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Session X. Airborne Doppler Radar / Industry

N 9 1 - 2 4 1 4 8

Status of General Motors Hughes Electronics Research
Dr. Brian Gallagher, Delco
Mark Selogie, Hughes

**NASA/FAA
THIRD COMBINED MANUFACTURERS' AND
TECHNOLOGISTS' AIRBORNE WIND SHEAR
REVIEW MEETING**

**DELCO SYSTEMS OPERATIONS
DIVISION OF GENERAL MOTORS HUGHES ELECTRONICS**

**FORWARD LOOKING
WINDSHEAR DETECTION PROGRAM
1989/1990 STATUS REPORT**

**Delco Systems
Operations**

**Brian J. Gallagher
October 18, 1990**

**DELCO SYSTEMS R&D PROGRAM ON
FORWARD LOOKING WINDSHEAR DETECTION**

COOPERATIVE EFFORT WITH HUGHES AIRCRAFT

- **OBJECTIVES**
- **APPROACH**
- **PROGRESS**
- **CONCLUSIONS**

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OBJECTIVES

**Develop Predictive Windshear Detection System
Based on Passive IR Remote Sensing Technology**

- **Advance Warnings of 10 to 30 seconds**
 - **Acceptable False Alarm Rate $<10^{-4}$**
 - **Small, Lightweight, Affordable**
-
- **Original Objective was Stand Alone Sensor**
 - **Integrated Sensor Approach Studied in 1989**

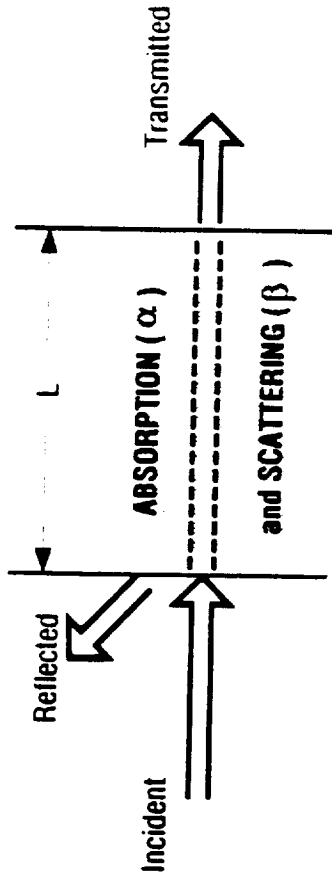
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APPROACH

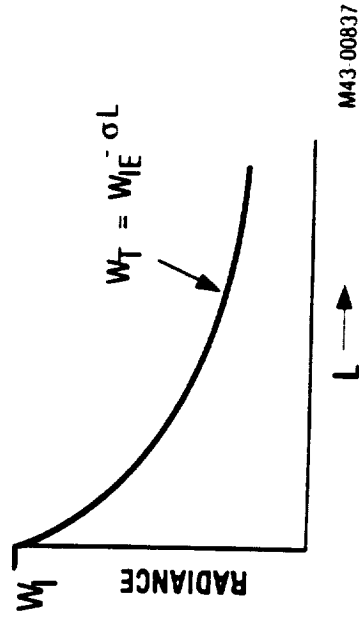
- **Inferential Approach Based on Temperature Differential of Downbursts Correlated with Vertical Velocity**
- **Sensor is Multi-Spectral Scanning Radiometer Operating in 10-14 micron Atmospheric Window**
- **Reliance on Measurement of Both Horizontal and Vertical Temperature Gradients of Atmosphere**
- **Primary Issue is Random Spatial Temperature Variations or Atmospheric Background 'Noise'**

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EXTINCTION OF RADIANCE BY ABSORBING AND SCATTERING MEDIA

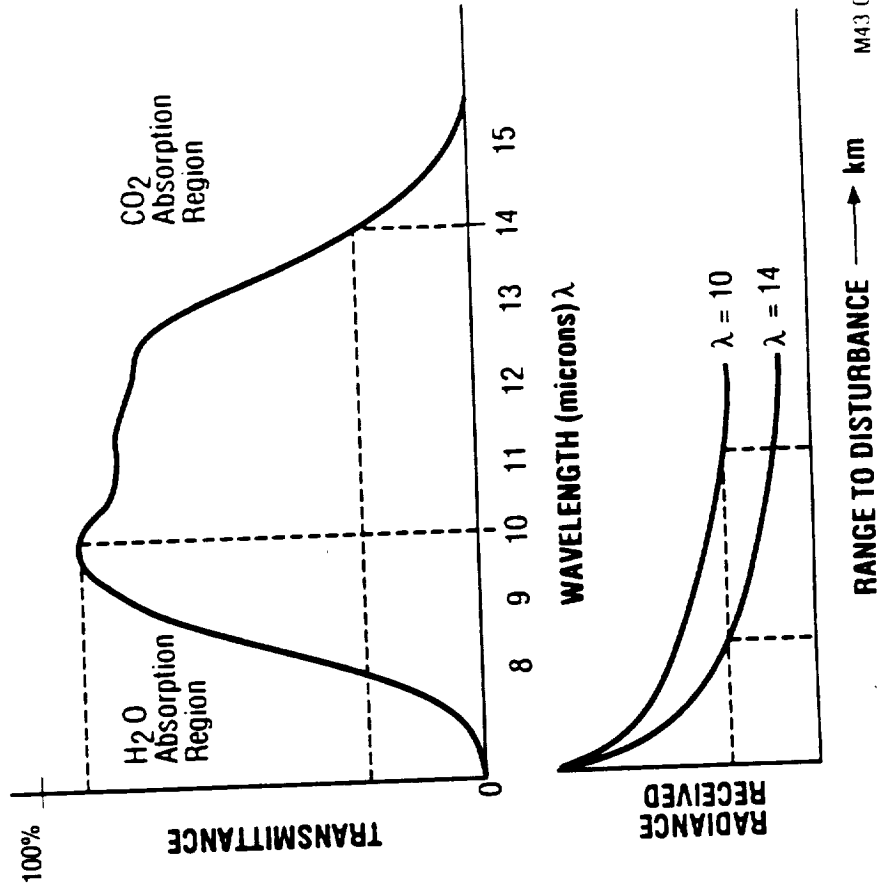


$\sigma = \text{Absorption} + \text{Scattering} = \text{Extinction Coefficient (km}^{-1}\text{)}$



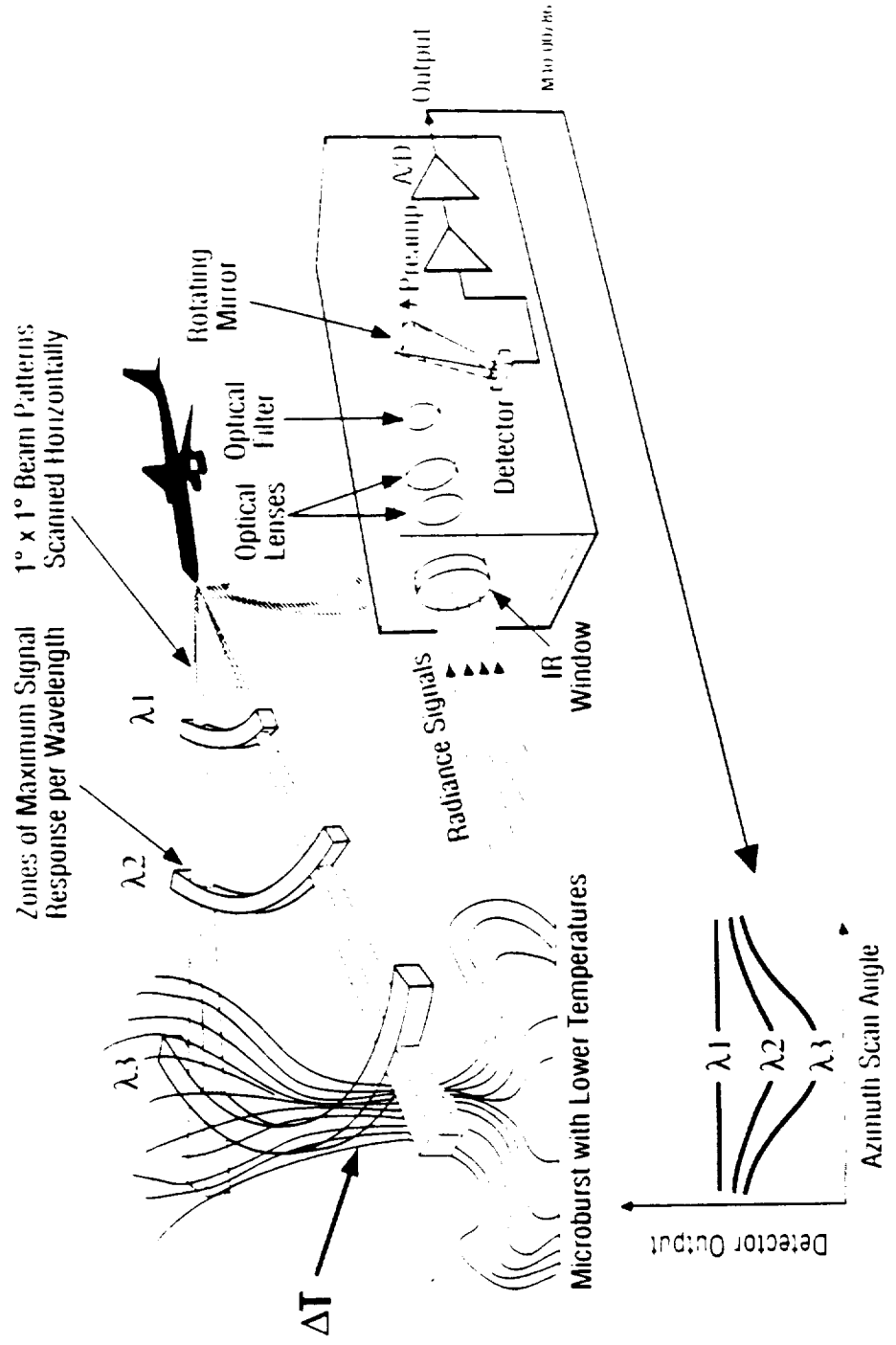
M43-00837

ATMOSPHERIC ABSORPTION IN FAR IR REGION

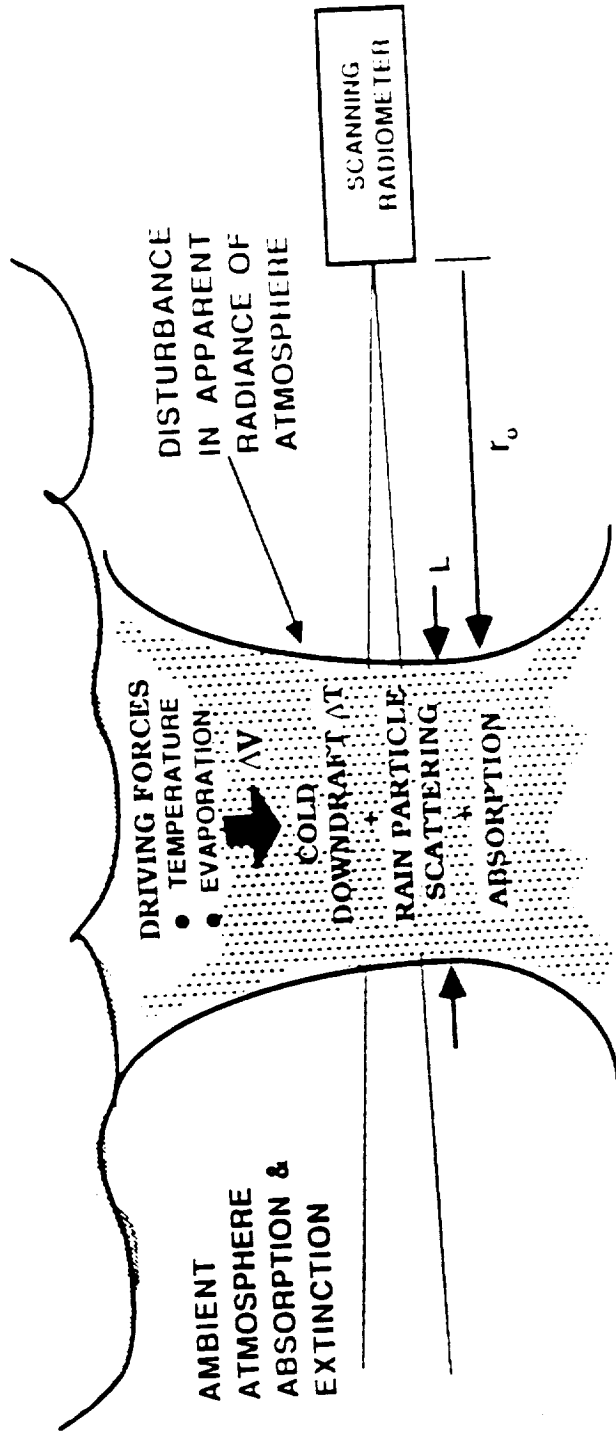


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INFRAMETRICS IMAGING RADIOMETER



BASIC RADIANCE SIGNAL EQUATION



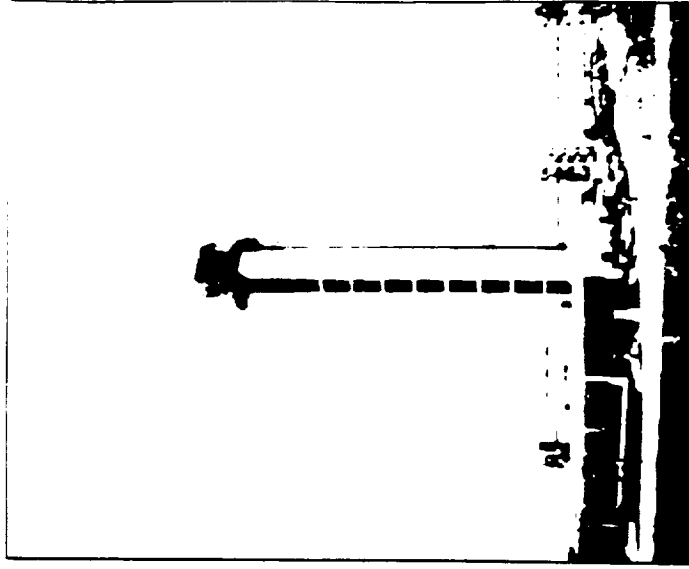
PEAK SIGNAL RADIANCE AT λ IN CO₂ ABSORPTION BAND

$$S_{\lambda} \approx G_{\lambda} W_{\lambda b} \frac{4\Delta T}{T} \left[1 - e^{- (\sigma_{\lambda} + \Delta\sigma) L} \right] e^{-\sigma_{\lambda} r_0}$$

ΔT proportional to ΔV
emissivity
atmospheric transmission

TOWER TEST PLAN

- Install test radiometer on 150-foot high control tower at Milwaukee airport to simulate airplane environment
- Collect atmospheric radiance data for different weather conditions during June and July 1989
- Reduce and analyze data using thermogram card and VAX computer programs
- Checkout computer algorithms, verify lapse rate measurements, and investigate atmospheric noise



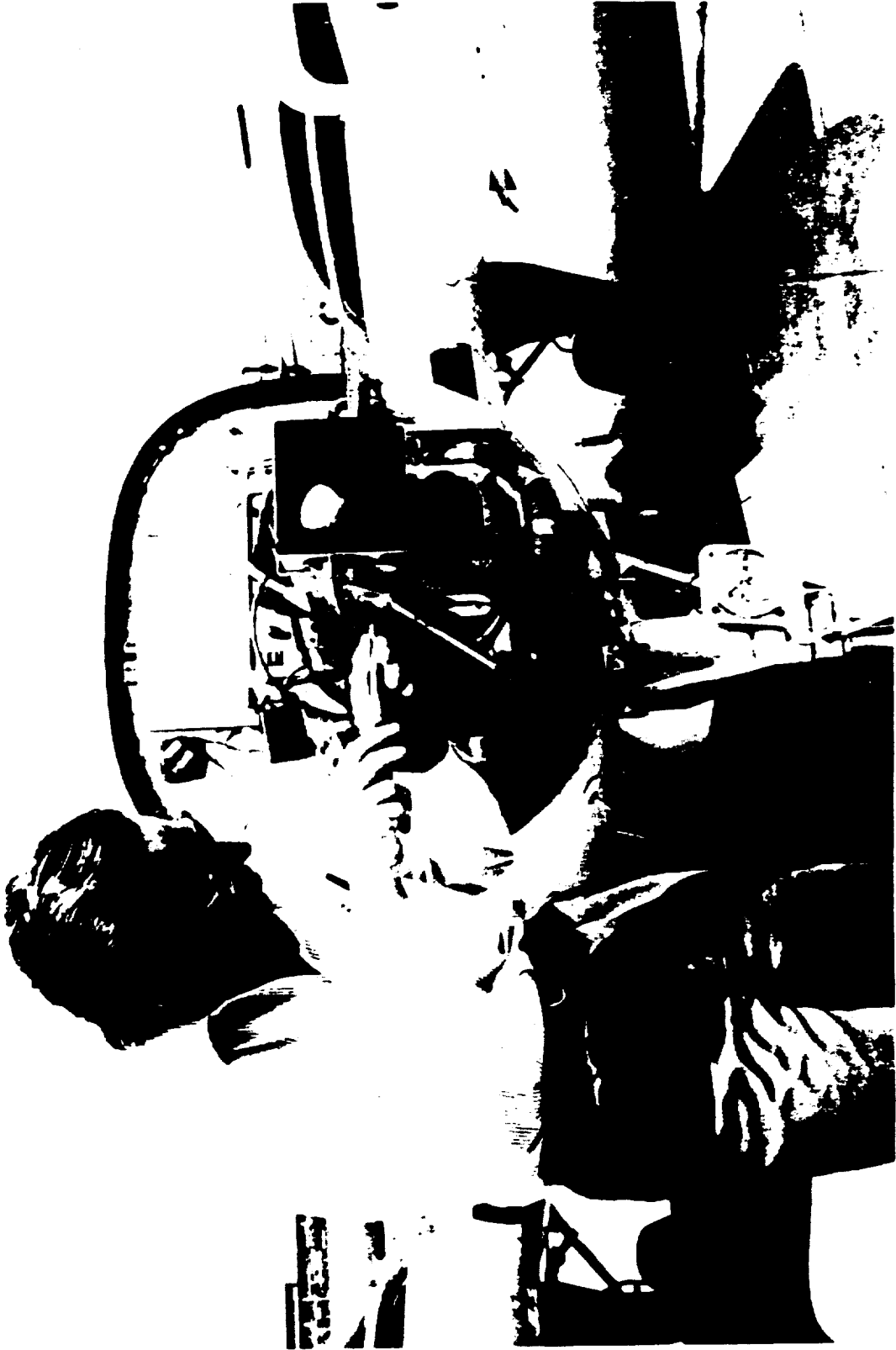
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FLIGHT TEST PLAN

- Install test radiometer in modified nose cone of flight test aircraft with TV camera, video recorders, and controls
- Install test computer and monitors with in-flight data collection, display, analysis, and recording software
- Instrument aircraft with Kollman Research Systems Data Acquisition and Recording System
- Perform in-flight data collection and real-time analysis test flights during August and September 1989, under different weather conditions, and correlate with meteorological sounding data
- Reduce and analyze data and determine atmospheric noise distribution and lapse rates

APPROACH

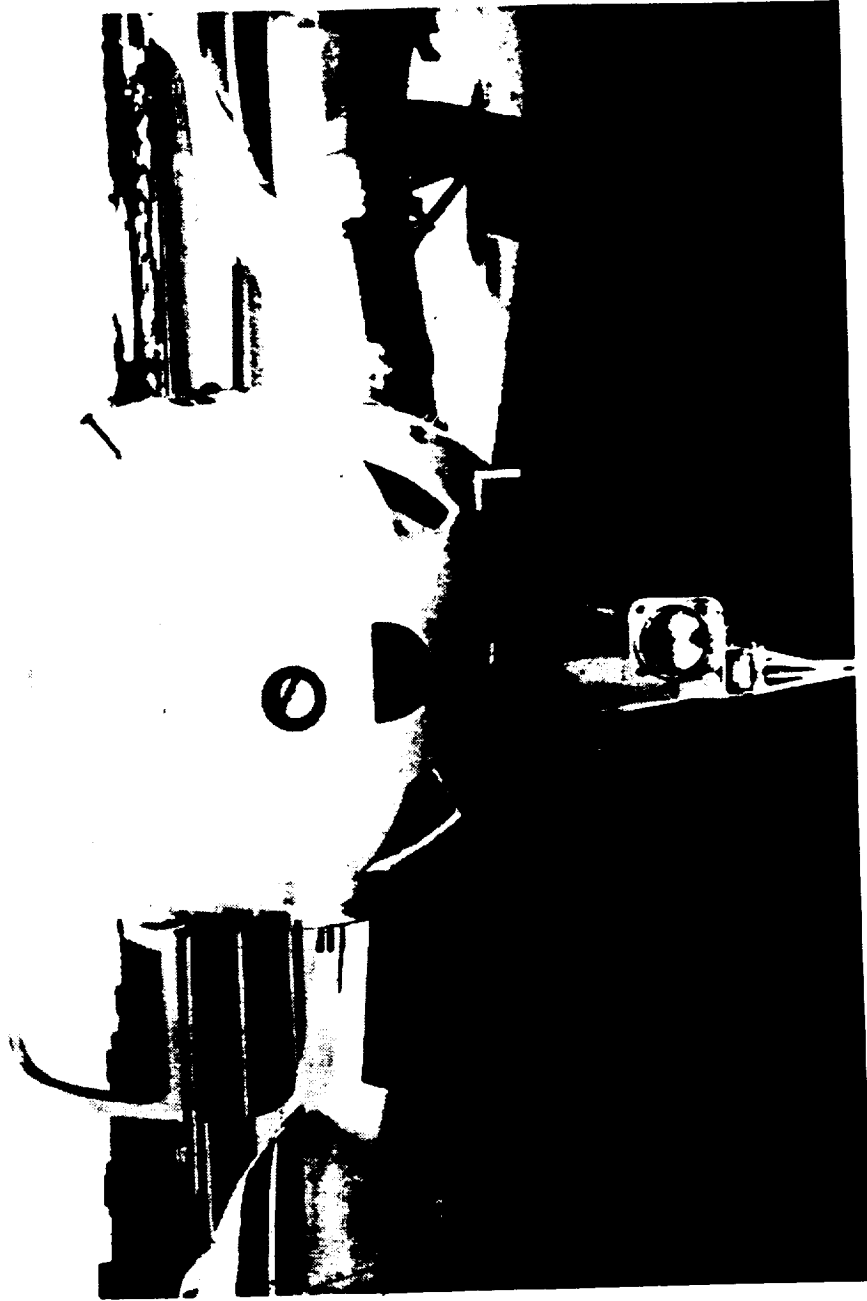
EXPERIMENTAL RADIOMETER INSTALLED IN FLIGHT TEST AIRCRAFT



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APPROACH

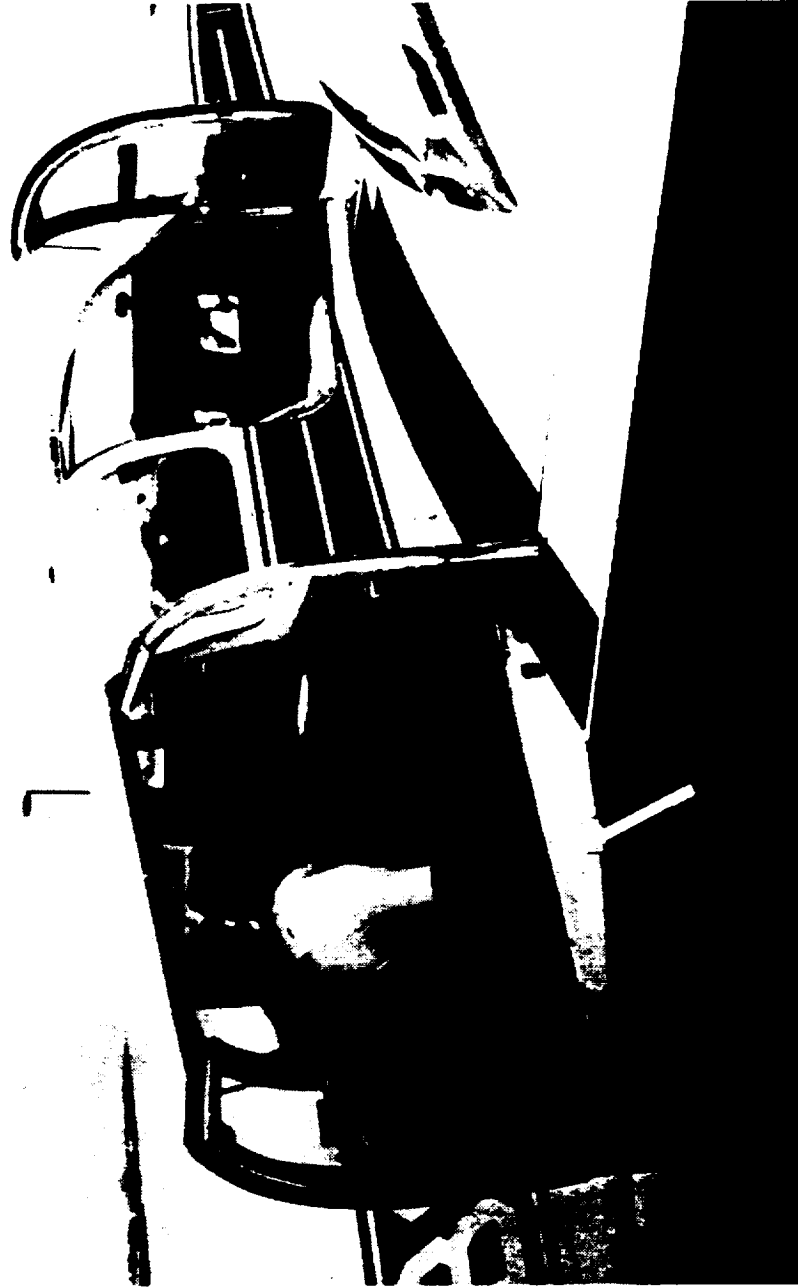
**MODIFIED NOSECONE SHOWING INFRARED AND
VISIBLE WINDOWS FOR RADIOMETER AND TV CAMERA**



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APPROACH

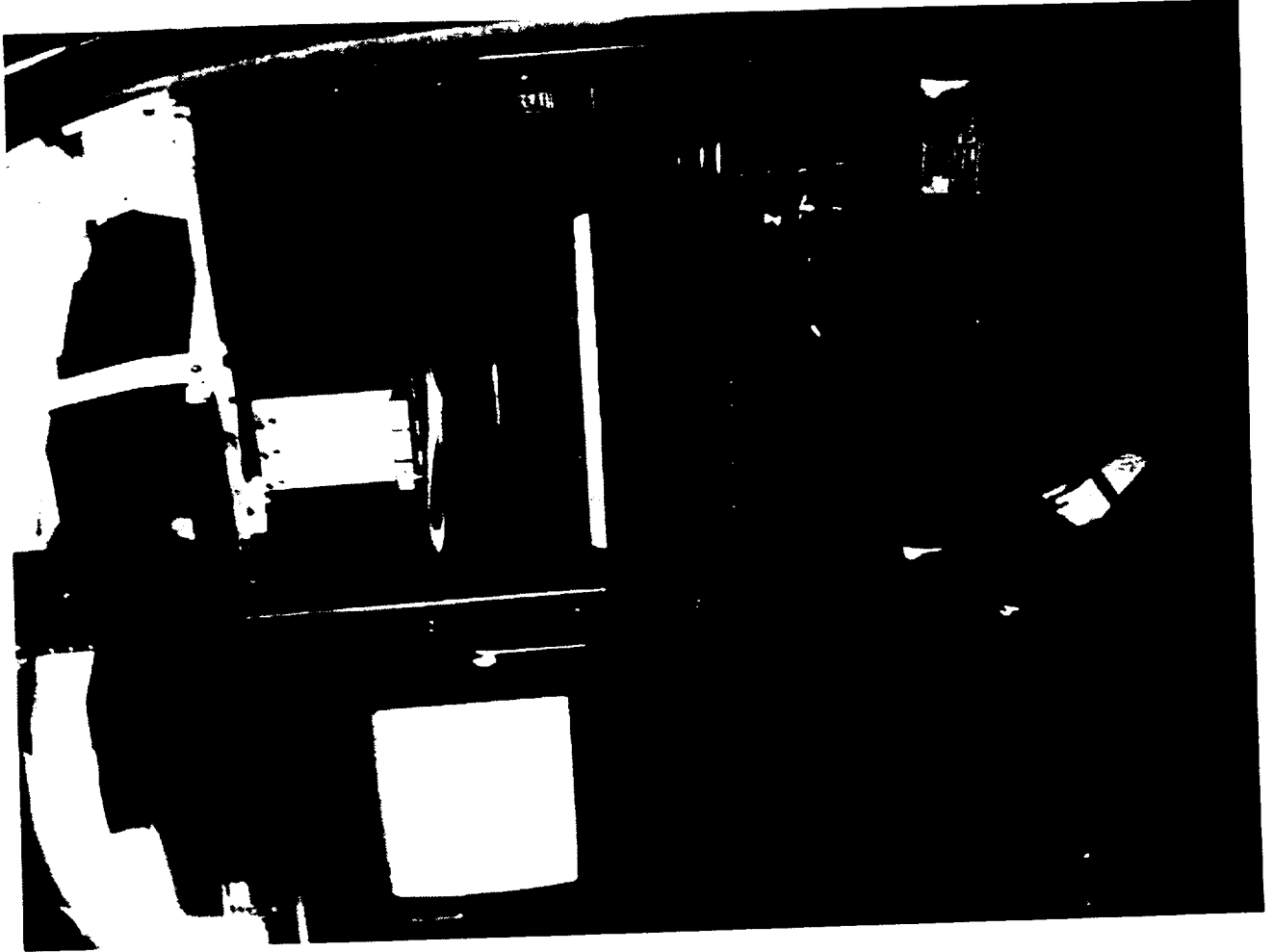
**FLIGHT TEST INSTRUMENTATION, DISPLAYS,
AND OPERATING CONTROLS CONSOLE**



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APPROACH

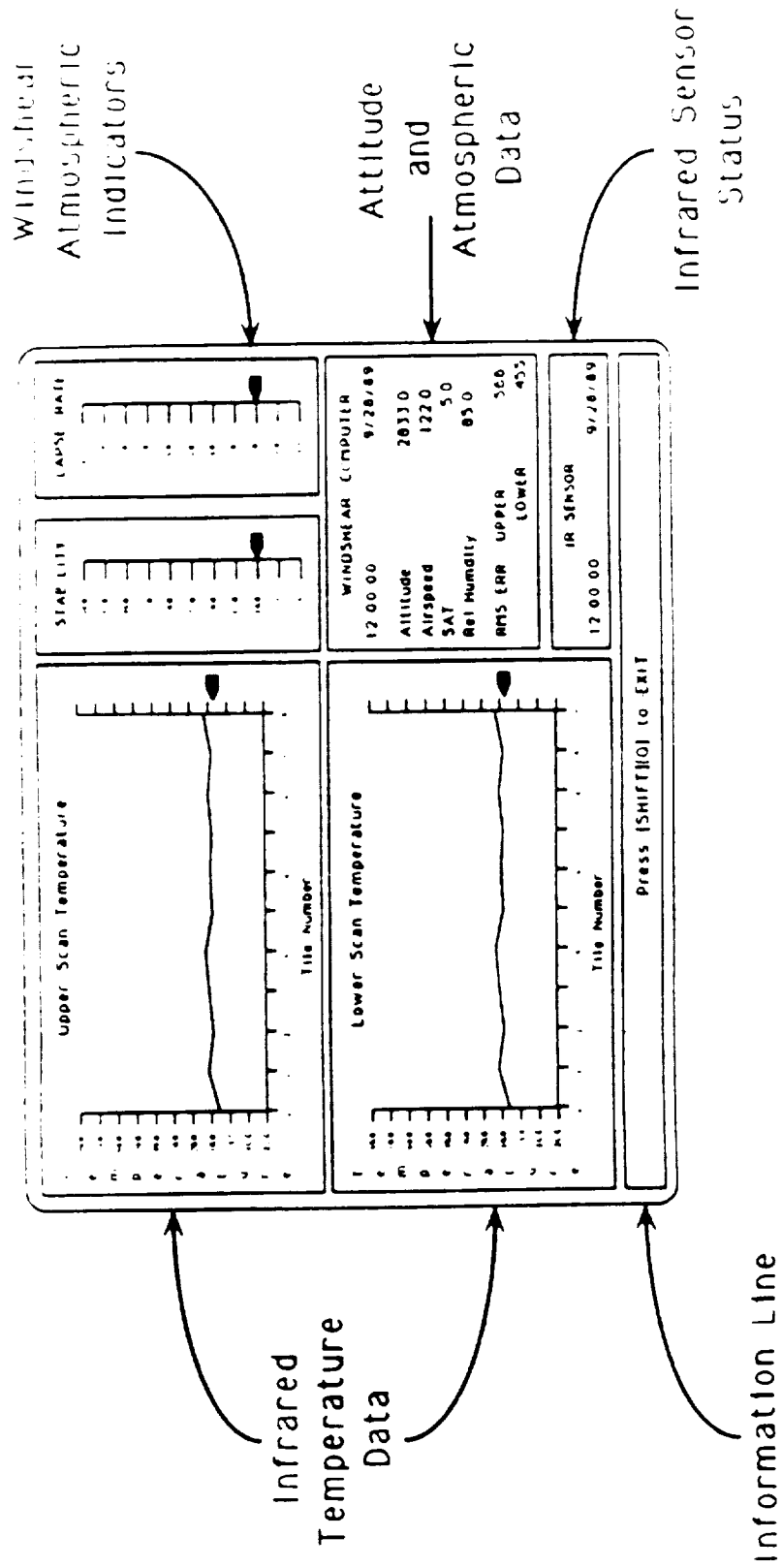
**FLIGHT TEST
DATA ACQUISITION
AND
DISPLAY CONSOLE**



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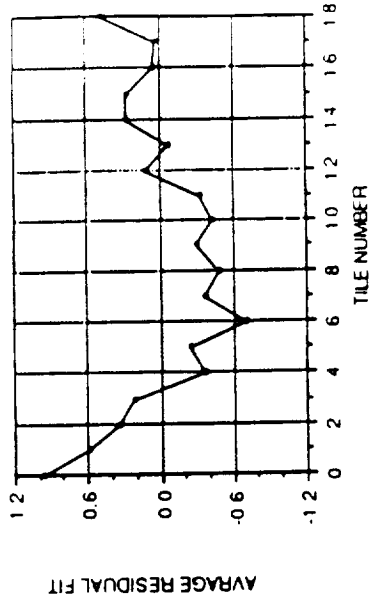
DATA ACQUISITION SYSTEM DISPLAY



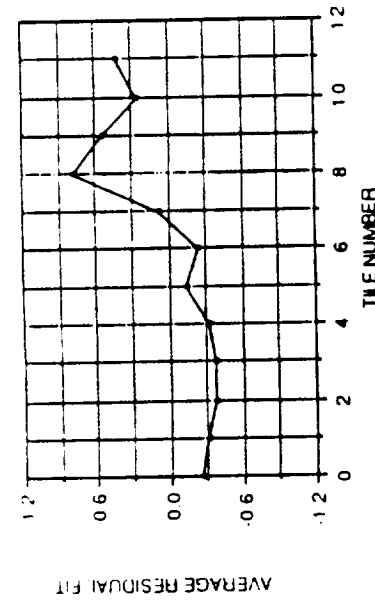
PROGRESS

FORWARD LOOKING WINDSHEAR DETECTION SYSTEM

1014_13, CLEAR/WEST, 10.5 FILTER, ROW 4
** TEMPERATURE ANALYSIS **

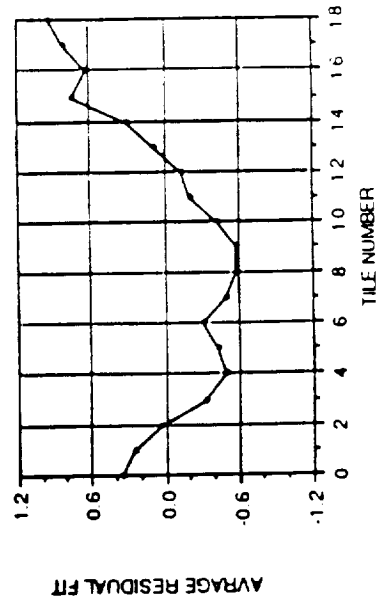


1014_49, CLEAR/EAST, 10.5 FILTER, ROW 4
** TEMPERATURE ANALYSIS **

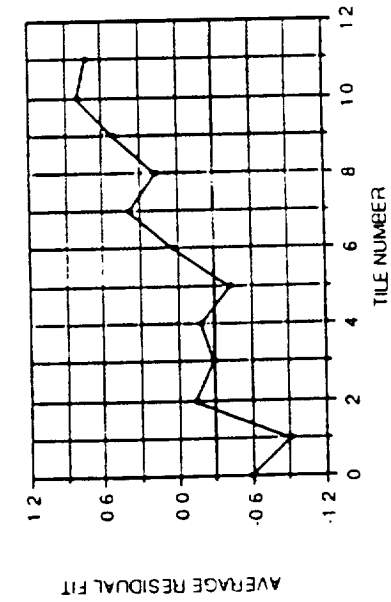


FOV.
1 deg x 1 deg

1014_13, CLEAR/WEST, 10.5 FILTER, ROW 5
** TEMPERATURE ANALYSIS **



1014_49, CLEAR/EAST, 10.5 FILTER, ROW 5
** TEMPERATURE ANALYSIS **

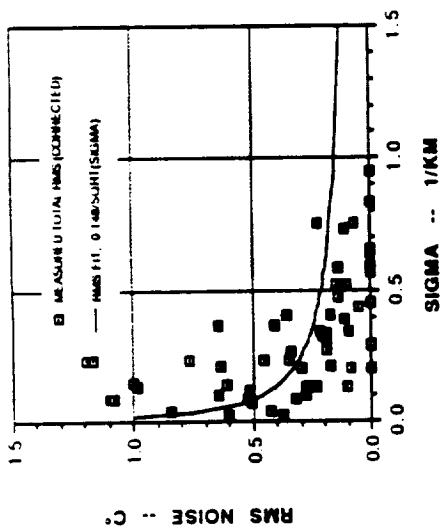


Parabolic Slope

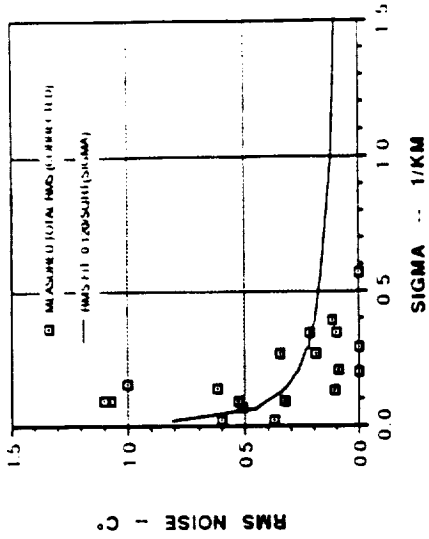
Linear Slope

Examples of Data Showing Linear and Parabolic Slope

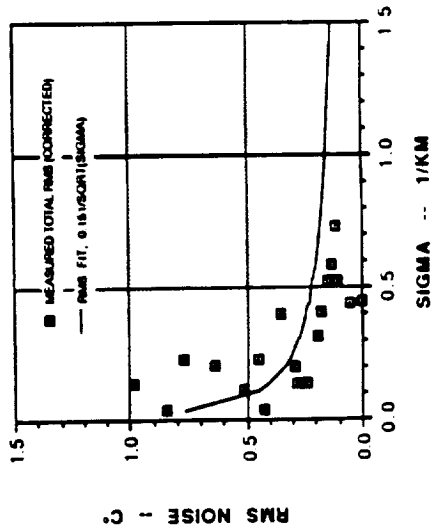
ALL FILTER, 1 FRAME, CORRECTED TOTAL RMS NOISE



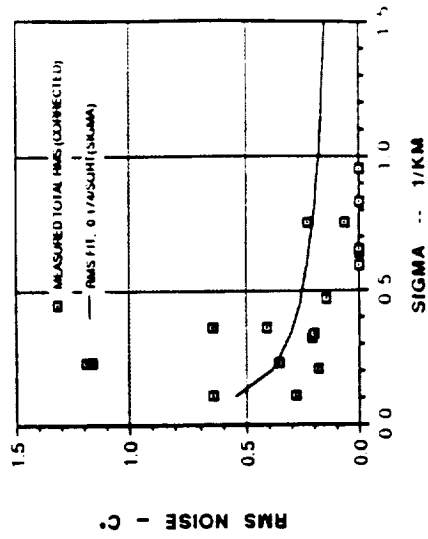
10.5 MICRON, 1 FRAME, CORRECTED TOTAL RMS NOISE



11.9 MICRON, 1 FRAME, CORRECTED TOTAL RMS NOISE



12.7 MICRON, 1 FRAME, CORRECTED TOTAL RMS NOISE



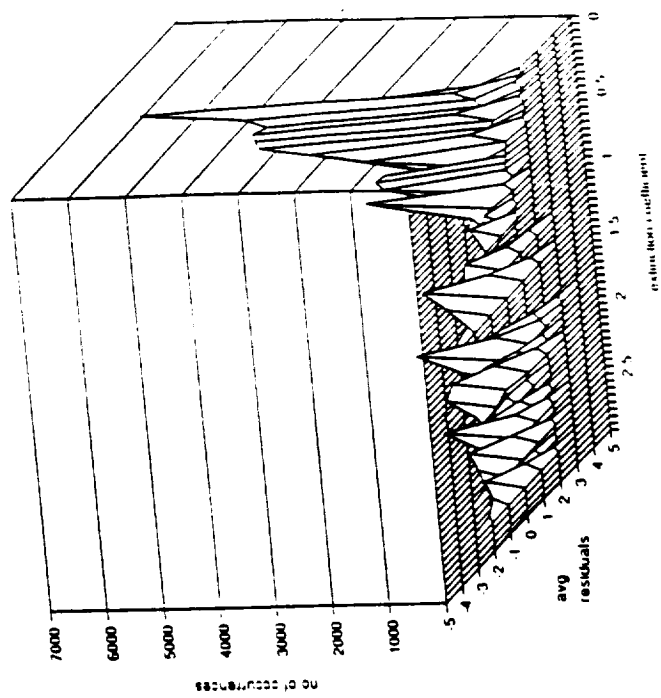
Corrected Total RMS Noise versus Extinction Factor

PROGRESS

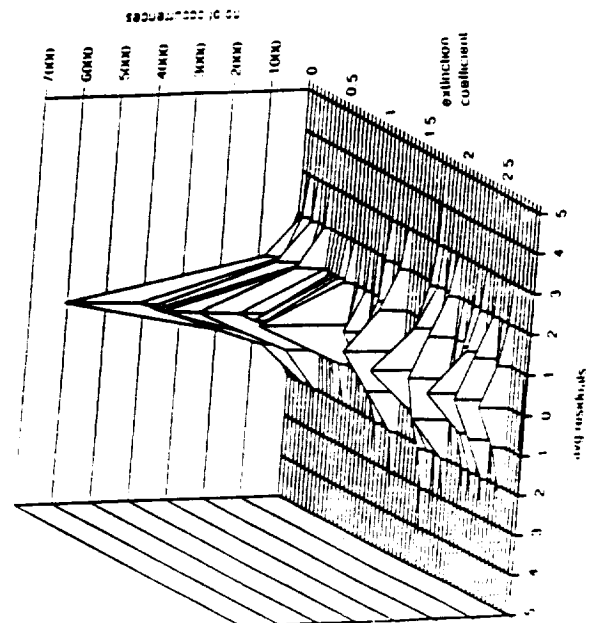
FORWARD LOOKING WINDSHEAR DETECTION SYSTEM

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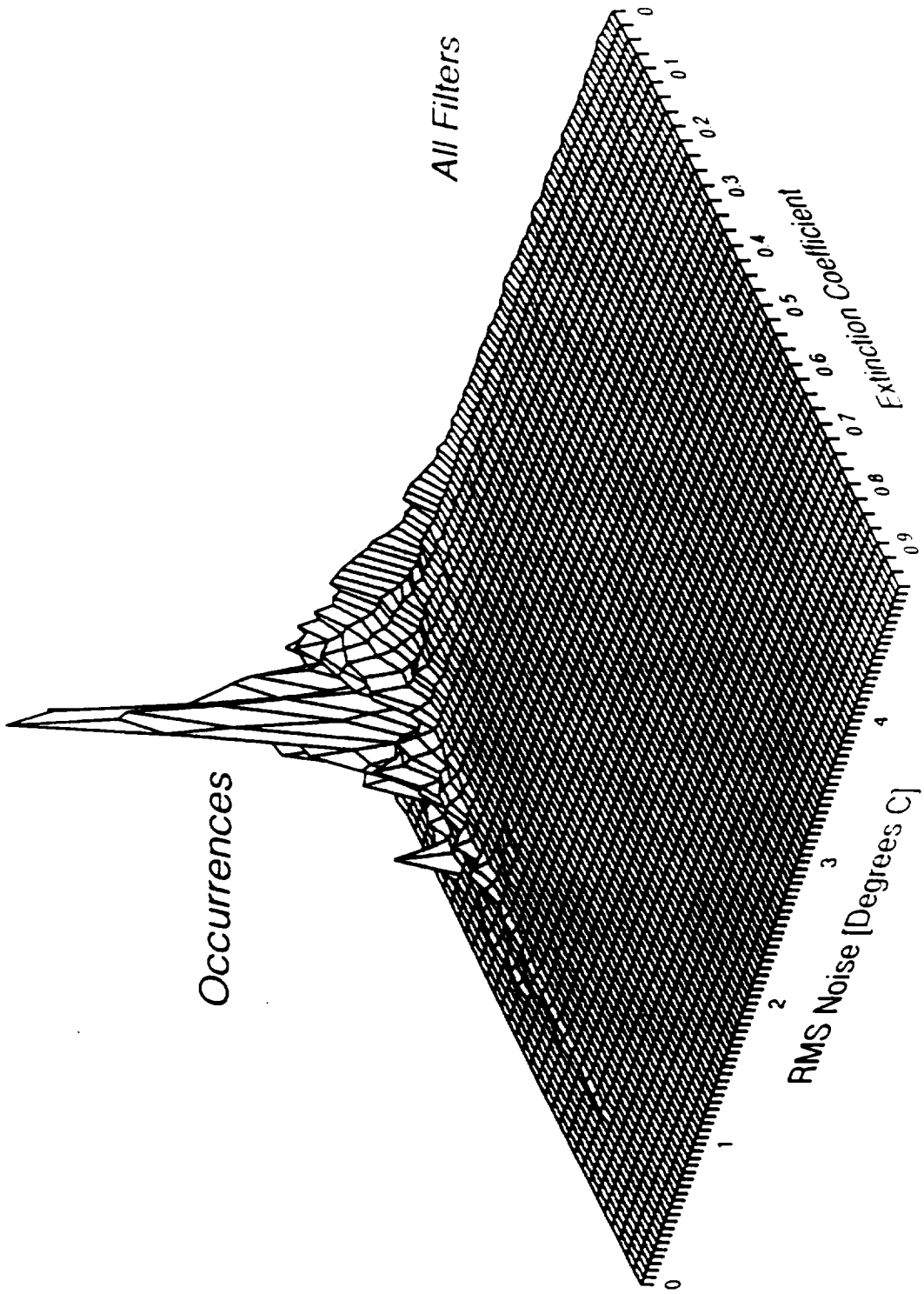
Avg residual values vs ext coef for all filters
(all frozen images)



Avg residual values vs ext coef for all filters
(all frozen images)

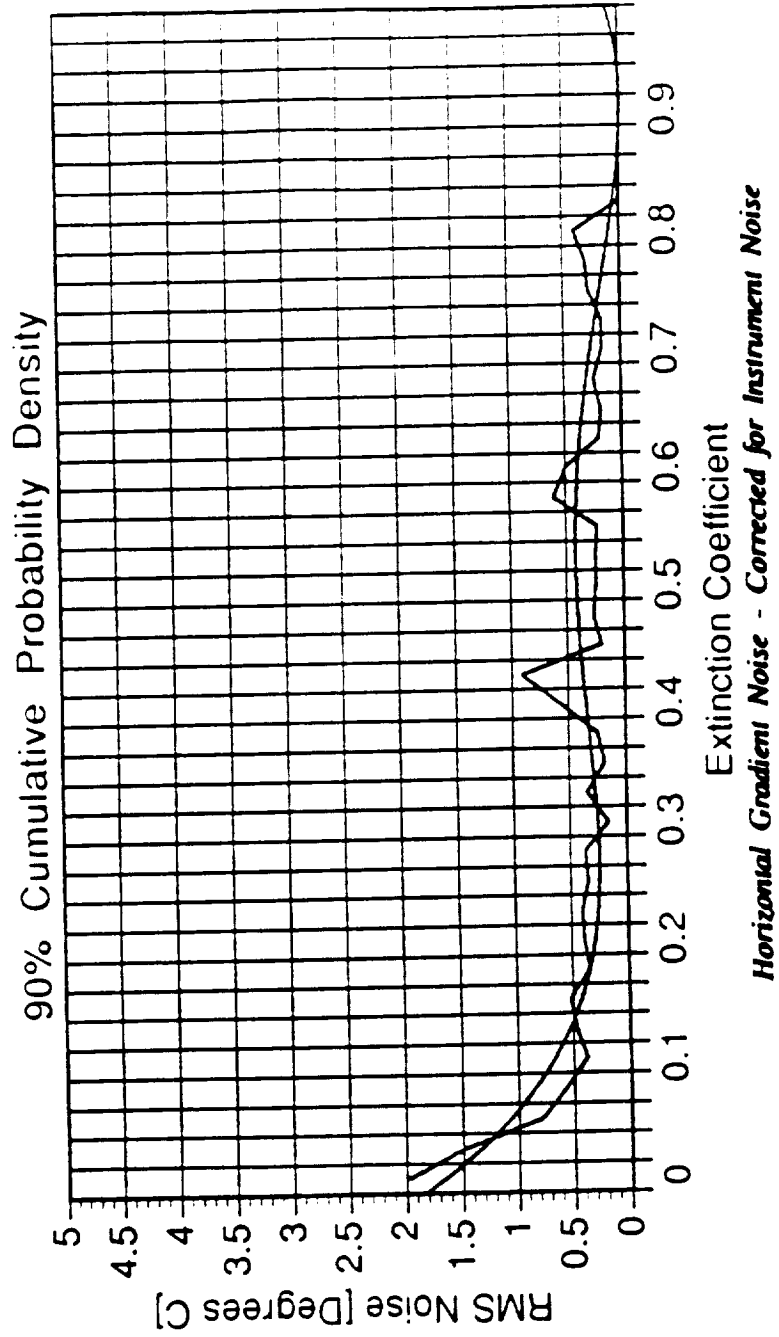


Frozen Image Total Residual Error Distributions

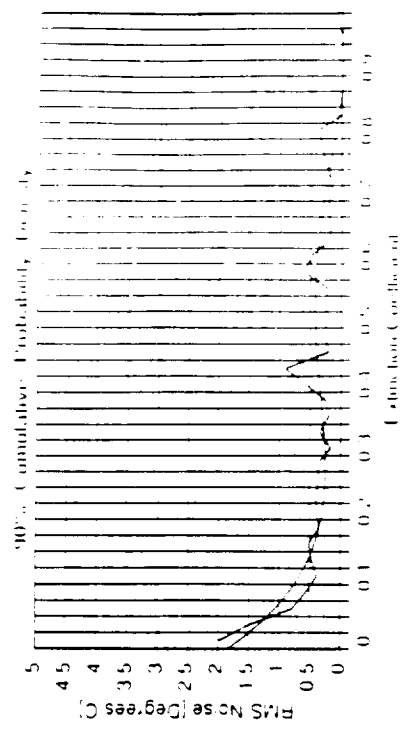
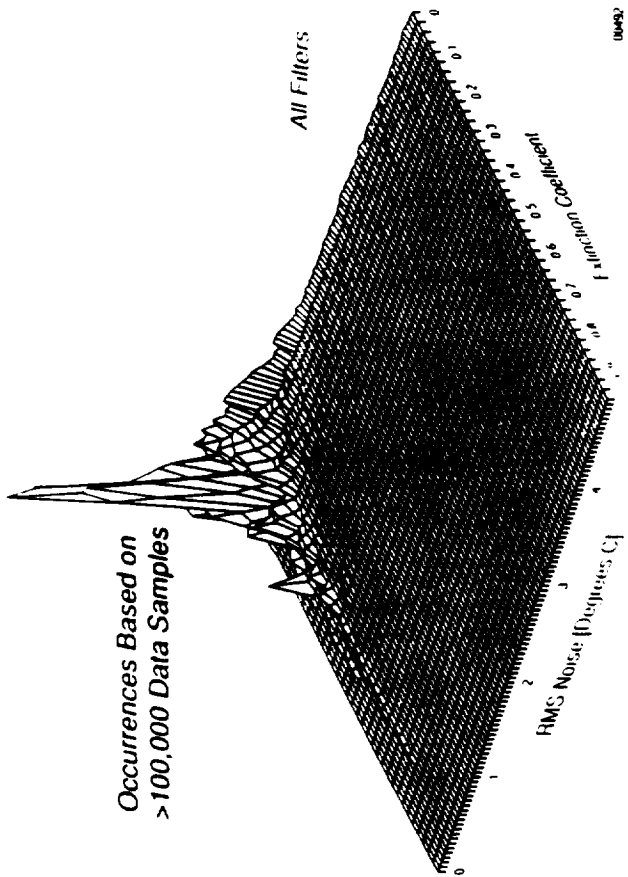


Atmospheric Noise - Corrected for Instrument Noise

FORWARD LOOKING WINDSHEAR DETECTION SYSTEM



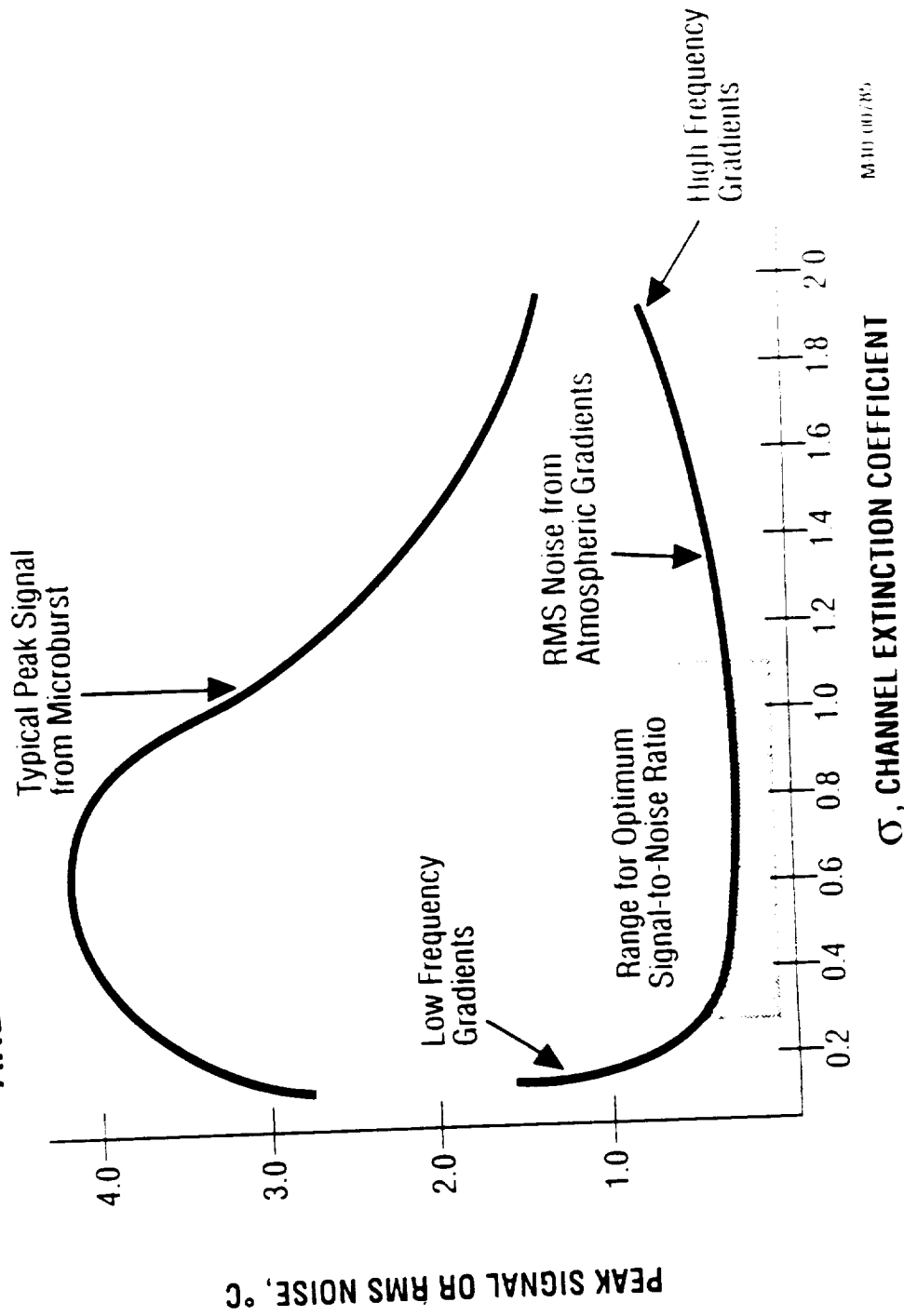
FROZEN IMAGE RMS NOISE SUMMARY



<u>IR FILTER (micron)</u>	<u>APPROX σ (km⁻¹)</u>	<u>APPROX RANGE (km)</u>	<u>LOW FREQUENCY SPATIAL NOISE (°C)</u>
10.5	0.1	10	0.446
11.9	0.33	3	0.405
12.7	0.5	2	0.458
13.8	1.0	1	0.389

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RESULTS OF ATMOSPHERIC SIGNAL, NOISE, AND RADIOMETER RESPONSE ANALYSIS



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σ , CHANNEL EXTINCTION COEFFICIENT

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CONCLUSIONS

- In worst case, atmospheric low frequency noise appears twice as high as desirable for reliable detection of minimum velocity microbursts without false alarms (0.4°C instead of 0.2°C rms)
- Neural network study of University of Wisconsin-Milwaukee shows promise of significant noise reduction technique through adaptive filtering
- Forward Looking Windshear Detection using IR technology has definite potential as a complementary integrated sensor

RECOMMENDATIONS

- Need to correlate noise data with winds to determine how much "noise" is actually turbulence induced versus random background
- Low noise multispectral radiometer and real microburst data collection program essential for final concept verification
- Fusion of IR sensor data with Doppler radar, Ladar, and inertial sensor systems to reliably detect windshears and clear air turbulence should be pursued in future programs

DESIGN CONSIDERATIONS FOR AN AIRBORNE WINDSHEAR DETECTION RADAR

OCTOBER 18, 1990

HUGHES

DESIGN CONSIDERATIONS FOR AN AIRBORNE WINDSHEAR DETECTION RADAR

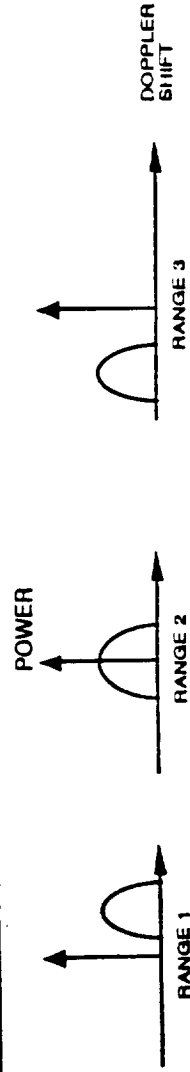
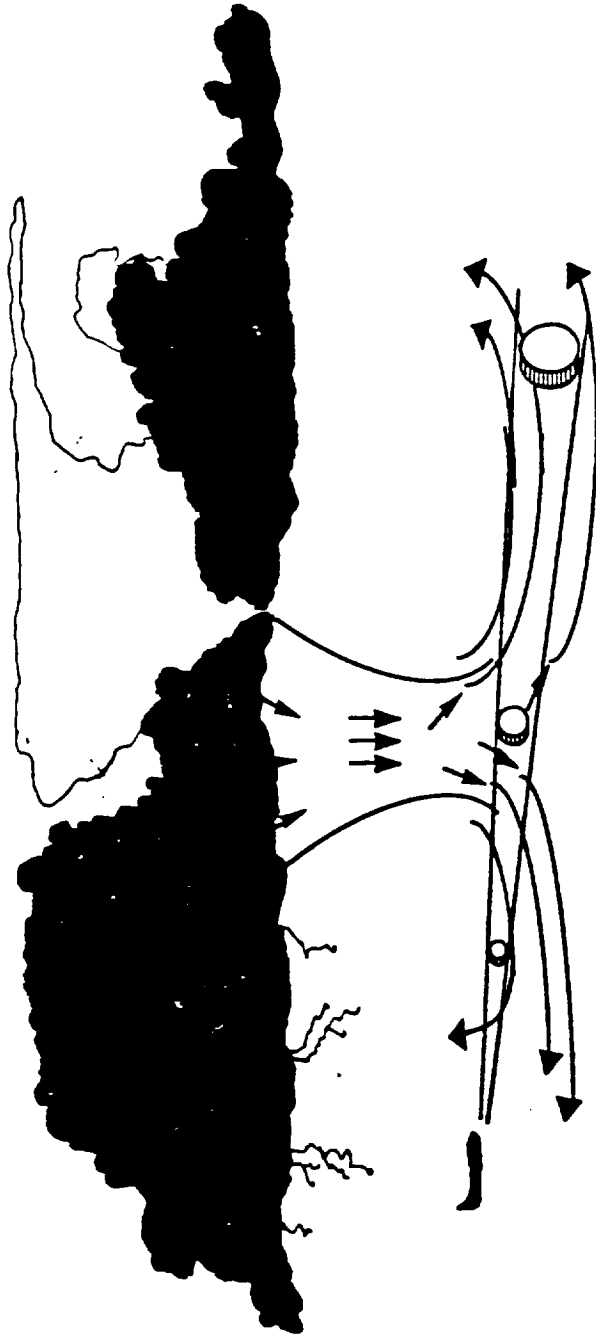
Hughes Aircraft Company

An airborne radar can be used to provide reliable forward looking windshear detection. The radar uses a direct measure of wind velocity to determine the hazard F-factor and issue a warning to the pilot. The radar measures wind velocity as a function of range and determines the presence of windshear if there is an abrupt change in wind direction over a short range interval. This change in wind direction is recognized by the radar as a distinct S-shaped curve in the range-velocity domain. The NASA windshear simulation has been used to verify the radar's ability to detect this S-shaped windshear curve.

In order to provide a useful alert to the pilot, the radar must provide at least 15-20 seconds of warning and provide this warning with a very low false alarm rate. In addition, the radar must have adequate range to penetrate the windshear to enough depth to discriminate dangerous shears from benign shears. Scan-to-scan correlation logic may be employed to lower the false alarm rate. The overall design issues involved in specifying a radar to detect windshear include its frequency, transmitter power, antenna beamwidth, coherent doppler processing, range resolution and interference rejection.

RADAR MEASURES WIND VELOCITY TO DETECT WINDSHEAR

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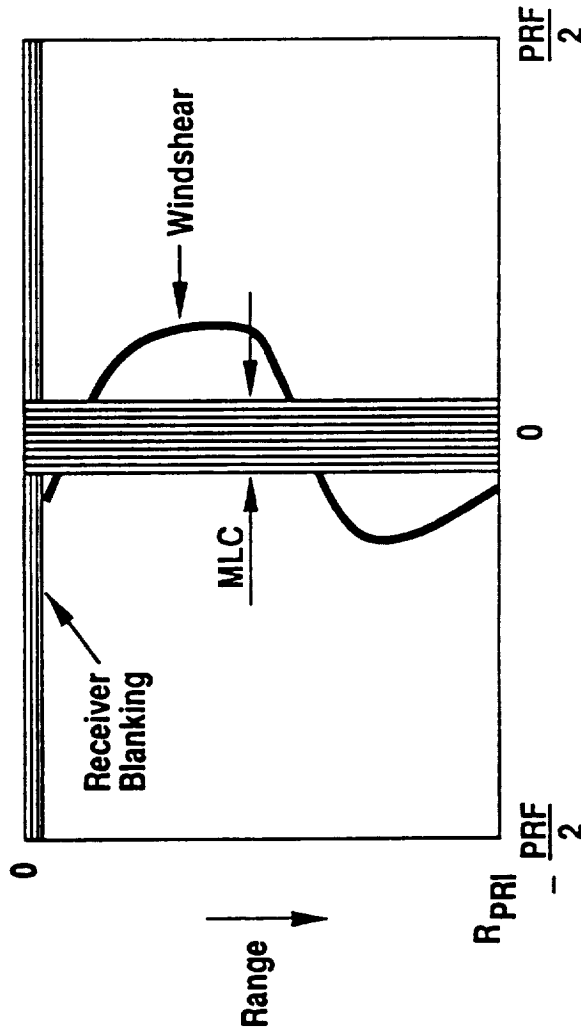


- RADAR MEASURES RADIAL VELOCITY VS. RANGE

RADAR WINDSHEAR SIGNATURE

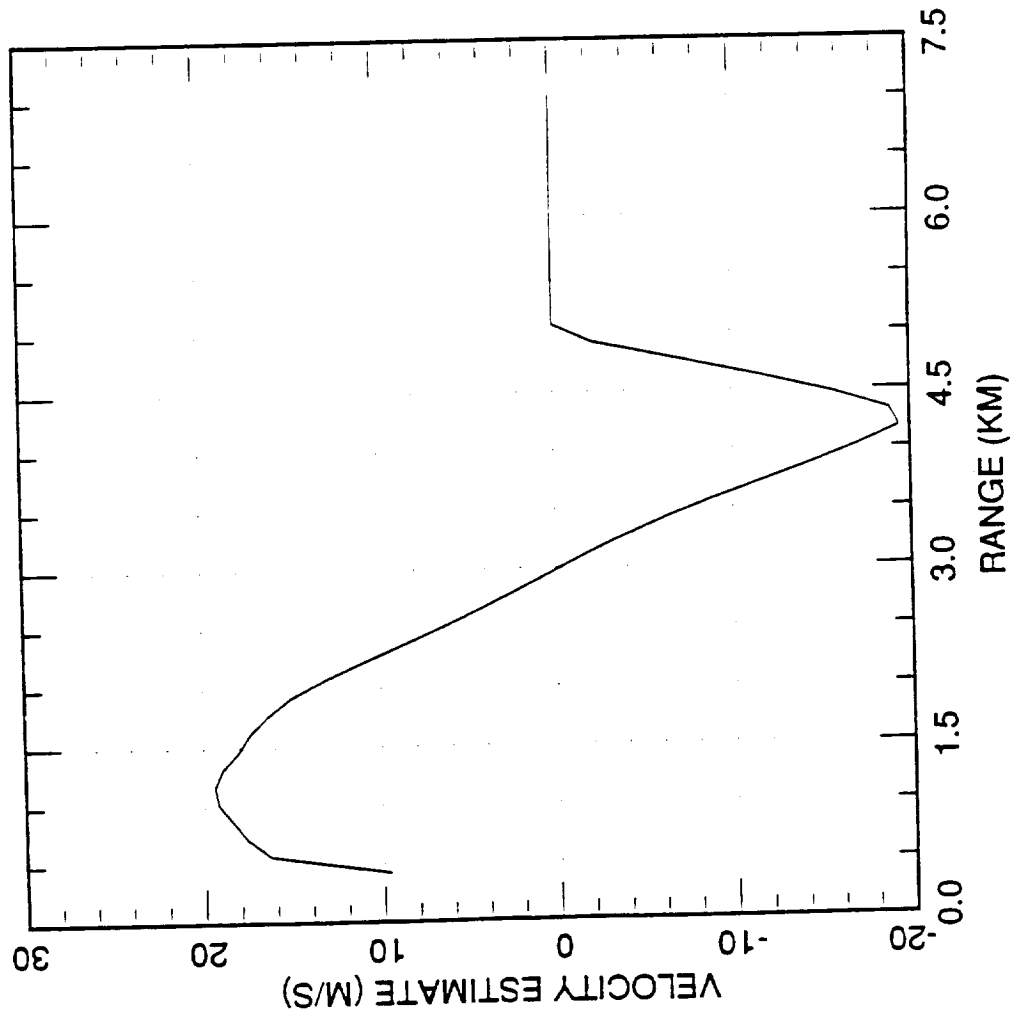
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- RADAR GENERATES RANGE - VELOCITY MATRIX AT EACH BEAM POSITION



- RADAR DETECTS S-SHAPED WINDSHEAR SIGNATURE AND CALCULATES HAZARD F-FACTOR

TYPICAL WINDSHEAR PROFILE PREDICTED BY THE NASA SIMULATION



NO CLUTTER AND NO GMTS

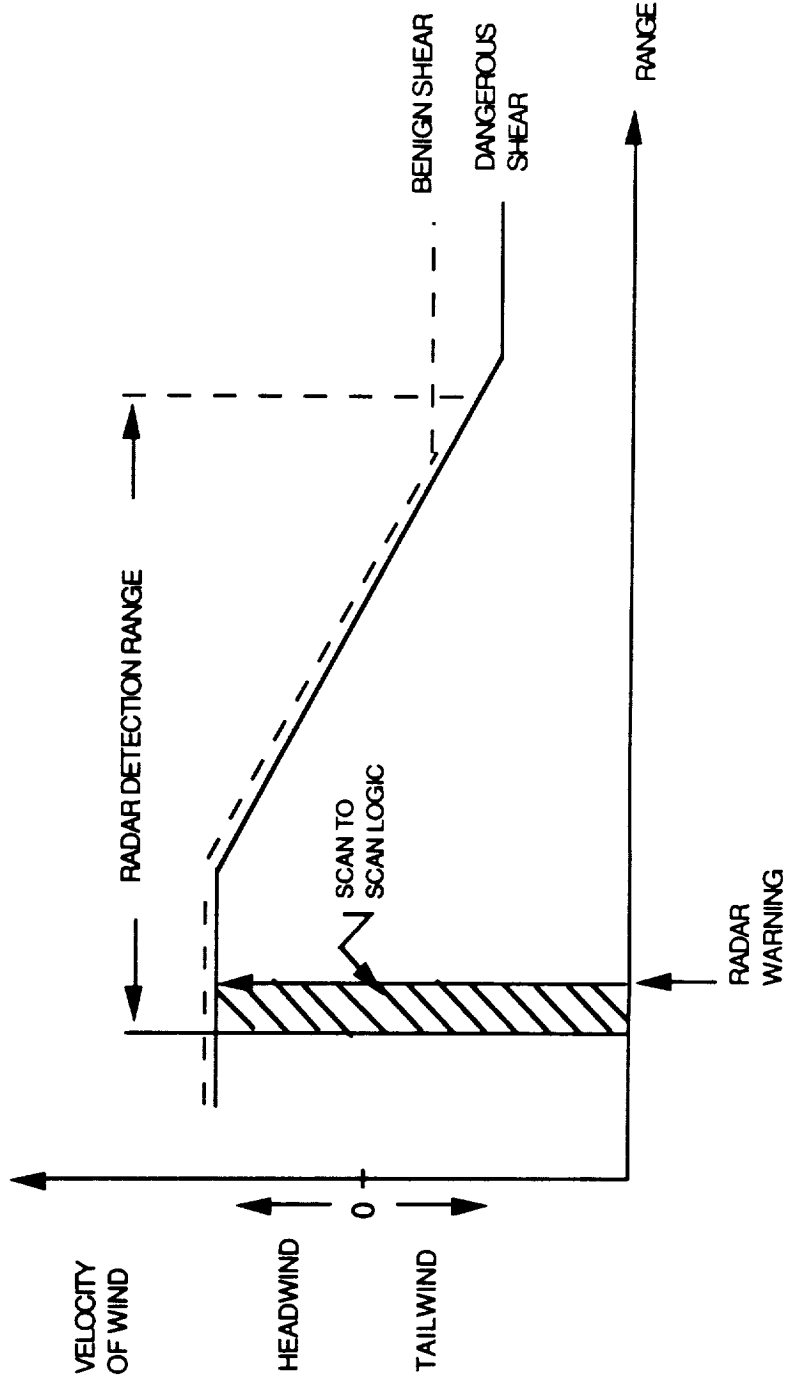
WET MICROBURST (T11)

LOOKING STRAIGHT AHEAD ALONG GSL

WINDSHEAR DETECTION RANGE



DESIGN GOAL: PROVIDE THE PILOT WITH AT LEAST 15-20 SECONDS WARNING TIME WITH LOW FALSE ALARM RATE



RADAR DESIGN ISSUES

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MLS1012.1

- **FREQUENCY**
- **TRANSMITTER POWER**
- **ANTENNA BEAMWIDTH**
- **COHERENT DOPPLER PROCESSING**
- **RANGE RESOLUTION**
- **INTERFERENCE REJECTION**

Status of General Motors Hughes Electronics Research Questions and Answers

Q: SUSAN KIM (Boeing) - You mentioned your goal is a targeted false alarm/nuisance rate of 1 per 10,000 flight. How do you plan to test/verify/achieve this rate?

A: BRIAN GALLAGHER (Delco) - We plan to achieve the rate through the discrimination techniques that we are developing which primarily rely on the horizontal temperature gradient. For example, angular size would be an important means of discriminating cold fronts, gust fronts, things that are non threatening. As far as verifying that, or testing that, that's a good question. I'll give you a pat answer. This is per discussions that we had with the FAA Los Angeles Certification Office. The answer is primarily through systems' simulations with "sufficient data to support the integrity of the simulation model." The question is what is sufficient data. And that data will be collected through flight tests and in-service evaluations that are being planned.

Q: SUSAN KIM (Boeing) - How do you define a false alarm?

A: BRIAN GALLAGHER (Delco) - Another word for a false alarm is a false alert. It's an alert which occurs when the design wind shear threshold conditions do not exist. An example that I could give is an atmospheric temperature gradient that emulates or masks or emulates a microburst without any turbulence whatsoever. Those things do exist out there and as a result we're going to have nonperfect systems.

Session X. Airborne Doppler Radar / Industry

Saberliner Flight Test
Bruce Mathews, Westinghouse

