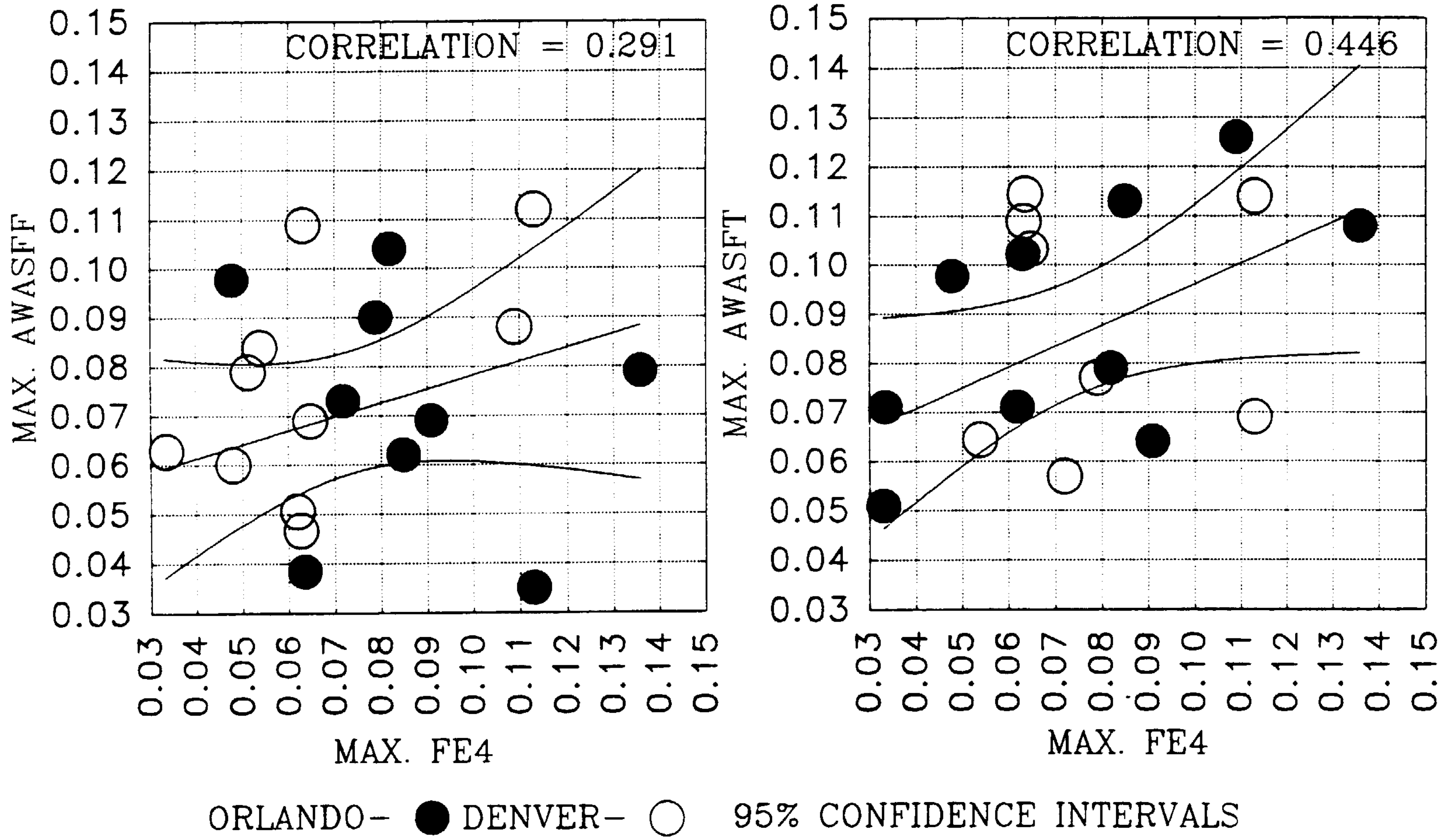
*The cross correlation coefficient (-0.440) for the two detection times is not significantly (p=0.323) different than zero.

**Calculations of advanced detection times use a ground speed of 230 knots and mean look distances.

***The mean of column three is significantly larger (p=.0365 for a paired t-test) than the mean of column two.

Note that the test excluded the data from events 465 and 483.

SCATTER PLOT FOR EVENTS FOR 1992 DEPLOYMENTS



Contingency Tables for Stable 1992 Events

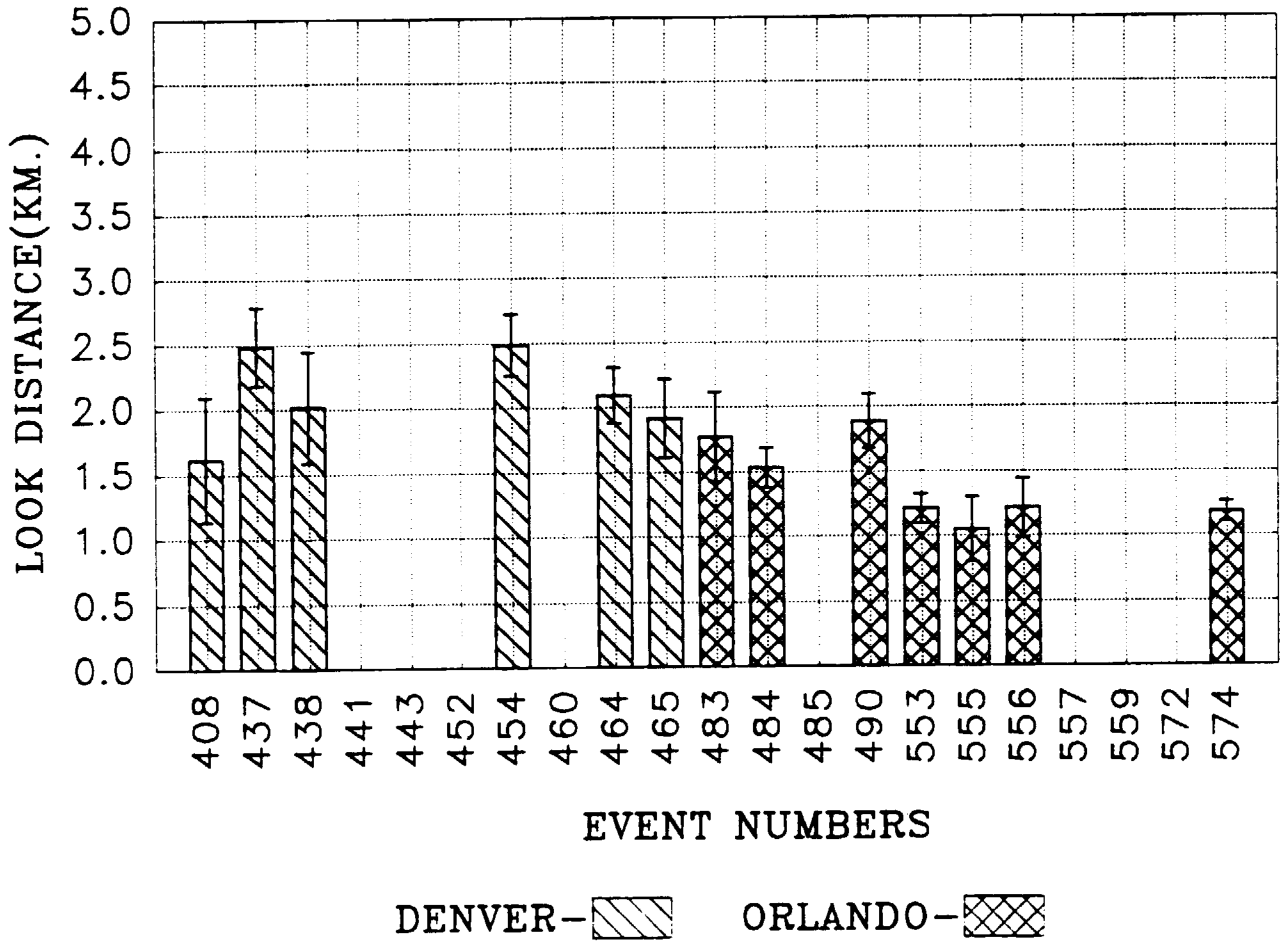
	FE4<0.105	FE4>0.105	TOTAL	ROW #
AWASFT< 0.105	61.11%	5.56%	66.67%	12
AWASFT> 0.105	16.67%	16.67%	33.33%	6
TOTAL	77.78%	22.22%	100.00%	
COLUMN #	14	4		18

FISHER EXACT TEST (TWO-TAIL)
P-VALUE=0.083

	FE4<0.105	FE4>0.105	TOTAL	ROW #
AWASFF< 0.105	76.19%	14.29%	90.48%	19
AWASFF> 0.105	4.76%	4.76%	9.52%	2
TOTAL	80.95%	19.05%	100.00%	
COLUMN #	17	4		21

FISHER EXACT TEST (TWO-TAIL)
P-VALUE=0.352

LOOK DISTANCES FOR STABLE EVENTS FOR 1992 DEPLOYMENTS



Conclusions

Conclusions

The correlation analysis shows that AWASFF is a predictive index base on temperature measurements from 11 to 55 seconds before peak in situ f-factor values.

The scatter plots indicate that AWAS III's wind shear hazard indices were not reliable predictors of in situ f-factor in this experiment.

AWAS III's indices look promising but the transformation from temperature measurement to a reliable windshear hazard index is not complete.

Flight Test Evaluation of a Data Link and Aircraft Integration of TDWR Wind- shear Information.

D. Hinton,

NASA Langley Research Center

Flight Test Evaluation of Data Link and Airborne Integration of TDWR Wind Shear Information

David A. Hinton

NASA Langley Research Center

Presented at Fifth Combined Manufacturers' and Technologists' Airborne Wind Shear Review Meeting

Hampton, VA

September 28-30, 1993

OUTLINE

- Introduction and Terminal Doppler Weather Radar (TDWR) System Review
- 1992 System Enhancements
- Flight Test
- Results
  - Algorithm Performance
  - System Alerting Performance
- Summary

Research Goal

- Continue effort conducted during 1991 deployments to:

  - Identify TDWR information products required for airborne processing of wind shear hazard index and executive-level crew alerting.

  - Demonstrate feasibility of data link and airborne utilization of TDWR information in an operational environment.

- Evaluate system improvements made after the 1991 deployments.

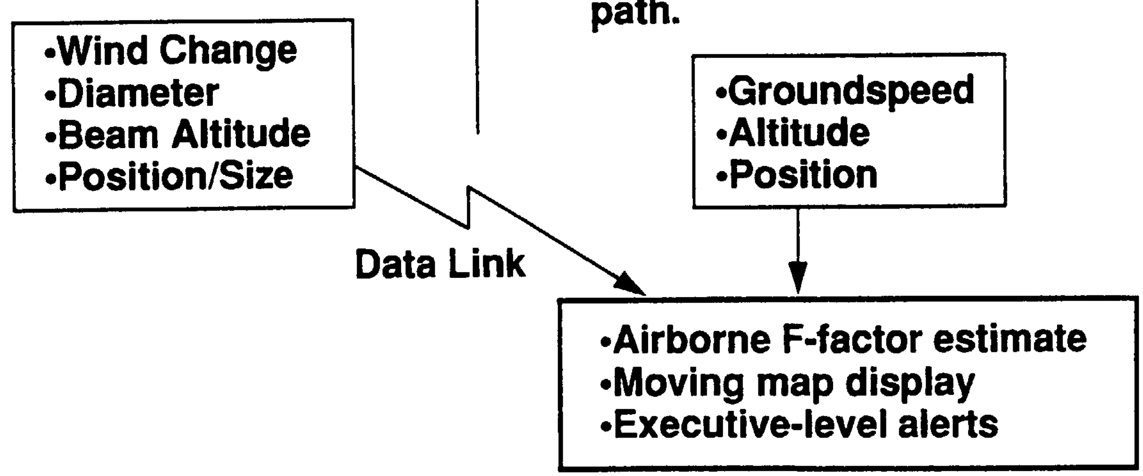
Information Integration Concept

TDWR Product

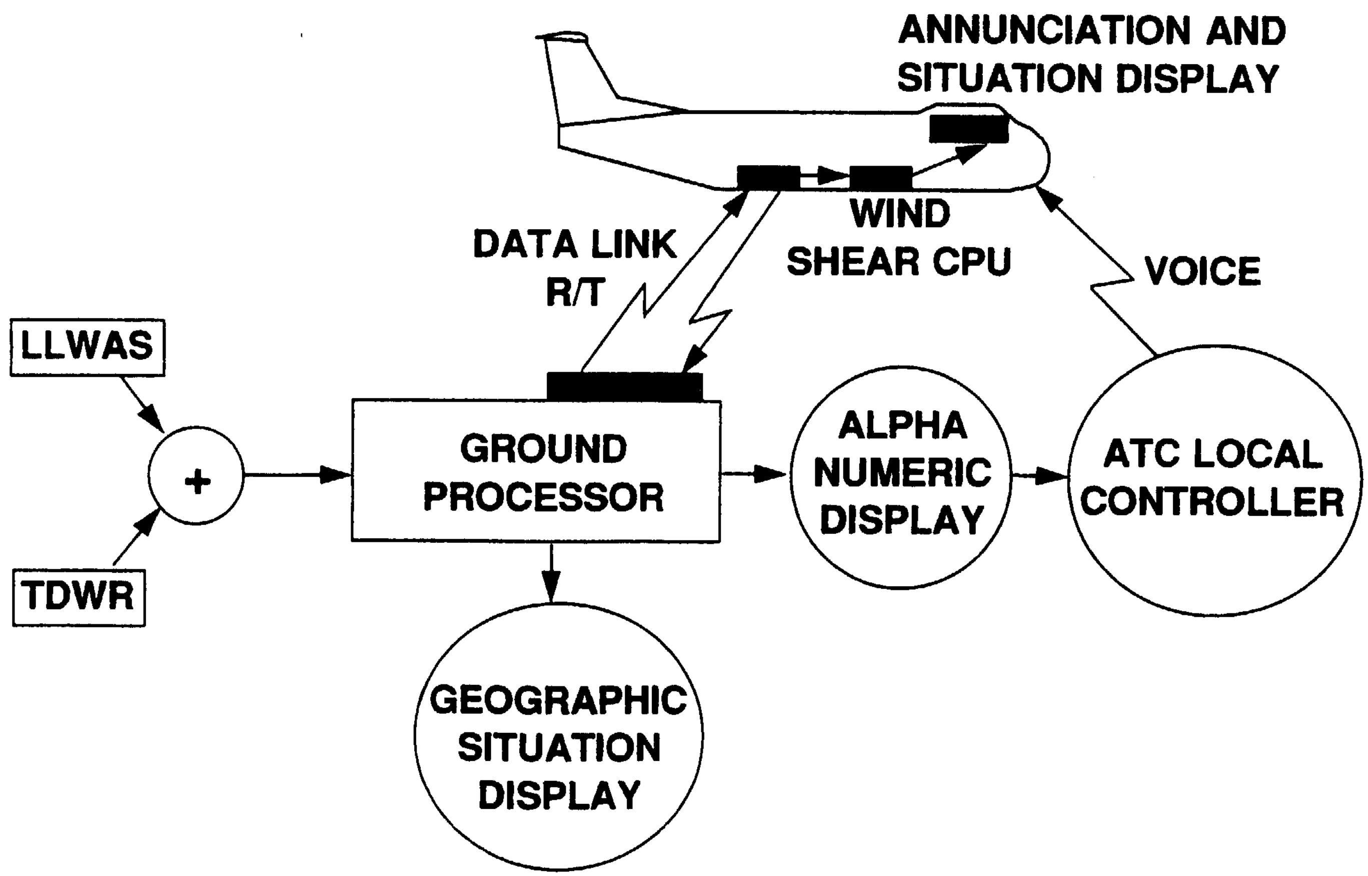
Global representation of microburst wind change and diameter.

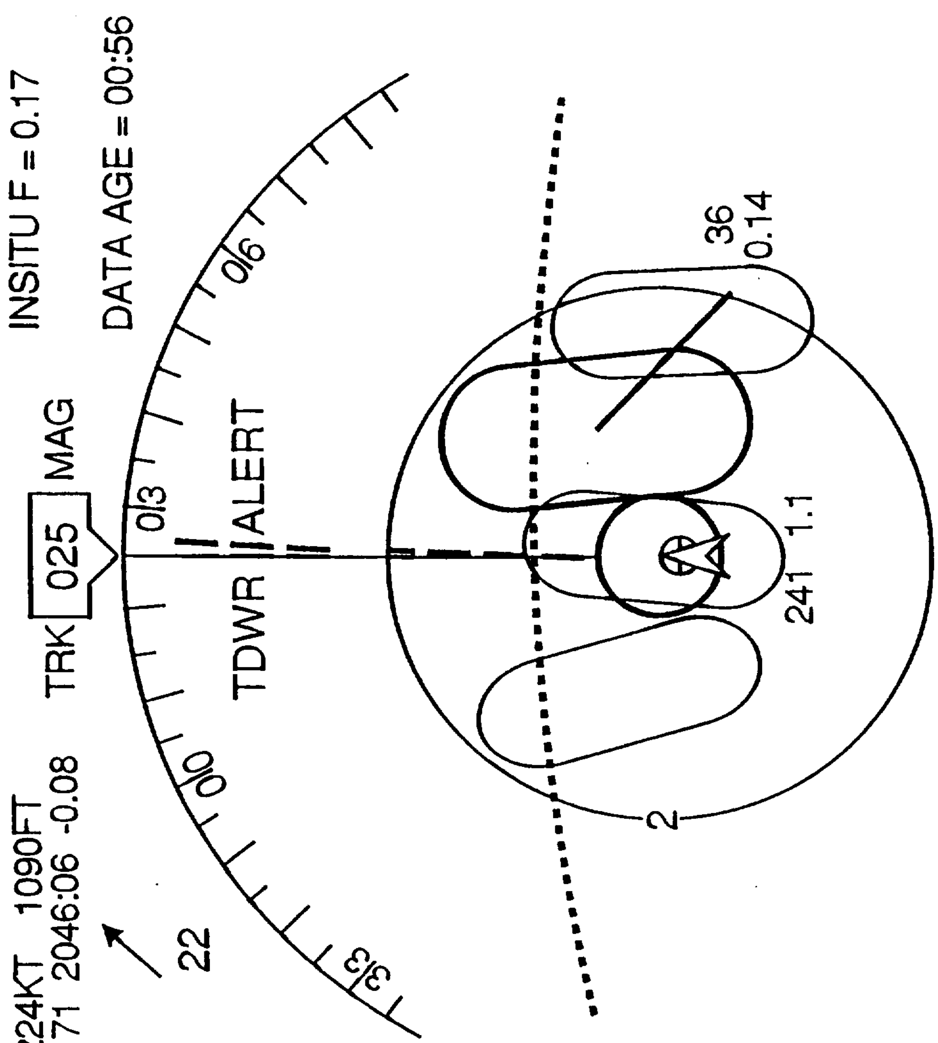
Aircraft Hazard Index

Hazard quantified by 1-kilometer average F-factor (function of wind gradient, downdraft speed, and airplane speed) along flight path.



System Architecture



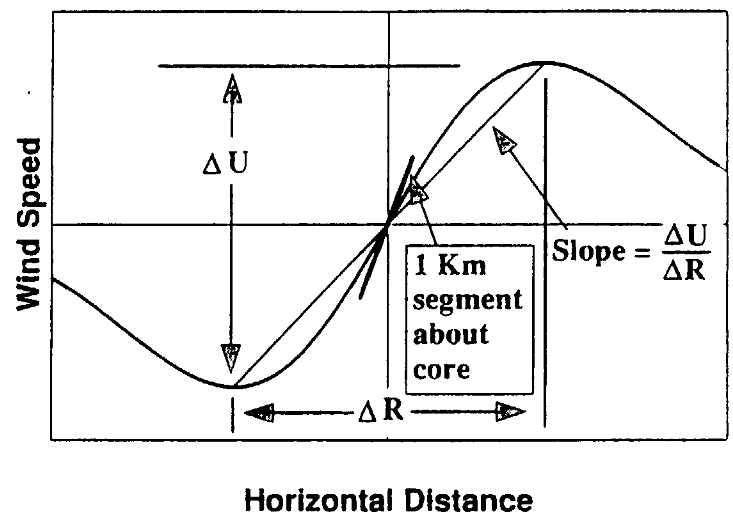


224KT 1090FT
171 2046:06 -0.08
22
TRK 025 MAG
INSITU F = 0.17
DATA AGE = 00:56
TDWR ALERT
0|3
0|6
0|0
3|3
36
0.14
241 1.1
2

1992 System Enhancements

- Modified F-factor algorithm.
- Real-time altitude correction for radar beam/aircraft altitude differences.
- Speed/altitude values limited for on-ground use of system (80 m/s, 60 m AGL).
- Data downlink provided for automatic "pilot report".
- Additional data link products implemented to support flight tests, baud rate increased to 2400.
- Airborne doppler sensor alerts added to moving map display.

F-factor Equation



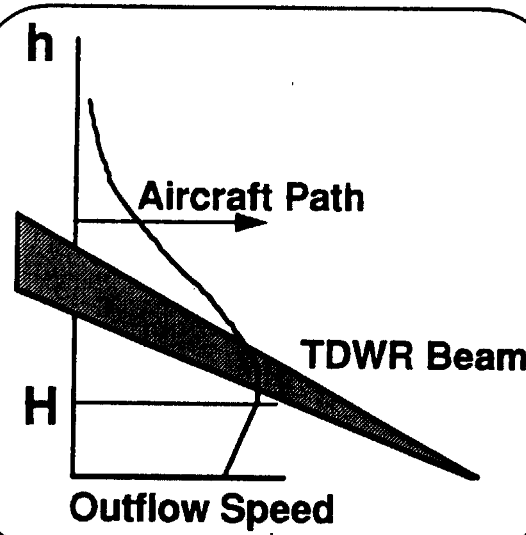
β = Slope of 1 km segment about microburst core, least squares fit.

$$\beta = 1.6487 \frac{\Delta U}{\Delta R} \left(1 + \frac{462900}{\Delta R^{2.1}}\right) e^{-(707.11/\Delta R)^2}$$

ΔR, meters

$$F_{base} = \beta \left(V/g + 2h_r/V \right)$$

Real-Time Altitude Correction



H = Altitude of maximum outflow speed, 90m chosen.

h_a = Airplane altitude.

h_r = Radar beam altitude.

V = Airplane ground speed.

$$p(h) = \frac{e^{-0.22h/H} - e^{-2.75h/H}}{0.7386} \quad \text{for } h \geq H$$

$$p(h) = 1 - 0.00167(H - h) \quad \text{for } h < H$$

$$F = F_{base} \frac{p(h_a)(V/g + 2h_a/V)}{p(h_r)(V/g + 2h_r/V)}$$

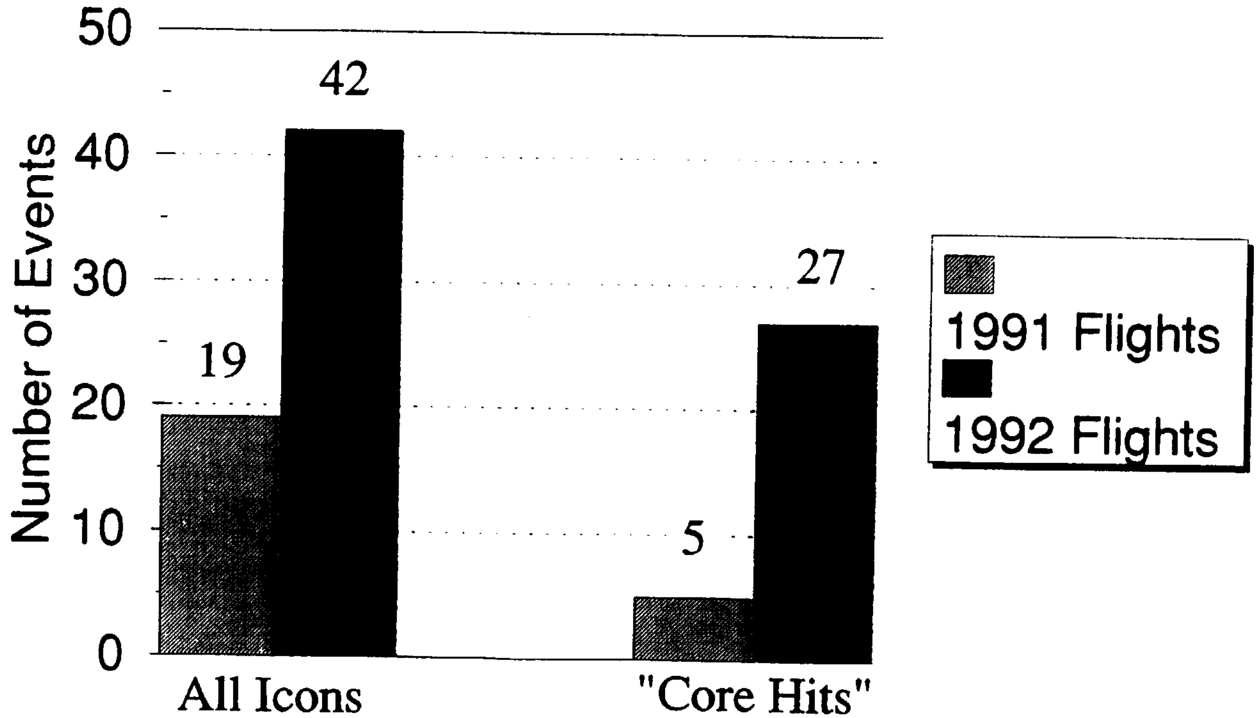
Flight Tests

Concept tested during combined sensor flight tests at Orlando and Denver during July/August 1992.

- TDWR interface supported by MIT Lincoln Laboratory and NCAR.
- Suitable weather conditions at both deployment sites provided numerous microburst penetrations.

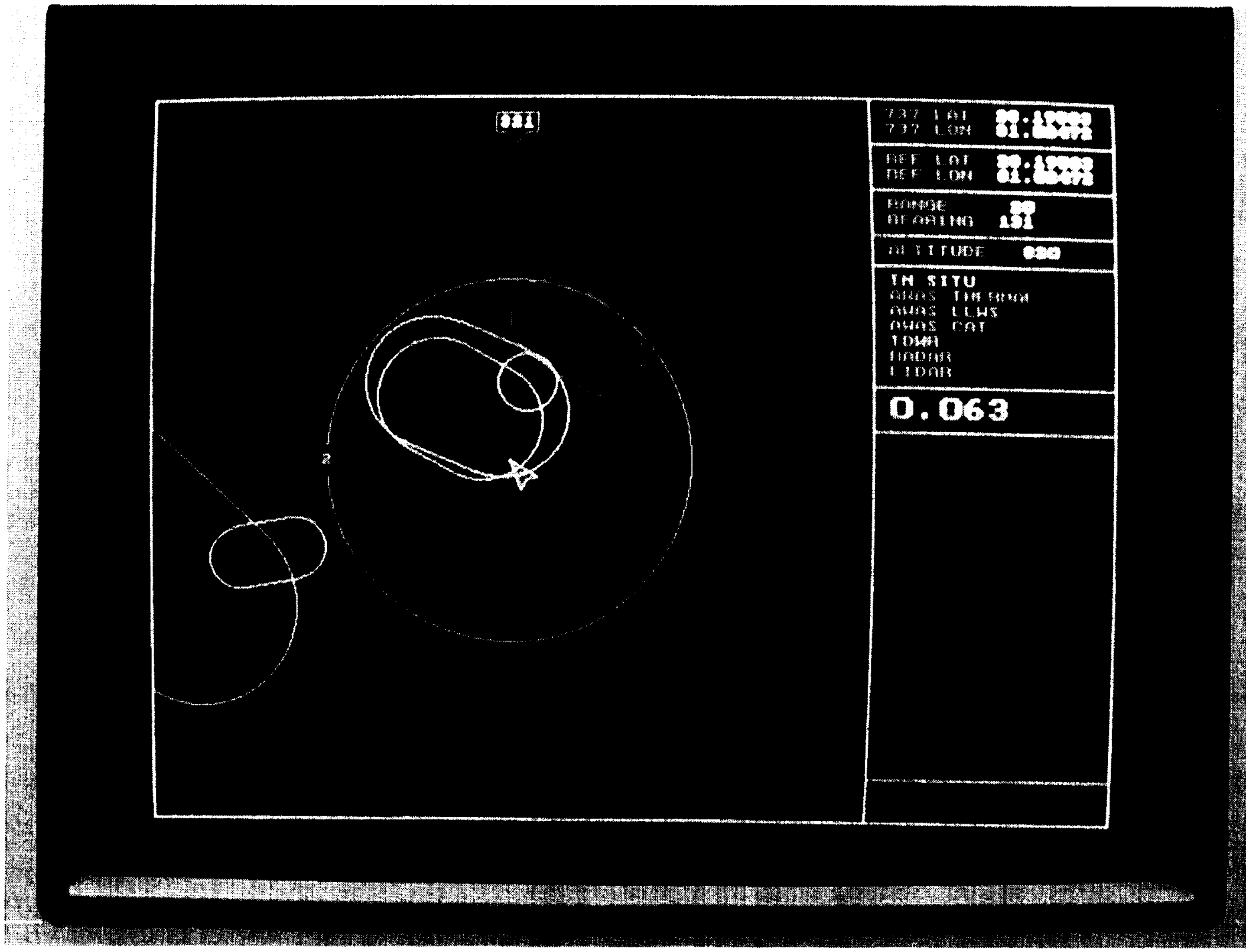
Flight Test Results

TDWR Microburst Icons Encountered



Operational Results

- Situation display proved effective for aircraft positioning as well as post-flight data analysis.
- Shear-based windshear icons derived from airborne sensors used to fine-tune trajectories.
- Data downlink provided ground crew with real-time aircraft position, altitude, track, speed - as well as the status of alerts from onboard windshear sensors.



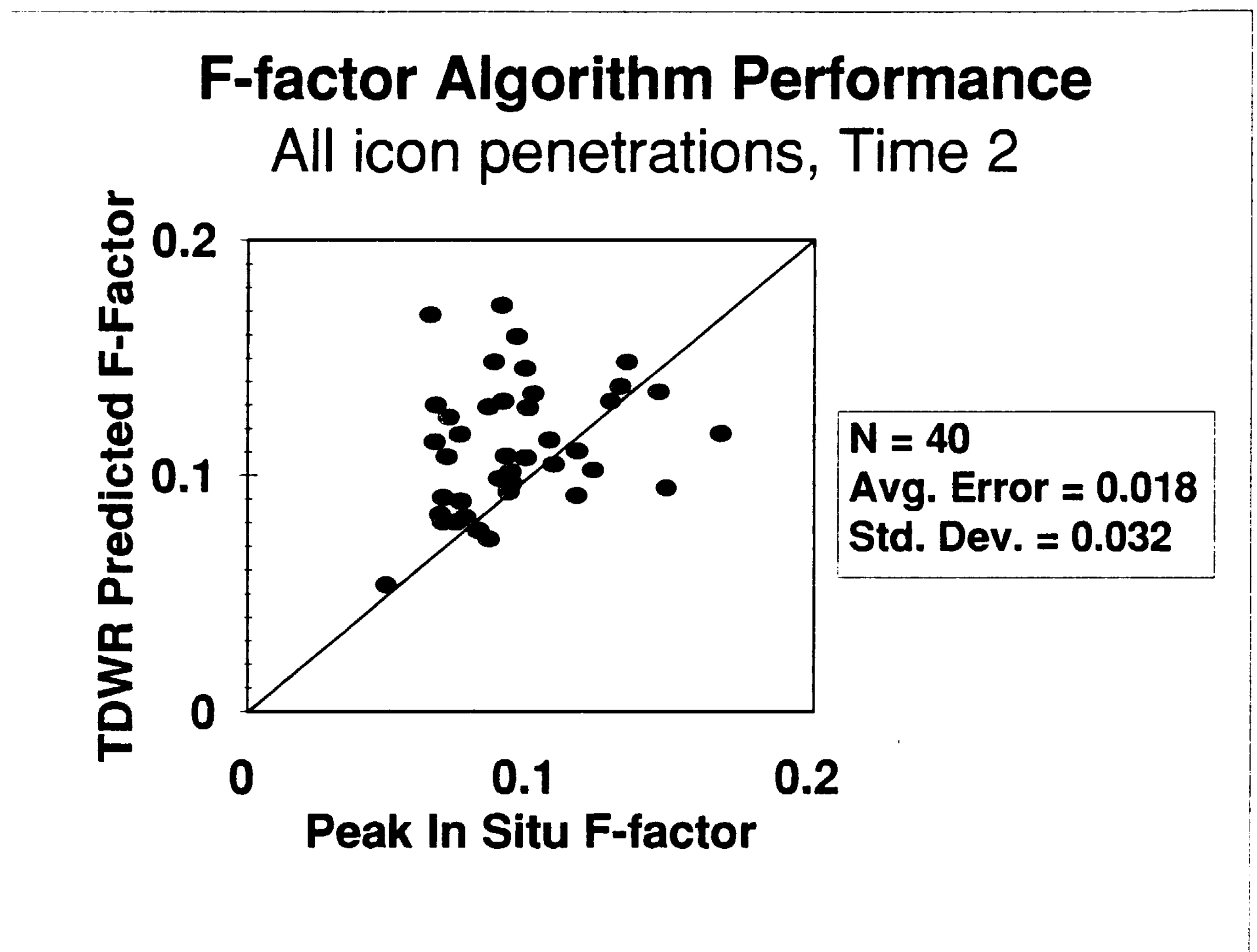
Situation Display

F-factor Algorithm Performance

- "Core Hit" cases and other cases produced similar results, combined for analysis.
- 5 "core hit" events from 1991 deployment included.
- Two TDWR information updates used:
  - Time 1: Last data update on airplane at microburst entry time. Used for prediction performance evaluation.
  - Time 2: Next data update, TDWR measurement taken nearest time of airplane in situ measurements. Used for algorithm performance evaluation. Some data points lost at time 2 from microburst decay.

Prediction Error Sources

- Spatial - Aircraft may miss region of strongest shear.
- Altitude - Difference in microburst strength between TDWR measurement altitude and airplane altitude.
- Temporal - Microburst growth and decay between TDWR 1-minute updates.
- Shear Estimation Algorithm - Attempt to reconstruct microburst core shear using only microburst outflow region data.

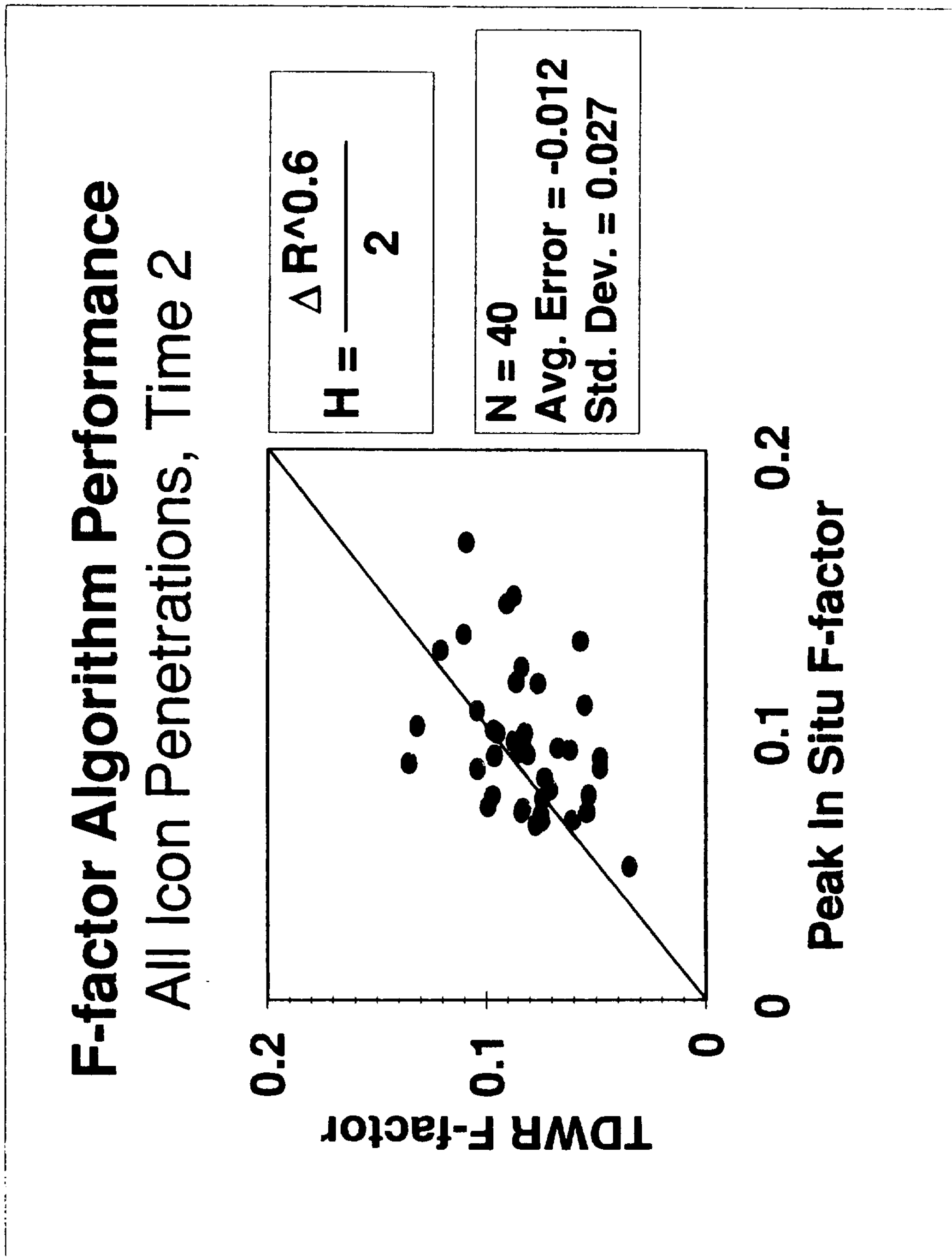

F-factor Algorithm Performance
All icon penetrations, Time 2
TDWR Predicted F-Factor
0.2
0.1
0
0
0.1
0.2
Peak In Situ F-factor
N = 40
Avg. Error = 0.018
Std. Dev. = 0.032

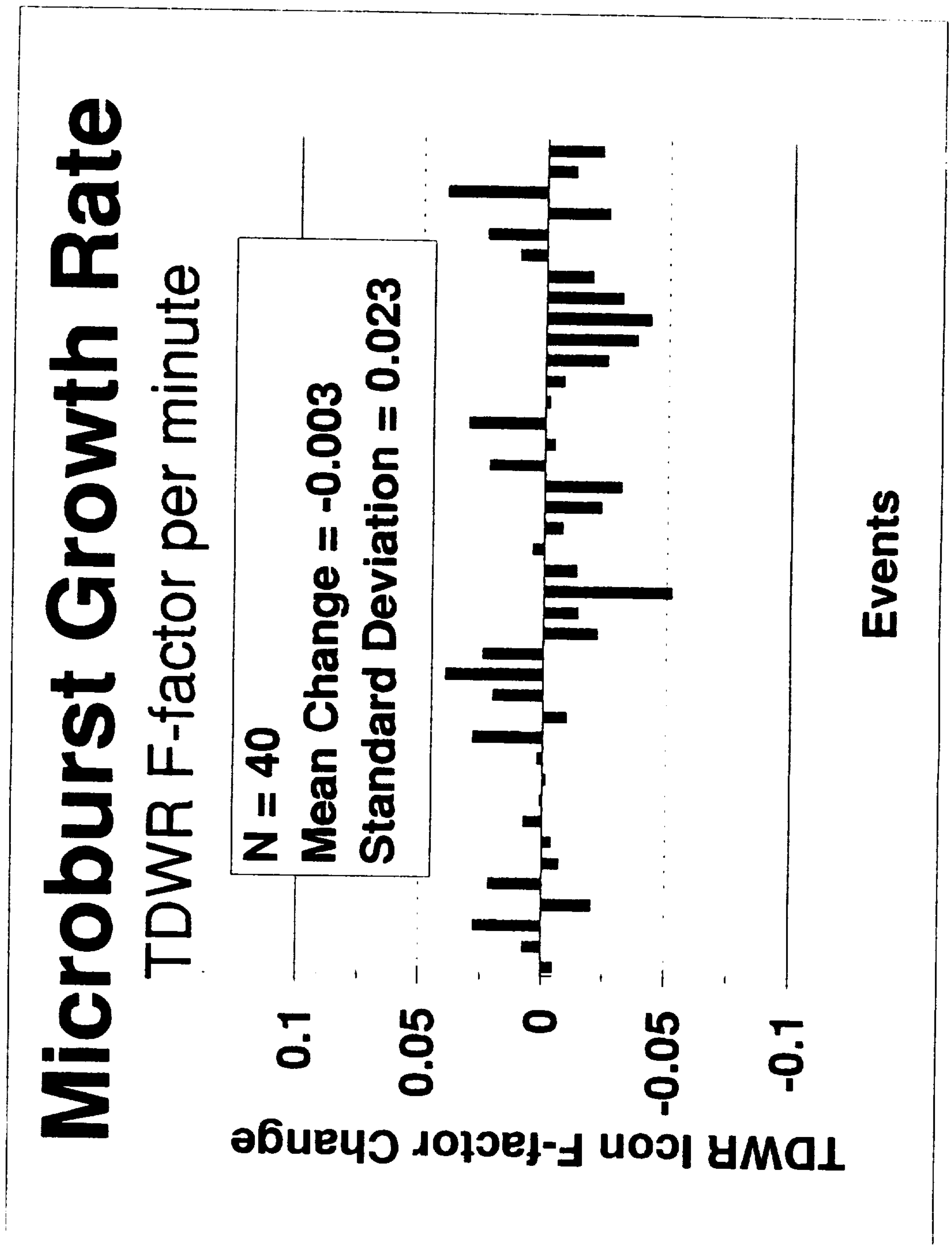
Altitude Correction Effect

- Real-time altitude correction assumed peak outflow speed at 90 meters altitude, based on 5 events from 1991 deployment.
- Evidence suggests lower value of H.
- H for minimum average prediction error = 62 m.
- Empirical relationship of H to diameter (Proctor):

$$H = 0.5\, \Delta R^{0.6}$$

- Proctor formula produces average H of 52 m.


F-factor Algorithm Performance
All Icon Penetrations, Time 2
H = Δ R^0.6 / 2
N = 40
Avg. Error = -0.012
Std. Dev. = 0.027
TDWR F-factor
0.2
0.1
0
Peak In Situ F-factor
0
0.1
0.2

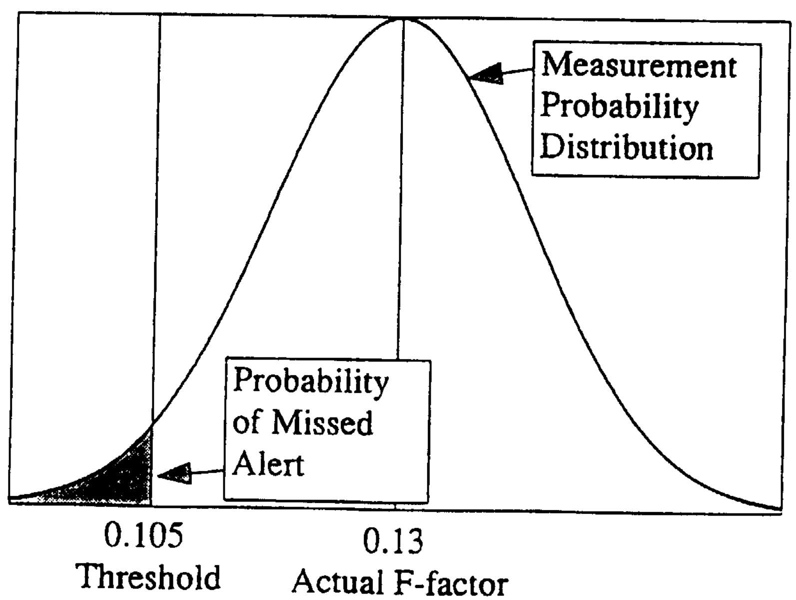

Microburst Growth Rate
TDWR F-factor per minute
N = 40
Mean Change = -0.003
Standard Deviation = 0.023
0.1
0.05
0
-0.05
-0.1
TDWR Icon F-factor Change
Events

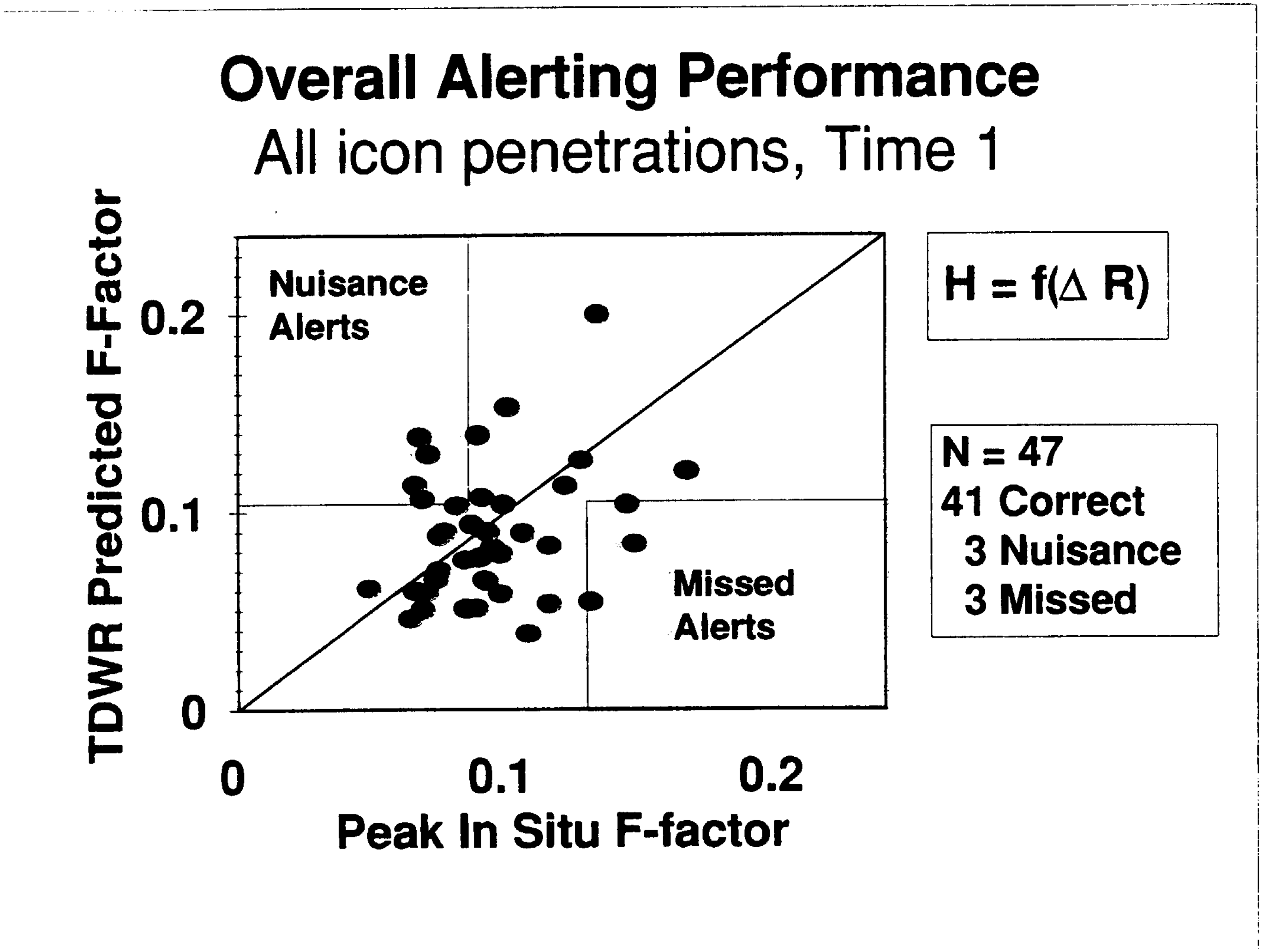
Detection Statistics

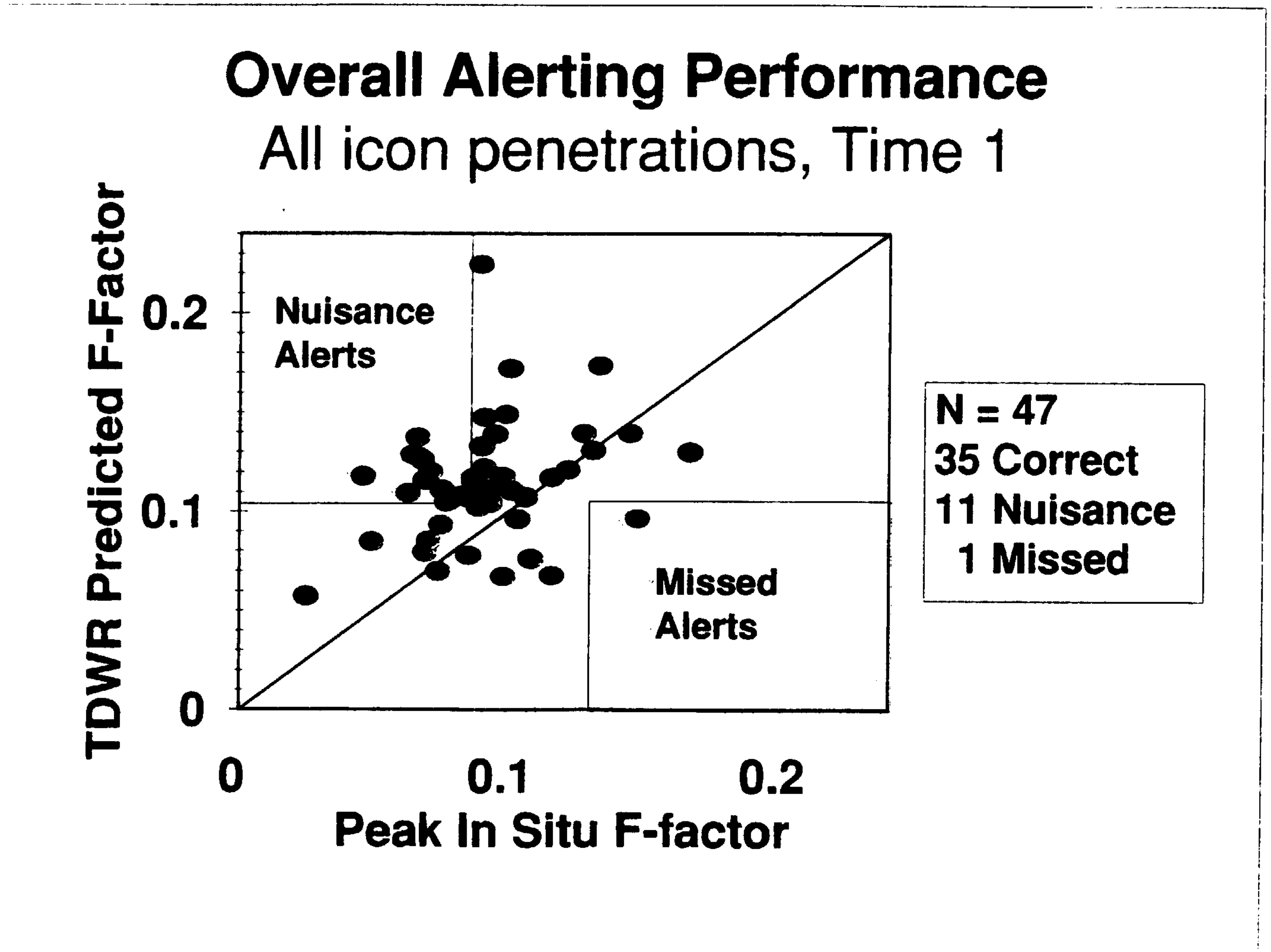
Condition	Mean & Standard Deviation of Prediction Error	P(Miss)	P(Nuisance)
Ideal error & observed S.D.	0 & 0.03	0.20	0.25
Observed error & S.D.	0.018 & 0.032	0.09	0.48
Observed with H = f(diameter)	-0.012 & 0.027	0.32	0.12
Significant improvement	0 & 0.01	0.006	0.02

Detection Statistics

- Compute probability of missed or nuisance alert:
  - Assume normal distribution.
  - Single measurement, threshold = 0.105.
  - Use FAA "must not" & "must" alert values.




Overall Alerting Performance
All icon penetrations, Time 1
H = f(Δ R)
N = 47
41 Correct
3 Nuisance
3 Missed
Nuisance Alerts
Missed Alerts
TDWR Predicted F-Factor
0
0.1
0.2
0
0.1
0.2
Peak In Situ F-factor



Overall Alerting Performance
All icon penetrations, Time 1
TDWR Predicted F-Factor
0.2
0.1
0
0
0.1
0.2
Peak In Situ F-factor
Nuisance Alerts
Missed Alerts
N = 47
35 Correct
11 Nuisance
1 Missed

Discrete Alerting Performance

- Analyze TDWR icon F-factors at time 1
- Compare to FAA systems requirement document, "Must Not Alert" and "Must Alert" criteria.
    - Actual F-factor of > 0.13 must create alert, miss rate $< 10^{-5}$.
    - Actual F-factor of < 0.085 must not create alert, nuisance rate $< 4 \times 10^{-3}$.

Summary

- Demonstrated feasibility of data link and airborne use of TDWR microburst information.
- F-factor estimation from TDWR data is good in majority of microburst icon penetrations.
- Inherent limitations in achieving crew alerting performance suitable for executive-level protocol.
  - Variation due to along-path vs. global measurement of hazard.
  - Variation between updates exceeds required value.
- System performance excellent for advisory information and microburst awareness.
- Some improvements in shear location may be achieved with shear-based ground algorithms.

A Performance Evaluation of Airborne Coherent Lidar Wind Shear Sensors,

P. Robinson,

Lockheed Engineering and Sciences Co.

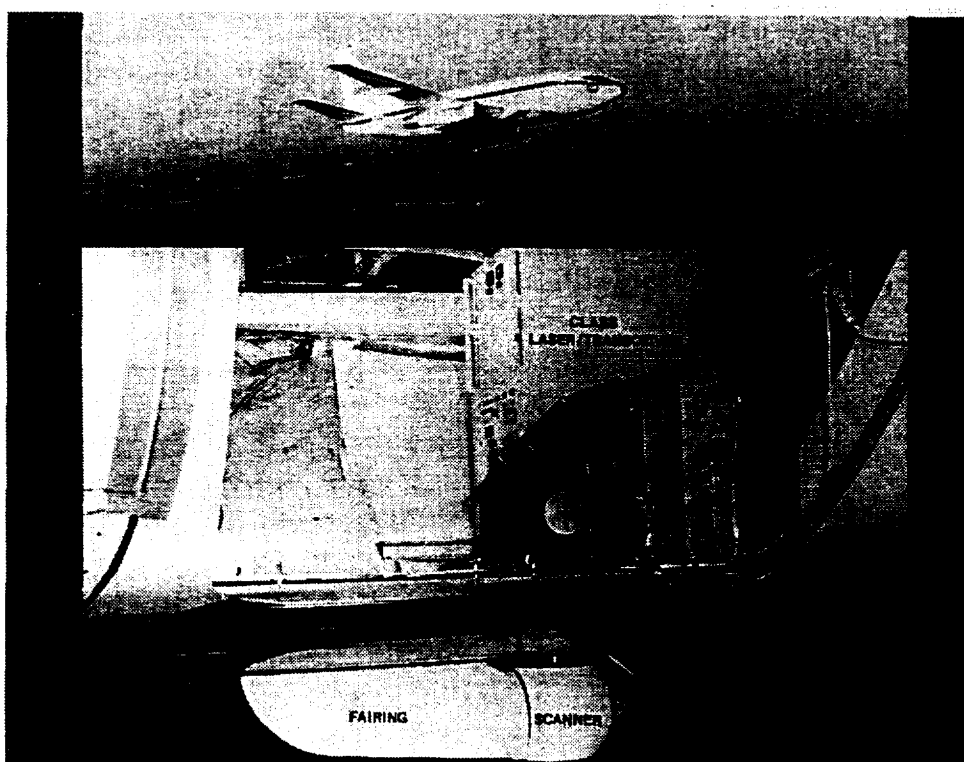
A Performance Evaluation of Airborne Coherent Lidar Wind Shear Sensors

Paul A. Robinson

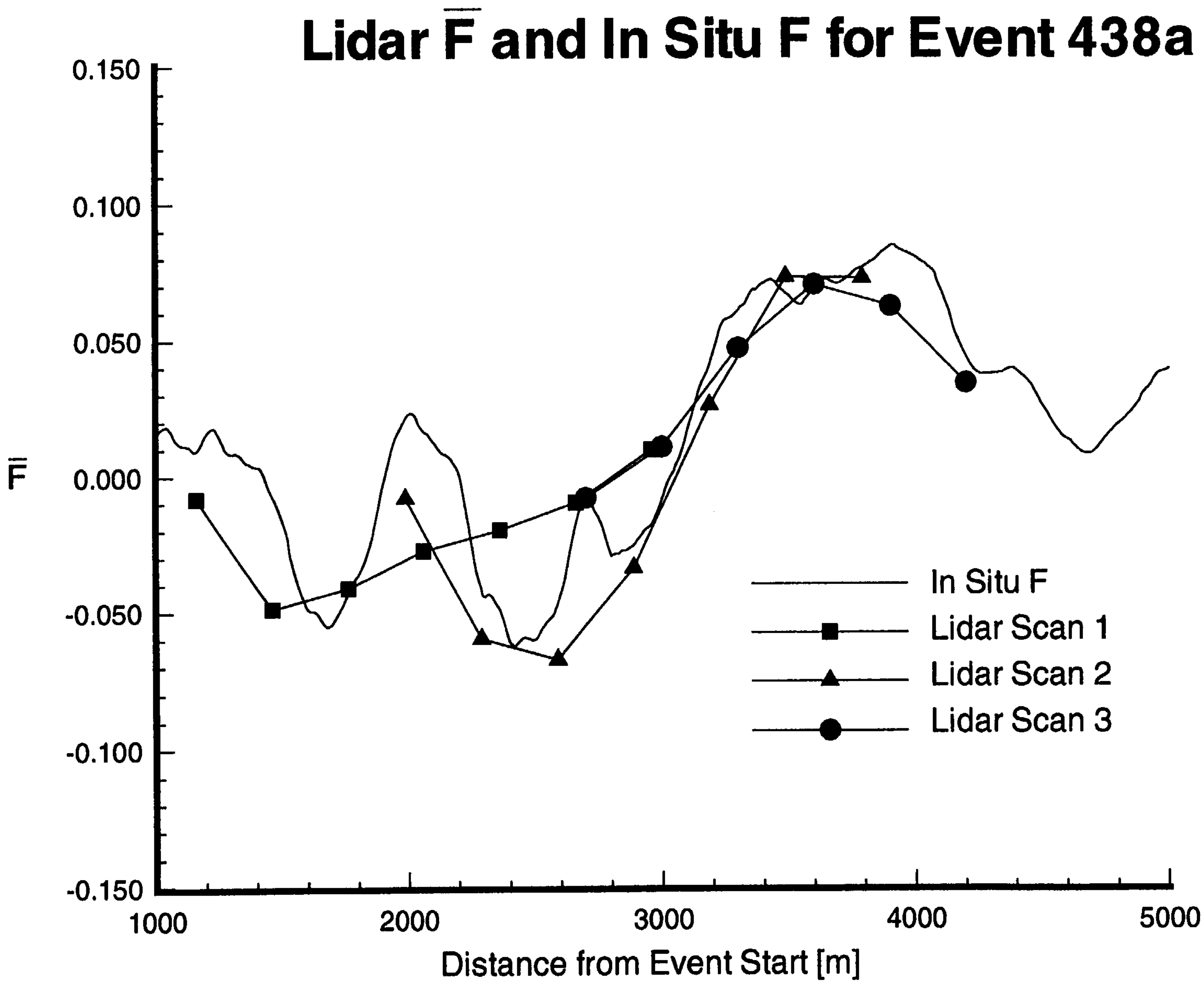
Lockheed Engineering and Sciences Co.,
NASA Langley Research Center

2 and 10 μm Lidar Systems

	CLASS - 10	CLASS - 2
Wavelength	10.591μm CO_2	2.0218 μm Th:YAG
Pulse Power	8 mJ	3.5 mJ
PRF	100	200
Range Resolution	300 m	75 m

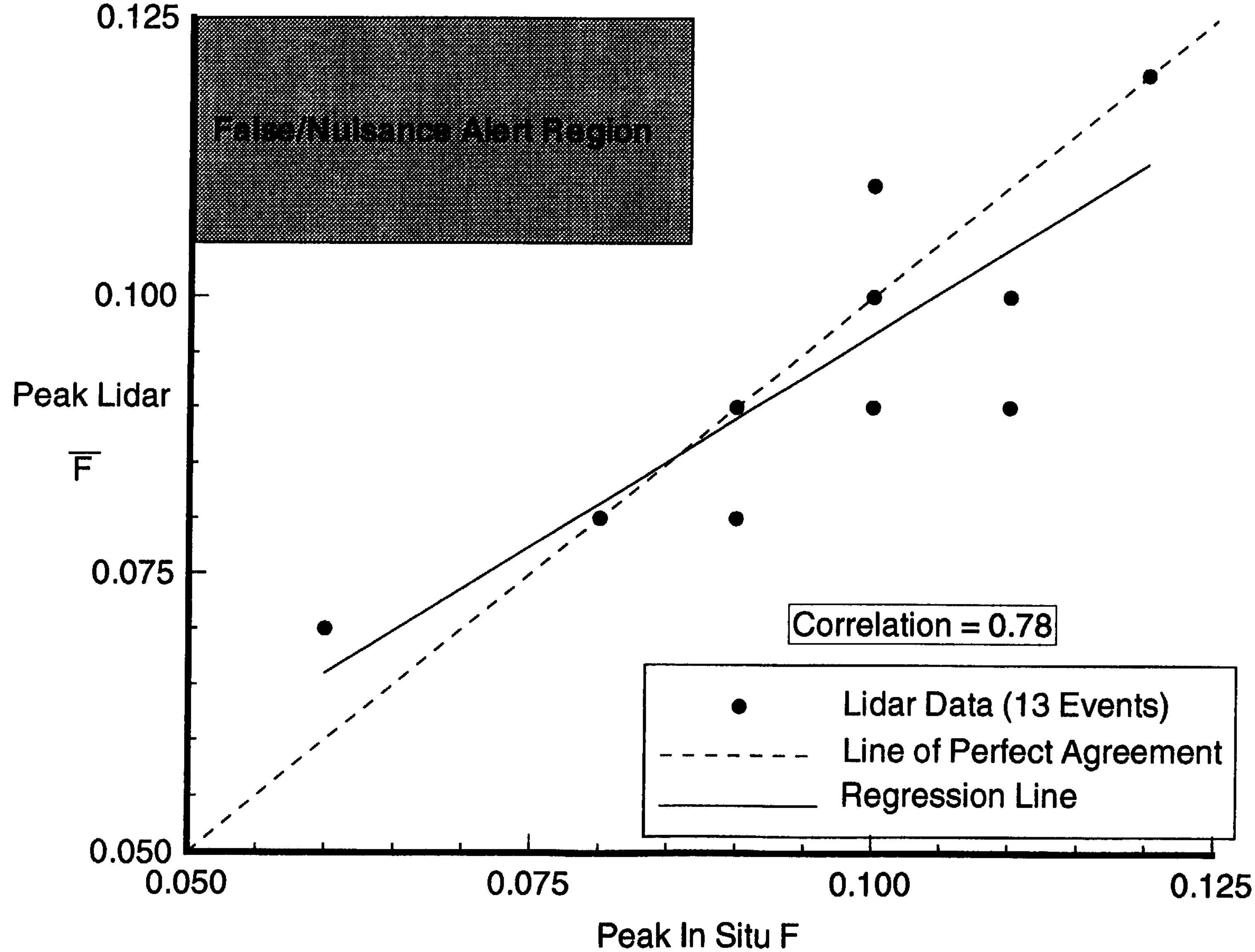


<u>CLASS - 10 Installation</u>

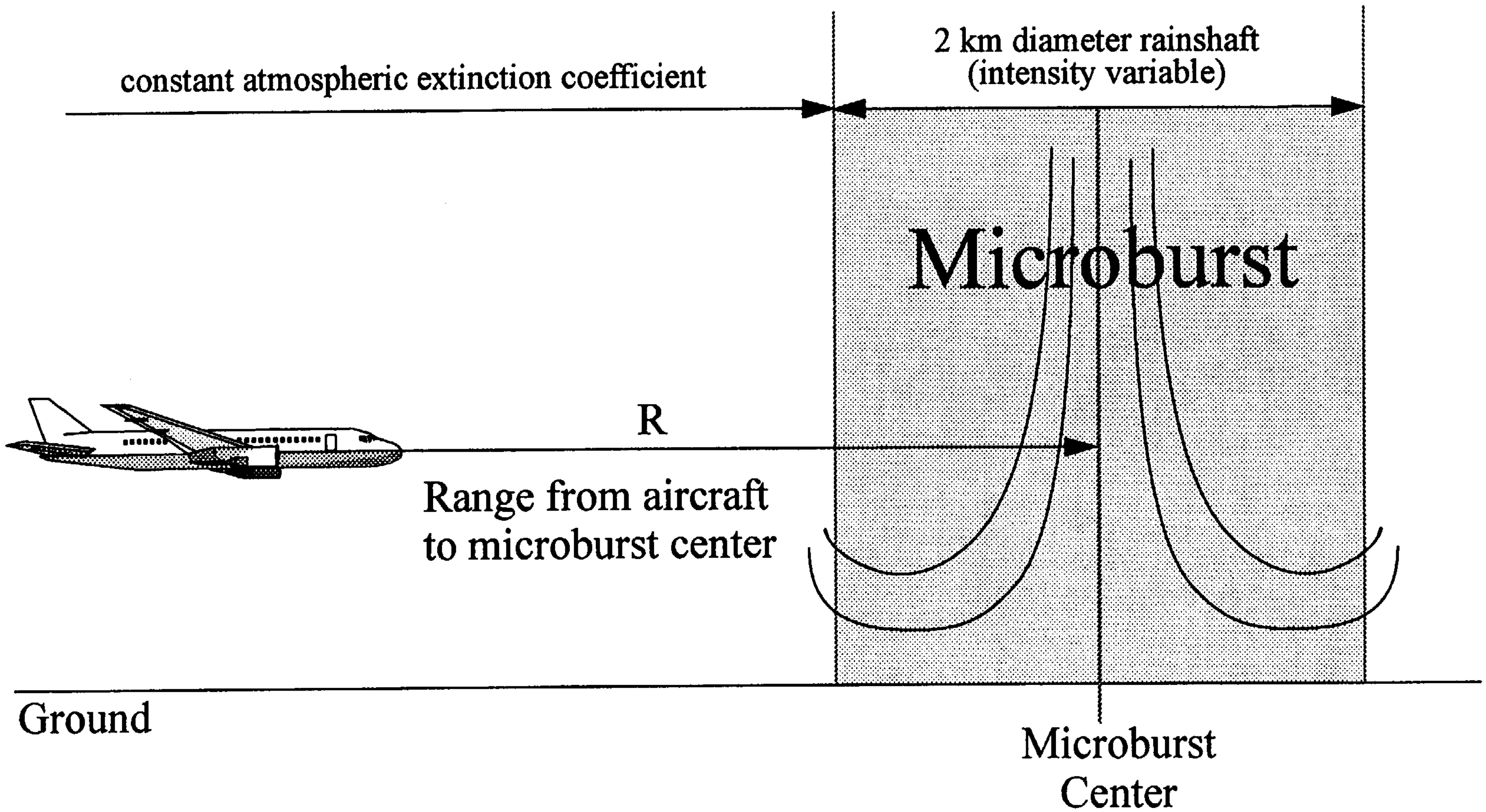


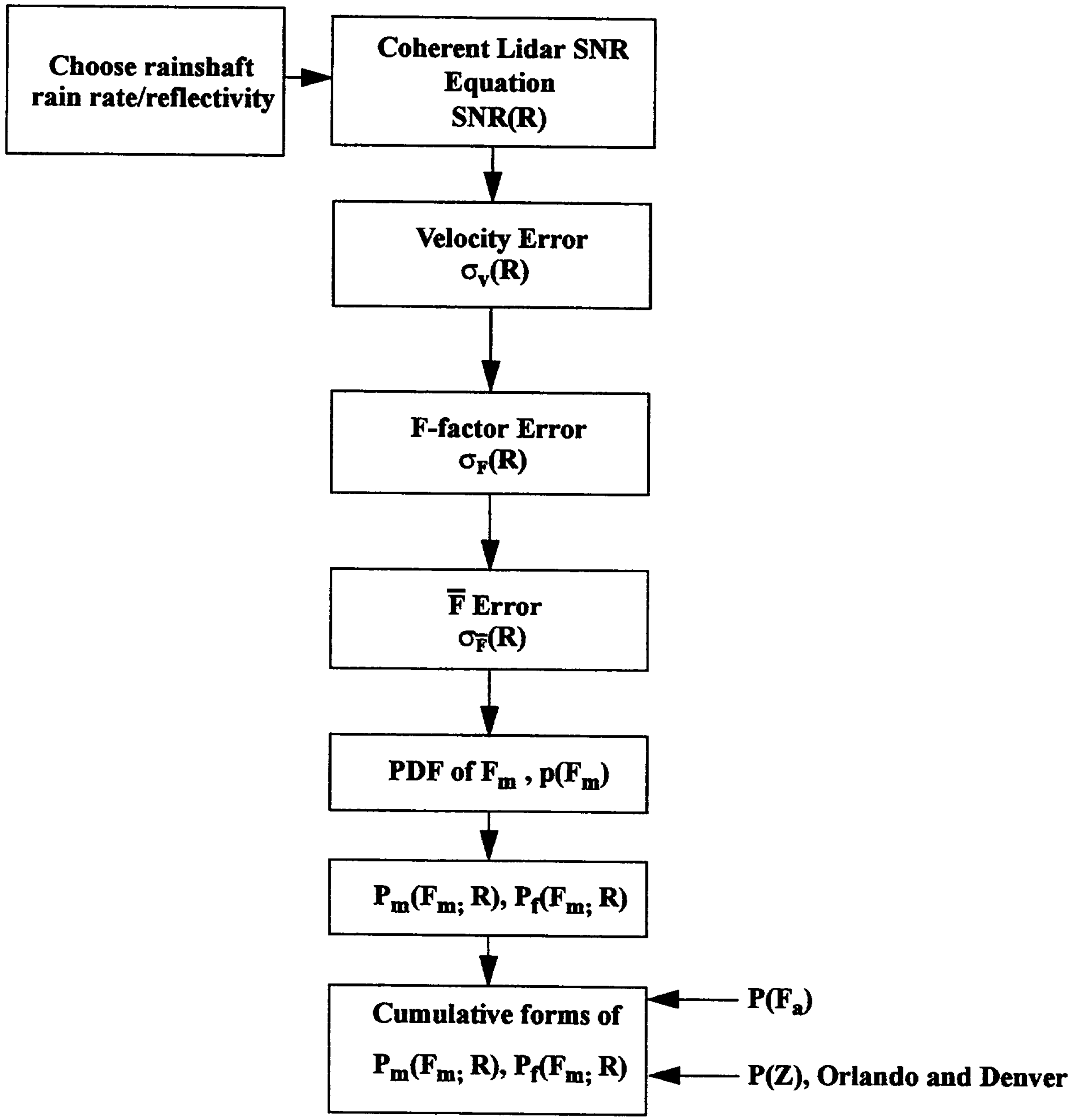
Lidar $\overline{F}$ and In Situ F for Event 438a
0.150
0.100
0.050
0.000
-0.050
-0.100
-0.150
$\overline{F}$
1000
2000
3000
4000
5000
Distance from Event Start [m]
In Situ F
Lidar Scan 1
Lidar Scan 2
Lidar Scan 3

Correlation of Lidar and In Situ Results



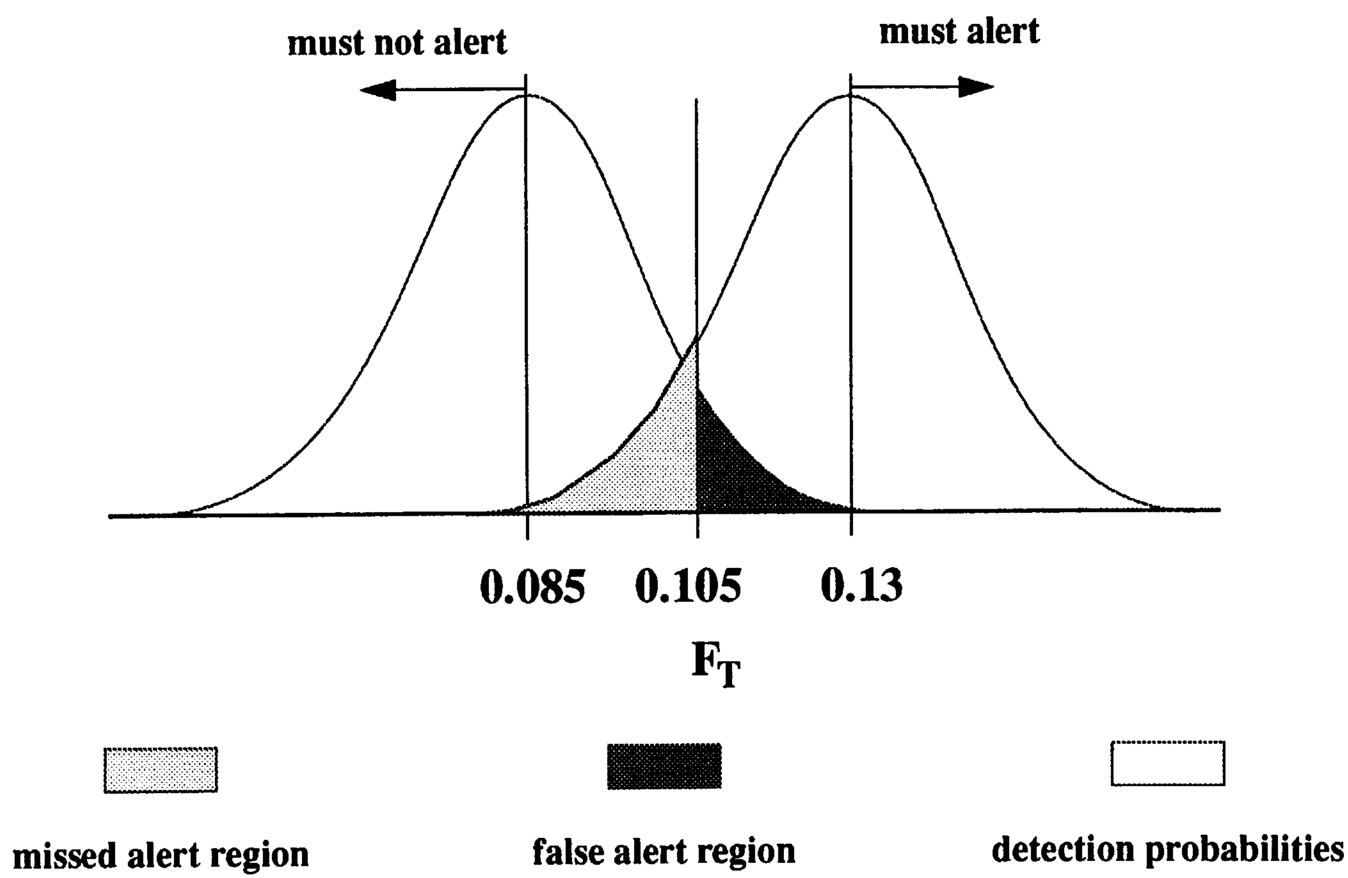
Lidar Wind Shear Detection Scenario



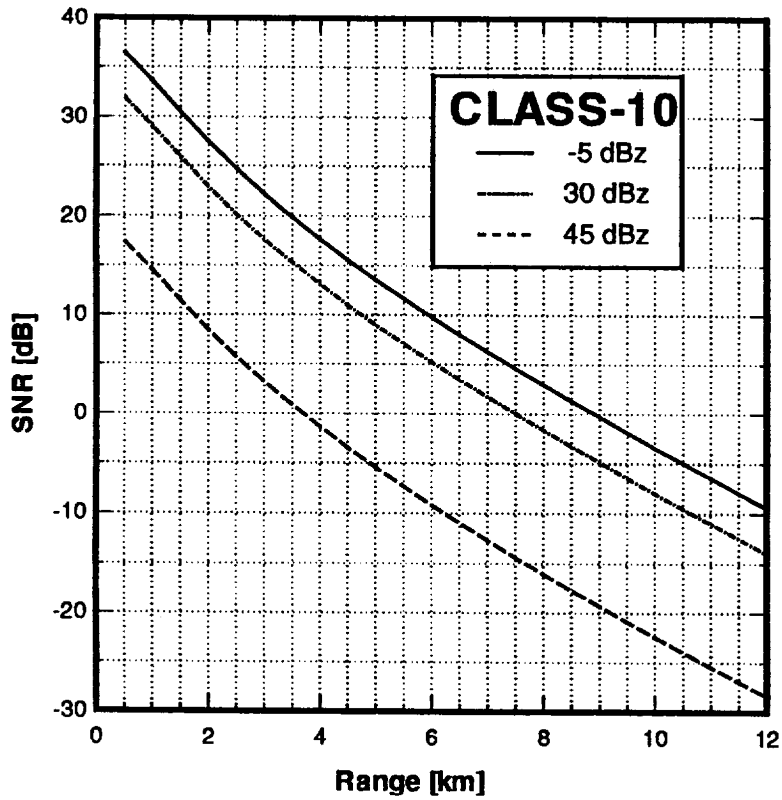


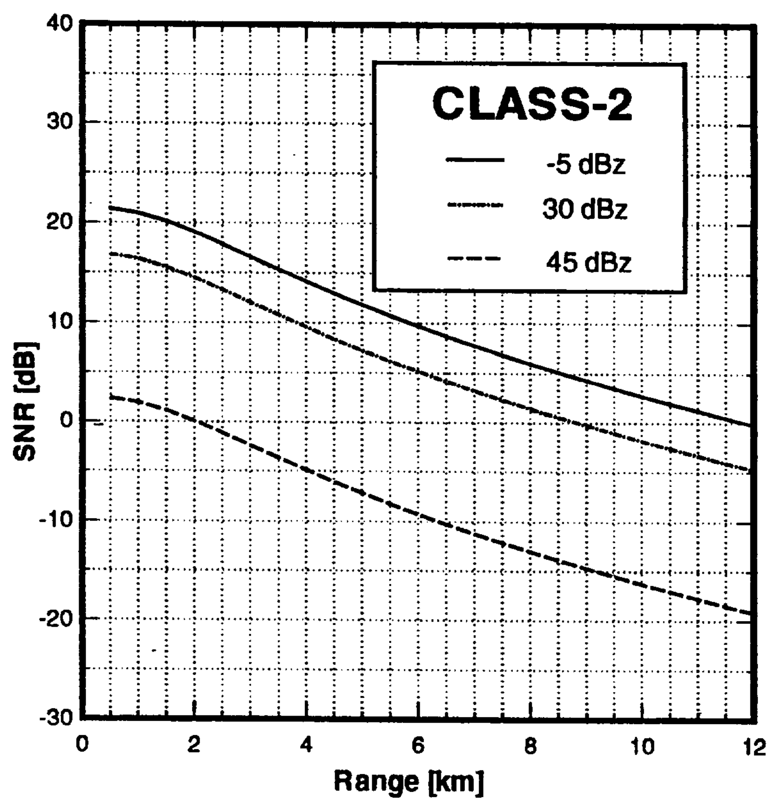
Detection Statistics Calculation Procedure

False and Missed Detection Probabilities

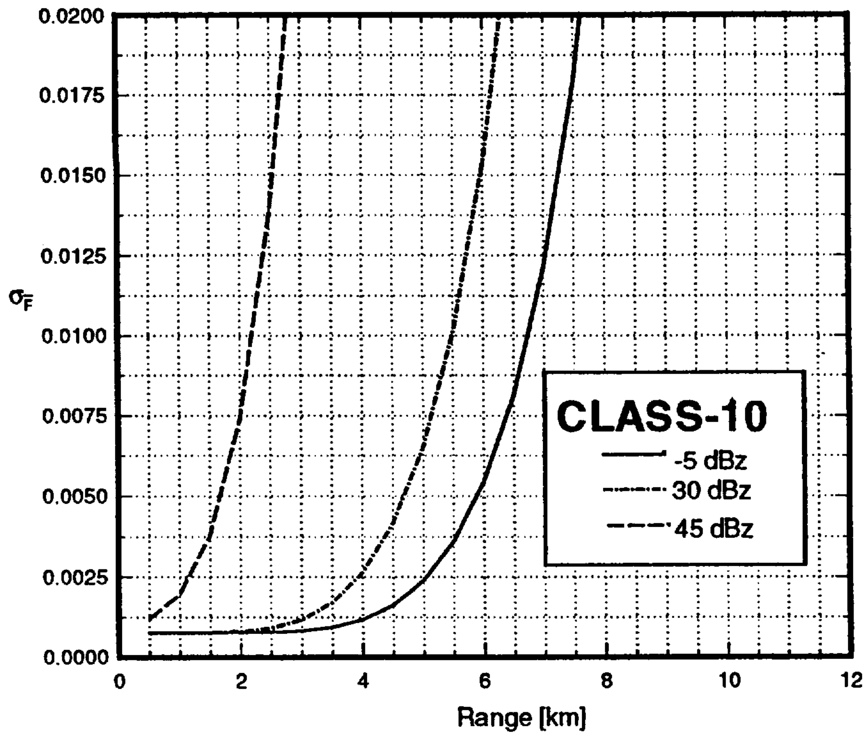


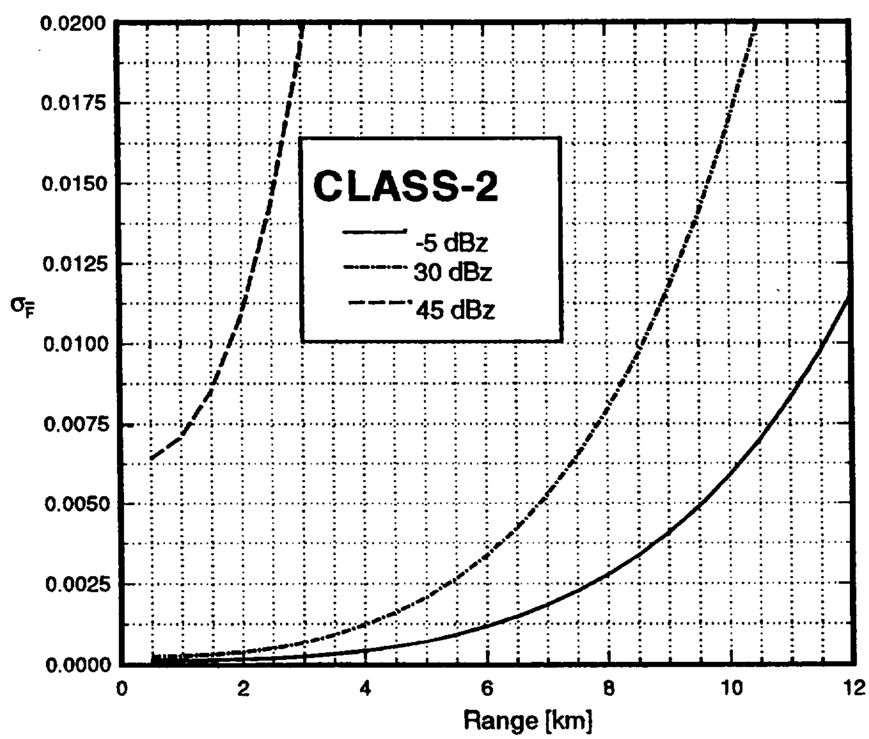
Signal-to-Noise Ratio Variation with Range



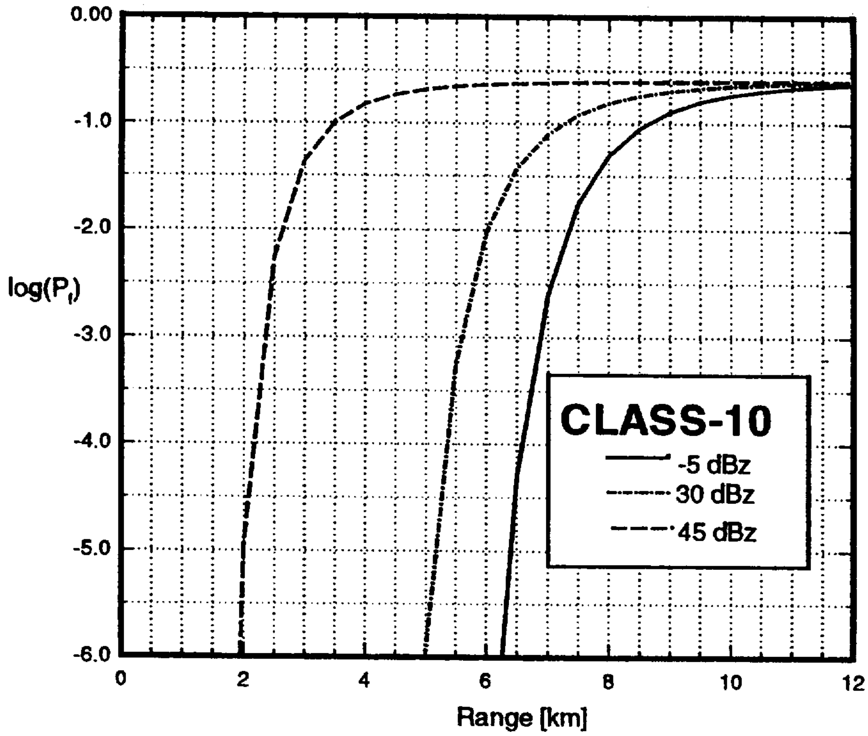


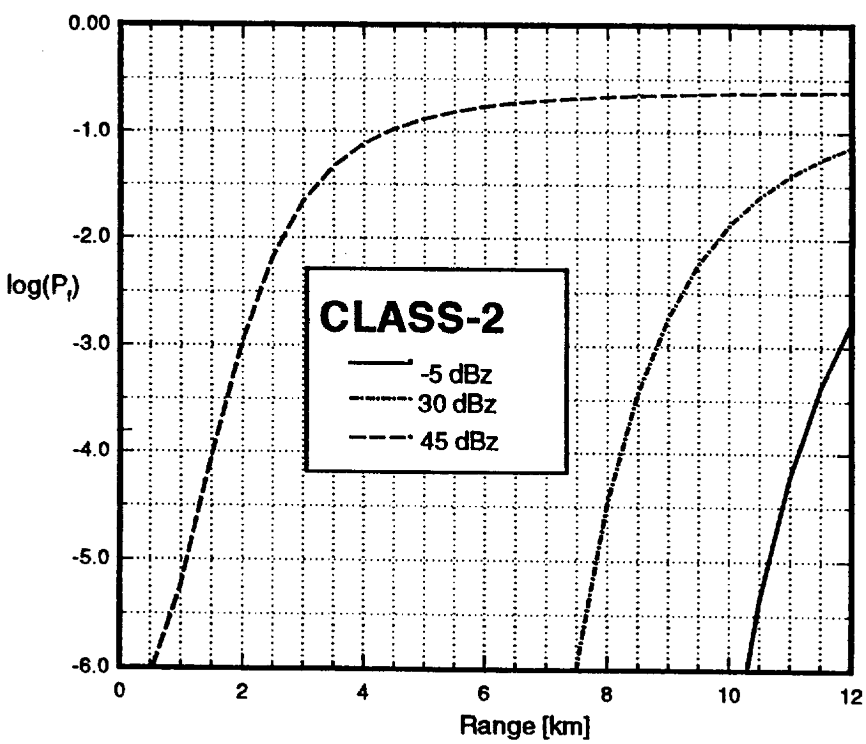
Measurement Error Standard Deviation of $\bar{F}$



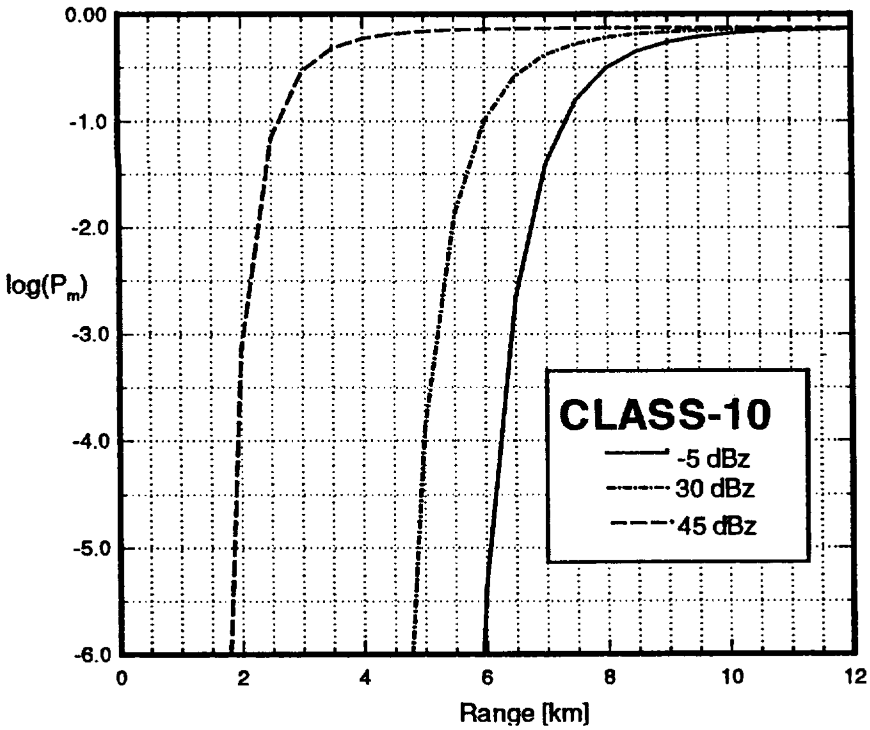


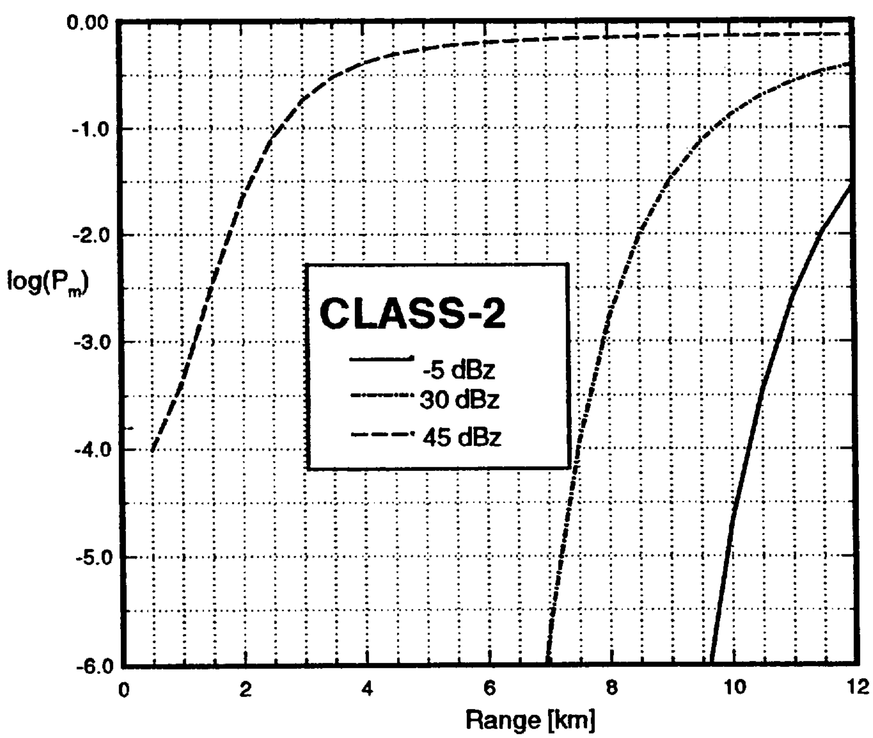
False Detection Probabilities of a 0.085 Hazard



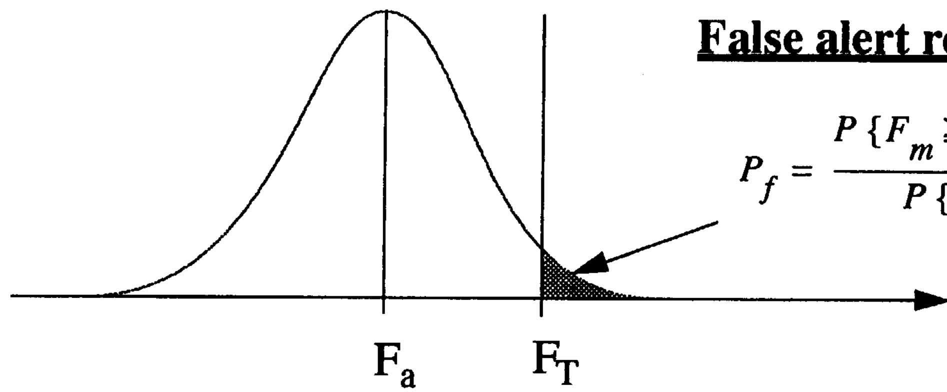


Missed Detection Probabilities of a 0.13 Hazard





Cumulative Probabilities

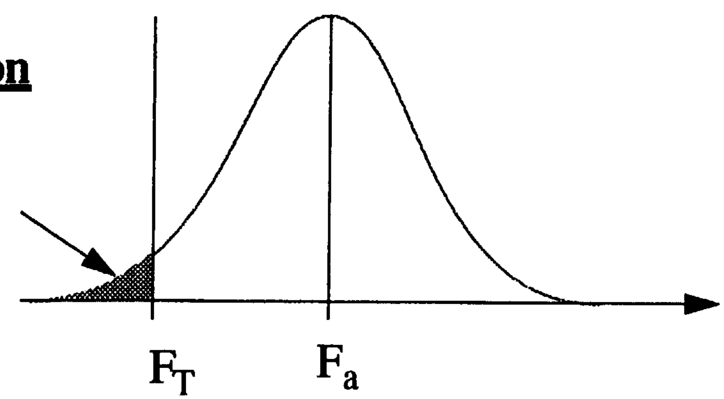


False alert region

$$P_f = \frac{P\{F_m \geq F_T; F_a \leq 0.085; -20 \leq Z \leq 60\}}{P\{F_a \leq 0.085; -20 \leq Z \leq 60\}}$$

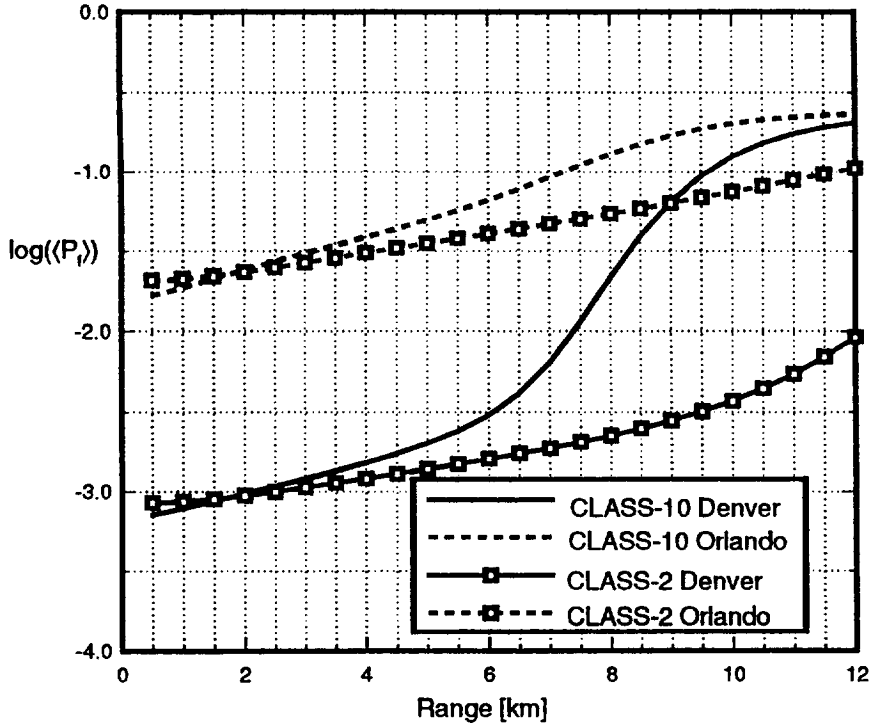
Missed alert region

$$P_m = \frac{P\{F_m < F_T; F_a \geq 0.13; -20 \leq Z \leq 60\}}{P\{F_a \geq 0.13; -20 \leq Z \leq 60\}}$$

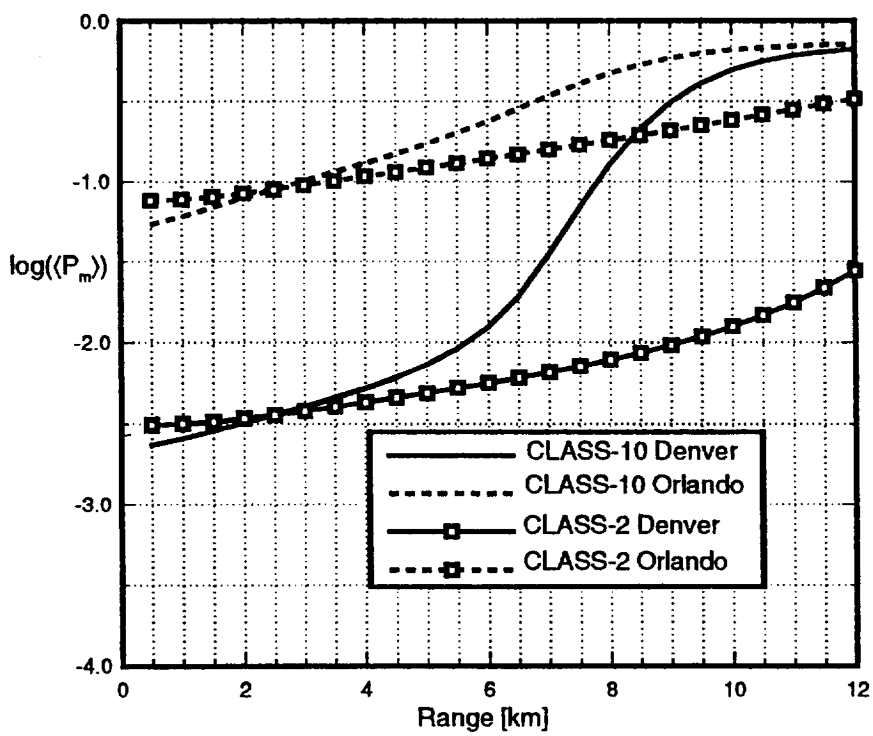


Cumulative Probabilities for Orlando and Denver

False Detection Probabilities



Missed Detection Probabilities



CLASS-10 Results Summary

- CLASS-10 performance in Denver environment was good; many shears detected and corroborated

- CLASS-10 performance in Orlando degraded due to environment and hardware difficulties

- Statistical technique of performance assessment applied with good results for CLASS-10; a useful tool in the design of future lidar systems.

CLASS-2 Performance Summary

- CLASS-2 promises improved range resolution over CLASS-10 (75 m vs 300 m).
- CLASS-2 promises better range performance than CLASS-10 - rain is still a problem.
- Little improvement in overall wind shear detection probabilities over CLASS-10: need improved detection algorithms.

Westinghouse MODAR 3000 Flight Test Results.

W. Patterson and M. Eide,
Westinghouse Electric Corp.

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MODAR 3000 FLIGHT TEST RESULTS

5th (and Final)

Combined Manufacturers' and Technologists'

Airborne Windshear Review Meeting

28 September, 1993

Westinghouse ESG
Walt Patterson
Bruce Mathews
Mike Eide

MODAR MILESTONES

- May 1989 — Initiate Boeing "MFS" Study
- April 1990 — Washington National Approach Clutter
- Jan. 1991 — Windshear Program Go
- June 1991 — BAC 1-11 Deployment at Orlando
- Sept. 1991 - Sept. 1992 — Continental Airlines A300
- Jan. 1992 — MODAR Production Go
- June - July 1992 — Orlando and Denver Deployments
- Mar. 1993 — Delivered First Windshear Capable Production Radar (180 Lot C-130)
- April 1993 — Request "BAC 1-11" Windshear STC
- Current (Sept. 1993)
  - Conformed MODAR 3000 Flights with Class D Radome
  - Bulk of Evidence From Simulation
  - Certification Data Submittal

FLIGHT TEST EXPECTATIONS

Development

Gather Data to Support Low Risk Production Configuration Decision

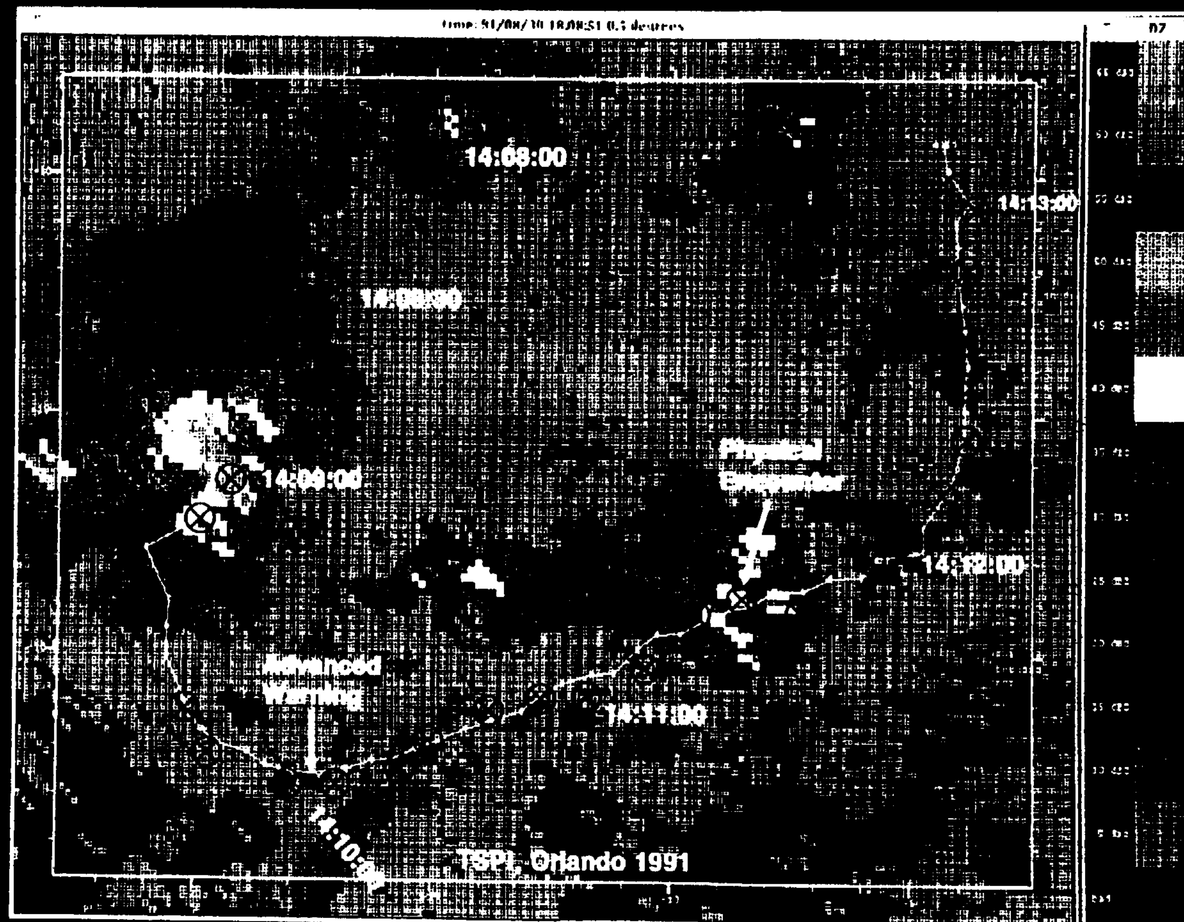
Conformed System STC

- Provide Evidence which Verifies Windfield Measurement Expectations
- Provide Recorded Clutter and Navigation Data to the Simulation

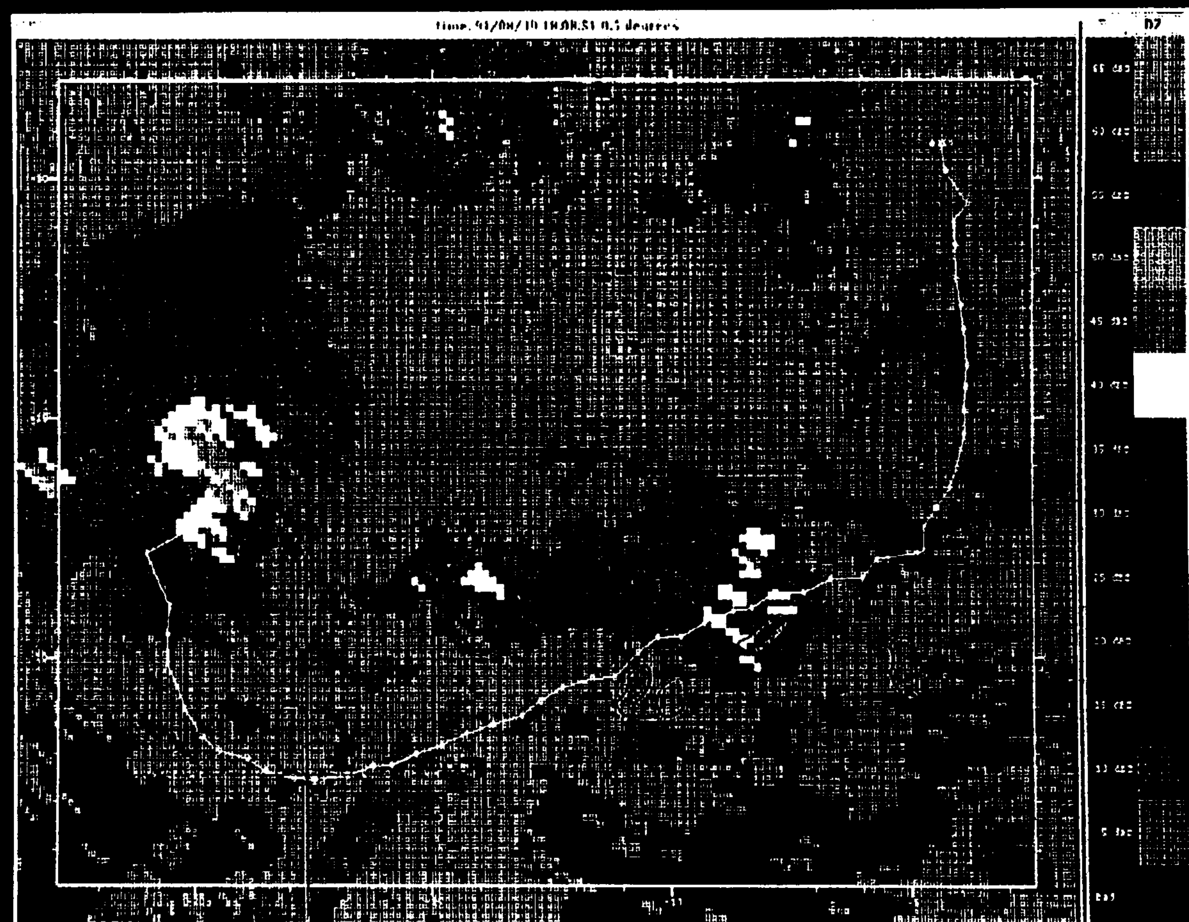
MODAR-3000 HIGH INTEGRITY PERFORMANCE

Development		
Analysis	[Noise Limited and Estimated Clutter Residue]	Radar Range Equation Analytic Expectations
Flight Wash. National Orlando/Denver Continental A/L	[Windfield Activity Clutter Record]	Separate Verification of Windfield Detection and False Alert
Simulation	[Combine Windfield, Clutter and Approach/Takeoff Geometry]	Expectations Freeze Production Parameters
Certification (Conformed System STC)		
Analysis	[Production Parameter]	Missed Hazard Nuisance Alert False Alert Unannunciated Failure
Flight	[Validated Windfield Measuremen Clutter/Environment Record]	Support Analysis and Simulation
Simulation	[Bulk of Windshear Hazard Alert Evidence]	FAA Hazard Alert Test Cases

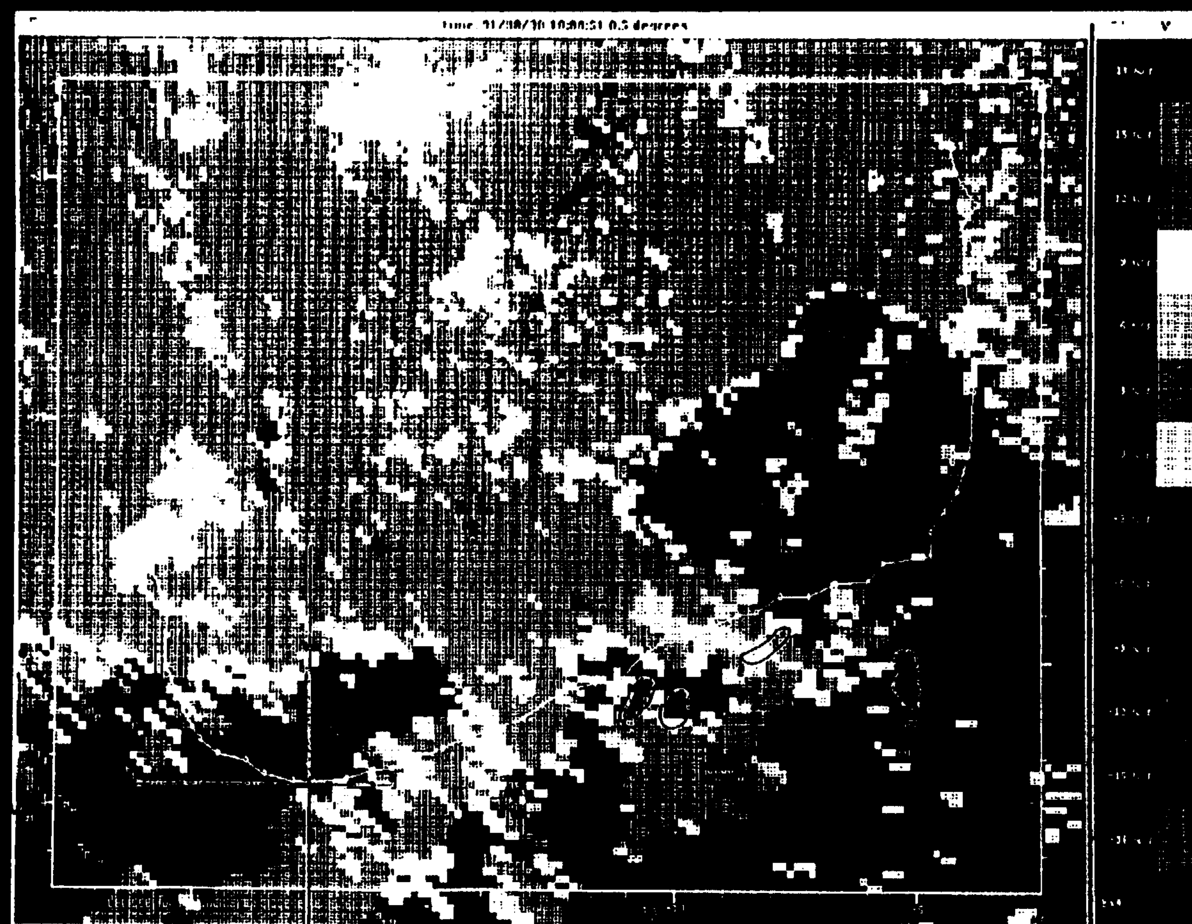
Westinghouse TSPI Overlay With TDWR Transponder Location on Reflectivity (dBz) Map (28-Aug-91, 18:08:51 Zulu)



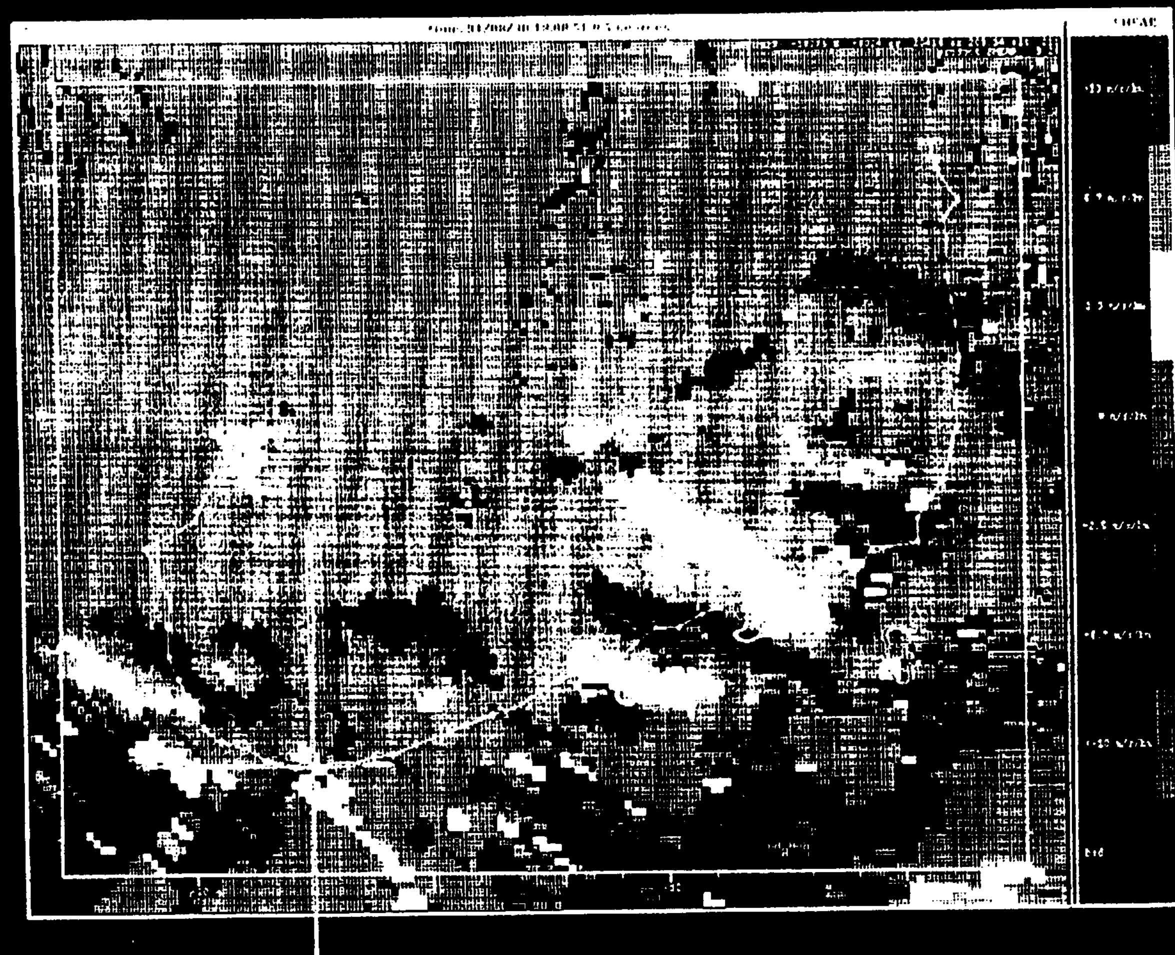
Comparison of Westinghouse Hazard Map Display (14:10:04) With TDWR Reflectivity (dBz) at (28-Aug-91, 18:08:51 Zulu)



Comparison of Westinghouse BAC 1-11 Hazard Display (14:10:04) With TDWR Doppler Velocity Map (28-Aug-91, 18:08:51 Zulu)

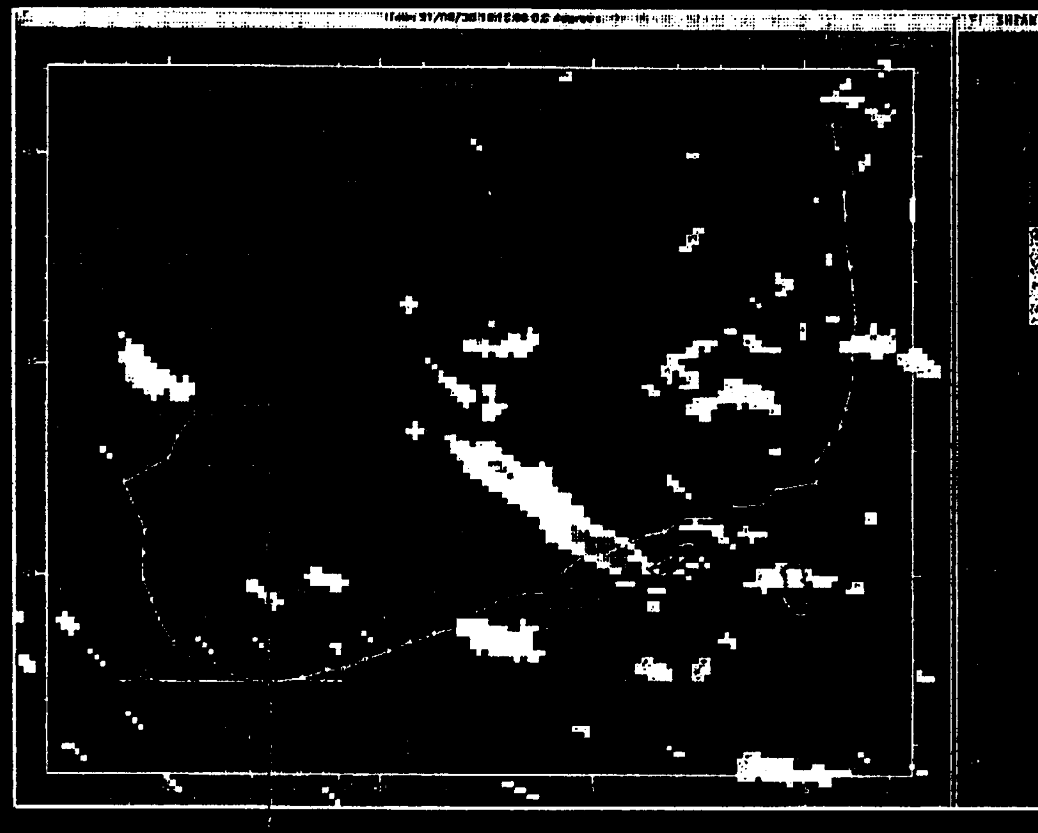


Comparision of Westinghouse BAC 1-11 Display (14:10:04) With TDWR Hazard Map (28-Aug-91, 18:08:51 Zulu)

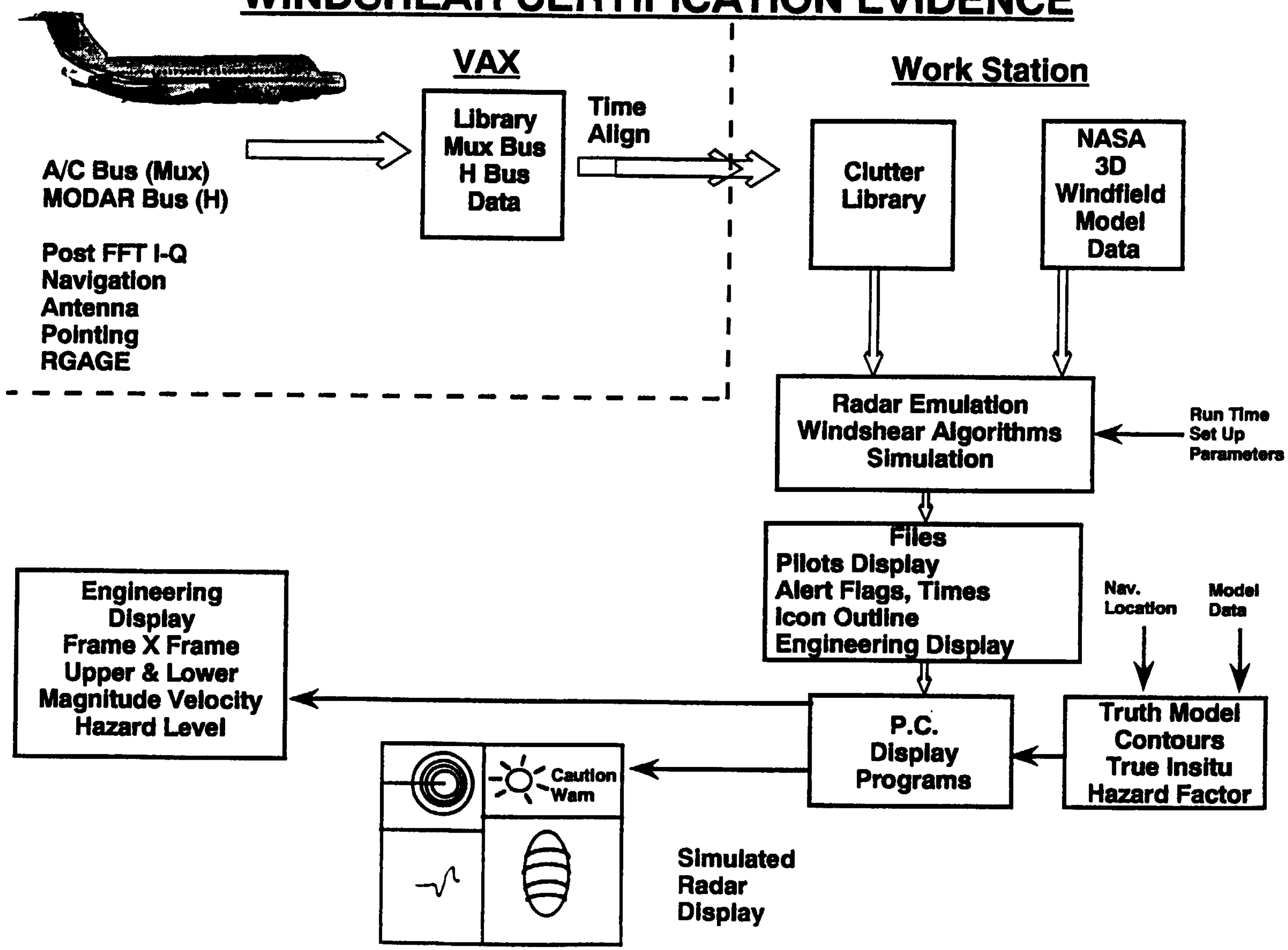


Comparision of Westinghouse Hazard Map Display With TDWR Reflectivity (dBz) at (28-Aug-91, 18:15:00 Zulu)

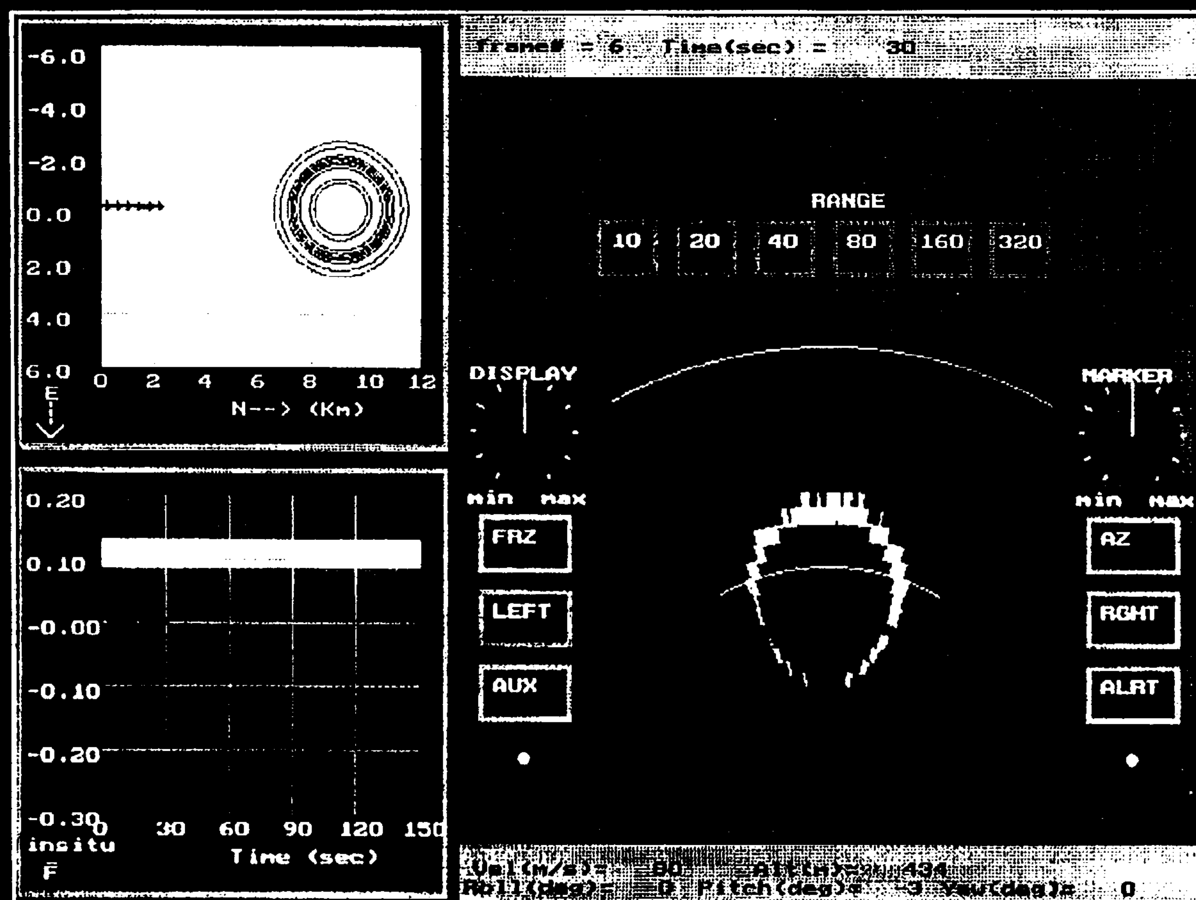
Comparision of Westinghouse Hazard Display (14:10:04) With TDWR Hazard Map (28-Aug-91, 18:15:00 Zulu)



WINDSHEAR CERTIFICATION EVIDENCE



DFW 8/2/85 as Viewed by MODAR



Westinghouse

MODAR-3000 FLIGHT RESULTS

- **Provided Data Leading to Conformed MODAR-3000 Production Configuration**
  - **Continental Airline Airbus - No False Alert**
  - **TDWR Confirmed 0 dBz Event**

- **Provided Evidence for MODAR-3000
Forward Looking Windshear Air Worthiness STC
Certification Data Package**

- **STC Application with** CLASS D **Radome**

  Low Missed Hazard Alert (Safety Enhancement)
  Low Nuisance/False Alert (Operational Cost)

- **STC Flights With FAA 27, 28 September 1993**

NASA's Airborne Doppler Radar for Detection of Hazardous Windshear.

E. Bracalente,
NASA Langley Research Center

NASA's AIRBORNE DOPPLER RADAR FOR DETECTION OF HAZARDOUS WIND SHEAR

Flight Results

EMEDIO M. BRACALENTE, STEVEN D. HARRAH, AND PHILIP R. SCHAFFNER
NASA LANGLEY RESEARCH CENTER
ANTENNA & MICROWAVE RESEARCH BRANCH
HAMPTON, VA 23681-0001

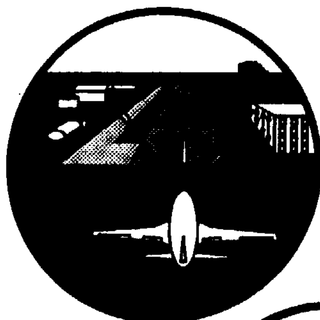
CHARLES L. BRITT
RESEARCH TRIANGLE INSTITUTE
LANGLEY PROGRAM OFFICE
HAMPTON, VA 23666-1339

OUTLINE

- Flight Program
- Hardware Description
- Processing Characteristics
- Performance Analysis
- Issues Addressed
- Leasons Learned
- Summary

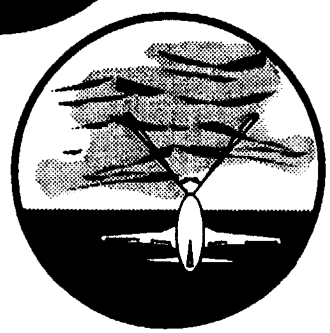
AIRBORNE WIND SHEAR RADAR

OBJECTIVES



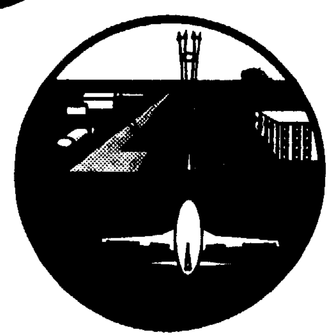
PHASE I

- Establish Comprehensive Ground Clutter Database
- Characterize Ground Clutter NRCS Statistics at Selected Urban Airports
  Philadelphia, PA (PHL)
  Denver, CO (DEN)
  Orlando, FL (MCO)



PHASE II

- Establish Radar Characteristics of Weather Targets (At Altitude NO Clutter)
- Characterize Airborne Radar Predictive Performance Using Ground Radar and In Situ Measurements from Limited Aircraft Storm Penetrations



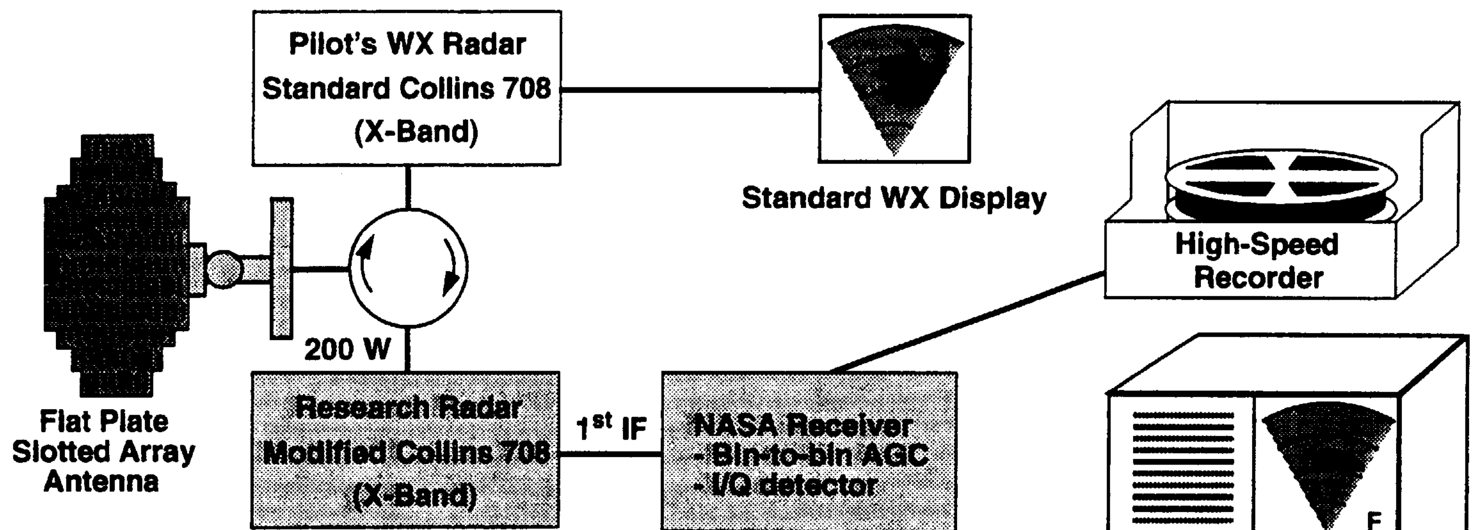
PHASE III

- Develop Processing Algorithms Necessary for Wind Shear Detection & Severity Estimation
- Evaluate Real-Time System's Predictive Performance
- Establish Minimum Operational Performance Standards for Commercial Systems

C-2.

AIRBORNE WIND SHEAR RADAR

BASIC LAYOUT



Beamwidth	3.5°
Ant. Gain:	34.6 dB
Polarization:	Linear (H/V)
Scan:	PPI/RHI
Stabilized:	Pitch/Roll

Pulse Width:	1 - 8μs
PRF:	1 - 10 kHz
Sys. Gain:	123.5 dB
Dyn. Range:	100 dB
MDS:	-132 dBW (@ 1μs)

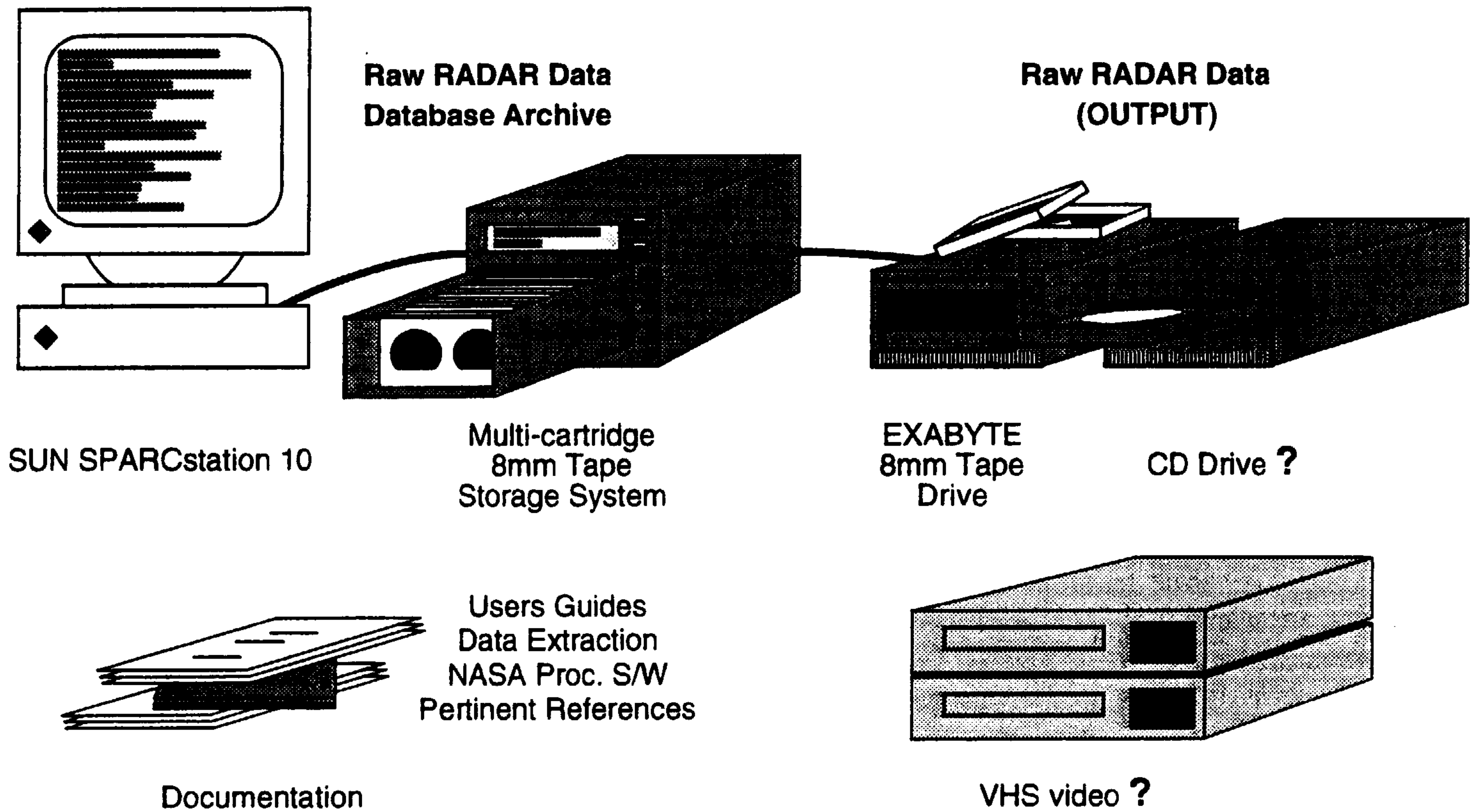
AIRBORNE WIND SHEAR RADAR

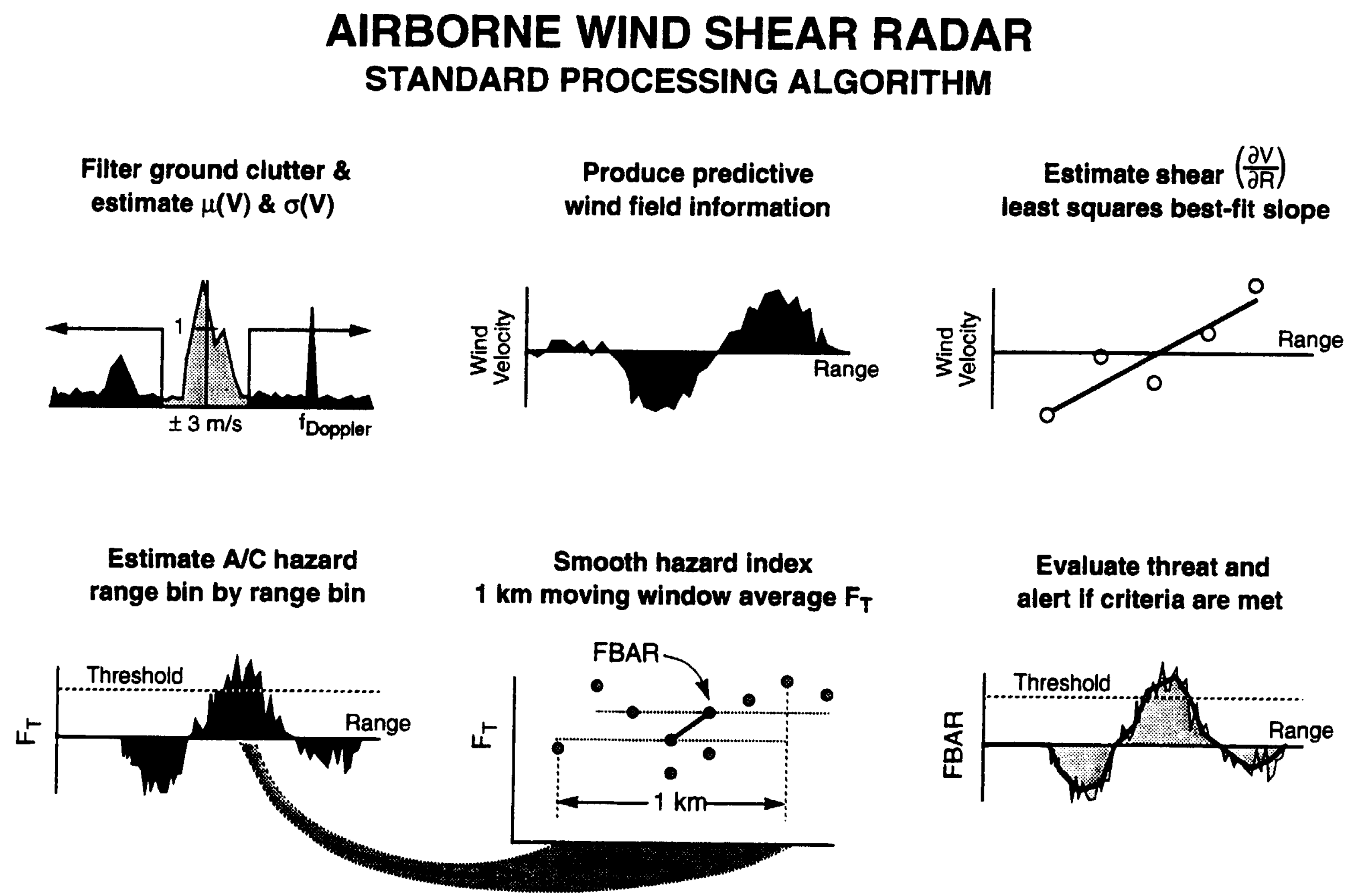
FLIGHT EXPERIMENT

Location	A/C Flights	Data Runs	Clutter Runs	Weather Runs	Processed Data (GB)	A/C Wind Shear Encounter (In Situ $F_T > 0.05$)		Airborne Radar Detection
						$F_T < 0.10$	$F_T > 0.10$	
Local	7	147	105	10	1.6	0	0	1
PHL	2	46	46	0	0.5	0	0	0
MCO	19	253	32	221	2.7	43	12	70
DEN	19	215	81	134	2.4	15	6	27
STL	4	4	4	0	0.02	0	0	0
DCA	1	1	1	0	0.005	0	0	0
Total	52	666	269	365	7.2	58	18	98

- First consistent, multi-parameter, extremely high-incident angle ground clutter database
- Large database allows statistical analysis of radar returns from a variety of targets
- I/Q dataset allows reprocessing with user-defined processing algorithms

→ • Nearly 100 microburst observation by airborne radar & 76 aircraft penetrations


Raw RADAR Data
Database Archive
Raw RADAR Data
(OUTPUT)
SUN SPARCstation 10
Multi-cartridge
8mm Tape
Storage System
EXABYTE
8mm Tape
Drive
CD Drive ?
Users Guides
Data Extraction
NASA Proc. S/W
Pertinent References
Documentation
VHS video ?


AIRBORNE WIND SHEAR RADAR
STANDARD PROCESSING ALGORITHM
Filter ground clutter & estimate μ(V) & σ(V)
1
± 3 m/s
$f_{Doppler}$
Produce predictive wind field information
Wind Velocity
Range
Estimate shear $\left(\frac{\partial V}{\partial R}\right)$ least squares best-fit slope
Wind Velocity
Range
Estimate A/C hazard range bin by range bin
F_T
Threshold
Range
Smooth hazard index 1 km moving window average F_T
FBAR
F_T
1 km
Evaluate threat and alert if criteria are met
FBAR
Threshold
Range

F-FACTOR CALCULATION

Measured	$F_H = \frac{V_G}{g} \times \frac{\partial V_R}{\partial R}$	
Calculated	$F_V = F_H \left(2 \frac{g}{V_G} \frac{ALT}{V_A} \right)$	for $F_H > 0$
Threshold	$F_T = F_H + F_V$	

$F_H \equiv$ **Horizontal component of hazard index**

$F_V \equiv$ **Vertical component of hazard index**

$\frac{\partial V_R}{\partial R} \equiv$ **Spatial shear of radially measured wind field**

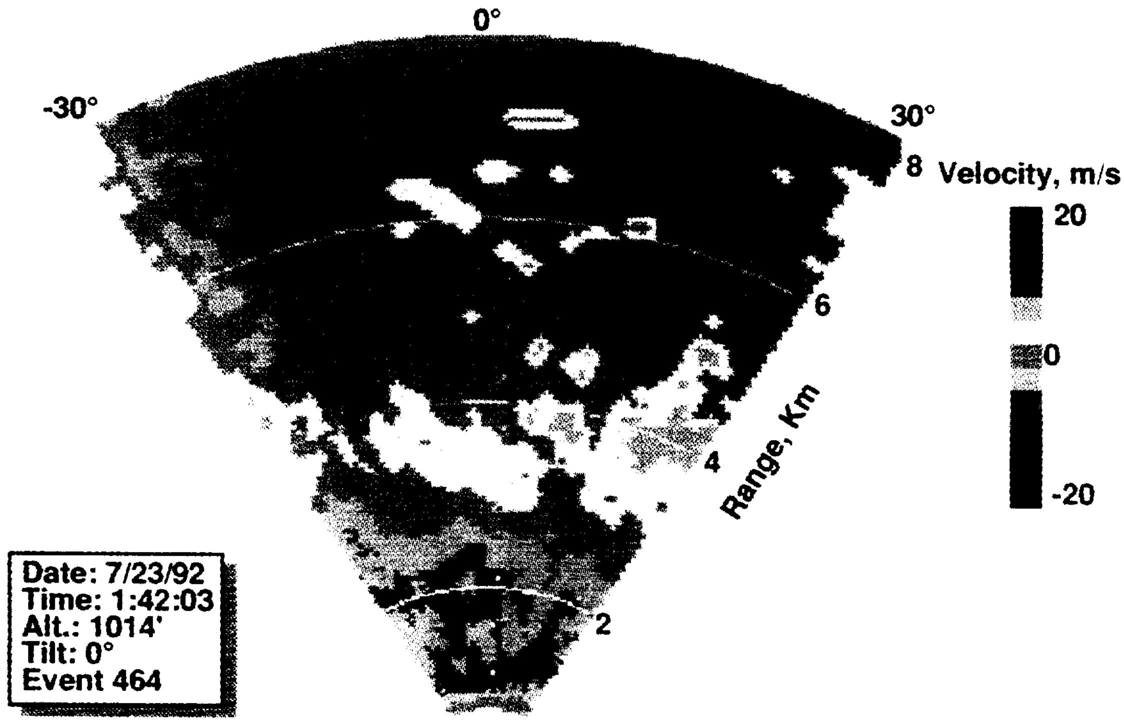
$V_A \equiv$ **Aircraft airspeed**

$V_G \equiv$ **Aircraft groundspeed**

$ALT \equiv$ **Aircraft altitude (AGL)**

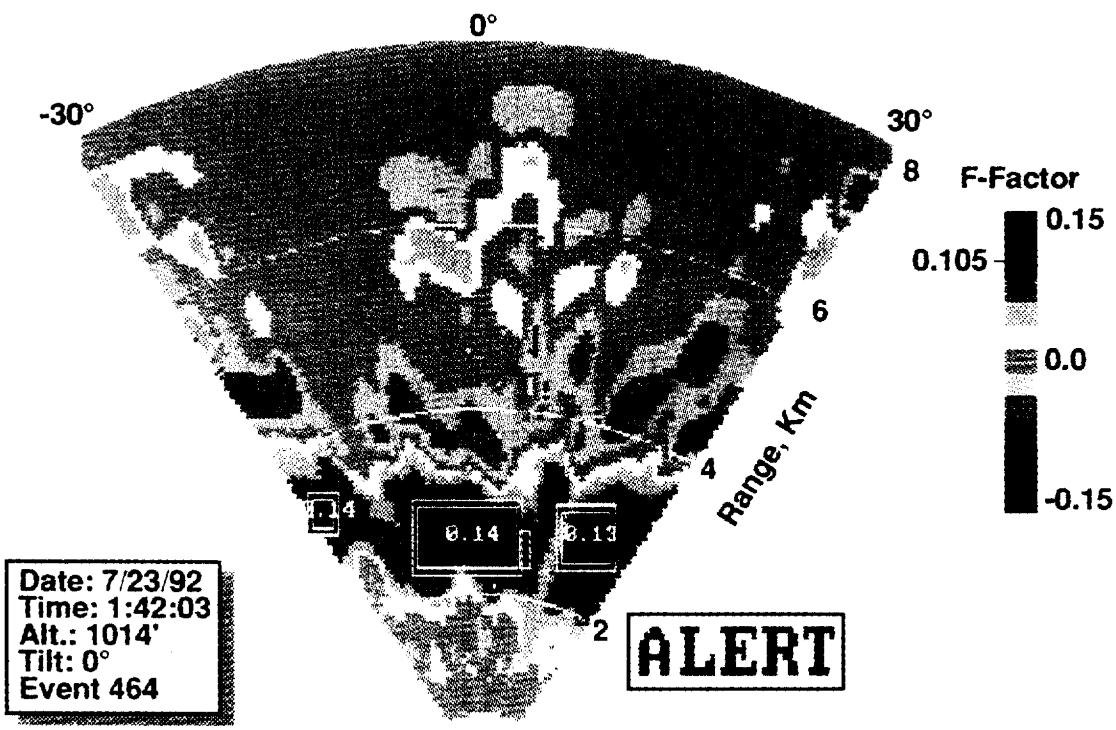
DRY MICROBURST DETECTION

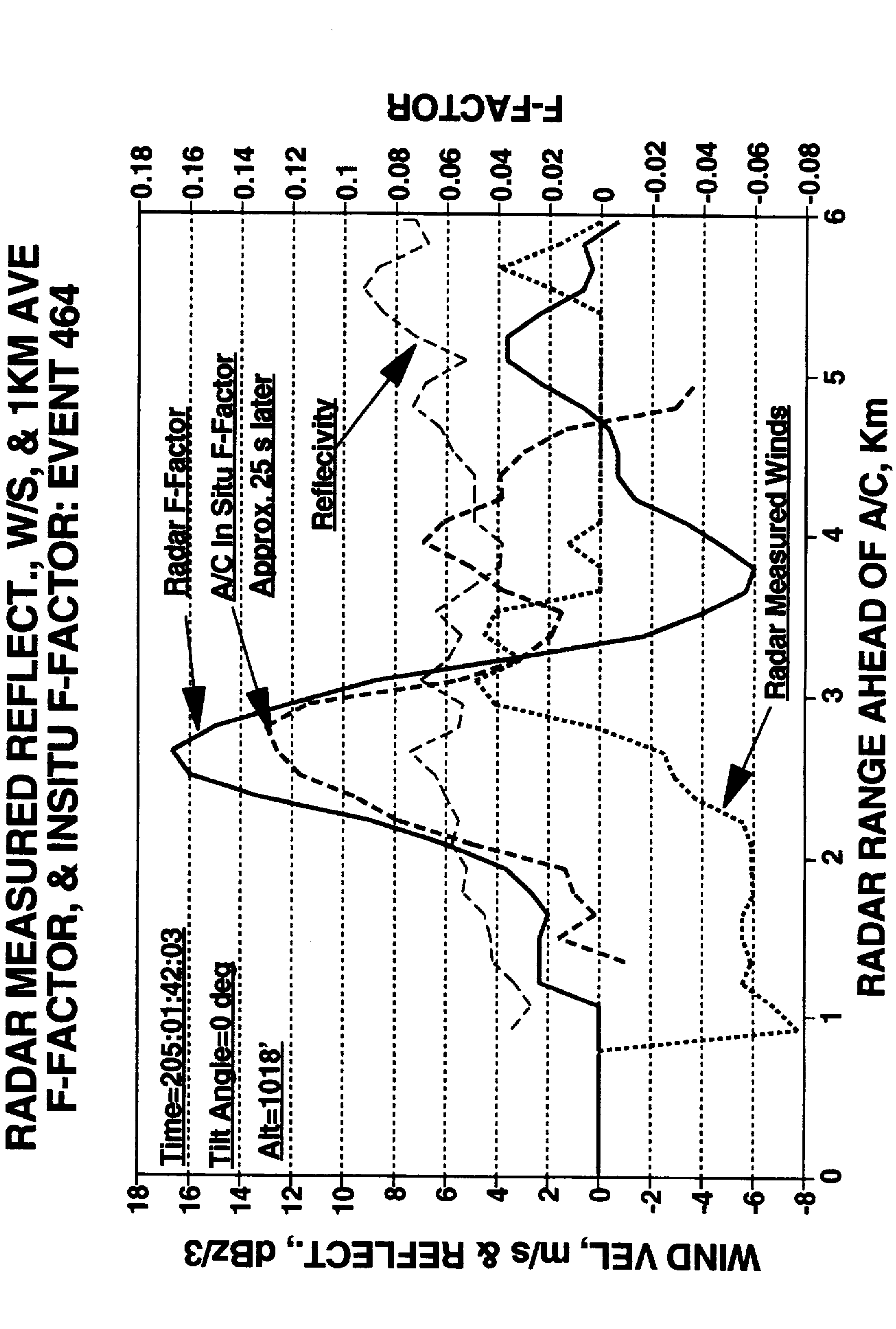
Radar Detected Dry Microburst, event 464, Denver CO, 25 sec. Before A/C Penetration. Display of measured wind speed. White Dots Indicate A/C Track.



DRY MICROBURST DETECTION

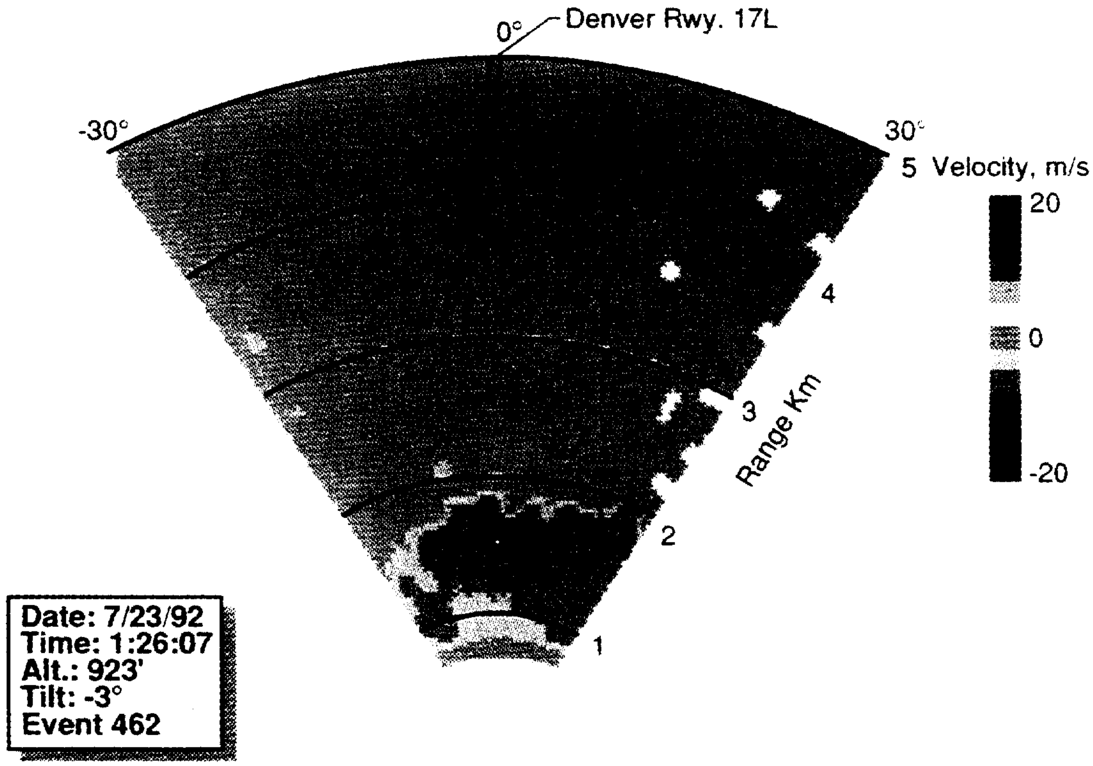
Radar Detected Dry Microburst, event 464, Denver CO, 25 sec. Before A/C Penetration. Display of 1 km average F-factor, showing multiple alert areas. White Dots Indicate A/C Track.




RADAR MEASURED REFLECT., W/S, & 1KM AVE
F-FACTOR, & INSITU F-FACTOR: EVENT 464
Time=205:01:42:03
Tilt Angle=0 deg
Alt=1018'
Radar F-Factor
A/C In Situ F-Factor
Approx. 25 s later
Reflecivity
Radar Measured Winds
WIND VEL, m/s & REFLECT., dBz/3
F-FACTOR
RADAR RANGE AHEAD OF A/C, Km
18
16
14
12
10
8
6
4
2
0
-2
-4
-6
-8
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
0
1
2
3
4
5
6

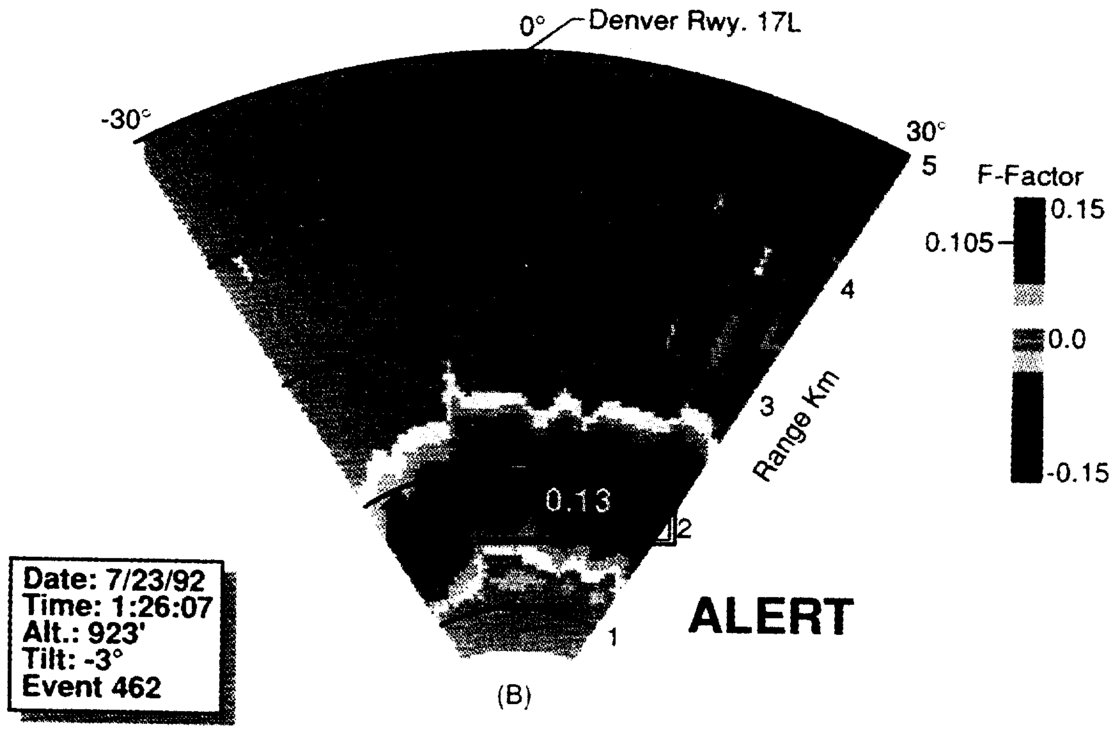
DRY MICROBURST DETECTION

Radar Detected Dry Microburst, event 462, Denver CO, 15 sec. Before A/C Penetration. Display of measured wind speed. White Dots Indicate A/C Track.



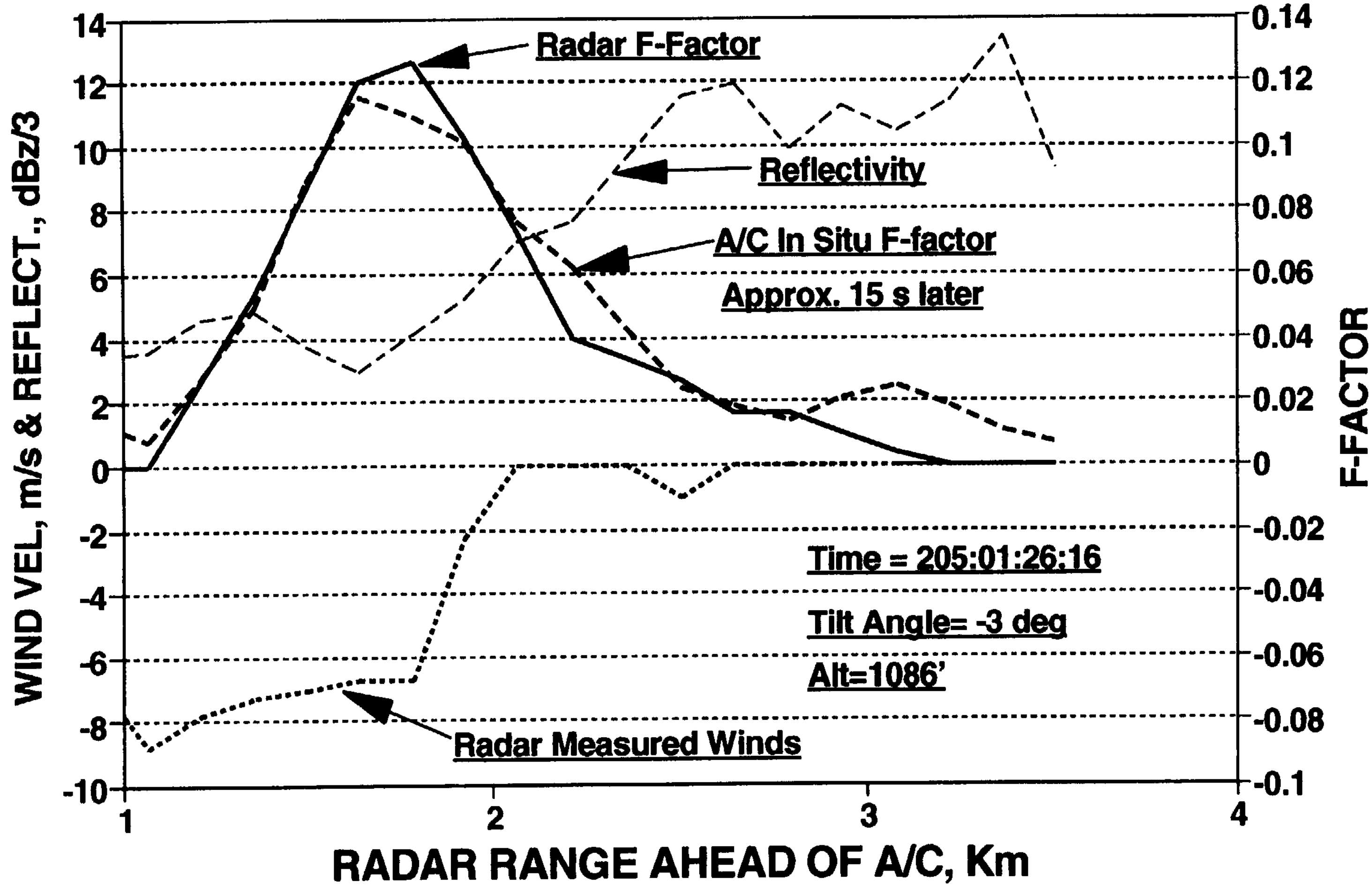
DRY MICROBURST DETECTION

Radar Detected Dry Microburst, event 462, Denver CO, 15 sec. Before A/C Penetration. Display of 1 km average F-factor, showing alert area. White Dots Indicate A/C Track.



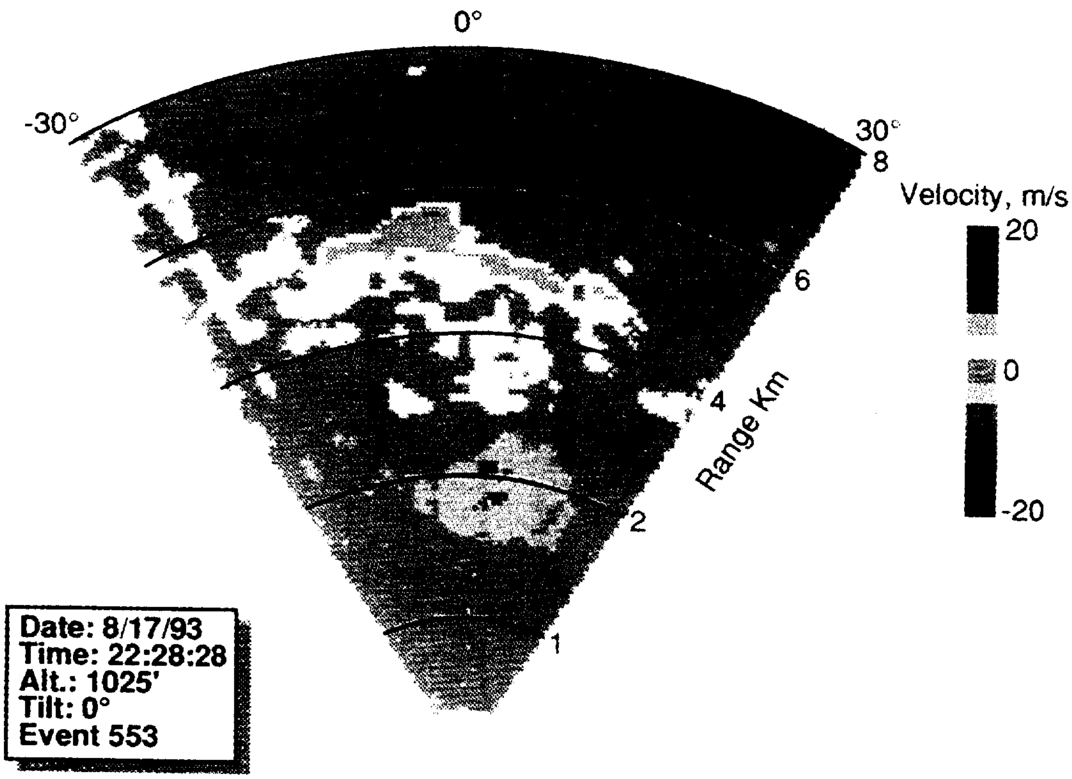
(B)

RADAR MEASURED REFLECT., W/S, & 1KM AVE F-FACTOR, & INSITU F-FACTOR: EVENT 462



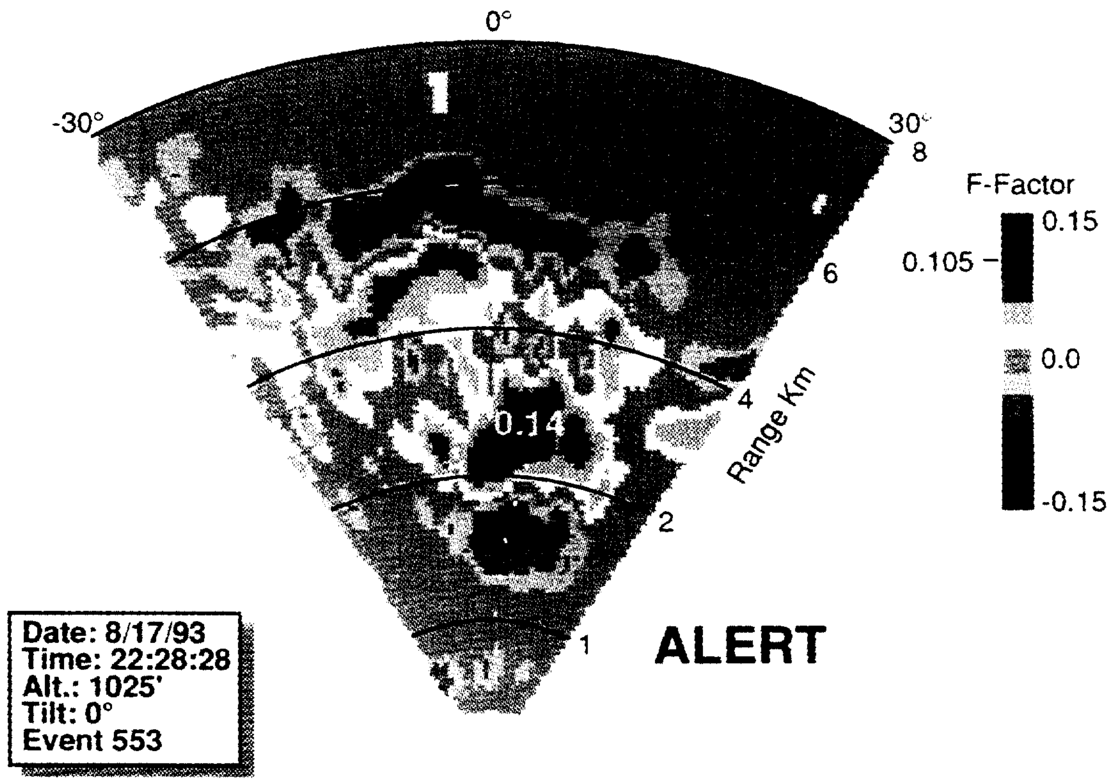
WET MICROBURST DETECTION

Radar Detected Wet Microburst, event 553, Orlando FL, 37 sec. Before A/C Penetration. Display of measured wind speed. White Dots Indicate A/C Track.

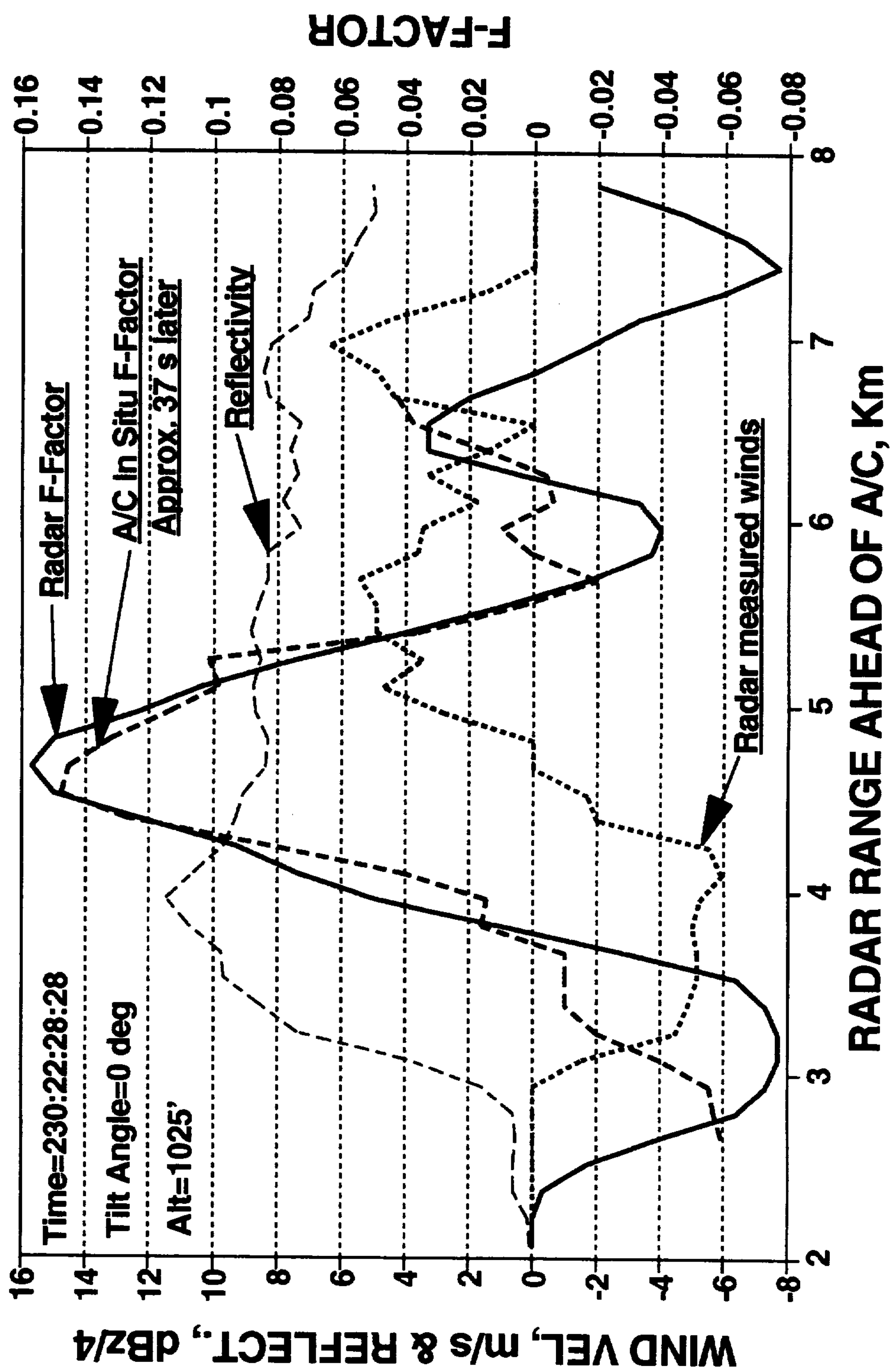


WET MICROBURST DETECTION

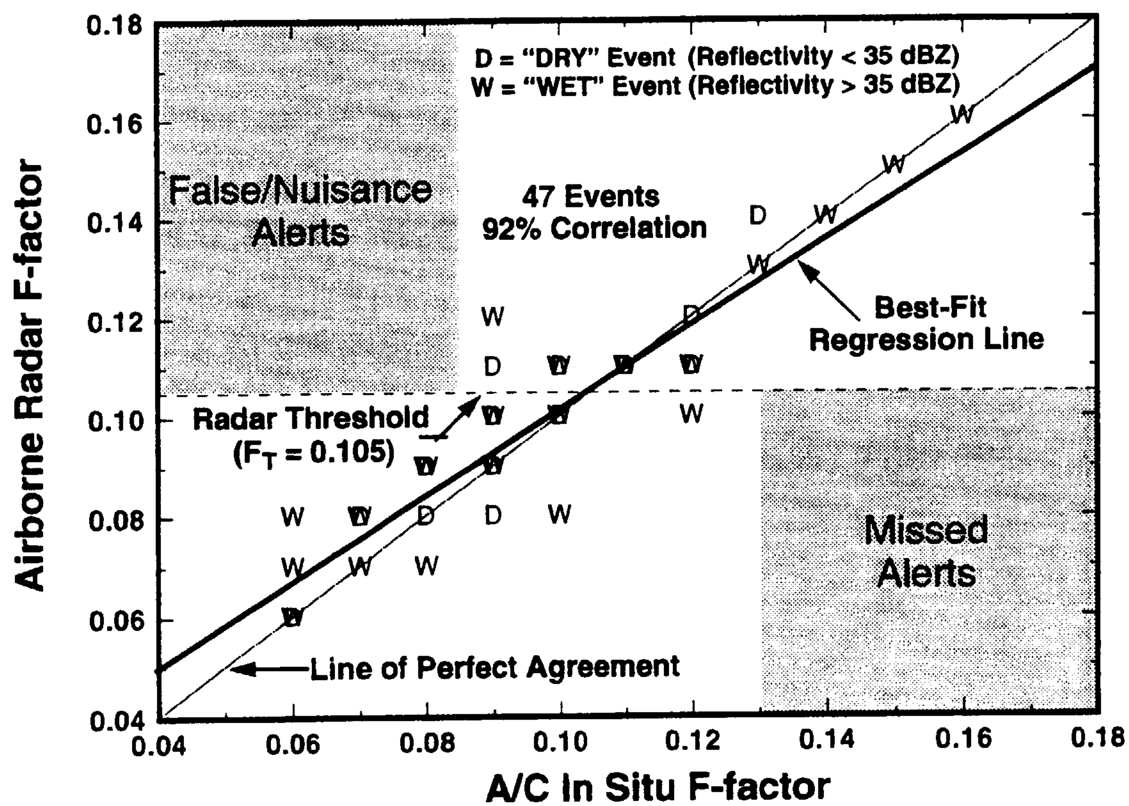
Radar Detected Wet Microburst, event 553, Orlando FL, 37 sec. Before A/C Penetration. Display of 1 km average F-factor. White Dots Indicate A/C Track.



RADAR MEASURED REFLECT., W/S, & 1KM AVE F-FACTOR, & INSITU F-FACTOR: EVENT 553



COMPARISON OF AIRBORNE RADAR PERFORMANCE WITH IN SITU MEASUREMENTS



ISSUES

- Can an airborne Doppler radar reliably detect wind shear hazards?
- Will it work in the presence of severe ground clutter?
- Can it detect "dry" microbursts such as those often seen around Denver?
- How do you evaluate performance?
- How do you certify the system for operational use?

LESSONS LEARNED

- Clutter produces over 70 dB dynamic range, requiring fast bin-to-bin AGC
- 25 dB or greater notch filter needed to suppress large stationary clutter signal
- Clutter not as severe a problem as initially anticipated, with antenna tilt control (min tilt = -2°) it is manageable
- Velocity spectral width, least squares shear residual, and hazard area thresholds along with scan-to-scan persistence are good discriminants against ground clutter induced false alerts
- 2μs or greater pulse widths may be marginal for detecting small dry microbursts
- Airborne Doppler radar can reliably detect and provide advanced warning of hazardous wind shears, including both "wet" & "dry" microbursts, even in the presence of severe ground clutter

SUMMARY

- NASA has developed an airborne pulse Doppler radar for the detection and avoidance of low altitude wind shears
- Flight tests have demonstrated Doppler radar's capability to detect both WET and DRY microburst wind shears
- NASA developed algorithms produce a robust hazard estimation and discrimination process which did NOT produce any FALSE or MISSED ALERTS during the extensive flight test program
- NASA airborne Doppler radar's predictions of the wind field and hazard index produced (near perfect) agreement with the onboard reactive systems measurements
- NASA H/W & S/W design features have enabled commercial development of the next generation of airborne weather radars
- NASA research and personnel are providing leadership in the development and commercialization of this technology

Session 2:

WINDSHEAR MODELING, FLIGHT MANAGEMENT, AND GROUND-BASED SYSTEMS.

Chair: D. Vicroy,

NASA Langley Research Center.

Session 2:

WINDSHEAR MODELING, FLIGHT MANAGEMENT, AND GROUND-BASED SYSTEMS.

Chair: D. Vicroy, NASA Langley Research Center.

Microburst Avoidance Crew Procedures for Forward-Look Sensor-Equipped Aircraft. D. Hinton and R. Oseguera, NASA Langley Research Center

Piloted Simulator Evaluation of Forward-Look Windshear Crew Procedures. R. Oseguera and D. Hinton, NASA Langley Research Center

Vertical Wind Estimation from Horizontal Wind Measurements. D. Vicroy, NASA Langley Research Center

Characteristics of a Dry, Pulsating Microburst at Denver Stapleton Airport. F. Proctor, NASA Langley Research Center

Future Enhancements to Ground-Based Microburst Detection. M. Matthews, S. Campbell, and T. Dasey, Massachusetts Institute of Technology

Determining F-Factor Using Ground-Based Doppler Radar: Validation and Results. D. Elmore, D. Albo, and R. Goodrich, National Center for Atmos-pheric Research

Evaluation of Iconic vs. F-Map Microburst Displays. M. Salzberger, R. Hansman, and C. Wanke, Massachusetts Institute of Technology

Microburst Avoidance Crew Procedures for Forward-Look Sensor-Equipped Aircraft.

D. Hinton and R. Oseguera,

NASA Langley Research Center

Microburst Avoidance Crew Procedures for Forward-Look Sensor Equipped Aircraft

David A. Hinton

Rosa M. Oseguera

NASA Langley Research Center

Presented at Fifth Combined Manufacturers' and Technologists' Airborne Wind Shear Review Meeting

Hampton, VA

September 28-30, 1993

Microburst Avoidance Crew Procedures for Forward-Look Sensor Equipped Aircraft

David A. Hinton
Rosa M. Oseguera

Abstract

NASA and the FAA have conducted a joint program since 1986 to perform the hazard characterization, sensor development, and flight management research required to eliminate the threat of low-altitude windshear to transport aircraft. A series of NASA flight tests in 1991 and 1992 have demonstrated the practicality of forward-look windshear alerting, and industry has initiated development and FAA certification of windshear detection systems based on this technology. Commercially produced forward-look windshear sensors may be available to the airlines by the end of 1993.

No industry consensus or training program currently exists to provide crews with procedures for the use of forward-look sensor information to avoid windshear threats. Effective use of these sensors will require standardized performance and display requirements, industry consensus on crew procedures, and pilot training to provide confidence in the alerts and in the performance capabilities of the airplane in forward-look alert situations. This presentation presents a summary of microburst, airplane, and sensor characteristics relevant to the development of crew procedures as well as preliminary sensor performance standards developed by industry working groups. A crew procedure and elements of a required training program are suggested. More detailed rational and suggested training objectives/scenarios are contained in AIAA 93-3942, "Microburst Avoidance Crew Procedures for Forward-Look Sensor Equipped Aircraft" by Hinton and Oseguera, which was presented at the AIAA Aircraft Design, Systems and Operations Meeting, August 11-13, 1993, Monterey, Ca.

OUTLINE

- Background
- Operational Considerations
  - Microburst/Sensor Characteristics.
  - Airplane Performance.
  - Procedural Issues.
- Suggested Crew Procedures/Displays/Training
- Summary

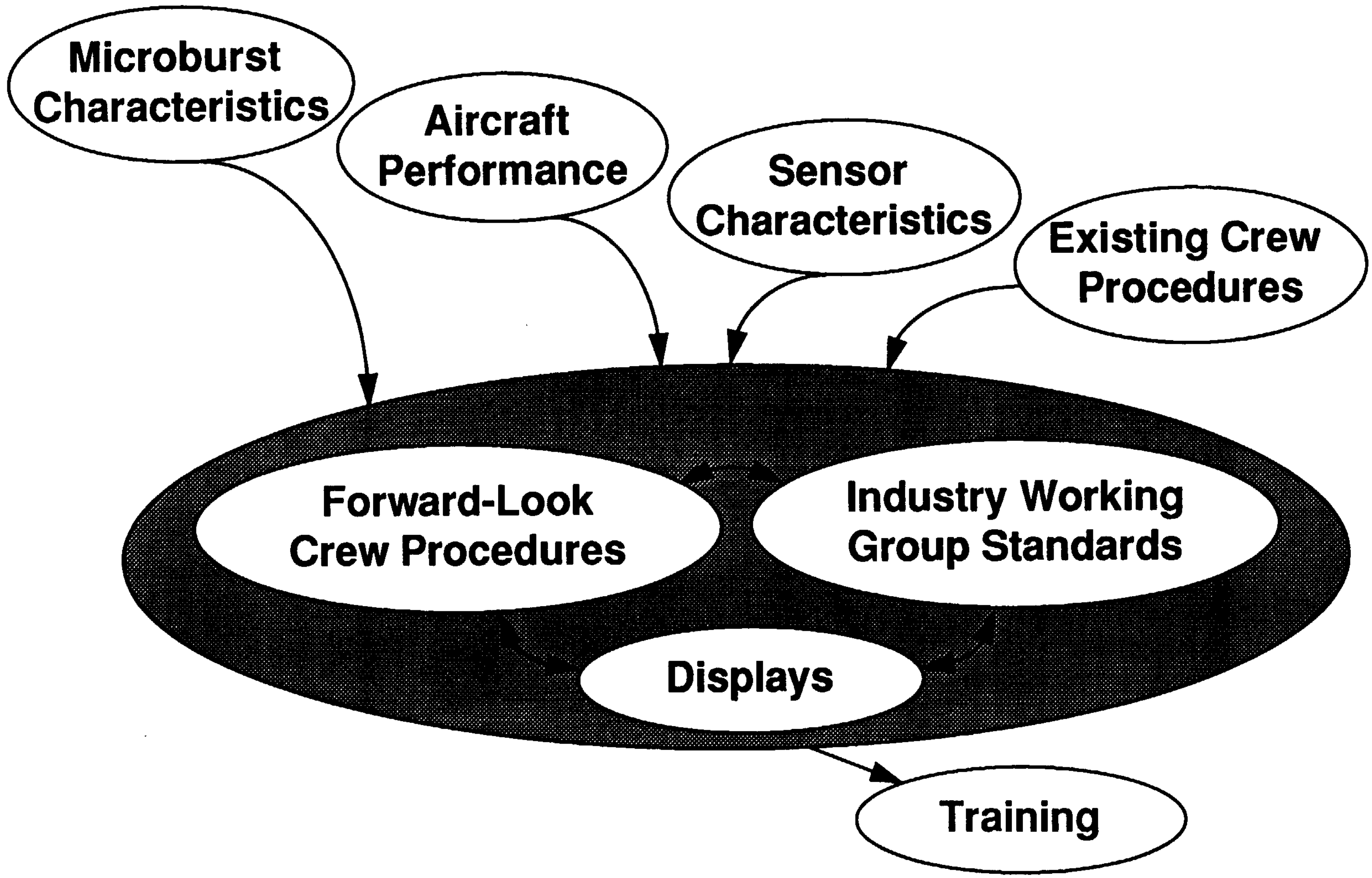
BACKGROUND

- Forward-look sensors are being certified.
- Operational issues have been identified.
- No training consensus or program is in place.
- FAA Training Aid extremely effective for "reactive" capability.
- SIMILAR INDUSTRY CONSENSUS AND TRAINING PROGRAM NEEDED FOR FORWARD-LOOK CAPABILITY.

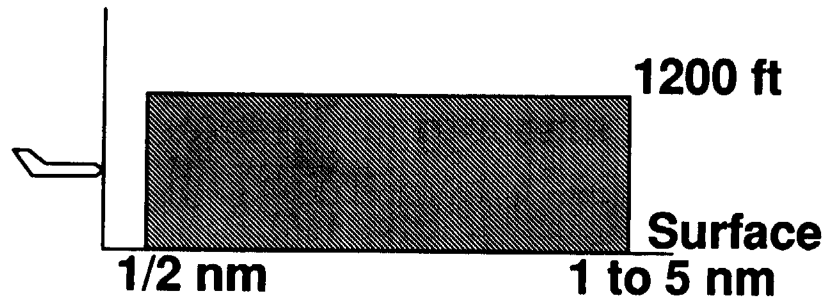
OPERATIONAL ISSUES

- What potential problems will be created by the introduction of forward-look systems?
  - Transfer of "thunderstorm" training.
  - Excessive miss distances.
  - Unnecessary emergency maneuvering.
- When are straight ahead or turning escape maneuvers most effective?
- What crew procedures should be followed and how should training be modified?

CONSIDERATIONS



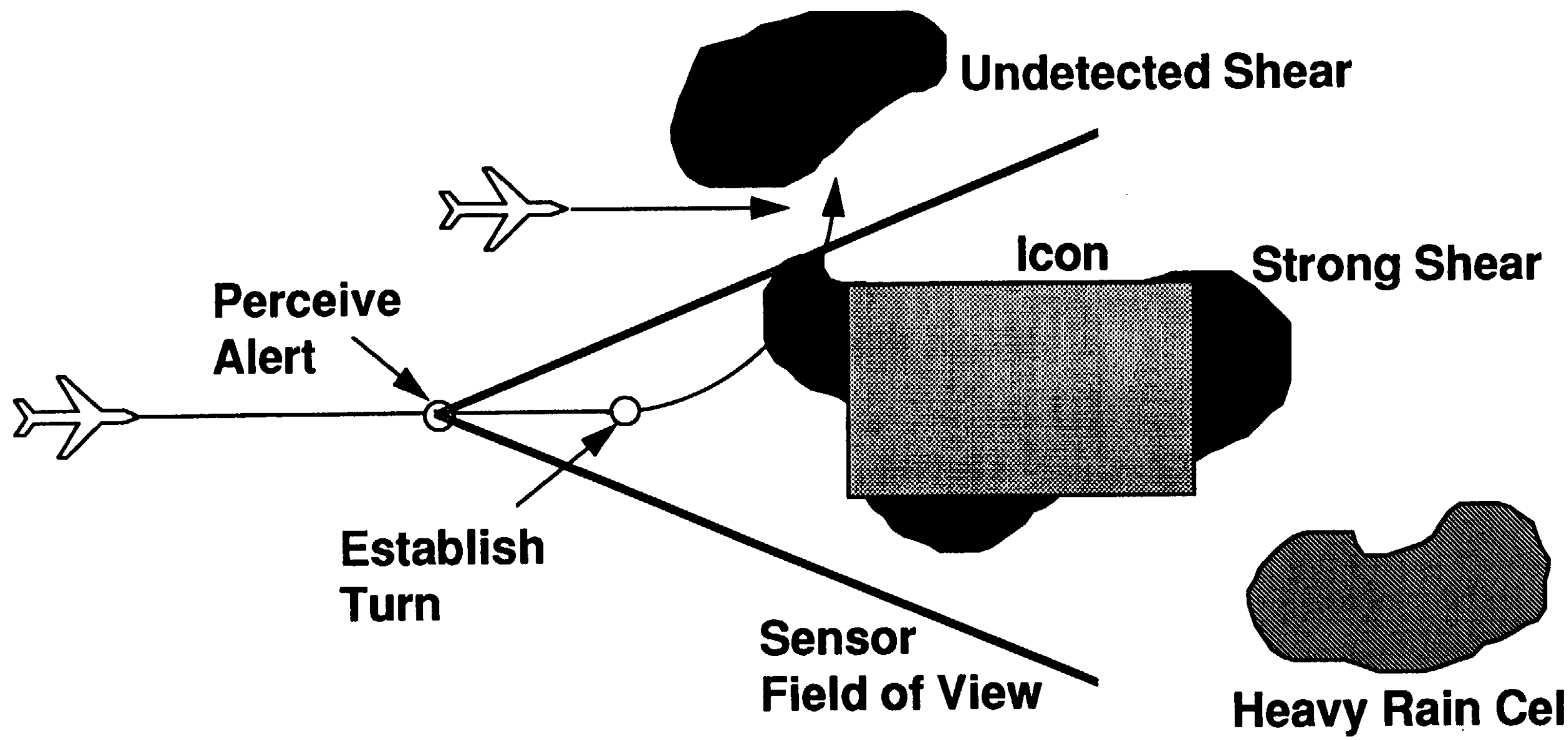
SENSOR CHARACTERISTICS



Sensor Detection Envelope

- Threshold values compatible with reactive systems - to avoid exposing aircraft to shears that will activate reactive warning systems.
- 10^{-5} probability of missed detection of a critical, “must-alert” shear intensity.
- 20 to 40 seconds advance warning nominal, 10 to >90 second range possible.
- Possible missed detection due to extreme atmospheric conditions, aircraft maneuvers, system failures.

TURN LIMITATIONS

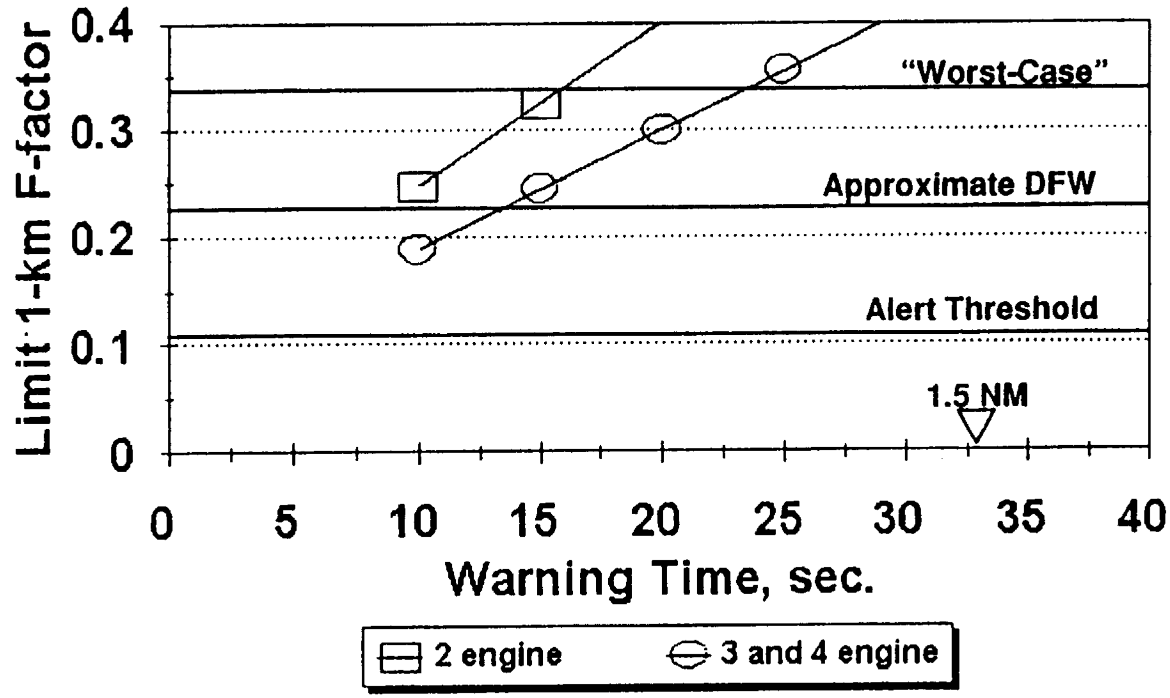


- 1/2 to 1 nm cross-track needed for effective shear reduction.
- Turn radius about 1 nm at 165 knots, 20 degree banked turn.
- Turn radius, decision delays, uncertainty in microburst size and position will require alert distance of about 1.5 nm to ensure the turn is effective.

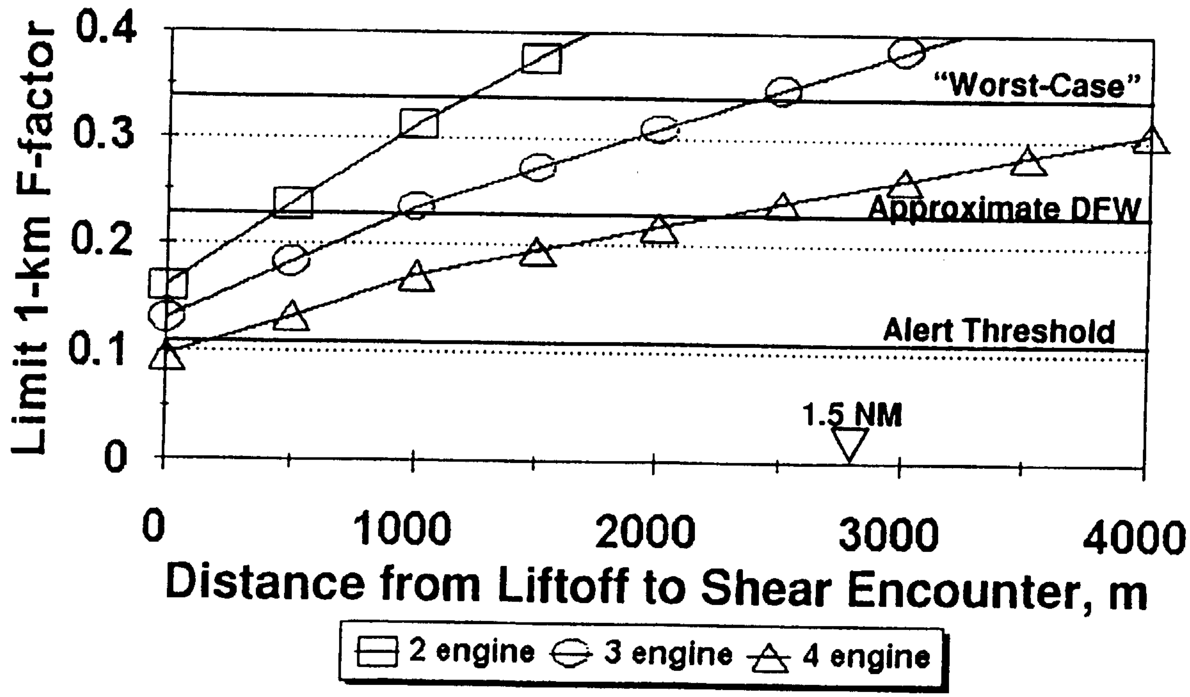
AIRCRAFT ENERGY ANALYSIS

- Integrate energy lost to windshear and gained from aircraft thrust across a windshear encounter.
- Determine limiting microburst strength for airplane straight-ahead escape maneuvers, with specified energy reserves.
- Assume "worst-case" 2, 3, & 4 engine aircraft performance and microburst location, 10 second engine spoolup time from alert.
- Required energy reserves after windshear of 20 knots over stick-shaker and 200 ft altitude, and 0.03 clearance plane for departure climb.

LIMIT WINDSHEAR DURING APPROACH



LIMIT WINDSHEAR DURING DEPARTURE



ESCAPE MANEUVERING RULE

- **At distances less than 1.5 miles, a turn is not effective.**
- **At distances beyond 1.5 miles, a turn is not required.**

(But should be made if time remains for ATC coordination.)

IF THERE IS ROOM TO AVOID A MICROBURST BY TURNING, THE TURN IS NOT REQUIRED FOR AIRPLANE SURVIVAL.

CREW PROCEDURES, GROUND RULES

- Do not challenge the authority of the Pilot-in-Command.
- Procedures are for windshear protection only - other hazards (hail, violent storms, etc.) to be avoided with current procedures.
- Avoid all significant windshear encounters when feasible - absolutely avoid low airplane energy windshear encounters.
- Avoid creating hazards that may be more severe than the windshear (obstacle clearance, ATC conflicts, near-collisions).

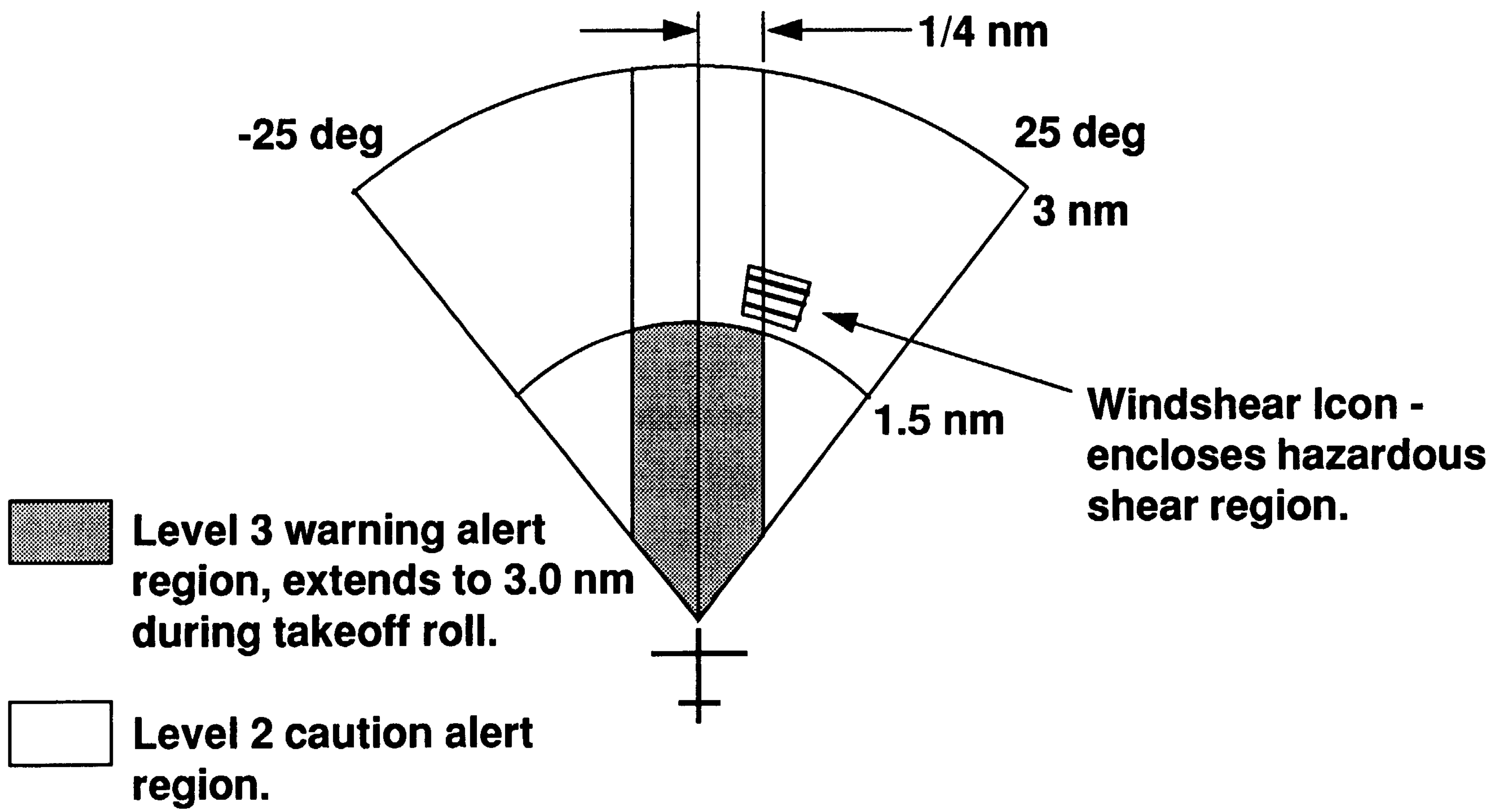
CREW PROCEDURES
(SIMPLIFIED)

- **If windshear detected by reactive system - use existing training.**
- **If windshear detected ahead, less than 1.5 miles away - escape straight ahead.**
- **If windshear detected ahead, beyond 1.5 miles - maximize energy & negotiate to avoid. Follow ATC clearances.**
- If windshear detected ahead, beyond 5 miles - continue and consider alternate paths.

CREW DISPLAYS

- Suggested Information Requirements:
  - Ensure awareness of threats on path, < 1.5 miles range.
  - Indicate range status (< 1.5 nm or > 5 nm).
  - Do not provide new information on takeoff roll after V1.
  - Do not indicate non-hazardous shears.
  - Any display of windshear location should use icon, scaled to size of threat region.
  - Note: These requirements do not dictate a display.
- Implementation:
  - Use discrete (level 3) warning alert to indicate threat closer than 1.5 nm, level 2 caution alert for threat less than 3 nm.
  - Initial sensors do not support ranges > 5 nm.
  - Utilize industry/FAA/NASA defined displays and alert regions.

DISPLAYS AND ALERTS



CREW TRAINING ELEMENTS

- Include ground and simulator training:
  - Relation to prior training aid.
  - Sensor performance and limitations.
  - Experience with procedures and airplane performance in critical scenarios (simulation).
- Provide general rule:

Use previous training and forward-look systems to avoid windshear. If avoidance is not feasible (missed or close detection) use available warning to escape straight ahead.

- Use "realistic" microburst model, severe intensity.

SUMMARY

- Introduction of forward-look systems creates operational and training issues, yet to be resolved.
- Anticipated forward-look sensors and simple procedures and pilot interfaces will provide substantial protection.
- The current crew training program should be modified for effective fleet implementation of forward-look systems.
- Additional detail in “Microburst Avoidance Crew Procedures for Forward-Look Sensor Equipped Aircraft”, AIAA 93-3942.

Piloted Simulator Evaluation of Forward-Look Windshear Crew Procedures.

R. Oseguera and D. Hinton,

NASA Langley Research Center

Piloted Simulator Evaluation of Forward-Look Windshear Crew Procedures

Rosa Oseguera David Hinton
NASA Langley Research Center

5th Combined Manufacturers and Technologists
Airborne Windshear Review Meeting
September 28, 1993

Outline

- Background
- Objective
- Windshear Crew Procedures
- Displays and Alerting
- Simulation
- Preliminary Results
- Concluding Remarks

Background

- Forward-look windshear systems close to certification
- Certification of systems requires definition of information display requirements
- Previous research:addressed information display formats and "untrained" crew procedures
- Effective use of forward-look windshear systems requires appropriate procedures

Objective

Evaluate proposed Windshear Crew Procedures and supporting displays:

- pilot acceptance of procedures
- effectiveness of training for given task
- appropriateness of procedure to threat

Windshear Crew Procedure

- Microburst at > 5 nm from airplane: advisory, continue on current path and monitor
- Microburst at < 5 nm, but >1.5 nm: caution, negotiate with ATC for alternate path
- Microburst at <1.5 nm: warning, proceed with straight-ahead recovery

Procedure developed as baseline; can be modified slightly by users. Objective was to develop an effective procedure that could be easily taught to all pilots.

Display Options

- no graphical display
- 1-level graphical - icons red/gray crosshatch, representative of certification requirements document
- 3-level graphical, with levels (colors) corresponding to recommended procedures - icons blue/gray (range > 5 nm), yellow/gray (1.5-5 nm), or red/gray (<1.5 nm)

Alerting

- With all three display options:

  forward-look aural and textual alert at 1.5 nm range ("WINDSHEAR AHEAD")

  in situ aural and textual alert ("WINDSHEAR")

- Graphical (icon) displays also included caution alert

Simulation

- "Glass-cockpit" fixed-base simulator
- Vicroy's analytic microburst model, with enhancements for growth, decay, and motion
- Simulated forward-look windshear detection and alerting systems
- Simulated in situ windshear detection and alerting system
- Denver terminal area with simulated ATC communications and traffic constraints
- Participation from 12 pilots - 8 active airline, 4 manufacturer test pilots

Simulation (cont'd)

Test Matrix - eight scenarios, two (one take-off, one approach) of each shown below:

- no windshear
- microburst appears at range of <1.5 nm
- microburst appears at range of >1.5 nm, but <5 nm
- microburst appears at range of > 5 nm

Simulation (cont'd)

Test Matrix - Displays

Each pilot flew all eight scenarios with each of the three display options. This resulted in four sets of runs:

- "untrained" (no windshear crew procedures), display option#1
- "trained", display option #1
- "trained", display option #2
- "trained", option #3

Preliminary Results

Pilot Subjective Feedback:

- all pilots preferred having icons displayed
- 10 of 12 pilots preferred 3-level icons, but half of these were not strong preferences
- overall, pilots tended to rate both display options with icons nearly the same, and better than no-icon option
- All pilots indicated that procedure was acceptable for windshear avoidance, however procedure was not always followed

Preliminary Results (cont'd)

Number of turns vs. straight-ahead recoveries for close-range detection of microburst on:

	take-off		approach	
display	turns	straight	turns	straight
no icon	0	12	0	12
1-level	4	8	7	5
3-level	4	8	4	8

Preliminary Results (cont'd)

Mean and standard deviation of minimum recovery height in feet for close-range detection of microburst on approach:

display	turns	straight
no icon	--	797(118)
1-level	831(79)	715(204)
3-level	793(91)	777(63)

Preliminary Results (cont'd)

Mean and standard deviation of altitude loss in feet for close-range detection of microburst on take-off:

display	turns	straight
no icon	--	136(195)
1-level	112(132)	78(149)
3-level	116(135)	18(28)

Preliminary Results (cont'd)

Mean and standard deviation of minimum airspeed (in knots) experienced during turns vs. straight-ahead recoveries for close-range detection of microburst on:

	take-off		approach	
display	turns	straight	turns	straight
no icon	-	166(11)	-	140(11)
1-level	159(8)	153(8)	145(3)	145(11)
3-level	157(11)	151(12)	144(3)	147(4)

Concluding Remarks

- turns at close range to microburst do not significantly reduce hazard exposure over straight-ahead recoveries
- recovery performance equivalent with or without icons displayed, not statistically significant by display type
- with greater advance warning, procedure becomes more intuitive, but more tendency to react too soon
- carefully designed training program necessary to ensure best use of information given