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Evaluation of Iconic vs. F-Map Microburst Displays.

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and C. Wanke,
Massachusetts Institute of Technology

ASL ✓

Evaluation of Iconic vs. F-map Microburst Displays

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Dr. R. John Hansman and Craig Wanke
Aeronautical Systems Laboratory
Department of Aeronautics and Astronautics
Massachusetts Institute of Technology

Presentation to Attendees of the 5th (and Final) Combined Manufacturers' and Technologists' Airborne Wind Shear Review Meeting

28 September 1993

Radisson Hotel, Hampton, VA

Abstract:

Previous studies have shown graphical presentation methods of hazardous wind shear to be superior to textual or audible warnings alone. Positional information and the strength of the hazard were observed to be and were cited by pilots as the most important factors in a display.

In this experiment the use of three different graphical presentations of hazardous wind shear are examined. Airborne predictive detectors of wind shear enable the dissemination of varying levels of information. The effectiveness of iconic and mapping display modes of different complexities are addressed through simulation and analysis. Different positional and time-varying situations are presented in a "part-task" Boeing 767 simulator using data from actual microburst events. Experienced airline pilots fly approach profiles using both iconic and F-map wind shear alerting displays. Microburst events employed are based on recorded data from Orlando and Denver. Theweather that accompanied each event is also shown to the pilot.

Mapping display types are expected to be found exceptionally efficient at conveying location comparison information while iconic displays simplify the threat recognition process. Preliminary results from the simulator study will be presented. Recommendations concerning the suitability of multilevel iconic and mapping displays will be made. Situational problems with current display prototypes will also be addressed.

ASL

Evaluation of Iconic vs F-map Microburst Displays

Mark Salzberger
Dr. R. John Hansman and Craig Wanke
Aeronautical Systems Laboratory
Department of Aeronautics and Astronautics
Massachusetts Institute of Technology

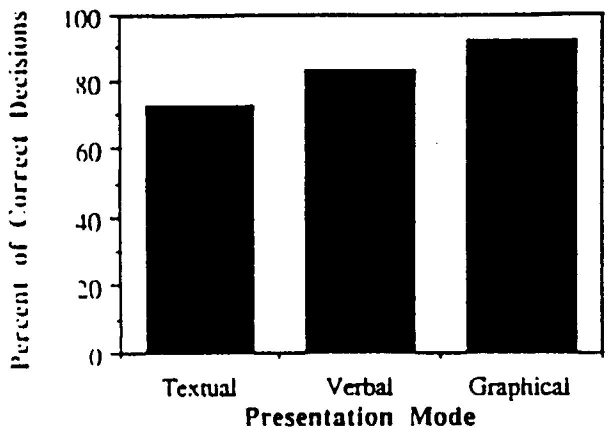
5th (and Final)
Combined Manufacturers' and Technologists' Airborne Wind Shear Review Meeting
September 28-30, 1993

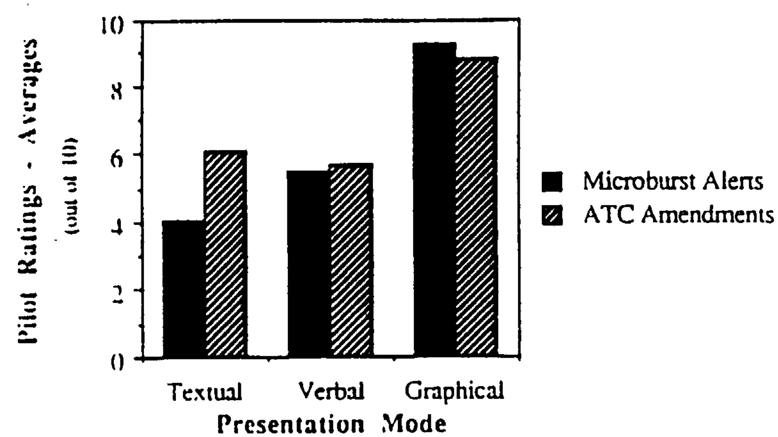
PROBLEM STATEMENT

- **Need for display of airborne-measured MB data**
- **Graphical icons best on ground-measured data Airborne detectors have singular problems**

GOAL

- **Examine the differences between Iconic and FBAR mapping displays**

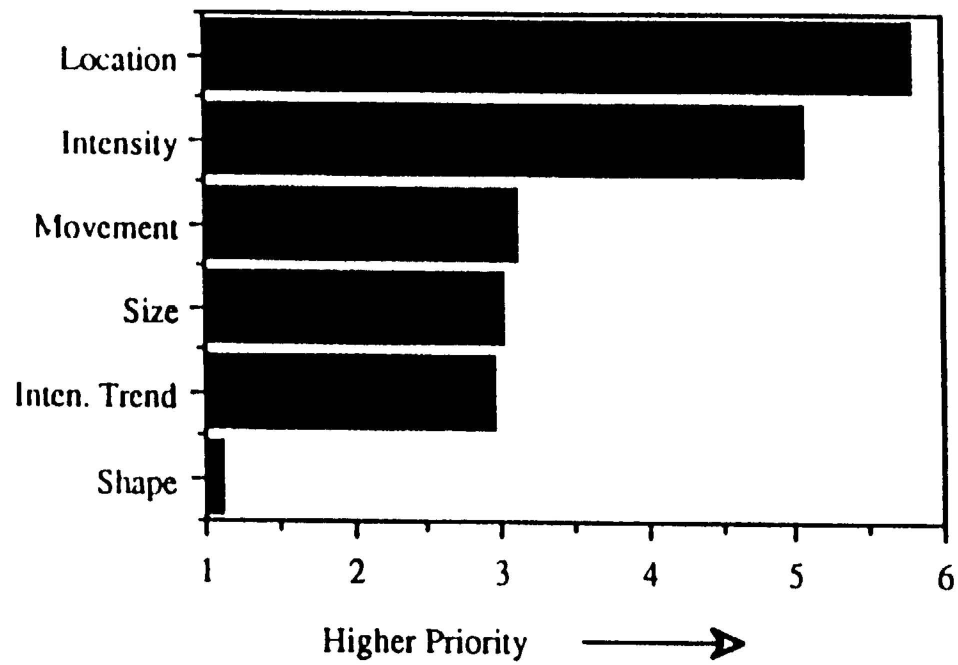




Decision-making Pilot Ratings

GRAPHICAL FORMAT SUPERIOR

Wanke & Hansman 1990



Pilot ranking of microburst information by importance

Attributes most desired:

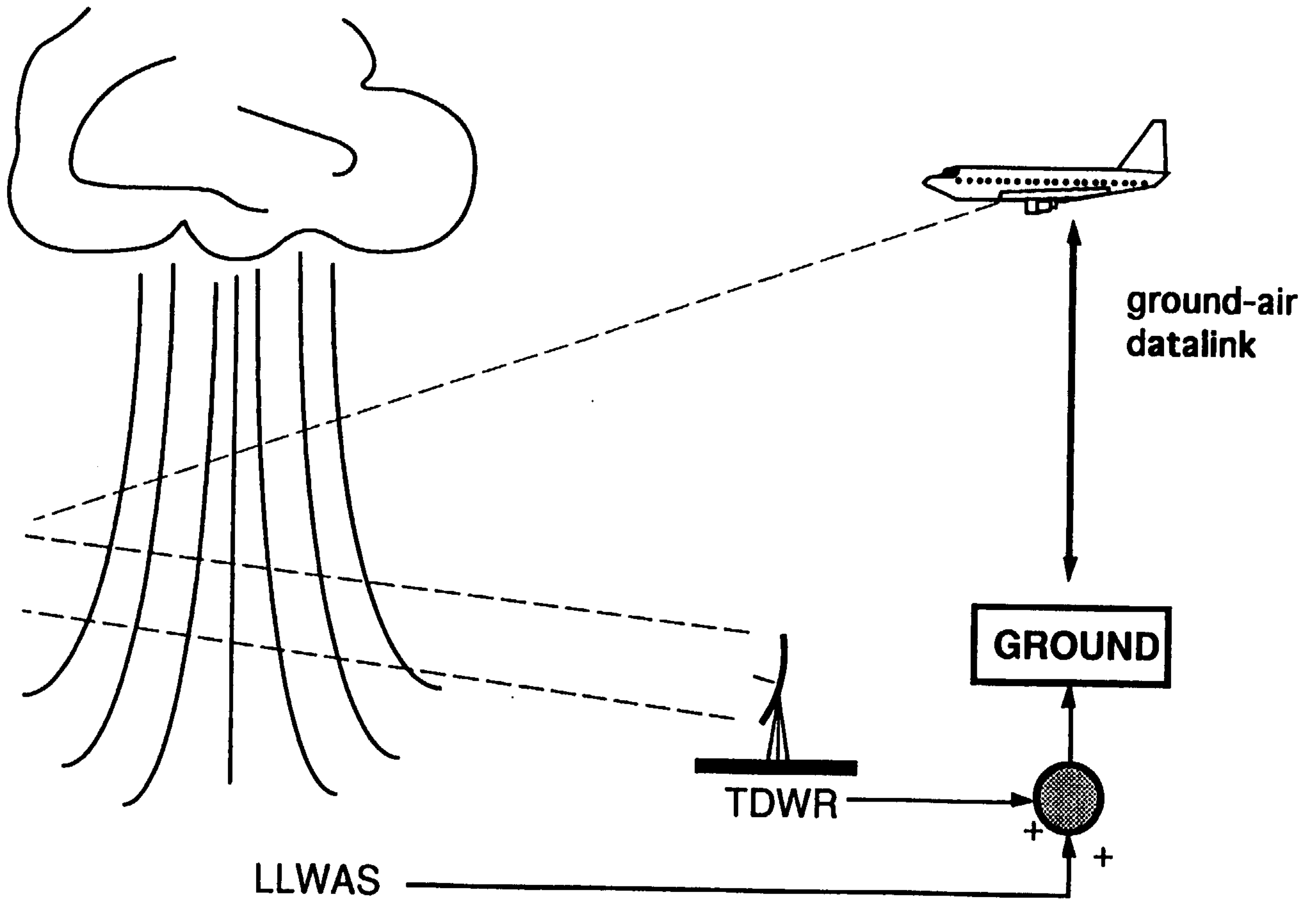
MICROBURST
LOCATION AND INTENSITY

Wanke & Hansman 1990

Formats
Of Microburst
Graphical Presentations

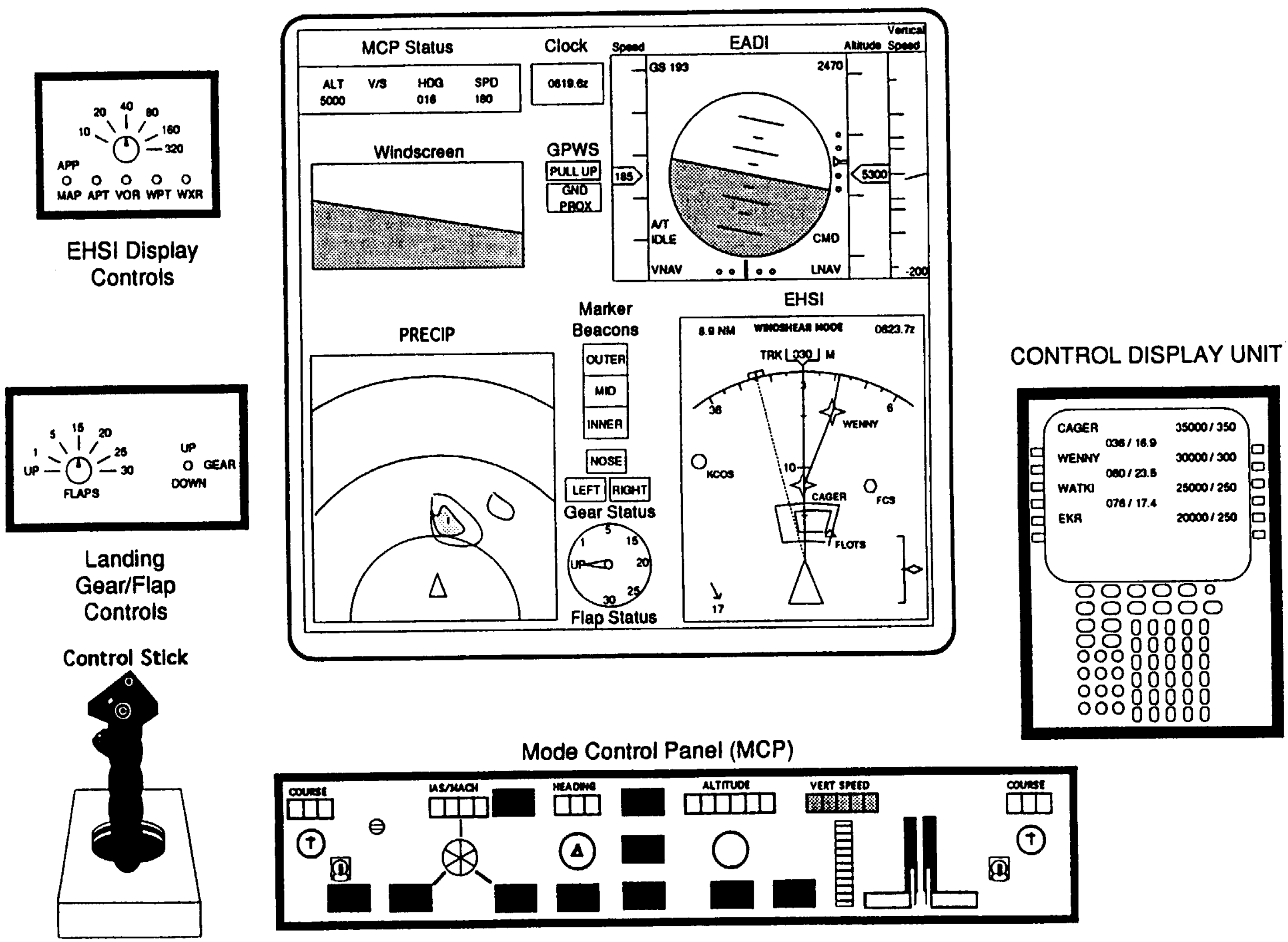
SINGLE ICON
MULTILEVEL ICONS
F-FACTOR or FBAR MAP

MICROBURST DETECTION
Experiment Modeling



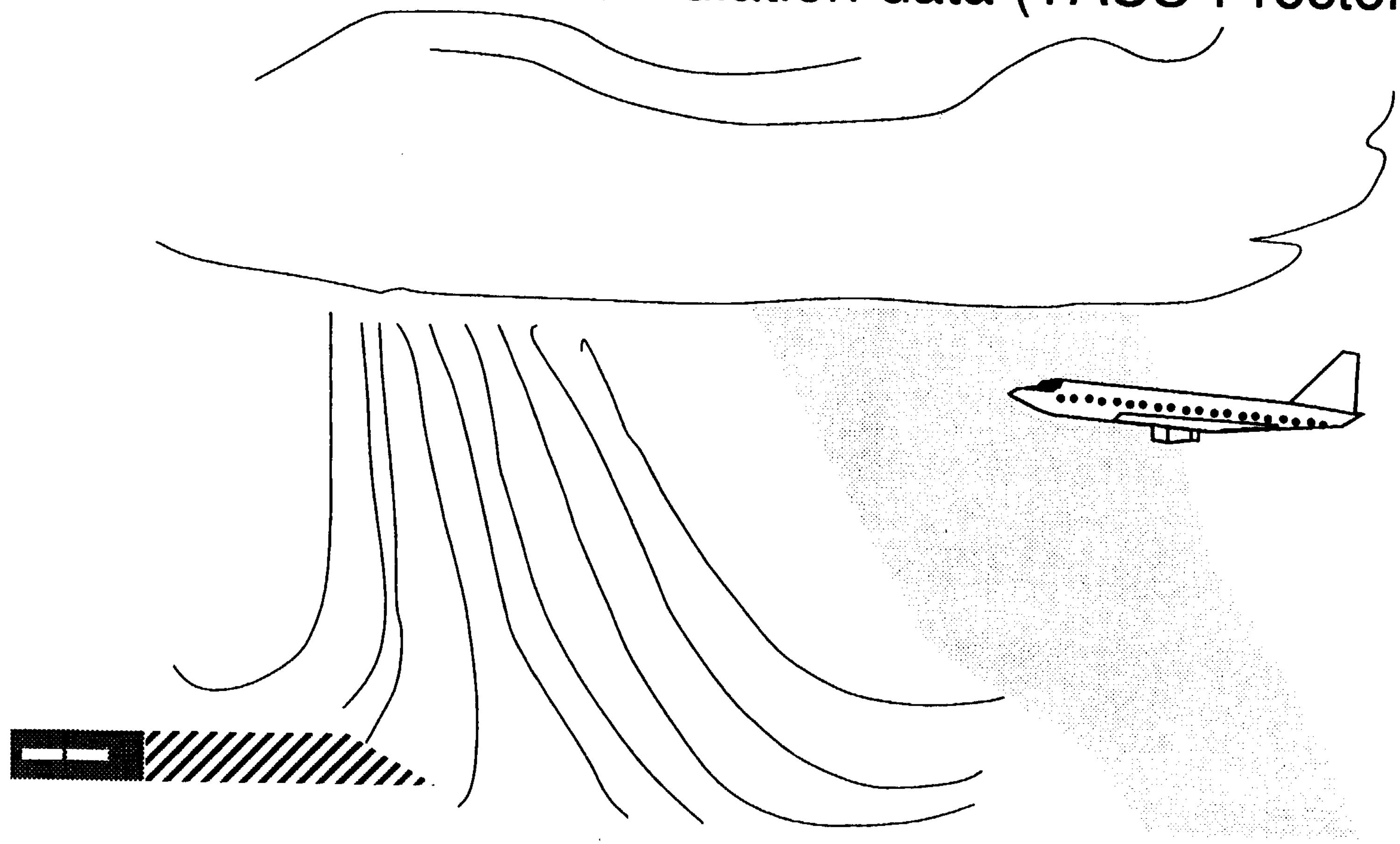
MIT ADVANCED COCKPIT SIMULATOR

ELAN 4000



Utilize: Microburst winds and reflectivity data from actual events

- Triple doppler radar data (Lincoln Lab)
- Numerical simulation data (TASS-Proctor)



SCENARIOS

Straight-in ILS, Building MB
Box to short final
Angled approach, Dimishing

12 runs using test matrix

SCENARIO VARIABLES

Aside from presentation type, consider:

Location -------------- All threatening. Force decisions.

Intensity -------------- All threatening.

** **Intensity Trend** ----- Increasing or decreasing?

Wet/Dry -------------- All wet.

** **View Time** ----------- Vary by field of view limits.

ATIS ---- "Convective activity," similar verbal advisory.

MEASURES

1. Decision accuracy.
2. Decision distance.
3. Proximity to microburst -- CPA.
4. Aircrew interrogation.
5. Subjective workload estimate.
6. Subjective ratings and comments.

EXPERIMENTAL ISSUES

PILOT TRAINING (F-Factor, Procedures,...)

DIFFICULTIES

- Icon algorithm
- Complexity of algorithm ==> Presentation
- Multiple microburst event

DYNAMIC ISSUES AND RESULTS

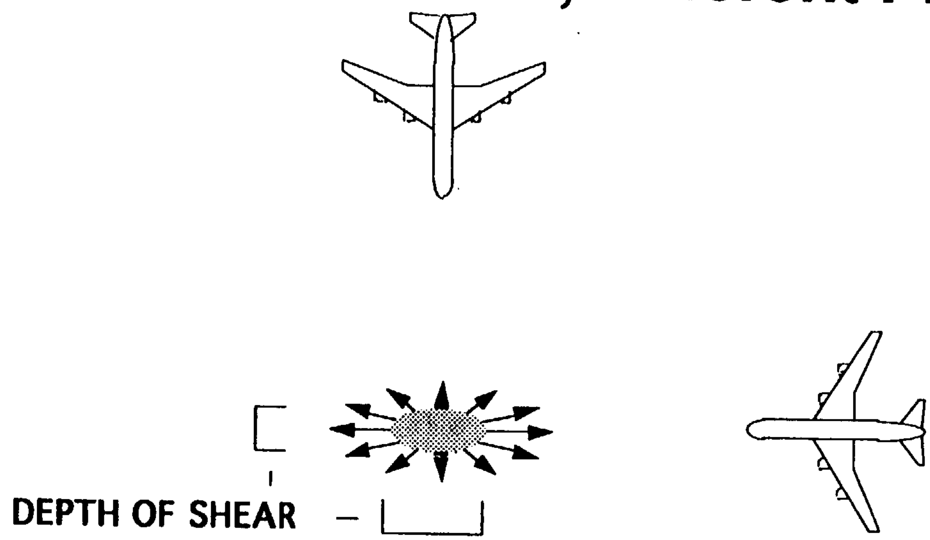
Display of Performance Gain Area:

--> Eliminate in multilevel icon format

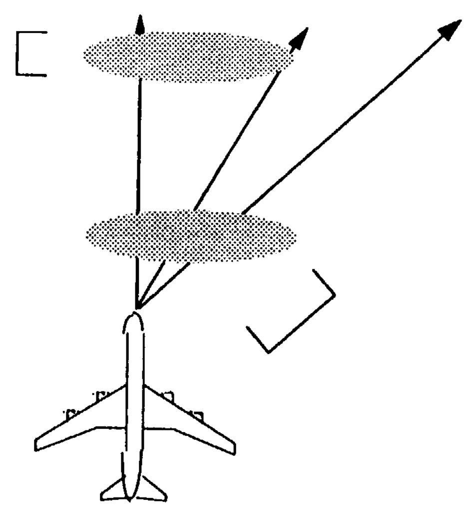
--> Retain in FBAR mapping

Aspect Angles -- Same Micoburst, Different Picture

- Asymetry



- Observability



Same Microburst Changes with Reduction in Speed

(Obvious result from calculation of F-factor)

- **Can lead to surprises on approach**

  --> "Predictive" display for approach

  Possible use of Bug speed.

PILOT REACTION

Single Icon	Multilevel	FBAR map
Acceptable	Least favored	Preferred
	Tendency to divert away from non-hazardous events.	

FBAR MAPPING POTENTIAL:

Adv	Disadv
Truer picture	
--> Credibility	Needless aborts
--> SA in dynamic environment	Difficult to interpret
Field of view enhancer	Crowded EHSI
...	...

OTHER FACTORS THAT MAY EFFECT F-MAP USE

- Data transmission techniques
- Widespread use of airborne detectors
- Differentiation of ground and air detection?
- Standardization

Session 3:

AIRBORNE WINDSHEAR DETECTION SYSTEMS.

Chair: S. Harrah,

NASA Langley Research Center.

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Session 3:

AIRBORNE WINDSHEAR DETECTION SYSTEMS.

Chair: S. Harrah, NASA Langley Research Center.

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

Overview and Highlights from Super-position Testing of the MODAR 3000, B. Mathews, F. Miller, K. Rittenhouse, L. Barnett, and W. Rowe, Westinghouse Electric Corp. [Because it deals primarilly with certification issues, the text portion of the material furnished for this presentation has been moved to Session 4, under the title "Certification of Windshear Performance with RTCA Class D Radomes."]

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

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, and F. Austin, Lockheed Engineering and Sciences Co.

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

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

Successful Infrared Prediction of Low Level Windshear.

P. Adamson,
Turbulence Prediction Systems

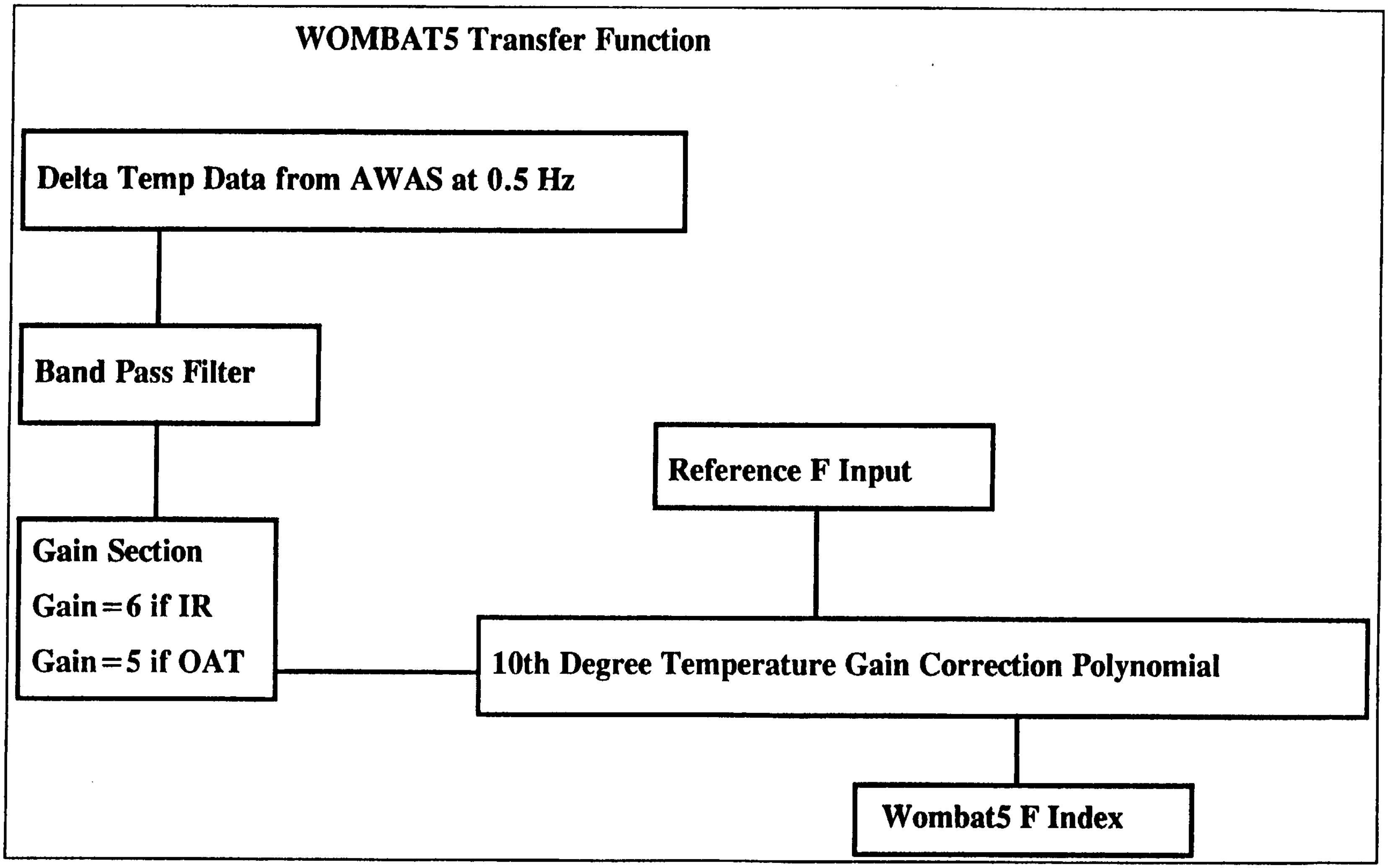
Successful Infrared Prediction of Low Level Wind Shear

NASA 5th Combined Airborne Windshear Review
September 28-30, 1993
Radisson Hotel
Hampton, Virginia

Pat Adamson
Turbulence Prediction Systems
Boulder, Colorado

Analysis to be Presented

- AWAS original algorithm was "noisy"
  - Susceptible to high frequency noise
- New Algorithm created from AWAS algorithm
  - WOMBAT5 passes only frequencies of interest
    - Easily modified
    - IR & OAT are processed the same
    - Future Development??
      - Specific algorithm for IR index (FF)
      - Specific algorithm for OAT index (FT)


WOMBAT5 Transfer Function
Delta Temp Data from AWAS at 0.5 Hz
Band Pass Filter
Gain Section
Gain=6 if IR
Gain=5 if OAT
Reference F Input
10th Degree Temperature Gain Correction Polynomial
Wombat5 F Index

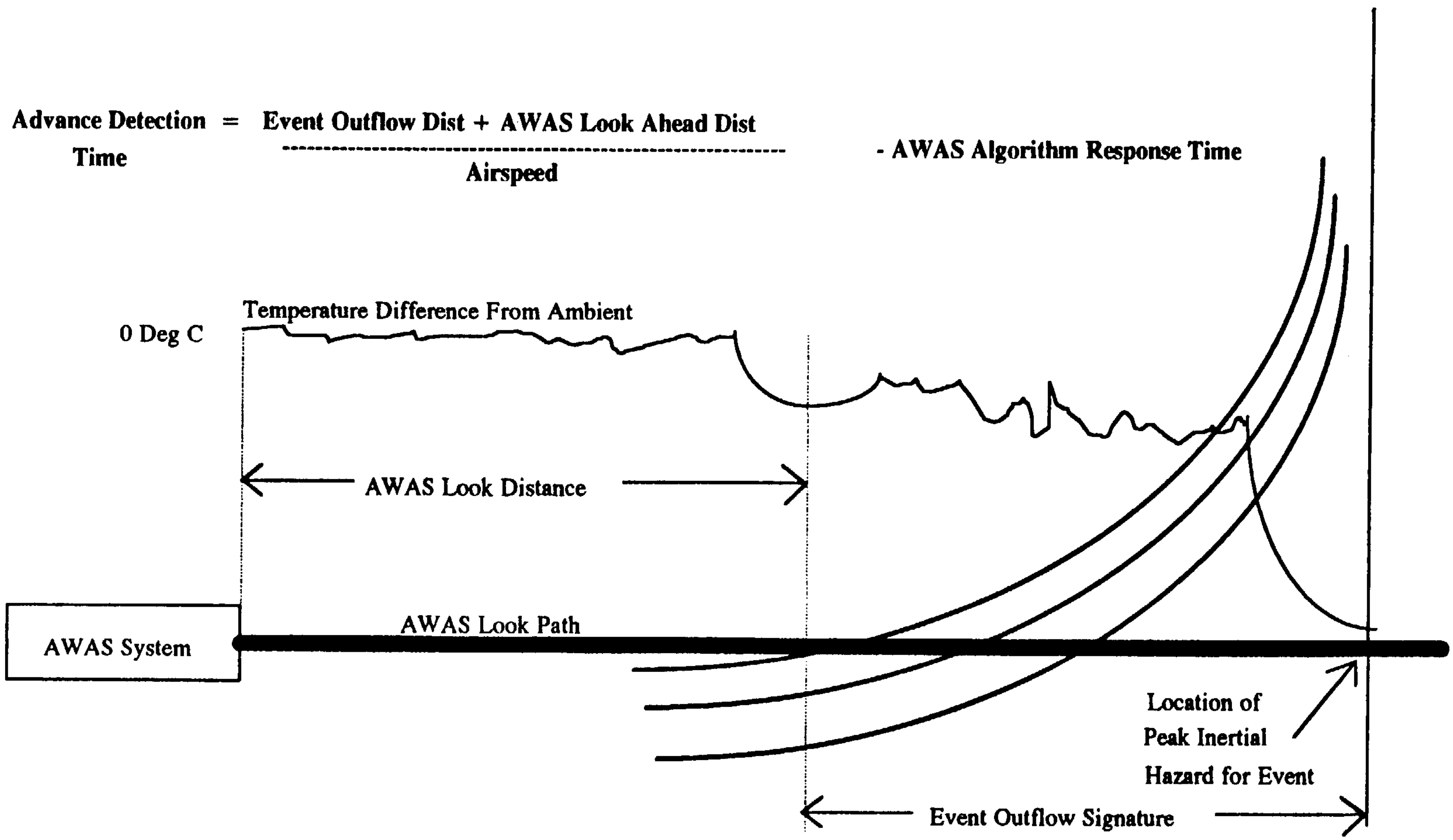
Analysis (continued)

Definition of Advance Detection Time (ADT)

ADT(IR) = IR look distance + outflow signature

ADT(OAT) = outflow signature

Definition of Advance Detection Time



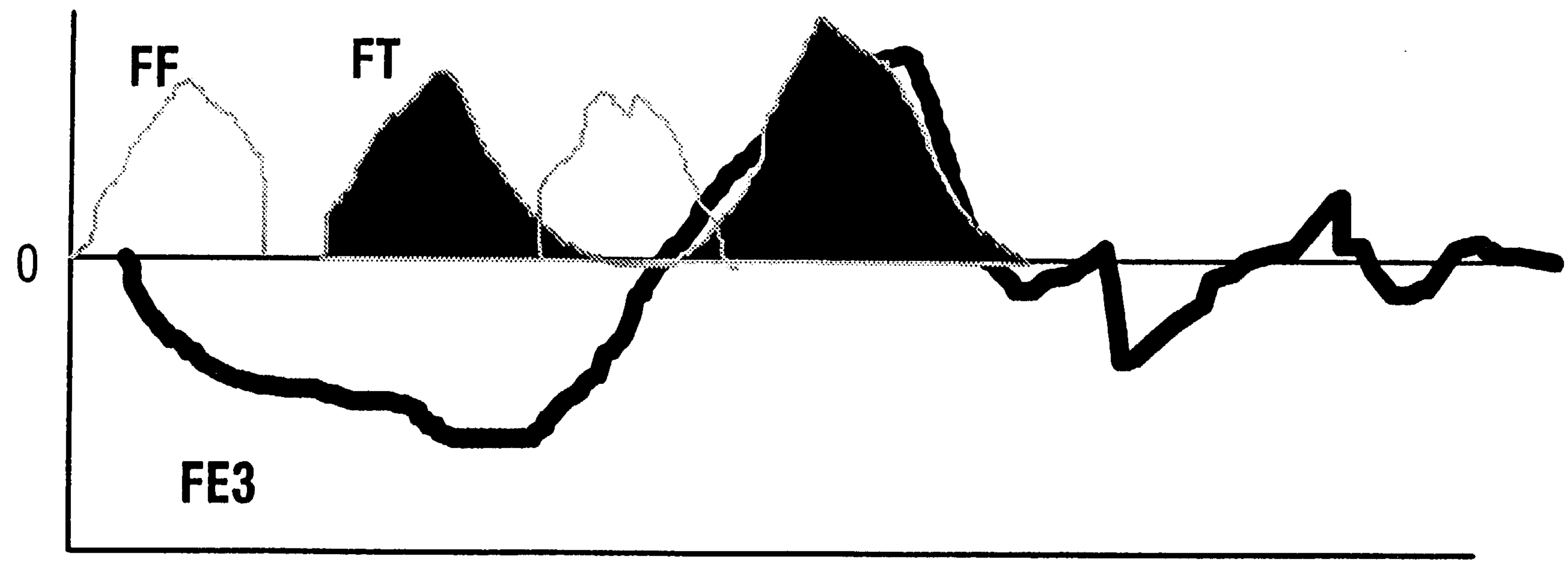
Cross Correlation

Cross correlations are used to define Advance Detection Time (ADT)

Cross correlate FE3 with:

1) IR index (FF)
2) OAT index (FT)
3) Positive values only >0.06

Typical Signals



Typical Signals FE3, FF, FT

FE3 and Remote Sensor Differences

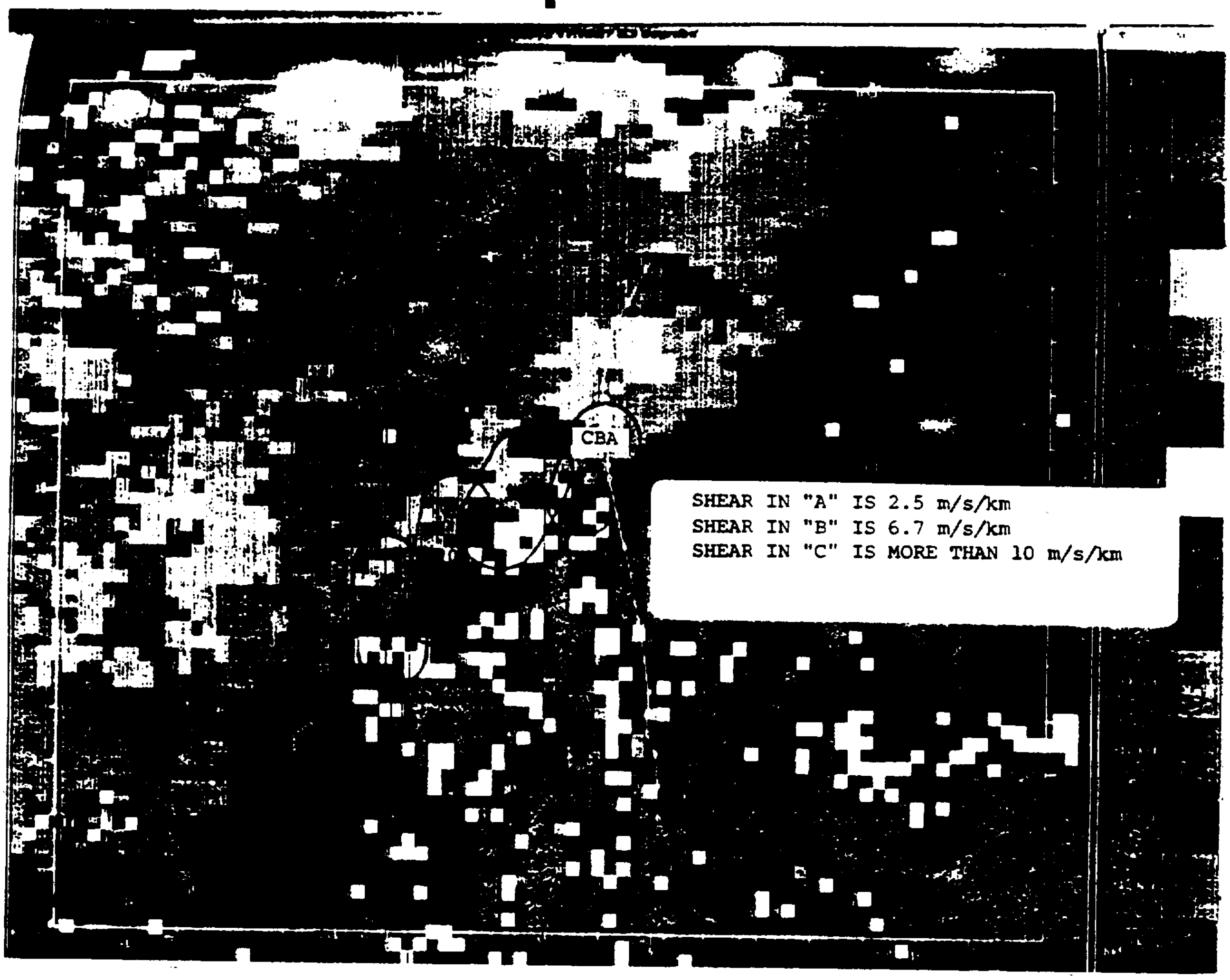
In Situ vs. Volumetric Sensors

- **Remote Sensor scans the event**
- **In Situ traces only one path through event**
  - **TDWR shear map for NASA Event #490**

Volumetric Sensors are:

1) **TDWR / RADAR / LIDAR**
2) **Thermal Sensors**
   a) **IR**
   b) **OAT**

TDWR Shear Map Event B490

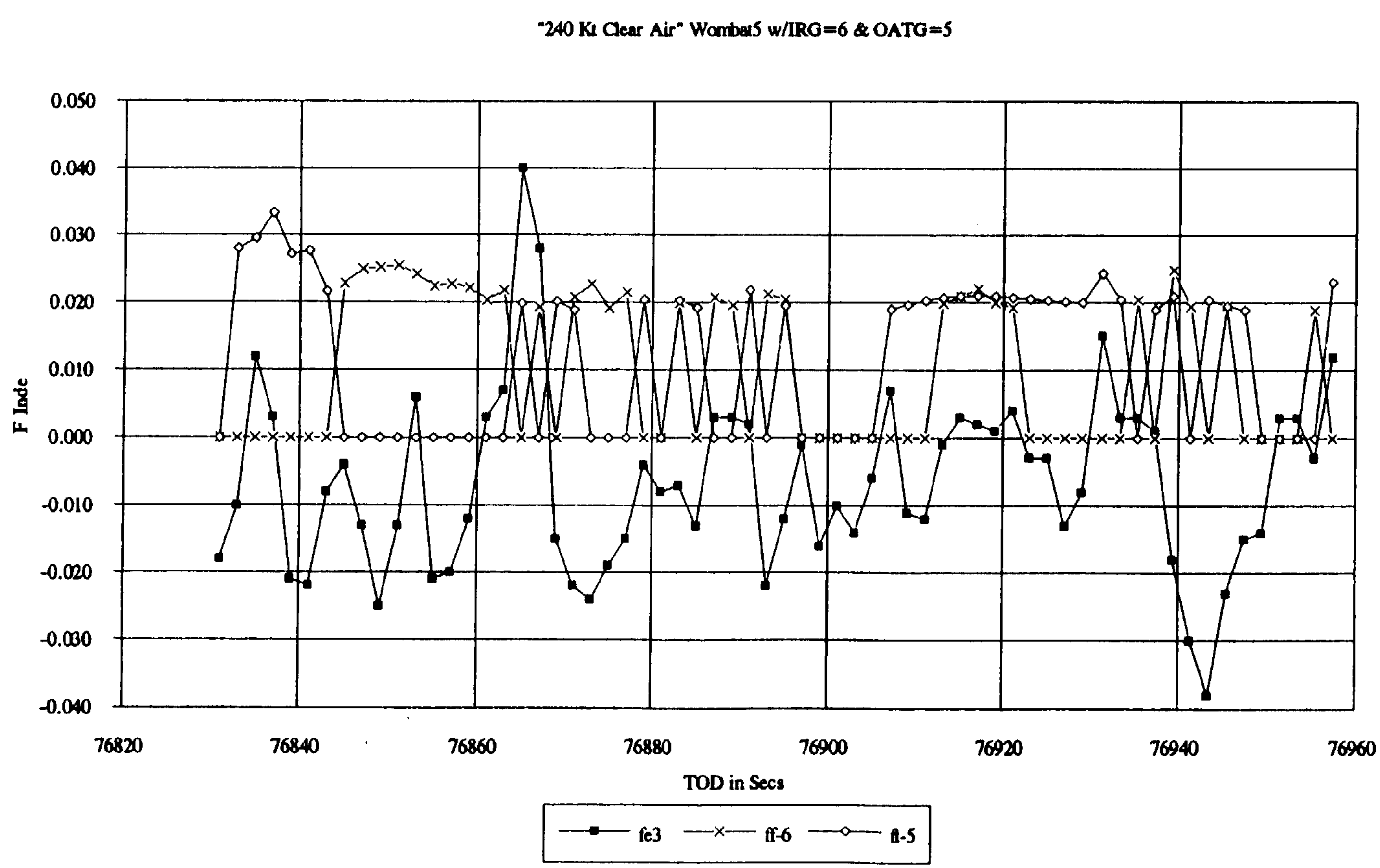


WOMBAT5 Performance

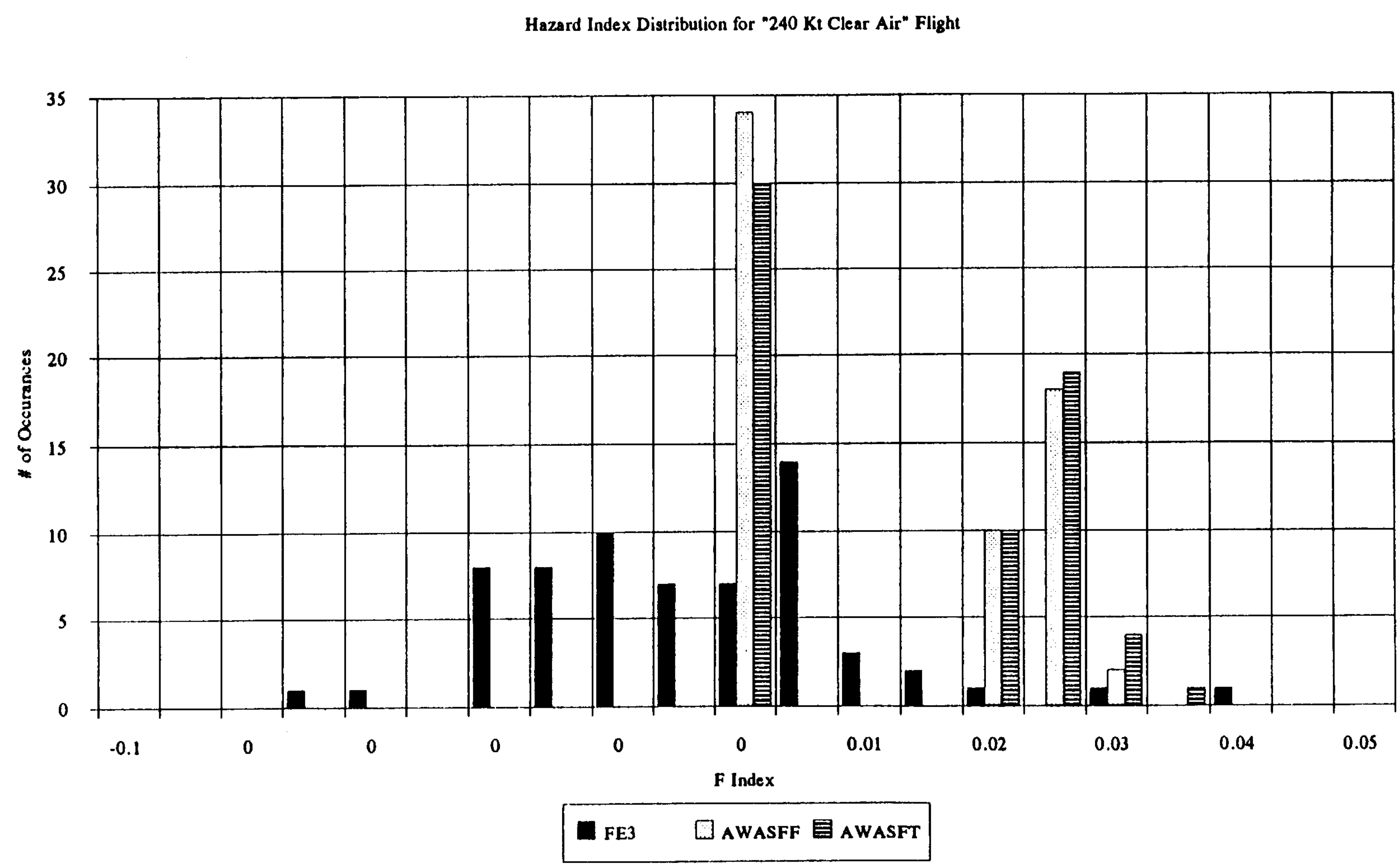
- No Event data
  - NASA clear air flight
- Event data
  - FE3 and WOMBAT5 power distribution (BITE 555)
  - NASA/TPS Agreement (meeting 12-14-92)
    - Success is FE3 $\pm$ 30% criterion
    - 9 significant events
    - FE3 vs TDWR, FF,FT

No Event Data - 240 kt "Clear Air"

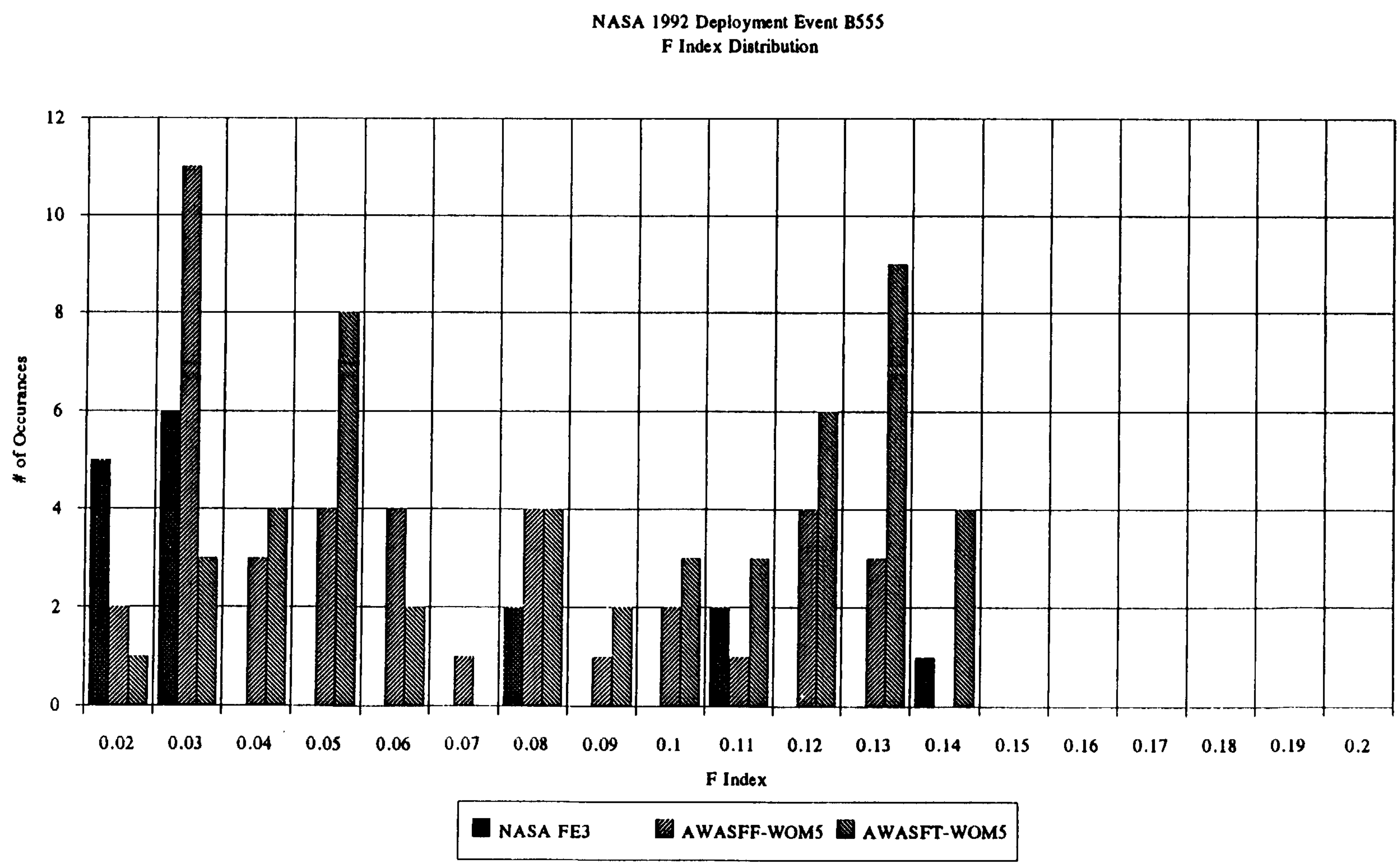
FE3, FF ,FT "noise" within ± 0.04



No Event Data Distribution



Event B555 Data Distribution



Evaluation of WOMBAT5

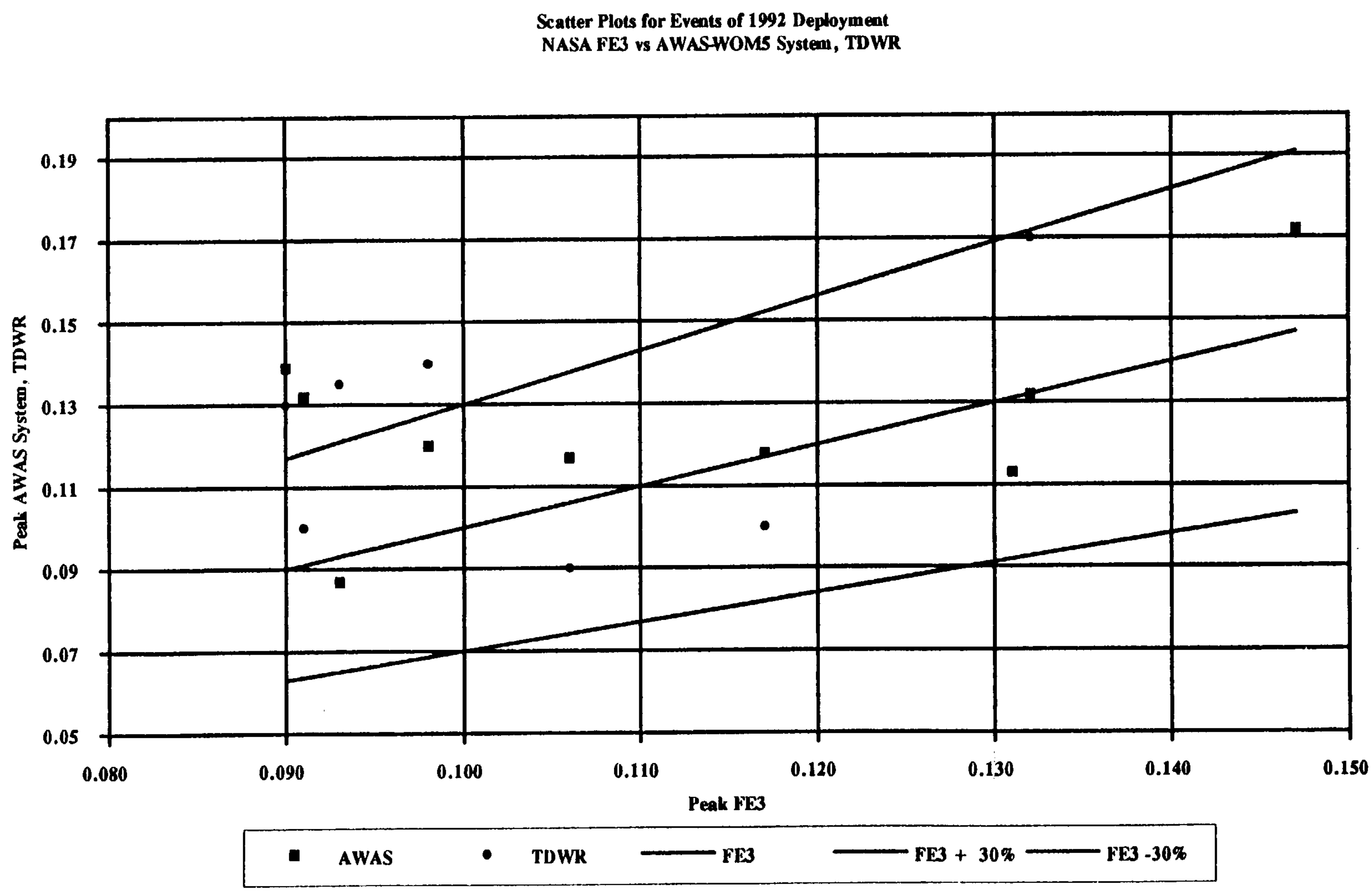
System Evaluation Rules

Most Predictive System value (either FF or FT) within 60 seconds of FE3 with a correlation coefficient >0.3 is chosen as the point to compare with FE3 (20 hertz data) peak

Results

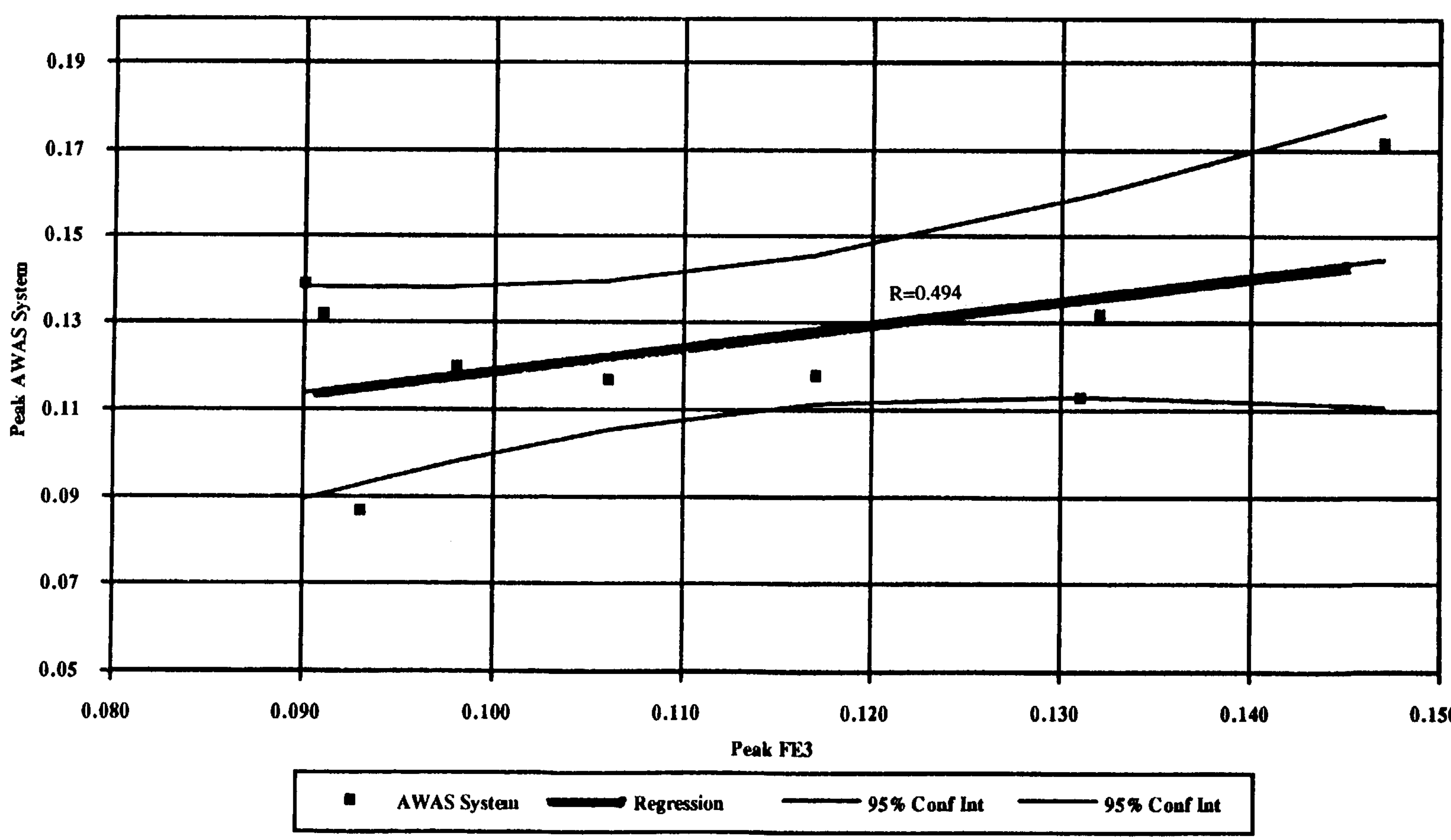
Event	Location	Peak FE3	Peak FE3 Time	Advance Detection Time	Difference WOMBAT5 vs. FE3	Correlation Value	FF chosen	FT chosen
B438	DEN	0.117	80150	40 seconds	+1%	0.437	X	
B454	DEN	0.098	1952	32 seconds	+22%	0.380		X
B464	DEN	0.131	6148	28 seconds	-14%	0.510		X
B465	DEN	0.090	6344	22 seconds	+54%	0.411	X	
B483	ORL	0.106	76024	46 seconds	+10%	0.450	X	
B484	ORL	0.091	76616	38 seconds	+45%	0.560		X
B490	ORL	0.093	62416	55 seconds	-6%	0.600		X
B553	ORL	0.147	80946	56 seconds	+17%	0.829		X
B555	ORL	0.132	81496	58 seconds	0%	0.801	X	

FE3 ± 30% Scattergram



95% Confidence Intervals

Scatter Plots for Events of 1992 Deployment
NASA FE3 vs AWAS-WOM5 System



Conclusions

System takes the earliest detection (either FF or FT), thus the complimentary functions (logical OR) of IR and OAT proved to be correct

IR/OAT system with new algorithm (WOMBAT5) predicted LLWS in both Denver and Orlando with average times of 41 seconds (min. 22 max.58 seconds)

Continued Development

LLWS Thermal Methods are successful

LLWS Algorithm development needs to continue with Specific Algorithms for IR and OAT

Future Applications

IR/Thermal Imaging is a valuable technology for Aviation

1) LLWS Imaging
2) Wake Vortex Imaging (successful SBIR Phase I)
3) Clear Air Turbulence Imaging
4) Volcanic Ash Imaging
5) Jet Stream Imaging

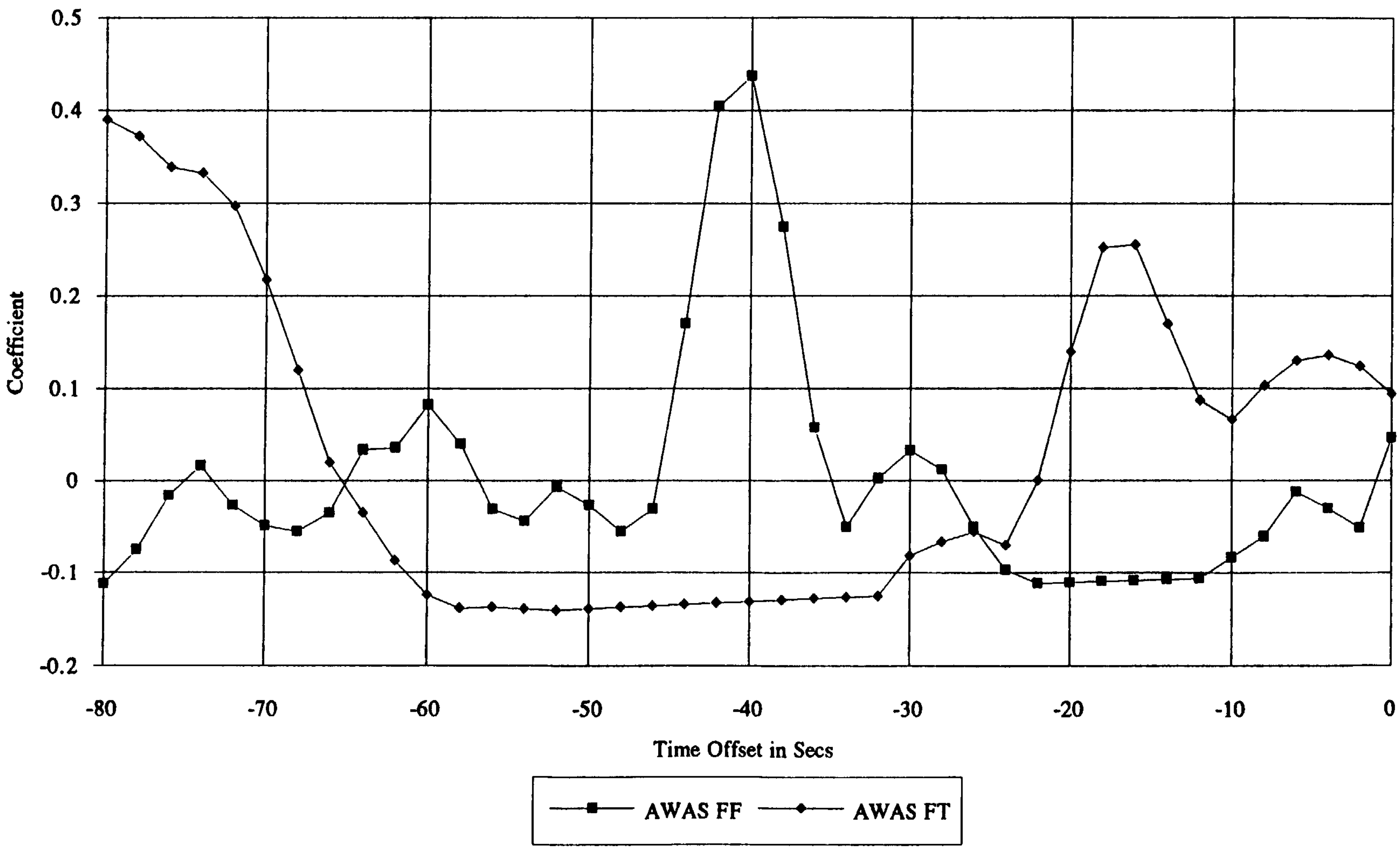
Conclusions

IR Weather Imaging Systems should be funded for Future contributions to aviation safety and efficiency.

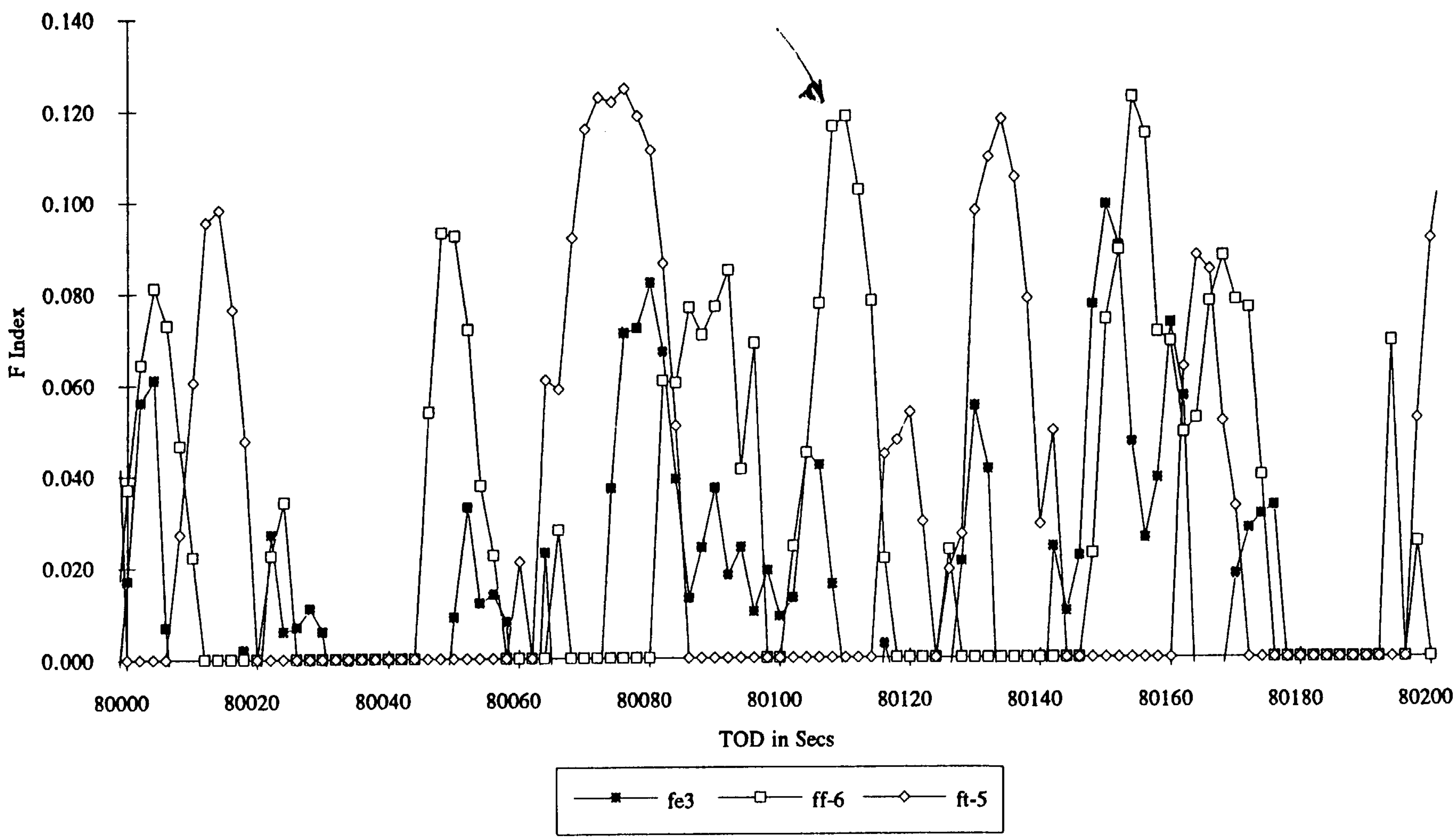
Appendix

Contains graphs of 1 second NASA FE3 and AWAS WOMBAT5 data used for analysis as well as the cross correlations done at a 0.06 noiseband level.

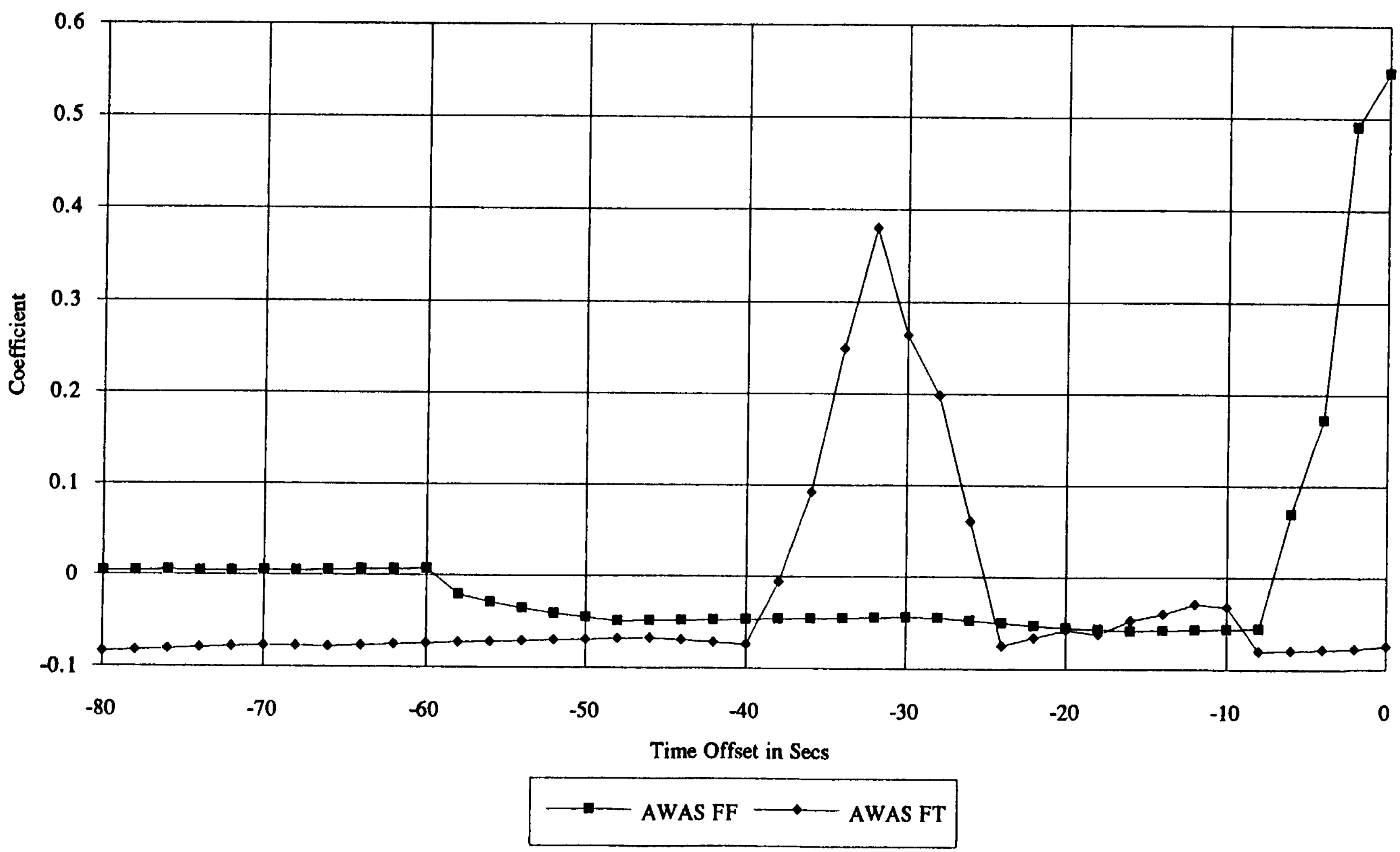
Cross Correlation for NASA Event B438
0.06 Noiseband Used

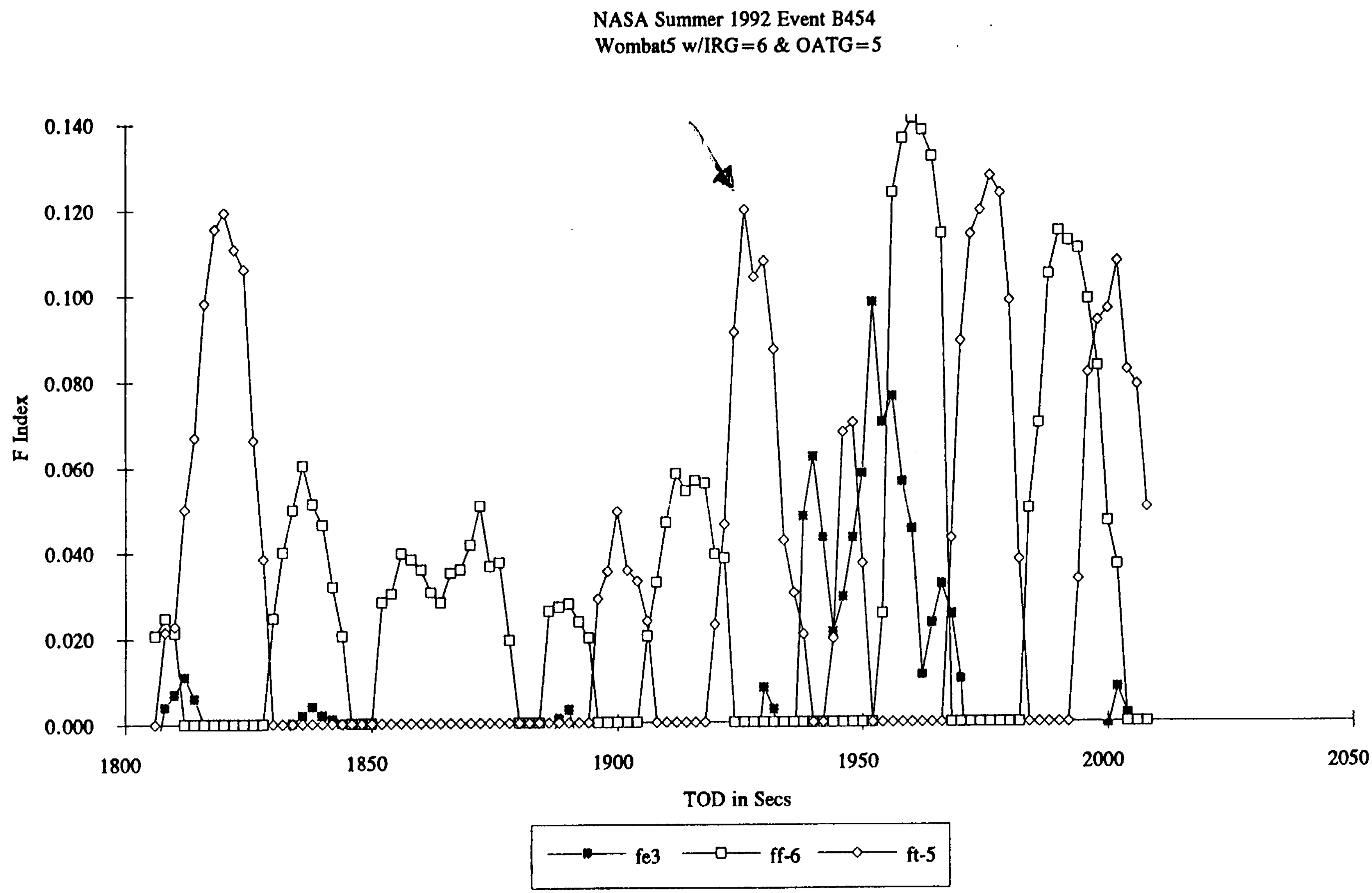


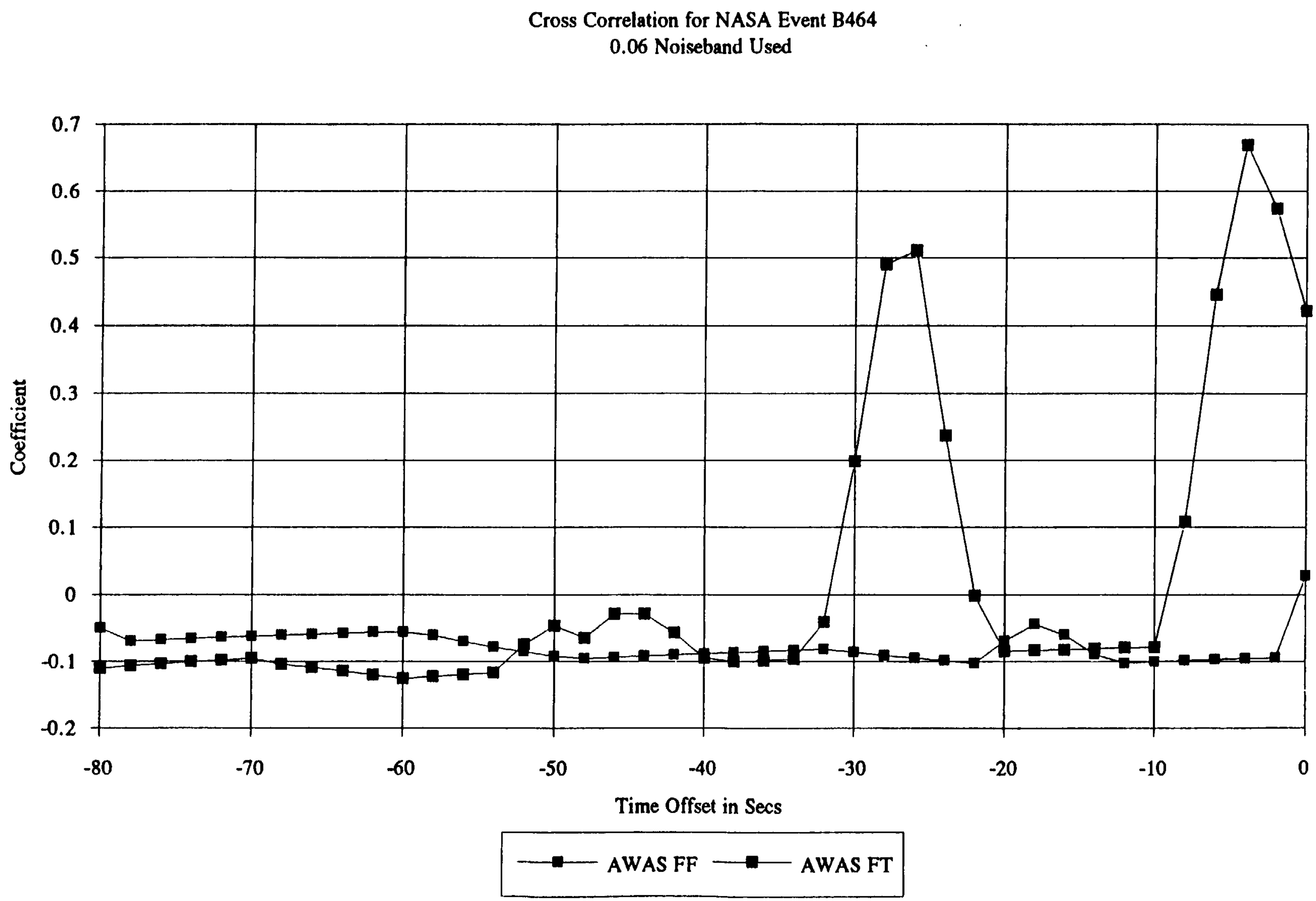
NASA Summer 1992 Event B438
Wombat5 w/IRG=6 & OATG=5



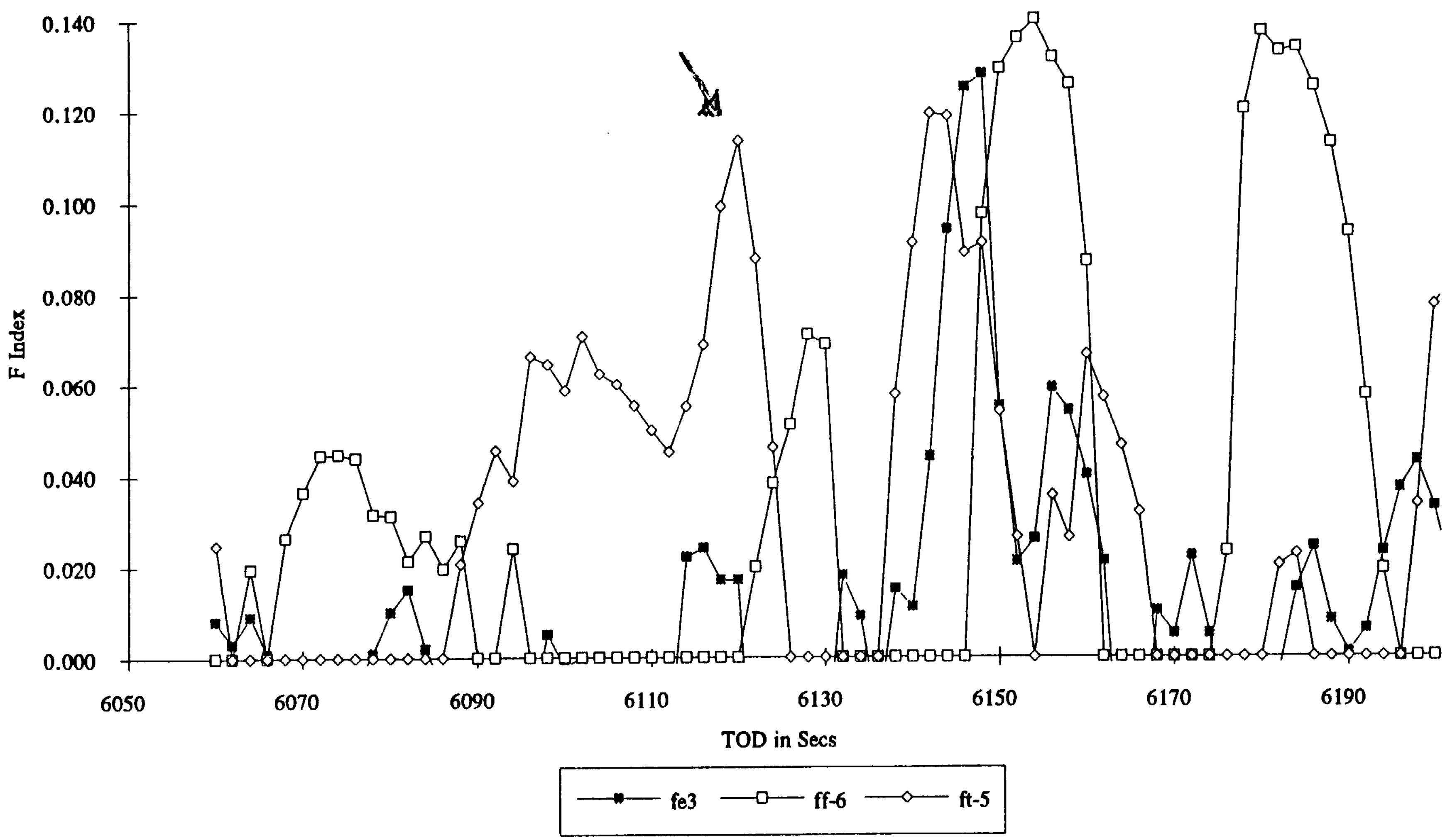
Cross Correlation for NASA Event B454
0.06 Noiseband Used



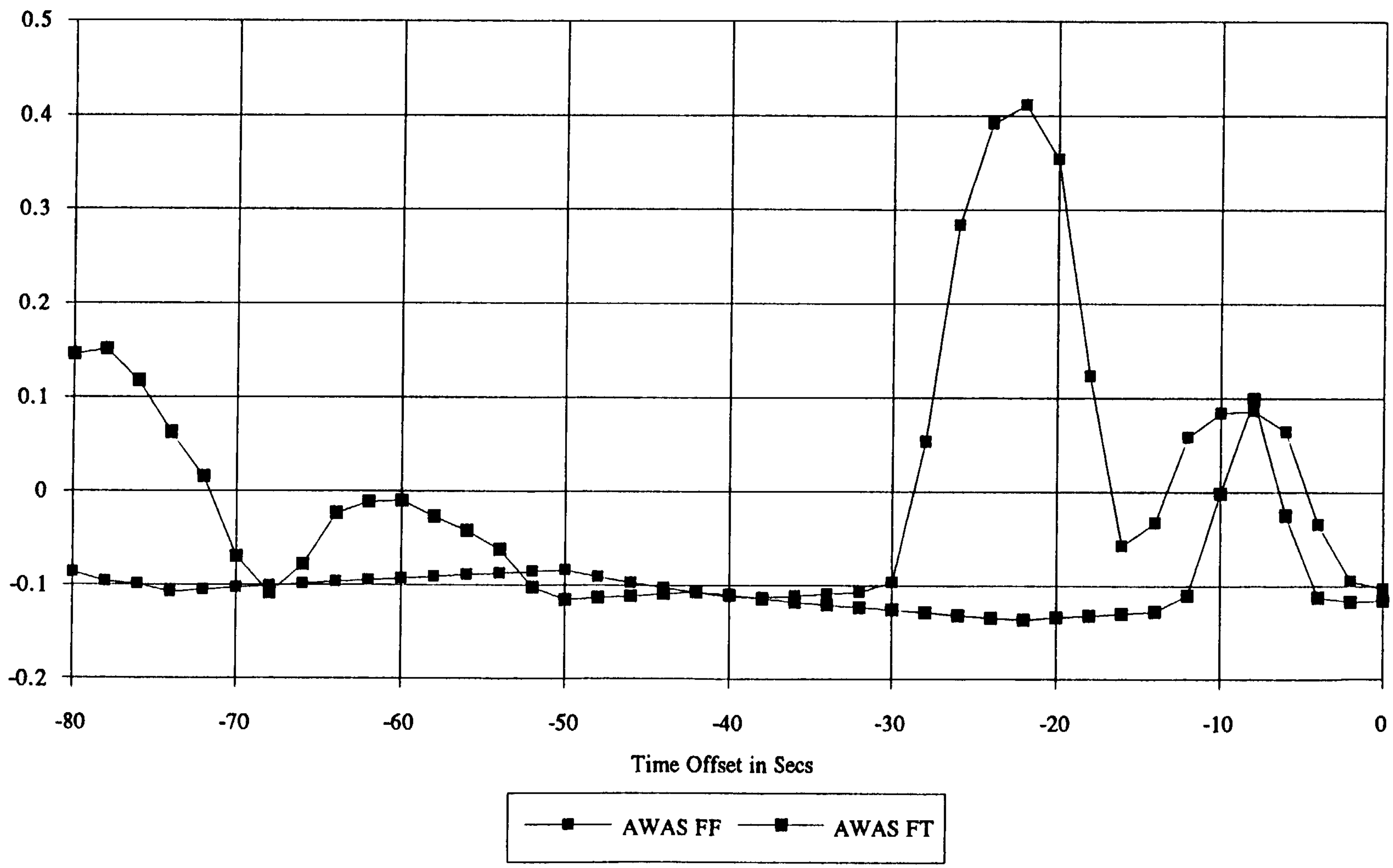

NASA Summer 1992 Event B454
Wombat5 w/IRG=6 & OATG=5
F Index
0.140
0.120
0.100
0.080
0.060
0.040
0.020
0.000
1800
1850
1900
1950
2000
2050
TOD in Secs
fe3
ff-6
ft-5

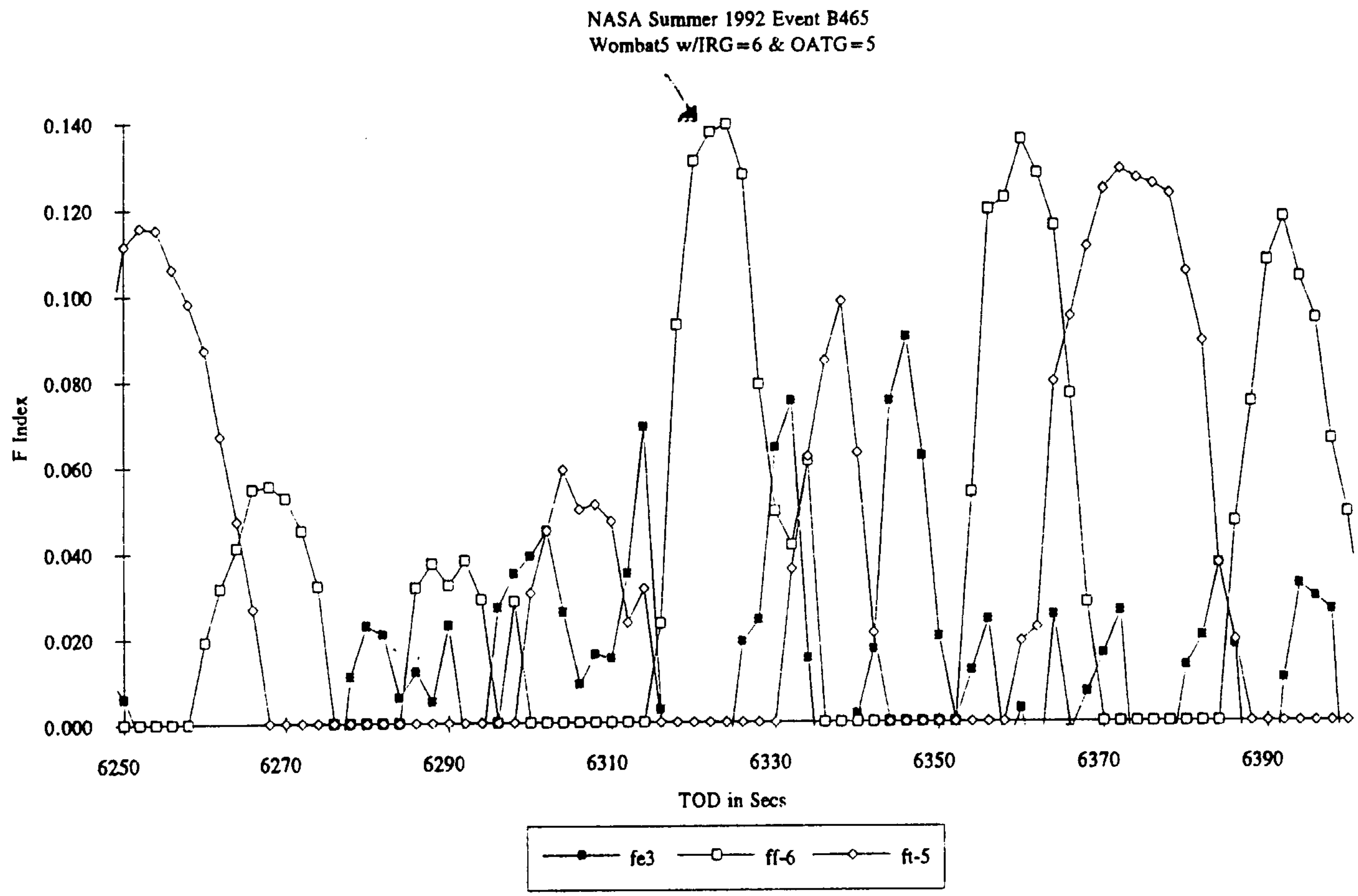

Cross Correlation for NASA Event B464
0.06 Noiseband Used
Coefficient
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-80
-70
-60
-50
-40
-30
-20
-10
0
Time Offset in Secs
AWAS FF
AWAS FT

NASA Summer 1992 Event B464
Wombat5 w/IRG=6 & OATG=5

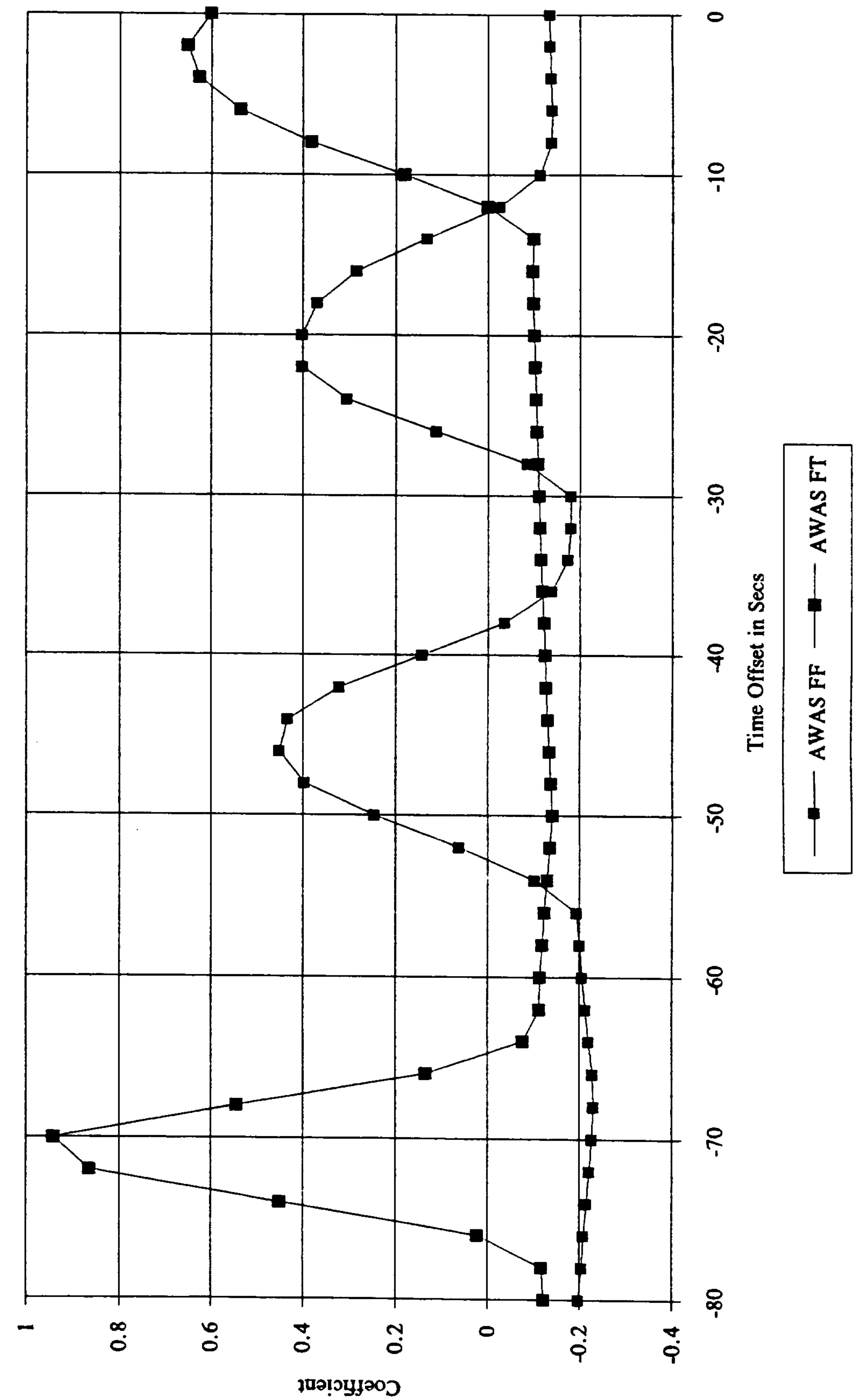


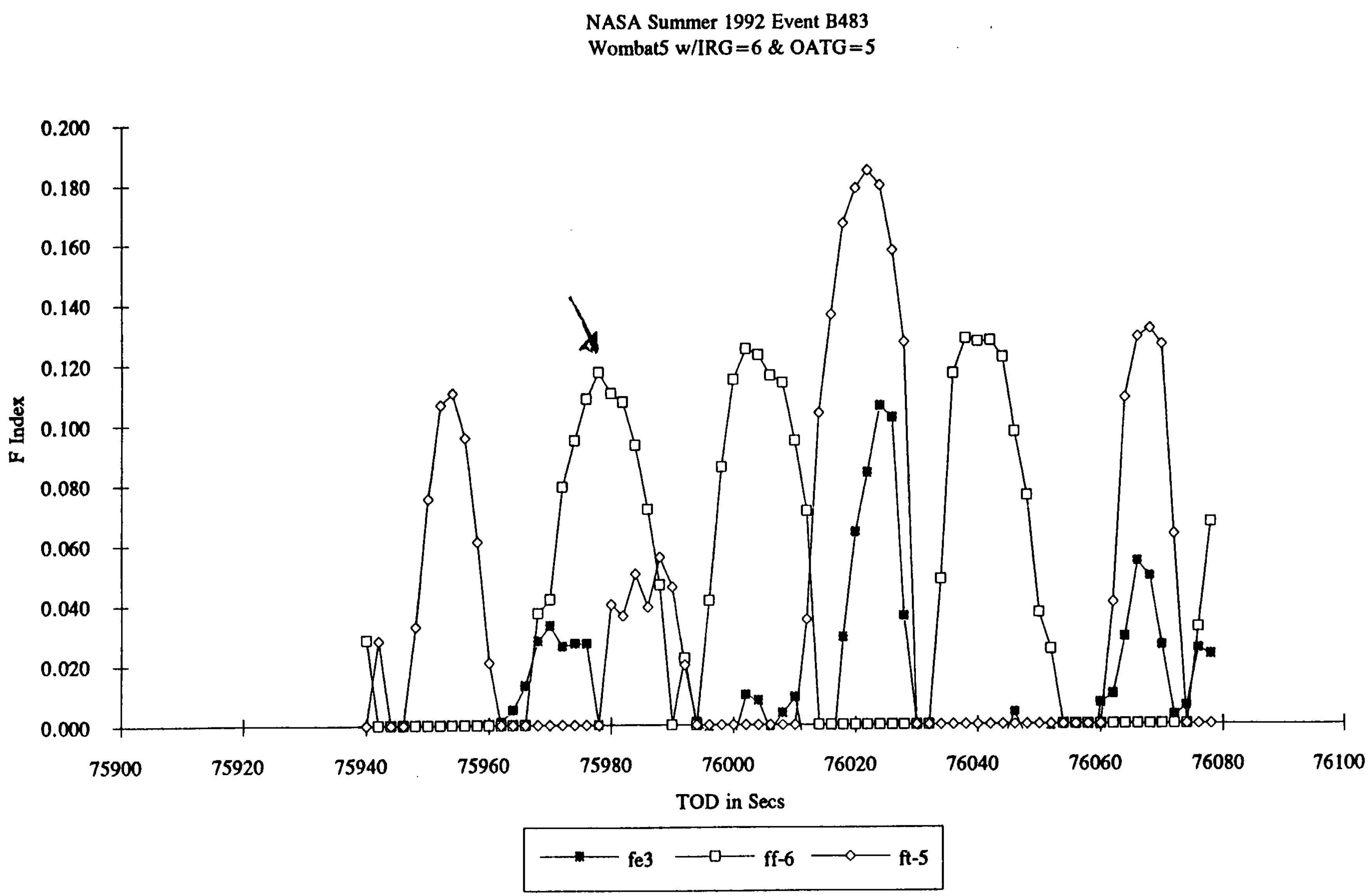
Cross Correlation for NASA Event B465
0.06 Noiseband Used



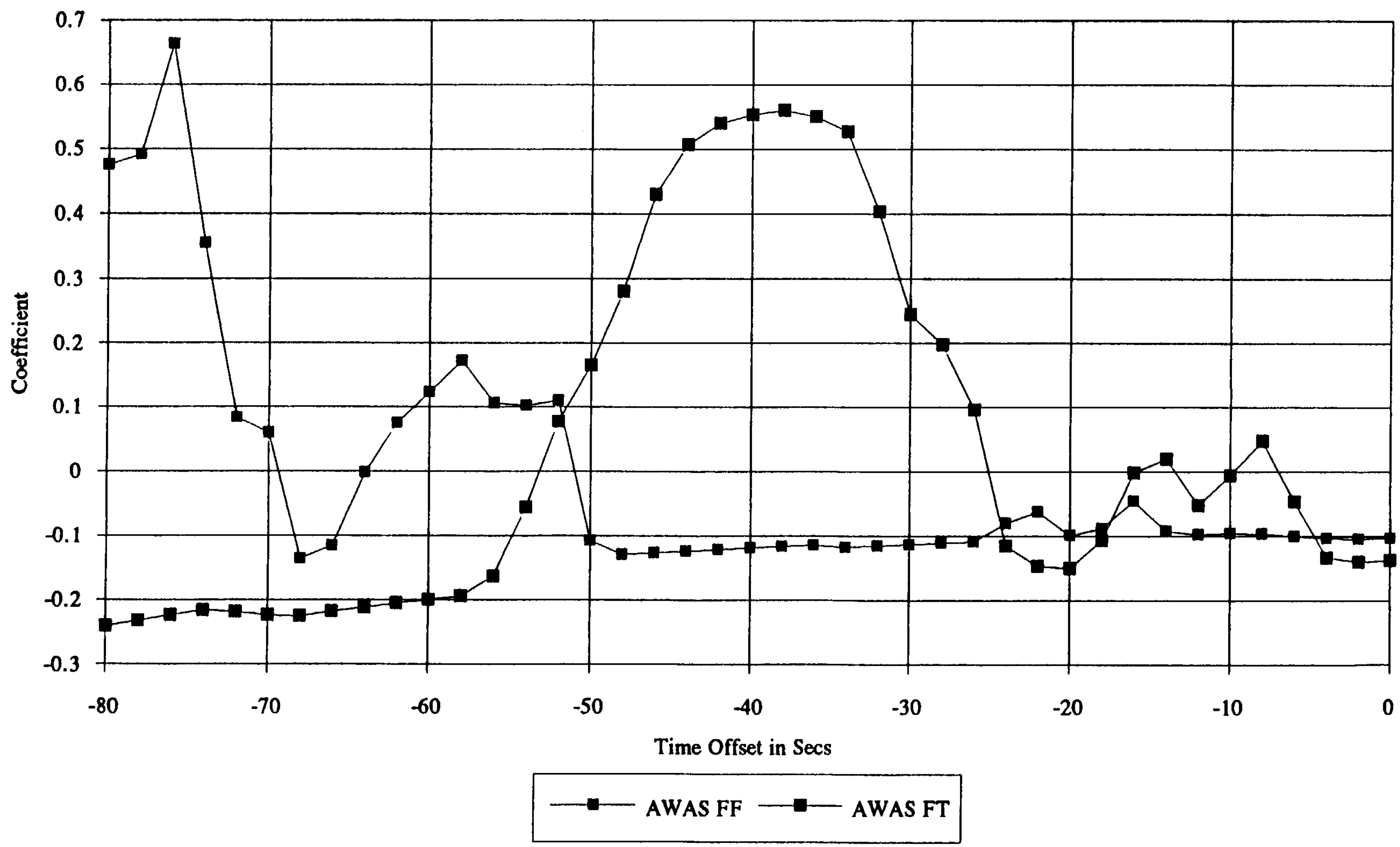

NASA Summer 1992 Event B465
Wombat5 w/IRG=6 & OATG=5
F Index
0.140
0.120
0.100
0.080
0.060
0.040
0.020
0.000
6250
6270
6290
6310
6330
6350
6370
6390
TOD in Secs
fe3
ff-6
ft-5

Cross Correlation for NASA Event B483
0.06 Noiseband Used

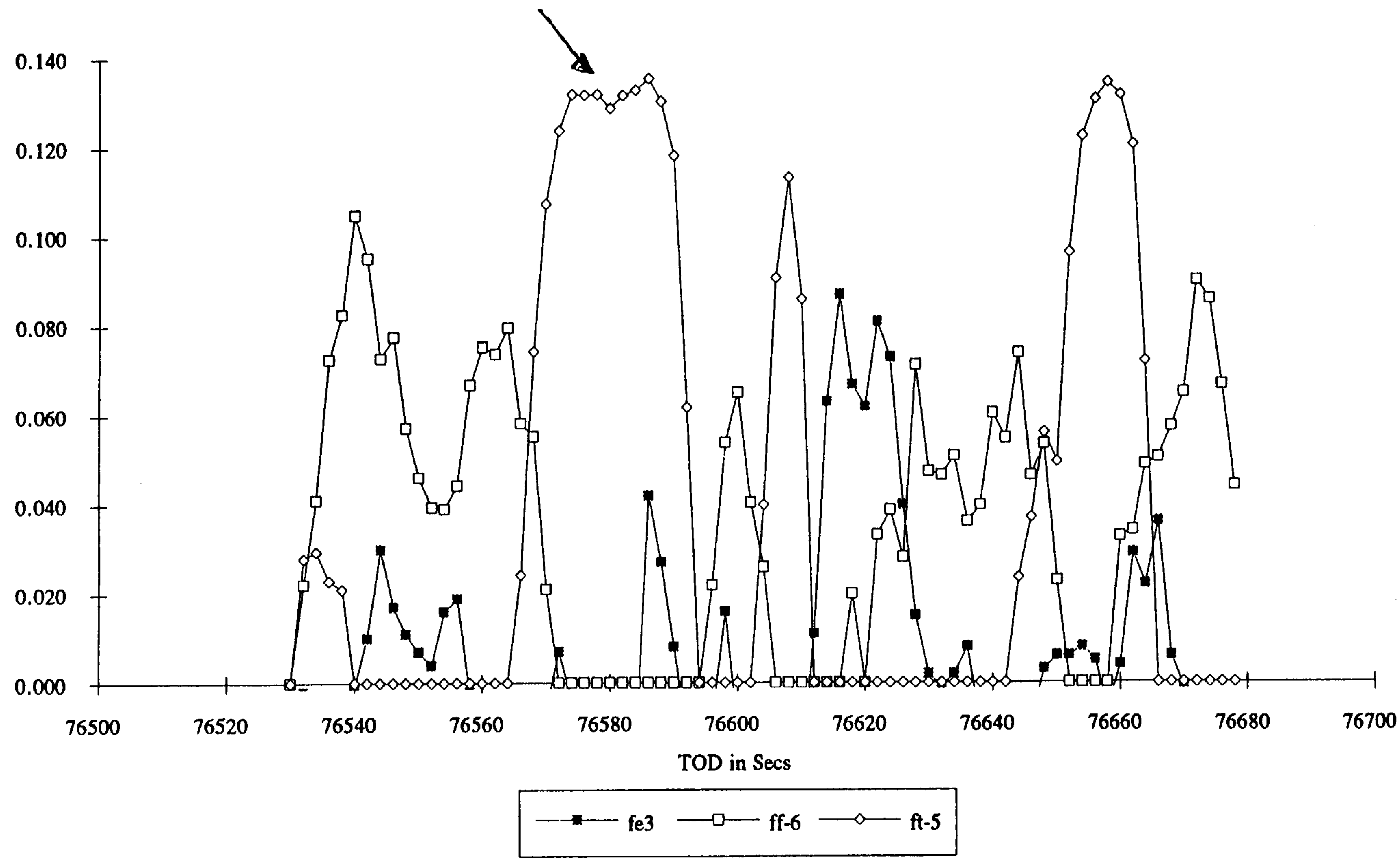


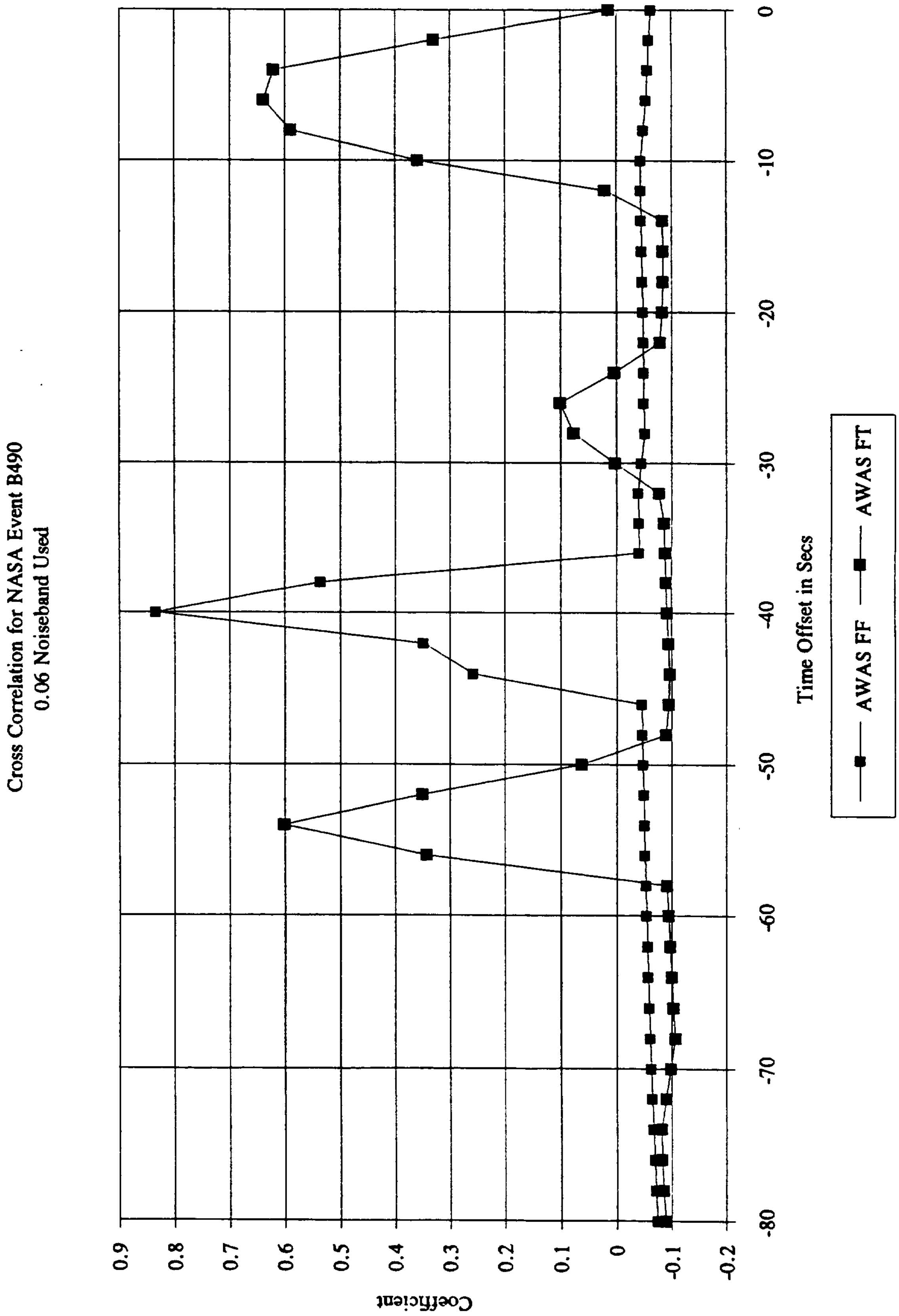

NASA Summer 1992 Event B483
Wombat5 w/IRG=6 & OATG=5
F Index
0.200
0.180
0.160
0.140
0.120
0.100
0.080
0.060
0.040
0.020
0.000
75900
75920
75940
75960
75980
76000
76020
76040
76060
76080
76100
TOD in Secs
fe3
ff-6
ft-5

Cross Correlation for NASA Event B484
0.06 Noiseband Used

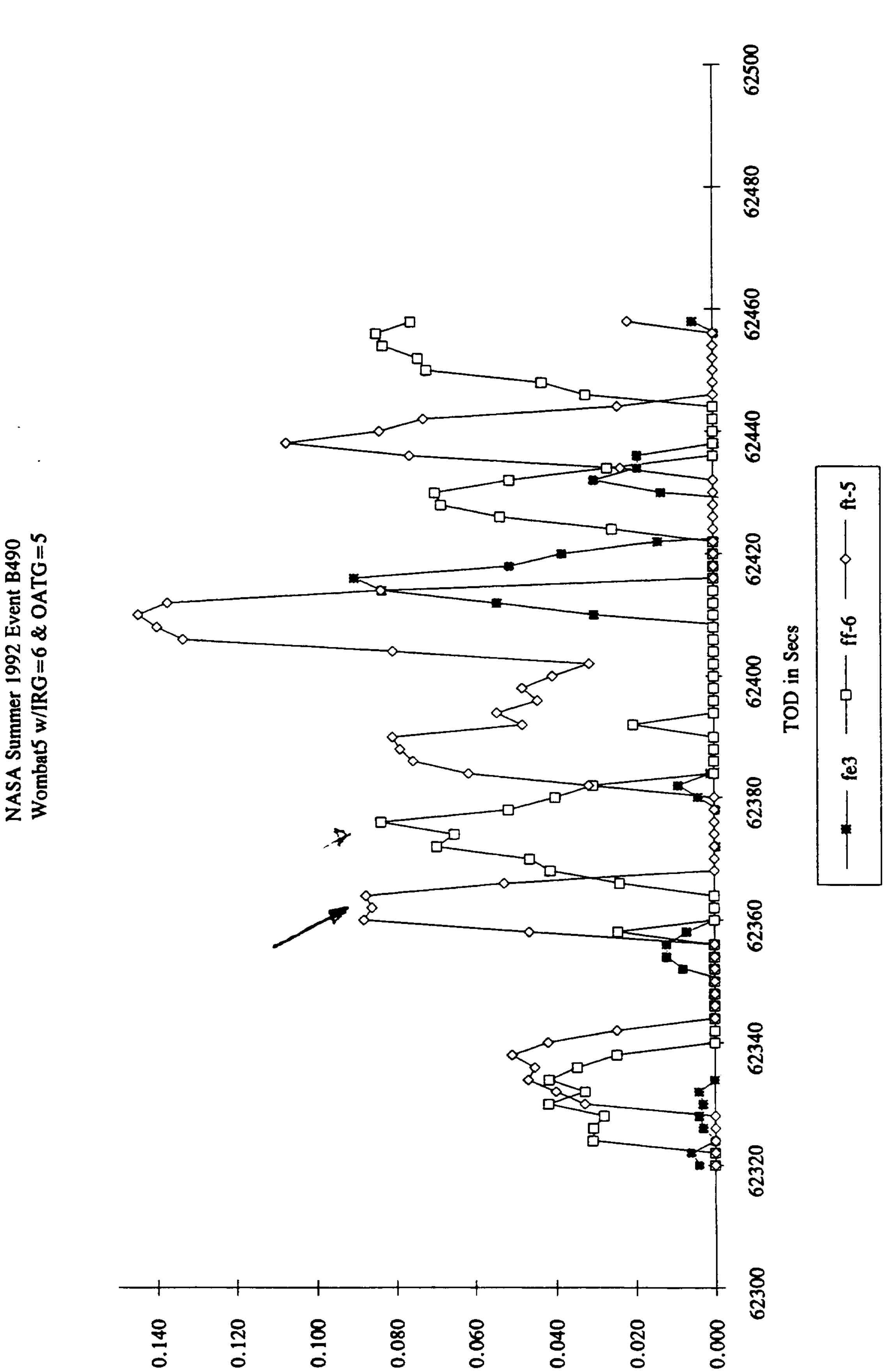


NASA Summer 1992 Event B484
Wombat5 w/IRG=6 & OATG=5

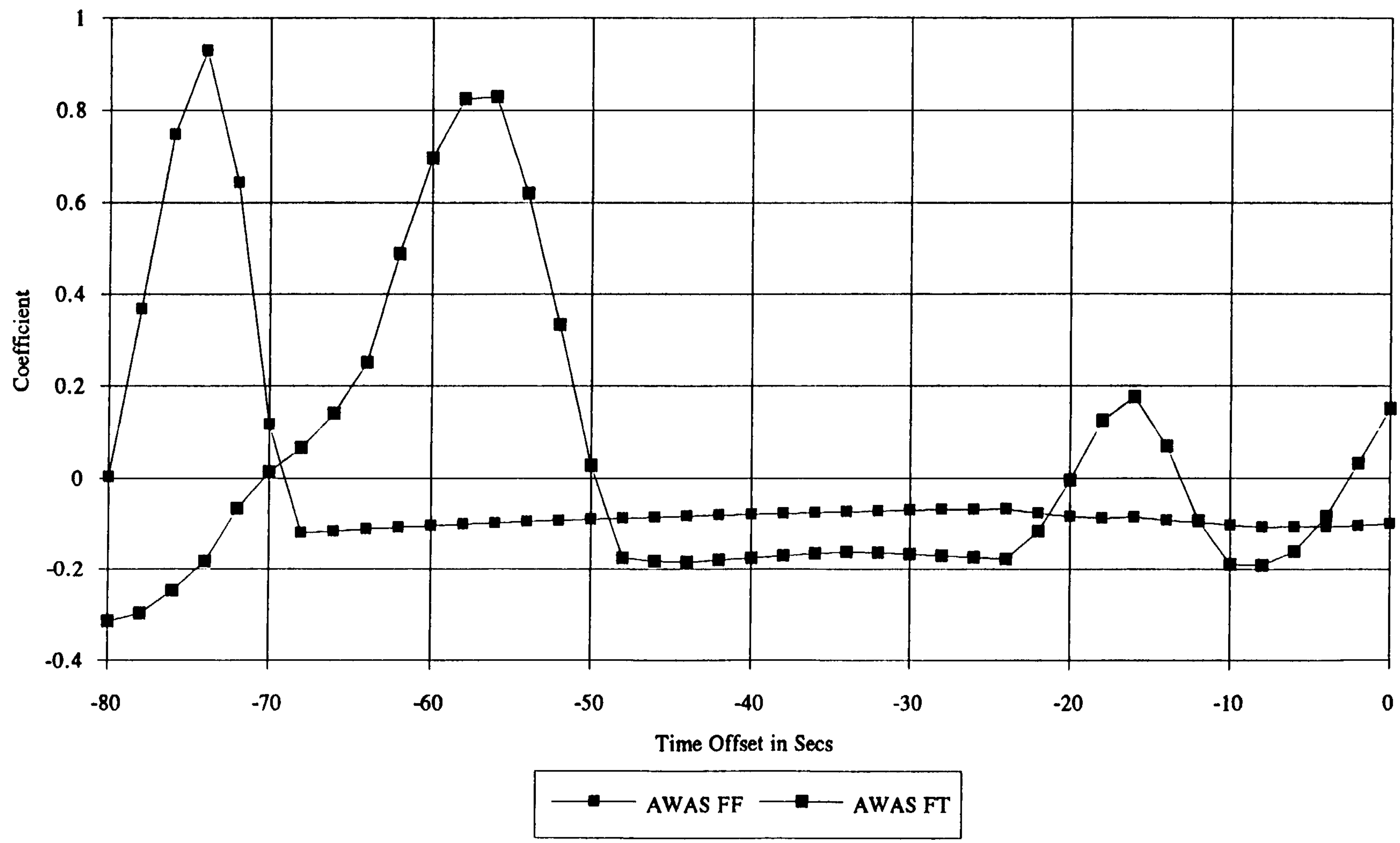


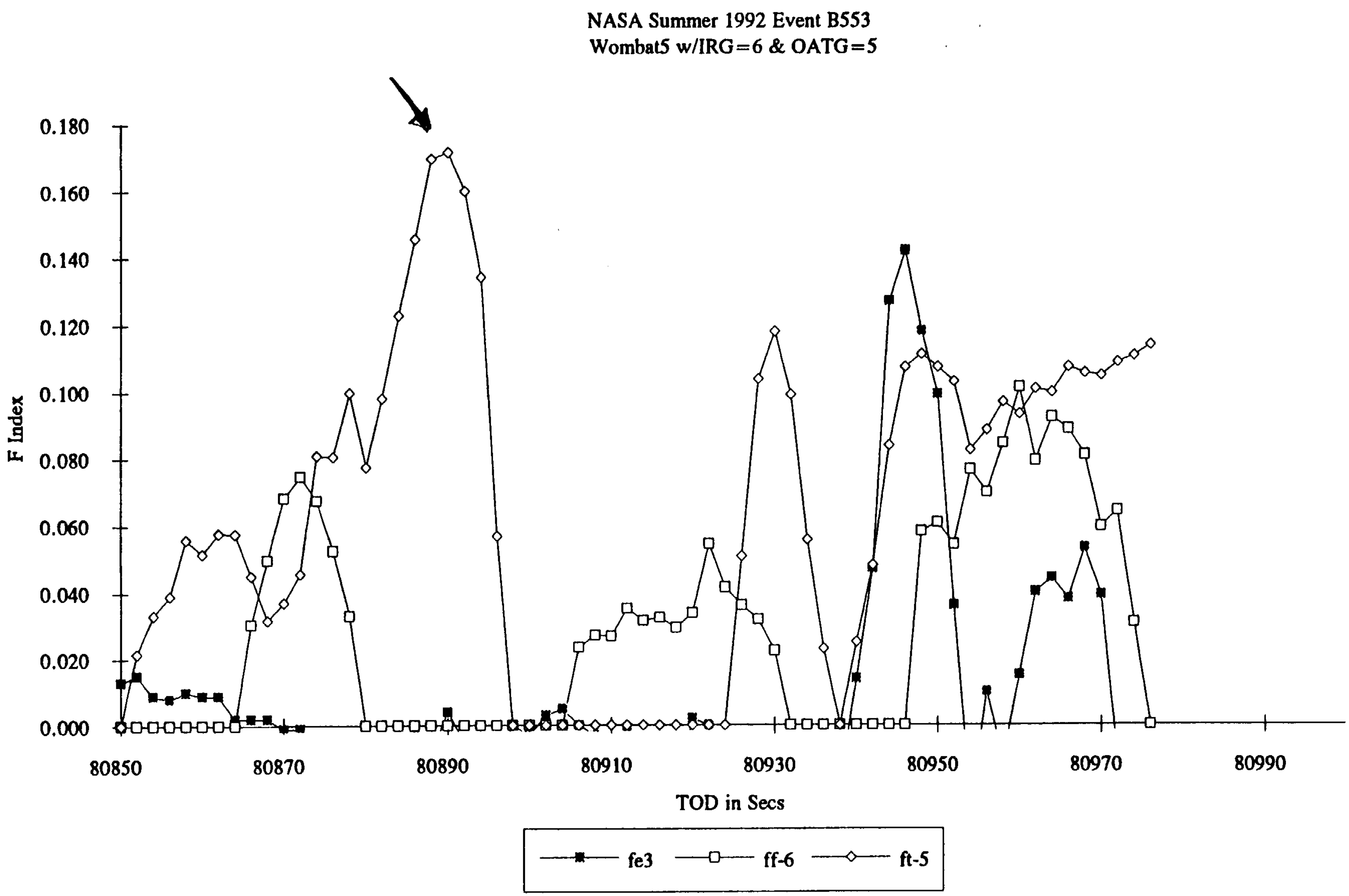


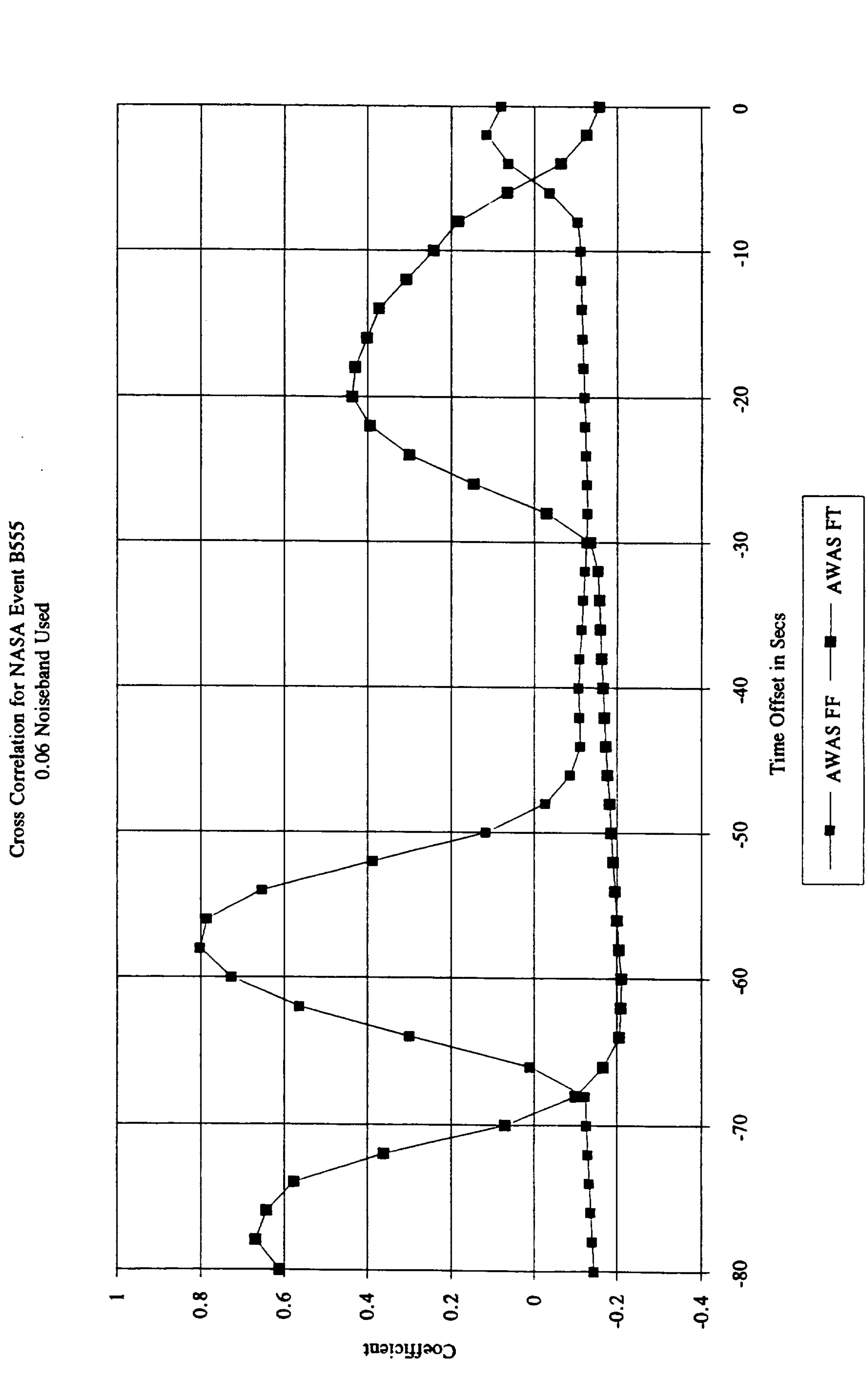
Cross Correlation for NASA Event B490
0.06 Noiseband Used
Coefficient
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
Time Offset in Secs
-80
-70
-60
-50
-40
-30
-20
-10
0
AWAS FF
AWAS FT

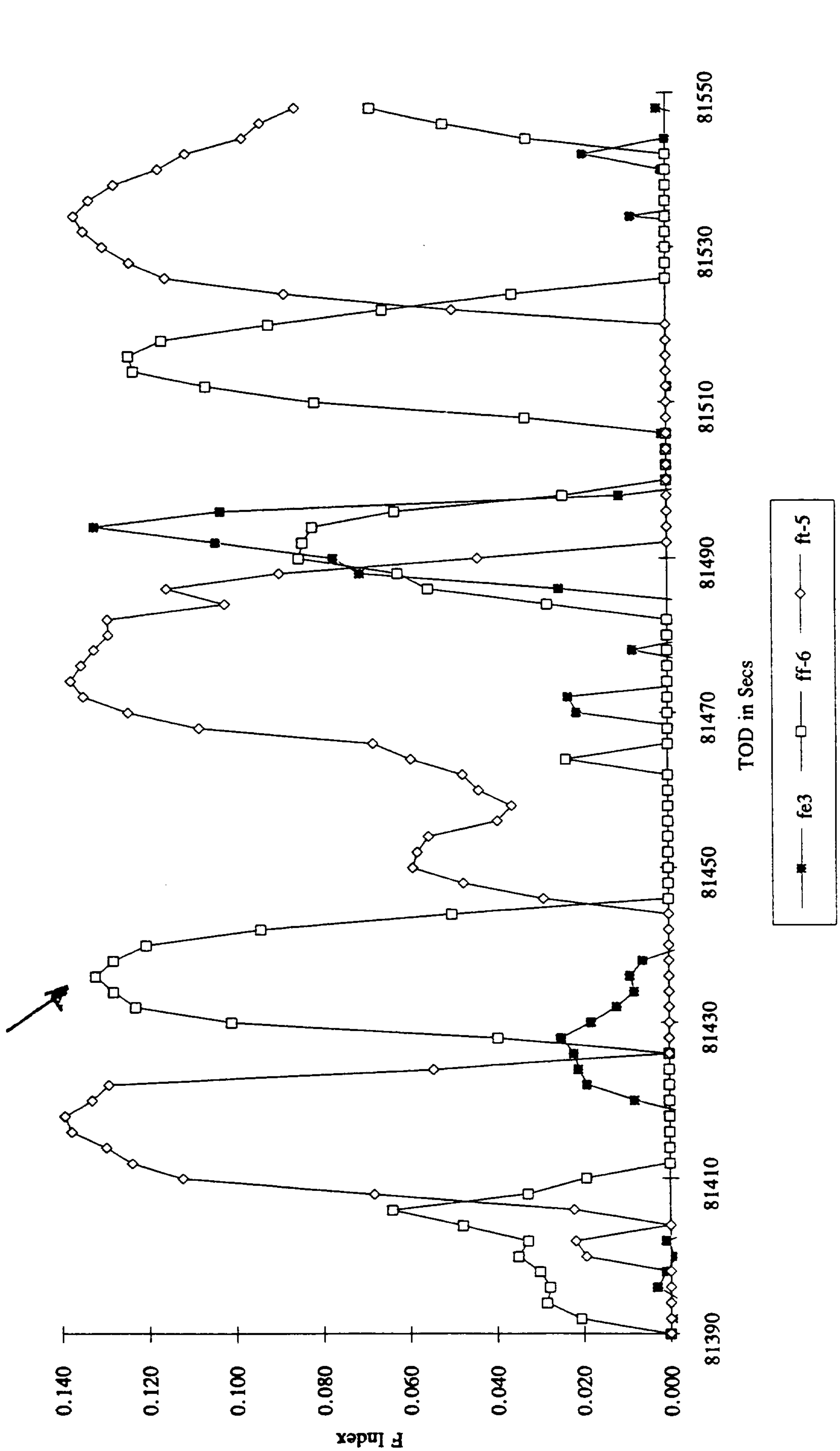

NASA Summer 1992 Event B490
Wombat5 w/IRG=6 & OATG=5
F Index
0.000
0.020
0.040
0.060
0.080
0.100
0.120
0.140
62300
62320
62340
62360
62380
62400
62420
62440
62460
62480
62500
TOD in Secs
fe3
ff-6
ft-5

Cross Correlation for NASA Event B553
0.06 Noiseband Used




NASA Summer 1992 Event B553
Wombat5 w/IRG=6 & OATG=5
F Index
0.180
0.160
0.140
0.120
0.100
0.080
0.060
0.040
0.020
0.000
80850
80870
80890
80910
80930
80950
80970
80990
TOD in Secs
fe3
ff-6
ft-5


Cross Correlation for NASA Event B555
0.06 Noiseband Used
Coefficient
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
Time Offset in Secs
0
-10
-20
-30
-40
-50
-60
-70
-80
AWAS FF
AWAS FT


NASA Summer 1992 Event B555
Wombat5 w/IRG=6 & OATG=5
F Index
0.000
0.020
0.040
0.060
0.080
0.100
0.120
0.140
81390
81410
81430
81450
81470
81490
81510
81530
81550
TOD in Secs
fe3
ff-6
ft-5

Overview and Highlights from Super-position Testing of the MODAR 3000,

B. Mathews, F. Miller,

K. Rittenhouse, L. Barnett,

and W. Rowe,

Westinghouse Electric Corp.

[Because it deals primarily with certification issues, the text portion of the material furnished for this presentation has been moved to Session 4, under the title Certification of Windshear Performance with RTCA Class D Radomes. What appears on the following 13 pages is the set of visuals depicting the appearance and attributes of the hardware used]

Westinghouse
Electronic Systems Group

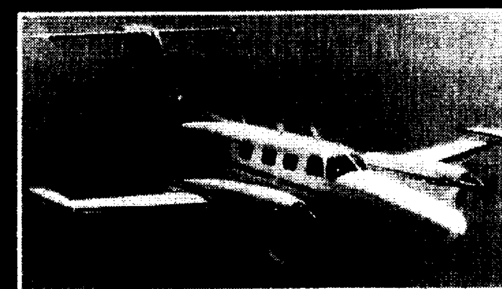
Modular Avionics
(MR-3000)

John Craner
(410) 765-0072

Introduces Family of MODular RadARs

MODAR 2000

Business and Commuter



MODAR 3000/3500

Commercial Air Transport

MODAR 4000

Military Tanker, Transport

MODAR

System Features for Advanced Performance

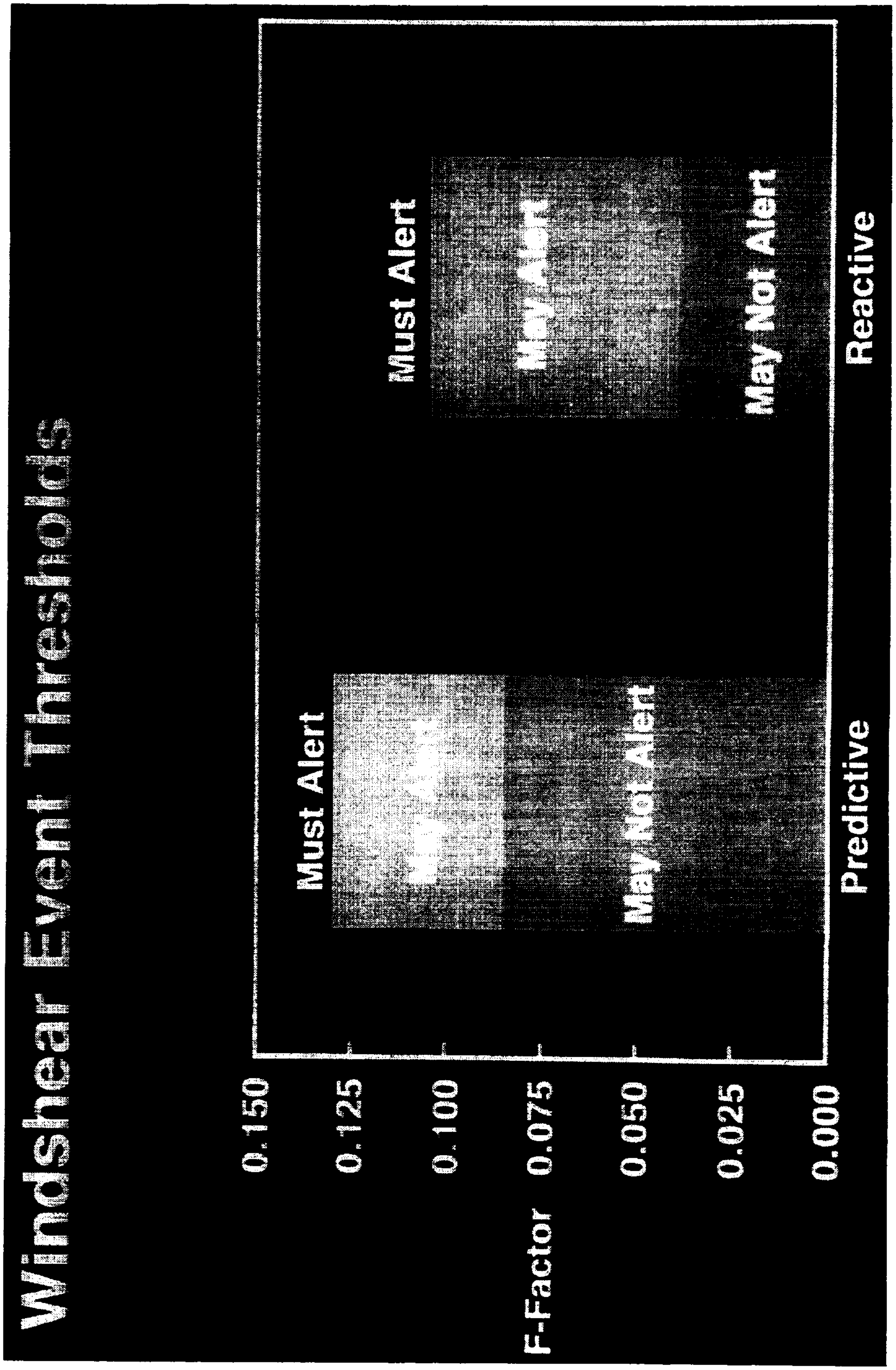
Critical: Accurate Velocity Measurement in "Dry" Events

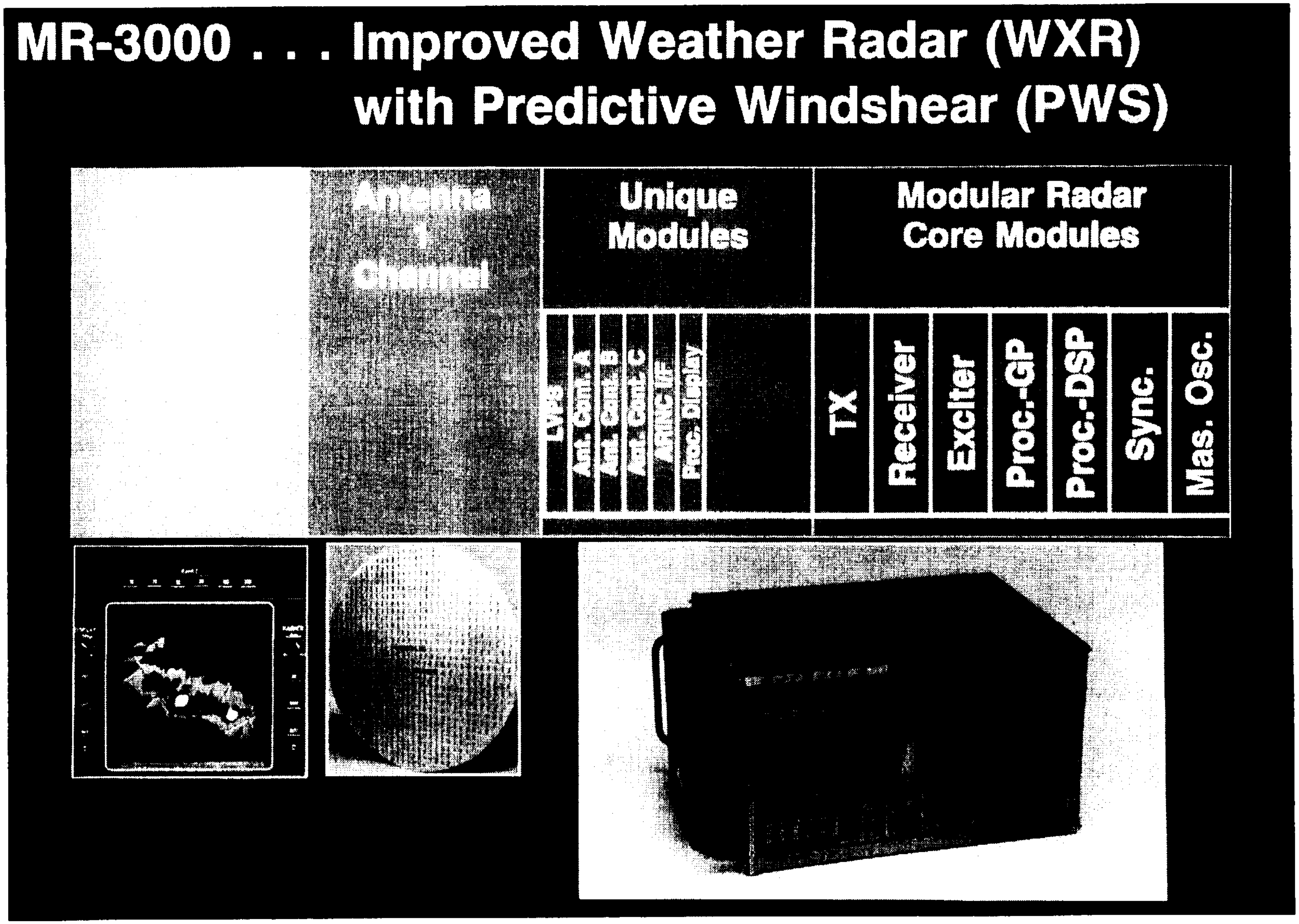
- Advanced clutter management
- Superior sensitivity
- Consistent performance over product life
  - Continuous built-in test and calibration

Predictive Windshear

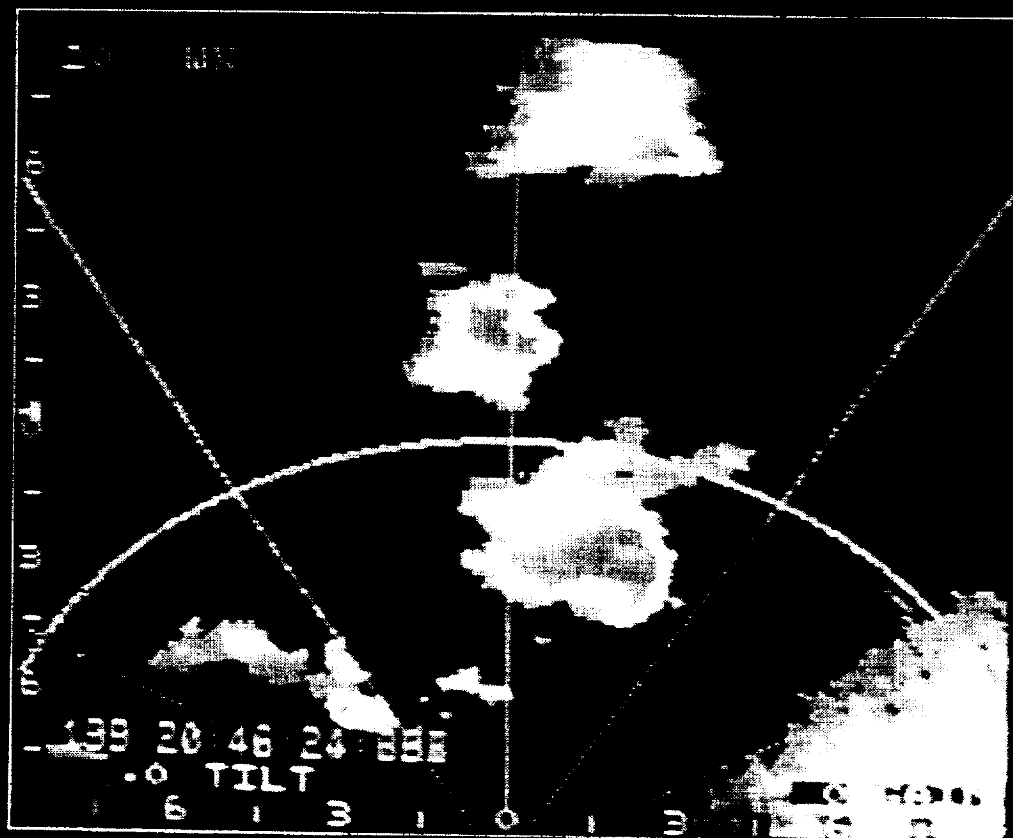
Confidence Insured Through Tough Specifications

Predictive	Reactive
• Probability of unannunciated failure $\leq 10^{-5}$/ flight hour of system operation	Same
• Probability of false alert $\leq 10^{-4}$ / take off, landing or go around	$\leq 10^{-4}$ /flight hour
• Probability of nuisance alert $\leq 4 \times 10^{-3}$ /windshear event	$\leq 4 \times 10^{-3}$ / hour of exposure
• Probability of missed detect $\leq 10^{-5}$ / hazardous event	N/A
• Warning $\geq$ 10 seconds ahead of event	<5 seconds after
• Proper icon scoring and display	N/A
• Detection of events as "dry" as 0 dBz	N/A
• Windshear event may alert region 0.045	May alert region 0.065


Windshear Event Thresholds
F-Factor
0.150
0.125
0.100
0.075
0.050
0.025
0.000
Must Alert
May Alert
May Not Alert
Predictive
Must Alert
May Alert
May Not Alert
Reactive

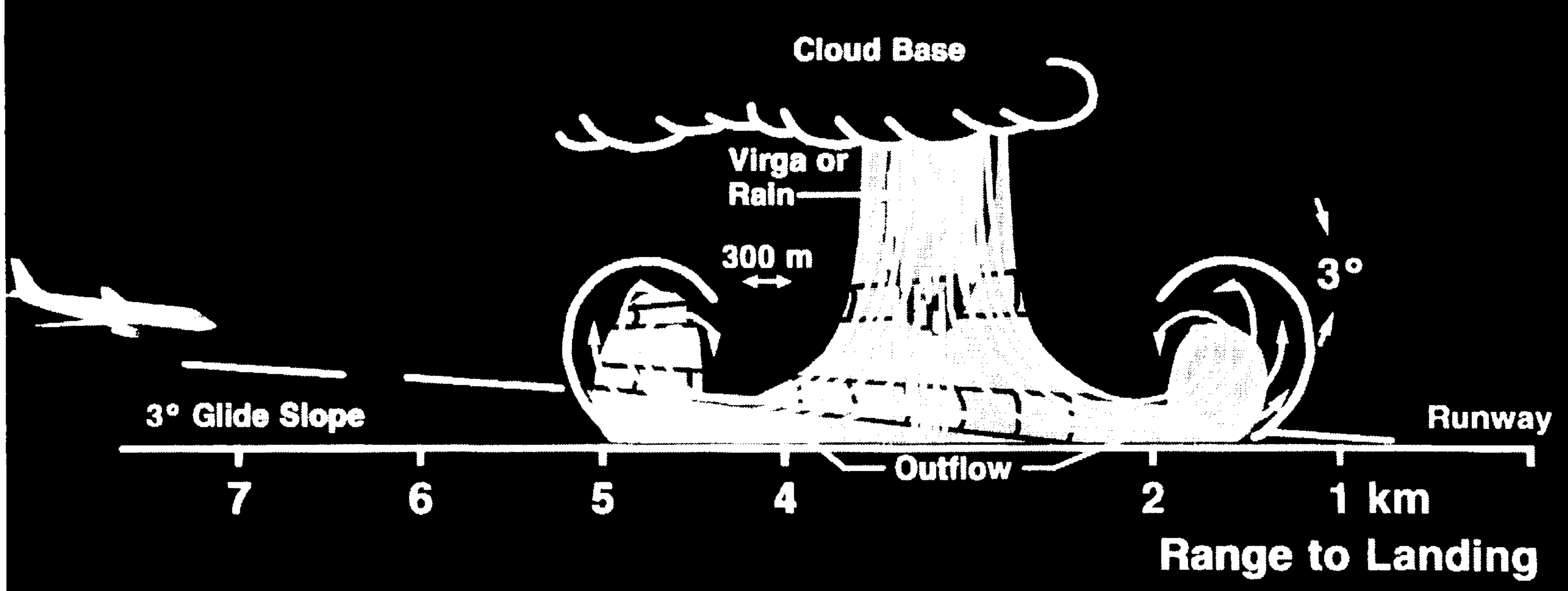

MR-3000 . . . Improved Weather Radar (WXR)
with Predictive Windshear (PWS)
Antenna
1
Channel
Unique
Modules
LVPS
Ant. Cont. A
Ant. Cont. B
Ant. Cont. C
ARINC I/F
Proc. Display
Modular Radar
Core Modules
TX
Receiver
Exciter
Proc.-GP
Proc.-DSP
Sync.
Mas. Osc.

System Features for Windshear Benefit Weather Performance



From Orlando Flight Tests 7/92

Proven, Reliable Windshear Detection in the Presence of Heavy Ground Clutter



MR-3000 Operational Modes

- Standby (Default)
- Weather
- Weather plus turbulence
- Map
- Windshear
- Test (BIT)

Automatic Turn-On

- Programmable configuration options:
  - Custodial mode enabled for CMC communication only
  - Full up auto turn-on
- Automatic power-up and transition to windshear mode
- Qualifiers
  - Altitude less than 2300 feet and,
  - Oil pressure high (in one of two engines) and,
  - Transponder on (one of two transponders)

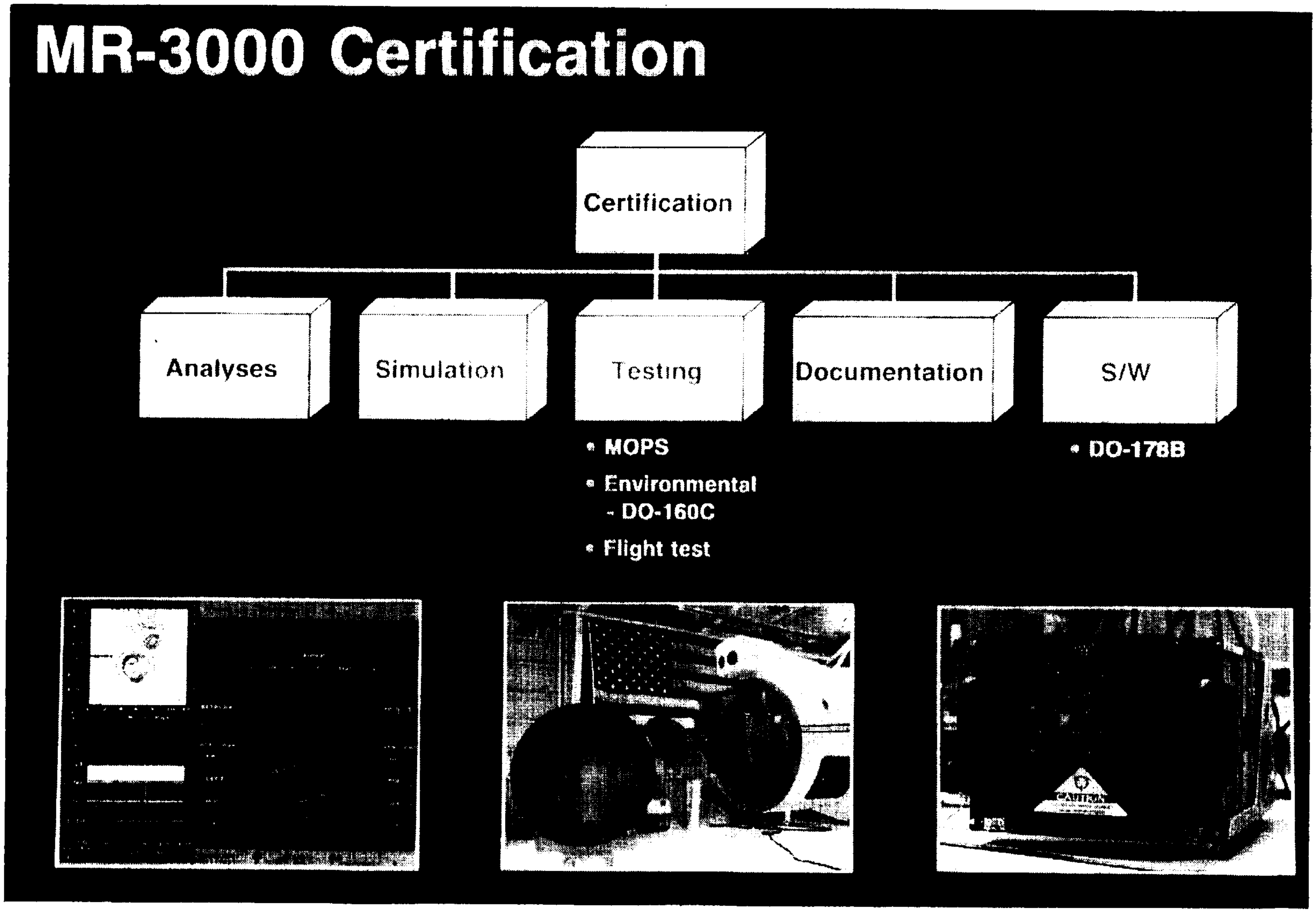
Extensive BIT = Consistent Performance + Accurate Fault Detection/Isolation

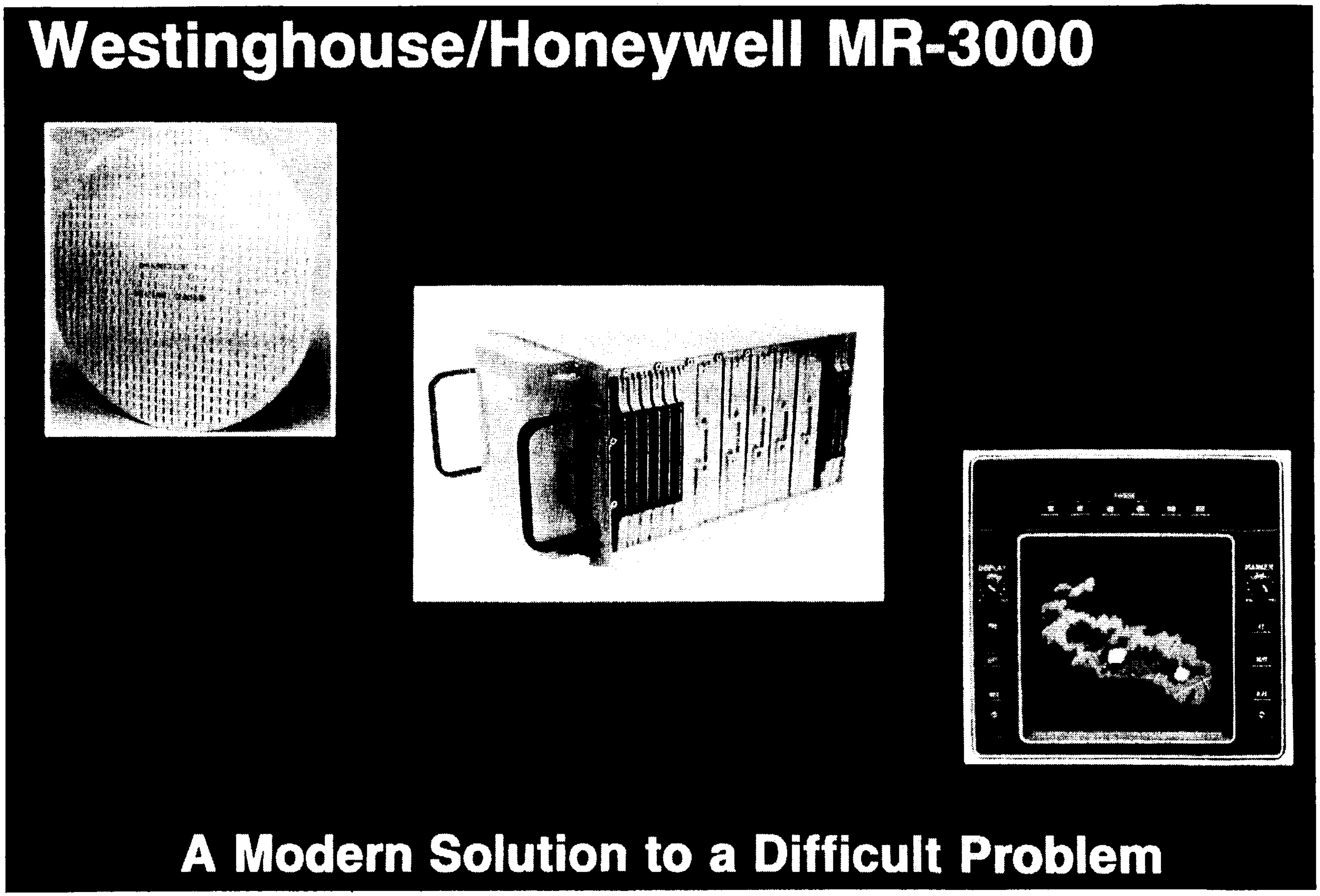
- Continuous
- Fault isolates to LRU level
- RTP fault isolates to LRM level (FD/FI > 99%)

Performance Features Reduce Cost of Ownership

- Modularity (combined with fault isolation)
  - Reduces sparing (LRU vs LRM)
  - Simplifies troubleshooting
  - Reduces no-fault-found rate
- Minimal investment for test equipment
  - Hot bench only for RTP, no special test equipment
  - Existing for other LRUs
- NO ...
  - Alignment or adjustment
  - Radar "pulls" for RF drift
  - "Matching" of LRUs, LRMs, or components

Introducing Tomorrow's IMA Concepts ... Today!


MR-3000 Certification
Certification
Analyses
Simulation
Testing
Documentation
S/W
• MOPS
• Environmental
- DO-160C
• Flight test
• DO-178B



Westinghouse/Honeywell MR-3000
A Modern Solution to a Difficult Problem

Wind Hazard Detection with a CO_2 Airborne Laser Radar.

R. Targ,
Lockheed Research and Development Co.,

P. Robinson,
Lockheed Engineering and Sciences Co.,

and

R. Bowles and P. Brockman,
NASA Langley Research Center

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

WIND HAZARD DETECTION WITH A CO_2 LASER RADAR

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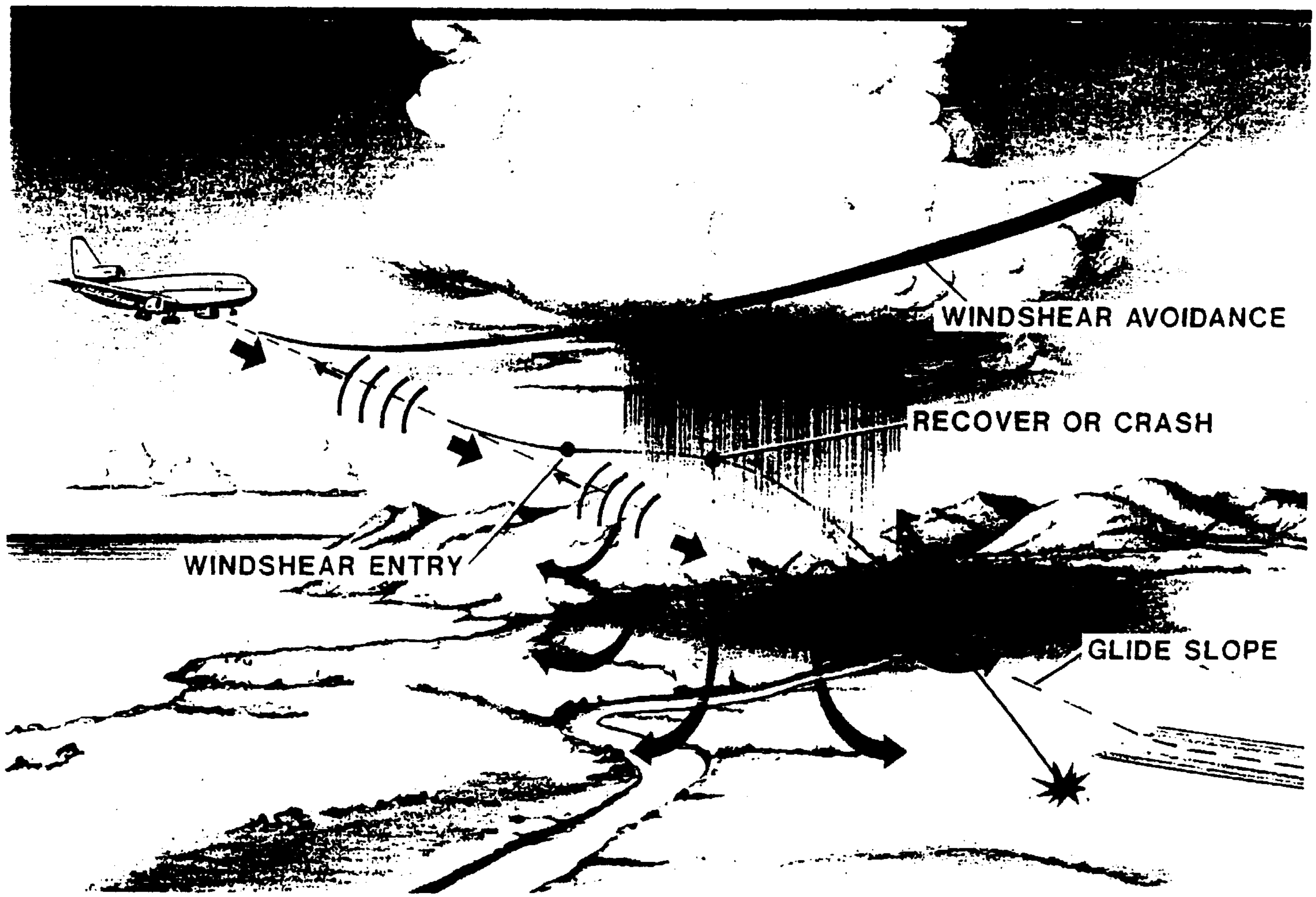
Paul A. Robinson
Lockheed Engineering and Sciences Co.
NASA Langley Research Center, Hampton, VA

September 28 - 30, 1993
Hampton, Virginia

PROGRAM OVERVIEW

- THIS $5M NASA-SUPPORTED INVESTIGATION IS PART OF THE NASA/FAA NATIONAL INTEGRATED WIND SHEAR PROGRAM
- FLIGHT-VALIDATION WIND SHEAR DATA WERE COLLECTED FROM DEPLOYMENTS AT DENVER AND ORLANDO USING A CO_2 LASER RADAR
- THESE HAZARD DATA WERE ANALYZED AND SENT FORWARD TO THE PILOT IN REALTIME AS A RANGE AZIMUTH F-FACTOR MAP
- LOCKHEED MISSILES & SPACE COMPANY WAS THE SYSTEM INTEGRATOR
- THE LIDAR TRANSCEIVER WAS BUILT BY UNITED TECHNOLOGY OPTICAL SYSTEMS (WEST PALM BEACH, FLORIDA)
- THE SIGNAL PROCESSOR AND DISPLAY SYSTEM WERE BUILT BY LASSEN RESEARCH (MANTON, CALIFORNIA)

THE WINDSHEAR PROBLEM



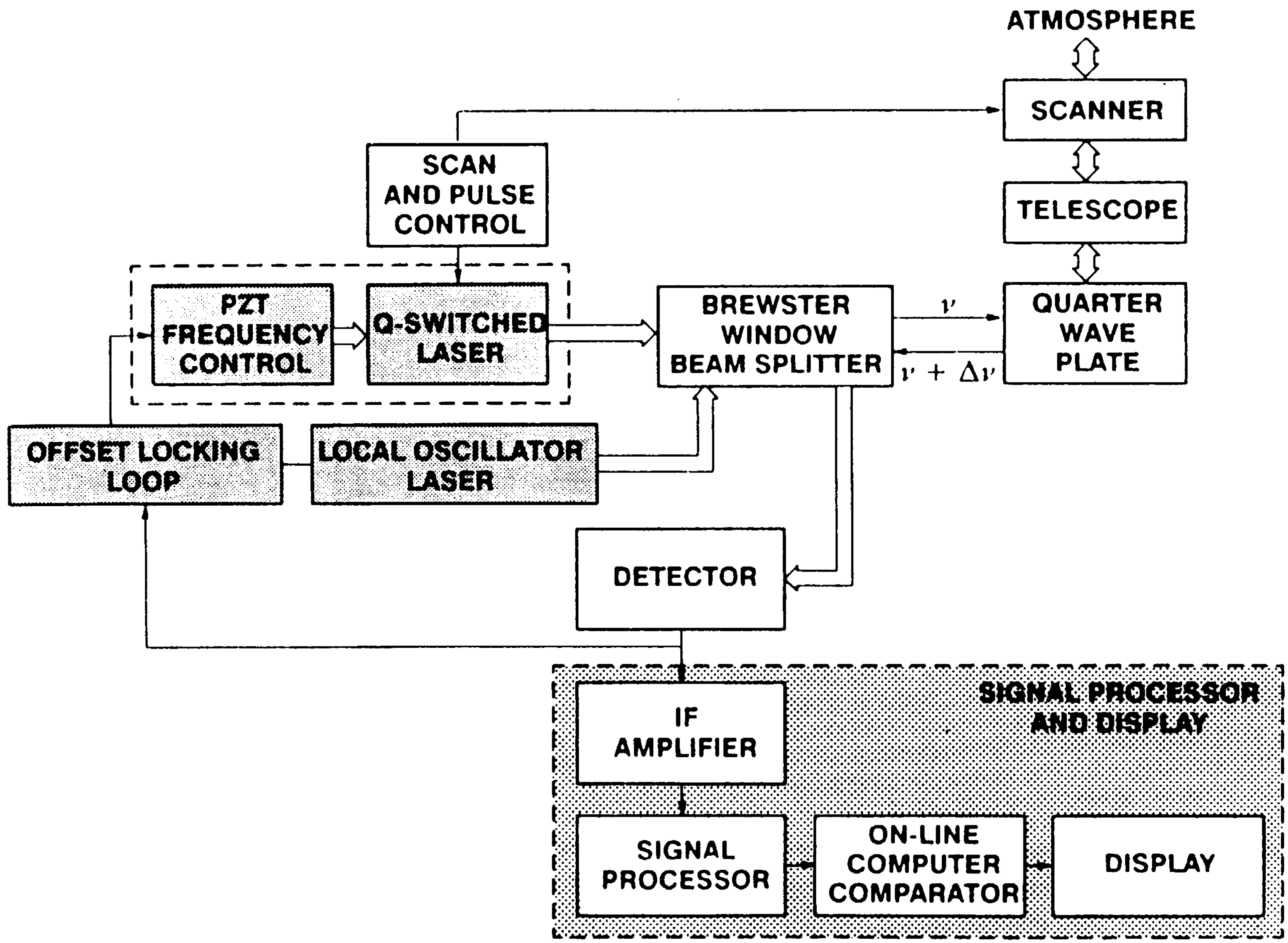
AIRBORNE WINDSHEAR DETECTION: GENERAL REQUIREMENTS

- MEASURE LINE-OF-SIGHT COMPONENTS OF WIND VELOCITY FROM AIRCRAFT
- DETECT THUNDERSTORM DOWNBURST EARLY IN ITS DEVELOPMENT
- EMPHASIZE AVOIDANCE RATHER THAN RECOVERY
- RESPOND IN REAL TIME WITH LOW FALSE-ALARM RATE
- MONITOR APPROACH PATH, RUNWAY, AND TAKEOFF PATH
- OPERATE IN BOTH RAIN AND CLEAR-AIR CONDITIONS
- OPERATE RELIABLY WITH MINIMUM MAINTENANCE IN AIRCRAFT ENVIRONMENT

CLASS SYSTEM REQUIREMENTS

- RANGE OF THE SYSTEM SHOULD BE 2–4 km
- WARNING – AT LEAST 20 s IN ADVANCE TO PILOT
- RANGE RESOLUTION SHOULD BE 300 m, FOR MICROBURST STRUCTURE
- MAXIMUM RADIAL VELOCITY ERROR <1 m/s, FOR F-FACTOR HAZARD
- DESIGN OF SYSTEM SHOULD BE CONSISTENT WITH COMMERCIAL AVIATION USE

BLOCK DIAGRAM USING PULSED LASER



SIGNAL-TO-NOISE EQUATION FOR REMOTE ATMOSPHERIC SENSING LASER VELOCIMETER

$$\mathrm{SNR}\ (R) = \frac{E\eta\beta(R)\lambda K^2 \pi D^2}{8\ hB_N R^2}\left[1 + \left(\frac{D}{2S_0}\right)^2 + \left(\frac{\pi D^2}{4\lambda R}\right)^2\left(1 - \frac{R}{F}\right)^2\right]^{-1}$$

where:

E = laser pulse energy (J)

D = telescope diameter (m)

$\beta(R)$ = backscatter coefficient ($m^{-1}\ sr^{-1}$)

λ = laser wavelength (m)

η = detector heterodyne and quantum efficiency

K = extinction for range R (1/m)

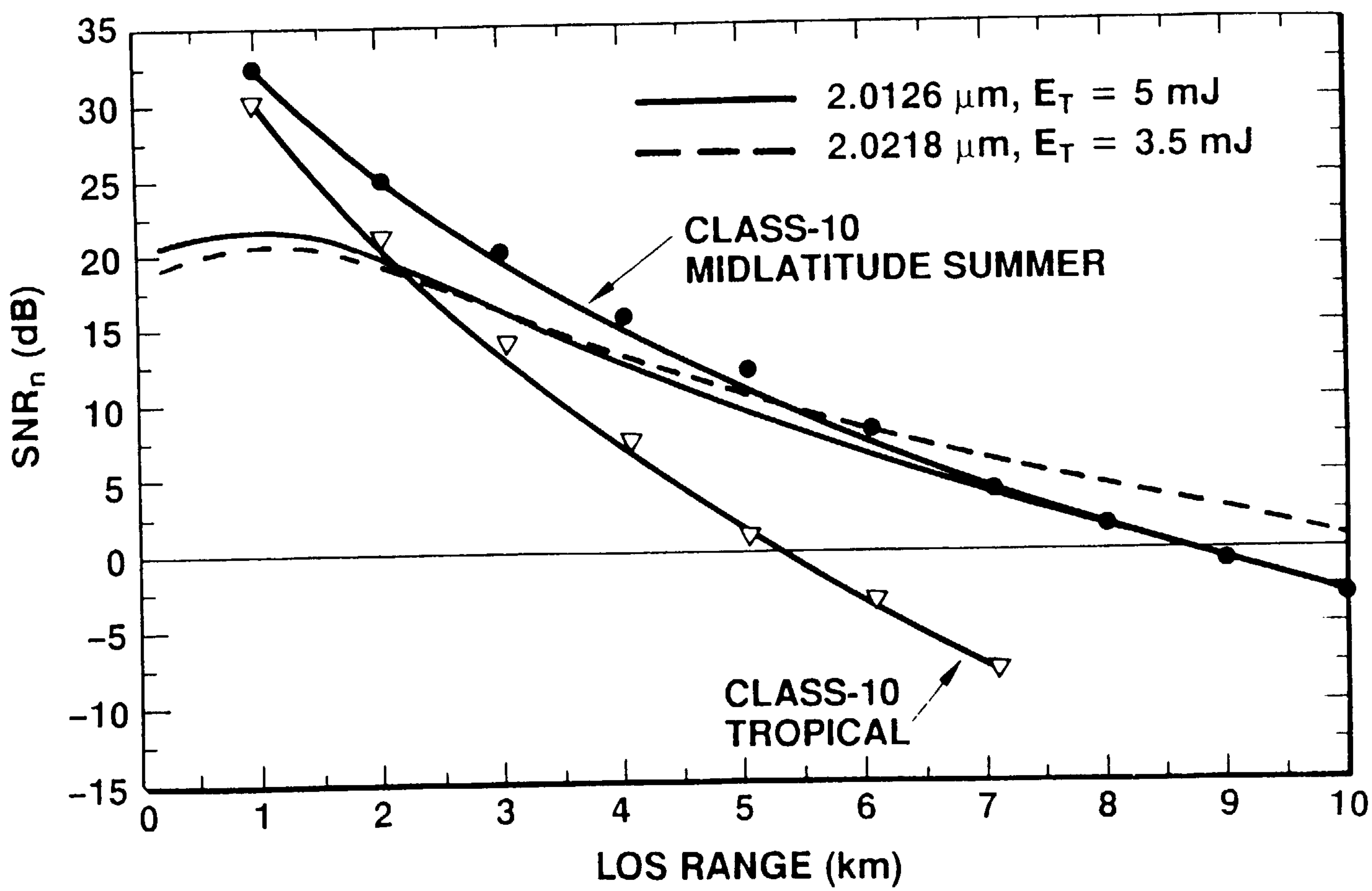
B_N = system narrow bandwidth ($1/\tau$)

h = Planck's constant

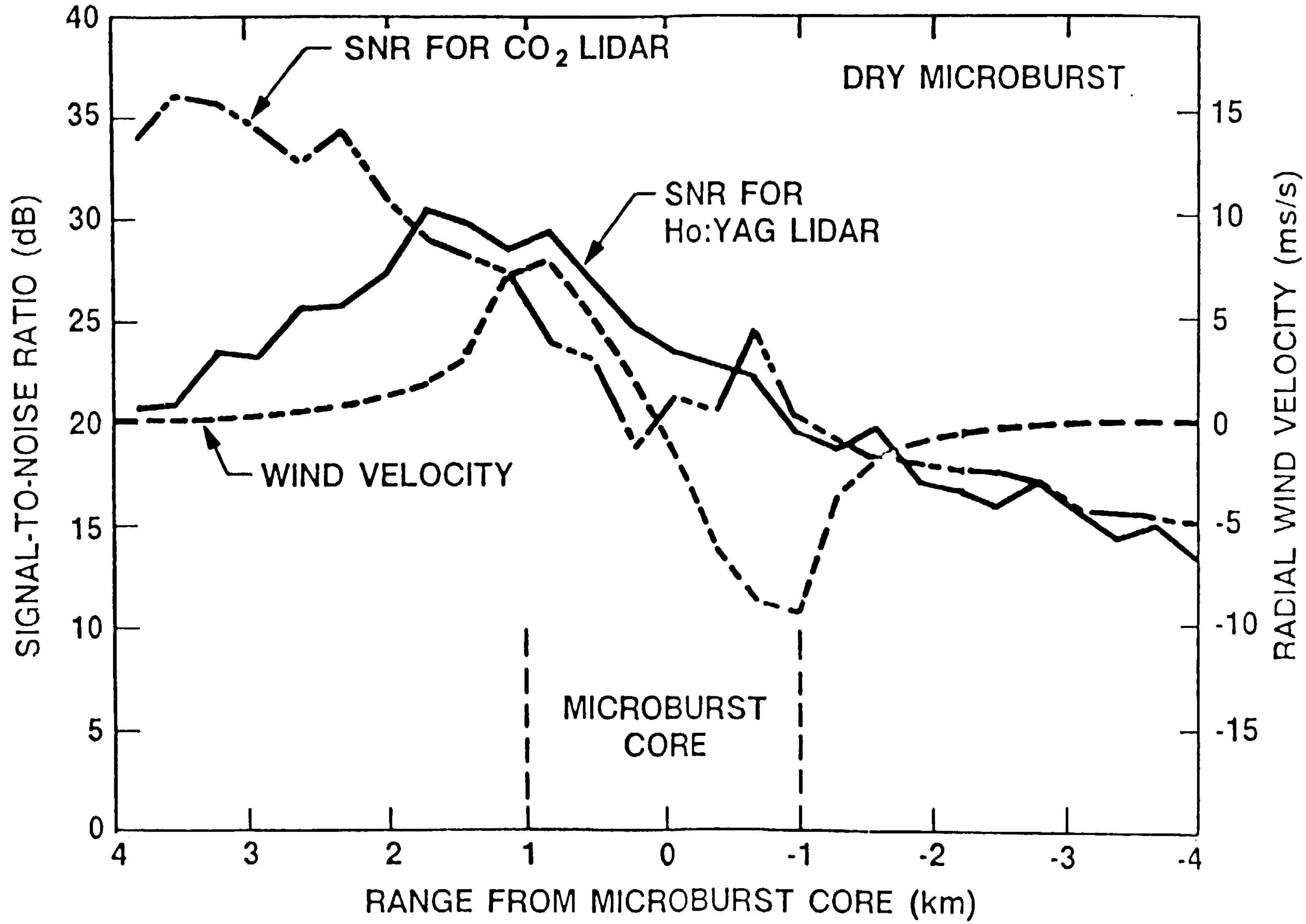
S_0 = transverse coherence length of the received field (m)

NARROWBAND SNR PERFORMANCE
(500 m ALTITUDE, CLEAR AIR)

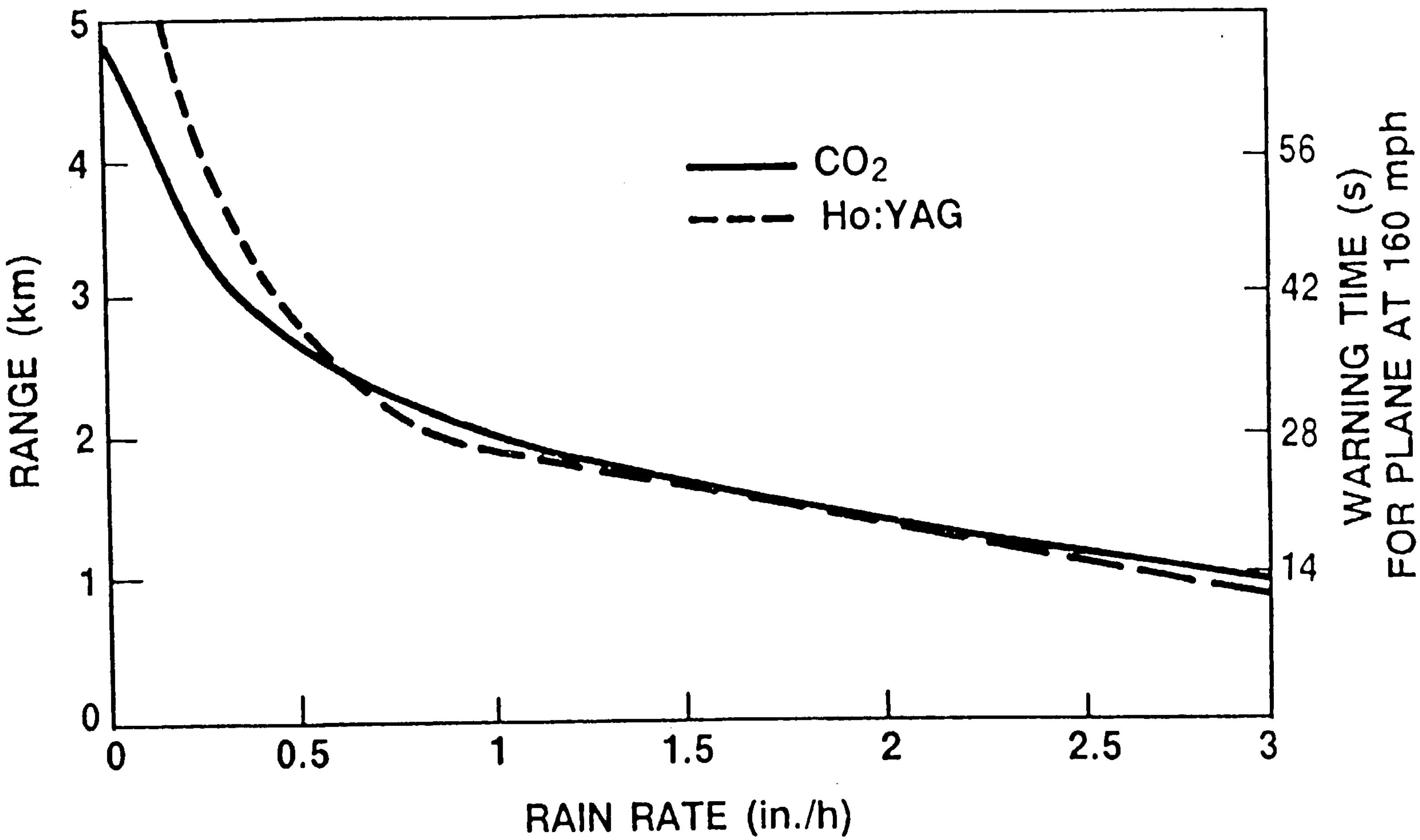
SCAN RATE 10°/s, D = 10 cm, f = 3 km



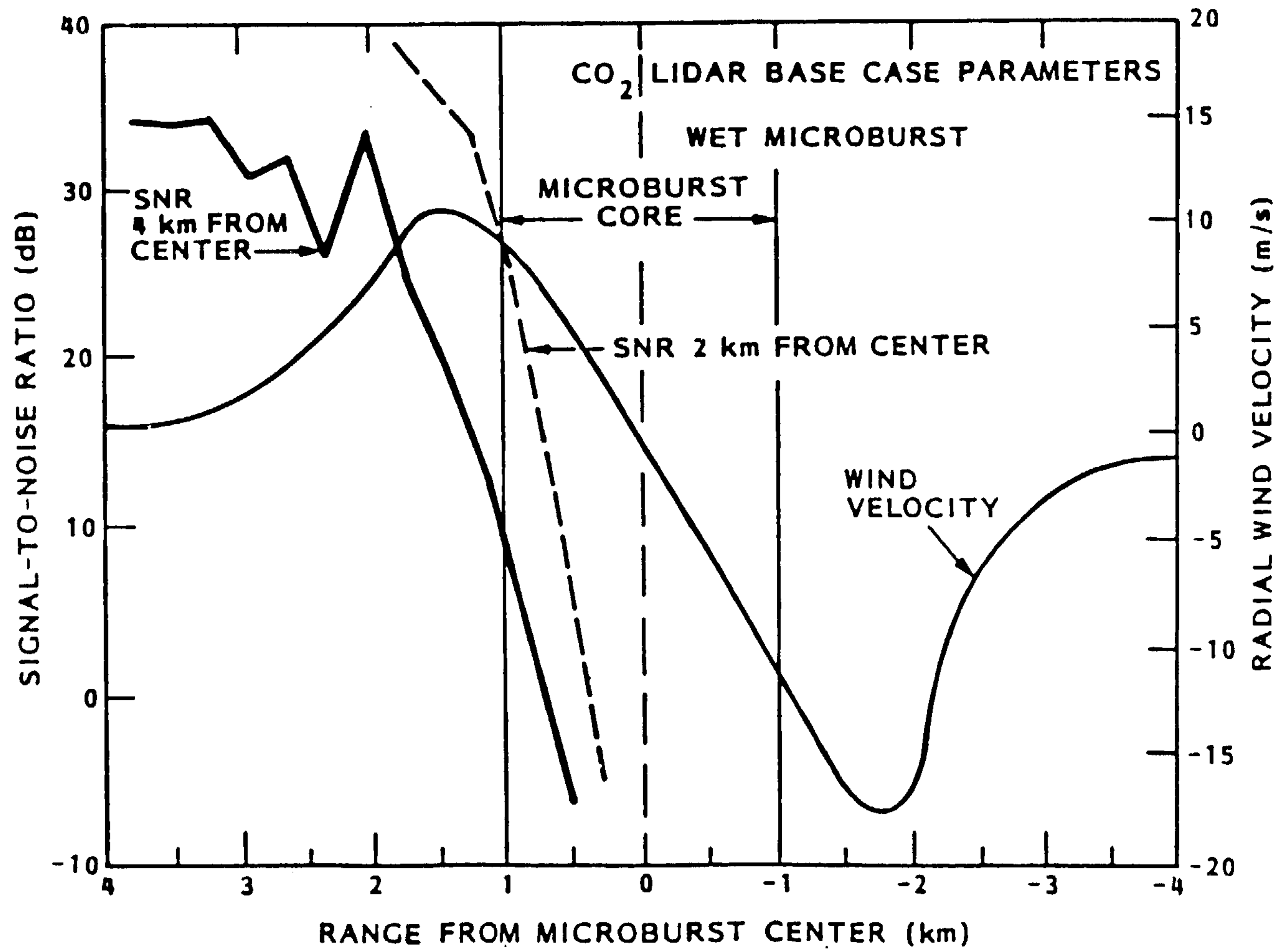
VARIATION OF SIGNAL-TO-NOISE RATIOS AND TRUE WIND VELOCITY WITH DISTANCE



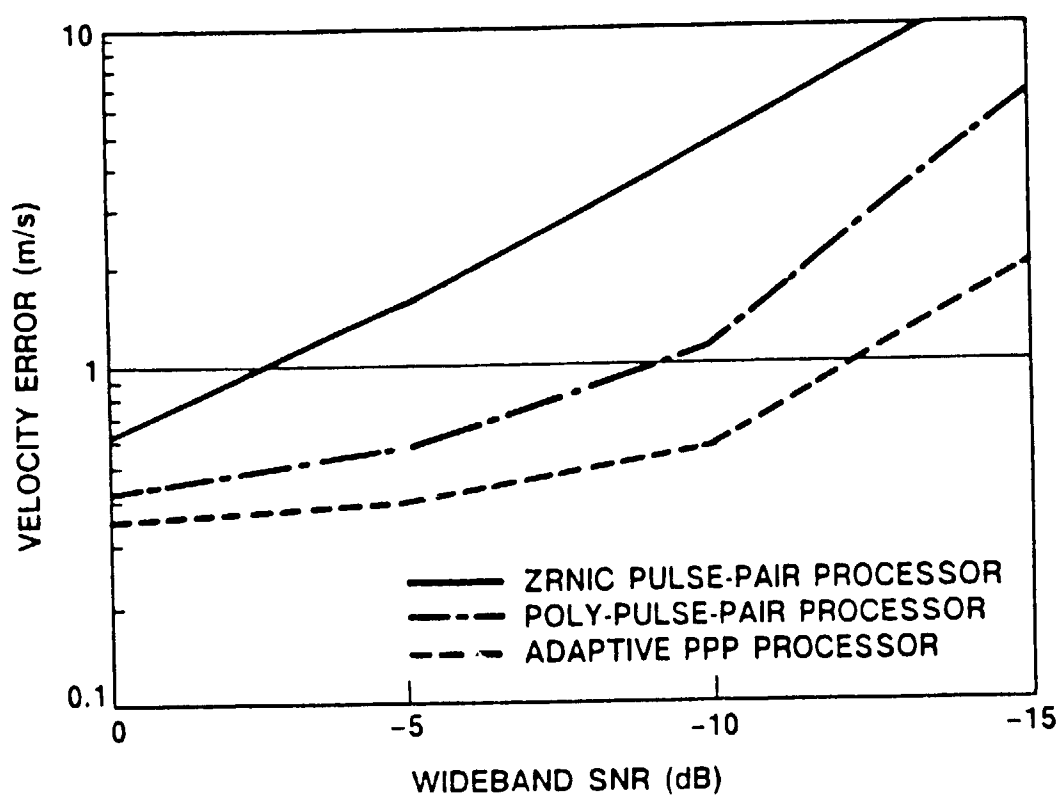
RANGE IN RAIN FOR UNITY SNR 5-mJ CO_2 AND Ho:YAG LIDARS



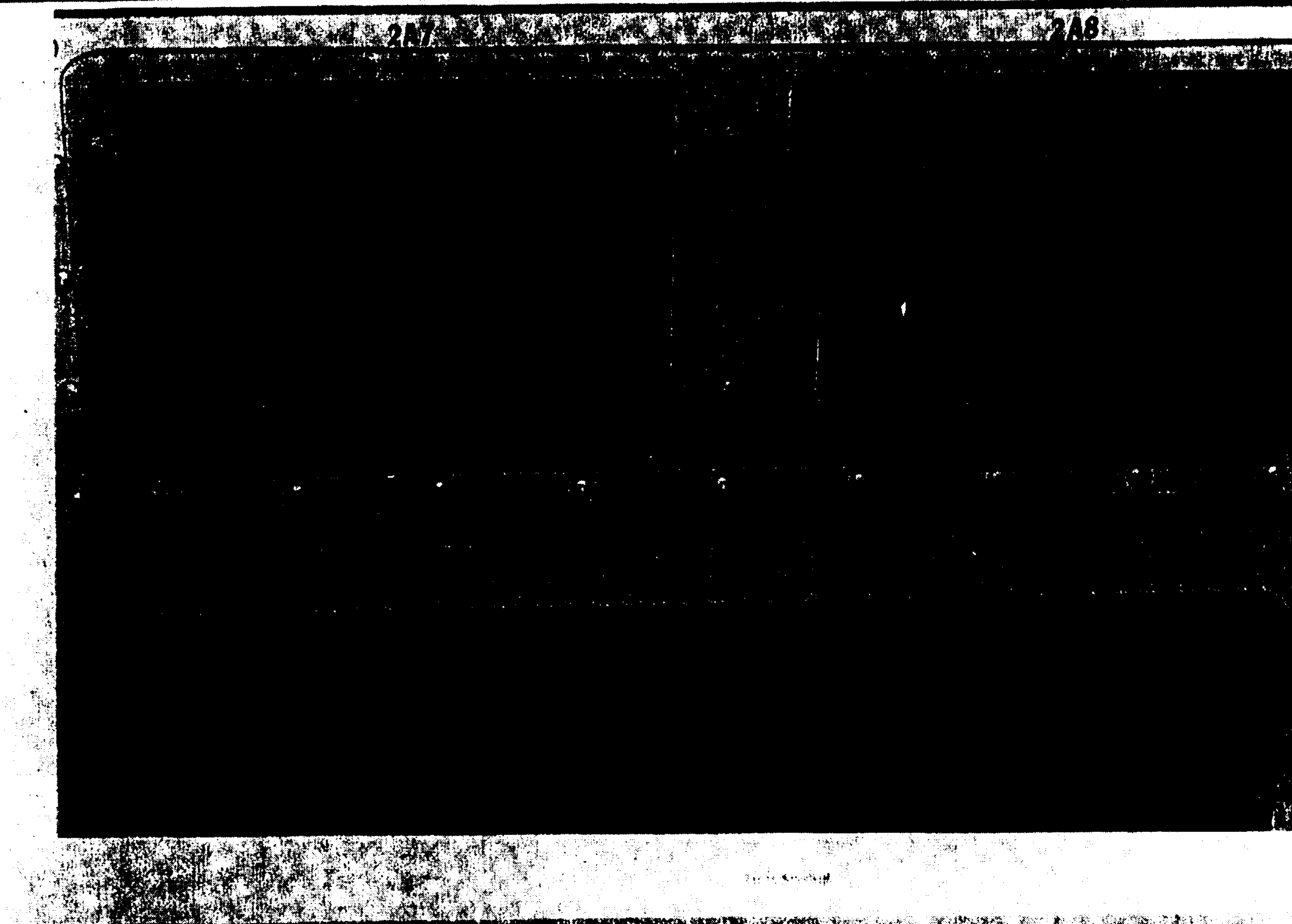
CO_2 LIDAR SIGNAL-TO-NOISE RATIO AND TRUE WIND VELOCITY VERSUS DISTANCE



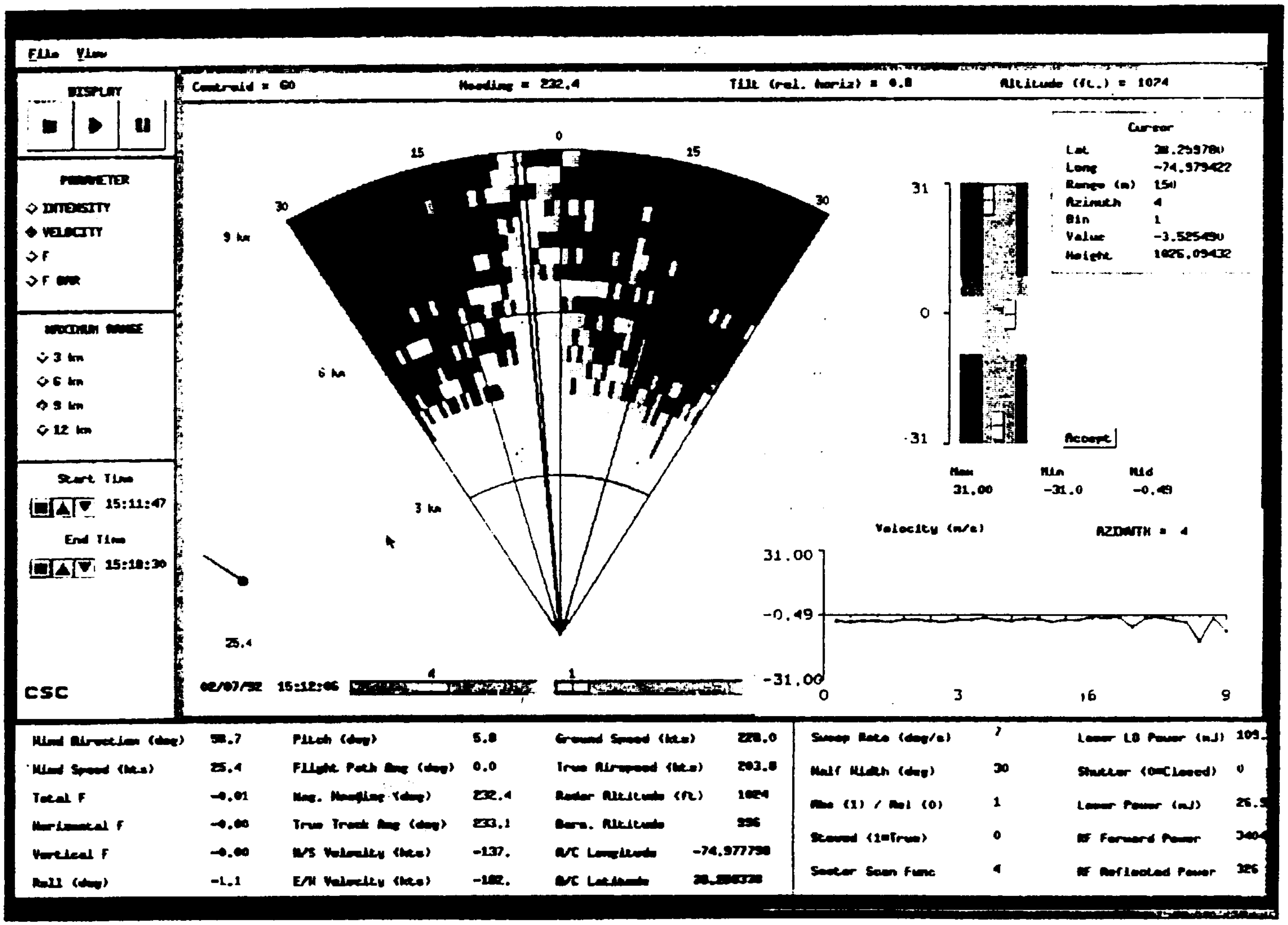
VELOCITY ERROR AS A FUNCTION OF SIGNAL-TO-NOISE RATIO, WITH TURBULENCE

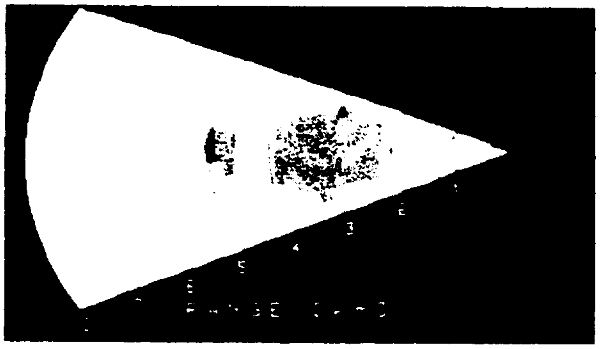


CLASS 10-μm LIDAR RETURNS FROM 8-km SHOWING INTENSITY (LEFT) AND WIND VELOCITY (RIGHT) ONBOARD NASA AIRCRAFT (4-17-92)

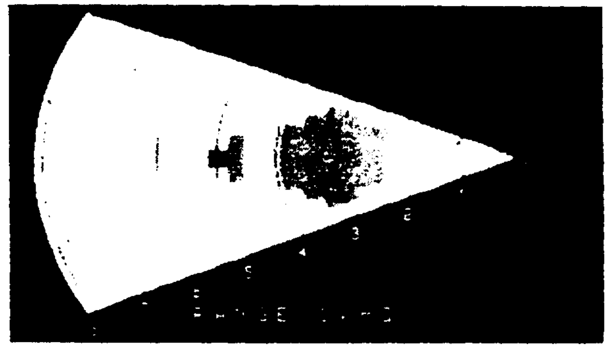


10.6-μm CLASS LIDAR, 1023-ft ALTITUDE, SCAN PERPENDICULAR TO 25-kt WIND SHOWING ± VELOCITY RETURNS TO 8-km RANGE (7-2-92)

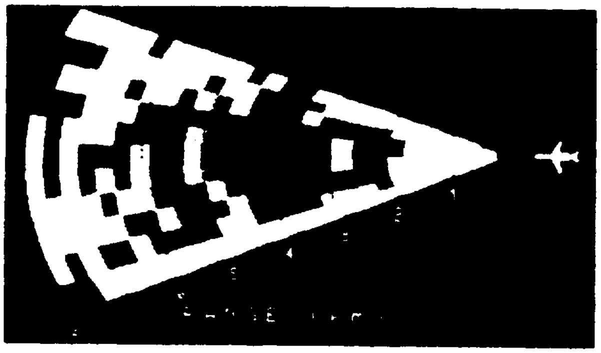




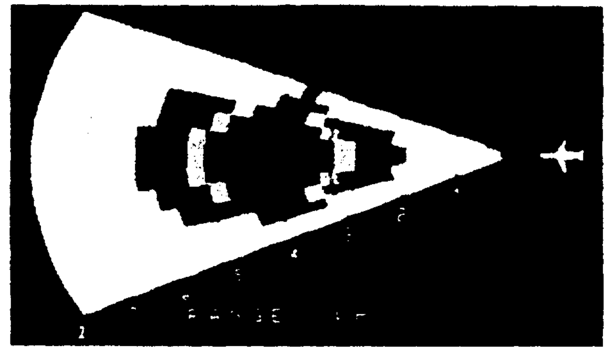
(a) CO_2 lidar wind velocity



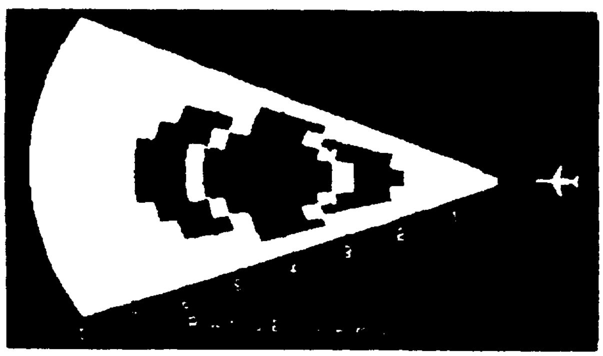
(b) Ho:YAG lidar wind velocity



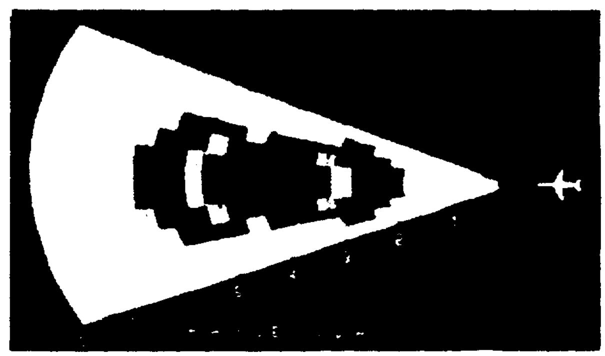
(c) CO_2 lidar hazard index



(d) Ho:YAG lidar hazard index

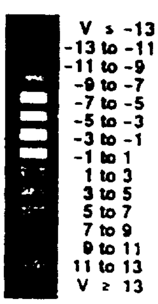


(e) True hazard index without vertical wind



(f) True hazard index with vertical wind

Radial Wind Velocity, V (m/s)



Hazard Index, F

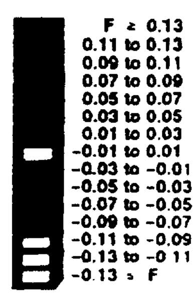
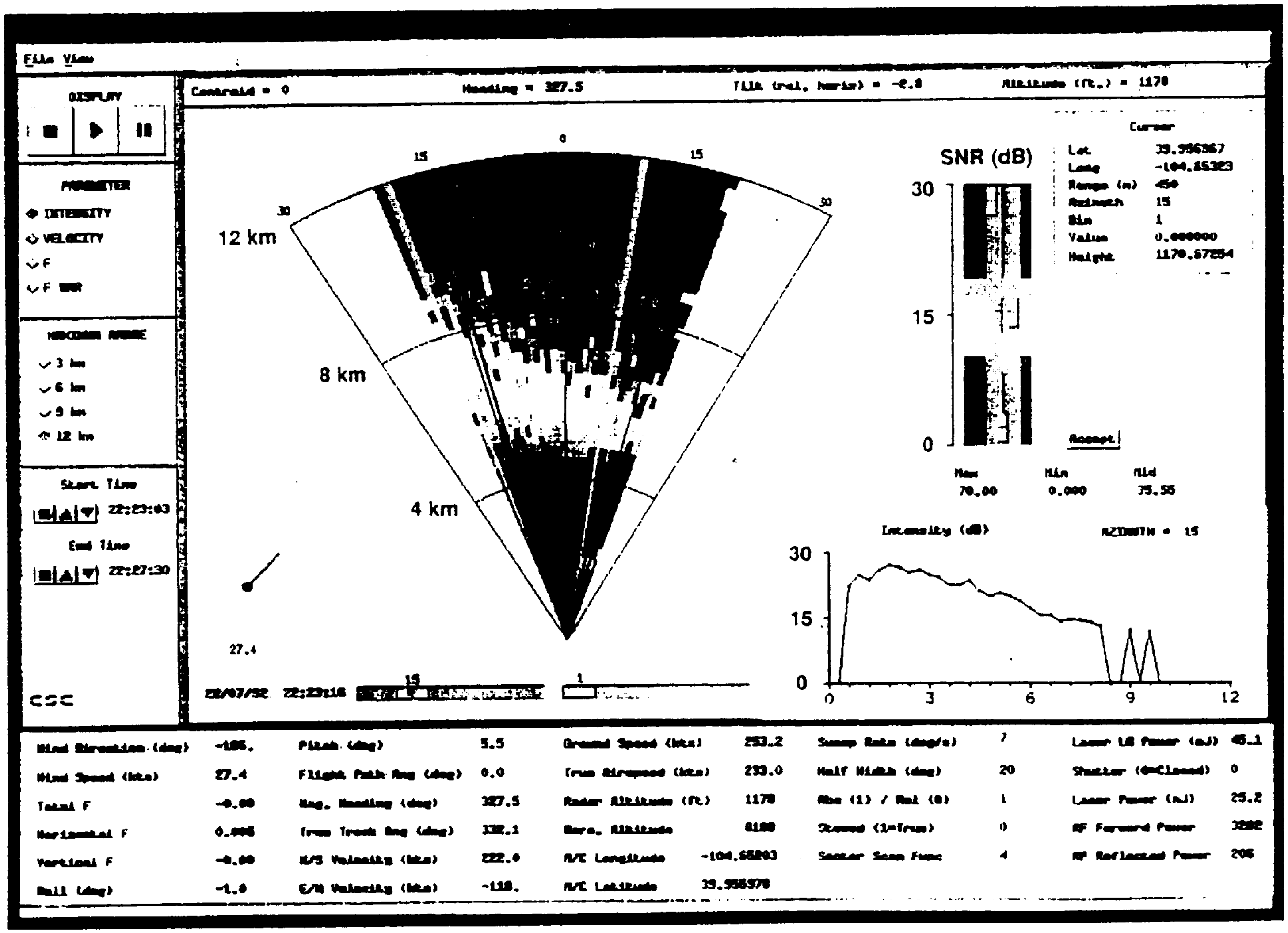


Fig. 6 Range azimuth scan of a dry microburst at Denver/Stapleton Airport. Simulated wind velocity measurements are shown for CO_2 lidar in (a) and for Ho:YAG lidar in (b); simulated lidar measurements of hazard index for the two lidars are shown in (c) and (d); the true hazard index is shown in (e), with LOS wind only, and in (f), with LOS and vertical wind.

DENVER WINDSHEAR DEPLOYMENT -- 10.6-μm CLASS LIDAR SHOWING INTENSITY OF RETURNS IN DRY AIR TO 8 km.



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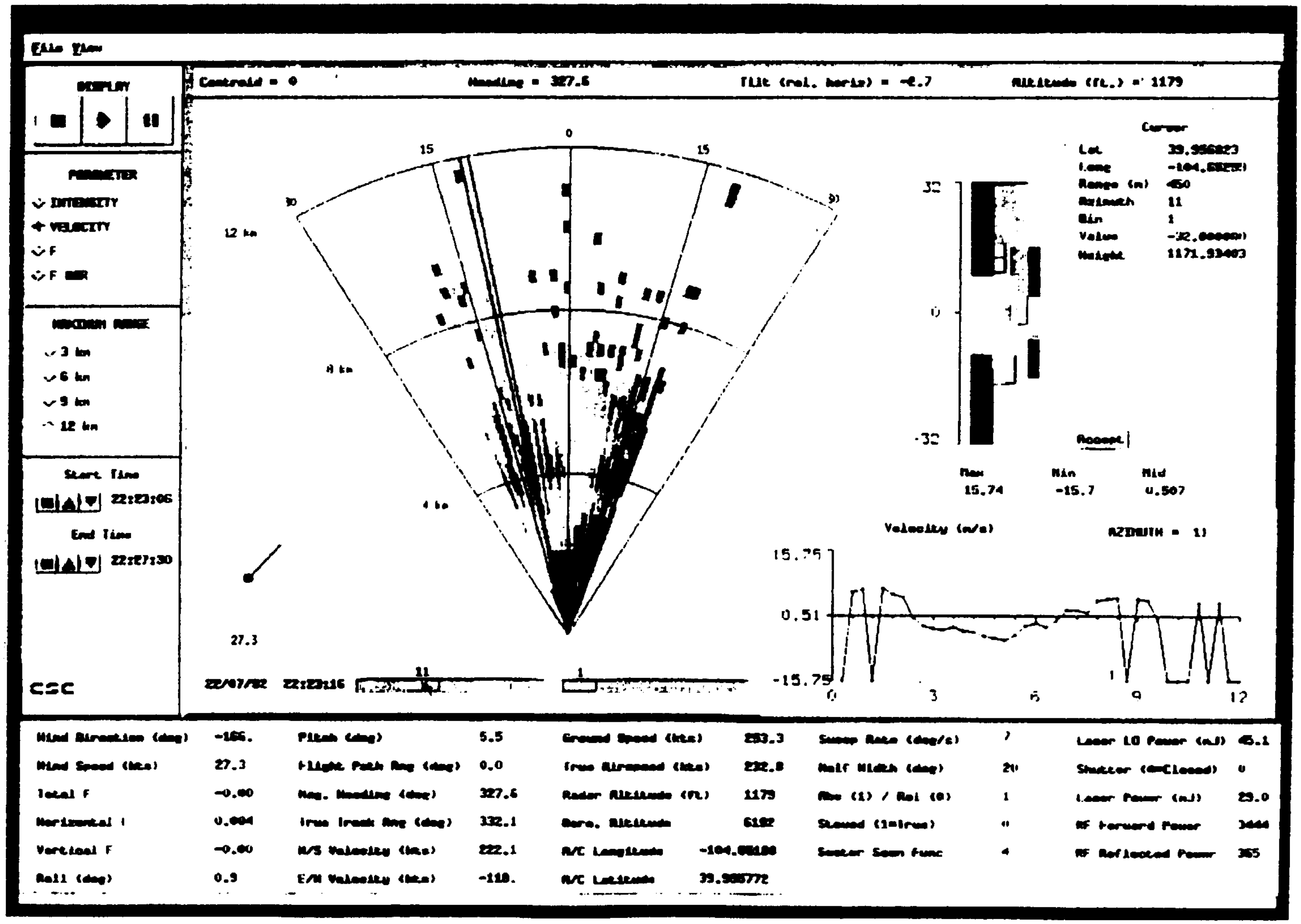
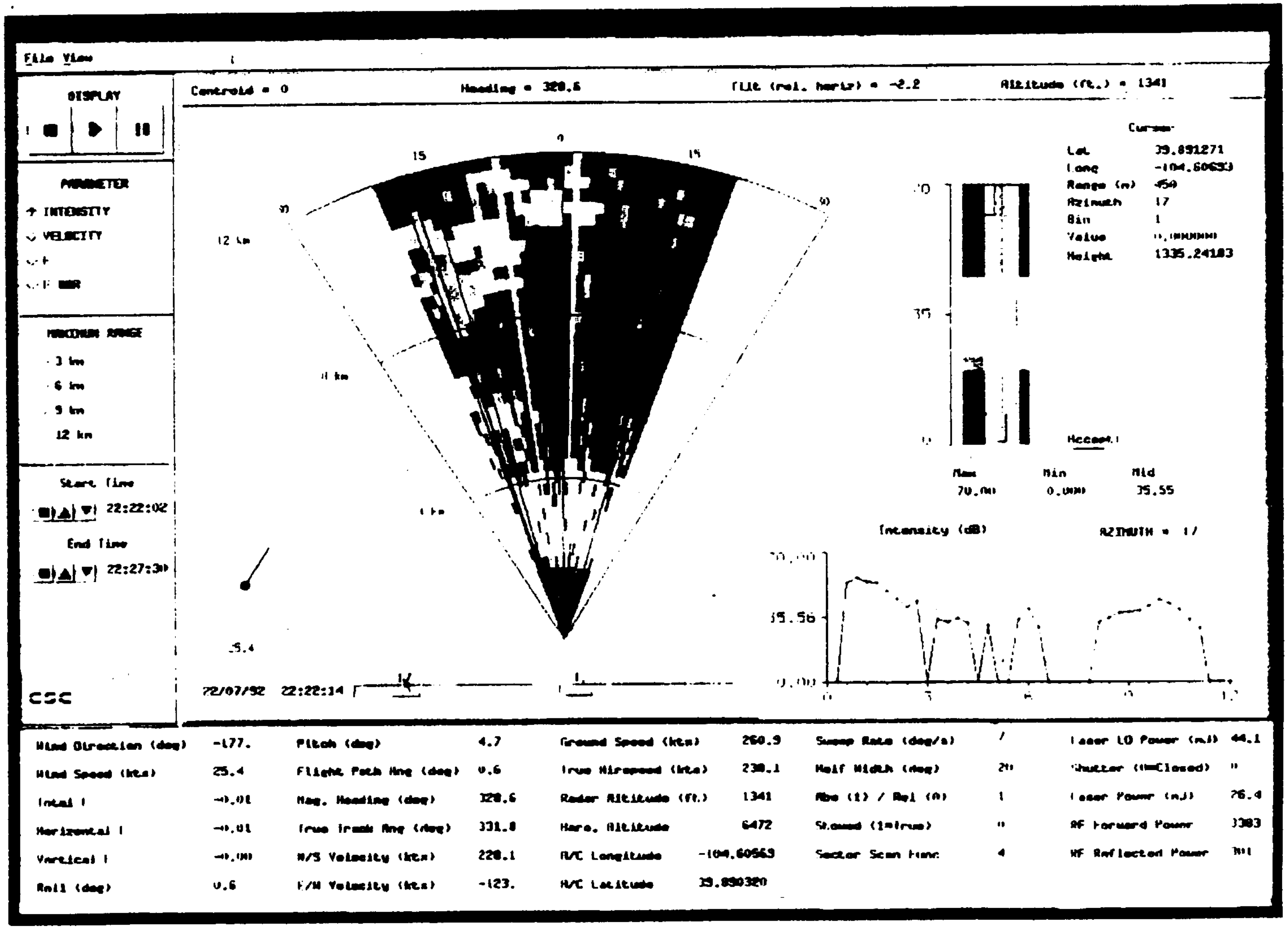
DENVER WINDSHEAR DEPLOYMENT -- 10.6-μm CLASS LIDAR WIND VELOCITY DIVERGENT OUTFLOW IN DRY AIR TO 8 km.



AT DENVER IN LIGHT RAIN -- 10.6-μm CLASS LIDAR RANGE AZIMUTH SCAN SHOWING RETURNS TO 11 km.



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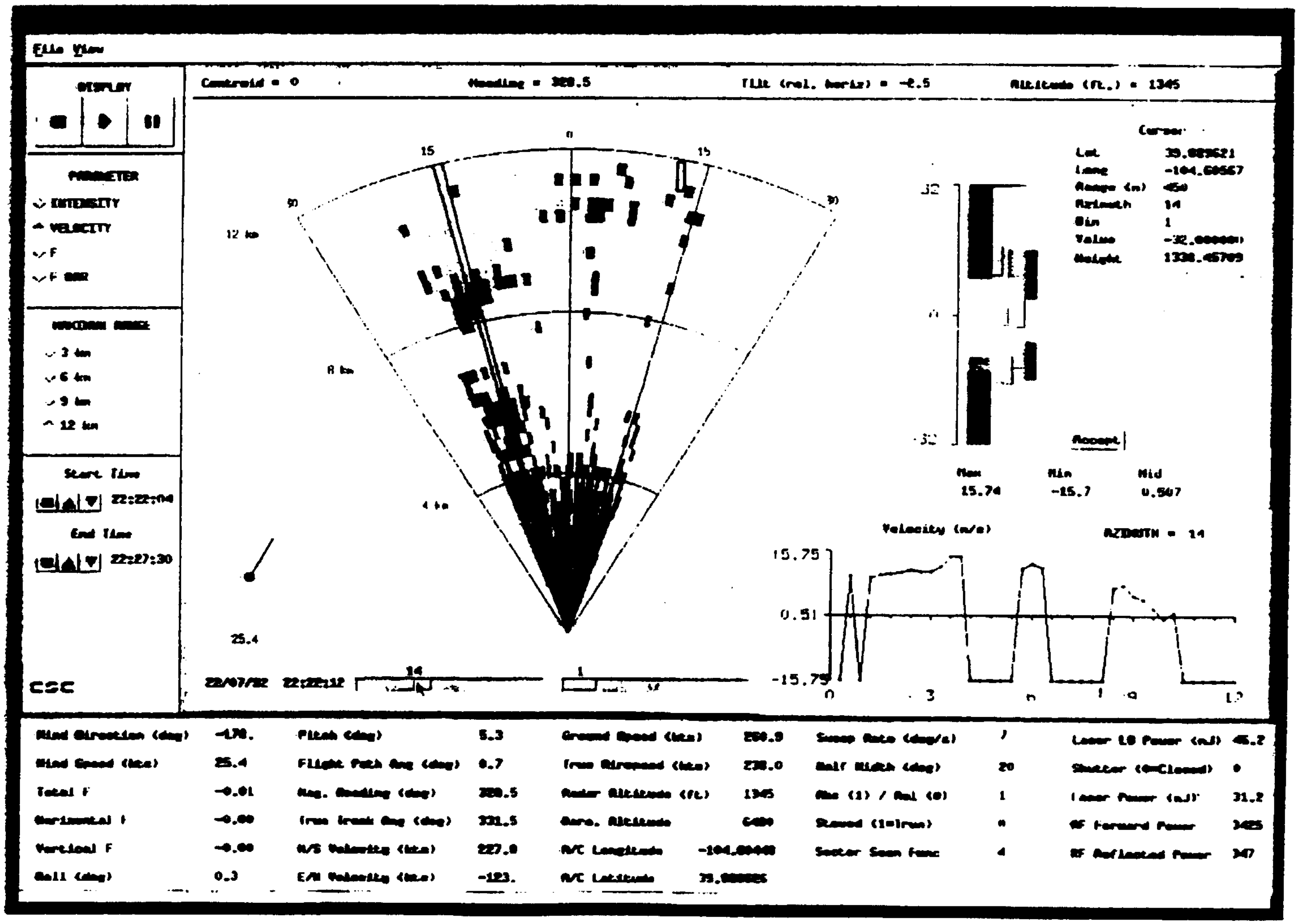
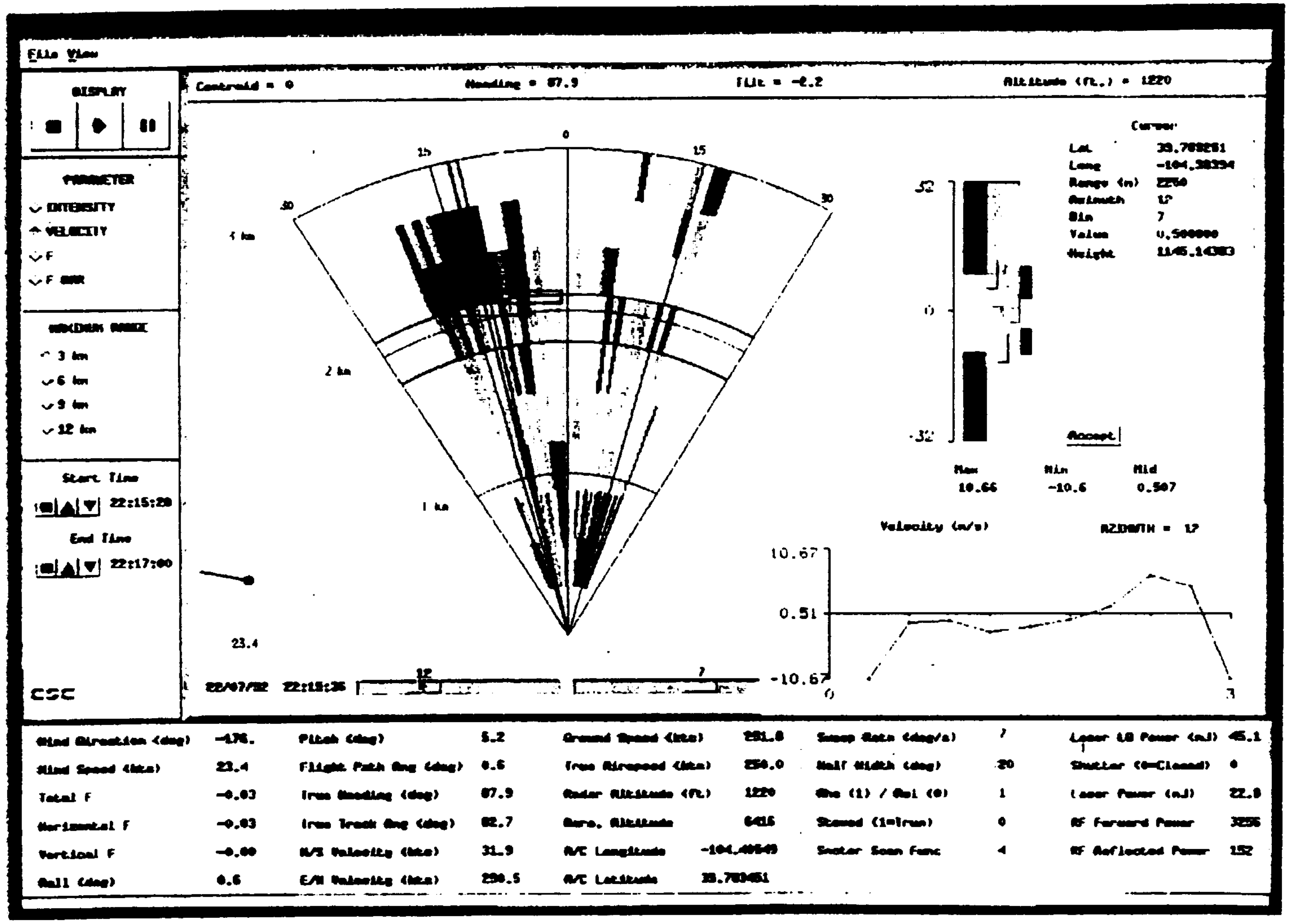
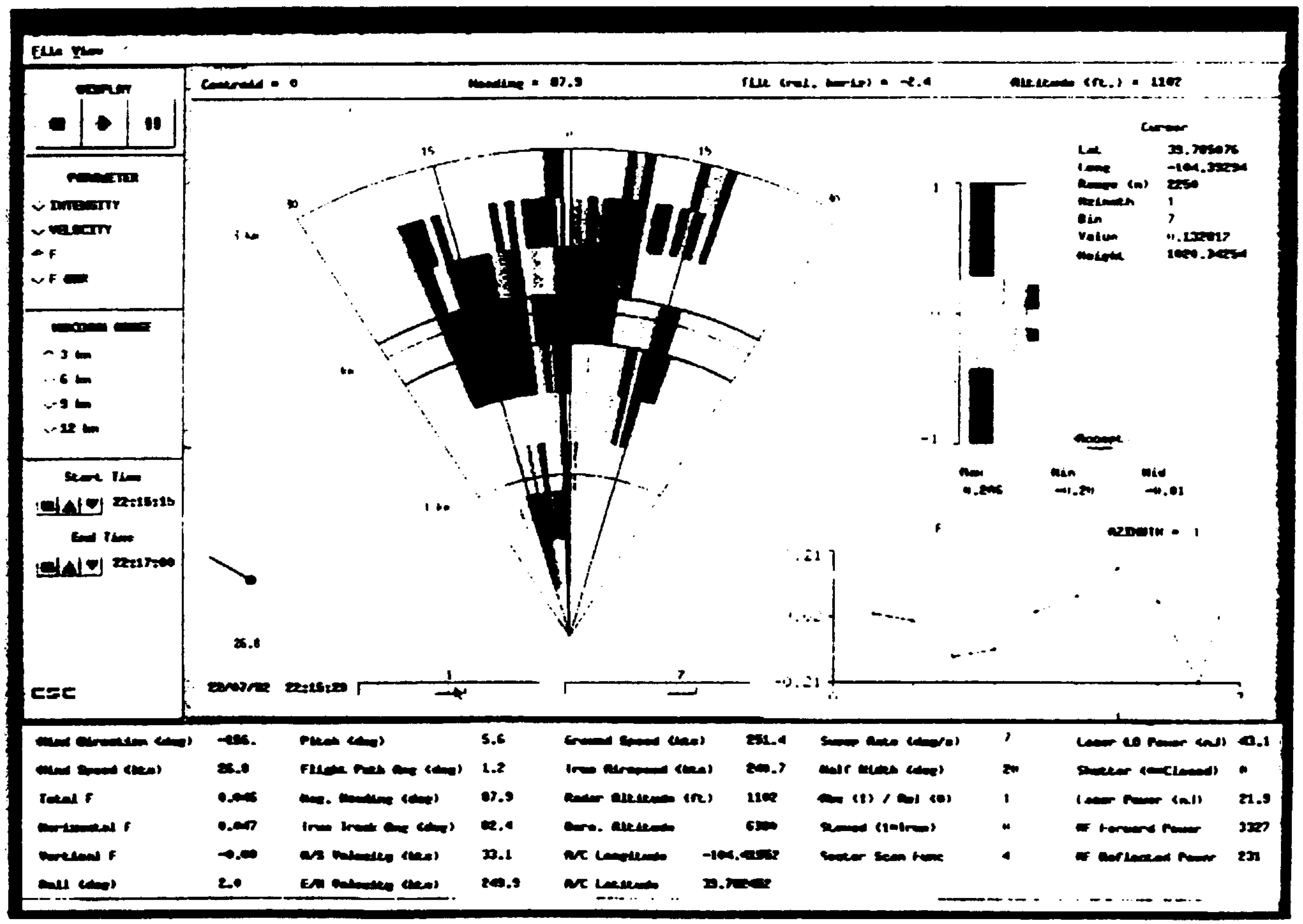
AT DENVER IN LIGHT RAIN -- 10.6-μm CLASS LIDAR SHOWING WIND VELOCITY MEASUREMENTS TO 11 km.



AIRBORNE CO_2 LASER WINDSHEAR WARNING SYSTEM MEASURES WIND HAZARD AT A RANGE OF 3 km, IN LIGHT RAIN: NASA/FAA DEPLOYMENT AT DENVER/STAPLETON AIRPORT-- JULY 1992



AT DENVER IN THE RAIN -- 10.6-μm CLASS LIDAR GIVES 20 SECONDS WARNING FOR HAZARDOUS WINDS AT 2-km RANGE



LIDAR SAW SAME F-FACTORS AS RADAR

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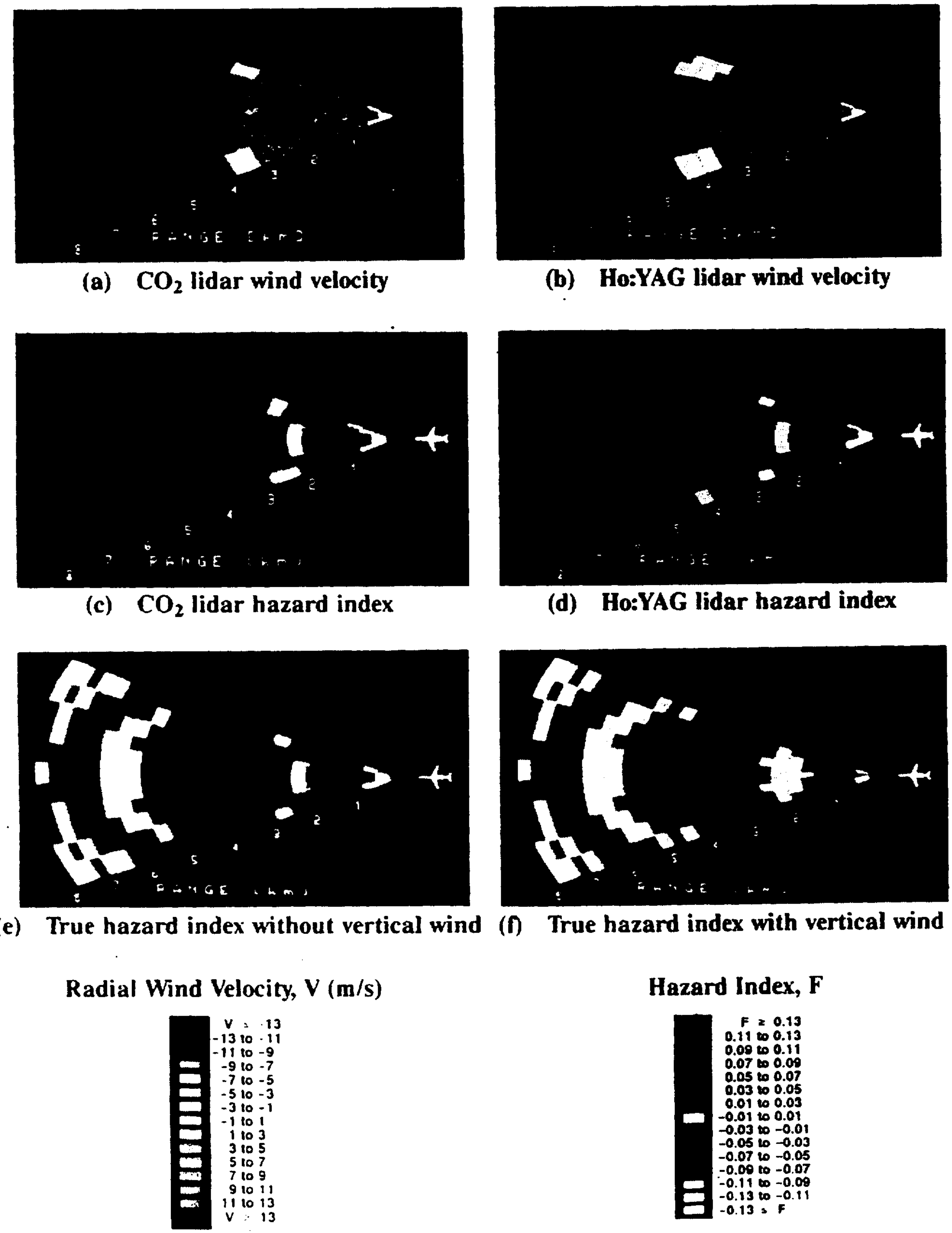

Fig. 7 Range azimuth scan of a wet microburst at Dallas Fort Worth Airport. Simulated wind velocity measurements are shown for CO_2 lidar in (a) and for Ho:YAG lidar in (b); simulated lidar measurements of hazard index for the two lidars are shown in (c) and (d); the true hazard index is shown in (e), with LOS wind only, and in (f), with LOS and vertical wind.

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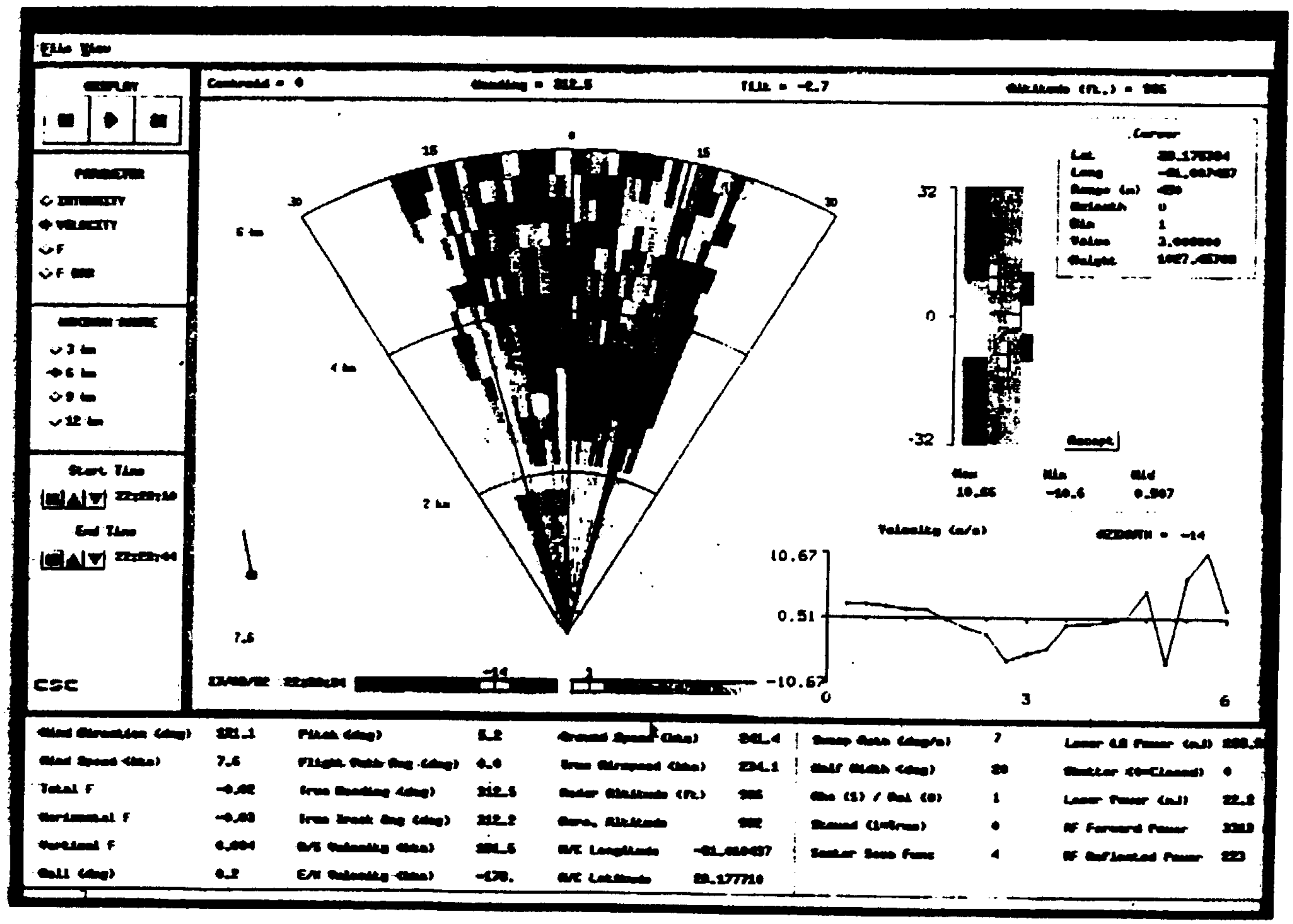
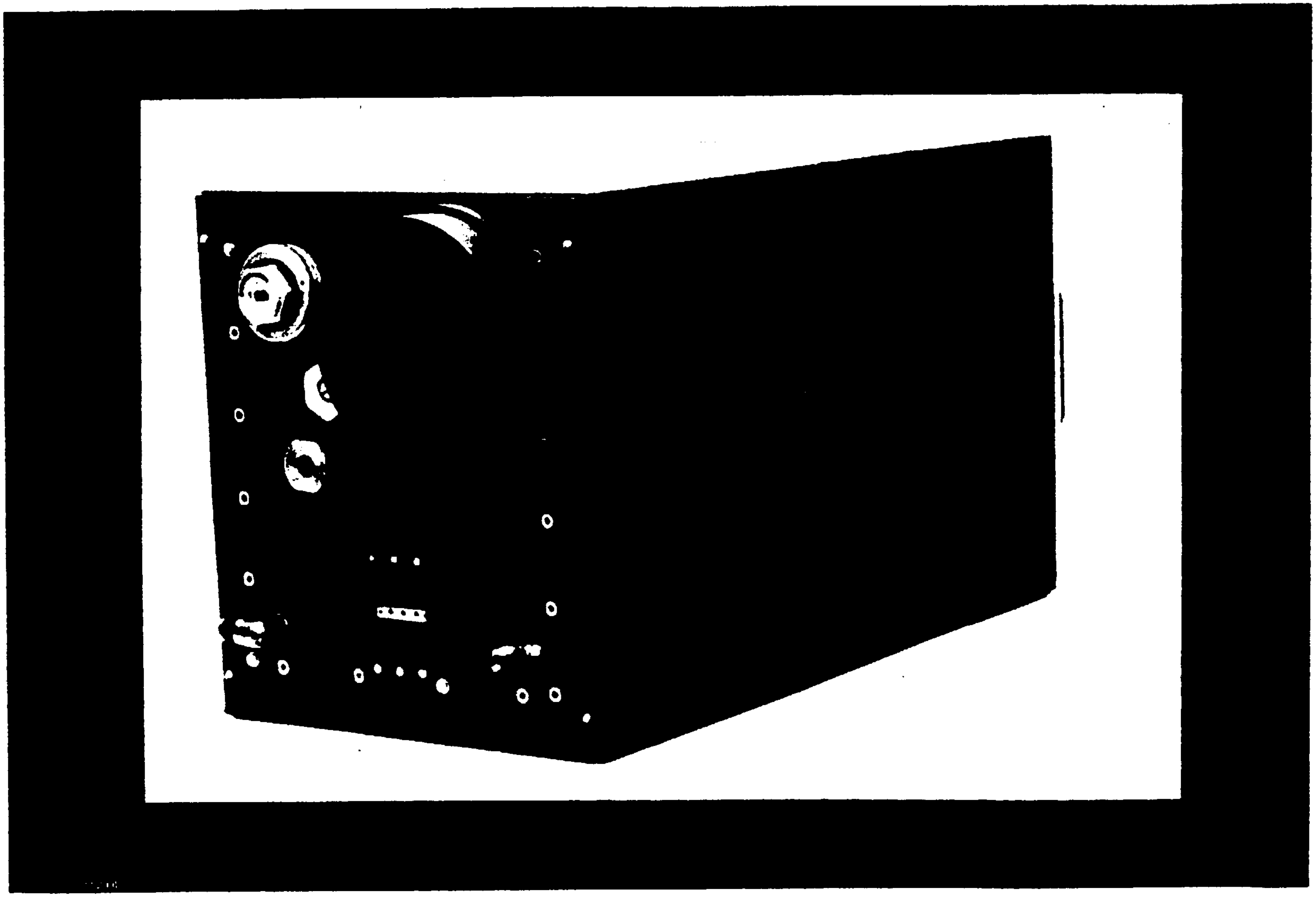
AIRBORNE CO_2 LASER WINDSHEAR WARNING SYSTEM MEASURES WINDS IN HIGH HUMIDITY TO A RANGE OF 4 km, IN NASA/FAA DEPLOYMENT AT ORLANDO AIRPORT -- AUGUST 1992*



* LIDAR DID NOT PENETRATE RAIN SHAFT TO SENSE HAZARD

ALTOS LASER TRANSCEIVER
IN ARINC STANDARD ENCLOSURE

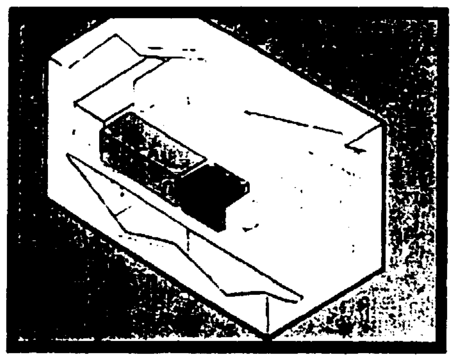


ALTOS-1/CLASS-2
PROGRAM OBJECTIVES & APPROACH

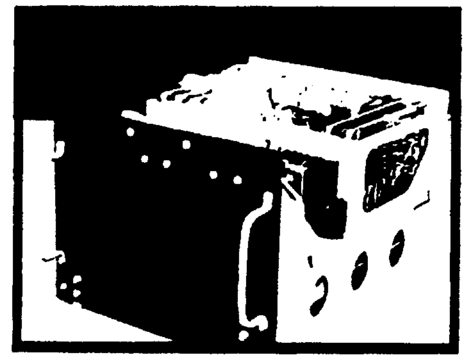
OBJECTIVE: VALIDATE PERFORMANCE OF 2-μm SOLID-STATE LIDAR AIRBORNE SENSOR SYSTEM TO MEASURE STEADY STATE WINDS. WINDSHEAR. WAKE VORTICES. etc.

APPROACH:

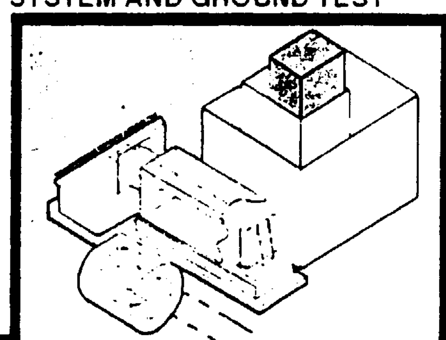
- LOCKHEED TO DEVELOP AND PROVIDE FLIGHTWORTHY SOLID-STATE TRANSCEIVER



- LOCKHEED TO DEVELOP AND PROVIDE FLIGHT-WORTHY LASER CONTROL AND ELECTRONIC COHERENT RECEIVER



- NASA AND LOCKHEED TO INTEGRATE WITH THE CLASS-10 LIDAR OPERATING SYSTEM AND GROUND TEST



- NASA AND LOCKHEED TO INTEGRATE SYSTEM INTO THE ADVANCED OPERATING SYSTEM B/737 AND CONDUCT COOPERATIVE FLIGHT EXPERIMENTS

CONCLUSIONS

* AT DENVER WE MEASURED WIND VELOCITIES TO 8 km IN DRY AIR, AS PREDICTED.

* AT ORLANDO WE MEASURED WIND VELOCITIES TO 4 km IN HIGH HUMIDITY, AS PREDICTED.

  WE DID NOT PENETRATE RAIN SHAFTS IN ORLANDO.

* MEASUREMENT OF F-FACTOR HAZARD INDEX WAS IN GOOD AGREEMENT WITH RADAR AND AIRCRAFT IN SITU SYSTEM.

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,

and

F. Austin,
Lockheed Engineering and Sciences Co.

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

CLASS
(Coherent LIDAR Airborne Shear Sensor) Wind Shear Detection System

By:

Paul Forney and Lon Celmer
Lockheed Missiles and Space Company
Research and Development Division
Palo Alto, CA

Raymond Calloway and Philip Brockman
NASA Langley Research Center
Hampton, VA

Fred Austin
Lockheed Engineering and Sciences Company
Hampton, VA

September 28 - 30, 1993
Hampton, VA

DESIGN REQUIREMENTS

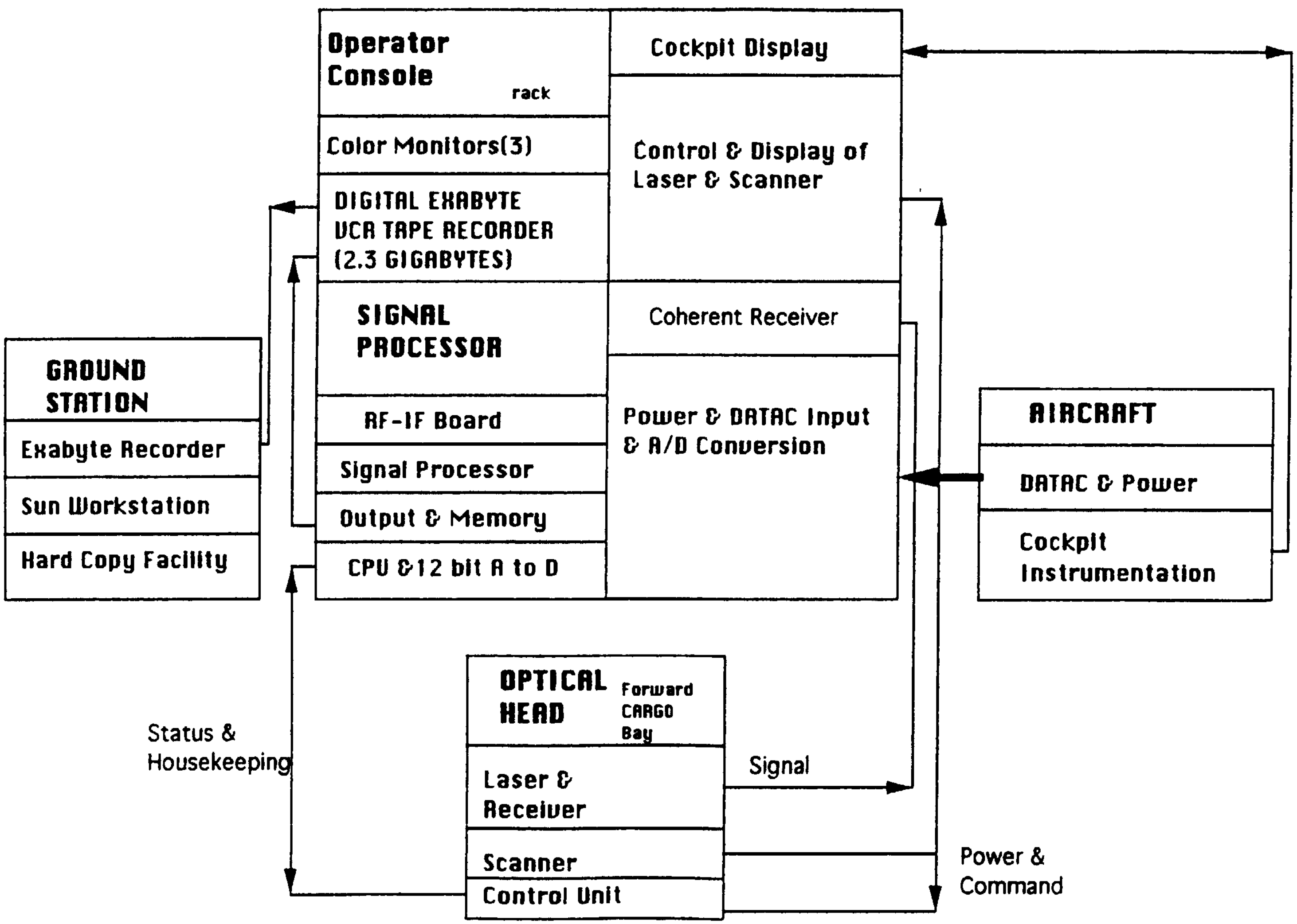
CLASS

PRINCIPAL REQUIREMENTS

- MEASURE DIRECTLY THE LOS COMPONENT OF WIND VELOCITY
- COMPATABLE WITH THE NASA B-737 TEST BED
  : VIBRATION ISOLATE LASER TRANSCEIVER, EMI COMPATABLE, COOLING & POWER AND FLIGHT SAFETY

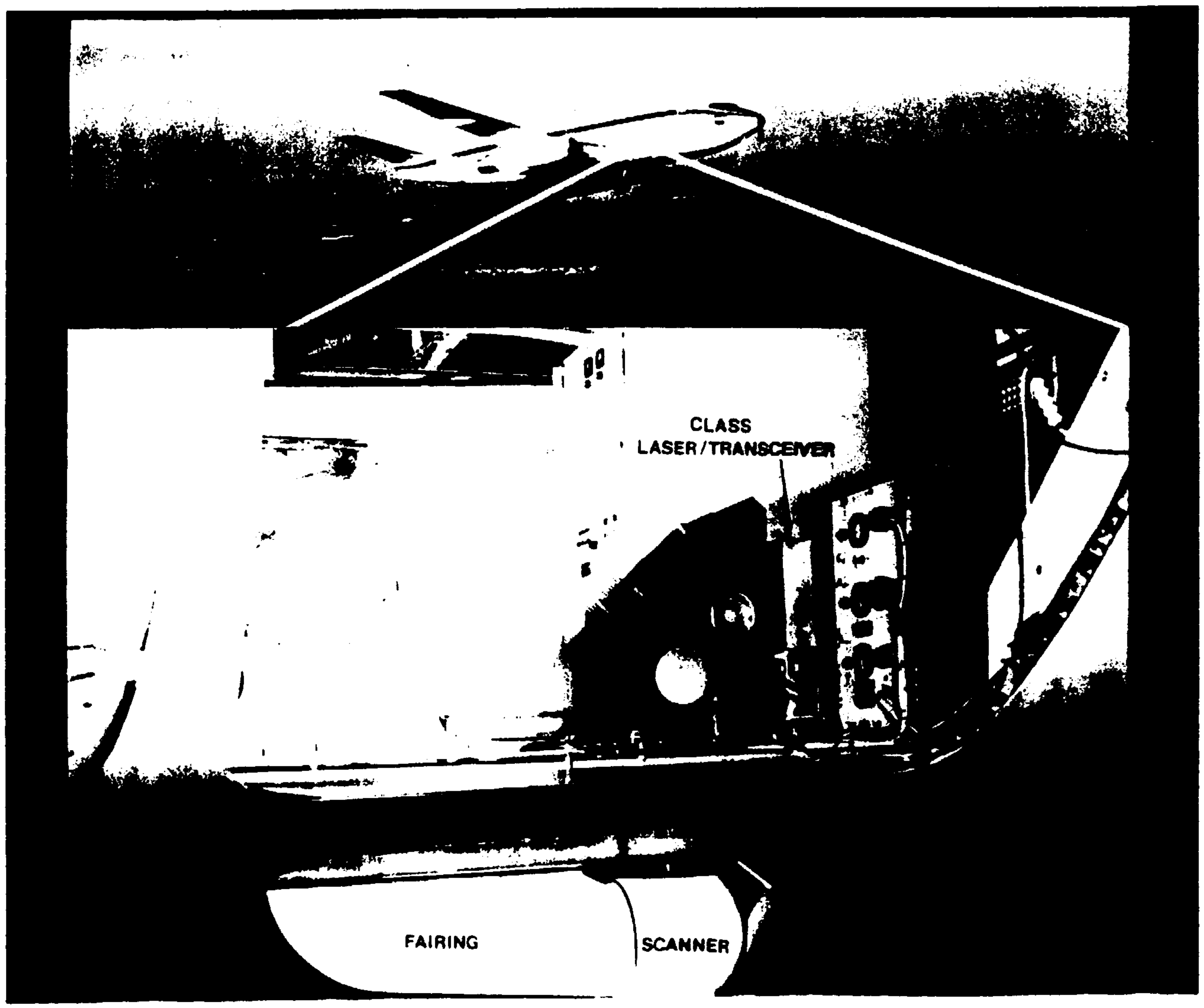
DESIGN ELEMENT	SELECTION	REASON
WAVELENGTH	10.6 MICRONS	EYE SAFETY/ MATURITY
LASER TYPE	RF WAVEGUIDE	RELIABILITY
PULSE ENERGY	10 mJ (8 mJ OUTPUT)	4 km RANGE
PULSE DURATION	2 MICROSECONDS	300 m RESOLUTION & < 1 m/s VELOCITY ERROR
PULSE REPETITION RATE	100 HZ	COVERAGE / PULSE AVERAGING
DETECTOR	PV HgCdTe	QUANTUM NOISE LIMITED PERFORMANCE
COOLING	MECHANICAL REFRIG.	NO EXPENDABLES
TELESCOPE DIAMETER	15 cm	APPROPRIATE FOR 4 km RANGE
SCANNING CAPABILITY	+/- 30° AT 7° / SEC	GEOMETRY

CLASS SYSTEM BLOCK DIAGRAM



CARGO BAY INSTALLATION

CLASS



OPERATORS CONSOLE

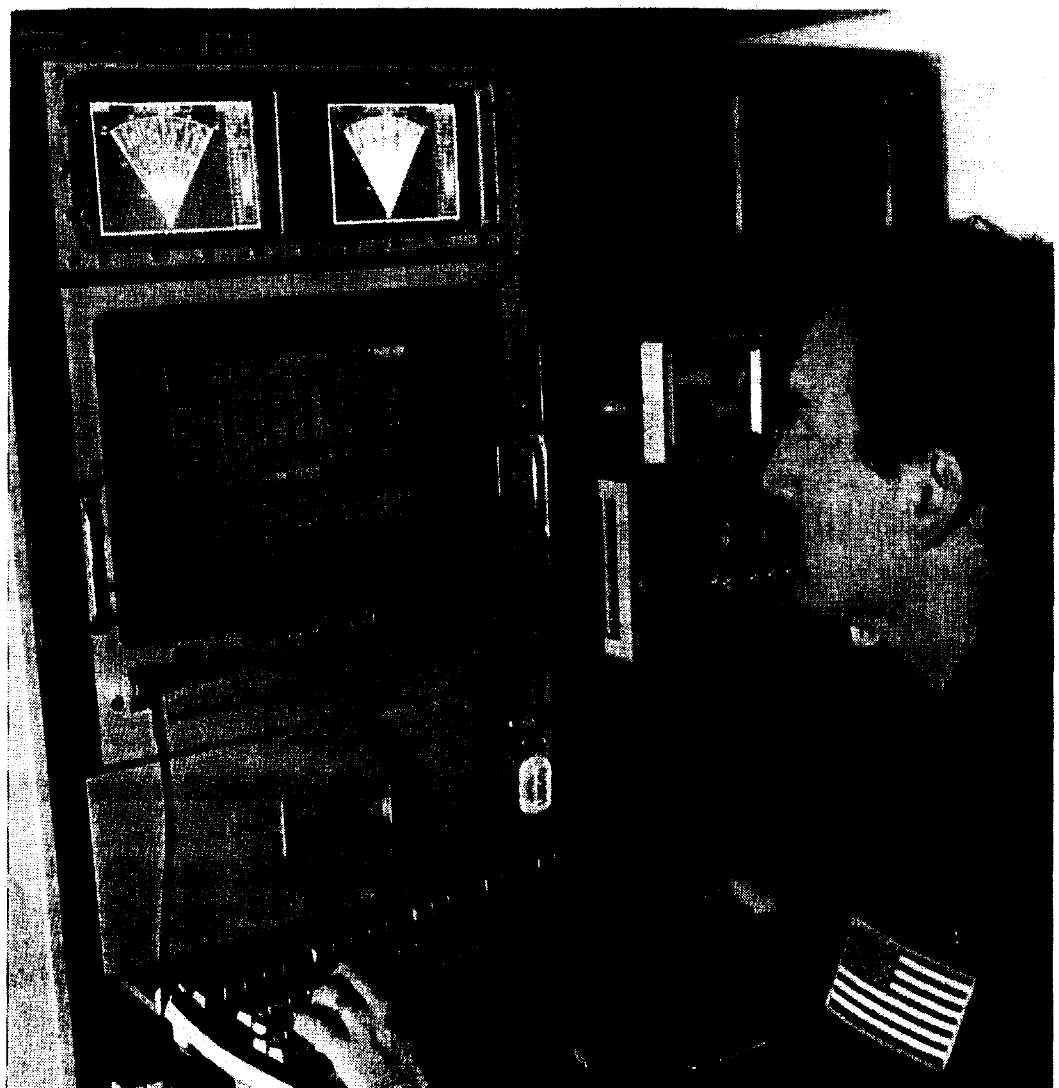
MENU DRIVEN SYSTEM

- SYSTEM CONTROL SCREEN ON LARGE MONITOR
- PRODUCT DISPLAYS ON SMALL MONITORS
- KEYBOARD AND TRACKBALL USER INPUTS
- CONTROL / DISPLAY SCREENS FOR :
  - SCAN MODE / DISPLAY CONTROL
  - SYSTEM STATUS AND CONFIGURABLE STATUS LIMITS
  - DISPLAY MODIFICATION
  - SIGNAL PROCESSING AND DATA MANAGEMENT
  - ALGORITHM CONFIGURATION AND OVERRIDES
  - STATUS PARAMETER (HOUSEKEEPING) DISPLAY

Lockheed LMSC/NASA

OPERATORS CONSOLE

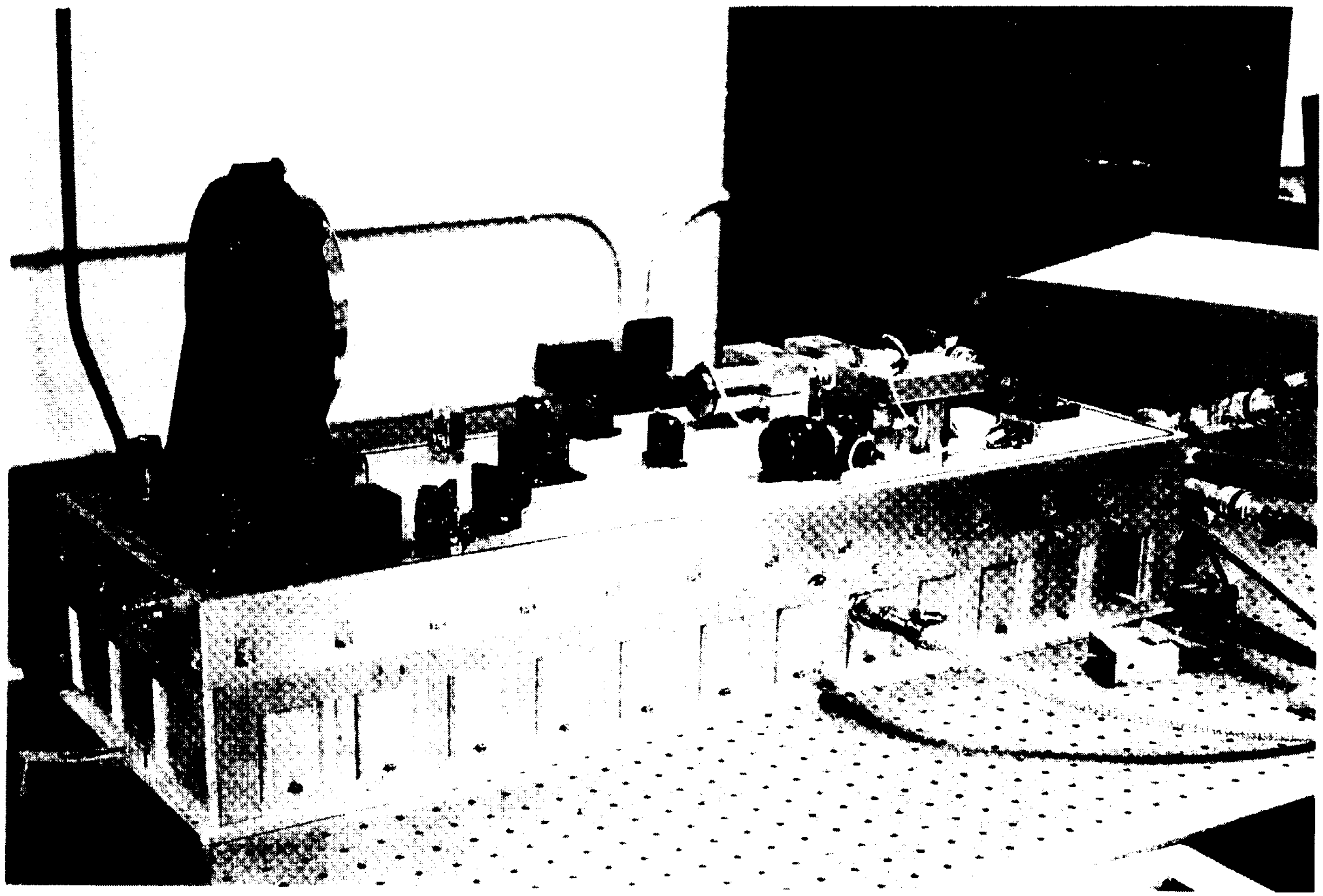
CLASS



Lockheed
LMSC/NASA

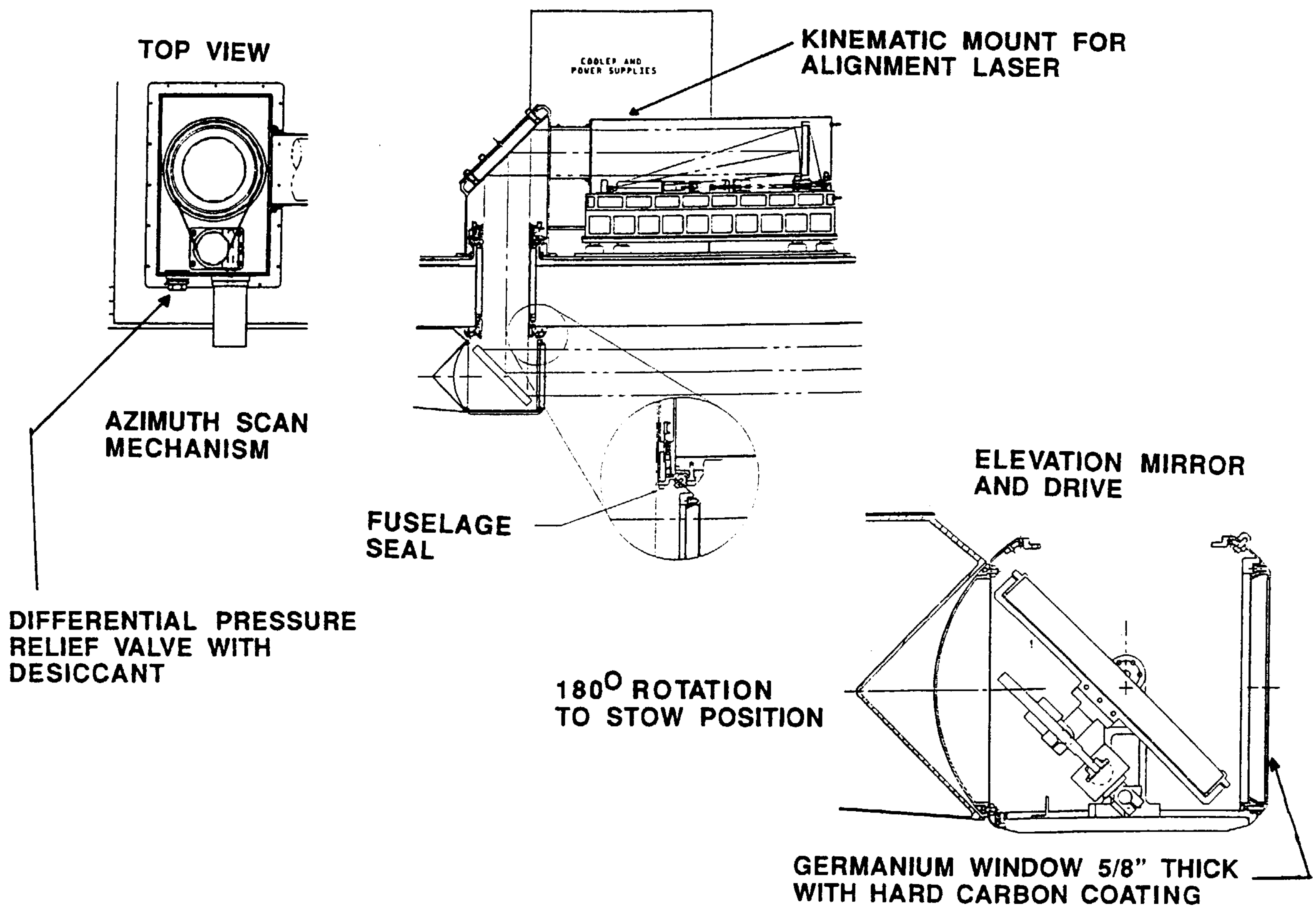
TRANSCEIVER INTERIOR (UNITED TECHNOLOGY OPTICAL SYSTEMS)

CLASS



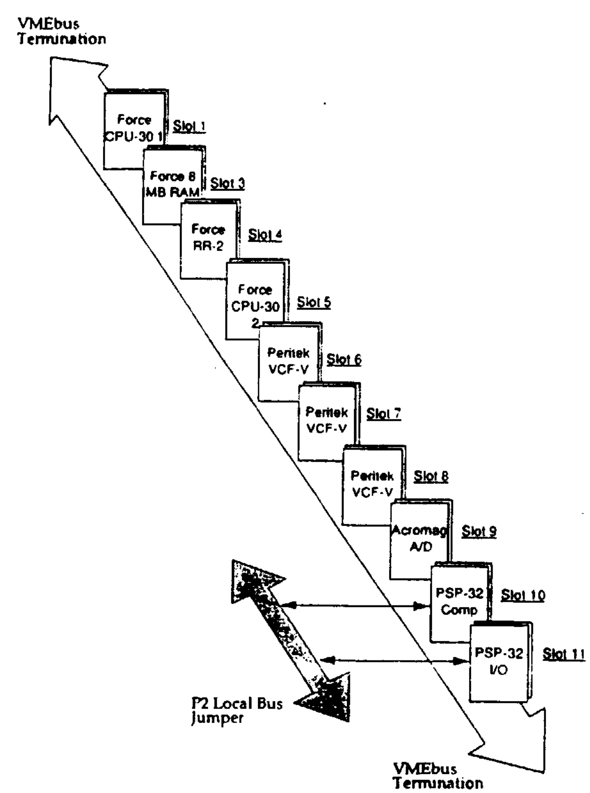
SCANNER SYSTEM DETAIL

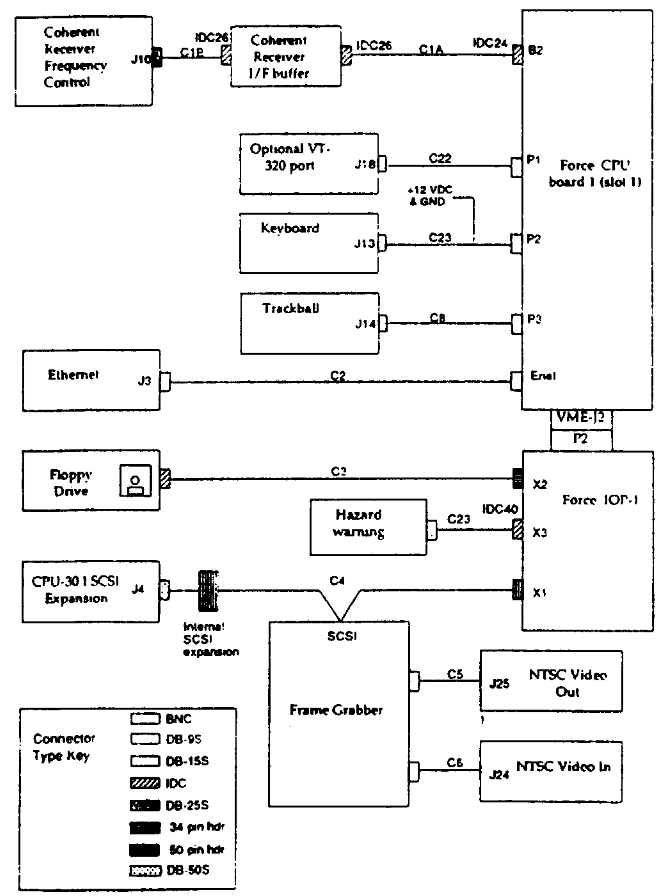
CLASS



RADEX COMPUTER (LASSEN RESEARCH)

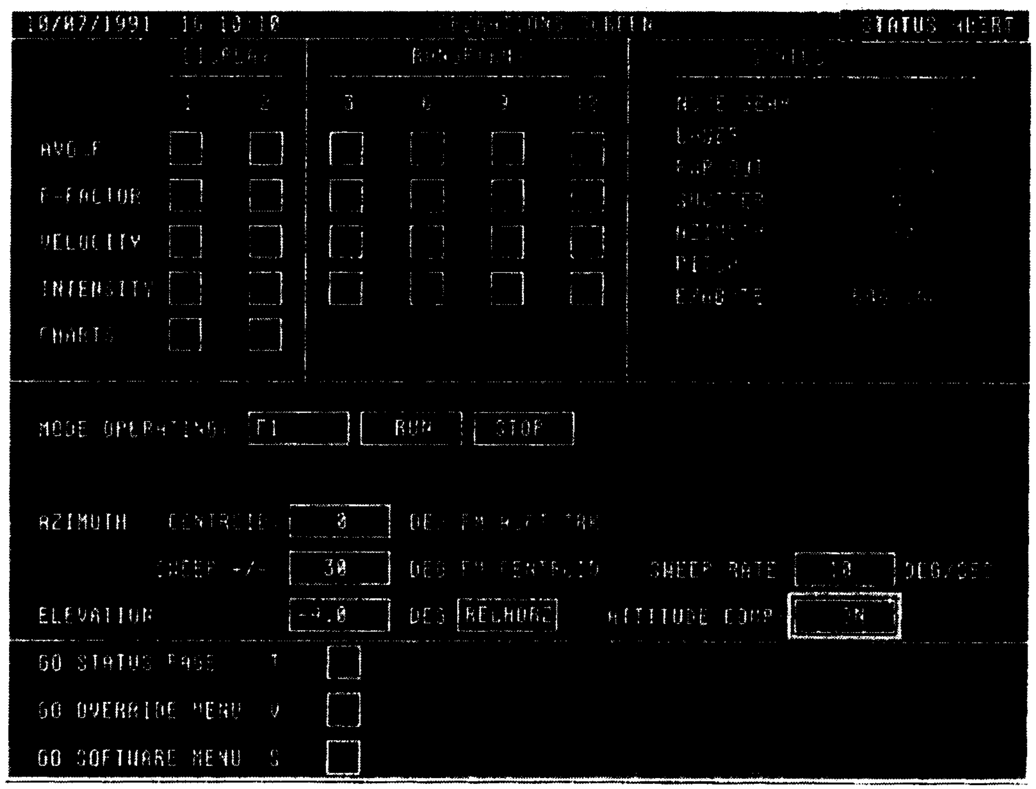
CLASS





REAL TIME DISPLAYS (1 of 3)

OPERATIONS SCREEN IS PRINCIPAL DISPLAY ON LARGE MONITOR



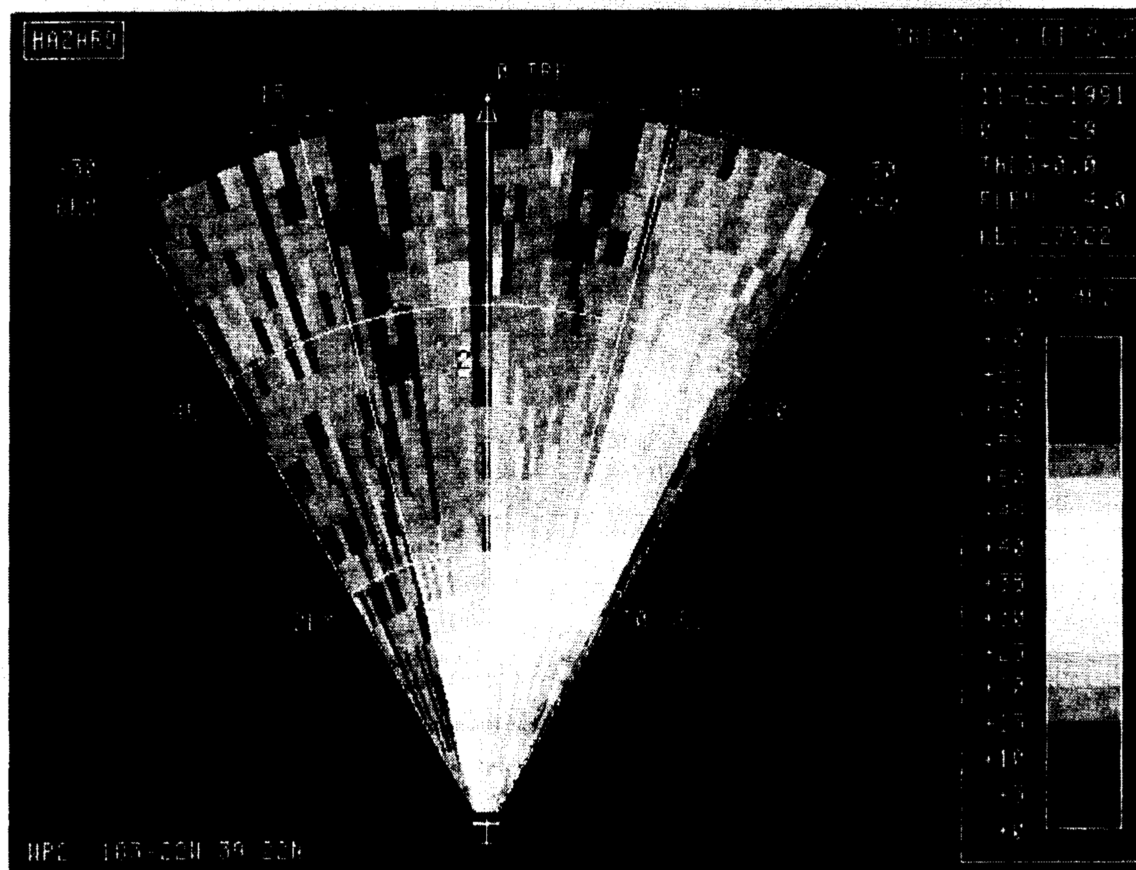
PRODUCT DISPLAYS

FEATURES:

- +/- 30° DISPLAY REFERENCED TO EITHER AIRCRAFT TRACK (DYNAMIC) OR AZIMUTH (POINTING)
- RANGE ON LEFT (3, 6, 9, OR 12 KM SELECTABLE)
- TIME TO RANGE ON RIGHT (AT PRESENT SPEED)
- WAYPOINT LOCATION AT BOTTOM LEFT (2 AVAILABLE)
- DISPLAY TYPE AND STATUS PARAMETERS AT TOP RIGHT
- COLOR DISPLAY SCALE (MODIFIED ON CONFIGURATION PAGE)

REAL TIME DISPLAYS (2 of 3)

THERE ARE FOUR "PIE" SCREENS TO DISPLAY IN THE TWO SMALL MONITORS.
THESE ARE : AVERAGE F FACTOR, F FACTOR, VELOCITY AND INTENSITY.



EACH SUCCESSIVE 15 DEGREE SECTOR SHOWS DIFFERENT POWER LEVEL. SETTINGS ARE : OFF, .3 mJ, 3mJ and 10mJ

REAL TIME DISPLAYS (3 of 3)

EXAMPLE OF A MENU PAGE ONE OF EIGHT AVAILABLE

STATUS LIMITS PAGE

- CRITICAL SYSTEM AND HOUSEKEEPING PARAMETER ALERT LIMITS
- ALERTS CAN BE ENABLED / DISABLED
- ACTIVE ALARMS SHOW UP AS RED PARAMETERS
- STATUS ALERT BOX FLASHES ON ALL CONTROL PAGES
- OPERATOR MUST ACKNOWLEDGE ALERT TO RESET

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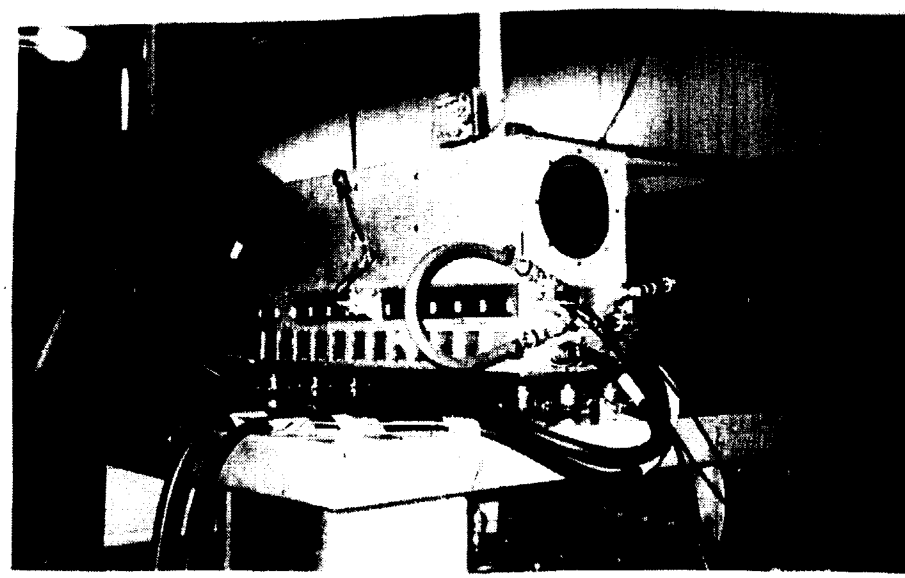
QUALIFICATION TESTING

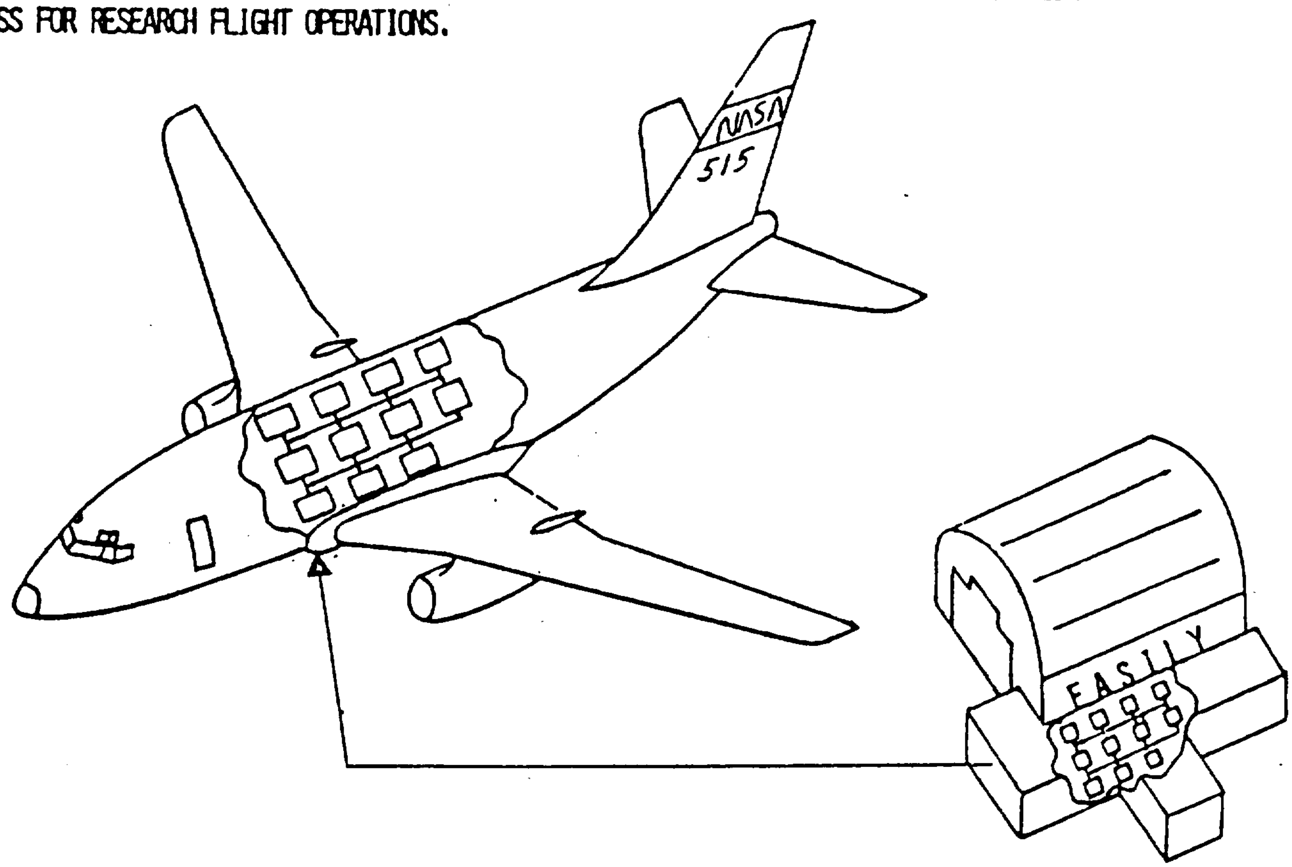
CLASS

- COMPLIANCE WITH RTCA / DO - 160C AND LHB 7910.1
- RANDOM VIBRATION TO 2.29 G'S RMS FOR 15 MINUTES IN THREE AXIS
- EMI BY PROBE AND SPECTRUM ANALYZER
- EMC AFTER INSTALLATION IN AIRCRAFT



PURPOSE

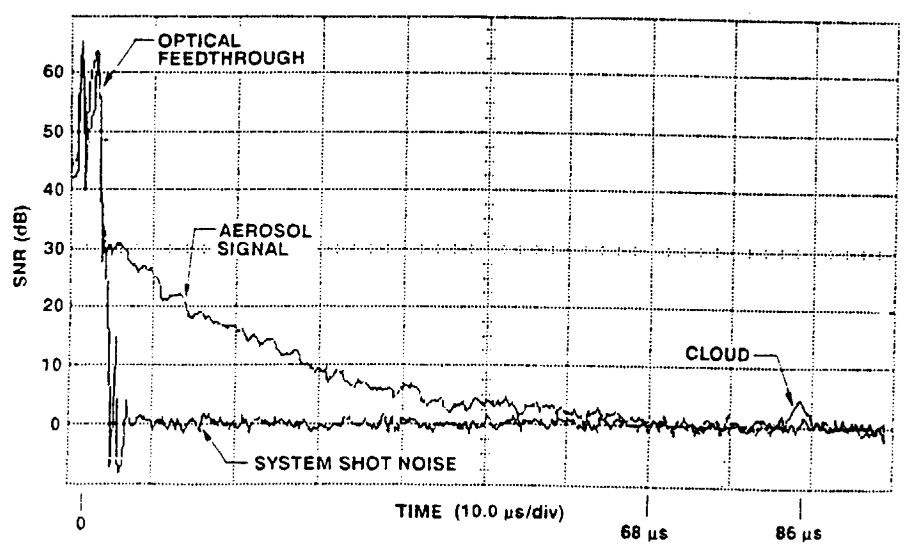
IN A FLIGHT LIKE CONFIGURATION, PERFORM EXPERIMENTAL FLIGHT AVIONICS HARDWARE AND SOFTWARE SYSTEMS INTEGRATION TESTS TO VALIDATE THEIR COMPATIBILITY AND DEMONSTRATE THEIR READINESS FOR RESEARCH FLIGHT OPERATIONS.



GROUND AND FLIGHT TESTING

CLASS

- EASILY LAB --> TEST INTEGRATION WITH AIRCRAFT DATAC AND POWER SYSTEMS
- LASER PREINSTALLATION ---> FINAL ADJUSTMENTS / ALIGNMENTS
- INSTALLATION ---> USE INSERTED HELIUM NEON LASER TO DETERMINE SCANNER ALIGNMENT AND FUSELAGE CUT OUTS
- TEST FLIGHTS ---> TEST ALL ORIENTATIONS AND POSSIBLE FLIGHT CONDITIONS AND DETERMINE OPERATING PARAMETERS



COHERENT LIDAR AIRBORNE SHEAR SENSOR (CLASS)

SIGNAL-TO-NOISE RATIO VS. RANGE: 10.6-MICRONS, 8.5 mJ

10-km AEROSOL RETURNS AT NASA, IN HAMPTON, VIRGINIA

PROCEDURES

CLASS

PREFLIGHT ACTIONS

- INSPECTION OF EXTERNAL (SCANNER) COMPONENTS AND CLEANING SCANNER WINDOW
- VERIFICATION OF ALL SWITCH POSITIONS
- POWER UP AND SYSTEM BOOT / WARM UP
- VERIFICATION OF OPERATOR CONTROLS, SCANNER AND CHILLER OPERATION
- VERIFICATION OF LASER STABILITY, POWER OUTPUT AND DATA RECORDING

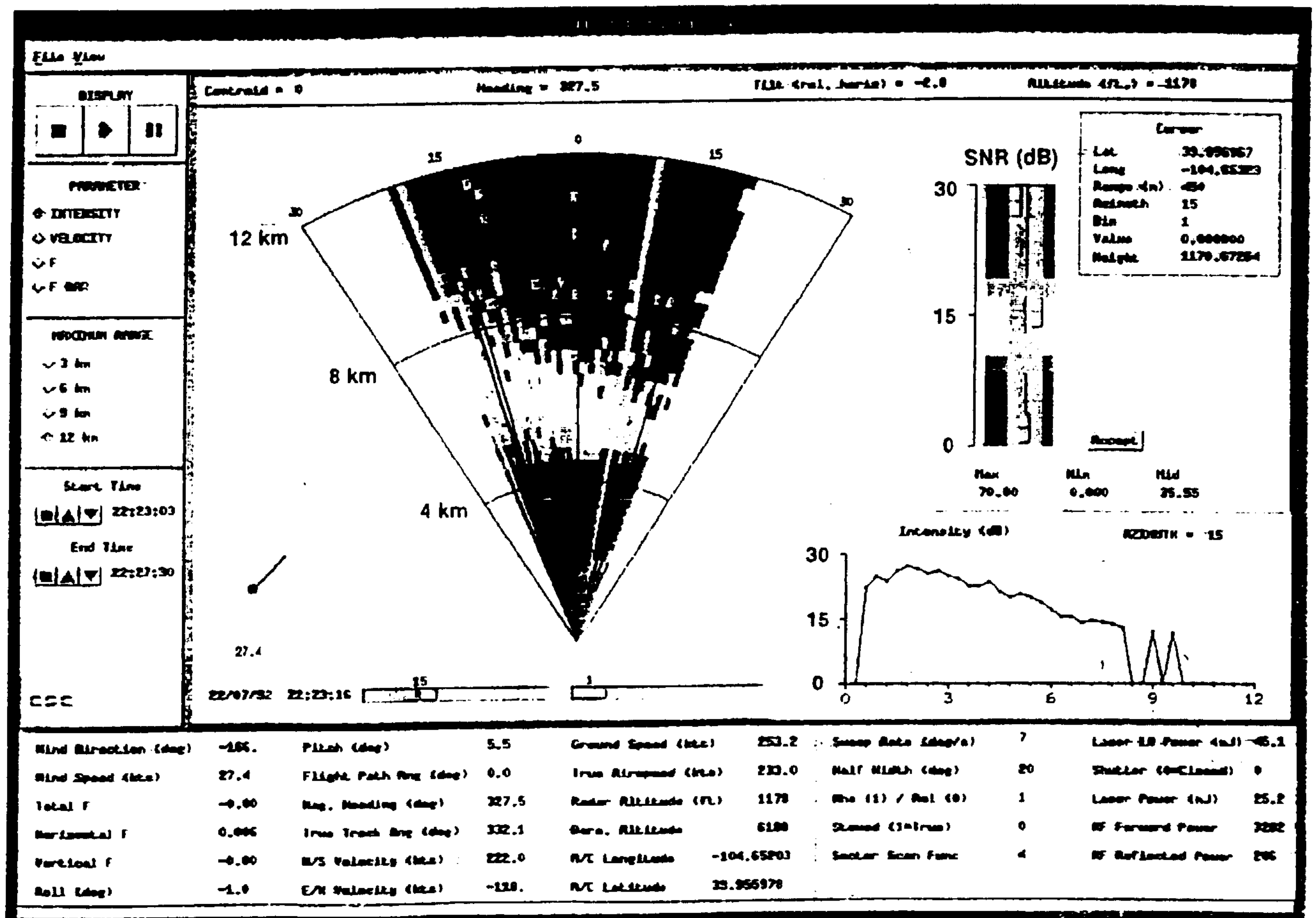
INFLIGHT ACTIONS

- SCANNER UNSTOWED AFTER NOSE GEAR UP
- NOISE SAMPLE TAKEN
- DATA RECORDING ENABLED
- SCAN PATTERNS SELECTED

POSTFLIGHT ACTIONS

- STOW SCANNER BEFORE NOSE GEAR DOWN
- REMOVE EXABYTE TAPES AND MARK ALL DATA
- POWER DOWN SYSTEM

DATA PRODUCT



SUMMARY

CLASS 10

CLASS 10 SYSTEM SUCCESSFULLY MEASURED 13 WINDSHEAR DATA EVENTS

- O 7 RESEARCH FLIGHTS DURING DENVER DEPLOYMENT
- O 8 RESEARCH FLIGHTS DURING ORLANDO DEPLOYMENT
- O 10 LOCAL TESTS FLIGHTS

SYSTEM HAD POTENTIAL TO MEASURE MORE EVENTS, BUT PERFORMANCE WAS DEGRADED BY

- O REDUCED LASER ENERGY
- O INTERMITTENT ERRATIC SCANNER BEHAVIOR

RDR-4B Doppler Weather Radar with Windshear Detection Capability.

D. Kuntman,

Bendix-Allied Signal Co.

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RDR-4B
DOPPLER WEATHER RADAR
WITH
WINDSHEAR DETECTION CAPABILITY

DARYAL KUNTMAN

5TH AIRBORNE WINDSHEAR REVIEW MEETING
SEPTEMBER 28-30, 1993

OUTLINE

- BACKGROUND
- STATUS OF DEVELOPMENT ACTIVITIES
- CERTIFICATION ACTIVITIES
- LESSONS LEARNED
- RECOMMENDATIONS FOR FUTURE ACTIVITIES

BACKGROUND

- ALLIEDSIGNAL MADE A COMMITMENT TO THE DEVELOPMENT AIRBORNE WEATHER RADAR WITH FORWARD LOOKING DETECTION CAPABILITY
- RDR-4B DEVELOPMENT ACTIVITIES STARTED IN EARLY 1990
- BASED ON EVOLUTION OF THE RDR-4A DOPPLER WEATHER RADAR, IN SERVICE SINCE 1980

RDR-4A / RDR-4B COMPARISON

- **NEW RECEIVER/FREQUENCY SYNTHESIZER MODULE**
- **NEW DIGITAL SIGNAL PROCESSING MODULES**
  - DSP'S WITH TOTAL OF 290 MFLOPS CAPABILITY
  - SURFACE MOUNT TECHNOLOGY
  - FLEXIBLE DESIGN FOR FUTURE GROWTH
- **MINOR MODIFICATIONS TO THE INDICATORS**
- **NO MODIFICATIONS TO THE ANTENNA OR CONTROL PANEL**
- **NO AIRCRAFT MECHANICAL MODIFICATIONS**
- **NO RADOME CHANGES**

STATUS OF DEVELOPMENT ACTIVITIES

- PRODUCTION HAS STARTED
- RECEIVED ORDERS FOR OVER 700 A/C SYSTEMS
- FINAL CERTIFICATION FLIGHT TESTS IN PROGRESS
- DELIVERIES WILL START IN NOVEMBER 1993

FLIGHT TESTS

- **STARTED IN 1991 ON ALLIEDSIGNAL CV-580**
- **DATA RECORDING PROGRAM ON CONTINENTAL A300 (CONTINUING)**
- **GROUND BASED RADAR CORRELATION FLIGHTS (1992)**
  - DRY AND WET MICROBURST PENETRATION
  - AT DENVER WITH MILE-HIGH RADAR
  - AT ORLANDO WITH TDWR
- **GROUND CLUTTER DATA COLLECTION FLIGHTS (1993)**
  - NEWARK
  - MIAMI (SUBSTITUTION FOR WASHINGTON, DC)
  - DENVER

CERTIFICATION ACTIVITIES

- **APPLIED FOR MASTER STC ON CV-580**
  - **FOLLOW ON STC'S TO MEET FAR 121.358 ARE FOR AIRCRAFT SPECIFICS ONLY**
- **CERTIFICATION TESTS ARE CONTINUING**
  - DO-173 WEATHER RADAR MOPS
  - DO-220 WINDSHEAR RADAR MOPS
- **WILL BE CERTIFIED TO TSO c63c**

WINDSHEAR CERTIFICATION

- **WINDSHEAR DETECTION CAPABILITY WILL BE BASED ON**
  - DO-220 AND,
  - FAA SYSTEM REQUIREMENTS DOCUMENT (VERSION 8.0)
- **FLIGHT TEST: CORRELATION WITH IN SITU DATA**
- **SIMULATIONS USING NASA MODELS AND COLLECTED GROUND CLUTTER DATA**
- **THEORETICAL ANALYSIS FOR MISSED DETECTION, NUISANCE ALARMS AND FALSE ALARMS**

LESSONS LEARNED (continued)

- CORRELATION OF AIRBORNE AND GROUND BASED RADARS ARE VERY DIFFICULT TO DEMONSTRATE, SHOULD NOT BE REQUIREMENT FOR CERTIFICATION
- GROUND CLUTTER DATA COLLECTION FLIGHTS ARE VERY DIFFICULT TO ARRANGE, A MODEL MIGHT BE USEFUL
- ATC HAS NOT BEEN INVOLVED

LESSONS LEARNED (continued)

- CORRELATION OF AIRBORNE AND GROUND BASED RADARS ARE VERY DIFFICULT TO DEMONSTRATE, SHOULD NOT BE REQUIREMENT FOR CERTIFICATION

- GROUND CLUTTER DATA COLLECTION FLIGHTS ARE VERY DIFFICULT TO ARRANGE, A MODEL MIGHT BE USEFUL

- ATC HAS NOT BEEN INVOLVED

RECOMMENDATIONS FOR FUTURE ACTIVITIES

- **A TSO FOR WEATHER RADAR WITH WINDSHEAR DETECTION CAPABILITY BASED ON RTCA DO-220**
- **AN ADVISORY CIRCULAR FOR CERTIFICATION CRITERIA BASED ON FAA SYSTEM REQUIREMENTS DOCUMENT**
- **DEVELOPMENT OF COMMON TERMINOLOGY BETWEEN TDWR AND AIRBORNE ALERTS**
  - MICROBURST AND WINDSHEAR SHOULD MEAN THE SAME THING BOTH ON THE GROUND AND IN THE AIR
  - UNIFORM HAZARD FACTOR CRITERIA SHOULD BE USED BY BOTH SYSTEMS

The Collins Windshear Program.

R. Robertson,

Rockwell-Collins Co.

COLLINS
FORWARD-LOOKING WINDSHEAR

FIFTH COMBINED AIRBORNE WINDSHEAR
REVIEW MEETING

SEPTEMBER 28 - 30, 1993

ROY E. ROBERTSON

COLLINS FORWARD-LOOKING WINDSHEAR

Presentation Topics

- WXR-700 / Windshear Overview
- Certification Topics

COLLINS FORWARD-LOOKING WINDSHEAR

- Leading Supplier of ARINC-708 Radars
  - FIRST SOLID STATE SYSTEM - 1980
  - FIRST TURBULENCE DETECTION - 1982
- 5,900 Systems Delivered
- 151 Airlines Worldwide
- Over 100 Million Flight Hours In Service

COLLINS
FORWARD-LOOKING WINDSHEAR

WXR-700 DEVELOPMENT PROGRAMS

- QUALITY INITIATIVE
- FORWARD-LOOKING WINDSHEAR

COLLINS
FORWARD-LOOKING WINDSHEAR

COLLINS WXR-700X QUALITY ENHANCEMENTS

- Transmitter Technology Update
- RF Stability Improvements
- Substantially Less Power Dissipation
- Increased Reliability

COLLINS
FORWARD-LOOKING WINDSHEAR

WINDSHEAR SYSTEM IMPROVEMENTS

- High Throughput Signal Processing
- Expanded Input/Output Capability
- Low Sidelobe Flatplate Antenna

COLLINS
FORWARD-LOOKING WINDSHEAR

WEATHER RADAR FUNCTIONS

- Weather Detection (320 NM Range)
- Turbulence Detection
- Path Attenuation Compensation
- Target Alert, Turbulence Alert
- Ground Clutter Suppression
- Forward-Looking Windshear

COLLINS
FORWARD-LOOKING WINDSHEAR

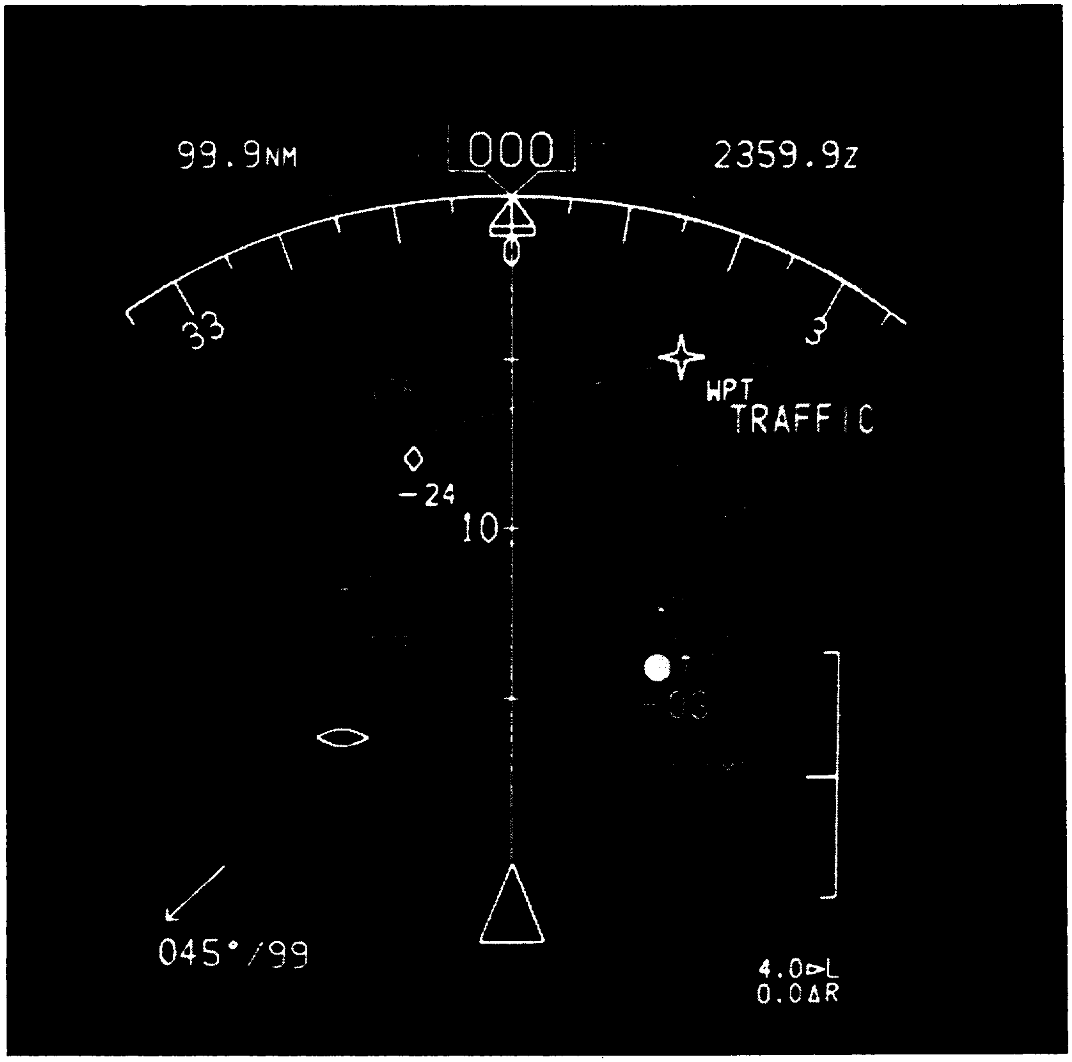
WINDSHEAR SYSTEM CHARACTERISTICS

- 5-Mile Range
- ± 30 Degree Azimuth Coverage
- Windshear Time-shared with Weather Detection
- Auto-Enabled Warnings Below 1,200 Ft. Radio Altitude
- Aural and Visual Alerts Outputs
- Situation Display (ICON Overlay on WX Display)

COLLINS
FORWARD-LOOKING WINDSHEAR

AIRCRAFT INSTALLATION

- ARINC 708A Interwiring
  - Radio Altitude Input
  - Air Data / Airspeed Input
  - Automatic Enable/Disable Discretes
- Cockpit Annunciators
  - Warning/Caution/Fail Indicator Lamps
  - Aural Speaker
- Radome Inspection / Test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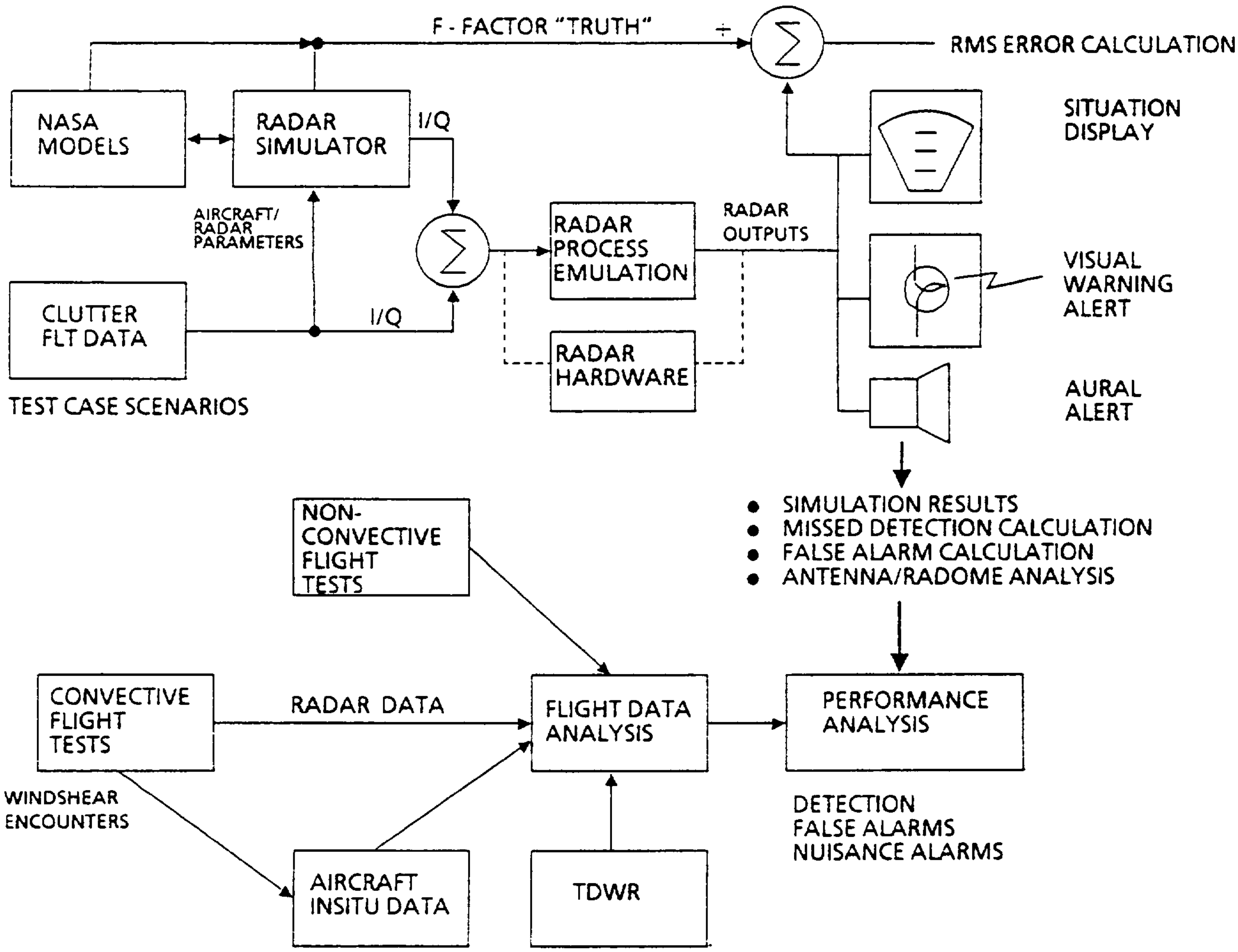
COLLINS
FORWARD-LOOKING WINDSHEAR

CERTIFICATION



Windshear Radar
Performance Validation

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13. ABSTRACT *(Maximum 200 words)*

The Fifth (and Final) Combined Manufacturers' and Technologists' Airborne Windshear Review Meeting was hosted jointly by the NASA Langley Research Center (LaRC) and the Federal Aviation Administration (FAA) in Hampton, Virginia, on September 28-30, 1993. The meeting was co-chaired by Dr. Roland Bowles of LaRC and Robert Passman of the FAA. The purpose of the meeting was to report on the highly successful windshear experiments conducted by government, academic institutions, and industry; to transfer the results to regulators, manufacturers, and users; and to set initiatives for future aeronautics technology research. The formal sessions covered recent developments in windshear flight testing, windshear modeling, flight management, and ground-based systems, airborne windshear detection systems, certification and regulatory issues, and development and applications of sensors for wake vortices and for synthetic and enhanced vision systems. The present document has been compiled to record and make available the technology updates and visual material from the formal sessions and the discussions and questions and answers which followed.

14. SUBJECT TERMS
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