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Airborne Wind Shear Detection and Warning Systems

First Combined Manufacturers' and Technologists' Conference

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Washington, D.C.

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Federal Aviation Administration

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Space Administration

FOREWORD

The "First Combined Manufacturers' and Technology Airborne Wind Shear Meeting" was hosted jointly by NASA Langley (LaRC) and the Federal Aviation Administration (FAA) in Hampton, Virginia on October 22-23, 1987. The meeting was co-chaired by Dr. Roland Bowles of LaRC and Herbert Schlickenmaier of the FAA. Amos Spady of LaRC and the Science and Technology Corporation's Meeting Division coordinated the meeting.

The purpose of the meeting was to transfer significant ongoing results gained during the first year of the joint NASA/FAA Airborne Wind Shear Program to the technical industry and to pose problems of current concern to the combined group. It also provided a forum for manufacturers to review forward-look technology concepts and for technolgists to gain an understanding of the problems encountered by the manufacturers' during the development of airborne equipment and the FAA certification requirements.

The present document has been compiled to record the essence of the technology updates and discussions which followed each. Updates are represented here through the unedited duplication of the vugraphs, which were generously provided by the respective speakers. When time was available questions were taken from the floor; if time was not available questions were requested in writing. Questions and answers from the floor are included with each presentation. The written questions were presented and answered in the final session and are included in the document. Several of the speakers did not have vugraphs; their talks were transcribed from the recordings of the sessions, edited by the speaker and are included. Additionally, the opening overview by Dr. Roland Bowles was transcribed and included to provide the reader with an understanding of the multiple elements included in the Joint Airborne Wind Shear program.

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ROLAND BOWLES - OVERVIEW

It has been real formal so far. Let's get it informal right now. Many of you have heard, basically, what I would have presented in a detailed overview. But because of the depth and demands of the technical program, I am going to try and relate what NASA is doing to what you are going to hear throughout the rest of the day. That may be a difficult transition for me, but I am going to try.

The motivating factors behind what NASA is doing, I think is important from the perspective of how we fit a broader activity within government and industry. This is no longer a wind shear program plan draft [pointing to viewgraph]. I understand that it is now an officially sanctioned document with all the appropriate signatures, and it is underway. It has a number of activities, many of you, or your companies, represent work and/or related activities, that are in effect, supporting this effort. NASA's role is strictly looking at the airborne systems technology side of the question. The bottom line is that NASA is looking at cockpit automation, crew decision aids, the appropriate information systems and sensor technologies to deal with reducing risk of low altitude wind shear encounter. Now (from a headquarters point of view) this program, as indicated previously, cuts across many of our base activities, it is tracked in headquarters under the aviation safety program with management provided by Code RC. Though NASA's principle role and mission is new vehicle technology, we have always had a keen and historically very productive history in aviation safety related activities.

The objective of the NASA program is very clear. To develop and demonstrate technology for low altitude wind shear risk reduction through airborne detection, warning, avoidance and survivability. Again, we are talking about cockpit automated pilot decision aids. That objective implies an operational requirement that basically puts systems on flight decks that will promote crew awareness of the presence of wind shear or microburst phenomena, with enough time to avoid the affected area or escape from the encounter.

We can only be successful in this program if we have a strong government industry interplay in carrying out these activities. The NASA program is broken down into three primary technical thrusts: [pointing to viewgraph] Characterizing and defining the hazard; appropriate sensor technology to detect from the moving platform itself; and the flight management system integration of those products.

Hazards: We realize a lot of activity has taken place and a lot of knowledge has been acquired about wind shear phenomena, particularly concerning the downburst-induced outflows. Our emphasis is focused at better understanding what is going on in the lowest 2000 ft. of the atmosphere--to do that in a way that we can correlate the vector winds with the other phenomenology that impacts the design assessment in the evaluation of the sensor technologies that we are dealing with. That is we must know wind correlates with reflectivity and rain, precipitation type, magnitude, quantities and also thermal properties involved in the atmosphere. This includes the heavy rain aerodynamics effort--A major facility has been developed and we are about ready to start those tests.

Sensors: Our effort in sensor technology is basically focused on a very strong in-house microwave doppler radar program, starting with a base line of X-band systems. We have put in place an out-of-house LIDAR program, it involves an industry consortium lead by Lockheed Missiles and Space, involving Spectra Technologists, and Coherent Technologies. We are examining the range of opportunity from 10.6 micron (gas lasers) to Homium (Ho:YAG) lasers at 2 microns. Today you are going to see two presentations after lunch that show where we stand after year one in our radar work and where we stand in looking at the technical horizons for LIDAR and performance assessments in the environments in which the sensor technologies must work.

Flight Management: Finally, if we can understand the hazard and if we can sense it from the moving platform, probably the crucial issues become: What information does the crew need? How will it be displayed? How will it be used (or how should it be used)? What impact does it have on operating procedure? So in that ^nse later today you will hear some early ideas emerging from a sponsored effort with Boeing to address flight deck issues associated with integration of predictive forward looking information. Then, Dave Hinton will discuss some recent studies looking at the comparison of wind shear recovery and escape techniques with conventional flight director command systems.

Funding: The program resources are split in this way. Net R&D are roughly equally split between FAA and the NASA R & T base. There is also a large NASA institutional resource requirement to conduct the kinds of research studies that we are talking about.

So, if we were to say: Where do we stand at this point? We think the NASA role in the overall national wind shear effort has been defined. NASA headquarters and the FAA have signed a 5 year memorandum of agreement for a cooperative program. The program elements, facilities and direction are finalized and we are completing on year one of activity. The budget picture looks pretty promising for us in '88. I shouldn't say that, because Congress really hasn't decided yet. But, if the plan holds as we understand it, it looks pretty good. And we think this program is enjoying strong industry support based on the products that we have developed in year one.

What I would like to do at this point is to spring into the technical discussions that exemplify a variety of research accomplishments achieved in year one.

JOINT NASA/FAA AIRBORNE WIND SHEAR DETECTION AND AVOIDANCE PROGRAM

Dr. Roland L. Bowles
NASA Langley
FltMD

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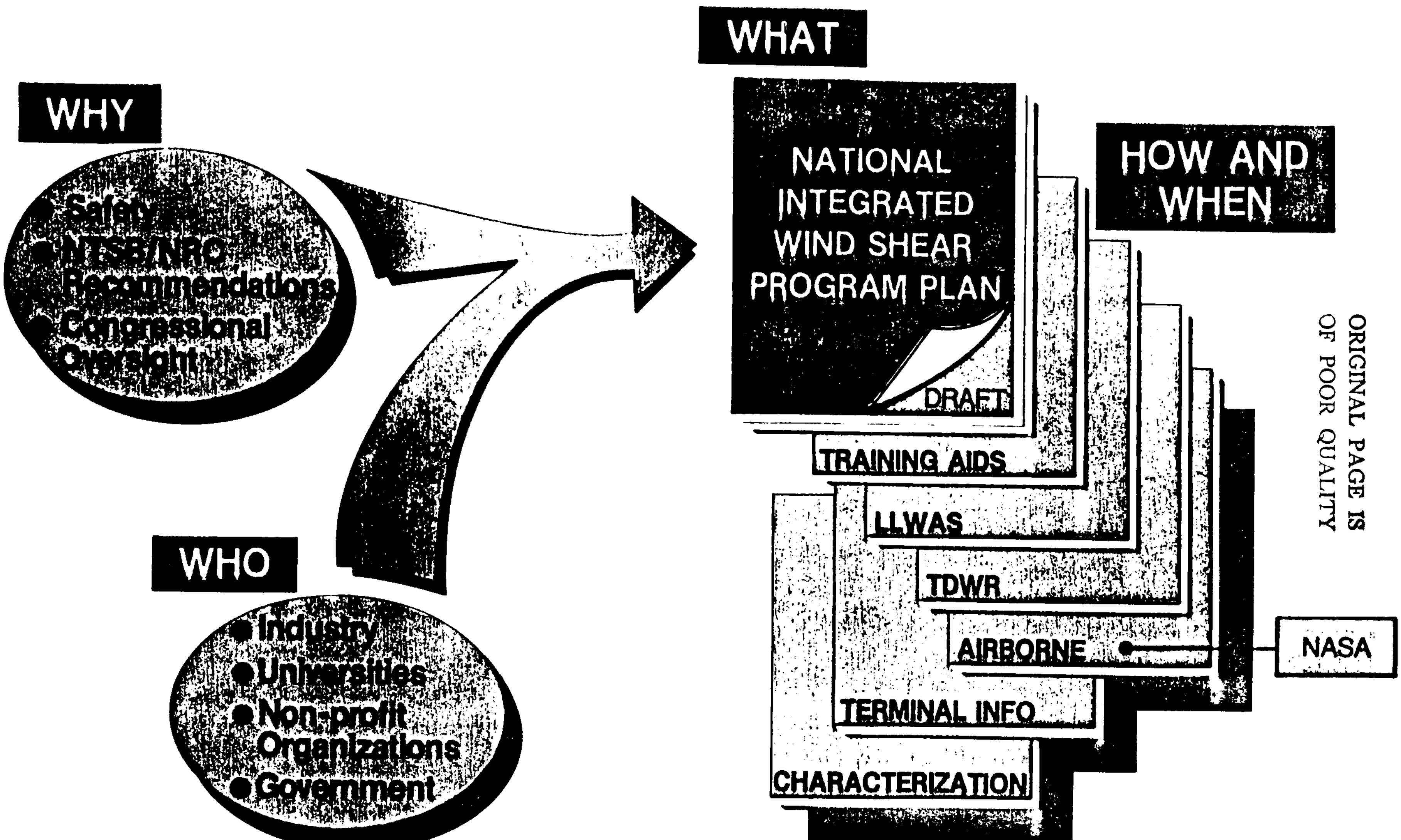

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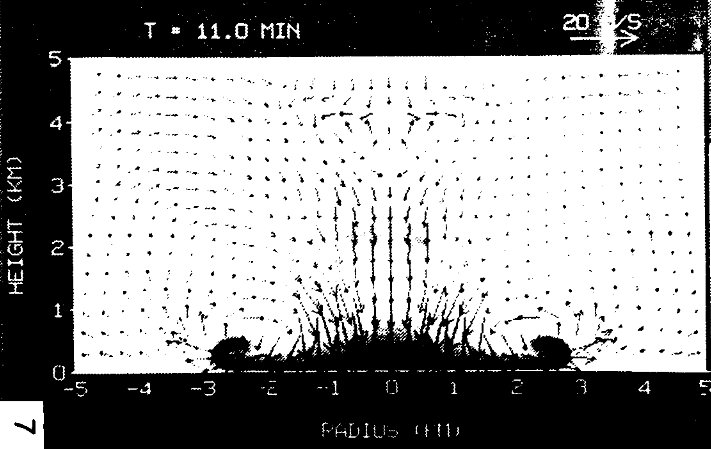
NASA/FAA AIRBORNE WIND SHEAR PROGRAM ELEMENTS

Hazard Characterization



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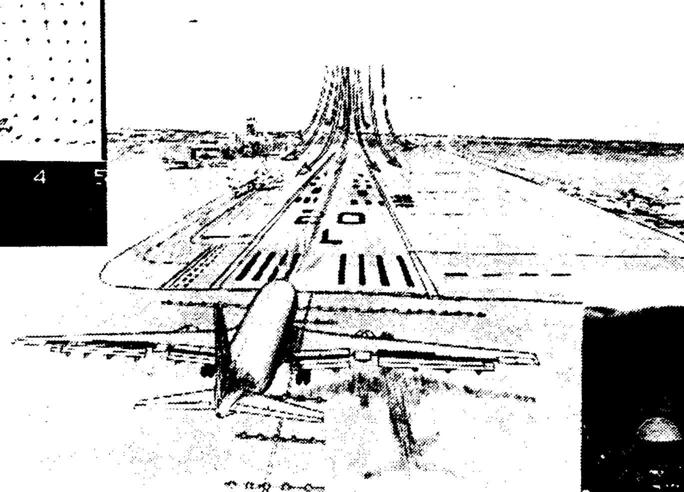
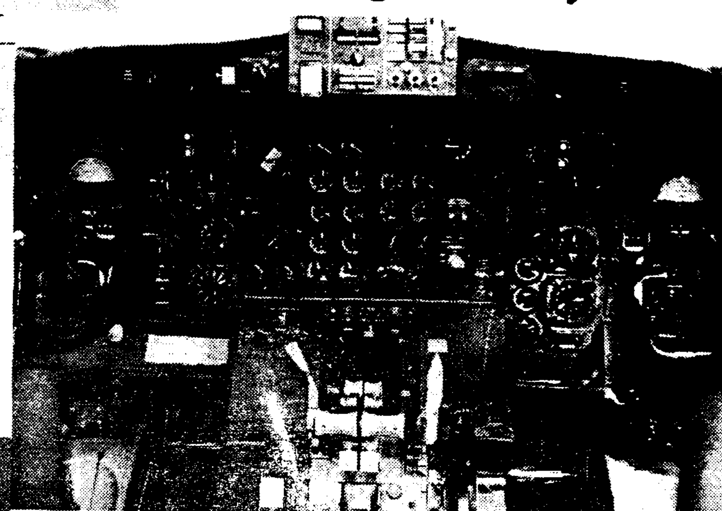
- Wind shear physics/modeling
- Heavy rain aerodynamics
- Impact on flight characteristics

Sensor Technology



- INSITU
- Airborne doppler radar/LIDAR
- Sensor fusion

Flight Management Systems



- System performance requirements
- Guidance/display concepts
- Pilot factors/procedures

AIRBORNE WIND SHEAR DETECTION WARNING AND AVOIDANCE SYSTEM

NATIONAL REQUIREMENT

- O FAA HAS ISSUED A NOTICE OF PROPOSED RULE MAKING (NPRM)
- O REGULATION WOULD REQUIRE AIRBORNE WIND SHEAR WARNING AND FLIGHT GUIDANCE EQUIPMENT
- O WARNING PROTOCOL TIGHTLY COUPLED TO EXPECTED CREW ACTION

INDUSTRY CONCERNS

- O TECHNOLOGY BASE AND SYSTEMS PERFORMANCE
- O COST:
- O LIABILITY

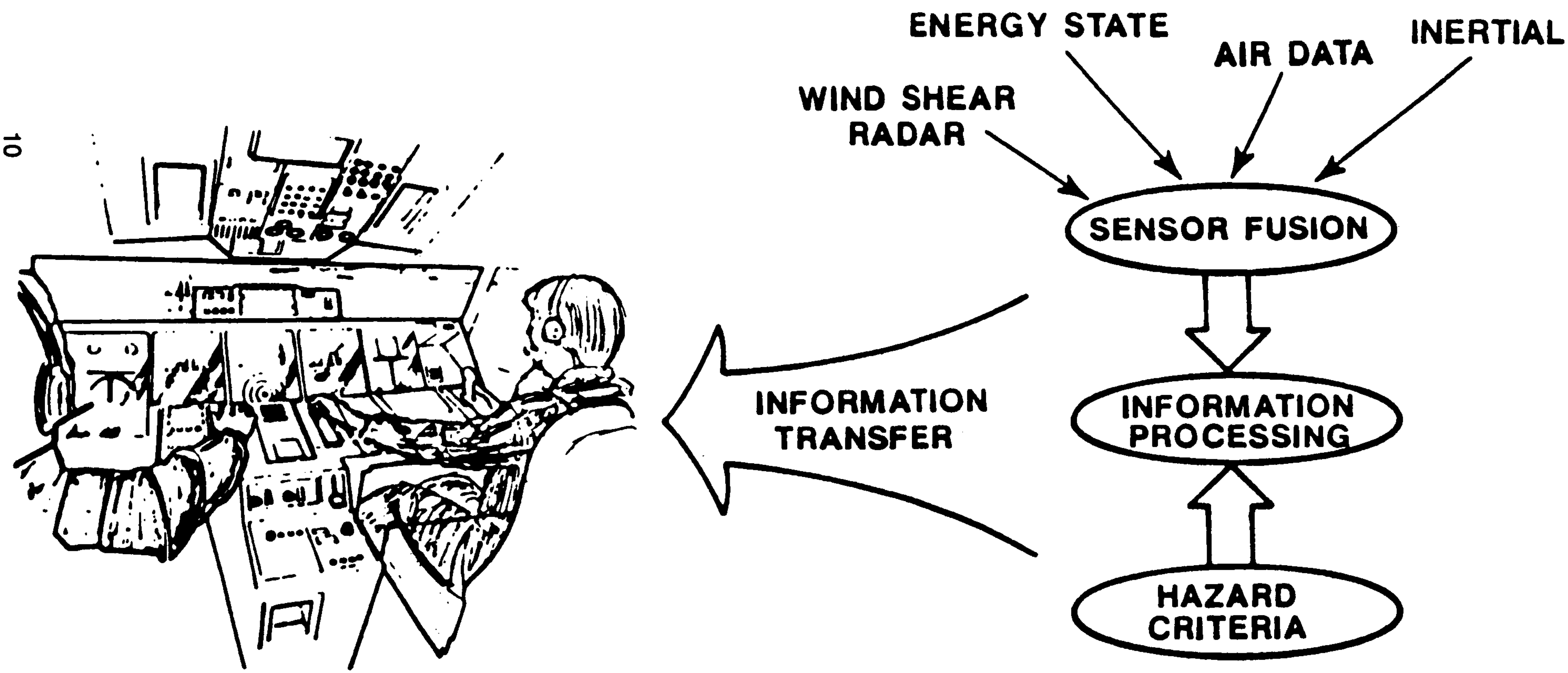
OPERATIONAL REQUIREMENT

AIRBORNE CAPABILITY THAT PROMOTES FLIGHT CREW AWARENESS OF THE PRESENCE OF WIND SHEAR OR MICROBURST PHENOMENA WITH ENOUGH TIME TO AVOID THE AFFECTED AREA OR ESCAPE FROM THE ENCOUNTER

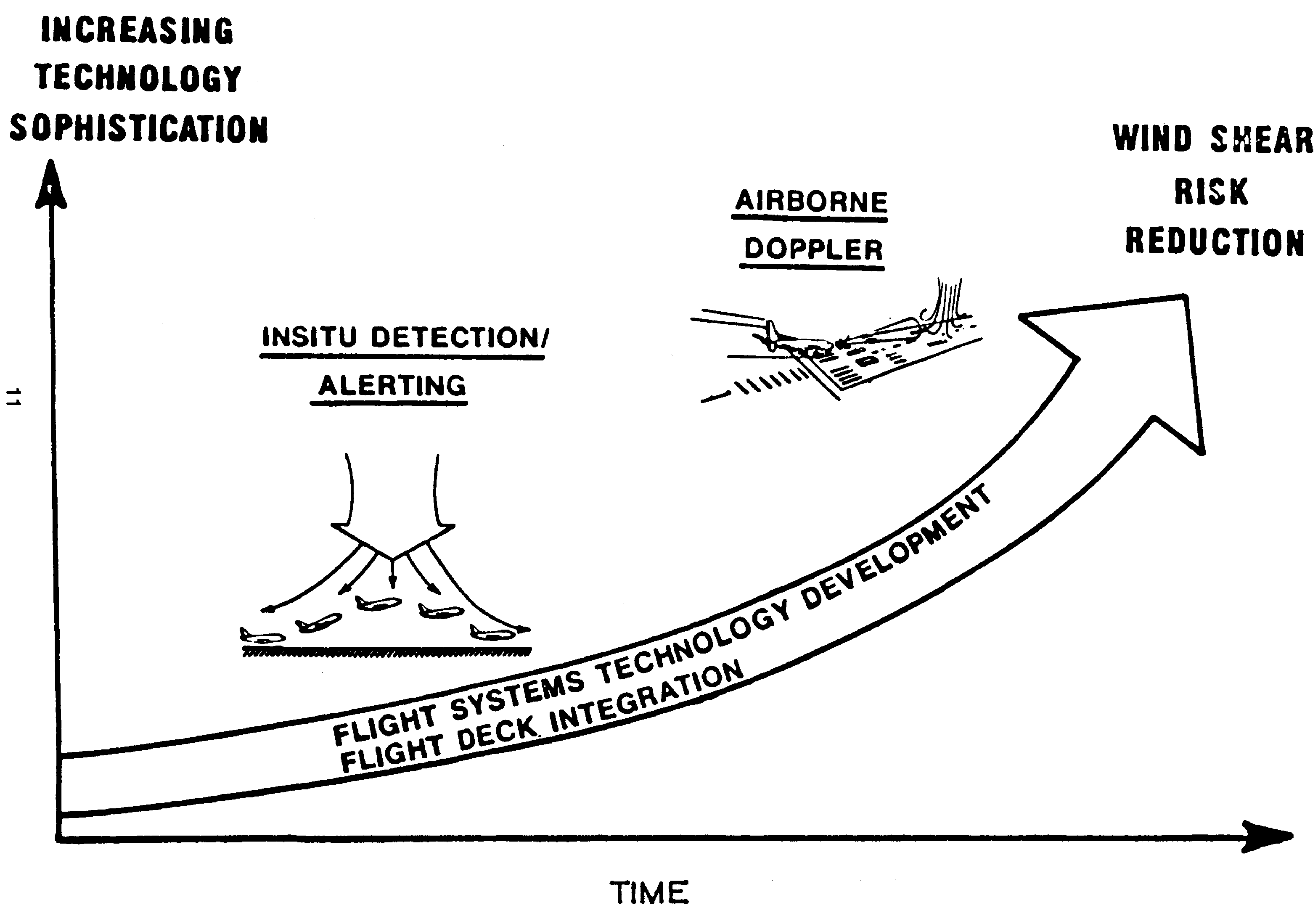
STRONG GOVERNMENT INDUSTRY INTERPLAY

WIND SHEAR DETECTION/WARNING AND AVOIDANCE SYSTEM

FLIGHT DECK INTEGRATION | **FLIGHT SYSTEMS TECHNOLOGY**



TECHNOLOGY INTEGRATION ROADMAP



PROGRAM STATUS

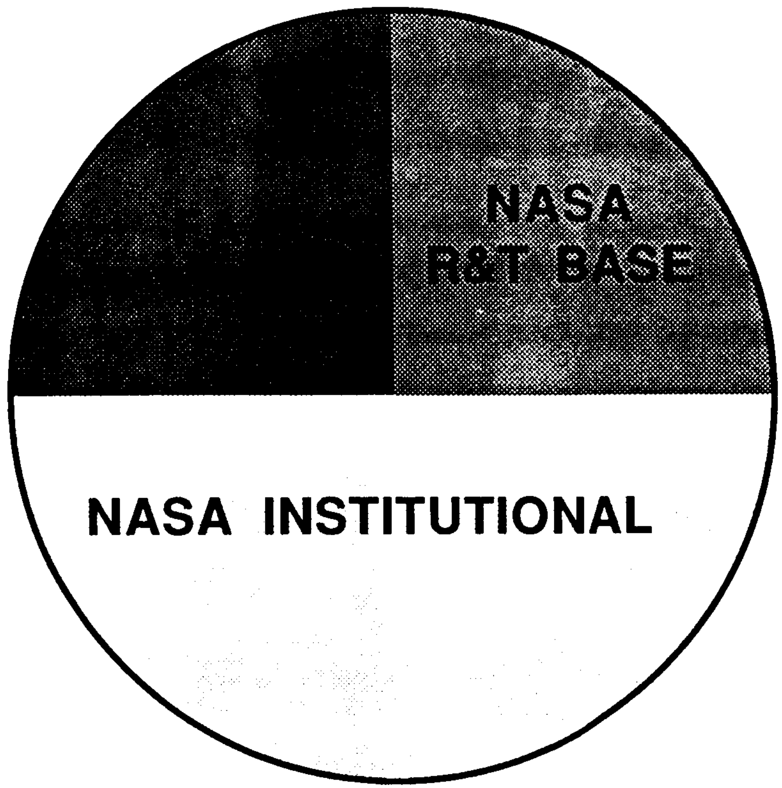
- O NASA ROLE IN SUPPORT OF NATIONAL WIND SHEAR EFFORT IDENTIFIED
- O MOA SIGNED BY NASA AND FAA WHICH ESTABLISHES 5-YR COOPERATIVE PROGRAM
- O PROGRAM ELEMENTS FACILITIES/RESOURCE REQUIREMENTS FINALIZED
- O PROJECTED FY 88 BUDGET ADEQUATE DUE TO FAA RESOURCE FRONT LOADING
- O STRONG INDUSTRY SUPPORT BASED ON FIRST YEAR ACCOMPLISHMENTS

NASA/FAA AIRBORNE WIND SHEAR PROGRAM

SPECIFIC PAYOFFS

- REMOTE DETECTION AHEAD OF AIRCRAFT HAS DISTINCT ADVANTAGES
  - FOR AIRPORTS NOT PROTECTED BY TDWR
  - SUPPLEMENTS TDWR WHERE TDWR EXISTS
- PROMOTE AND ACCELERATE DEVELOPMENT OF AIRBORNE REMOTE SENSOR TECHNOLOGY
- SENSOR FUSION CONCEPT PROVIDES FOR REDUNDANCY OF INSITU DETECTION AND ALERTING FOR CASES WHERE RADAR/LIDAR INEFFECTIVE
- SYSTEMS APPROACH MAY FOSTER EARLY ACCEPTANCE BY AVIATION COMMUNITY
- PROVIDES INDUSTRY WITH ENGINEERING DATA BASE AND DESIGN GUIDELINES FOR USE IN DEVELOPMENT AND MANUFACTURE OF CERTIFIABLE AIRBORNE WIND SHEAR SYSTEMS
- REALISTIC PROTECTION SYSTEM - FLY FLYABLE SHEARS/AVOID UNFLYABLE SHEARS

WIND SHEAR PROGRAM RESOURCES



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NASA/FAA Wind Shear Program

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Element	FY 87	FY 88	FY 89	FY 90	FY 91	Goals
Hazard Characterization	Wind Shear Physics/Modeling					Improved Models and Understanding of Wind Shear/ Heavy Rain Penalties
	Heavy Rain Tests/Physical Mechs/Scaling					
	Hazard Def/A/C Perf. Impact					
Sensor Technology	Ground Clutter					Technology for Airborne Wind Shear Detection and Avoidance
	Radar/Atmos. Modeling					
		Scatterometer/Sensor Dev.				
	Lidar Perf			TBD		
Flight Management	Crew Info. Reqs.					Provide Industry With Data Base/Design Guidelines for Wind Shear System
	Display Reqs/Integration					
	Wind Shear Adaptive Guid.					
	Avoidance System Perf. Reqs.					

HEAVY RAIN RESEARCH

R. BOWLES

HEAVY RAIN EFFECTS

TECHNICAL ISSUE

ARE THE AERODYNAMIC CHARACTERISTICS OF AN AIRPLANE ALTERED WHILE FLYING IN THE RAIN?

HEAVY RAIN AERODYNAMICS

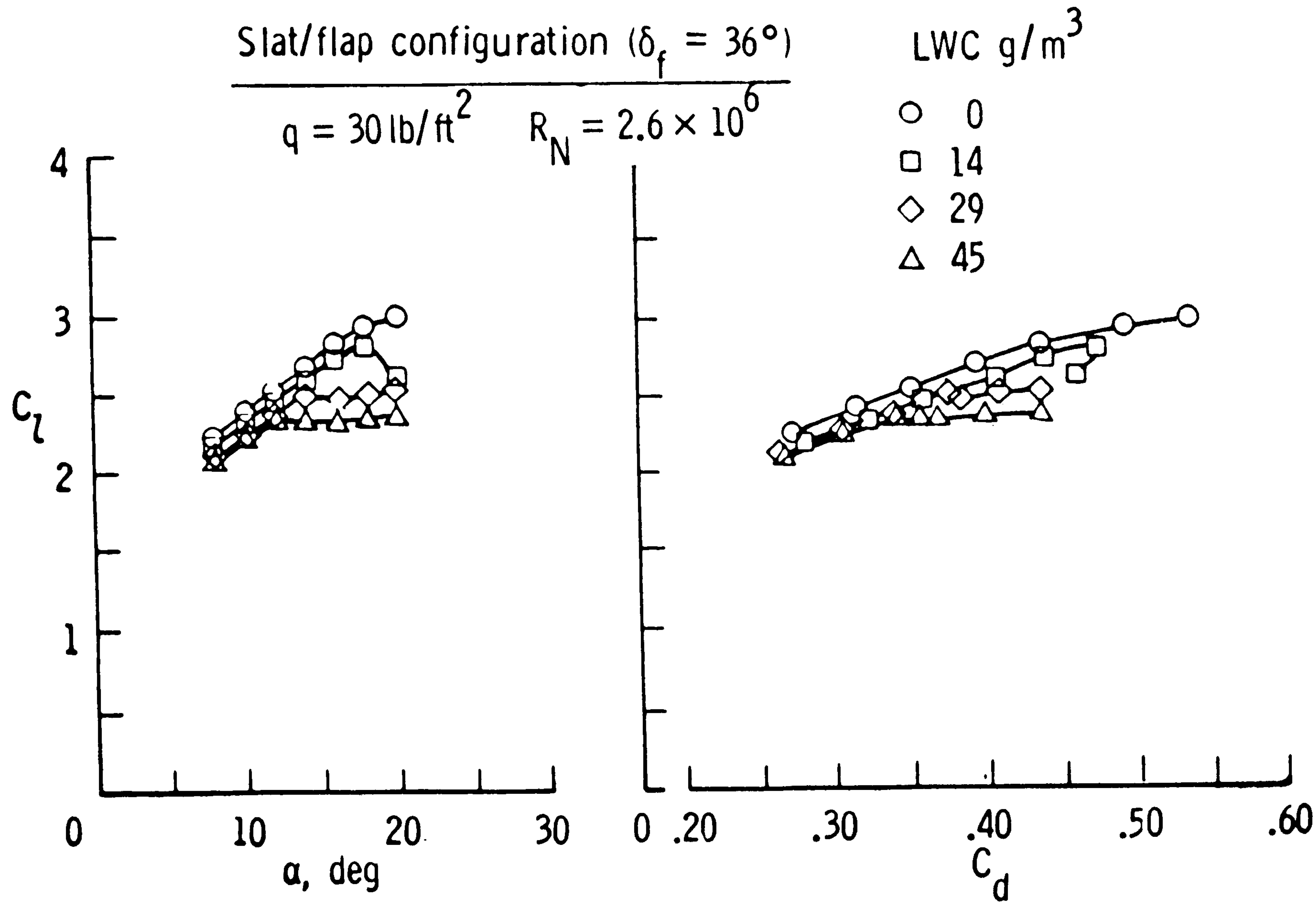
OBJECTIVE: TO DETERMINE IF AERODYNAMIC PENALTIES ARE ASSOCIATED WITH FLIGHT IN HEAVY RAIN

APPROACH: MODEL TESTS IN GROUND-BASED FACILITIES IN A SIMULATED RAIN ENVIRONMENT

RESULTS: SMALL-SCALE TESTS INDICATE SIGNIFICANT PERFORMANCE CHANGES. EXTRAPOLATION OF THESE RESULTS TO FULL-SIZE AIRCRAFT NOT CURRENTLY POSSIBLE.

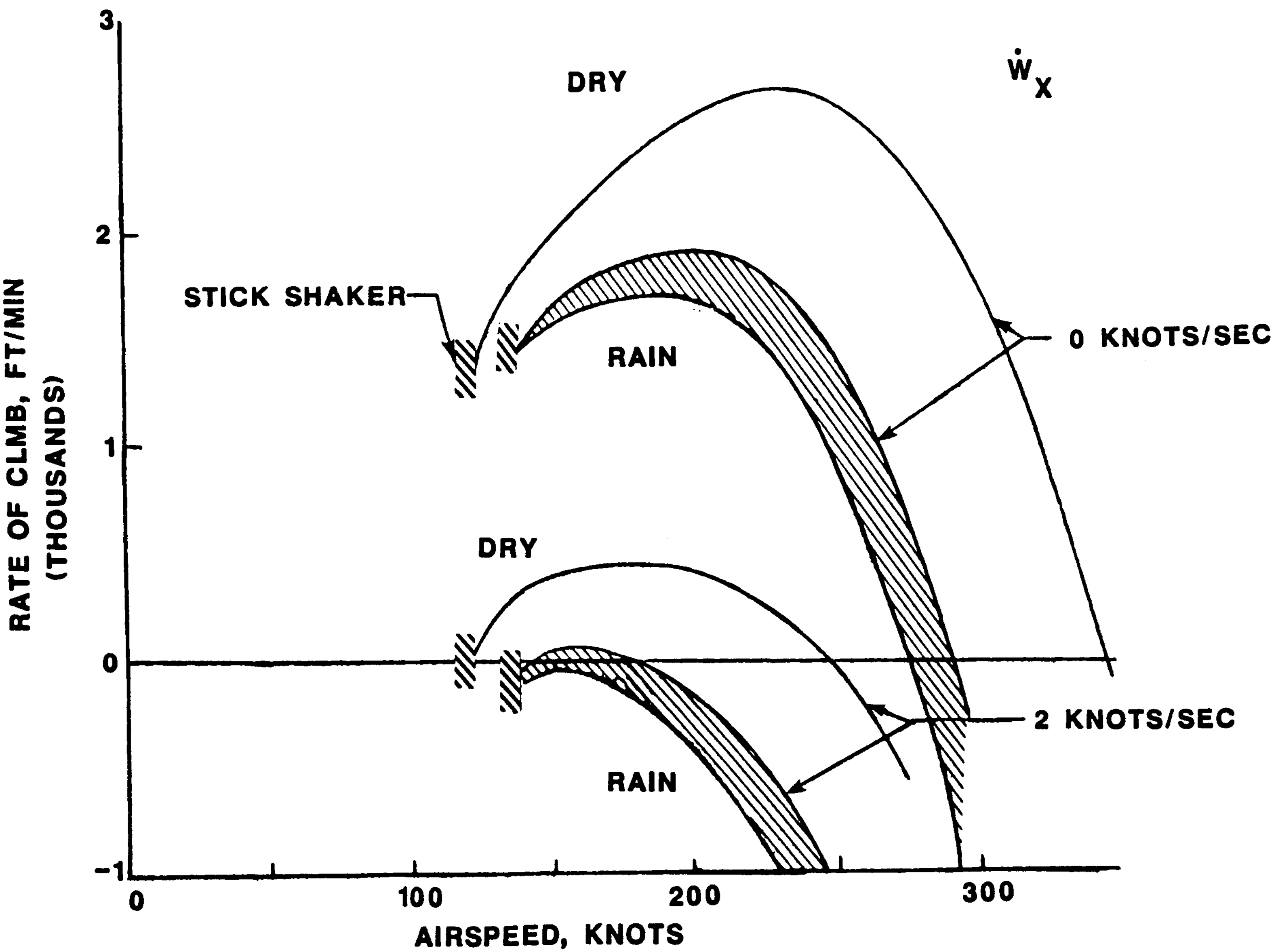
FUTURE: CONDUCT LARGE-SCALE TESTS (AIRCRAFT LANDING FACILITY) TO DETERMIINE EFFECT IN SIMULATED AND NATURAL RAIN AND TO DEVELOP SCALING LAWS.

NACA 64–210 SLAT/FLAP CONFIGURATION



CONSTANT SPEED CLIMB PERFORMANCE IN SHEAR AND HEAVY RAIN

BOEING 737-100 (PREDICTED)



TEST RESULTS

CONCLUDING REMARKS

- O TWO DIFFERENT MODEL TESTS HAVE INDICATED PERFORMANCE CHANGES WHEN OPERATING IN RAIN (TWO-PHASE FLOW ENVIRONMENT)
- O RESULTS HAVE SHOWN A STRONG DEPENDENCY ON SEVERAL OF THE SCALING VARIABLES
- O A LACK OF SCALING LAWS INDICATES A NEED TO OBTAIN DATA FOR FULL SCALE SIZE WINGS

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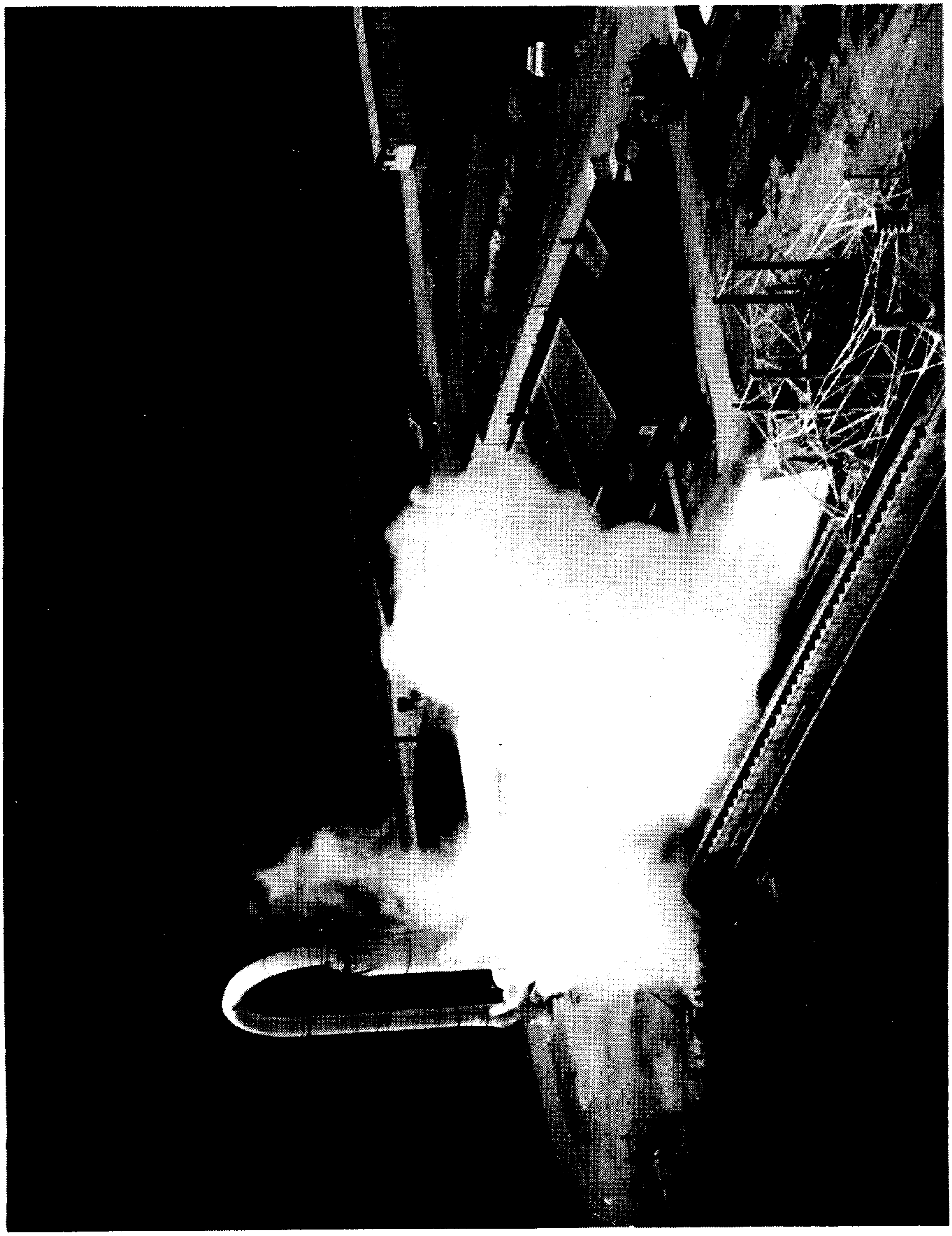

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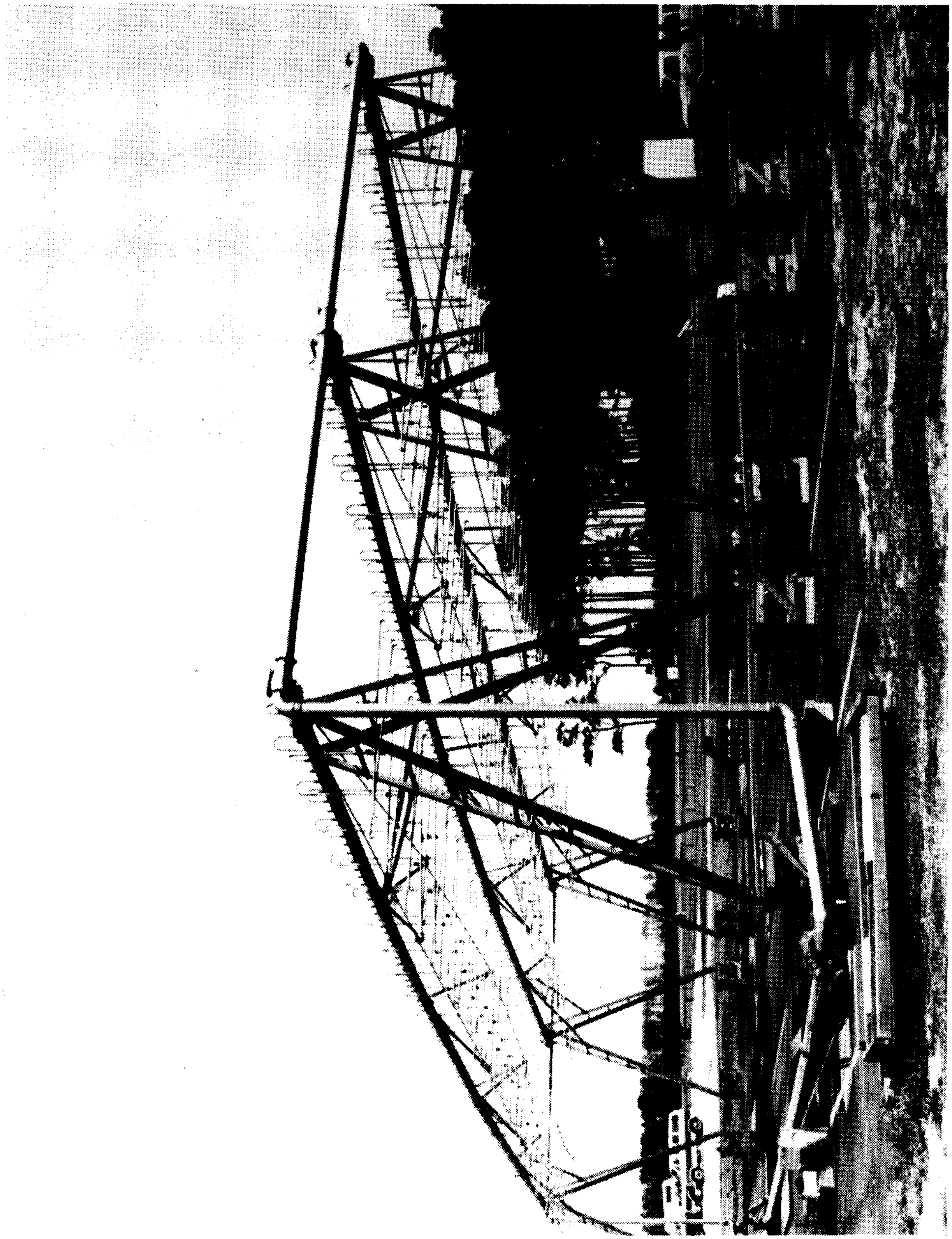

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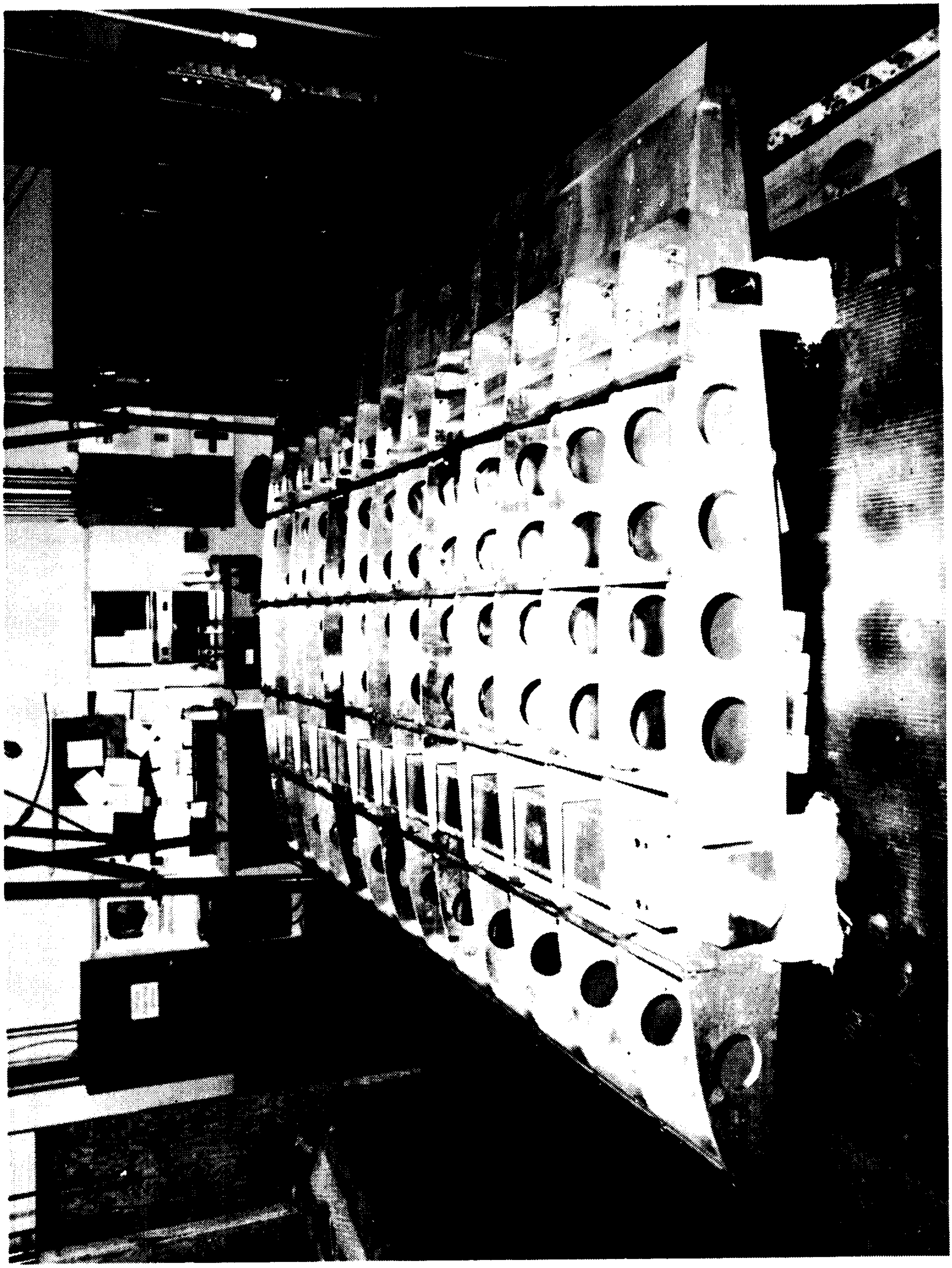

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ROLAND BOWLES (NASA LaRC) - The question is, in convective storms or in and around convective storms at altitude there is a great deal of evidence that we are talking about highly transient phenomenon and I might point out that one of the plans is to put a Lyman-x mass spectrometer, using engine bleed air to go up and make some liquid water content measurements in and around thunderstorms. What I am saying is, there is evidence of highly transient, time dependent, bursting of water going on, therefore you have to define carefully what you mean by rain.

JIM EVANS (MIT Lincoln Labs) - Again, let me make two comments. First, we are not talking about rain at 7000 and 8000 feet we are talking about rain probably below 1000 feet, so I think in planning that research program, flying around up where you may have frozen stuff doesn't make sense. Second, for example, in the programs that have been done in Memphis, Huntsville, and Denver, I mean, in everyone of those cases for example, we've flown at least in Memphis and Huntsville, through wet microburst with a plane that measures drop size distribution. So if you want insitu examples of what the drop size distribution is in the middle of wet microburst I would claim that you have that. And again, I simply can't understand why you can't compute the liquid water content per cubic meter given the drop size distribution.

ROLAND BOWLES (NASA LaRC) - Clearly you can. It is a textbook exercise as you know. My point is, we need not know that information to assess its impact on our data. Nowhere in the basic physics does rain rate enter the question. Liquid water content is the driving parameter. The point is, we just don't need that information Jim.

JIM EVANS (MIT Lincoln Labs) - I think the issue here is people are asking a very pragmatic element. How hard does it have to be raining before these penalties become appropriate. And you would like to be able, among other things, to relate that, for example, to something they can see on their airborne weather radar--that is radar reflectivity. I mean, the trouble is, nobody here, from what you have said, has any concept of how hard it really was raining. And you said, we don't even know how to talk about that, and that's what I said, I'm a little baffled.

ROLAND BOWLES (NASA LaRC) - Look, we are talking tests. We know what the liquid water content was. It is up to the sensor technologists to decide what that means in terms of rain rate as incurred for measures. Is that a fair statement?

JIM EVANS (MIT Lincoln Labs) - If you have the rain drop size distribution right, which you are trying to do in your simulation, then there is a rain rate presumably that corresponds exactly to whatever liquid water content you claim that you are using. And that is something that I think these users would have some sense for.

ROLAND BOWLES (NASA LaRC) - In the large scale tests you are right. We will certainly produce that. In the wind tunnel environment, we did not know how to do that based on the fact that we are using similarity of flow, similarity of model, and similarity of rain. I defy anybody to give us the scaling for that, that is my point. As we do the large scale test work, you are right. We will be able to relate the rain rate to the aerodynamic penalty.

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NASA WIND SHEAR MODEL

SUMMARY OF MODEL ANALYSES

Dr. Fred Proctor
MESO, Inc.

OUTLINE

I. INTRODUCTION AND MODEL DESCRIPTION
II. MICROBURST DYNAMICS AND STRUCTURE
  A. BASELINE CASE - DENVER 30 JUNE 82 SOUNDING
  B. HIGH RESOLUTION, AXISYMMETRIC SIMULATION OF DFW MICROBURST
III. SENSITIVITY STUDIES
  A. SENSITIVITY TO ENVIRONMENT
  B. SENSITIVITY TO PRECIPITATION TYPE (i.e.,HAIL GRAUPEL, RAIN, SNOW)
  C. SENSITIVITY TO PRECIPITATION RATE
  D. SENSITIVITY TO RADIUS OF PRECIPITATION SHAFT (i.e., DIAMETER OF DOWNDRAFT)
IV. SUMMARY AND CONCLUSIONS
V. FUTURE WORK

TERMINAL AREA SIMULATION SYSTEM (TASS)

- O TIME-DEPENDENT NEWTONIAN EQUATIONS FOR COMPRESSIBLE NONHYDROSTATIC FLUIDS

- O BOTH 3-D AND 2-D VERSIONS

  PROGNOSTIC EQUATIONS FOR 11 VARIABLES:

1. 3-COMPONENTS OF VELOCITY	5. CLOUD ICE CRYSTALS
2. PRESSURE	6. RAIN
3. TEMPERATURE	7. SNOW
4. LIQUID CLOUD DROPLETS	8. HAIL

- O SMAGORINSKY TURBULENCE CLOSURE WITH RICHARDSON NUMBER (BOUYANCY) DEPENDENCE

- O OPEN LATERAL BOUNDARY CONDITIONS

- O BULK PARAMETERIZATIONS OF CLOUD MICROPHYSICS INCLUDING: EVAPORATION OF RAIN, MELTING OF SNOW AND HAIL, SUBLIMATION OF HAIL AND SNOW, AND SUBSEQUENT LATENT HEAT EXCHANGES

- O SURFACE FRICTION LAYER BASED ON MONIN-OBUKHOV SIMILARITY THEORY

INPUT FOR AXISYMMETRIC MODEL

AMBIENT CONDITIONS

O VERTICAL PROFILE OF AMBIENT TEMPERATURE
O VERTICAL PROFILE OF AMBIENT HUMIDITY

TOP BOUNDARY SPECIFICATIONS (USUALLY AT 5 km AGL)

O RADIUS OF PRECIPITATION SHAFT
O TYPE OF PRECIPITATION AT TOP BOUNDARY
(e.g., RAIN, SNOW, GRAUPEL, OR HAIL)
O PEAK RADAR REFLECTIVITY OR MIXING RATIO OF
PRECIPITATION

2-D AXISYMMETRIC SIMULATIONS

O DOMAIN SIZE 5 KM X 5 KM
O CONSTANT GRID SIZE 40 M
O MICROBURST TRIGGERED BY ALLOWING PRECIPITATION FOR FALL FROM TOP BOUNDARY
O DOWNDRAFT DEVELOPS AS RESULT OF MICROPHYSICAL COOLING AND MASS LOADING DUE TO WEIGHT OF PRECIPITATION

SENSITIVITY EXPERIMENTS

O PARAMETERS VARIED

1. ENVIRONMENTAL SOUNDING
2. TYPE OF PRECIPITATION AT TOP BOUNDARY (HAIL, GRAUPEL, RAIN ,SNOW)
3. INTENSITY OF PRECIPITATION
4. WIDTH OF PRECIPITATION SHAFT

DEFINITIONS

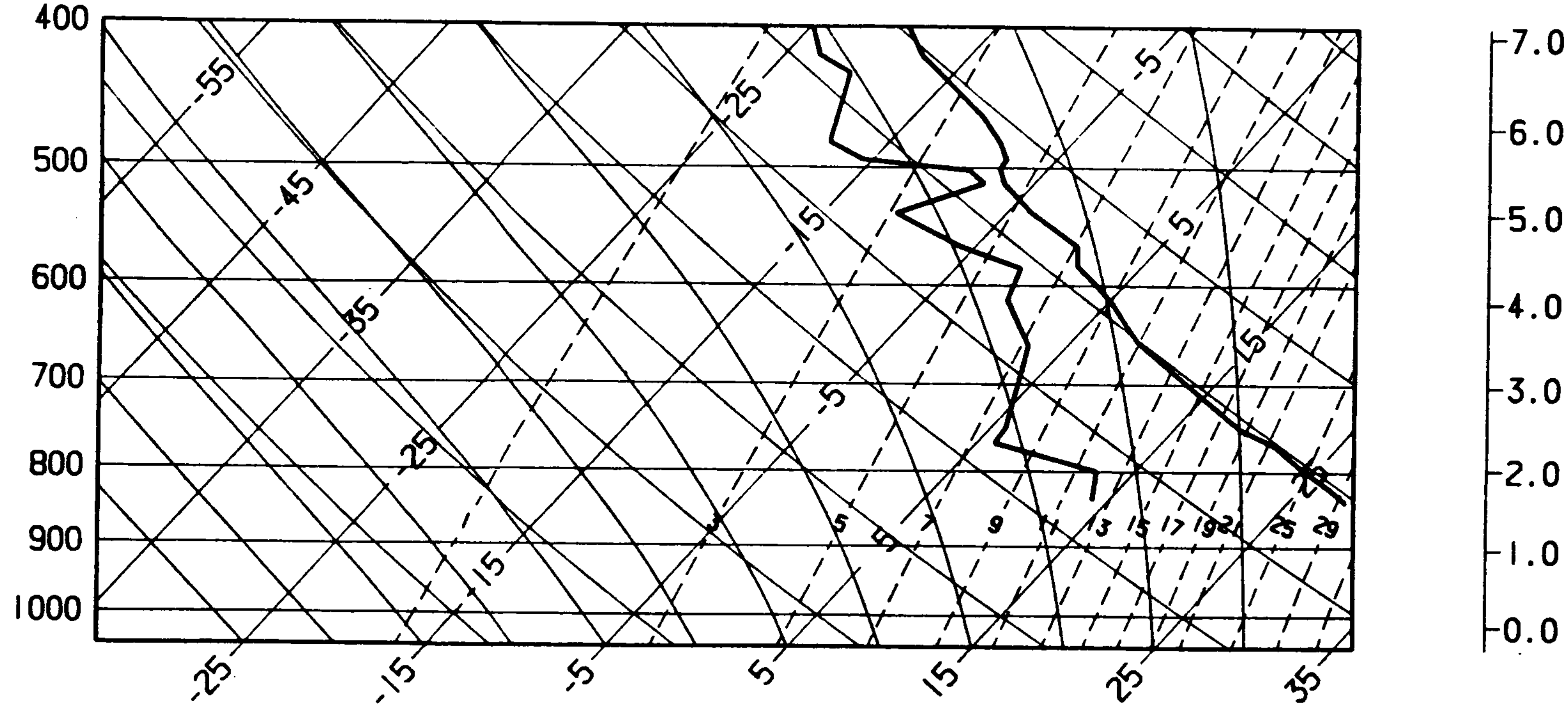
- MICROBURST CLASSIFIED AS HAVING $\Delta U \geq 10$ M/S AND A DISTANCE BETWEEN OUTFLOW PEAKS LESS THAN 4 KM

- DRY MICROBURST VS. WET MICROBURST
  WET IF 0.01" (0.25 MM) OR MORE IS MEASURED DURING THE EVENT

- A MICROBURST MAY BE ISOLATED, OCCUR WITHIN LINES, OR CLUSTERS

- THIS STUDY WILL CONCENTRATE ON ISOLATED MICROBURST, BOTH WET AND DRY

AMBIENT TEMPERATURE AND HUMIDITY PROFILES OBSERVED 2300 GMT 30 JUNE 1982 DENVER



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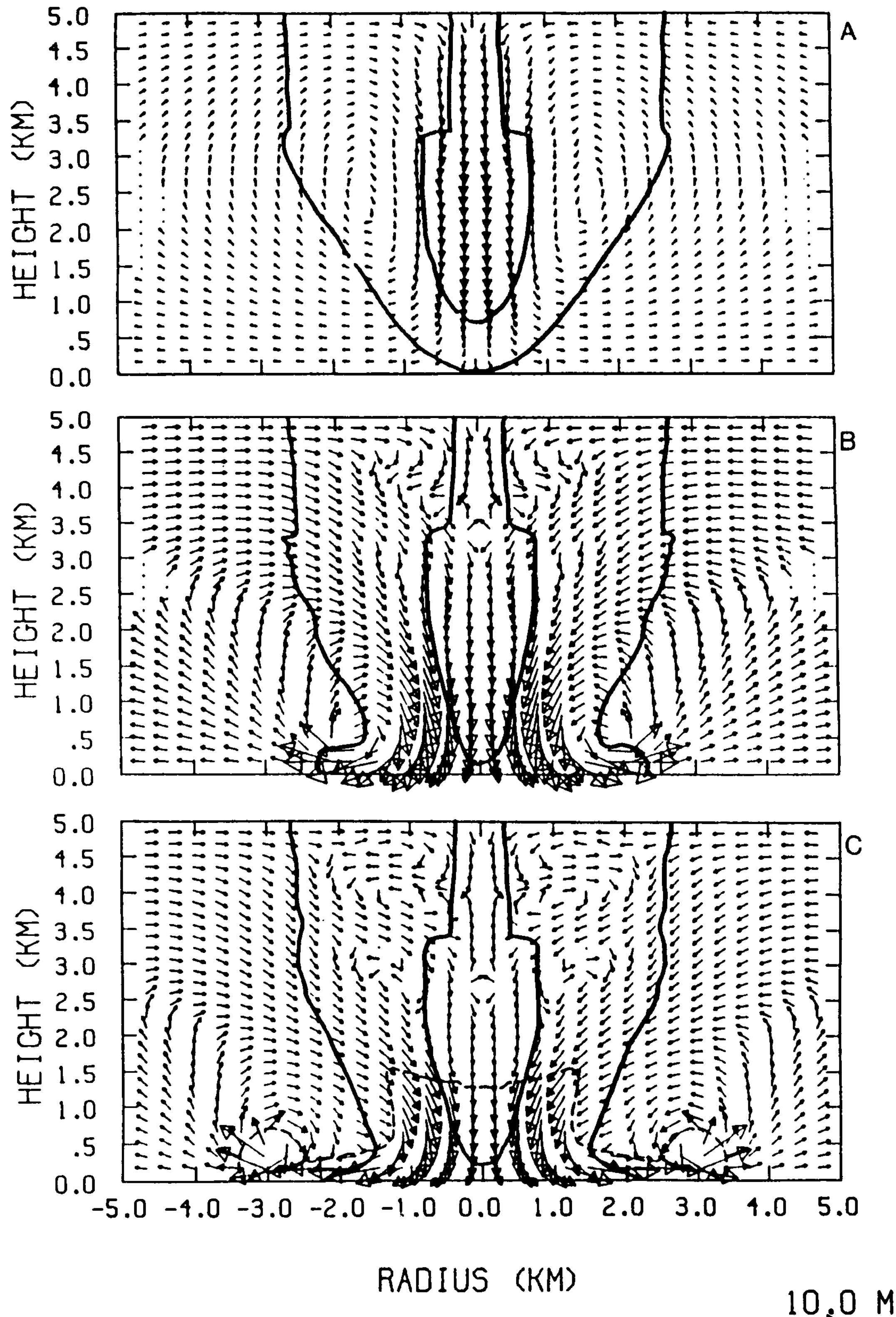
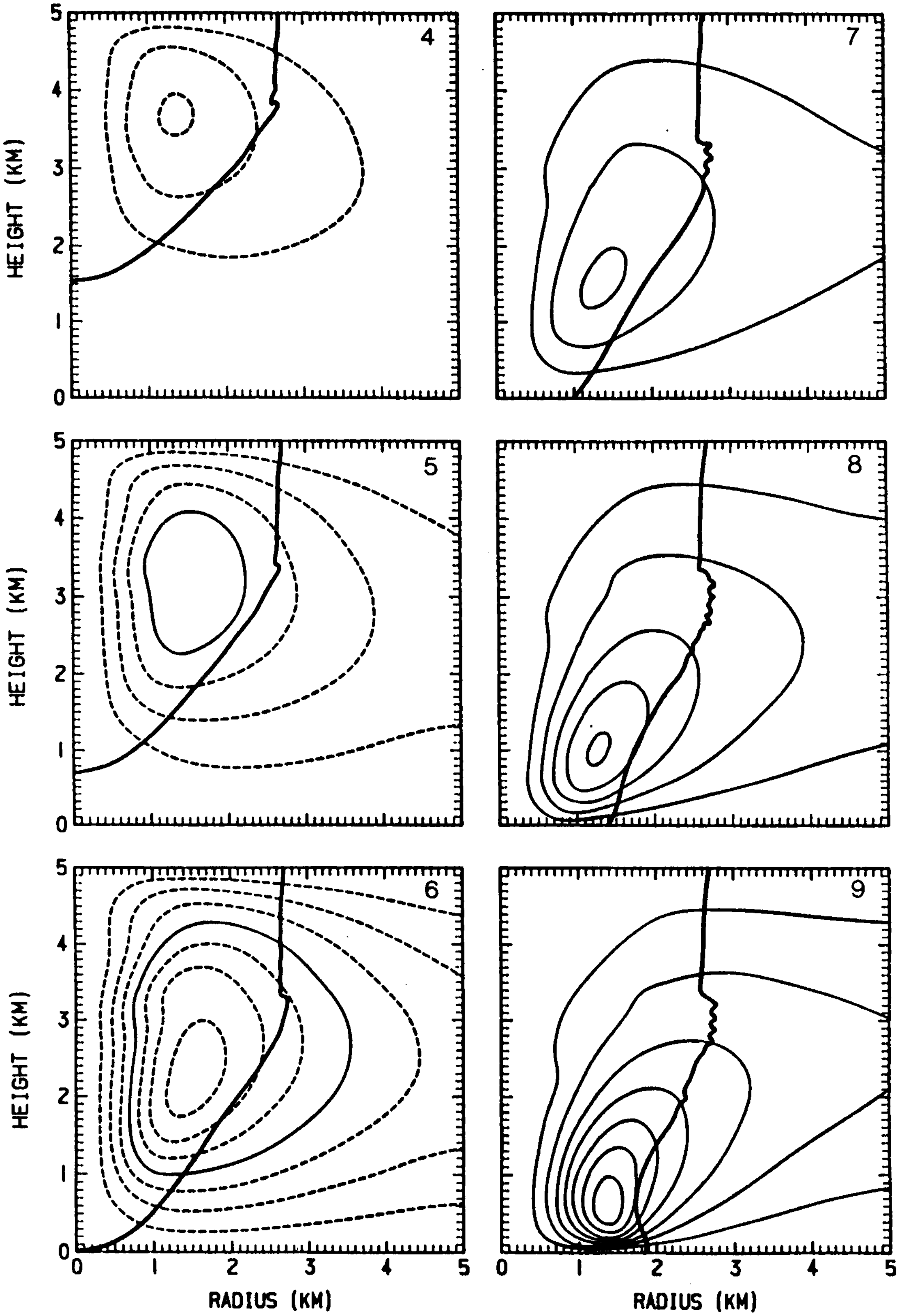
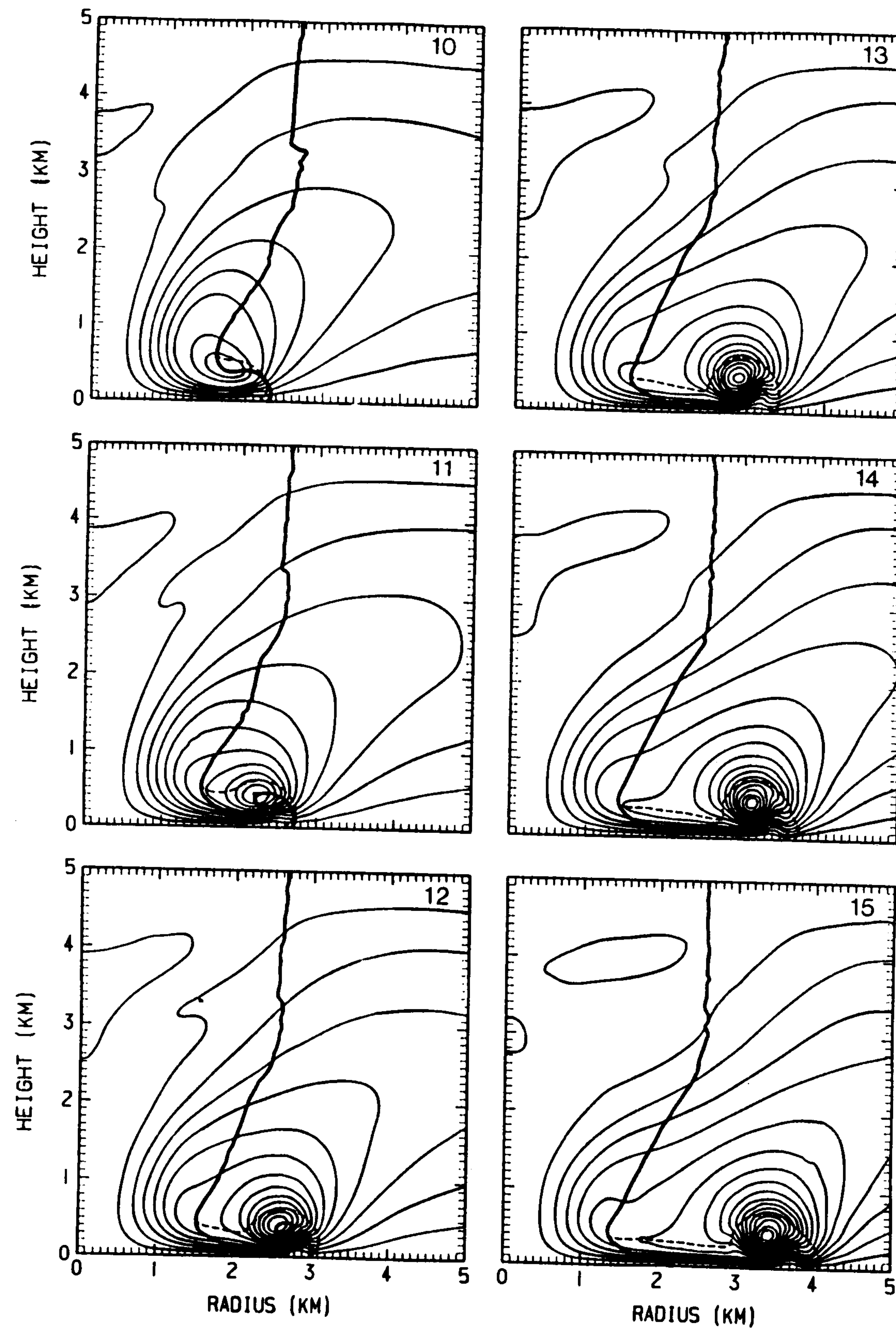
WIND VECTORS IN VERTICAL PLANE THROUGH MICROBURST CENTER FOR 30 JUNE 82 (BASELINE) SIMULATION



CROSS-SECTIONS OF STREAM FUNCTION FIELD AT 1 MIN INTERVALS FROM BASELINE SIMULATION



CROSS-SECTIONS OF STREAM FUNCTION FIELD AT 1 MIN INTERVALS FROM BASELINE SIMULATION



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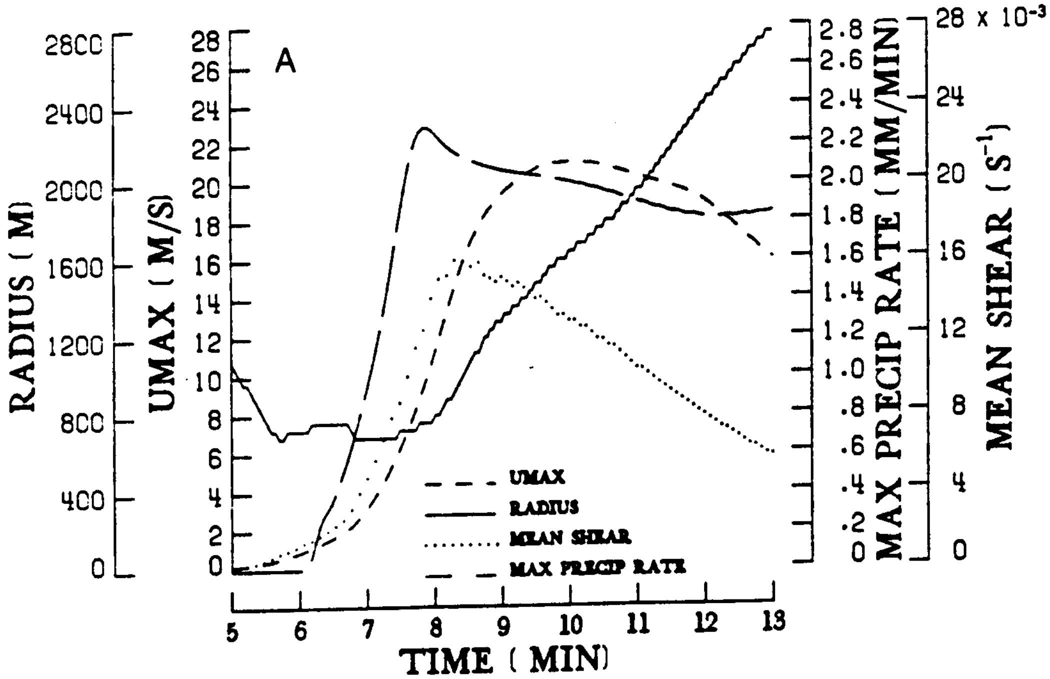
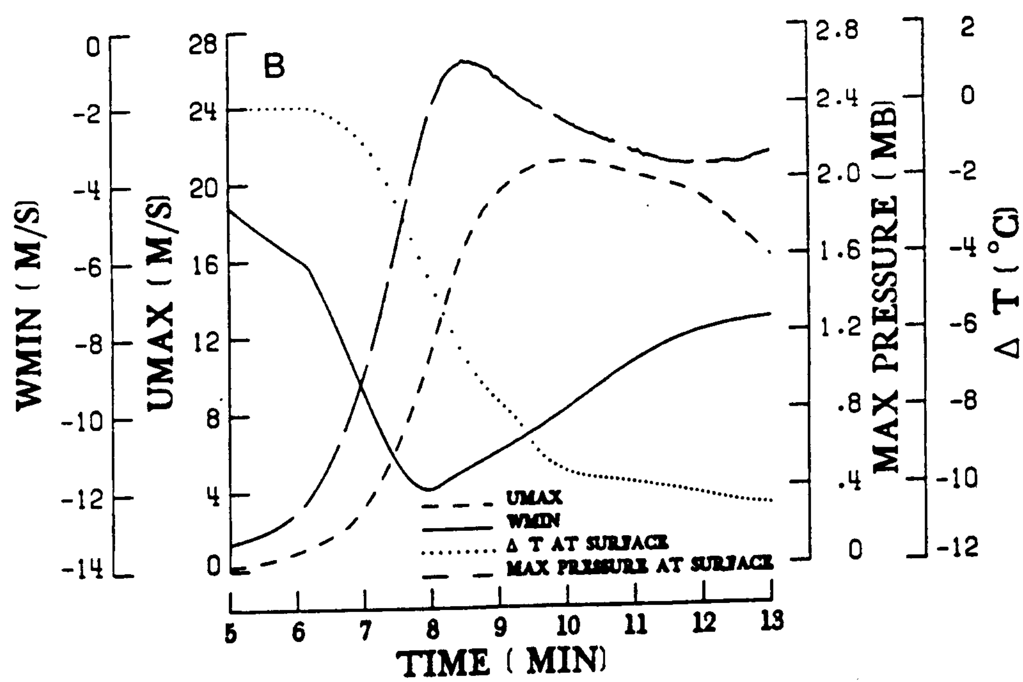
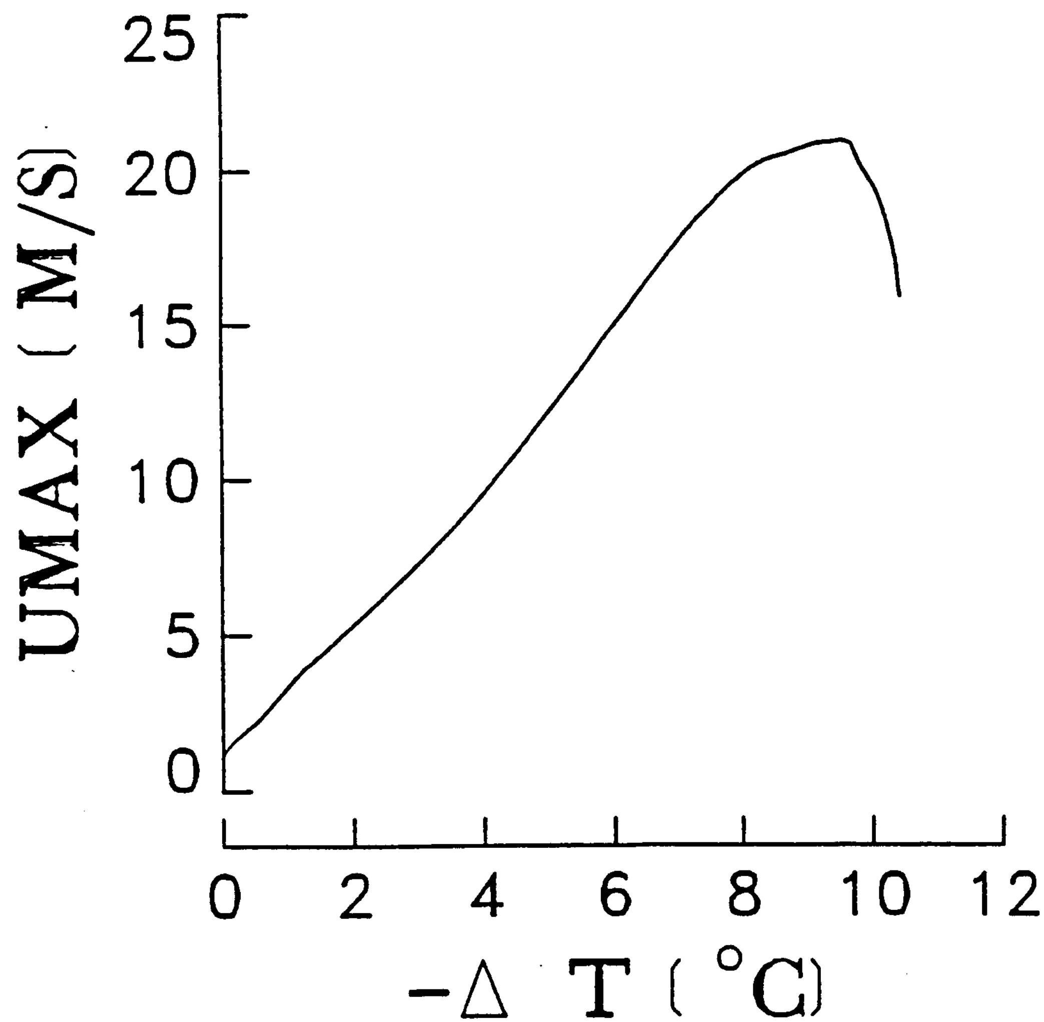
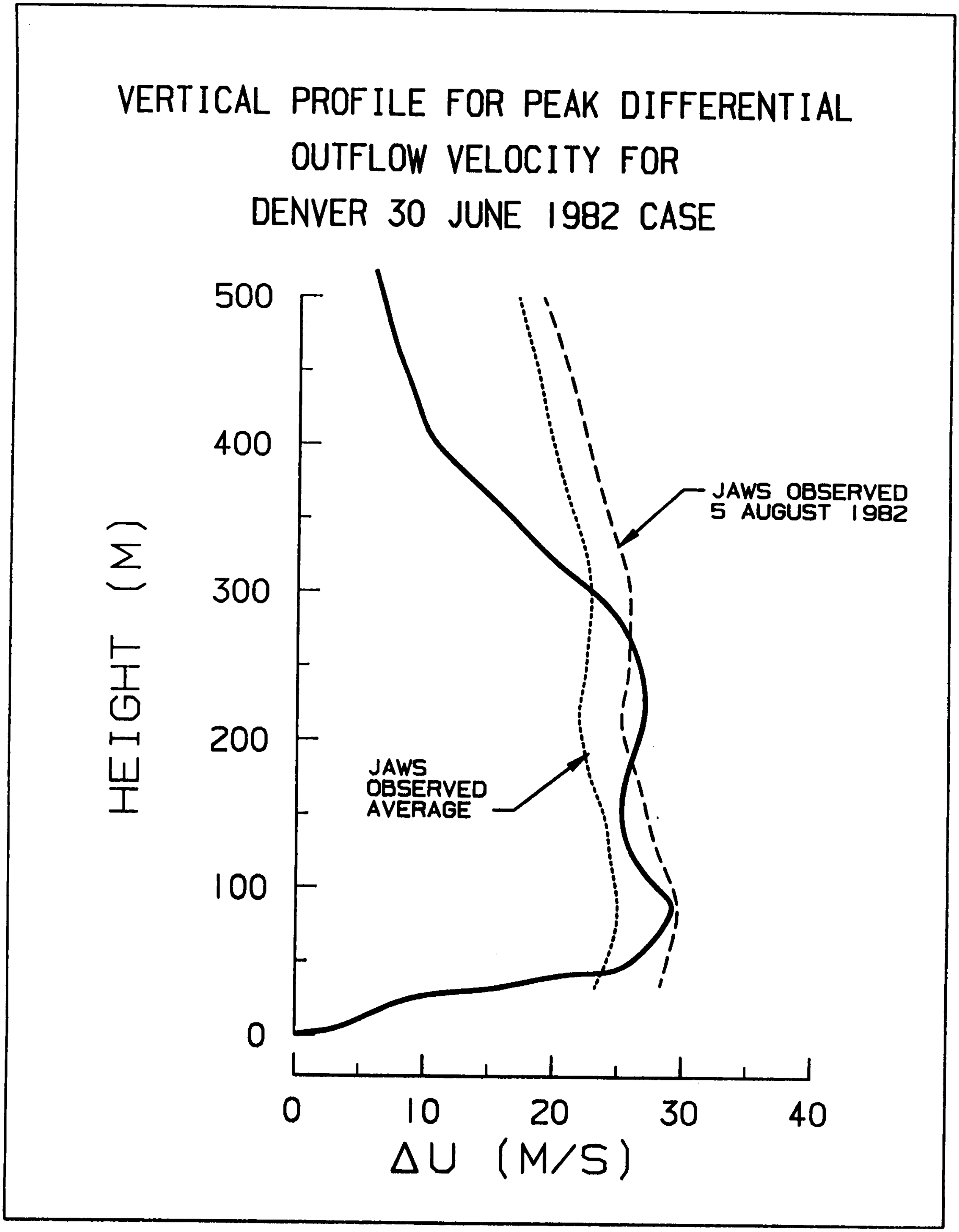
PEAK VALUES VS. TIME FOR BASELINE SIMULATION



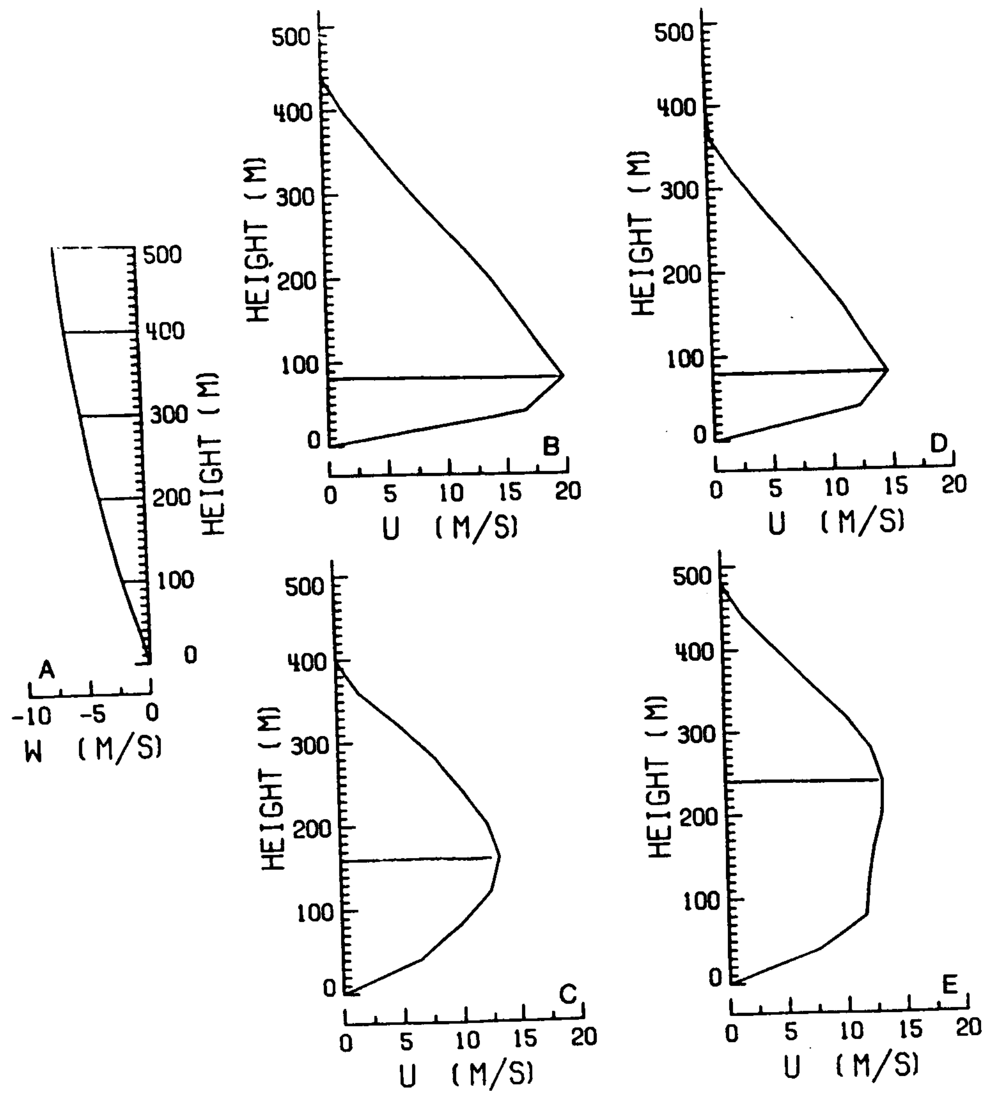


PEAK RADIAL VELOCITY VS. PEAK TEMPERATURE DROP FROM AMBIENT FOR BASELINE SIMULATION

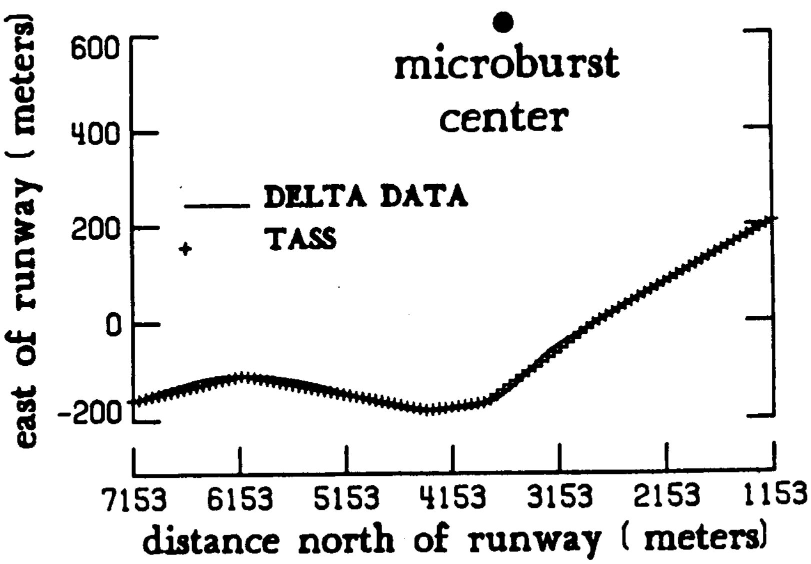


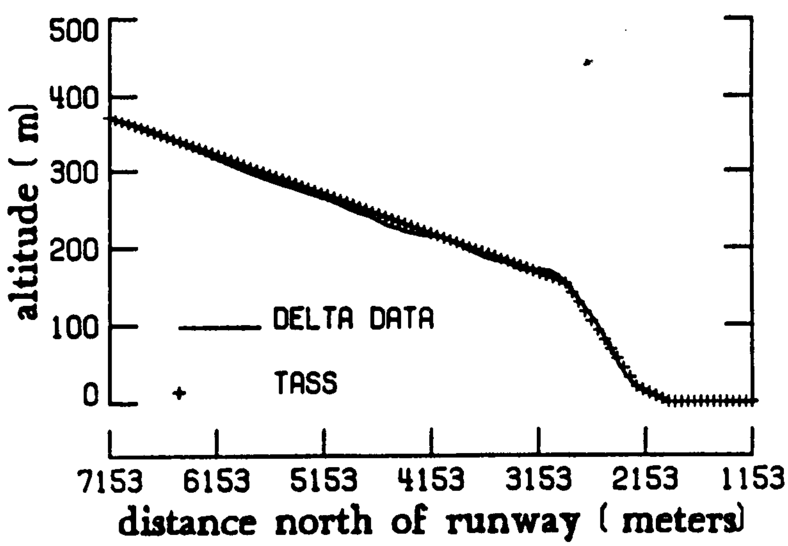

VERTICAL PROFILE FOR PEAK DIFFERENTIAL
OUTFLOW VELOCITY FOR
DENVER 30 JUNE 1982 CASE
HEIGHT (M)
500
400
300
200
100
0
0
10
20
30
40
ΔU (M/S)
JAWS OBSERVED
5 AUGUST 1982
JAWS
OBSERVED
AVERAGE

VERTICAL PROFILES FROM BASELINE SIMULATION

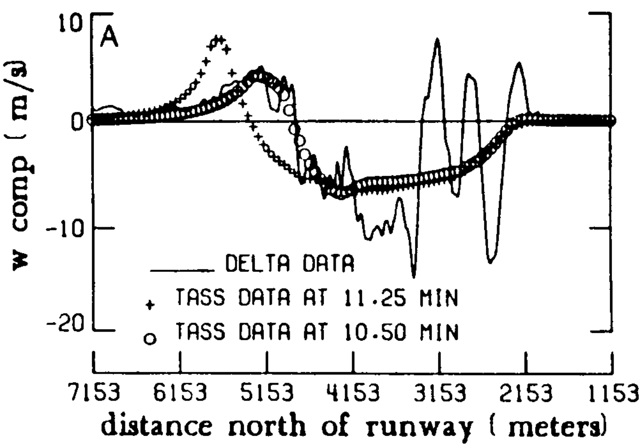


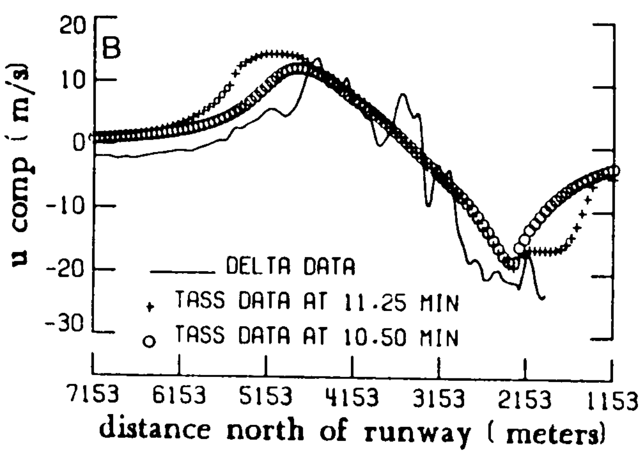
LOCATION OF DELTA 191 FLIGHT PATH AND DFW MICROBURST CENTER

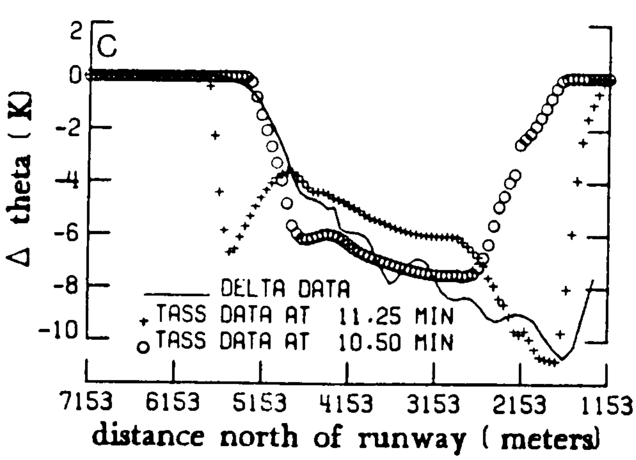




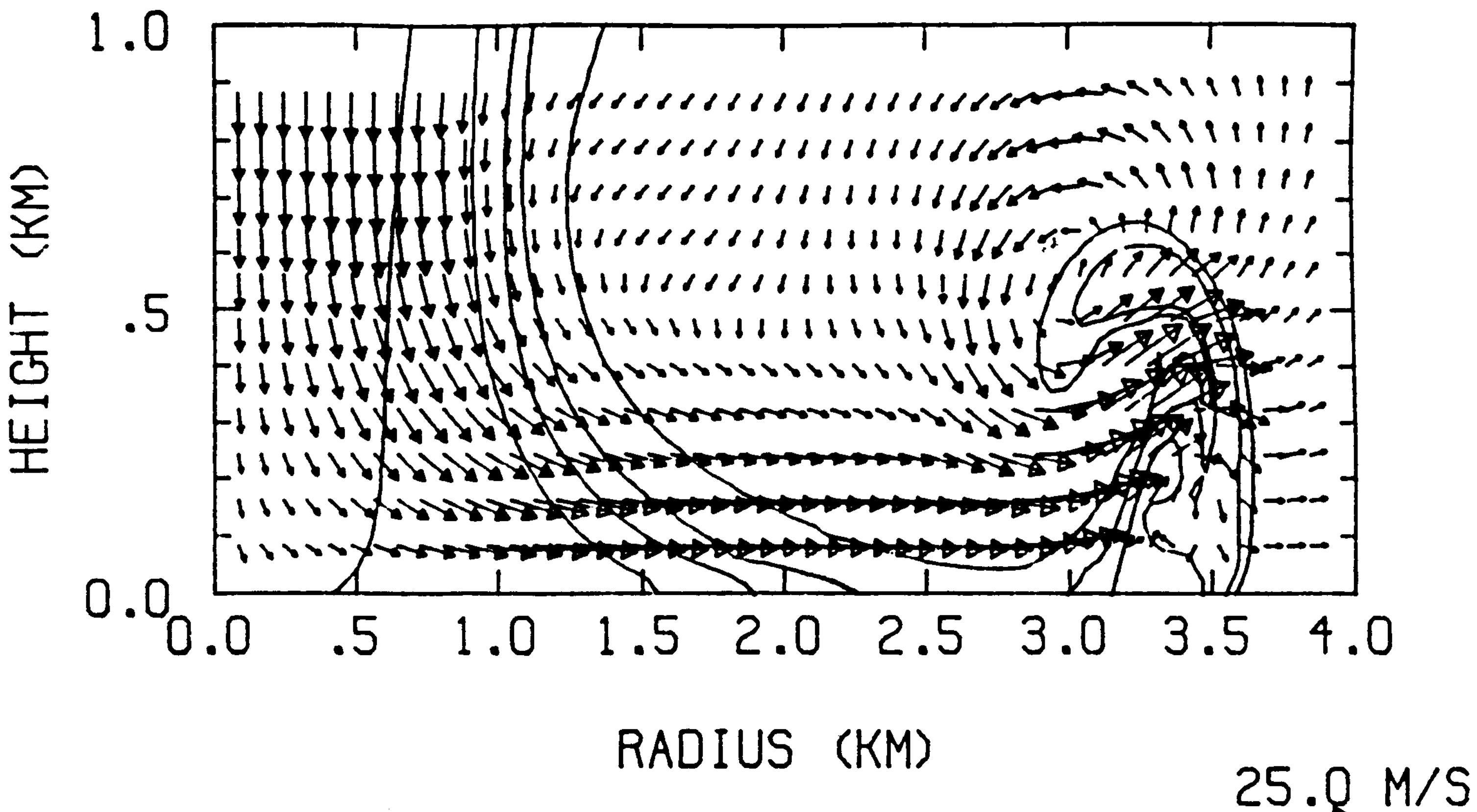
COMPARISON OF MODEL SIMULATED PROFILES AND ACTUAL PROFILES DERIVED FROM DELTA 191 FLIGHT RECORDER DATA







CROSS-SECTION OF RADAR REFLECTIVITY AND SUPERIMPOSED WIND VECTORS FOR DFW SIMULATION



(CI = 10dBZ)

SENSITIVITY EXPERIMENTS

MICROBURST SENSITIVITY TO ENVIRONMENT

KEY PARAMETERS FOR WET MICROBURST

O DEPTH OF THE MELTING LAYER (LAYER IN WHICH T > 0 deg C)

O MEAN LAPSE RATE WITHIN THE MELTING LAYER

O HUMIDITY WITHIN MELTING LAYER

INDEX FOR WET-MICROBURST POTENTIAL

$$I = \frac{\sqrt{H_M \left\{ T_S - 5.5 \times 10^{-3} H_M + \left[Q_V(1 \text{ km AGL}) - 1.5\, Q_V(H_M) \right] / 3 \right\}}}{5}$$

H_M - HEIGHT OF MELTING LEVEL (M AGL)

T_S - SURFACE TEMPERATURE (°C)

Q_V - VAPOR MIXING RATIO (G/KG)

$I > 50$	INTENSE
$45 \le I \le 50$	SEVERE
$36 \le I < 45$	HAZARD
$25 \le I < 36$	CAUTION

MODEL SIMULATION VS. INDEX FOR WET-MICROBURST POTENTIAL

SOUNDING LOCATION	DATE	MODELED ΔU (M/S)	I	DEPTH OF GROUND BASED ISOTHERMAL LAYER
DEN	30 JUN 82	42	37	
DEN	7 JUL 80	44	45	
DEN	14 JUL 82	43	41	
DEN	5 AUG 82	41	42	
DFW	2 AUG 85	54	54	
CHS	10 SEP 85	27	28	
DCA	4 JUL 56	23	33	
DEN	2 JUN 82	8	0	
DEN	30 JUN 82	31	29	500 M*
DEN	30 JUN 82	21	9	1000 M*

*SOUNDING ARBITRARILY MODIFIED.

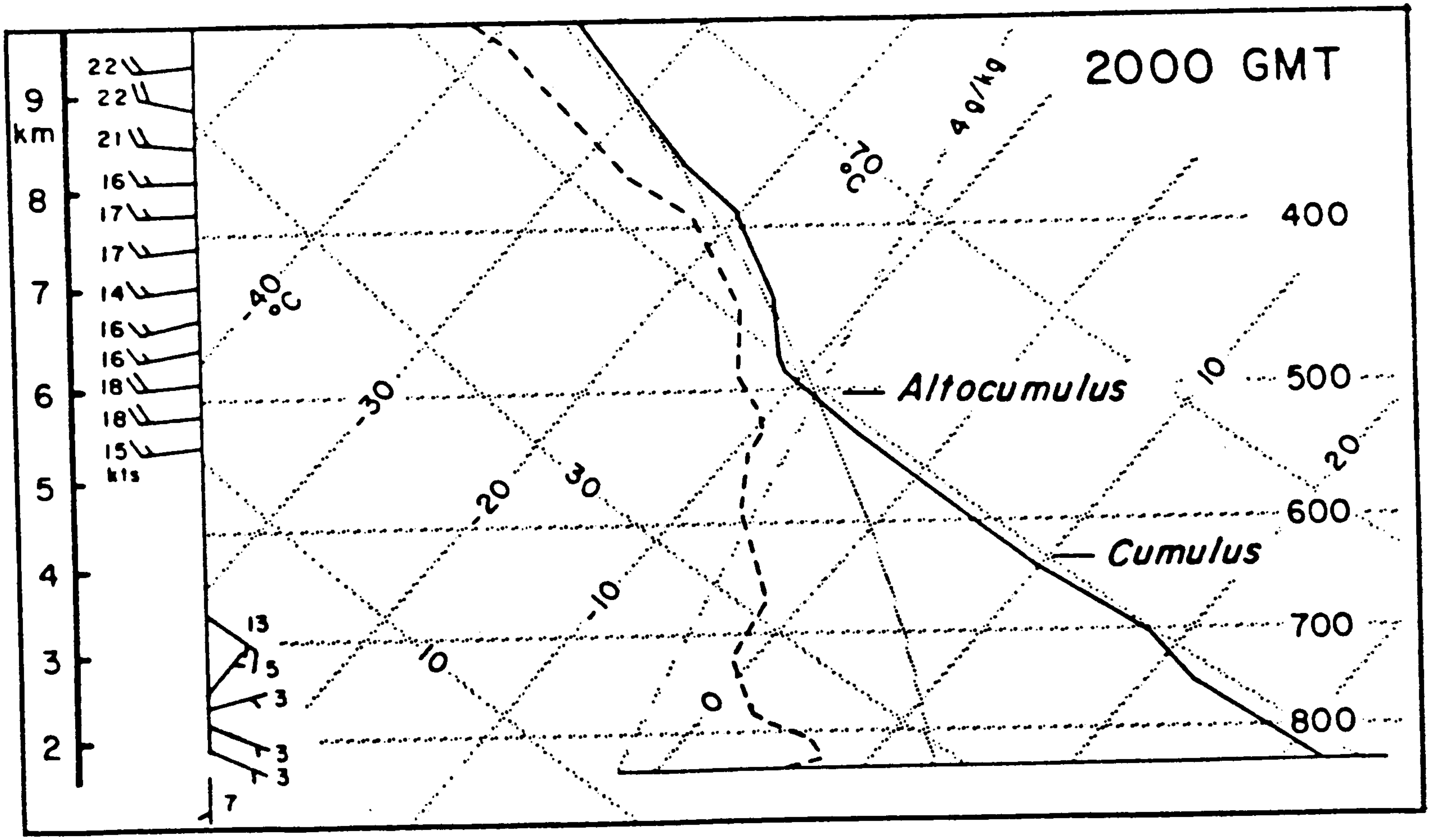
MODEL EXPERIMENTS BASED ON 61 DBZ HAILSHAFT WITH RADIUS OF 3 KM AT 5 KM AGL.

SENSITIVITY TO PRECIPITATION TYPE AT THE MODEL TOP BOUNDARY

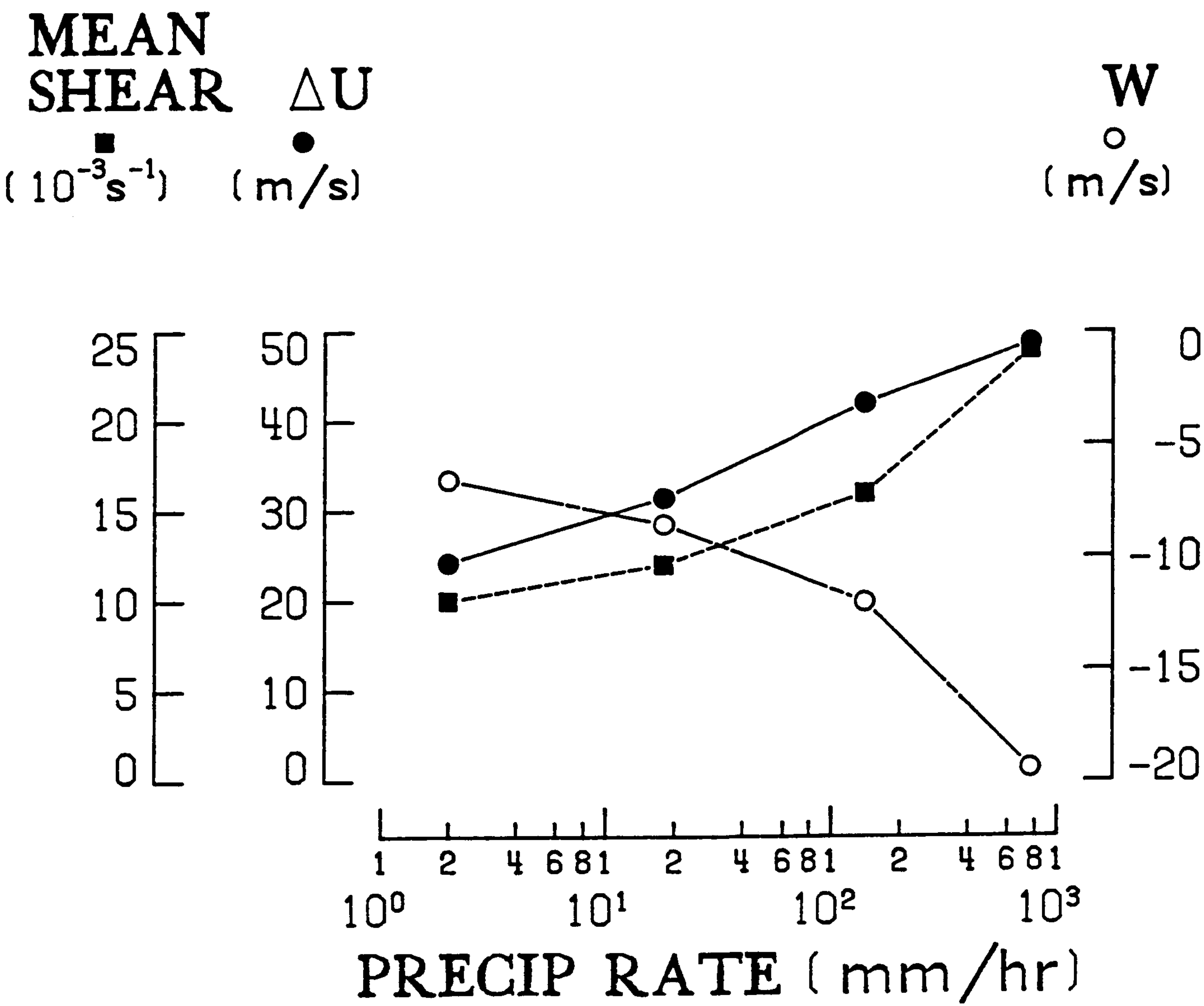
[RADIUS = 3000 M, Q(Z*) = 4.27 G KG^{-1} FOR ALL SIMULATIONS]

SOUNDING LOCATION	SOUNDING DATE	TOP BOUNDARY PRECIPITATION TYPE	ΔU (MS^{-1})	WMIN (MS^{-1})	ΔT (^oC)	OUTFLOW DEPTH (M)
DEN	30 JUN 82	HAIL	42	-12	-11	450
DEN	30 JUN 82	GRAUPEL	40	-15	-9	450
DEN	30 JUN 82	RAIN	34	-13	-8	400
DEN	30 JUN 82	SNOW	23	-13	-3	300
DEN	14 JUL 82	HAIL	43	-18	-13	475
DEN	14 JUL 82	SNOW	54	-31	-6	350

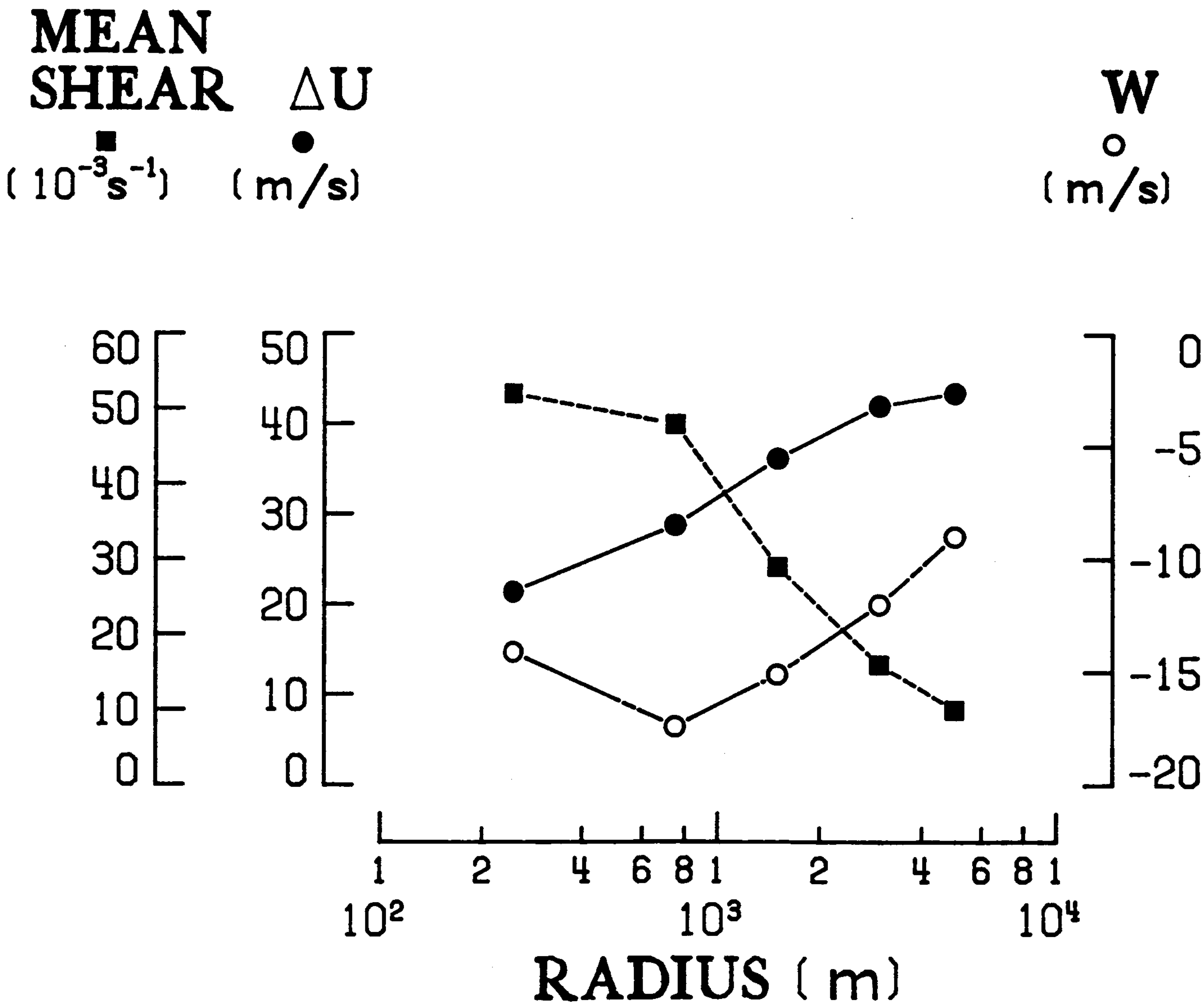
AMBIENT ENVIRONMENT OBSERVED 14 JULY 1982
DENVER – TYPICAL DRY MICROBURST SOUNDING



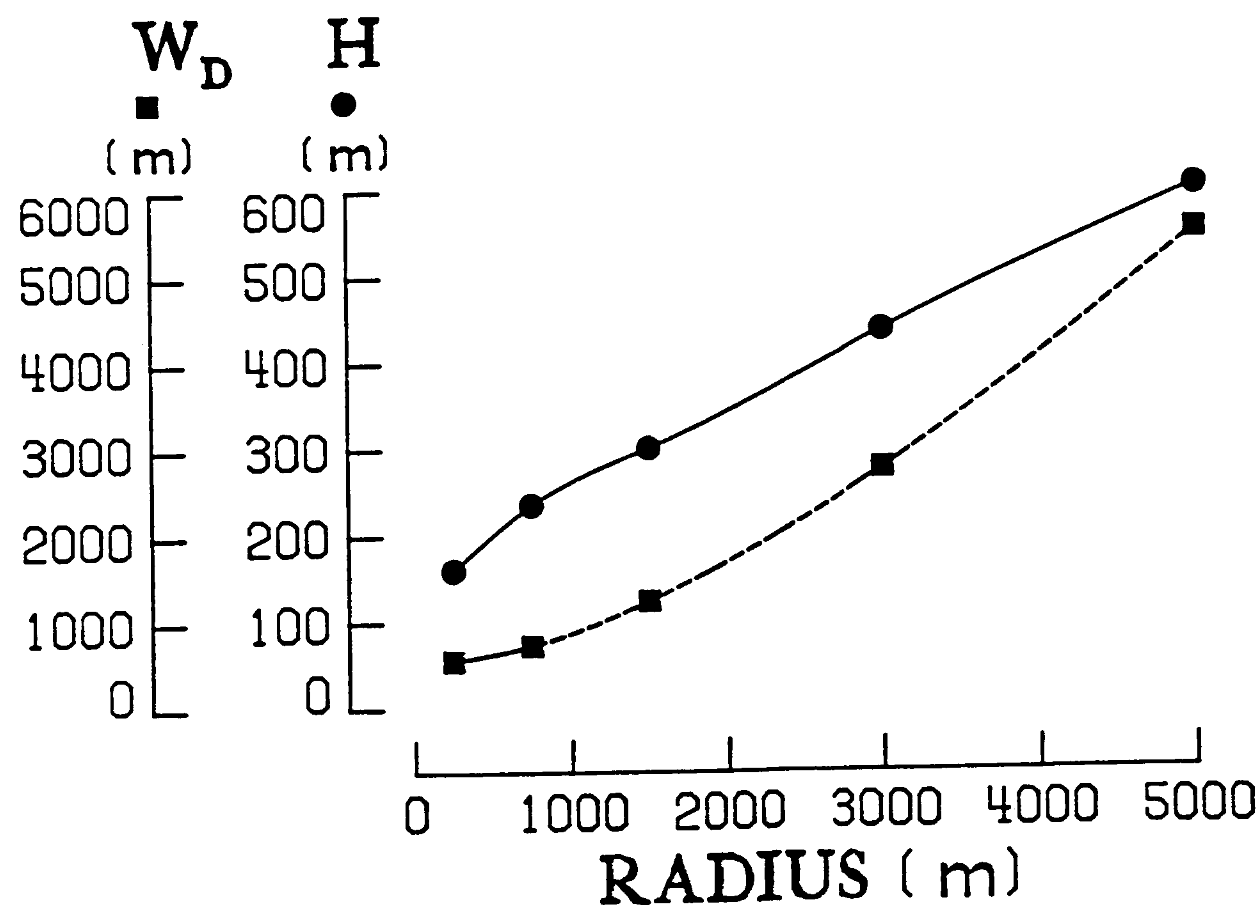
BASELINE MICROBURST SENSITIVITY TO PEAK PRECIPITATION RATE AT GROUND



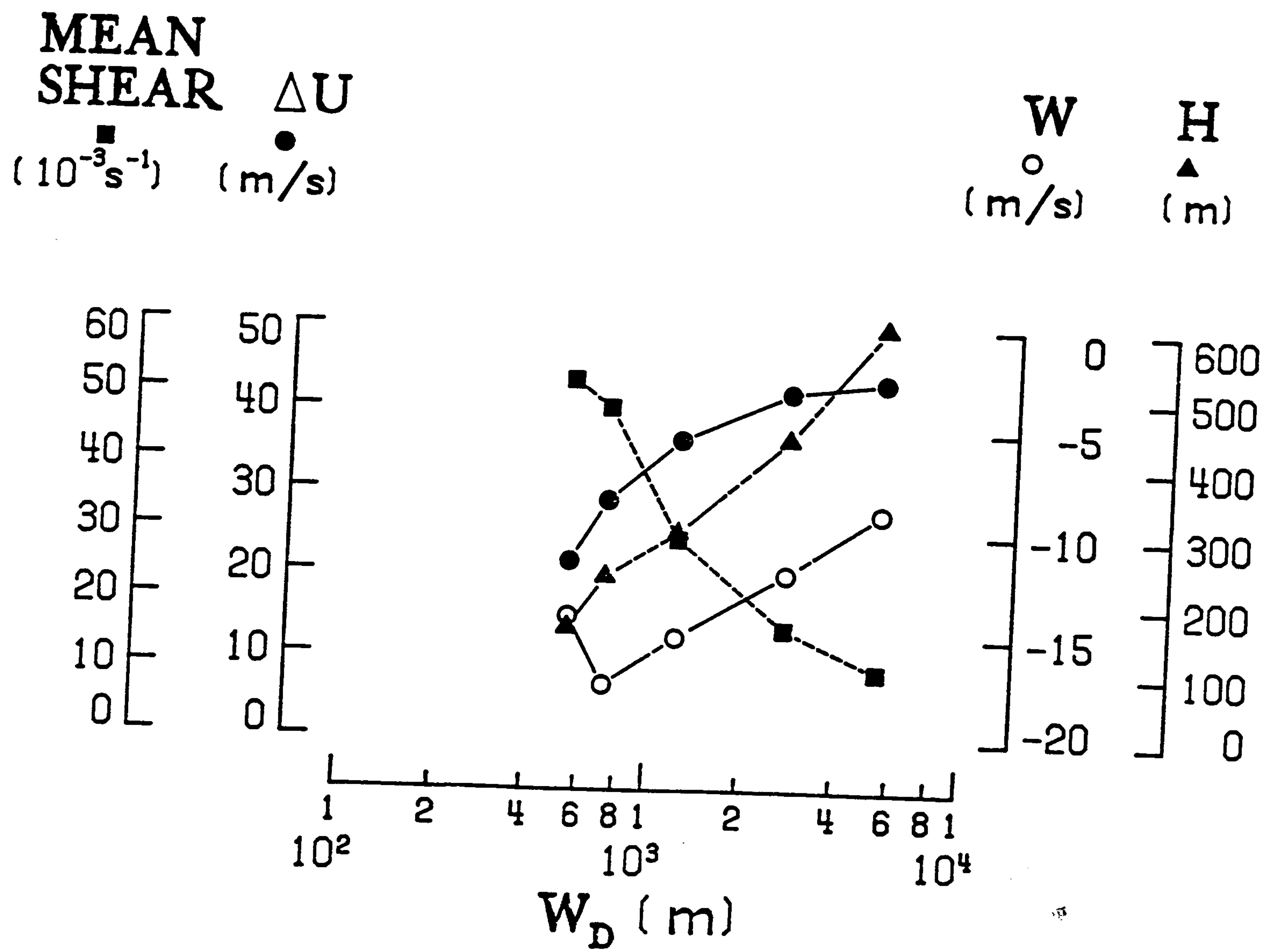
BASELINE MICROBURST SENSITIVITY TO RADIUS OF PRECIPITATION SHAFT (AT 5KM AGL)

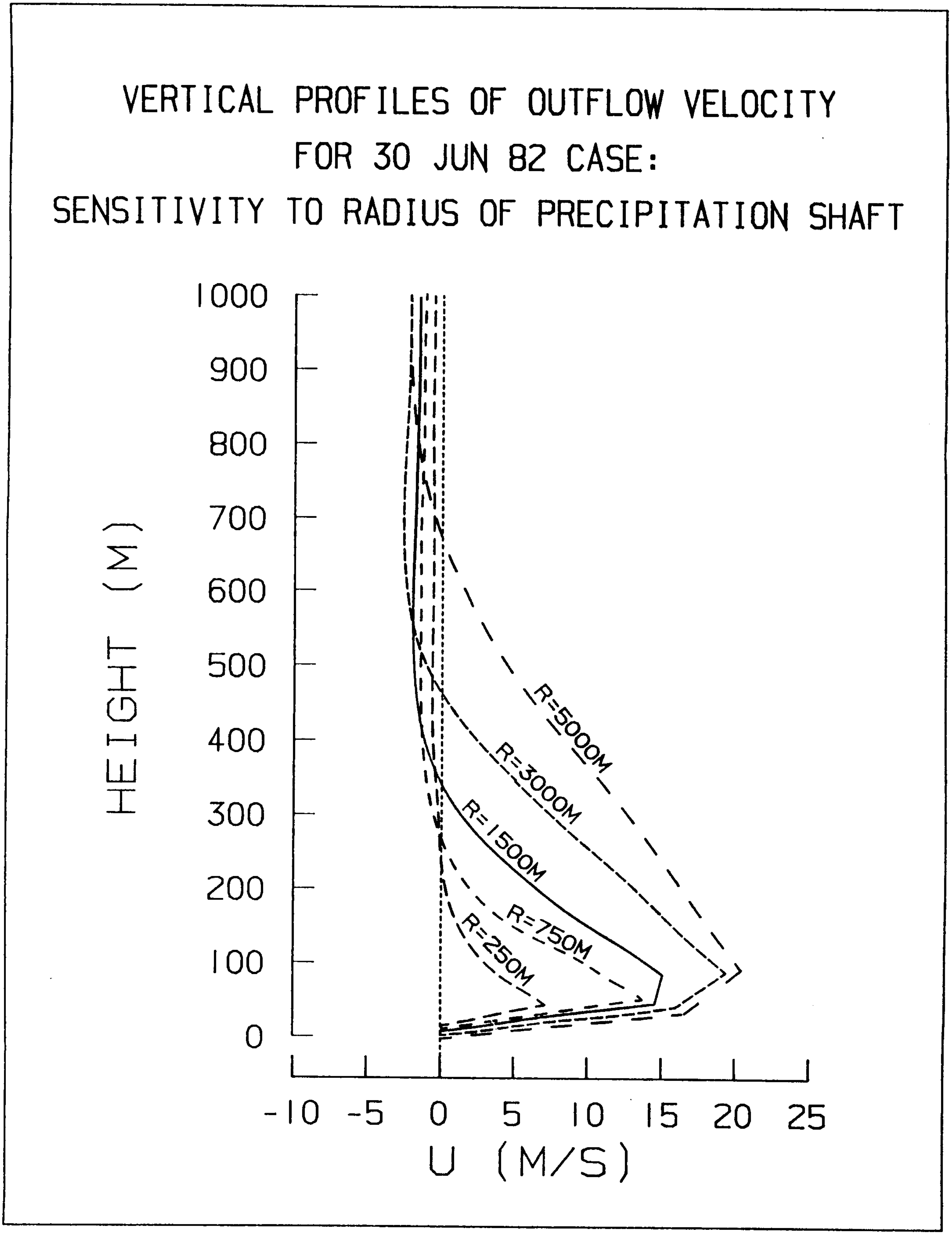


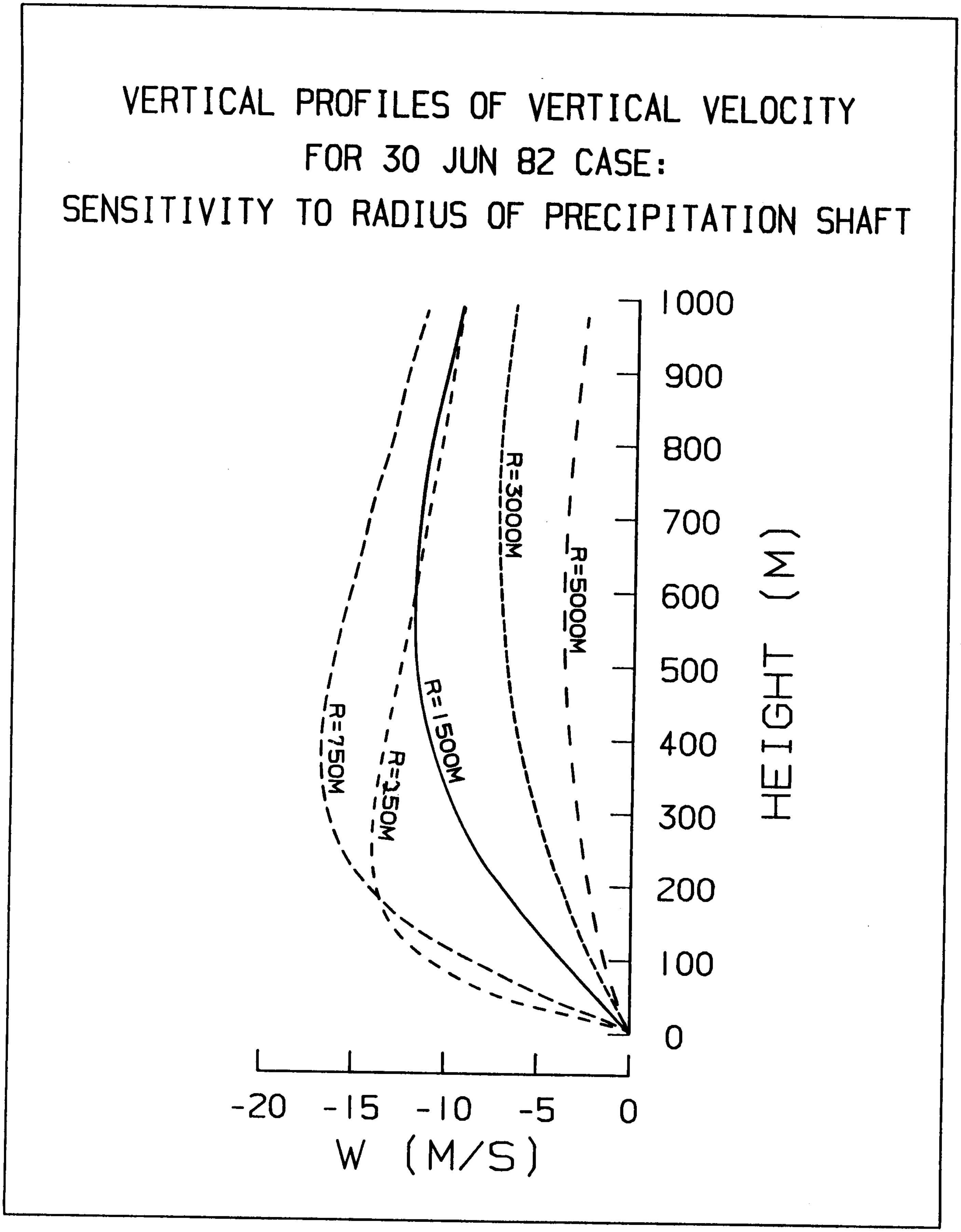
RELATION BETWEEN RADIUS OF PRECIPITATION SHAFT, DOWNDRAFT DIAMETER (WD), AND MEAN DEPTH OF OUTFLOW (H)

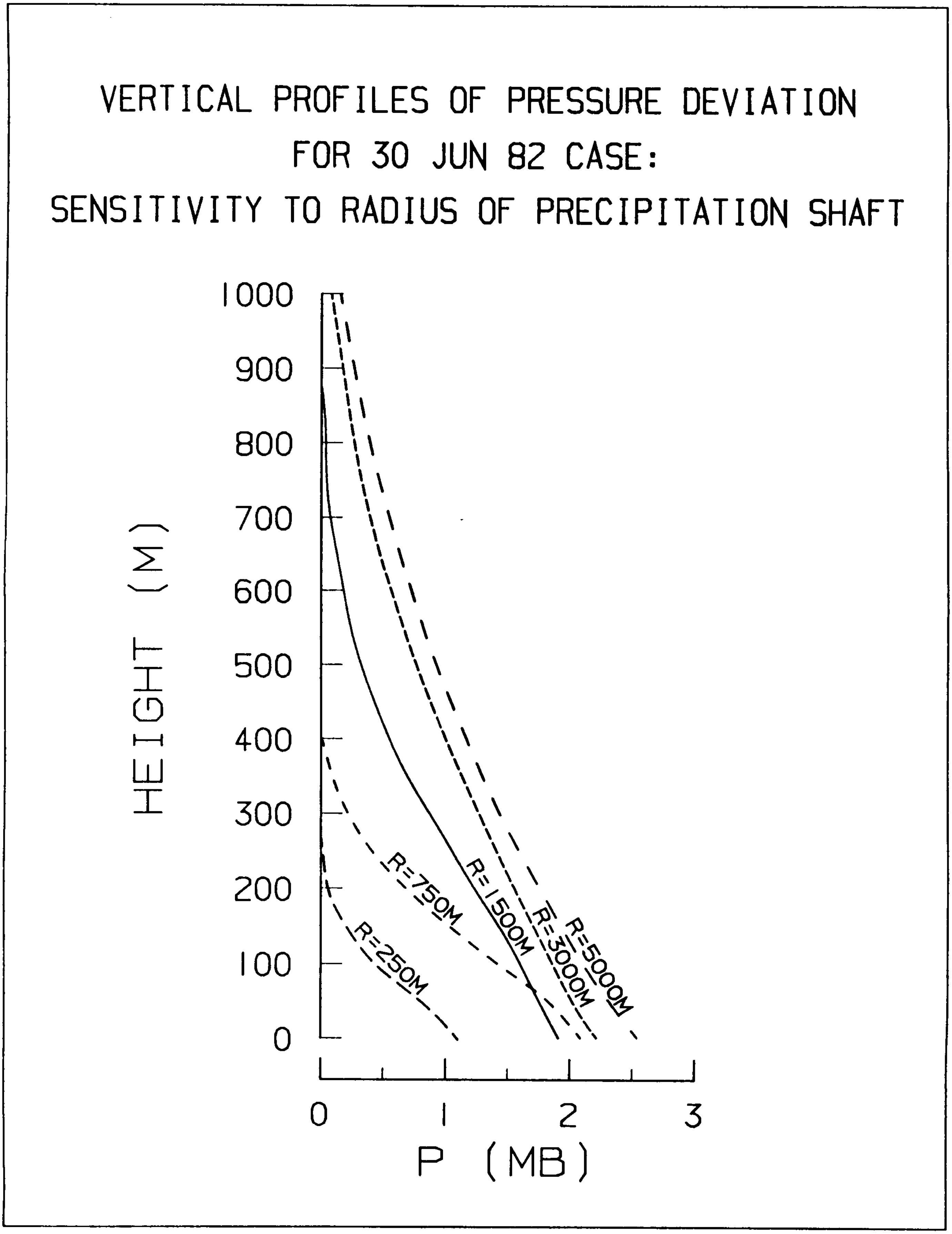


BASELINE MICROBURST SENSITIVITY TO DIAMETER OF DOWNDRAFT

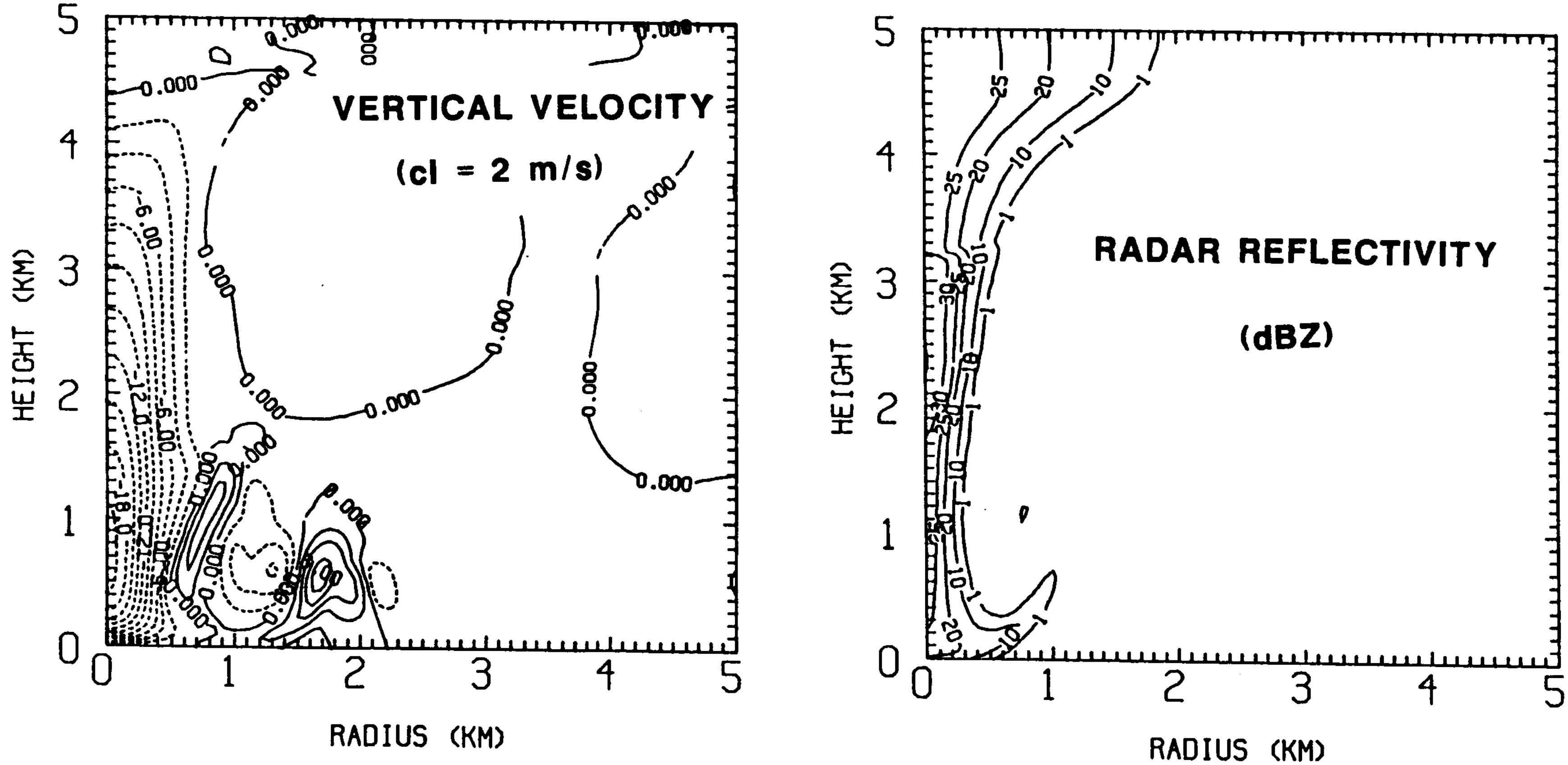


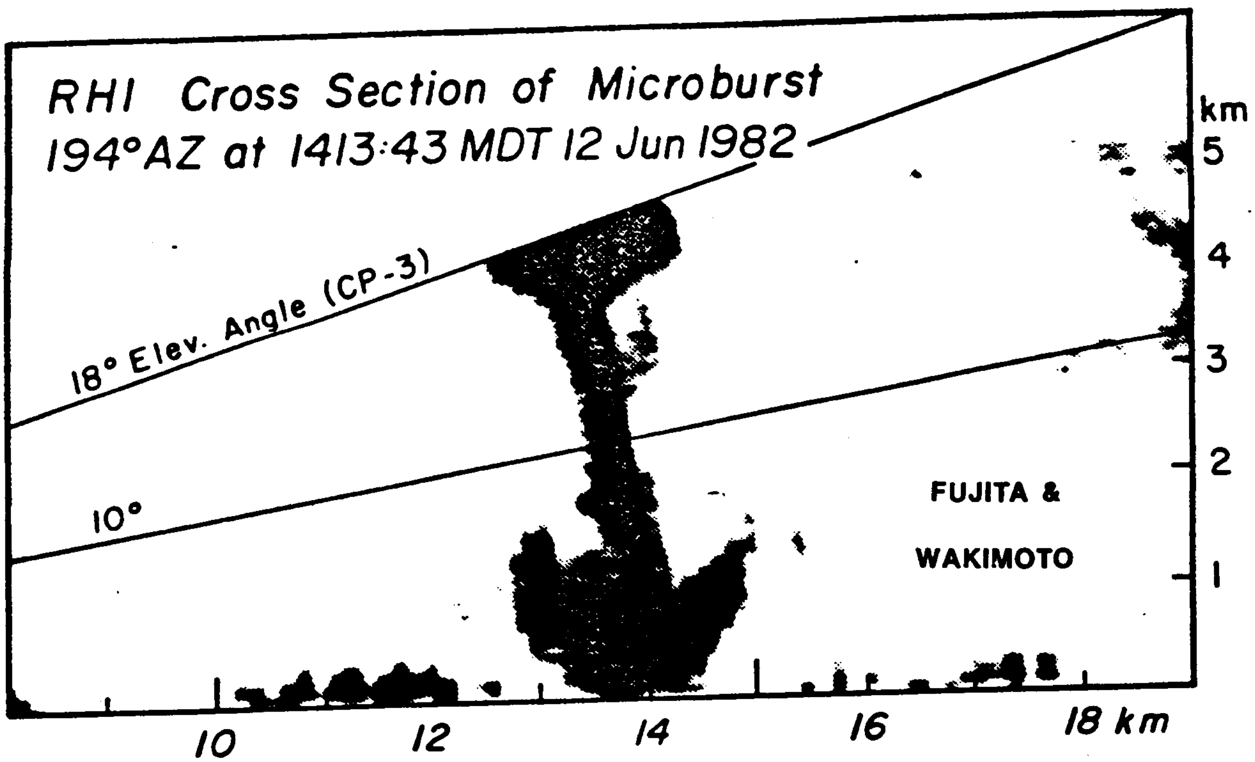

VERTICAL PROFILES OF OUTFLOW VELOCITY
FOR 30 JUN 82 CASE:
SENSITIVITY TO RADIUS OF PRECIPITATION SHAFT
HEIGHT (M)
1000
900
800
700
600
500
400
300
200
100
0
R=5000M
R=3000M
R=1500M
R=750M
R=250M
-10
-5
0
5
10
15
20
25
U (M/S)


VERTICAL PROFILES OF VERTICAL VELOCITY
FOR 30 JUN 82 CASE:
SENSITIVITY TO RADIUS OF PRECIPITATION SHAFT
R=750M
R=350M
R=1500M
R=3000M
R=5000M
1000
900
800
700
600
500
400
300
200
100
0
HEIGHT (M)
-20
-15
-10
-5
0
W (M/S)


VERTICAL PROFILES OF PRESSURE DEVIATION
FOR 30 JUN 82 CASE:
SENSITIVITY TO RADIUS OF PRECIPITATION SHAFT
HEIGHT (M)
1000
900
800
700
600
500
400
300
200
100
0
R=250M
R=750M
R=1500M
R=3000M
R=5000M
0
1
2
3
P (MB)

DRY MICROBURST SIMULATION: 14 JULY 82 DEN SOUNDING – MODIFIED FOR 500 M DEEP STABLE LAYER AT GROUND





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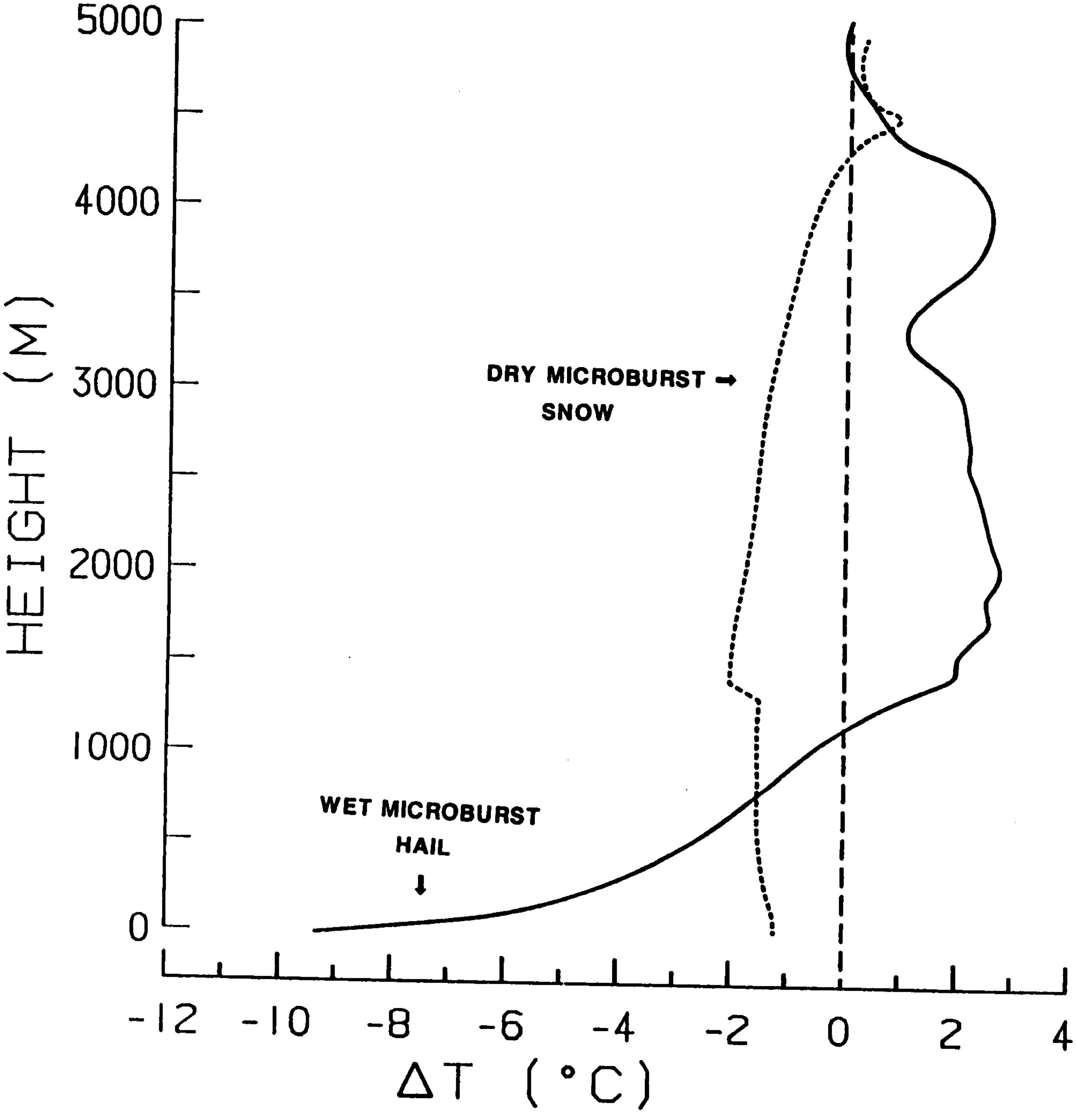
COMPARISON OF AXIAL PROFILES FOR TEMPERATURE DEVIATION FOR BOTH HAIL AND SNOW CASES

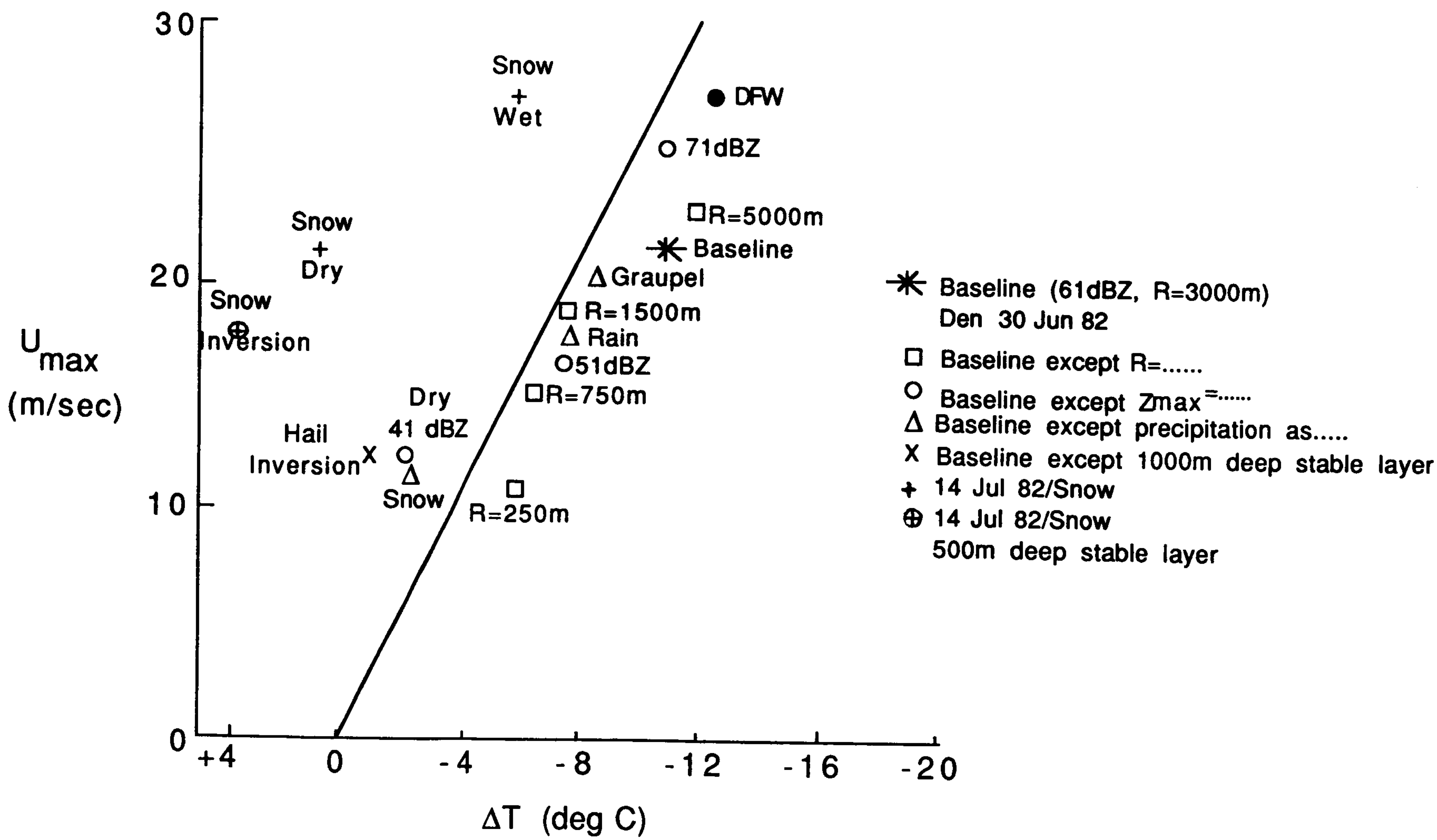


RELATION BETWEEN MAXIMUM TEMPERATURE DROP AND PEAK OUTFLOW SPEED

$$\boxed{\begin{array}{c}\mathrm{UMAX} = 2.5\ \Delta T \\ \text{(MKS UNITS)}\end{array}}$$

DOES NOT HOLD FOR EITHER: SNOW CASES, DRY MICROBURSTS, OR IF GROUND BASED STABLE LAYERS ARE PRESENT

SENSITIVITY STUDIES: MAXIMUM TEMPERATURE DROP VS. MAXIMUM OUTFLOW SPEED



CONCLUSIONS

STRUCTURE

O TOP OF MICROBURST DOWNDRAFT NEAR MELTING LEVEL

O RING VORTEX DESCENDS FOLLOWING LEADING EDGE OF PRECIPITATION SHAFT THEN EXPANDS OUTWARD FOLLOWING LEADING EDGE OF BURST FRONT

O STRONGEST OUTFLOW SPEEDS OCCUR WITHIN 100M ABOVE GROUND AND ASSOCIATED WITH RING VORTEX

O PEAK HORIZONTAL WINDS ABOUT 4 MIN AFTER INITIAL PRECIPITATION AT GROUND

O PEAK HORIZONTAL WIND SHEAR PRIOR TO PEAK OUTFLOW INTENSITY

O PEAK PRECIPITATION RATE AND VERTICAL VELOCITY AT TIME OF PEAK HORIZONTAL WIND SHEAR

O DEEPEST OUTFLOW WITHIN BURST FRONT HEAD

CONCLUSIONS

SENSITIVITY

- O INTENSITY OF MICROBURST DEPENDS UPON:
  1. ENVIRONMENT TEMPERATURE AND HUMUDITY PROFILE
  2. DIAMETER OF MICROBURST DOWNDRAFT
  3. TYPE OF PRECIPITATION
  4. PRECIPITATION RATE
- O DEPTH OF OUTFLOW LAYER DEPENDS PRIMARILY UPON DIAMETER OF DOWNDRAFT
- O DRY MICROBURST MORE LIKELY PRODUCED BY PRECIPITATION INITIALLY FALLING AS SNOW
- O INTENSE MICROBURSTS PRODUCED BY SNOW FALLING WITHIN CLASSICAL DRY MICROBURST ENVIRONMENT
- O RELATIONSHIP BETWEEN OUTFLOW SPEED AND TEMPERATURE DROP FOR SOME OF THE WET-MICROBURST CASES

FUTURE WORK

- O 3-D SIMULATIONS OF INTERACTING MULTIPLE MICROBURSTS
- O 3-D SIMULATIONS OF MICROBURSTS WITHIN VERTICALLY SHEARED ENVIRONMENTS

N88-17618

RESPONSE OF WIND SHEAR WARNING SYSTEMS TO TURBULENCE WITH IMPLICATION OF NUISANCE ALERTS

DR. ROLAND L. BOWLES
NASA Langley
FltMD

TURBULENCE RESPONSE OF WIND SHEAR WARNING SYSTEMS

STUDY OBJECTIVE

PREDICT THE INHERENT TURBULENCE RESPONSE CHARACTERISTICS OF CANDIDATE WIND SHEAR WARNING SYSTEM CONCEPTS AND ASSESS POTENTIAL FOR NUISANCE ALERTS

FACTORS CONSIDERED

- O DEVELOPMENT OF ANALYSIS TOOLS
- O SYSTEM CONCEPT BASED ON F-FACTOR HAZARD INDEX
- O TURBULENCE INDUCED THRESHOLD EXCEEDANCE PROBABILITY
- O HAZARD THRESHOLD VS. SYSTEM LATENCY TRADE STUDY

WIND SHEAR "HIT"

O HAZARD INDEX: $F = \frac{\dot{W}_x}{g} - \frac{W_h}{V}$

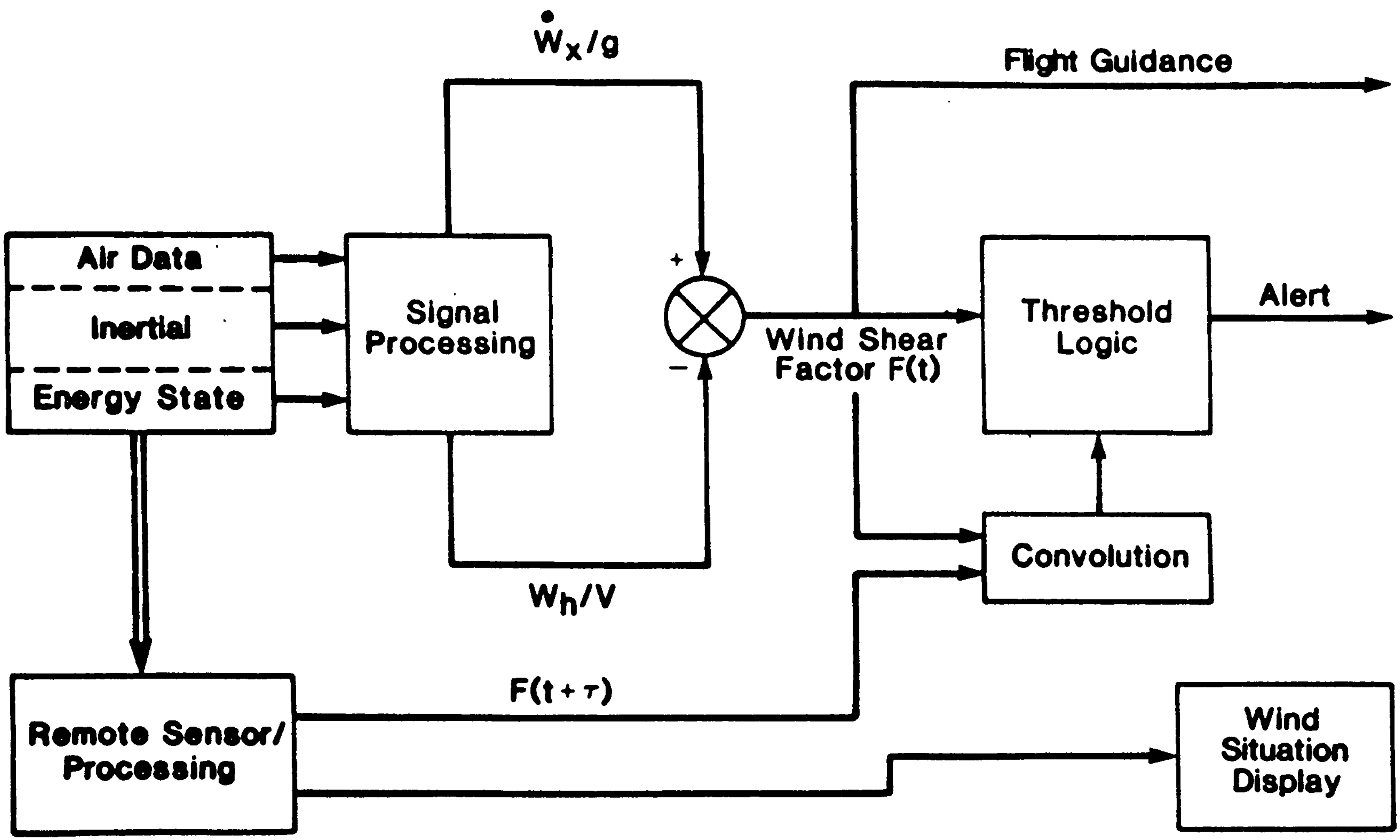
Q ALERT AND WARNING THRESHOLD DETERMINED BY MAX. PERMISSIBLE F IN RELATION TO AVAILABLE AIRCRAFT PERFORMANCE CAPABILITY

O F IS A SENSED QUANTITY

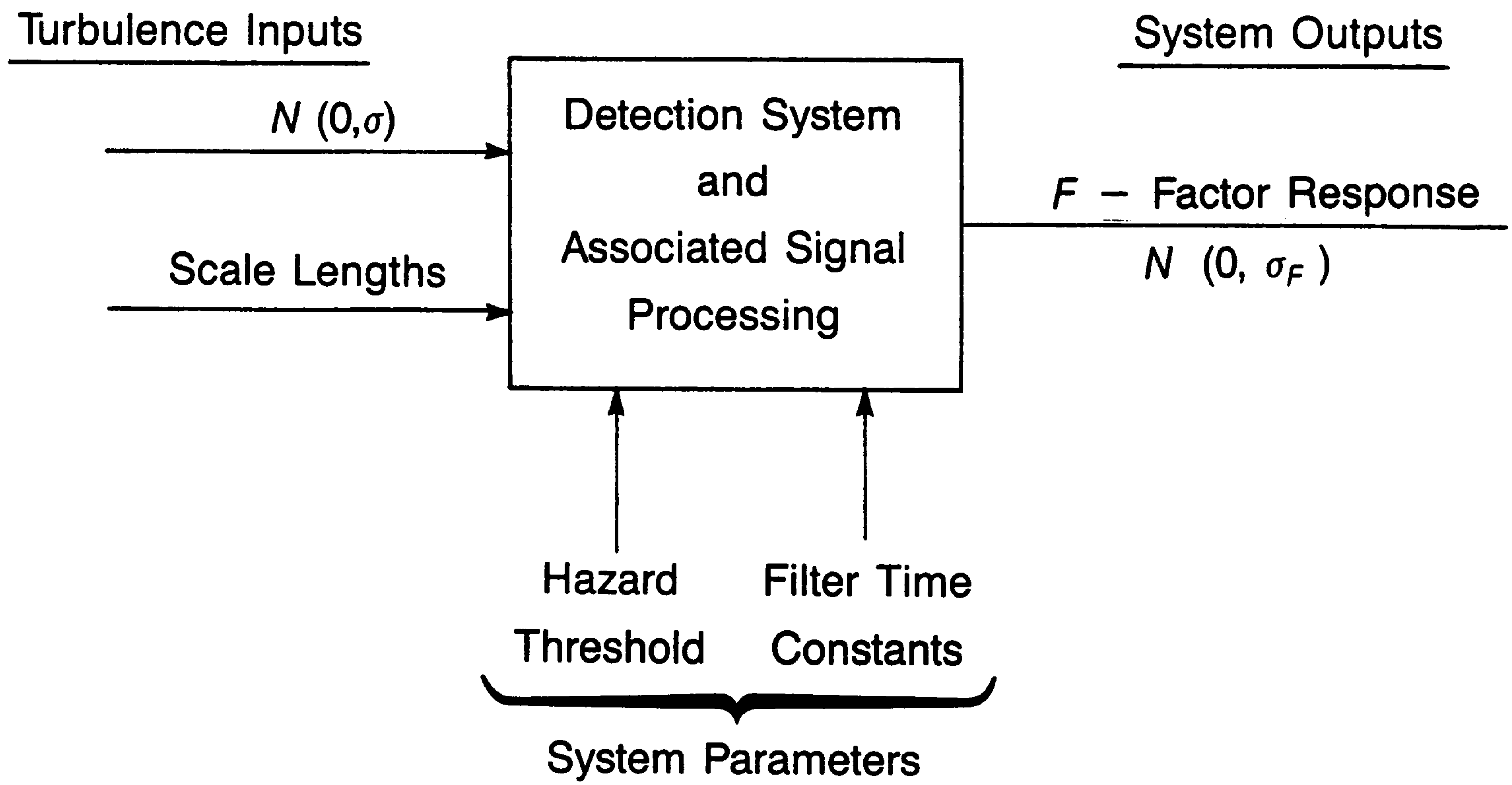
O HAZARD INDEX APPLICABLE TO BOTH INSITU–SENSED INFORMATION AND REMOTE–SENSED WIND SHEAR

FUSION OF PRESENT POSITION AND PREDICTIVE INFORMATION

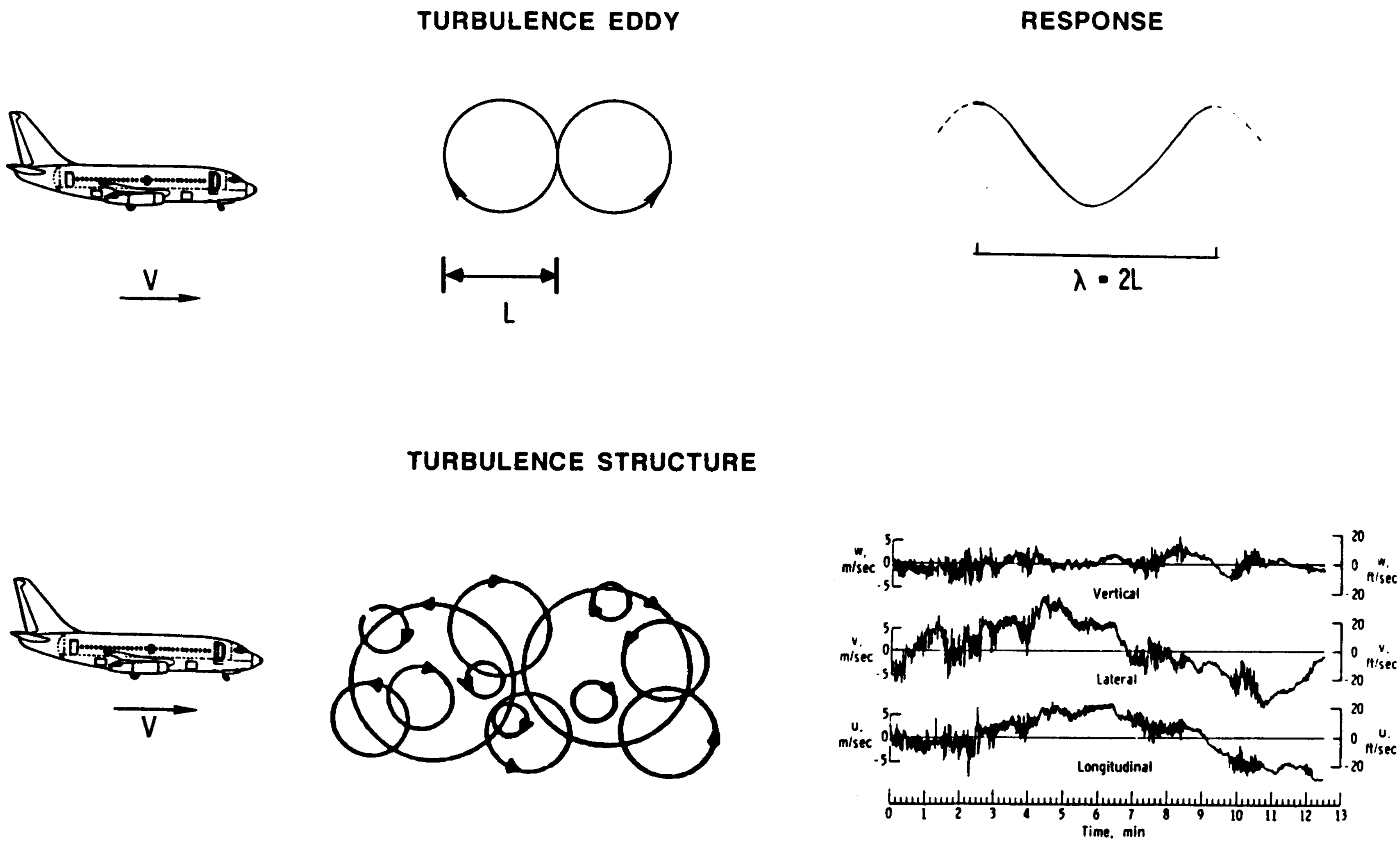
SYSTEM CONCEPT



TECHNICAL APPROACH



PHYSICAL MODEL



MATHEMATICAL MODEL

- $F = \dot{w}_{x/g} - w_{h/v}$
- w_x ; w_h Random Uncorrelated Turbulence
- $\sigma_F^2 = \sigma_{\dot{w}x/g}^2 + \sigma_{wh/v}^2 \qquad \sigma^2 = E[(x - \bar{x})^2], \bar{X} = E[x] = 0$
- $\sigma_F^2 = \int_{-\infty}^{\infty} (\phi_{\dot{w}x/g} + \phi_{wh/v})\, d\Omega$
- Dryden Turbulence Model Selected
- Rate Estimator

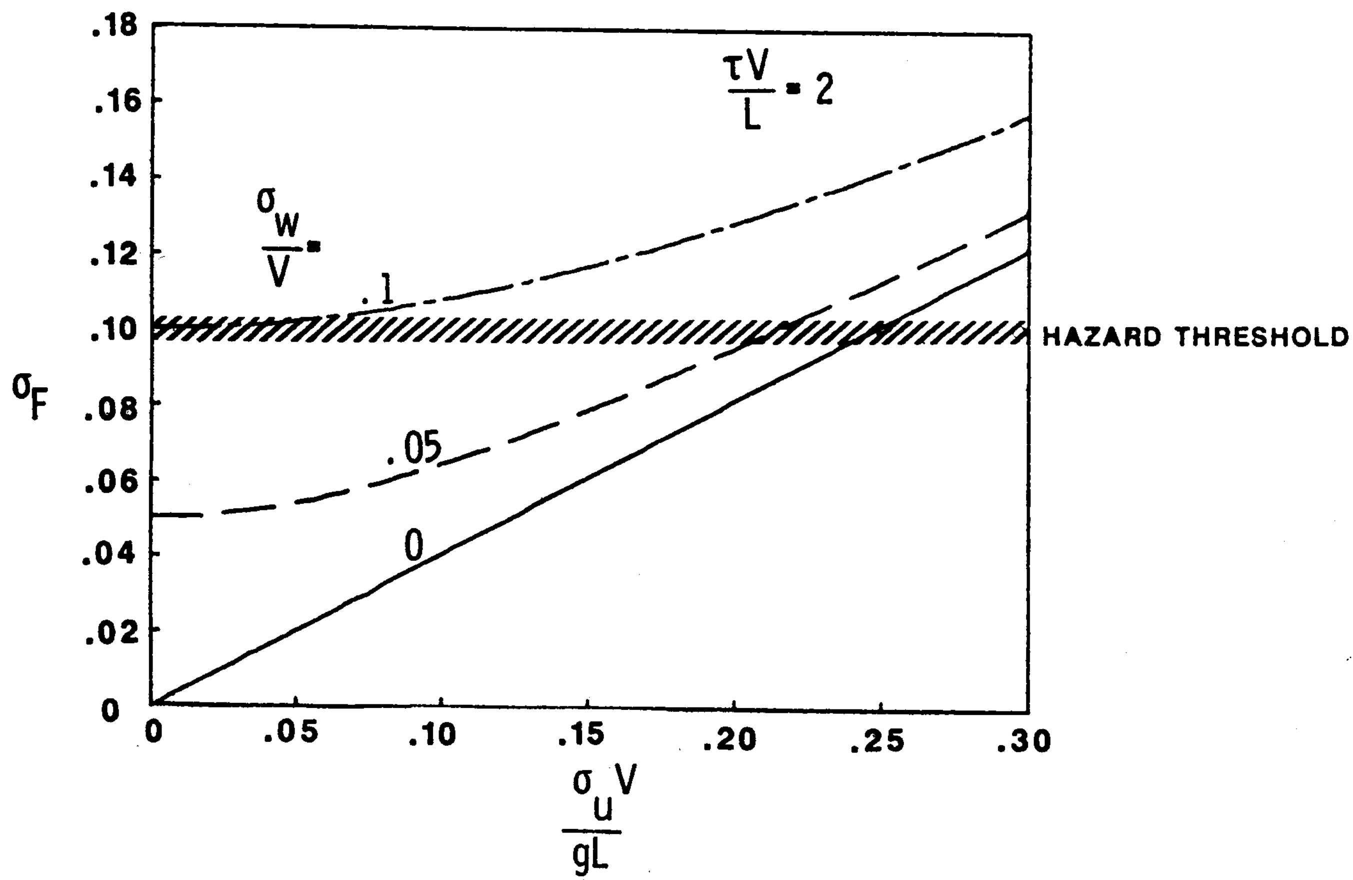
F–FACTOR ROOT MEAN SQUARE TURBULENCE RESPONSE

$$\sigma_F = \frac{\sigma_W}{V}\left[\frac{V^2}{\mu^2}\left(\frac{\sigma_U}{\sigma_W}\right)^2 + 1\right]^{1/2}$$

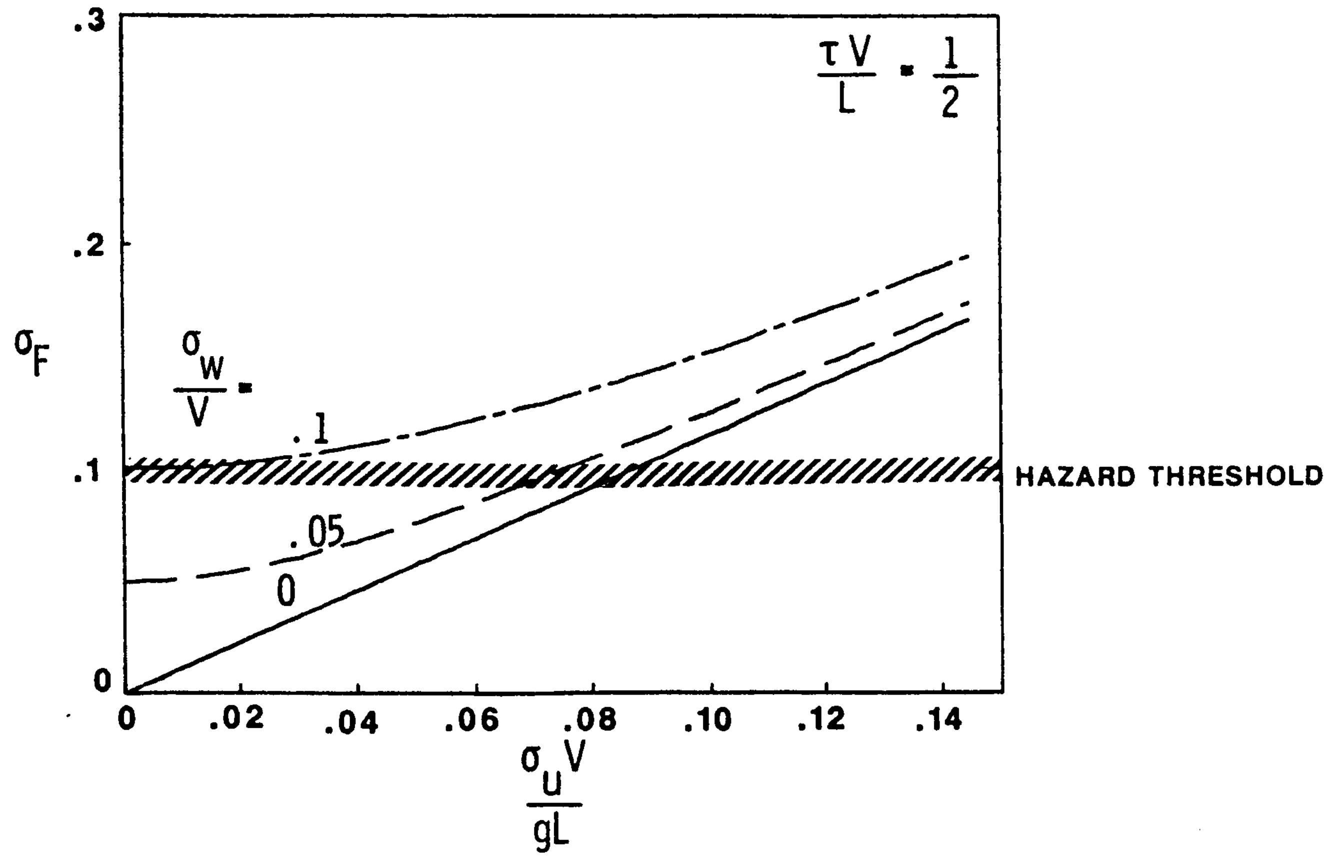
$$\mu = g\,\tau\,\sqrt{1 + L / V\tau}$$

$g =$ 32.2 ft/sec^2
$V =$ Airspeed ft/sec
$\tau =$ Rate Estimator Time Constant sec.
$L =$ Longitudinal Turbulence Scale Length ft
$\sigma_U =$ RMS Longitudinal Turbulence Intensity ft/sec
$\sigma_W =$ RMS Vertical Turbulence Intensity ft/sec

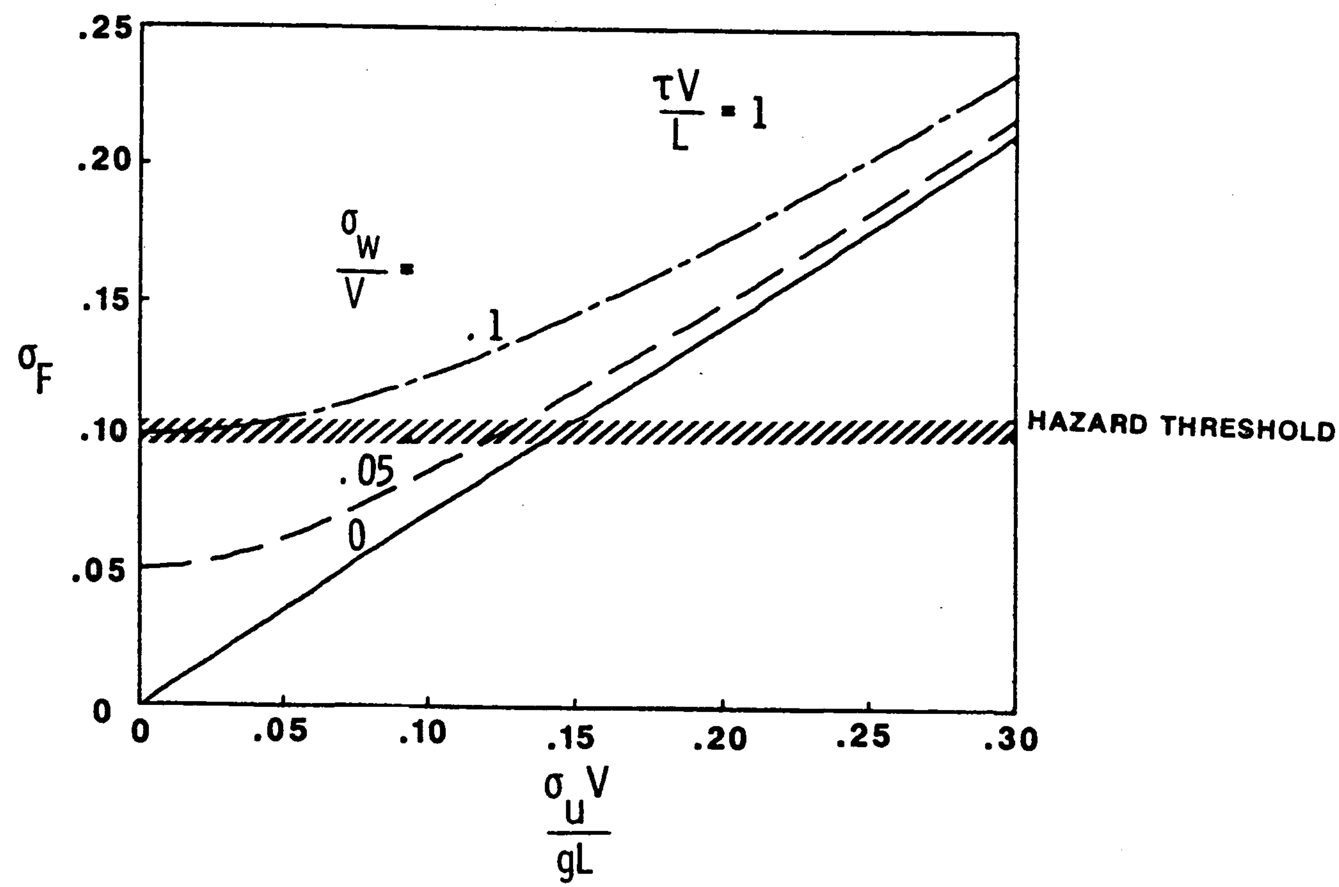
STANDARD DEVIATION OF F-FACTOR DUE TO TURBULENCE



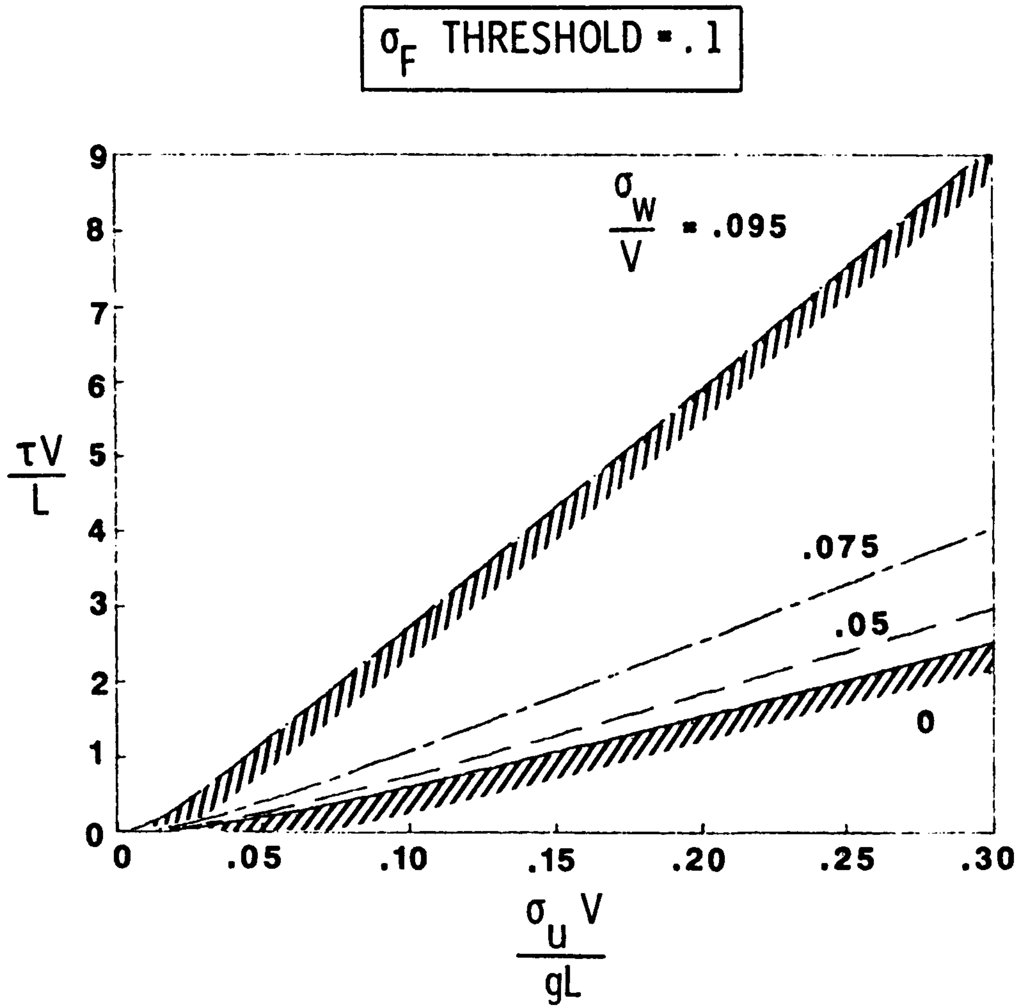
STANDARD DEVIATION OF F-FACTOR DUE TO TURBULENCE



STANDARD DEVIATION OF F-FACTOR DUE TO TURBULENCE

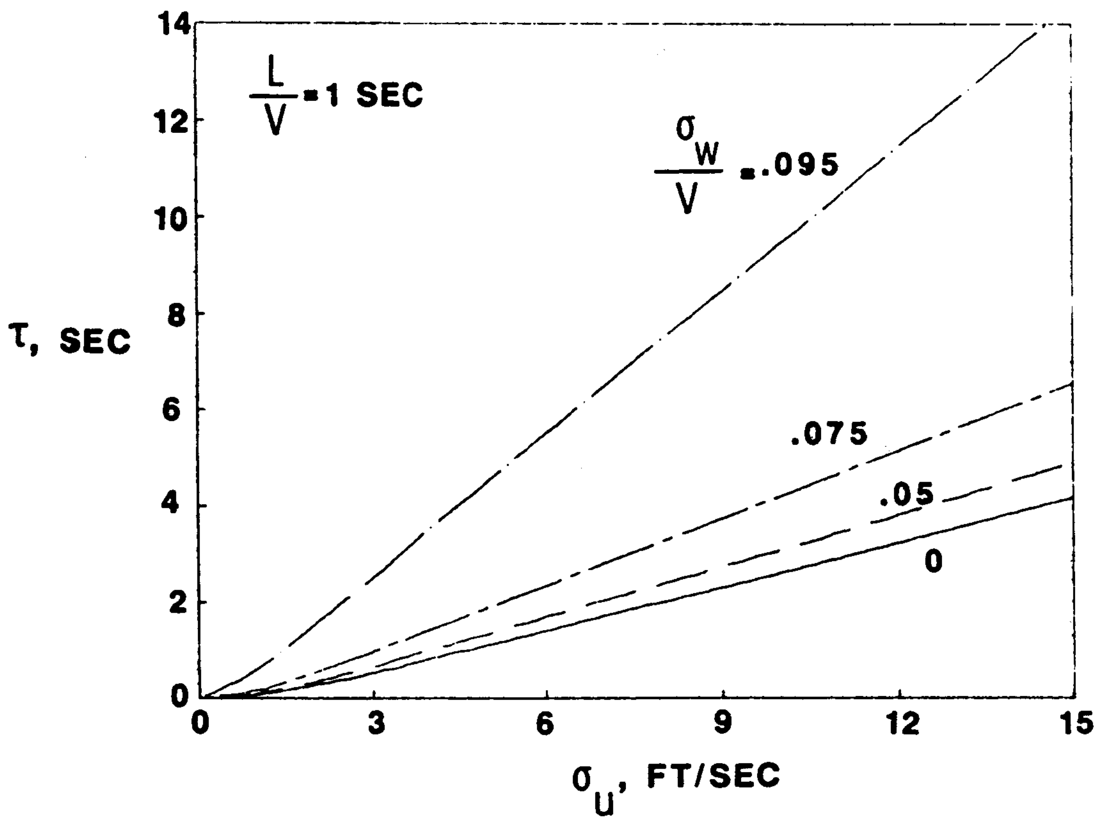


REQUIRED $\frac{\tau V}{L}$ BOUNDARIES TO MAINTAIN THRESHOLD INTEGRITY



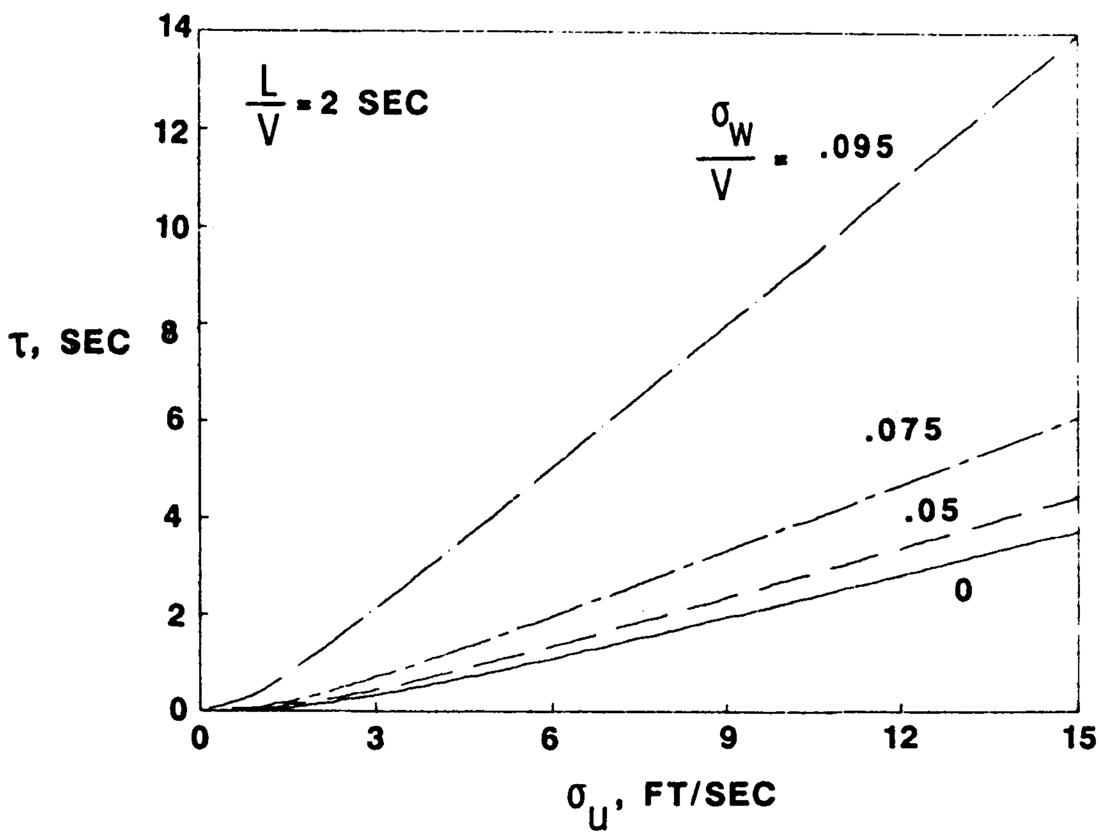
TAU REQUIRED TO SATISFY THRESHOLD CRITERIA

UNFILTERED VERTICAL CHANNEL



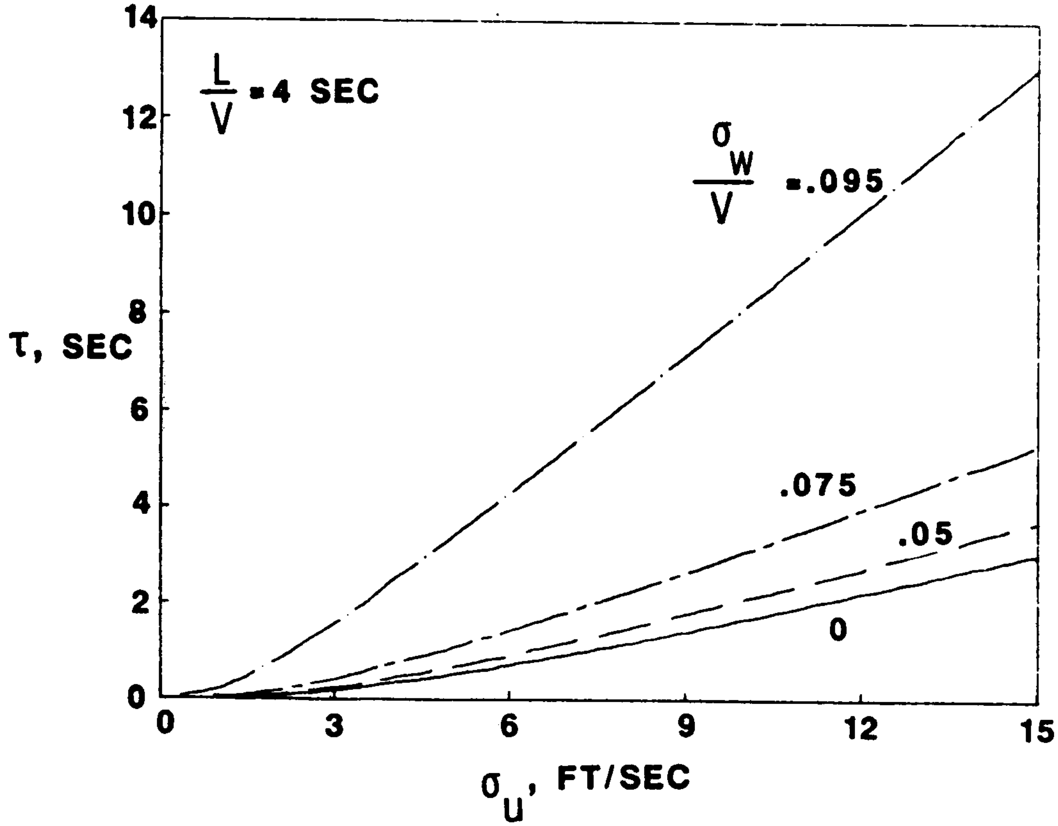
TAU REQUIRED TO SATISFY THRESHOLD CRITERIA

UNFILTERED VERTICAL CHANNEL



TAU REQUIRED TO SATISFY THRESHOLD CRITERIA

UNFILTERED VERTICAL CHANNEL



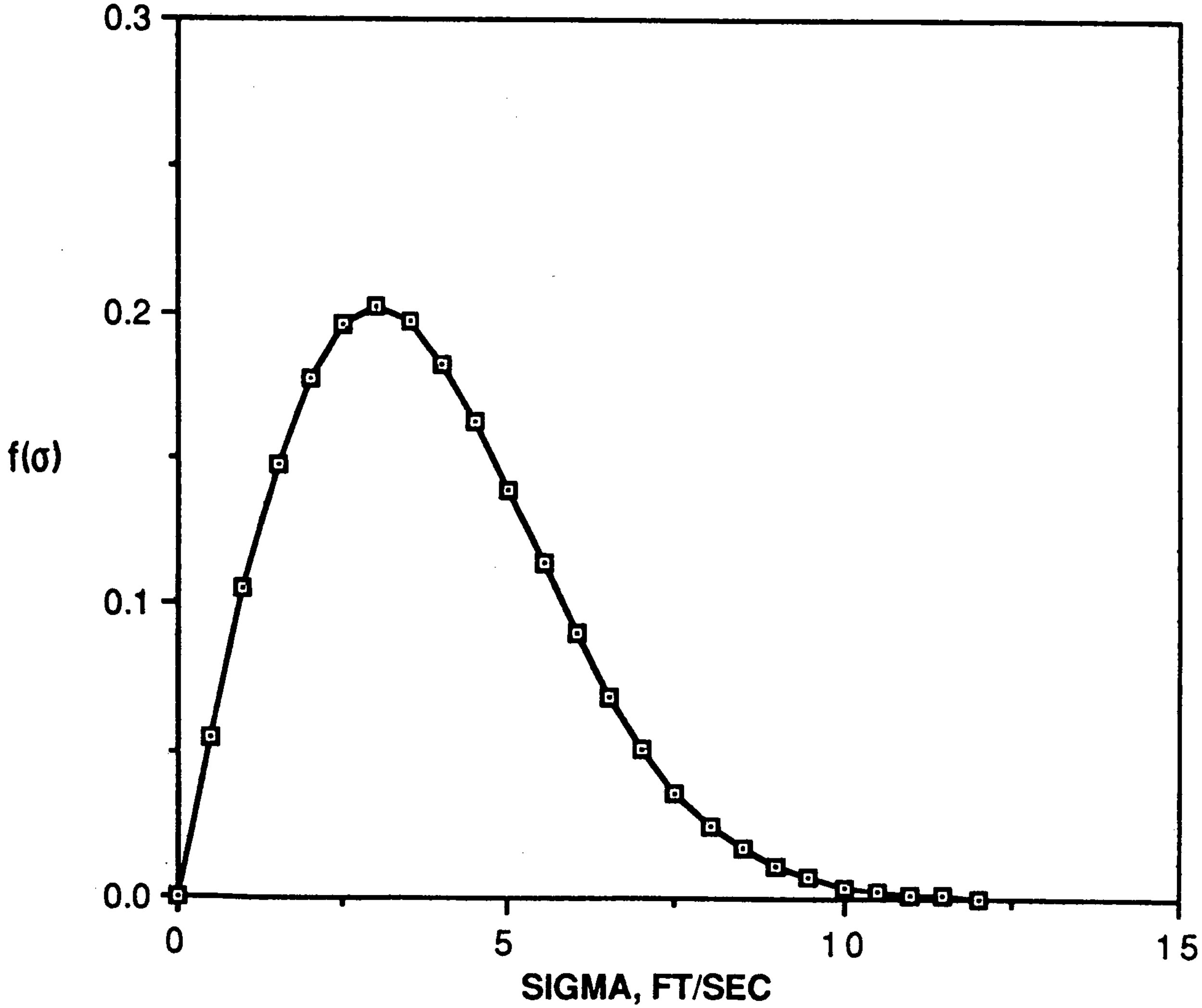
F–FACTOR EXCEEDANCE PROBABILITY ONCE TURBULENCE IS ENCOUNTERED

$$P(F \geq Z) = \int_0^\infty P\,(\,F \geq Z \,/\, \sigma_F\,(\,\sigma\,))\; f\,(\sigma)\; d\sigma$$

$$P\,(\,F \geq Z\,) = f\,(\,\tau,\, Z,\, V,\, L\,)$$

$\boxed{\text{Provides Basis for Parametric Trade Studies}}$

RMS GUST VELOCITY PROBABILITY DENSITY (NEUTRAL LAPSE RATE)



TURBULENCE CONDITIONS

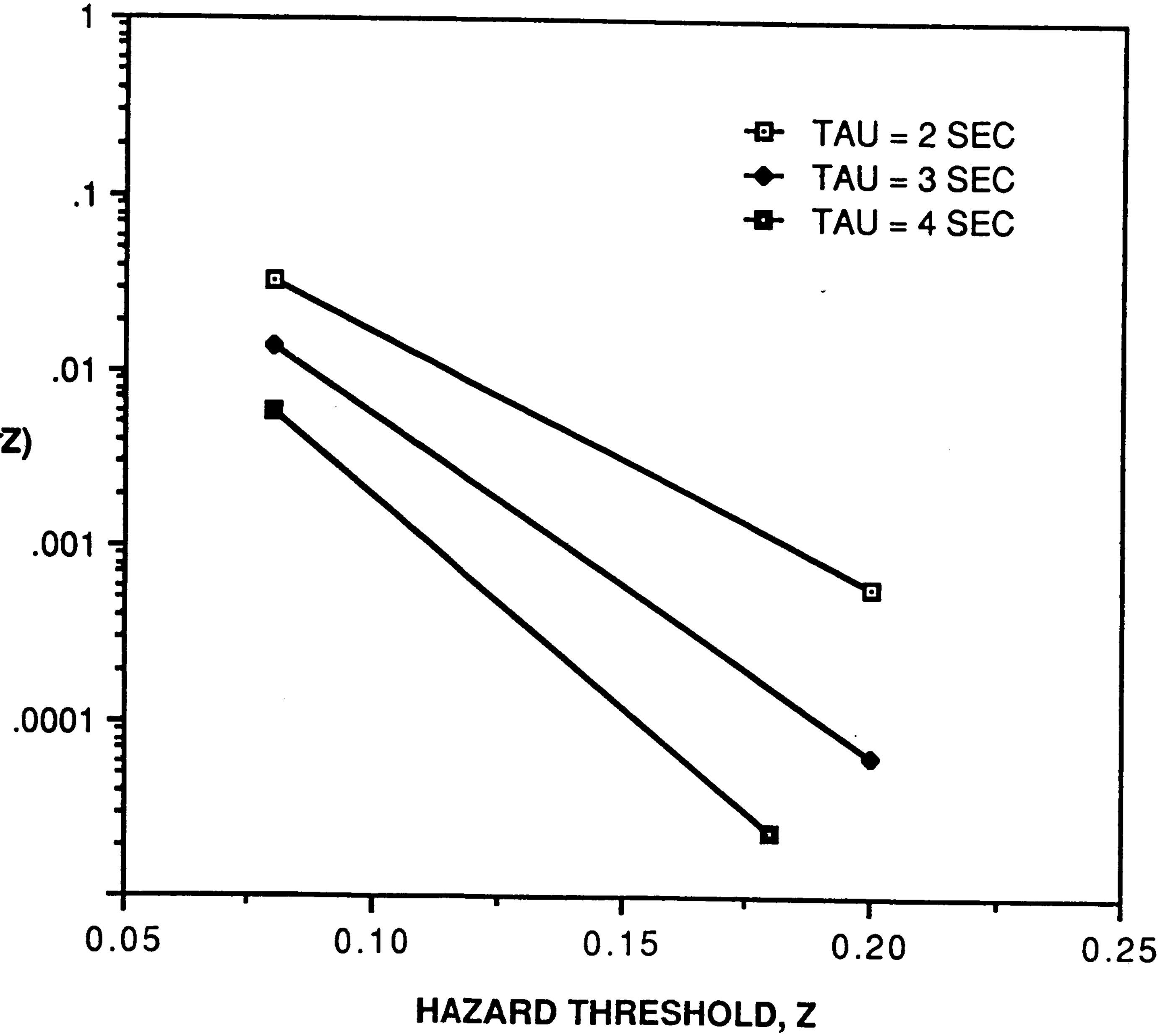
$$\sigma_u = \left(\frac{\sigma_u}{\sigma_w}\right) \sigma_w$$

Application:

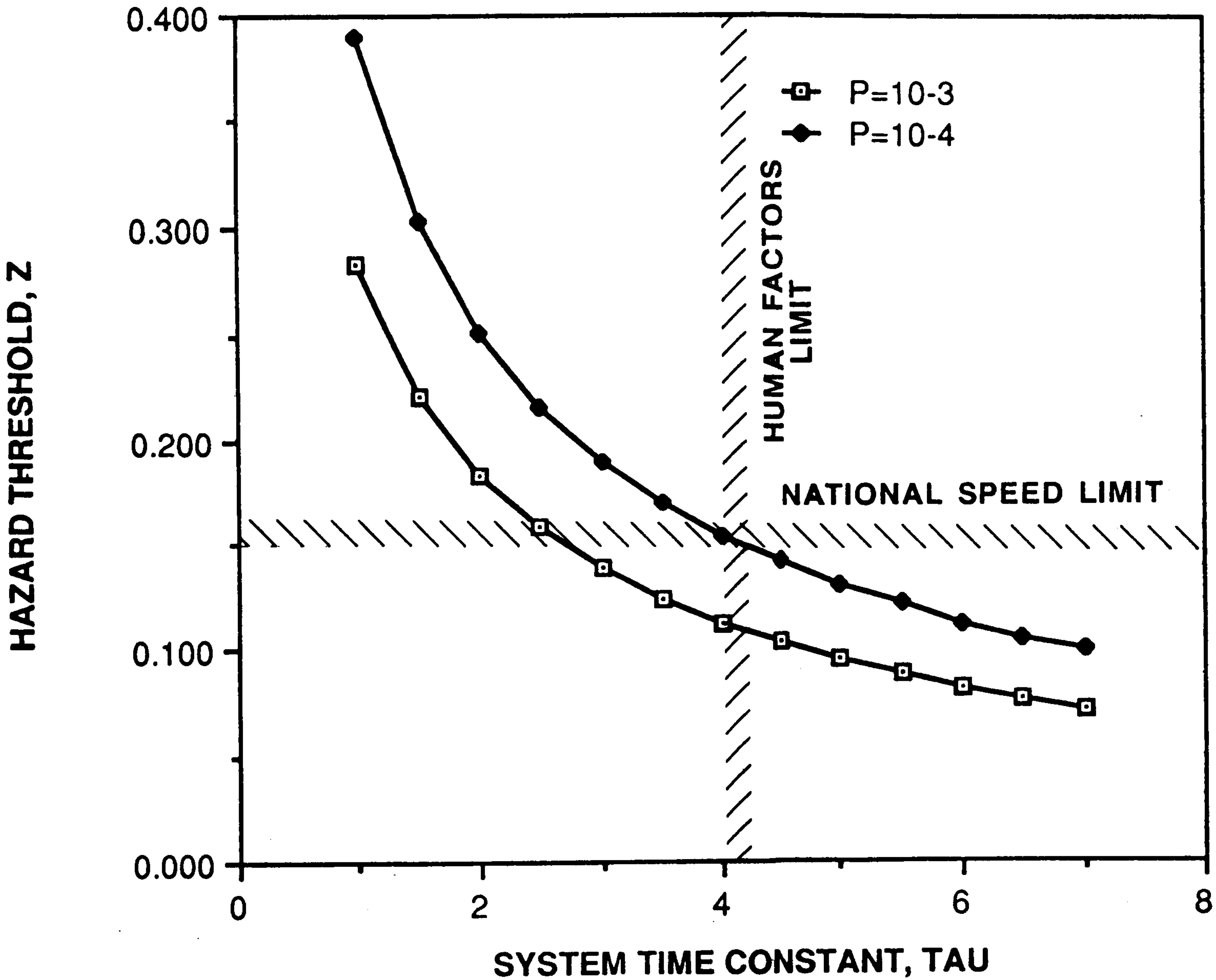
$\frac{\sigma_u}{\sigma_w} = 1$ Altitude $\geq$ 1000 ft (Isotropic)

$\frac{\sigma_u}{\sigma_w} = 2$ Altitude $<$ 1000 ft

F EXCEEDANCE PROBABILITY DUE TO TURBULENCE



HAZARD THRESHOLD VS. RATE ESTIMATOR TIME CONSTANT



SUMMARY REMARKS

- O DEVELOPED TECHNIQUES TO QUANTIFY TURBULENCE INDUCED WIND SHEAR THRESHOLD EXCEEDANCES

- O EXAMINED THRESHOLD VS. SYSTEM TIME CONSTANT TRADE TO ACHIEVE A GIVEN PERFORMANCE LEVEL IN TURBULENCE

- O EXTENSION OF ANALYSIS TO OTHER ATMOSPHERIC STABILITY CONDITIONS IS UNDERWAY

- O TECHNIQUES MAY PROVE USEFUL AND COST EFFECTIVE DURING SYSTEM DESIGN AND CERTIFICATION

QUESTIONS AND ANSWERS

JIM EVANS (MIT Lincoln Labs) - I guess I have a, you know, certainly tearing through these calculations gives some useful insight but I have a, I guess a real question as to whether this turbulence model really makes sense. In the regime that you are talking about really--in approach in landing, for example--where you are focusing on the region below 1000 feet in landing--you are focusing on takeoff at a much lower altitude. Does the turbulence model itself really hold up at such low altitudes--where obviously the surface is going to cause major breakdowns in the usual assumptions about isotropics. My model is a homogeneous turbulence model and people use it because they don't have anything better to work from, but that close to the surface I'm really wondering whether it doesn't make sense to just go at it, if you like, using actual experimental data. For example, this past summer in Denver, they found that one element of it is thermals. Now thermals don't fit into really what they consider as turbulence.

ROLAND BOWLES (NASA LaRC) - We have a set of those data for an unstable and yet convective environment. You've got a good point. Let me point out, there is an awful lot known about low altitude turbulence. From the mid-sixties through the late-seventies, the Air Force conducted an extensive in-flight measurements program looking at low altitude turbulence with thousands upon thousands of penetrations.

JIM EVANS (MIT Lincoln Labs) - You mean Rough Rider out in Oklahoma?

ROLAND BOWLES (NASA LaRC) - No, LOCAT, not Rough Rider. Rough Rider was a program done out there for other reasons. Secondly, the industry has to certify automatic landing systems and other things, using turbulence models at low altitudes. There is a great deal known. Nor am I using isotropic turbulence, if you look at the charts on the handouts, under 1000 ft. there are nonisotropic properties, implemented in a way that we have done before. Dick Bray may want to comment on this. We have done this in handling qualities work for years. But I am not departing from the "garden-variety-way" we've done handling qualities automatic landing system certifications. What I am doing is trying to apply that knowledge into this particular area to get some insight on how things trade. I must point out that--recall--there are 6% of the airplanes out there today, flying with some kind of wind shear equipment. The industry is having to wrestle with these kind of trades. (And maybe somebody from Boeing or Safe Flight or somebody else would like to follow up.) In other words, we don't have time to develop a new turbulence model. Obviously, we don't know what we desire to know about low altitude turbulenece, but I think we know enough to treat it probabalistically. As we approach the question of information fusion on the flight deck: How we are going to access information from LLWAS and TDWR and smart airplanes flying around with their own sources of information? We've got to sit back and take a good hard look at: (A) Are we defining threat in the same way? (B) Is the LLWAS threat and the TDWR threat, and what the airplane sees (whether it has a reactive system or forward look system) is that data consistent; and (C) Are we going to have airplane warning systems going off with LLWAS saying nothing or TDWR saying nothing? (Or visa versa?) That does get into a bit of what we do know about the lowest 3000 feet of the atmosphere, and how both the airplane side of the industry and the ground base side are working together on this problem: there is an information fusion question--of pretty significant magnitude--laying right around the corner.

JOHN HANSMAN (MIT) - If you look at your hazard threshold versus rate estimator time constant plot, it seems to me that the real limit is the human factors limit that you have thrown in there at 4 seconds? The question is, where does that come from?

ROLAND BOWLES (NASA LaRC) - What I am saying is if you can put people in a training device and if annunciation of warning comes too late, or if they come in a nuisance form too often, the system will not be accepted. There are strong lessons learned from ground proximity warning in this area.

JOHN HANSMAN - My only comment is that (cut off)

ROLAND BOWLES (NASA LaRC) - I did this as a step response (that I didn't show here) that if you are exceeding a preset threshold, you probably don't want to wait more than 2 to 3 time constants before you tell the pilot that the smart system has decided you have a potential hazard.

JOHN HANSMAN - The point that I am making is that it seems to me that the setting of that time constant (the maximum time constant you can live with) is really the parameter that determines the exceedance probability you are going to get. If you were to decide you could only live with 2 seconds from a human factors standpoint, then you would limit yourself to 10 to the -2.

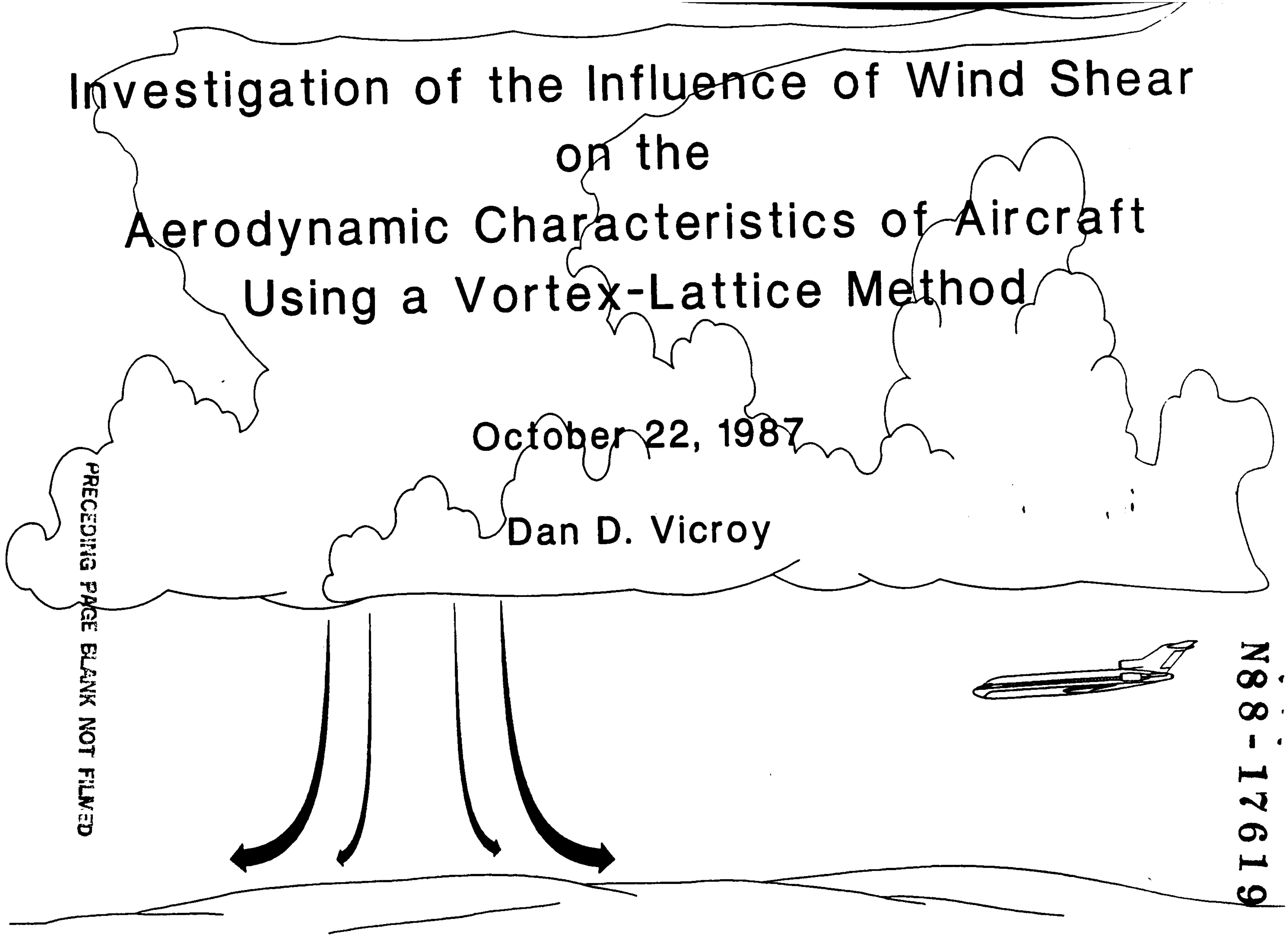
ROLAND BOWLES (NASA LaRC) - That may very well be the dominating factor, but there is also latitude here on the threshold. What you are willing to do with the new twin airplanes with big engines, is quite different than what you would do with an old four engine airplane. [Pointing to viewgraph] I don't think you are bracketted, in here, on how low you can go and on how high you want to go. Then the time constant becomes the dominating factor in the overall design.

N88-17619

Investigation of the Influence of Wind Shear on the Aerodynamic Characteristics of Aircraft Using a Vortex-Lattice Method

October 22, 1987

Dan D. Vicroy



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Abstract

Wind shear is considered by many in the aviation community to be one of the major safety issues facing their industry. The Federal Aviation Administration has addressed this problem through an Integrated Wind Shear Program Plan which incorporates the expertise of industry, universities, and various government agencies such as the National Aeronautics and Space Administration, the National Oceanic and Atmospheric Administration and the Department of Defense. The plan is aimed at reducing the hazard of low-level wind shear through improved training and operating procedures, wind shear detection systems and flight guidance systems.

The flight simulator is a important tool used to address the airborne aspects of the wind shear program. The fidelity of the analytical models which represent the airplane and the atmosphere within the flight simulators is therefore of critical importance. The bulk of the simulation and analytical studies conducted to date have concentrated on determining the effect of the changing free-stream velocity vector on the airplane performance, and on developing higher fidelity wind shear models. Very little work has been done to determine the effect of the spatial variation of the wind field about the airplane on the airplane's aerodynamic characteristics. It is important that these aerodynamic effects are characterized and presented in a form which can be incorporated into research and training simulators. The research presented in this paper is a preliminary effort to address this need.

The objective of this study was to investigate and characterize the aerodynamic effect of shear flow through a series of sensitivity studies of the wind velocity gradients and wing planform geometry parameters. The wind shear effect was computed using a modified vortex-lattice computer program and characterized through the formulation of wind shear aerodynamic coefficients. The magnitude of the aerodynamic effect was demonstrated by computing the resultant change in the aerodynamics of a conventional wing and tail combination on a fixed flight path through

a simulated microburst.

The results of this study indicate that a significant amount of the control authority of the airplane may be required to counteract the wind shear induced forces and moments in the microburst environment. It is important to note that the forces and moments presented in this report are only due to the spatial variation of the wind field, and are not currently accounted for in today's research and training simulators.

Outline

- [x] Introduction
- [ ] Modification of Vortex-Lattice Algorithm
  - Spatially Varying Wind Field
  - Boundary Condition
  - Force and Moment Equations
- [ ] Program Checkout and Validation
- [ ] Shear Coefficient Development
- [ ] Sensitivity Studies
  - Vortex-Lattice Distribution
  - Planform Geometry
  - Wing and Stabilizer Combination
- [ ] Concluding Remarks

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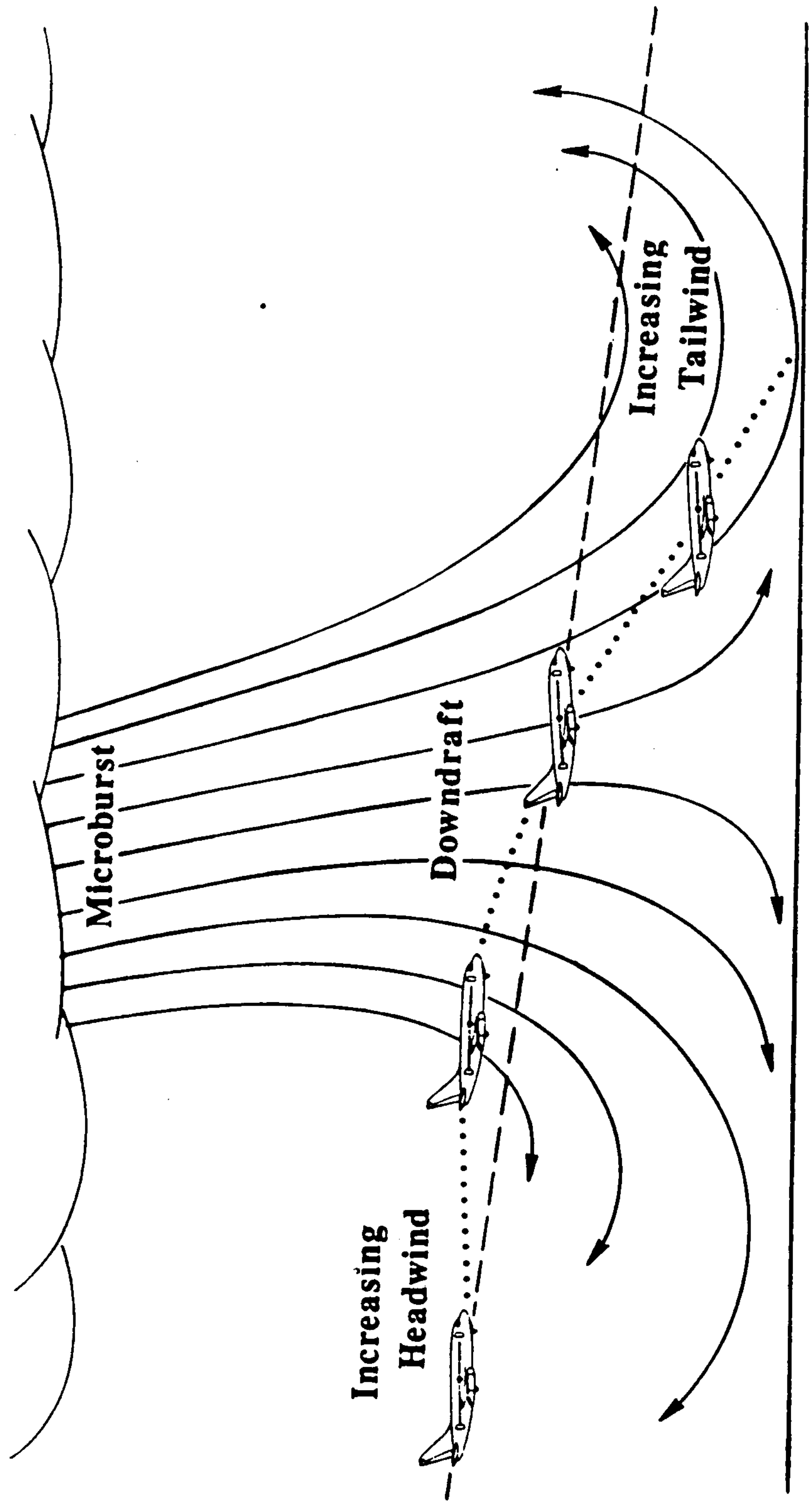
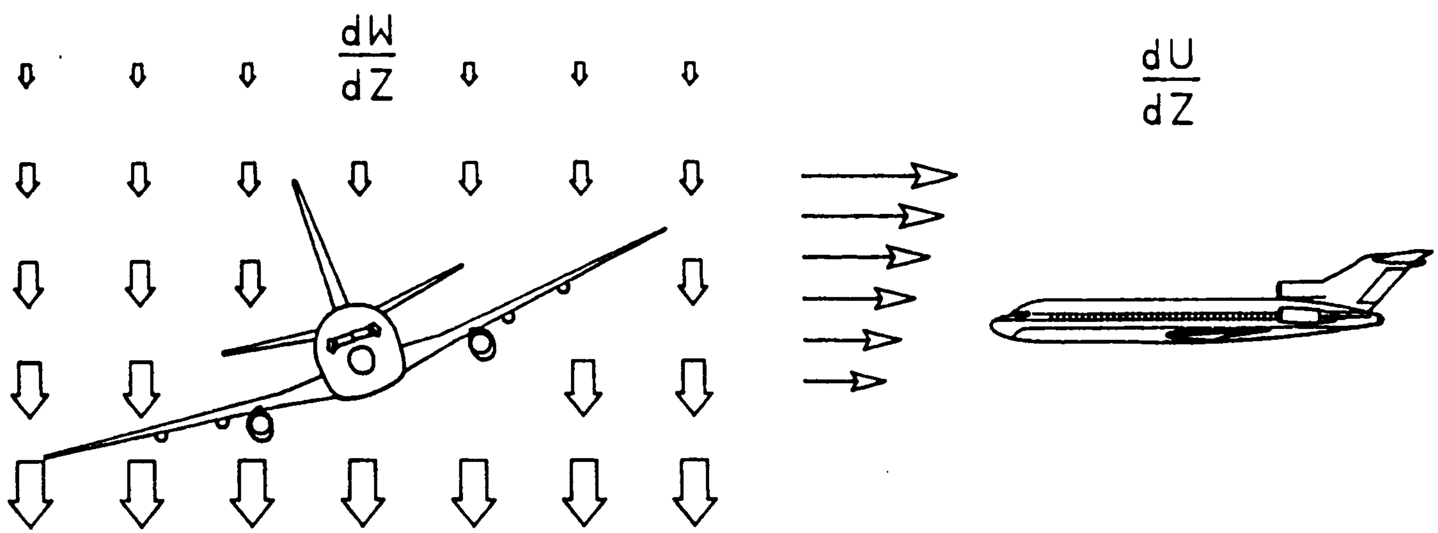

Microburst
Downdraft
Increasing
Tailwind
Increasing
Headwind

Research Objective

Investigate and characterize the aerodynamic effect of shear flow through a series of sensitivity studies of the spatial wind velocity gradients and wing planform geometry parameters



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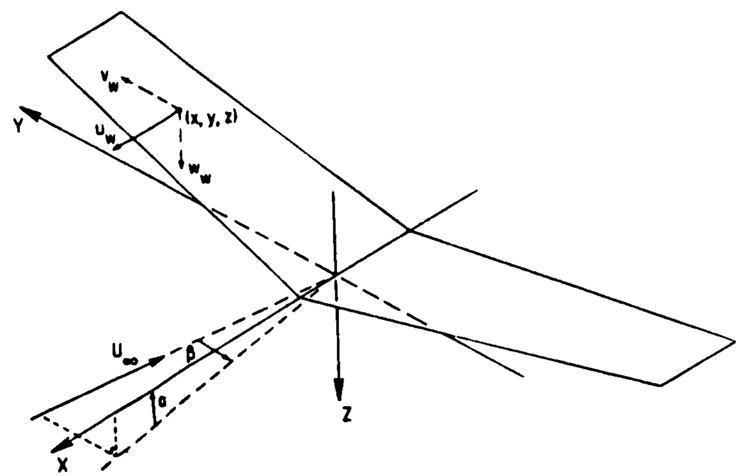
Defining Wind Field



Uniform Flow

$$\begin{pmatrix} u_w \\ v_w \\ w_w \end{pmatrix} = -U_\infty \begin{pmatrix} \cos\alpha\cos\beta \\ \sin\beta \\ \sin\alpha\cos\beta \end{pmatrix}$$

Nonuniform Flow

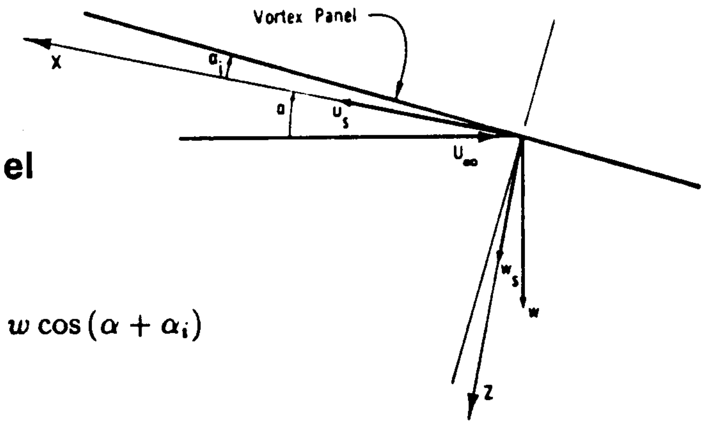
$$\begin{pmatrix} u_w \\ v_w \\ w_w \end{pmatrix} = \begin{pmatrix} u_s \\ v_s \\ w_s \end{pmatrix} - U_\infty \begin{pmatrix} \cos\alpha\cos\beta \\ \sin\beta \\ \sin\alpha\cos\beta \end{pmatrix}$$

where:

$$\begin{pmatrix} u_s \\ v_s \\ w_s \end{pmatrix} \equiv \begin{pmatrix} \frac{\partial u_s}{\partial x} & \frac{\partial u_s}{\partial y} & \frac{\partial u_s}{\partial z} \\ \frac{\partial v_s}{\partial x} & \frac{\partial v_s}{\partial y} & \frac{\partial v_s}{\partial z} \\ \frac{\partial w_s}{\partial x} & \frac{\partial w_s}{\partial y} & \frac{\partial w_s}{\partial z} \end{pmatrix} \begin{pmatrix} x \\ y \\ z \end{pmatrix}$$

Boundary Condition

Boundary Condition:



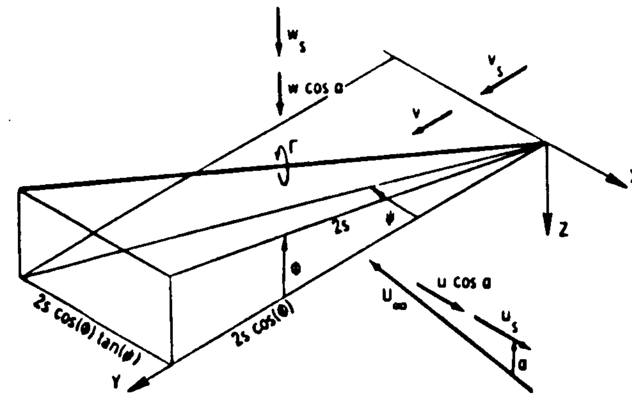
No flow through the panel

$$U_\infty \sin(\alpha + \alpha_i) - u_s \sin\alpha_i = w_s \cos\alpha_i + w \cos(\alpha + \alpha_i)$$

Force and Moment Equations

Lift of line vortex element per unit span

$$\tilde{\ell} = \rho V \Gamma$$



Spanwise bound vortex element

$$\ell_s = F_{x_s} \sin\alpha - F_{z_s} \cos\alpha$$

$$d_s = -F_{x_s} \cos\alpha - F_{z_s} \sin\alpha$$

where

$$F_{x_s} = \rho \Gamma 2s \cos\phi \left[U_\infty \sin\alpha - u \sin\alpha - w \cos\alpha - w_s - k\,(v + v_s) \tan\phi\right]$$

$$F_{y_s} = \rho \Gamma 2s \cos\phi \left[(U_\infty \cos\alpha - u \cos\alpha - u_s + w \sin\alpha) \tan\phi + k\,(v + v_s) \tan\psi\right]$$

and $k = +1$ (right side); -1 (left side)

Sideforce

$$F_{z_s} = \rho \Gamma 2s \cos\phi \left[-U_\infty \cos\alpha + u \cos\alpha - w \sin\alpha + u_s + (-U_\infty \sin\alpha + u \sin\alpha + w_s + w \cos\alpha) \tan\psi\right]$$

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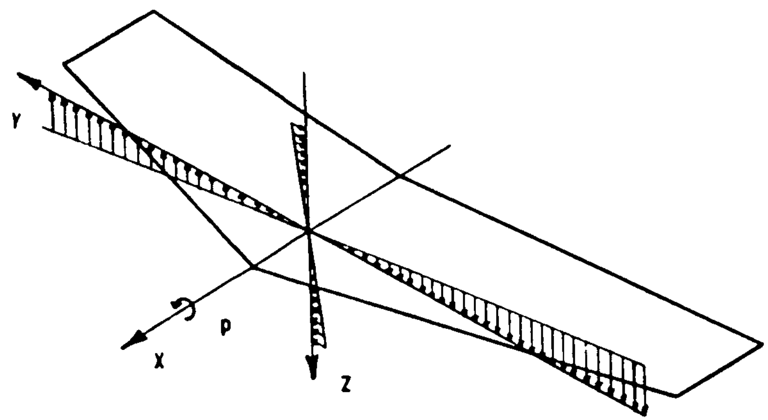
Rotary Motion

Rolling

$$p = \frac{1}{2}\left(\frac{\partial v_s}{\partial z} - \frac{\partial w_s}{\partial y}\right)$$



Pitching

$$q = \frac{1}{2}\left(\frac{\partial w_s}{\partial x} - \frac{\partial u_s}{\partial z}\right)$$

Yawing

$$r = \frac{1}{2}\left(\frac{\partial u_s}{\partial y} - \frac{\partial v_s}{\partial x}\right)$$

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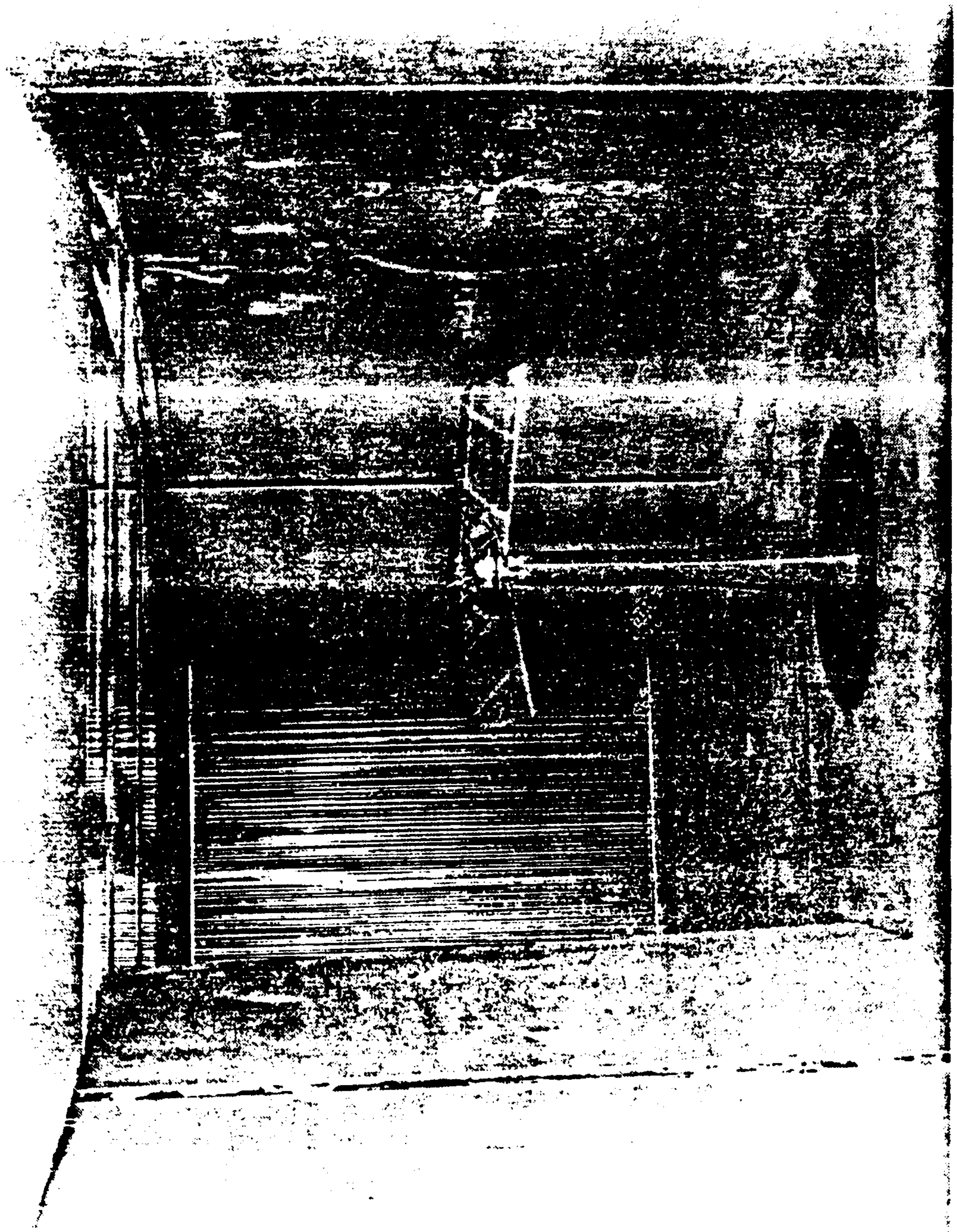

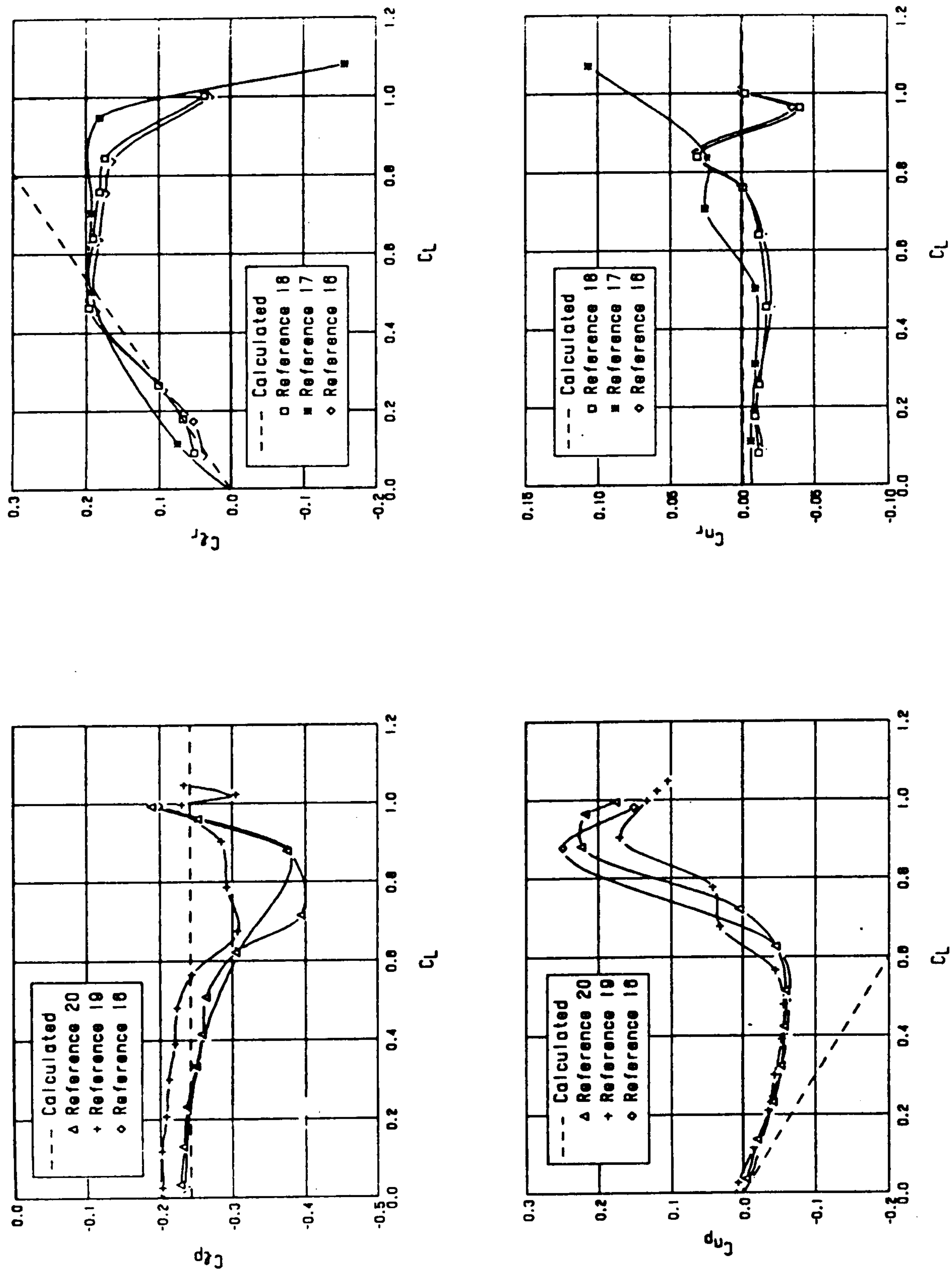

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Shear Coefficient Development

Shear lift coefficient as defined by Campos:

$$C_{L_S} = \frac{\partial C_L}{\partial\left(\frac{S\bar{c}}{2U_\infty}\right)}$$

Total lift coefficient now becomes:

$$C_L = C_{L_\alpha}\alpha + C_{L_o} + C_{L_S}\frac{S\bar{c}}{2U_\infty}$$

Change in force and moment coefficients due to shear

$$\begin{bmatrix} \Delta C_L (2U_\infty/\bar{c}) \\ \Delta C_D (2U_\infty/\bar{c}) \\ \Delta C_Y (2U_\infty/b) \\ \Delta C_l (2U_\infty/b) \\ \Delta C_m (2U_\infty/\bar{c}) \\ \Delta C_n (2U_\infty/b) \end{bmatrix} = [\alpha \mathbf{A} + \mathbf{B}] \begin{bmatrix} \partial u_s/\partial x \\ \partial u_s/\partial y \\ \partial u_s/\partial z \\ \partial v_s/\partial x \\ \partial v_s/\partial y \\ \partial v_s/\partial z \\ \partial w_s/\partial x \\ \partial w_s/\partial y \\ \partial w_s/\partial z \end{bmatrix}$$

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$$\mathbf{A} = \begin{pmatrix} C_{L_{\alpha u_x}} & C_{L_{\alpha u_y}} & C_{L_{\alpha u_z}} & C_{L_{\alpha v_x}} & \cdots & C_{L_{\alpha w_z}} \\ C_{D_{\alpha u_x}} & C_{D_{\alpha u_y}} & C_{D_{\alpha u_z}} & \cdot & \cdots & \cdot \\ C_{Y_{\alpha u_x}} & C_{Y_{\alpha u_y}} & \cdot & \cdot & \cdots & \cdot \\ C_{l_{\alpha u_x}} & \cdot & \cdot & \cdot & \cdots & \cdot \\ C_{m_{\alpha u_x}} & \cdot & \cdot & \cdot & \cdots & \cdot \\ C_{n_{\alpha u_x}} & \cdot & \cdot & \cdot & \cdots & C_{n_{\alpha w_z}} \end{pmatrix} \qquad \mathbf{B} = \begin{pmatrix} C_{L_{u_x}} & C_{L_{u_y}} & C_{L_{u_z}} & C_{L_{v_x}} & \cdots & C_{L_{w_z}} \\ C_{D_{u_x}} & C_{D_{u_y}} & C_{D_{u_z}} & \cdot & \cdots & \cdot \\ C_{Y_{u_x}} & C_{Y_{u_y}} & \cdot & \cdot & \cdots & \cdot \\ C_{l_{u_x}} & \cdot & \cdot & \cdot & \cdots & \cdot \\ C_{m_{u_x}} & \cdot & \cdot & \cdot & \cdots & \cdot \\ C_{n_{u_x}} & \cdot & \cdot & \cdot & \cdots & C_{n_{w_z}} \end{pmatrix}$$

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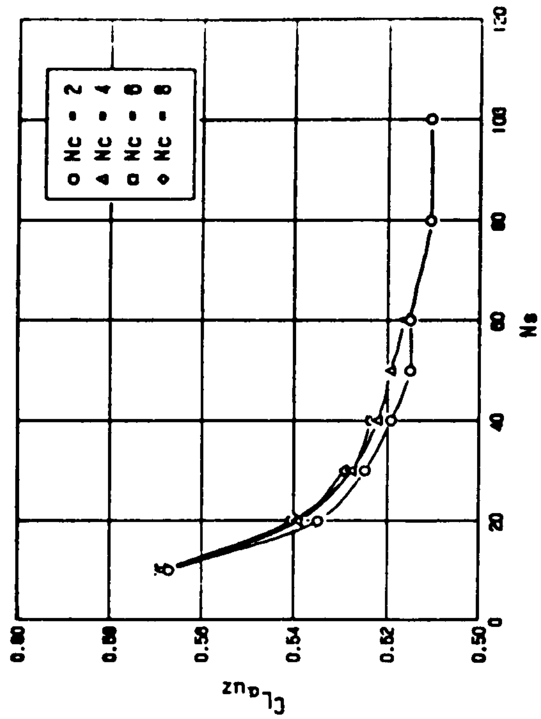

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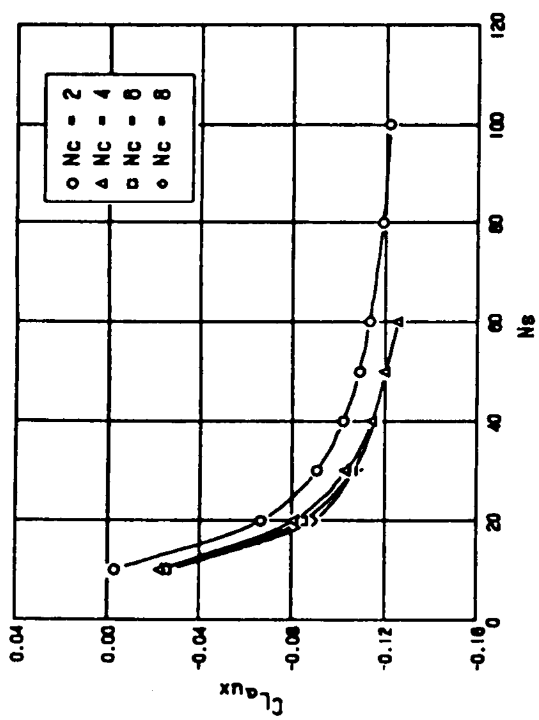
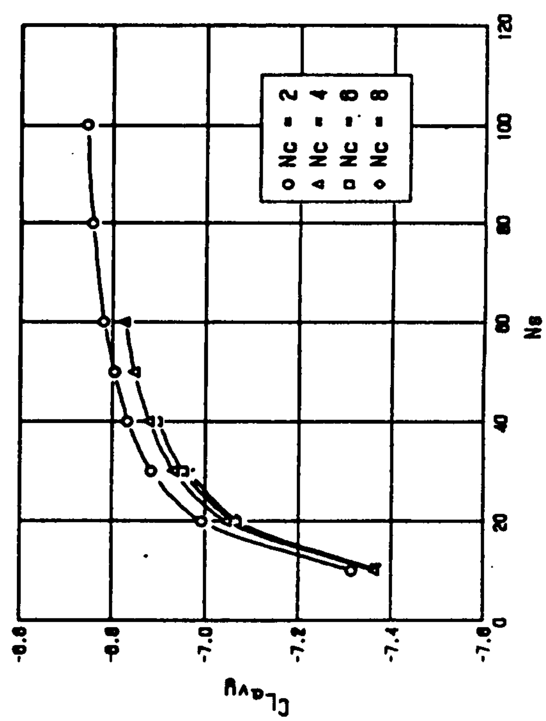
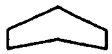
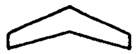
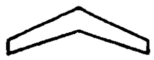
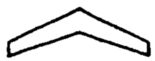
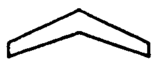
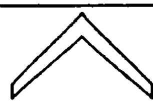
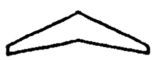
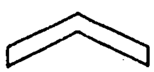


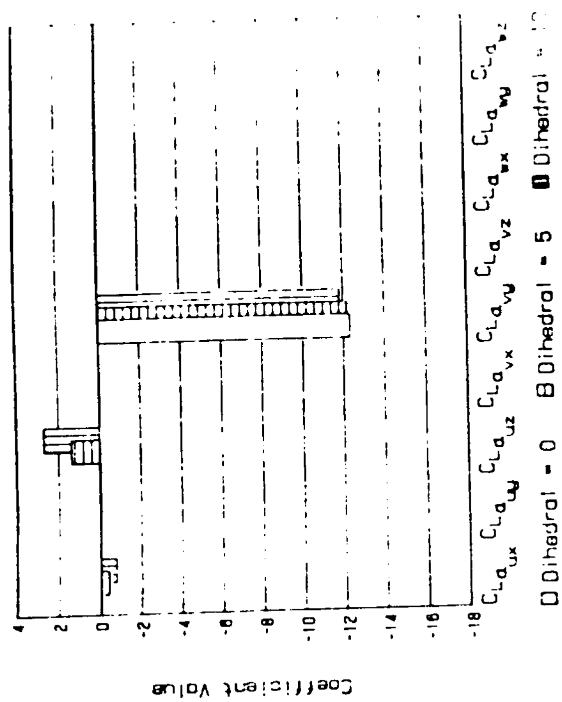


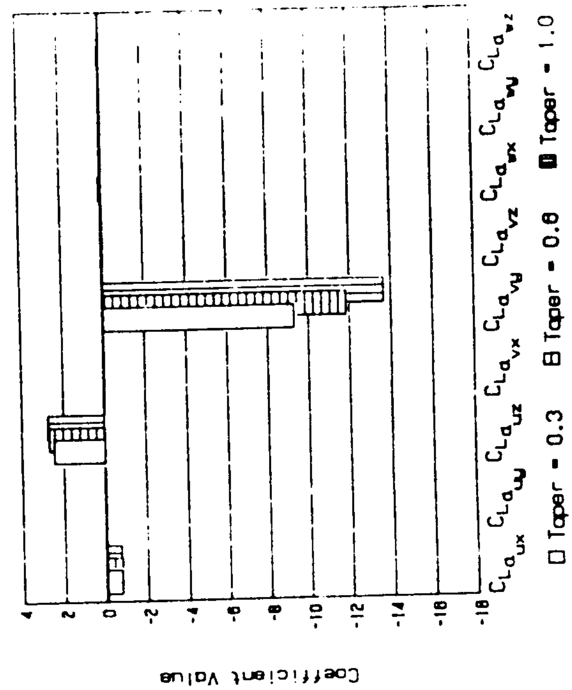
Sensitivity Study Results

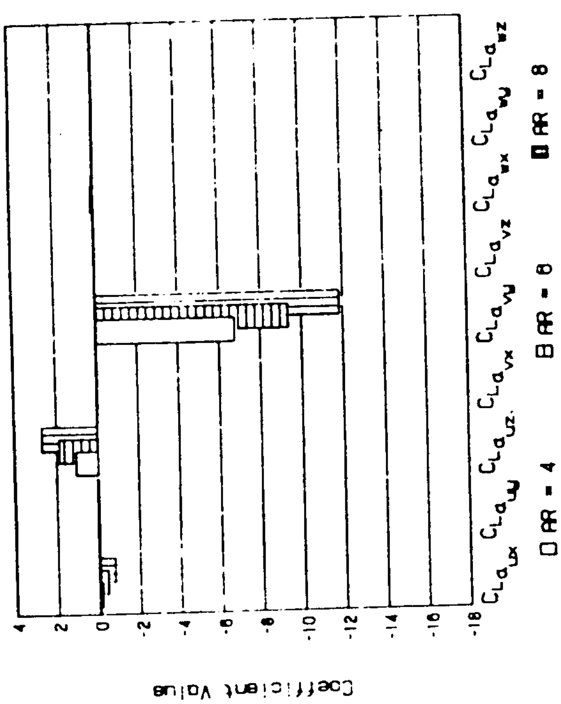
Vortex-Lattice Distribution

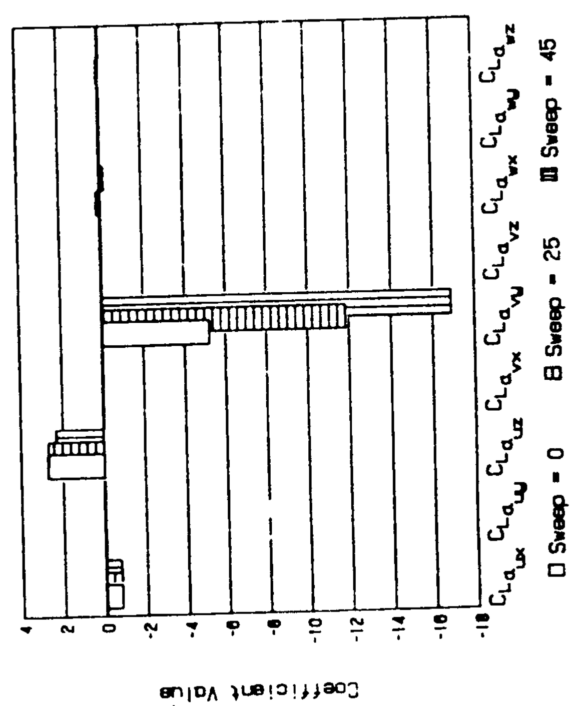
- Increasing Ns and Nc resulted in asymptotic convergence of shear coefficient values
- Ns<30 and Nc<4 resulted in significant variations in computed values
- Ns=40 and Nc=4 selected for remaining sensitivity studies

Configuration		Aspect Ratio	Sweep (deg)	Taper Ratio	Dihedral (deg)
1		2.61	45	1.0	0
2		2.61	45	1.0	10
3		4.0	25	0.6	10
4		6.0	25	0.6	10
5		8.0	25	0.6	10
6		8.0	25	0.6	0
7		8.0	25	0.6	5
8		8.0	0	0.6	10
9		8.0	45	0.6	10
10		8.0	25	0.3	10
11		8.0	25	1.0	10









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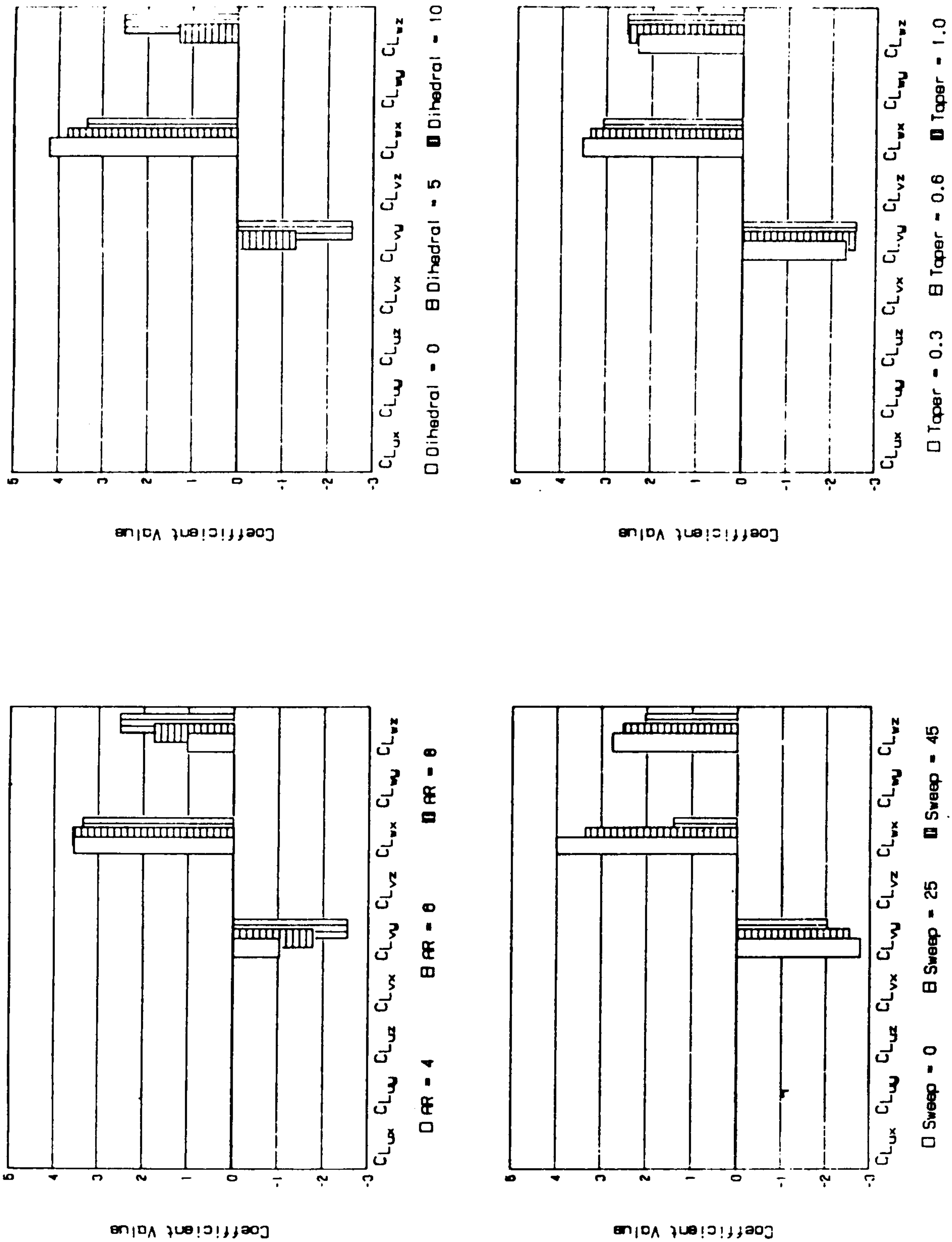

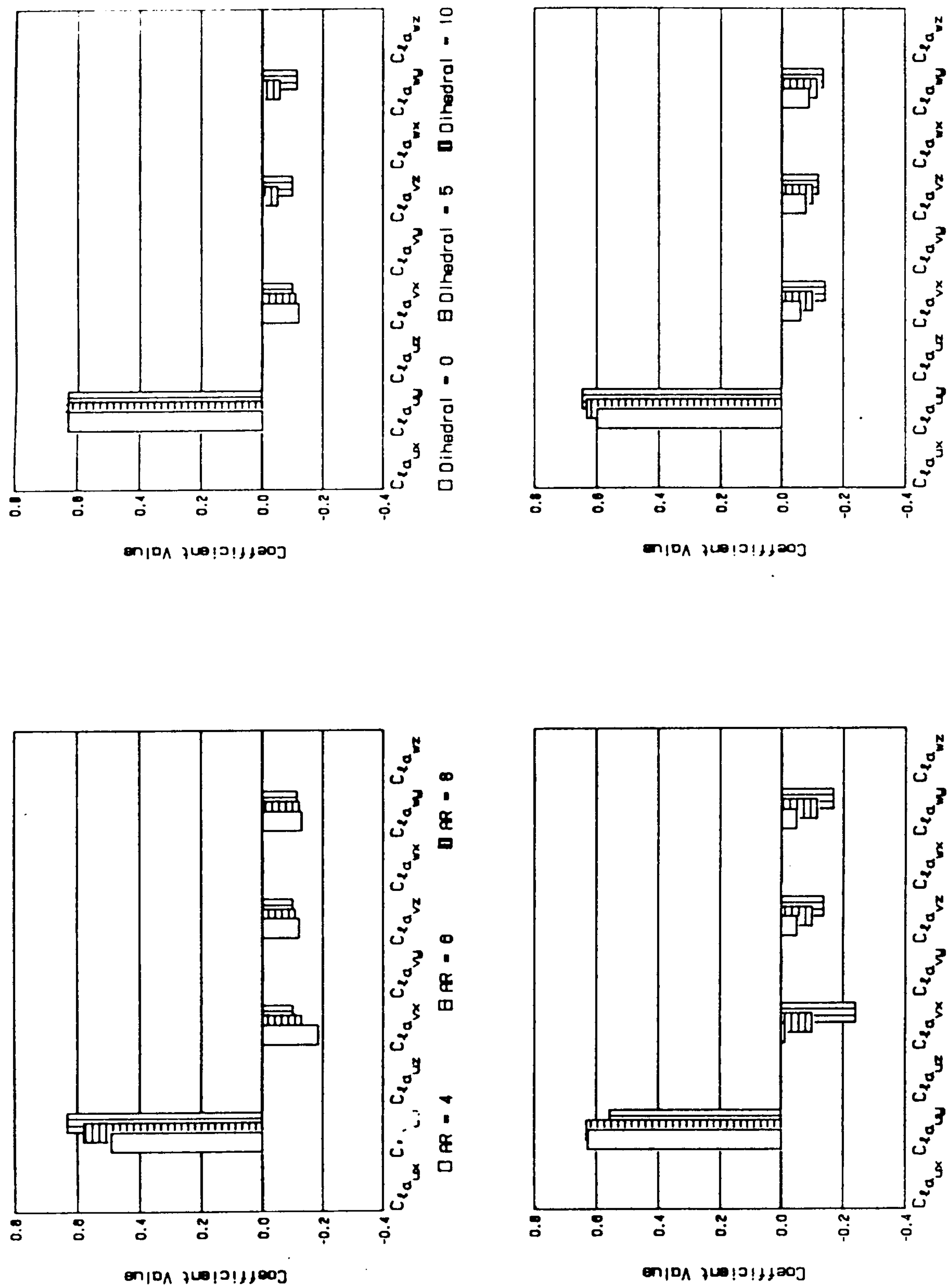
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0.6
0.4
0.2
0.0
-0.2
-0.4
Dihedral = 0
Dihedral = 5
Dihedral = 10
Taper = 0.3
Taper = 0.8
Taper = 1.0
AR = 4
AR = 6
AR = 8
Sweep = 0
Sweep = 25
Sweep = 45

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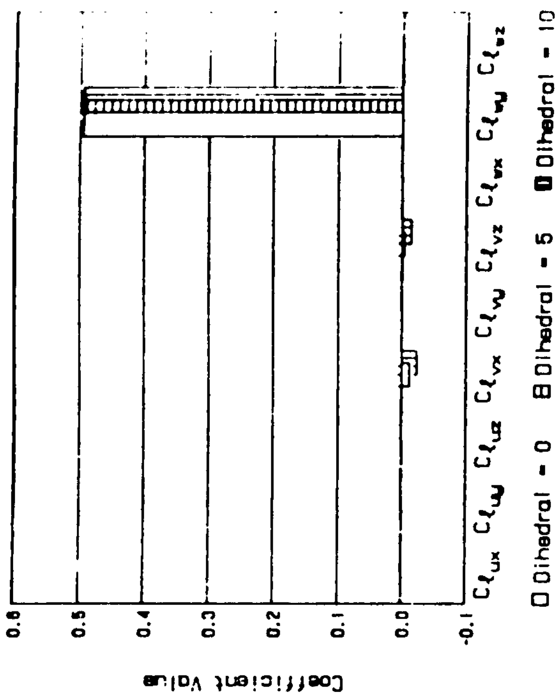

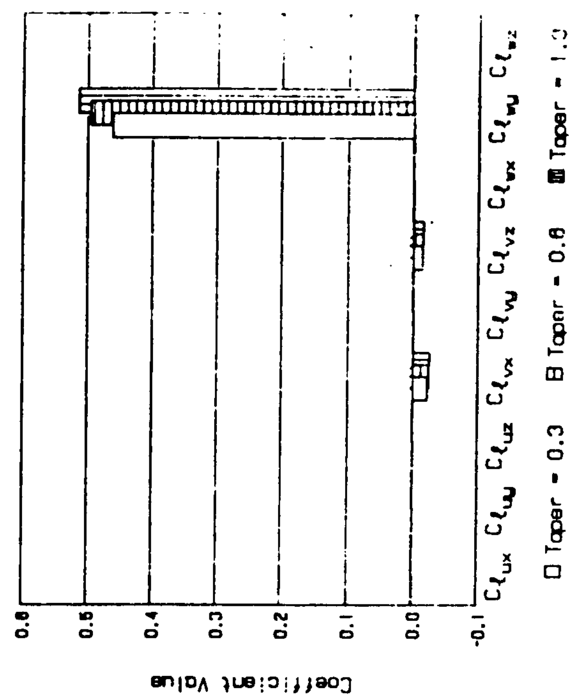

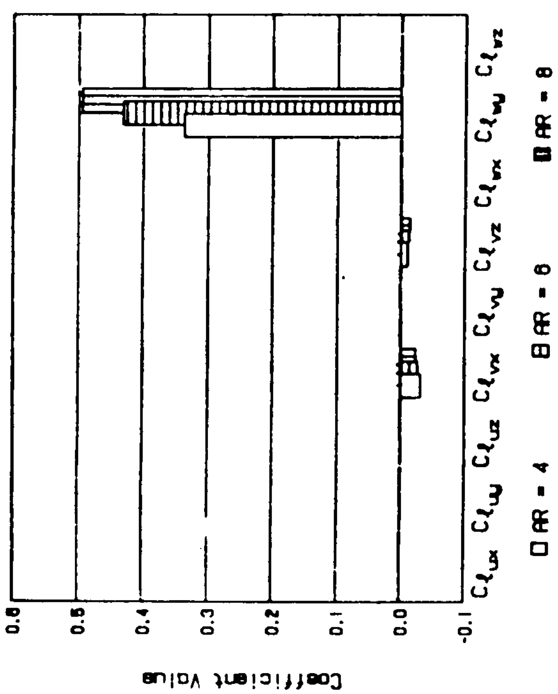

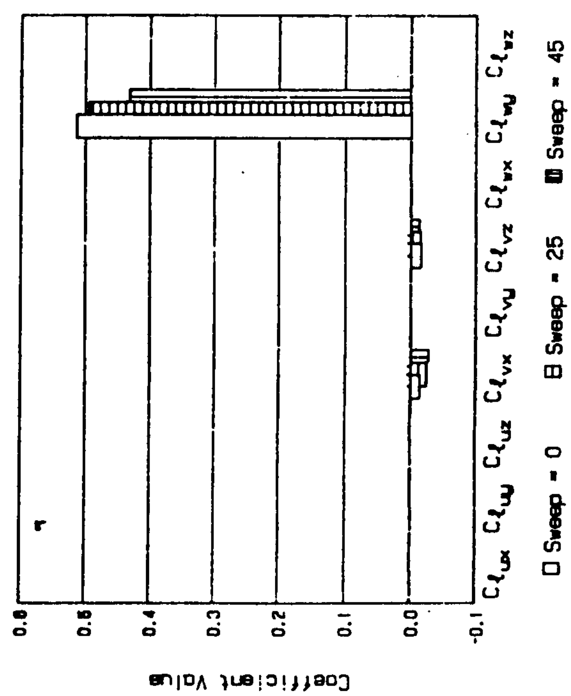

Sensitivity Study Results

Planform Geometry Effect

- Separation of gradient effects into longitudinal and lateral categories
- In general, sweep had the largest effect on the shear coefficients
- Taper ratio had the smallest effect

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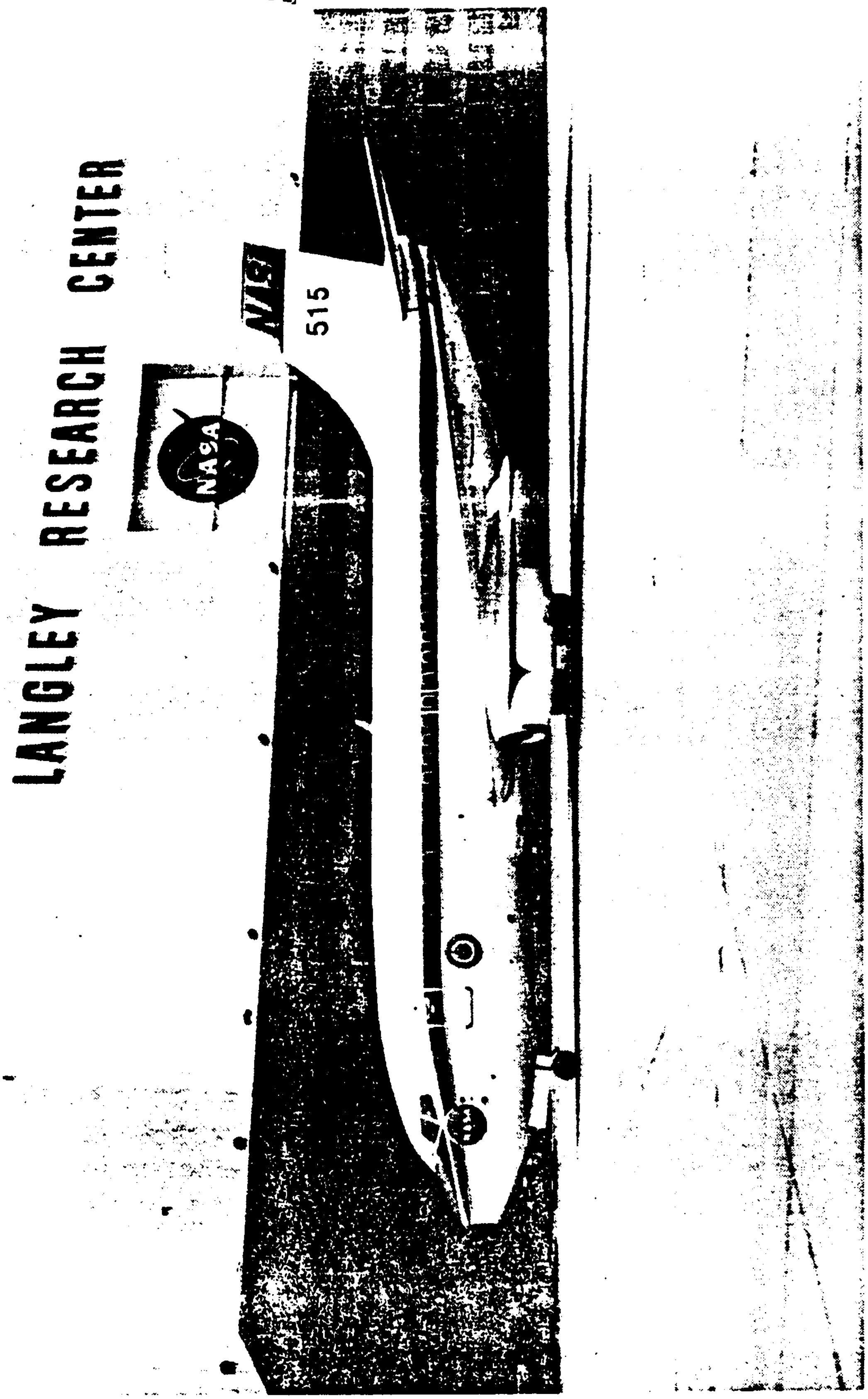
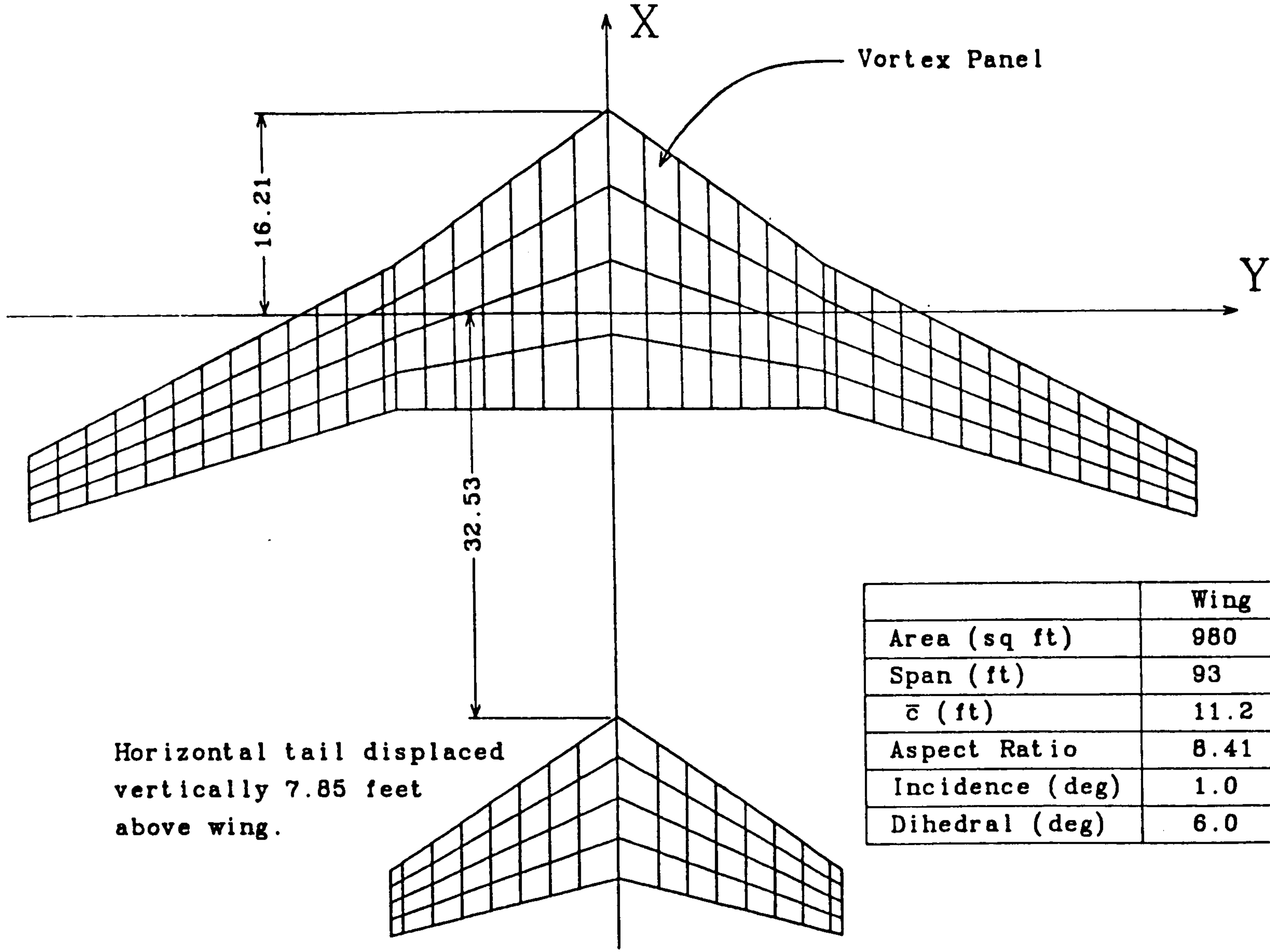
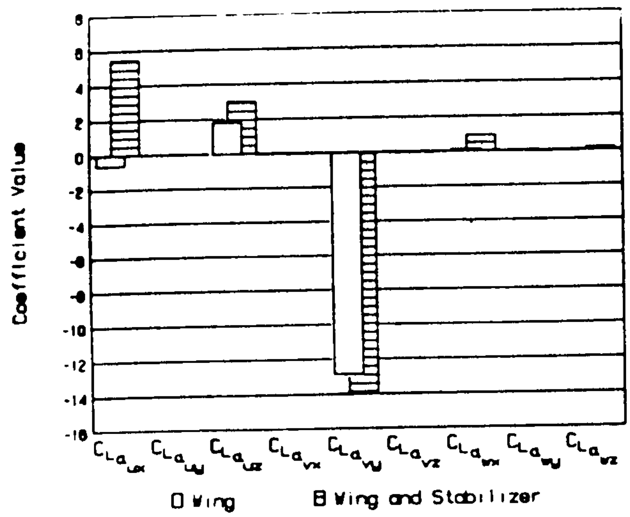




	Wing	Tail
Area (sq ft)	980	312
Span (ft)	93	36
$\bar{c}$ (ft)	11.2	9.6
Aspect Ratio	8.41	4.0
Incidence (deg)	1.0	0
Dihedral (deg)	6.0	7.0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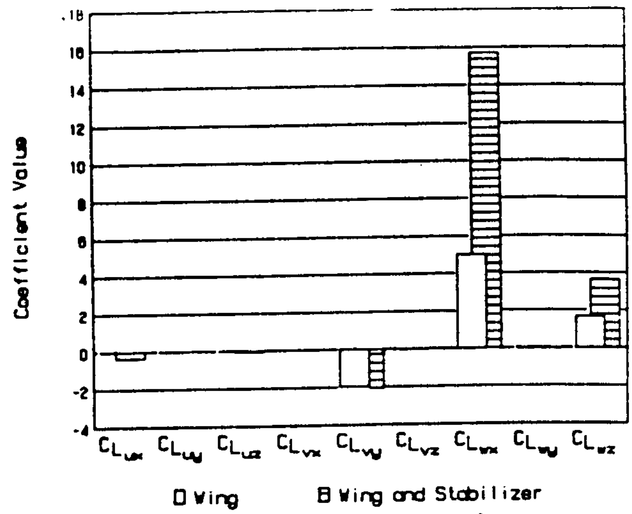
-2
-4
-6
-8
-10
-12
-14
-16
Wing
Wing and Stabilizer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10
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6
4
2
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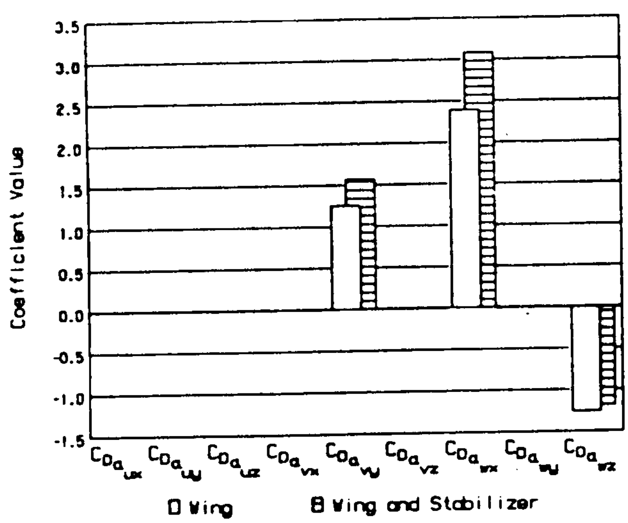
-4
Wing
Wing and Stabilizer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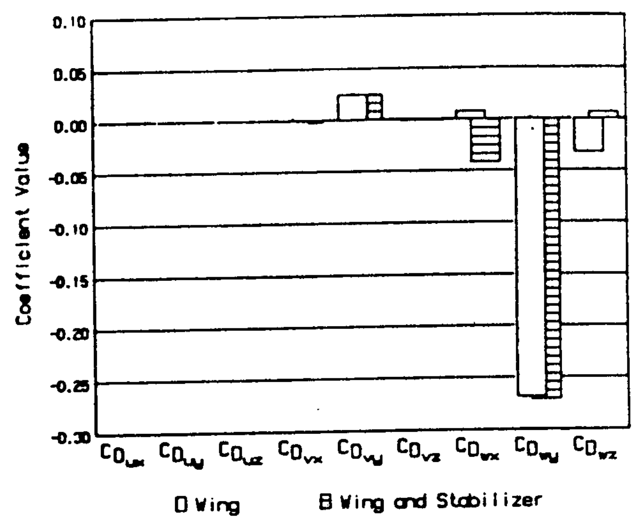
-1.5
Wing
Wing and Stabilizer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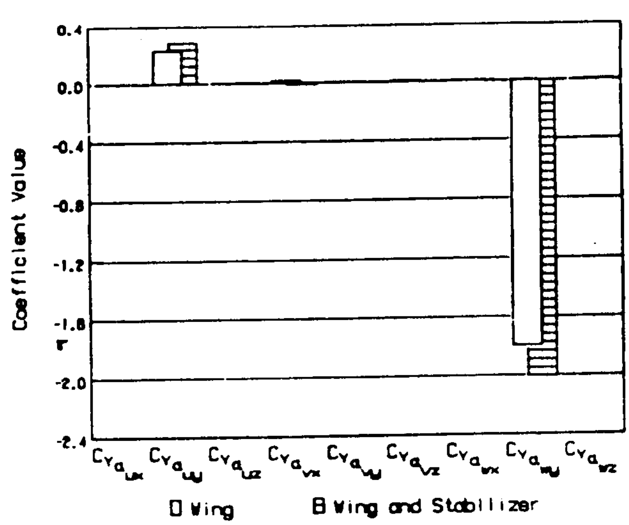
-0.25
-0.30
Wing
Wing and Stabilizer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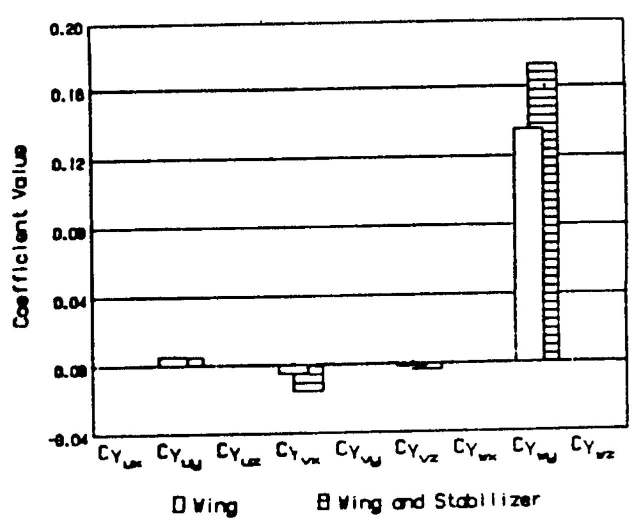
-1.6
-2.0
-2.4
Wing
Wing and Stabilizer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0.12
0.08
0.04
0.00
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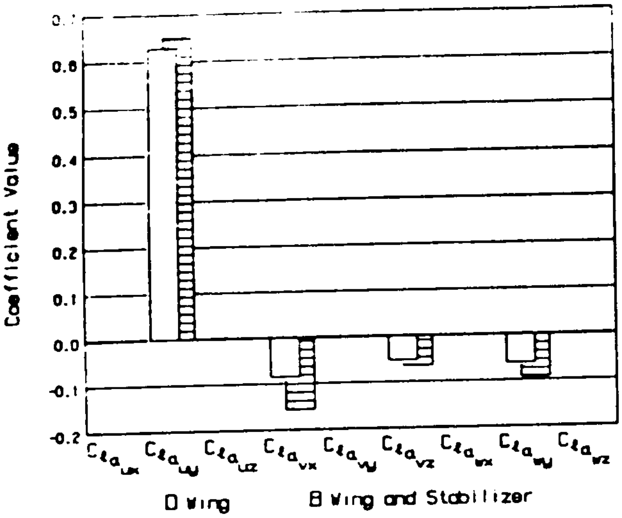
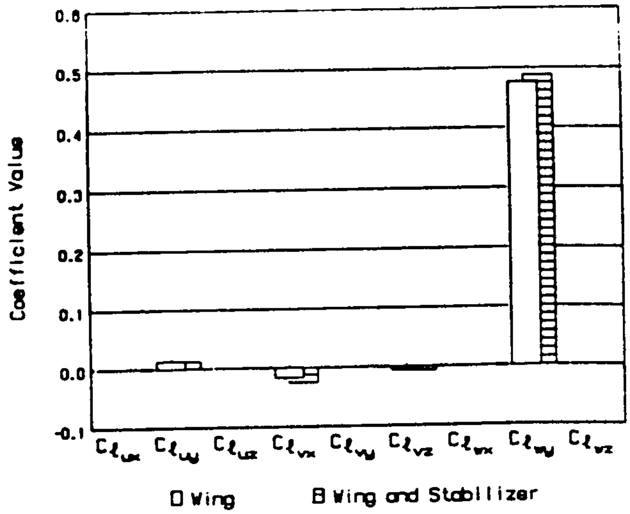
Wing
Wing and Stabilizer


Coefficient Value
Wing
Wing and Stabilizer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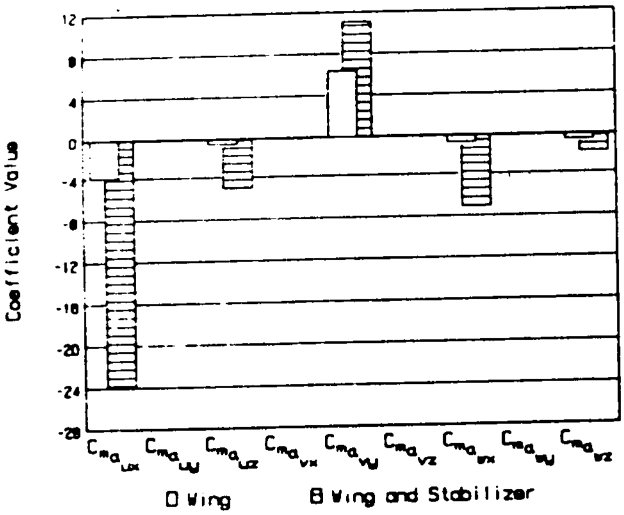
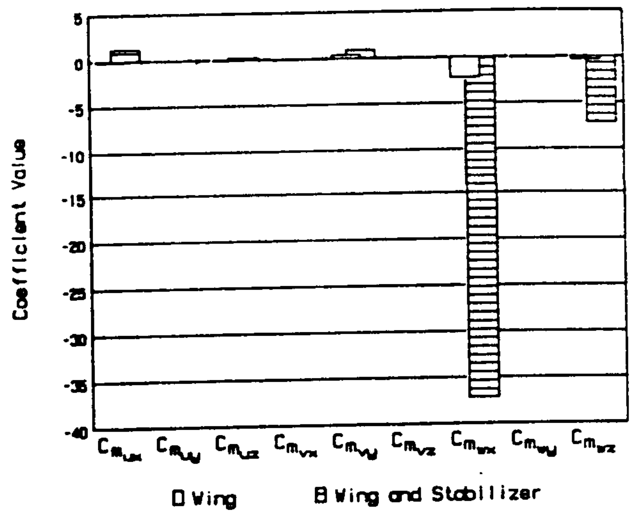
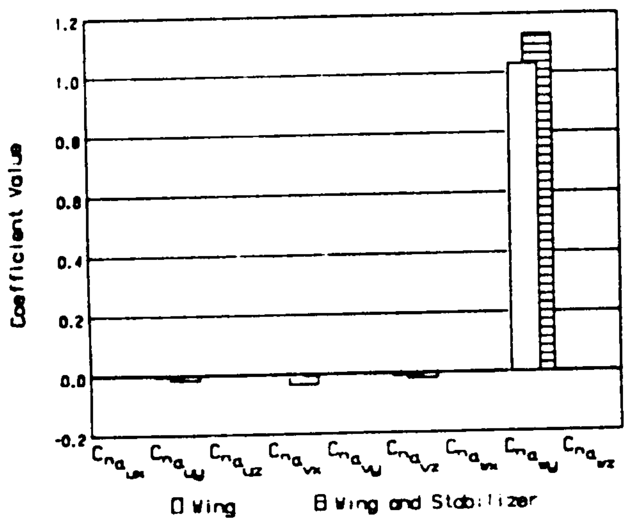
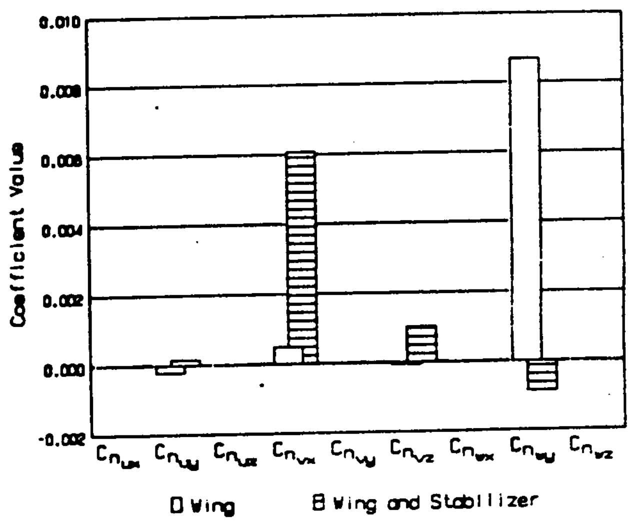
Wing and Stabilizer


Coefficient Value
Wing
Wing and Stabilizer


Coefficient Value
Wing
Wing and Stabilizer

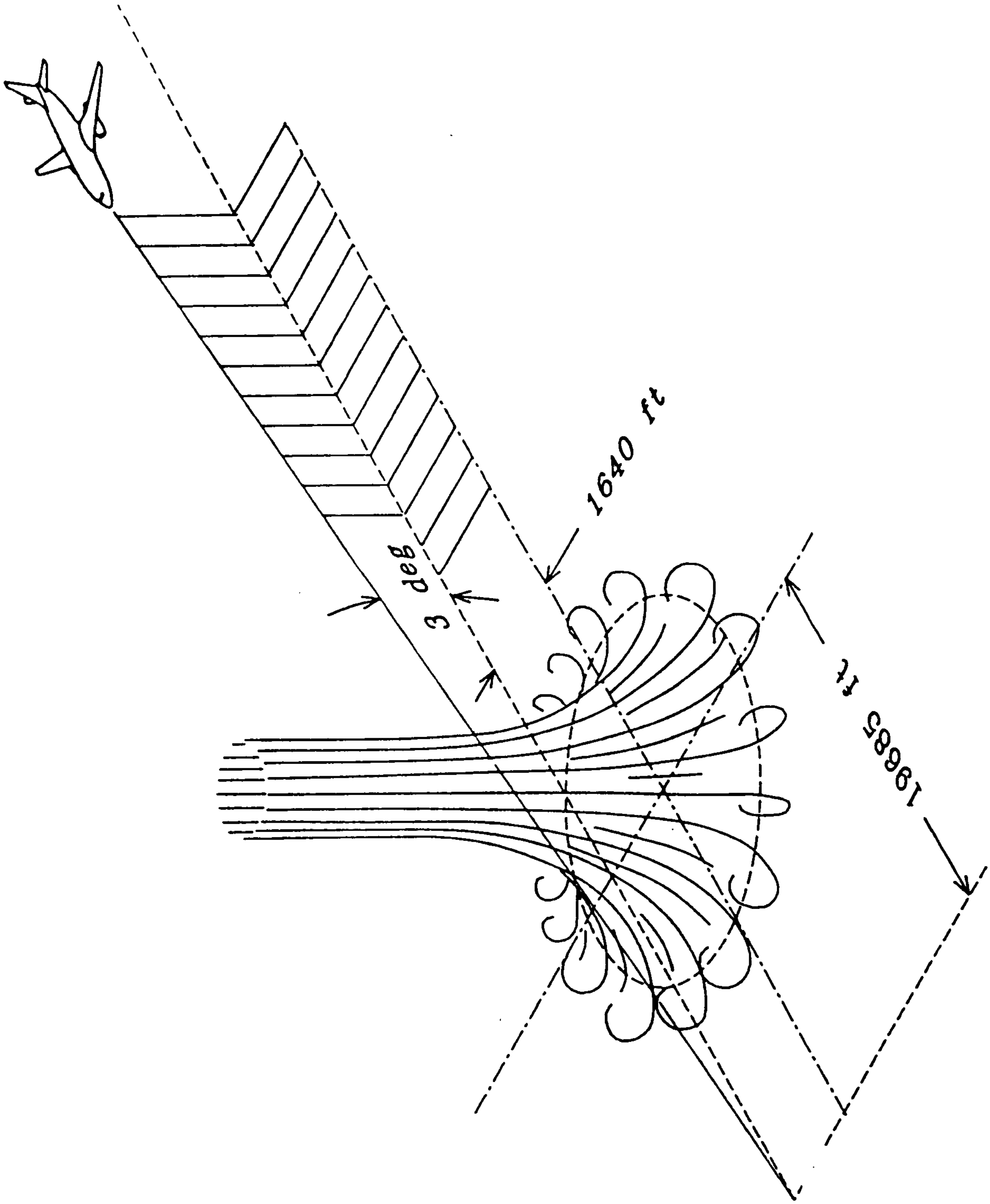

Coefficient Value
Wing
Wing and Stabilizer


Coefficient Value
Wing
Wing and Stabilizer

Sensitivity Study Results

Wing and Stabilizer

- Addition of stabilizer increased the magnitude of the shear coefficient in nearly every case
- Primarily a longitudinal effect
- Horizontal and vertical displacement of stabilizer led to large increases in x and z shear coefficients



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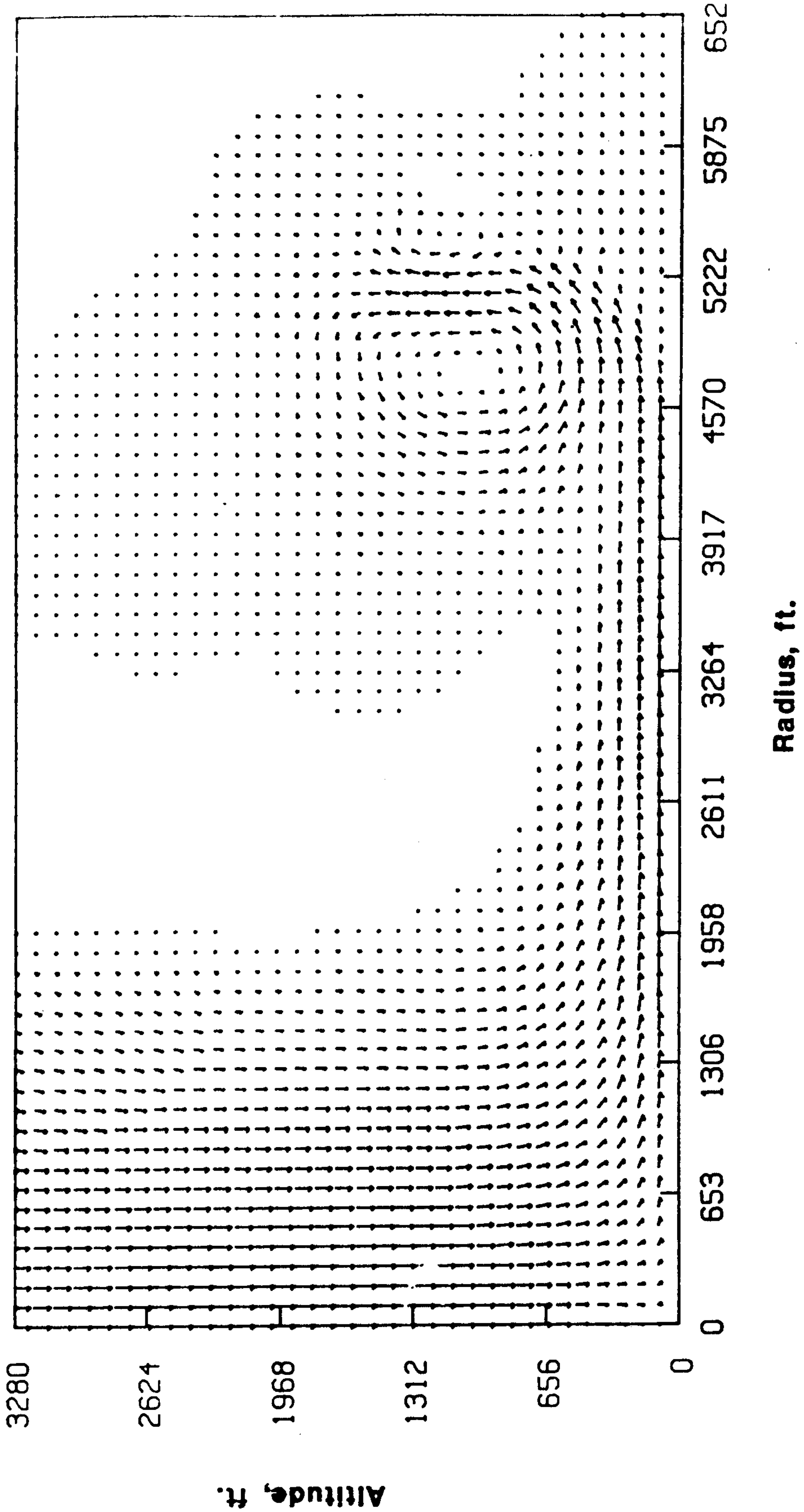
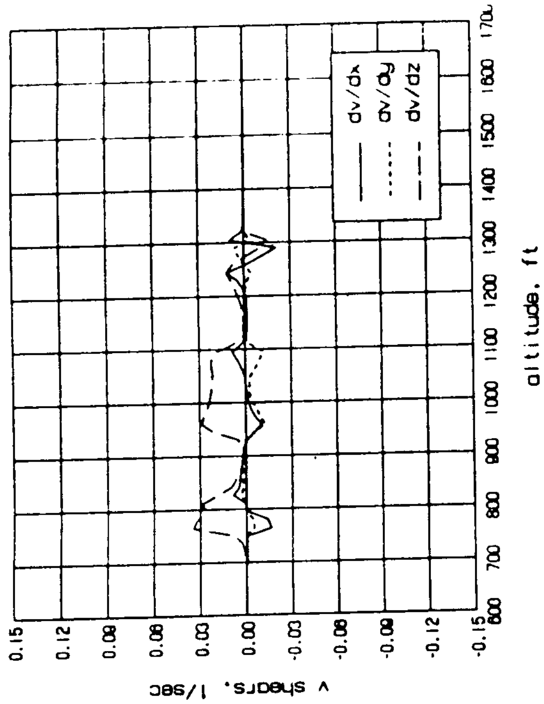
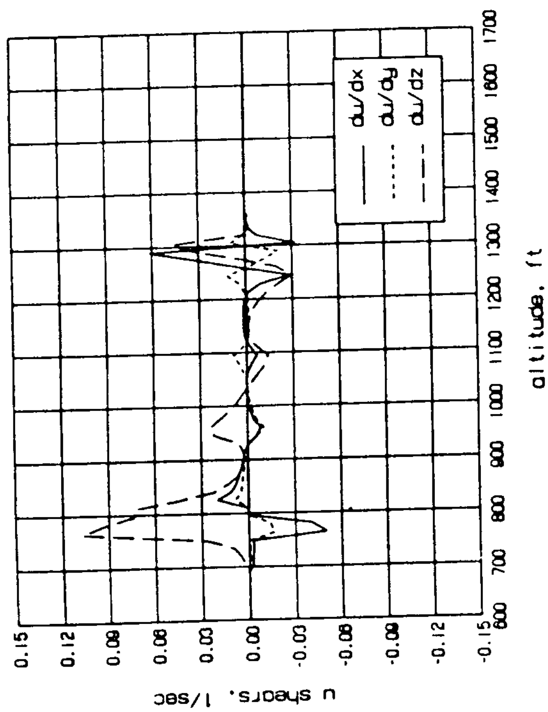
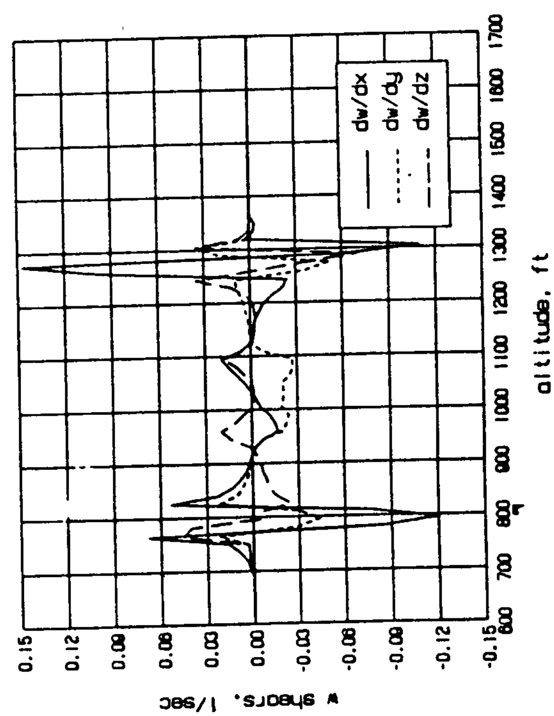
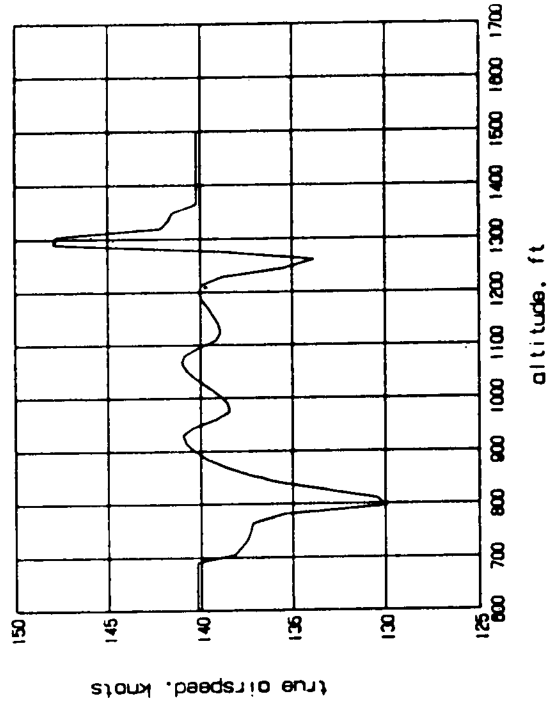
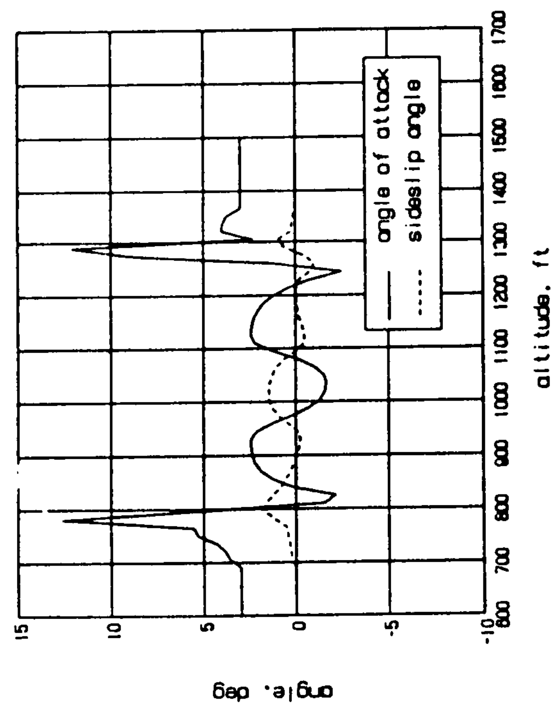

Altitude, ft.
3280
2624
1968
1312
656
0
Radius, ft.
0
653
1306
1958
2611
3264
3917
4570
5222
5875
6528

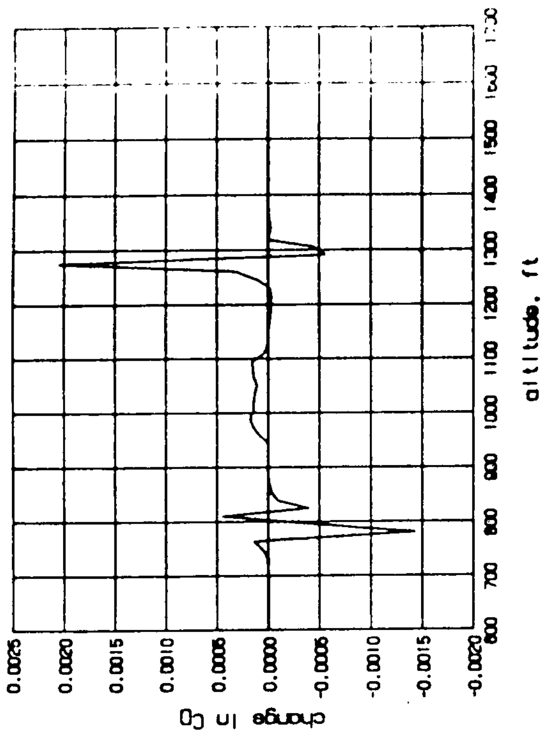

v shears, 1/sec
altitude, ft
dv/dx
dv/dy
dv/dz
0.15
0.12
0.09
0.06
0.03
0.00
-0.03
-0.06
-0.09
-0.12
-0.15
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700

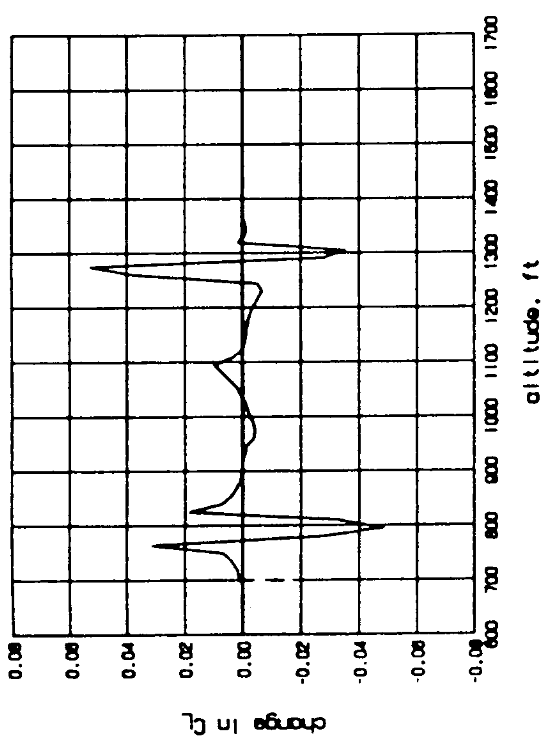

u shears, 1/sec
altitude, ft
du/dx
du/dy
du/dz
0.15
0.12
0.09
0.06
0.03
0.00
-0.03
-0.06
-0.09
-0.12
-0.15
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700

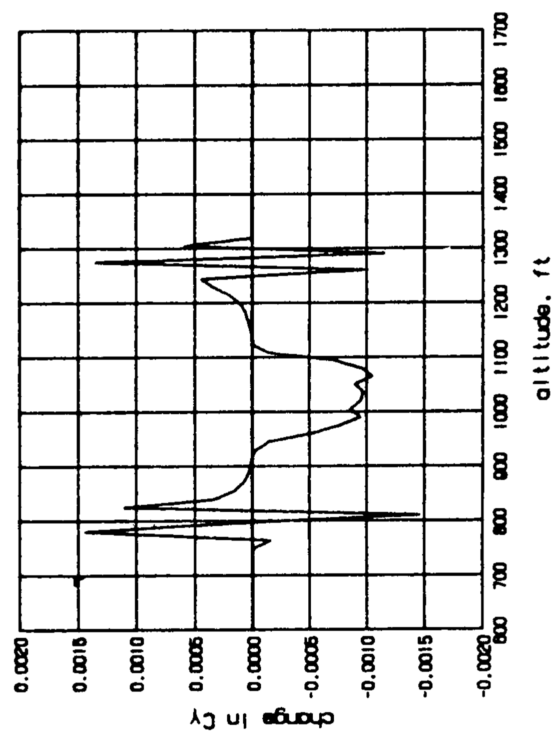

w shears, 1/sec
altitude, ft
dw/dx
dw/dy
dw/dz
0.15
0.12
0.09
0.06
0.03
0.00
-0.03
-0.06
-0.09
-0.12
-0.15
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700


true airspeed, knots
altitude, ft
150
145
140
135
130
125
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700


angle, deg
altitude, ft
angle of attack
sideslip angle
15
10
5
0
-5
-10
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700







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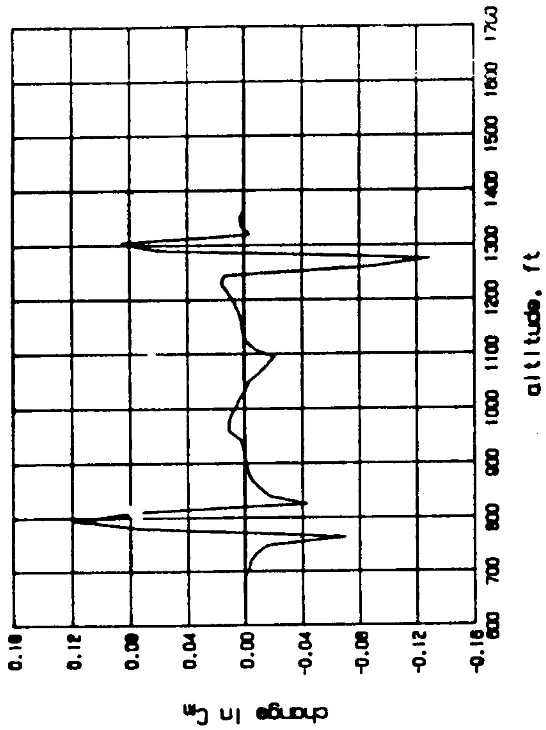

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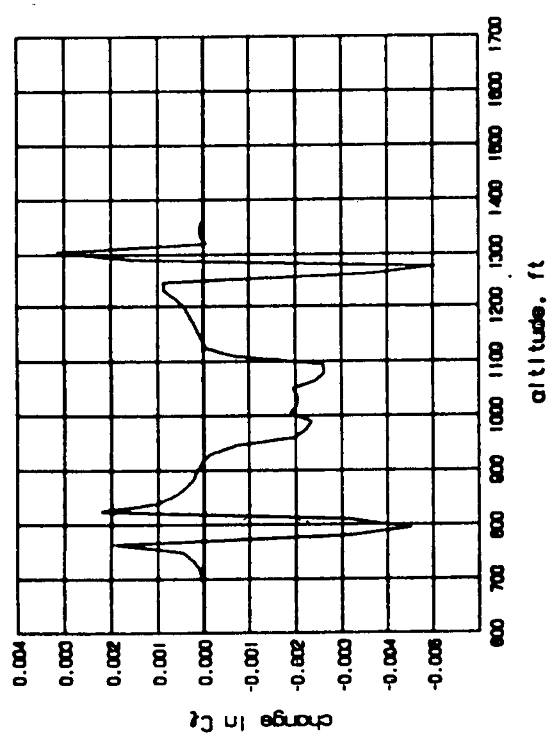
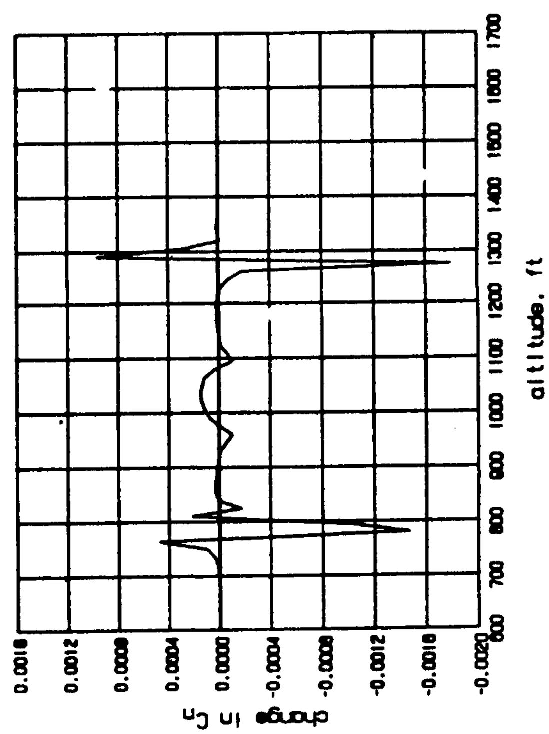
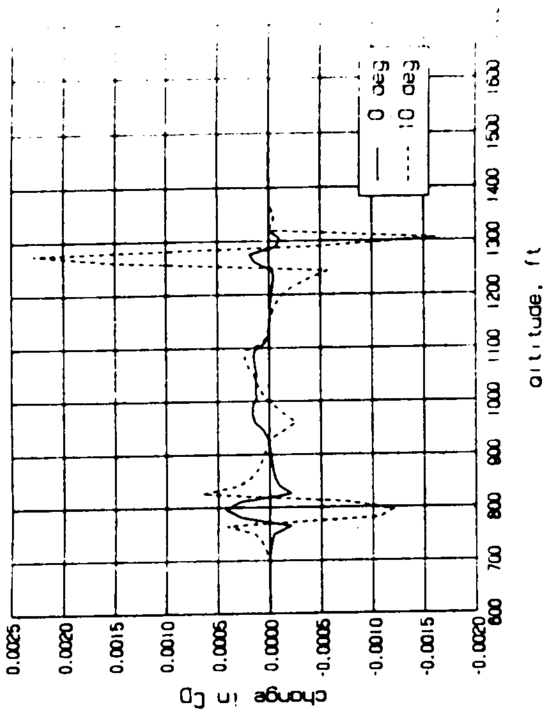
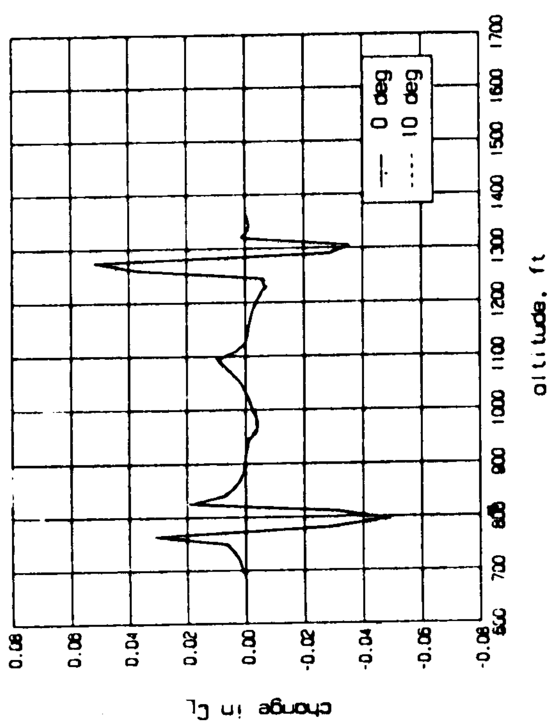


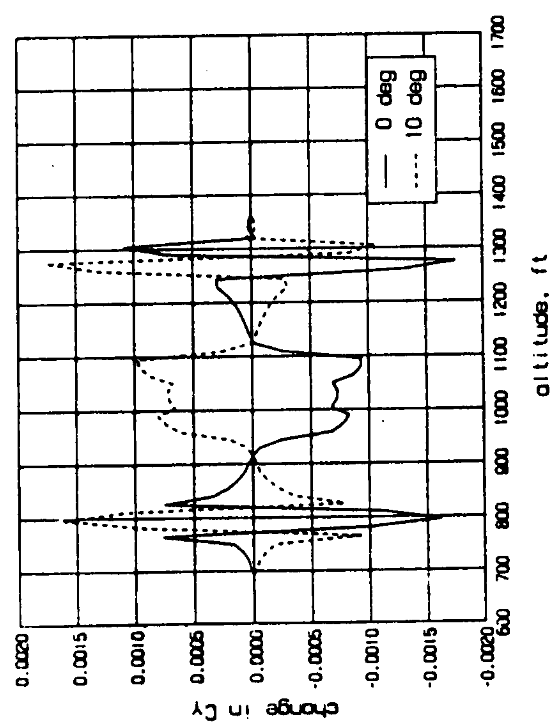




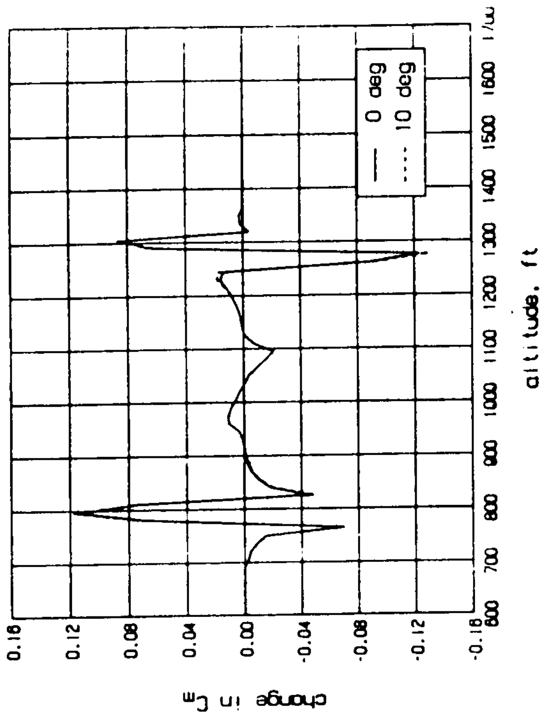
change in CD
altitude, ft
0 deg
10 deg

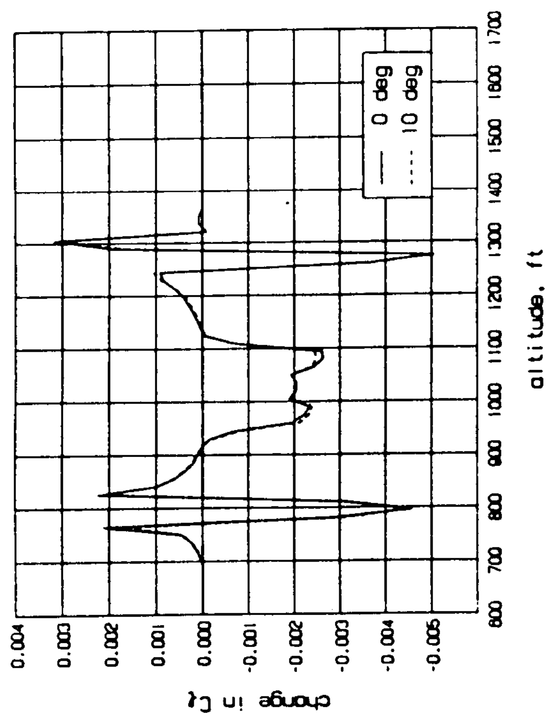


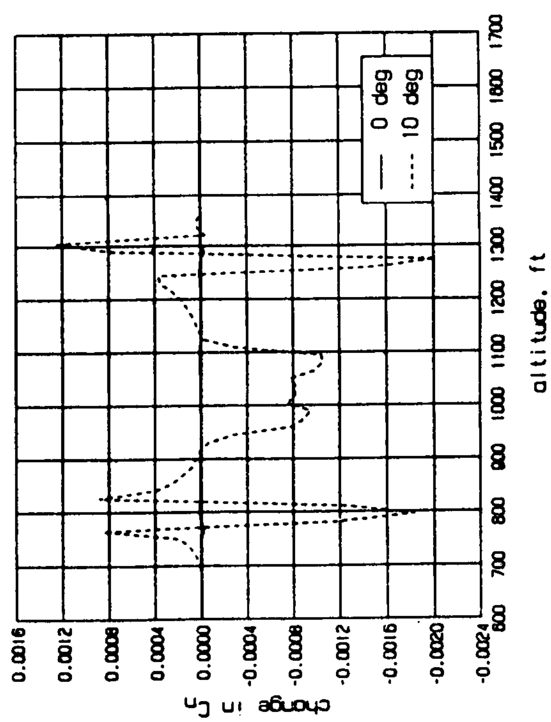
change in CL
altitude, ft
0 deg
10 deg

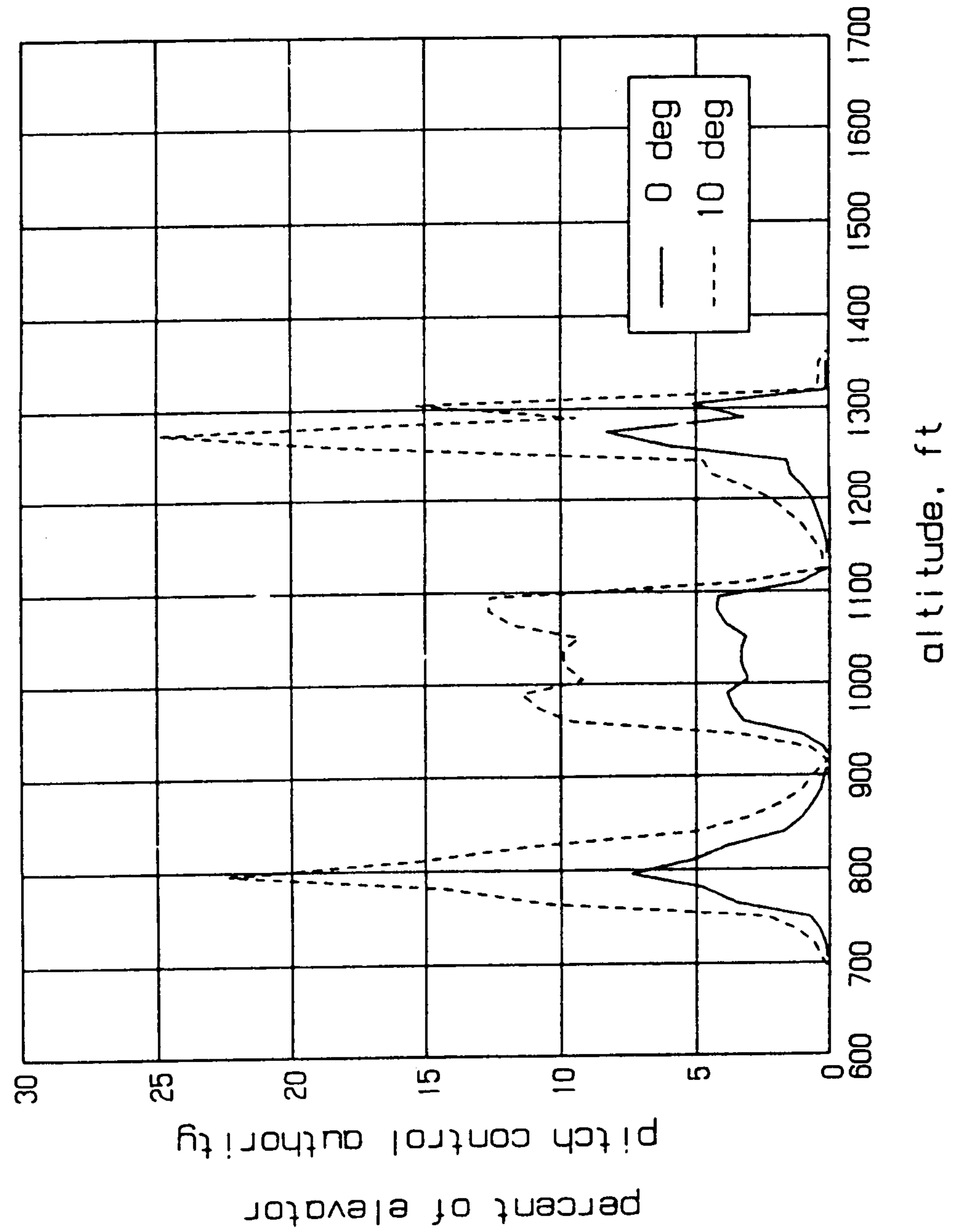


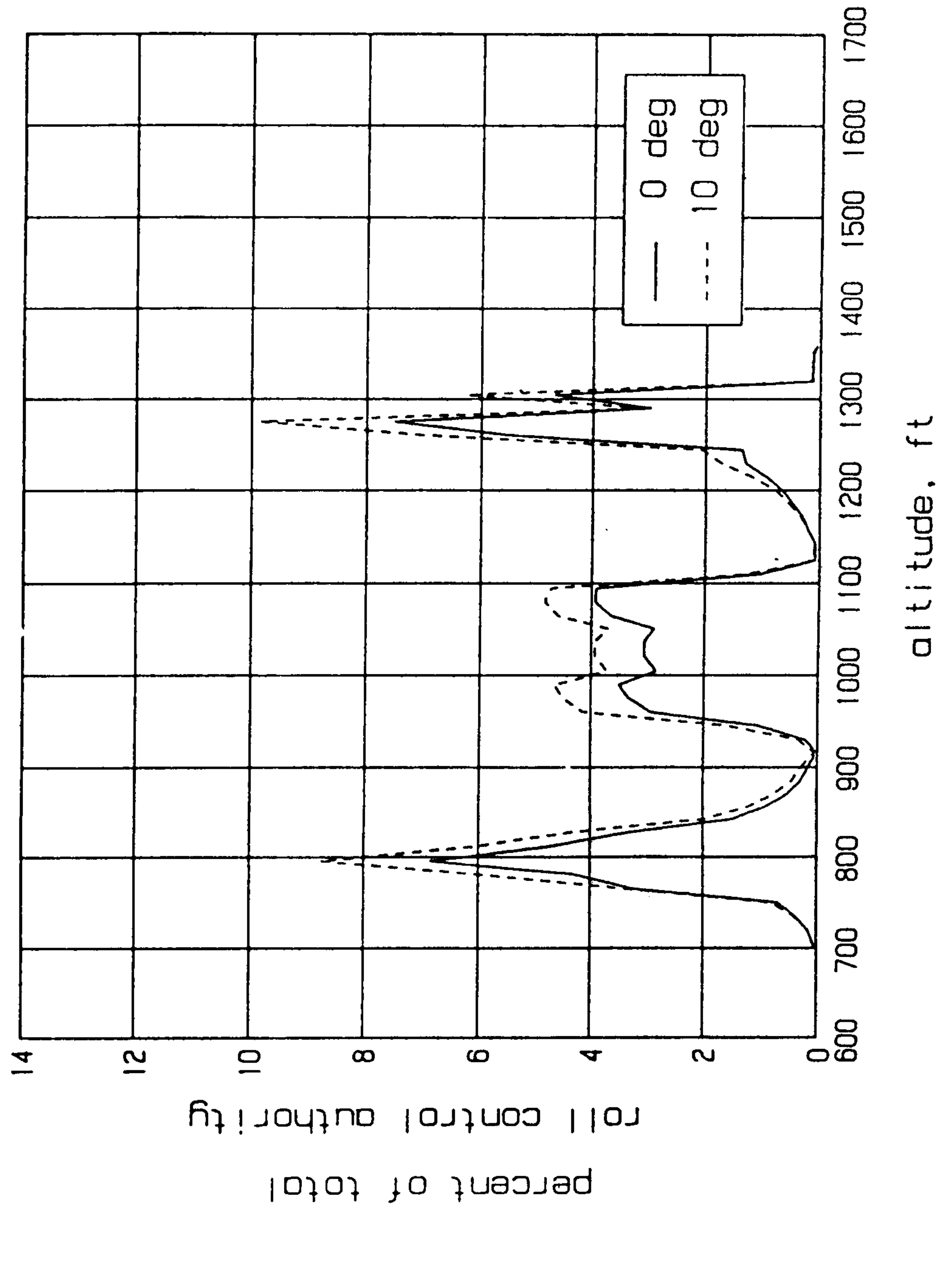
change in CY
altitude, ft
0 deg
10 deg


change in C_m
altitude, ft
0 deg
10 deg


change in C_ℓ
altitude, ft
0 deg
10 deg


change in C_n
altitude, ft
0 deg
10 deg


percent of elevator
pitch control authority
0
5
10
15
20
25
30
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
altitude, ft
0 deg
10 deg


percent of total
roll control authority
altitude, ft
0 deg
10 deg
0
2
4
6
8
10
12
14
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700

Outline

- ☑ Introduction
- ☑ Modification of Vortex-Lattice Algorithm
  - Spatially Varying Wind Field
  - Boundary Condition
  - Force and Moment Equations
- ☑ Program Checkout and Validation
- ☑ Shear Coefficient Development
- ☑ Sensitivity Studies
  - Vortex-Lattice Distribution
  - Planform Geometry
  - Wing and Stabilizer Combination
- ☑ Concluding Remarks

Concluding Remarks

Study Limitations

- Limited to small angle of attack range and thin airfoil approximation
- Effect of sideslip was not investigated
- Fuselage and vertical surface effects were not acconuted for

Concluding Remarks

Pertinent Results of Study

- A method of characterizing the aerodynamic effect of wind shear in the form of wind shear aerodynamic coefficients was formulated

- A method of modifying a vortex-lattice algorithm to compute the aerodynamic effect of wind shear was demonstrated

- An example of the magnitude of the wind shear aerodynamic effect was computed for a conventional wing and stabilizer configuration on a fixed flight path through a microburst

Concluding Remarks

Recommendations for Future Research

- Adaptation of more sophisticated aerodynamic codes to compute wind shear effect on complete configuration
- Simulation studies of pilots ability to manage the flight path with the wind shear induced aerodynamic effects
- Wind tunnel studies to confirm analytical results and explore high angle of attack effects

QUESTIONS AND ANSWERS

RICK PAGE (FAA Technical Center) - Do you intend to do any research work into asymmetrical microbursts and also multiple glidepaths?

DAN VICROY (NASA LaRC) - We used a symmetrical microburst in this case but flew off to the side of it about 1500 ft. so that we would get asymmetrical effects. The shears are transformed into the body axes yielding asymmetrical shear gradients as we penetrated the microburst. So, we essentially did take into account that effect. Certainly this is just one example. I plan to look at more complex aerodynamic codes to compute the shear coefficients of complete airplane configurations. Another study that could be done is to do more of a statistical analysis of what kind of changes you are going to see with a variety of different kinds of microbursts. I don't plan to do that myself, but that work certainly could be done.

N88-17620

LANGLEY 22/10/87

WINDSHEAR WARNING

AEROSPATIALE APPROACH

JL BONAFE

1. SUMMARY

Although our A300, A310, A300/600 are yet automatically windshear protected by the α floor system AEROSPATIALE has on study windshear warning system according to AC 25 XX and AC 120 XX.

All the numerical values used here after have not the mathematical rigour related to an exact science, they just allow us setting targets. They are milestones, they also lead to marks welcomed in our design process.

We set up targets, conservative as far as possible, and check using marks the good behaviour of the system.

We keep in mind at every moment that : the more confident the crew will be, the more flying safety will be improved.

The following paper is concerned by future onboard windshear warning system and the AEROSPATIALE approach.

2. MILESTONES : LOW ALTITUDF WINDSHEAR PROBABILITY

Several reports or study sponsored by the US Administration (NASA, FAA), Nimrod and Jaws projects, Professor T. FUJITA publications ...... etc ......, makes the windshear phenomenon more comprehensive.

Some parts of the world seem to be more sensitive. They are generally situated between the two 40 th parallels and more particularly in the continental areas.

Europe seems to be free of windshears. But, in France, we observed strong shears near by the mediterranean sea (MARSEILLE, MONTPELLIER, PERPIGNAN ...... TOULOUSE).

All those interesting remarks cannot help us in determining an occurrence probability for a low altitude windshear.

(Slide 1) Fortunately the amount of accidents or incidents observed over a 20 years period is low, nevertheless it allows us in defining a maximum milestone in a sensitive region of the world.

3. THE MARKS : WIND MODELS

Setting up our windshear warning systems we are supported by :

3.1. Accidents, incidents wind analysis mainly issued from BOEING studies, also called historical gradients (slide 2).

Their probability are such defined.

3.2. The AC 12041 (slide 3) whose probability is unknown.

3.3. The windshear training aid wind models whose probability is also unknown.

3.4. Some three-dimensional downburst models one can fit in size and intensity. Their occurrence probability are obviously unknown.

We will try to estimate the model's probability matching them with historical gradients.

To do so, we use the severity factor (slide 4) called "SF".

Using "SF" we define the weight of the shears for taking off historical gradients (slide 5) and for landing (slide 6).

Using the same observer we weight the windfields (slides 7, 8, and 9).

We can so appreciate whatever the wind modelization is.

Now we can compare the "SF" and balance the windfields versus the historical gradients (slide 10).

The same "SF" weighting can be used for windshear training aid wind models (slide 11).

Those weightings lead to the general comparison (slide 12) between historical gradients, windfields and wind models.

The comparison slides 12 and 10 comes from a visual analysis but two observers can help us in the comparison process :"WSF" and "PSF" (slide 13).

4. THE TARGETS - AEROSPATIALE WS WARNING SYSTEM

Considering our in flight experience, and the AC 25 XX and AC 120 XX demands we set the following targets (slide 14).

4.1. Performance

We have to detect the shears whose probability is equal or lower than 1.10-6. If the system does not detect such gradient we have to show that the aircraft can take off or land safely within the common safety rules.

4.2. Nuisances

Nuisance can have several origins nevertheless none of them could occur with probability greater than 10-4. Taking in account pilot training or protection of sensible areas by ground aids (LLAWS) we relax active or latent failures probabilities in accordance with AC 25 XX advices.

On the other hand, in the case of nuisance performance warning we cannot tolerate a warning rate 100 times or 1000 times greater than it could really exist.

So, as we did in the past with α floor system, we are developing for the future a windshear warning as credible as possible for crews, mainly in the most critical part of the flight : the landing case.

5. WINDSHEAR WARNING SYSTEM THE AEROSPATIALE APPROACH

(Slide 15) WS warning is balanced by comparing longitudinal shear, vertical wind ("SF") properly filtered, actual aircraft energy with minimal aircraft safe energy.

Warning is sensitized by each headwind increase (short period) and desensitized according to the longitudinal mean wind (long period input) avoiding as far as possible the effect of mean turbulence.

The computing principle of AEROSPATIALE Windshear Warning System is as follow (slide 16) ; it could be implemented in digital AFCS.

6. NORMAL PERFORMANCE NUISANCE WARNING

Considering the time of exposure and the nuisance for airlines or air traffic control of frequent undue go around AEROSPATIALE focused its research on landing case, without forgetting the take off case.

In landing case AC 2057A provides us with a simple means of atmosphere modelization allowing the knowledge of wind probability and related turbulence.

Just a problem : the observed wind probabilities don't go further 10-3 so we have to continue the model linearly maintaining the turbulence and mean wind relationship.

Results on (slide 17-1-2) allow to define a safe threshold in the world of AC 2057A. The warning threshold can be set at a point guarantizing a level of improbable nuisance warning by landing.

Similar analysis was performed for a fixed threshold (2 to 2,5 kt/s) according to a properly filtered "SF" (slide 17-3).

AC 2057A leads in that case to a nuisance warning level of 10-3 to 10-4 by approach.

Several piloting technics can also be implemented for decreasing the number of performance nuisance warning. Those technics such as decelarated approach, ground speed mini are not introduced in today's evaluation.

CONCLUSION

The theme we have here developed is mainly supported by engineers' assumptions considering the lack of reliable statistics.

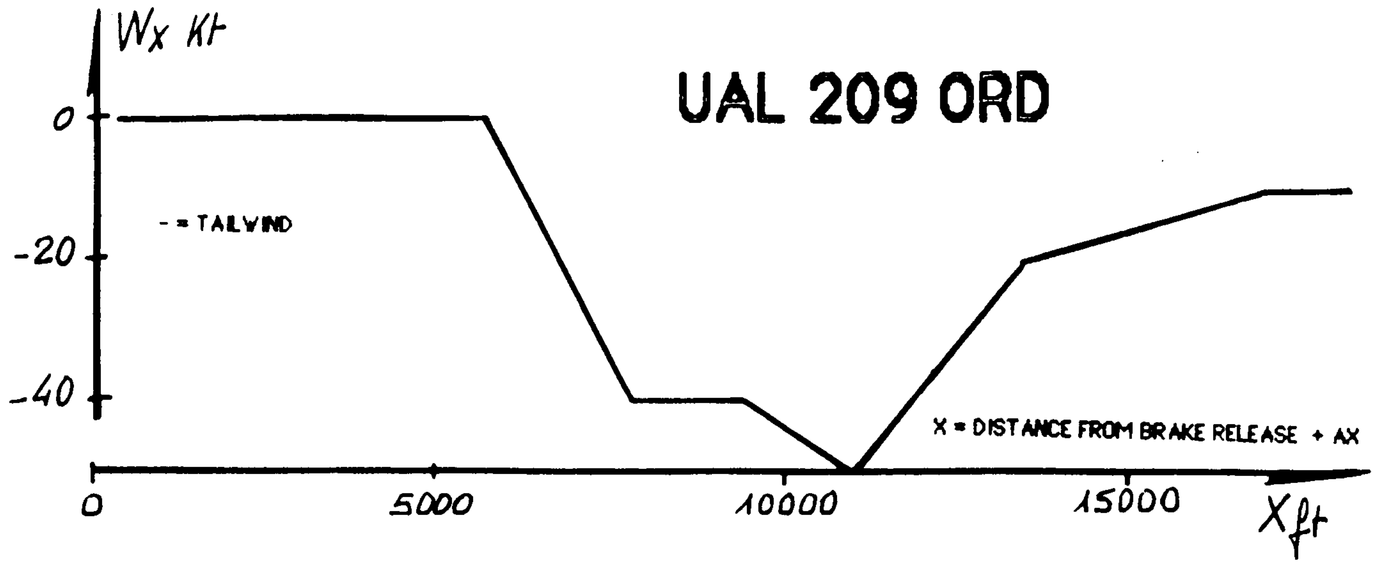
Nevertheless we have used as far as possible the windshear phenomenon knowledge for detection with sufficient credibility.

LOW ALTITUDE WINDSHEAR PROBABILITY

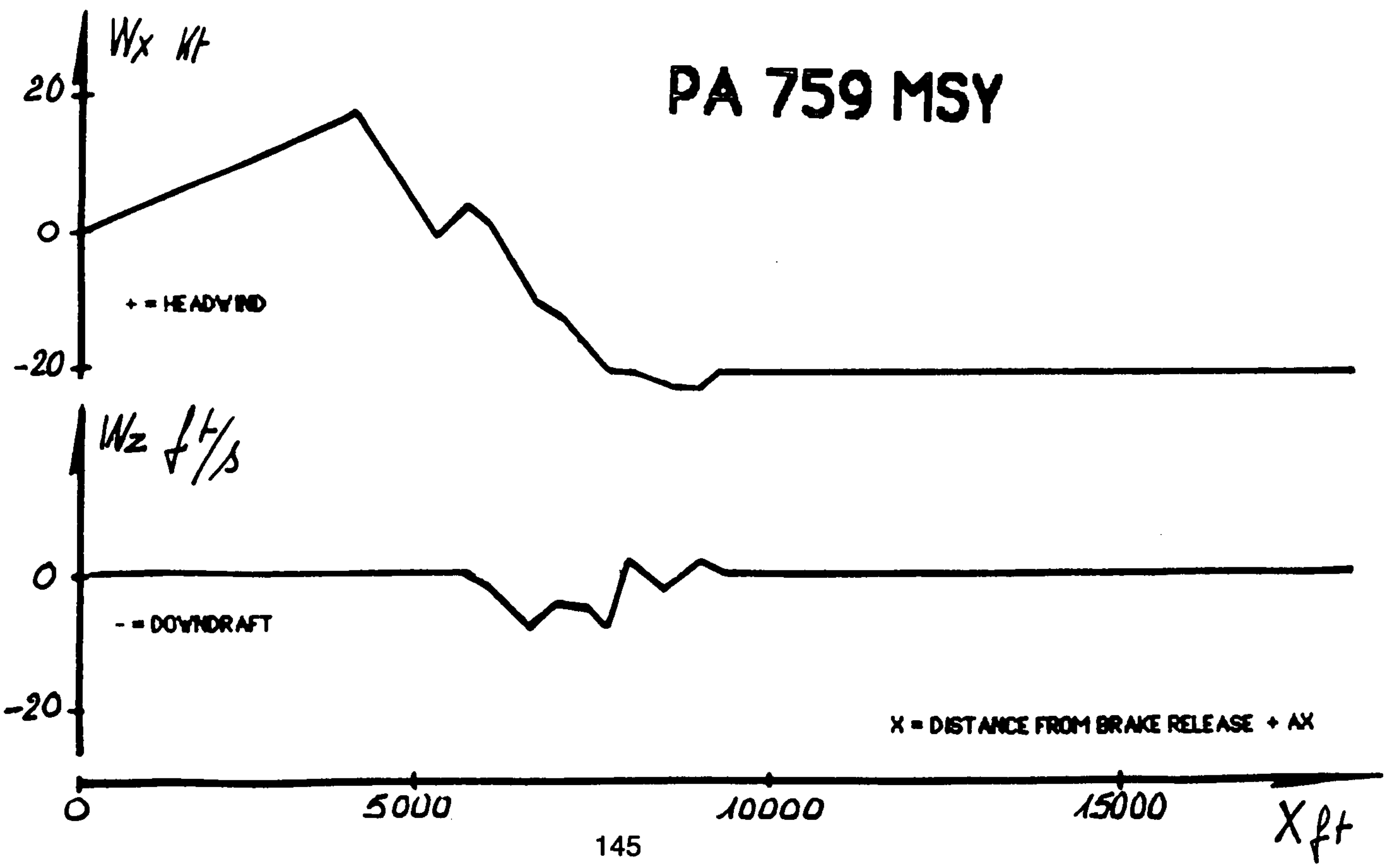
* From NTSB 28 accidents/incidents due to windshear in 1964-1983 period.

* About 3000 US AC Performs 5,000,000 take off or landing each year.

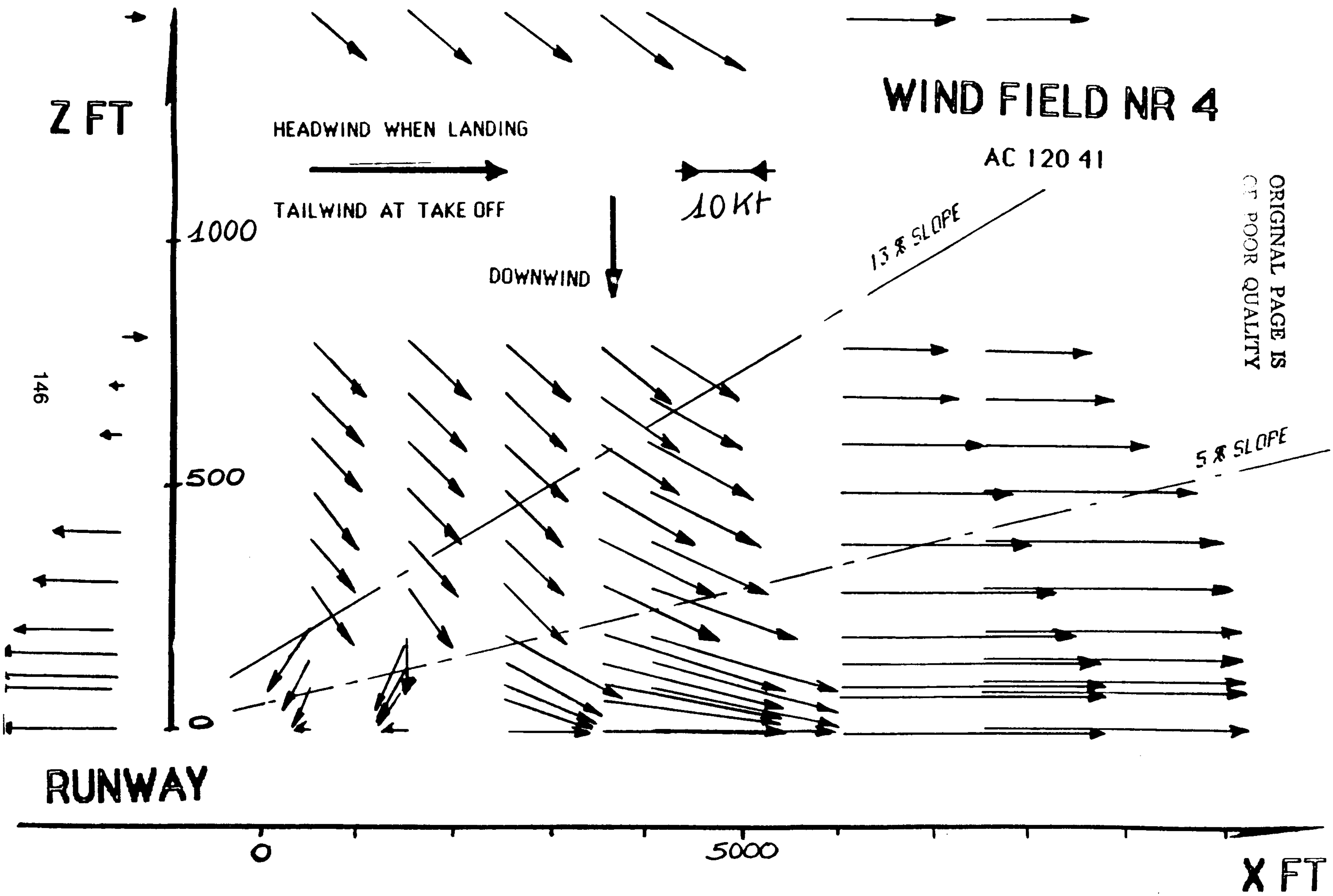
* Probability of severe low altitude windshear $\approx 10^{-6}$



UAL 209 ORD
Wx Kt
0
-20
-40
- = TAILWIND
X = DISTANCE FROM BRAKE RELEASE + AX
0
5000
10000
15000
X ft



PA 759 MSY
Wx Kt
20
0
-20
+ = HEADWIND
Wz ft/s
0
-20
- = DOWNDRAFT
X = DISTANCE FROM BRAKE RELEASE + AX
0
5000
10000
15000
X ft


WIND FIELD NR 4
AC 120 41
Z FT
HEADWIND WHEN LANDING
TAILWIND AT TAKE OFF
DOWNWIND
10 Kt
13 % SLOPE
5 % SLOPE
1000
500
0
RUNWAY
0
5000
X FT

* SHEAR SEVERITY FACTOR

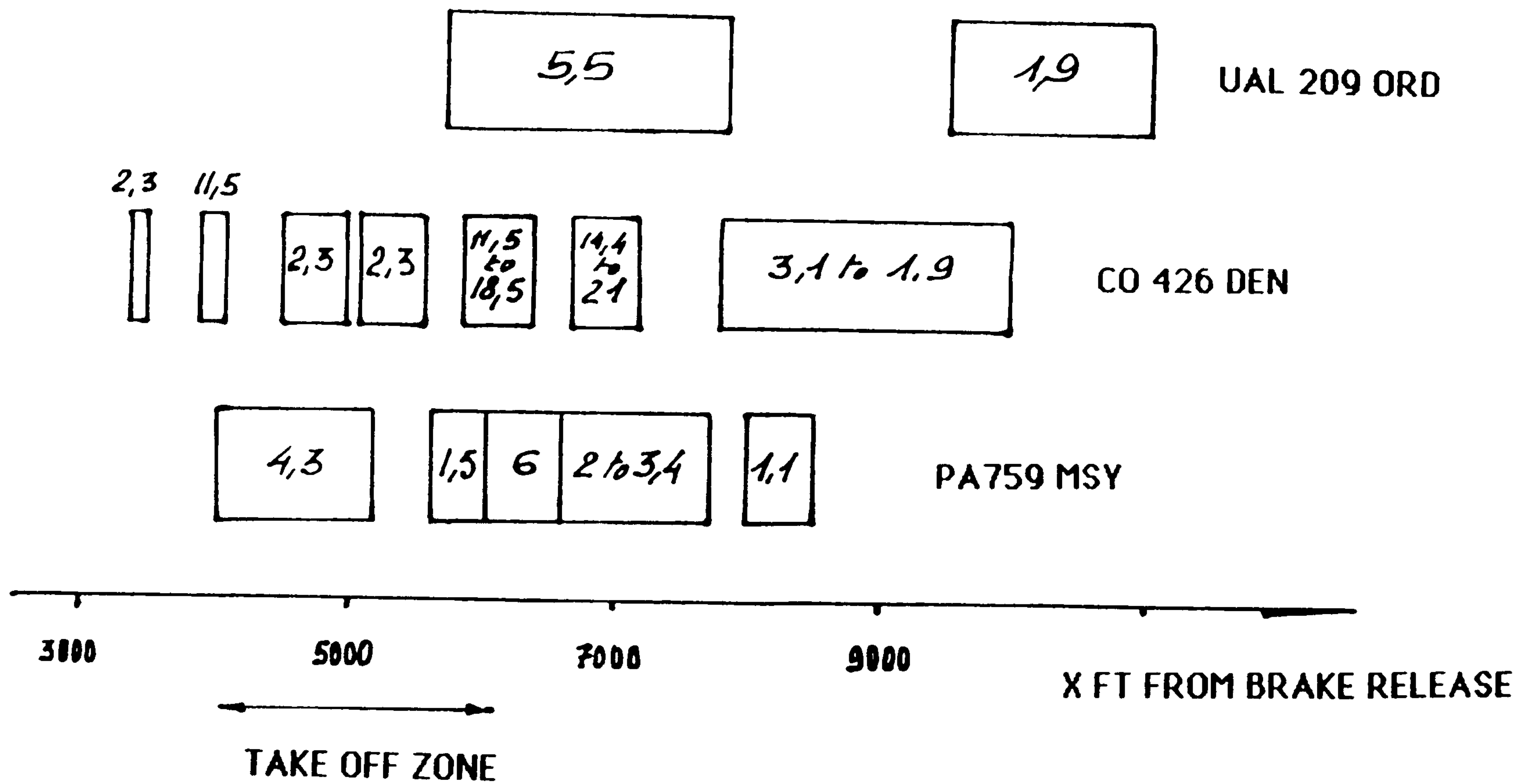
$$dE/dt = M * [\ C^{te} - Vx_{air} * \mathring{W}_X + g * W_Z\ ]$$

$$SF = [\ \mathring{W}_X - g/Vx_{air} * W_Z\ ]_{Lim\ {}^{+}_{0}}$$

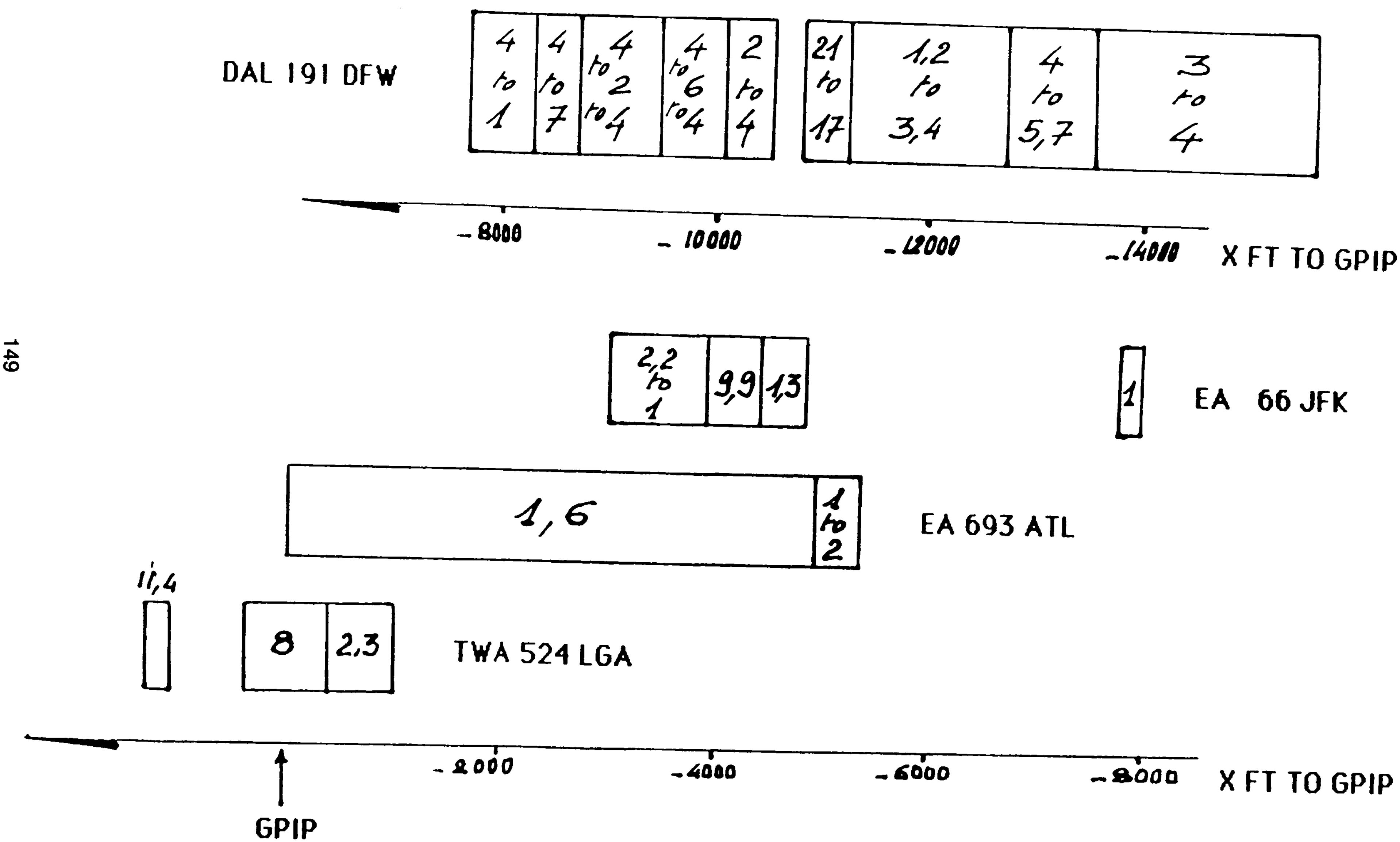
headwind < 0   downdraft < 0

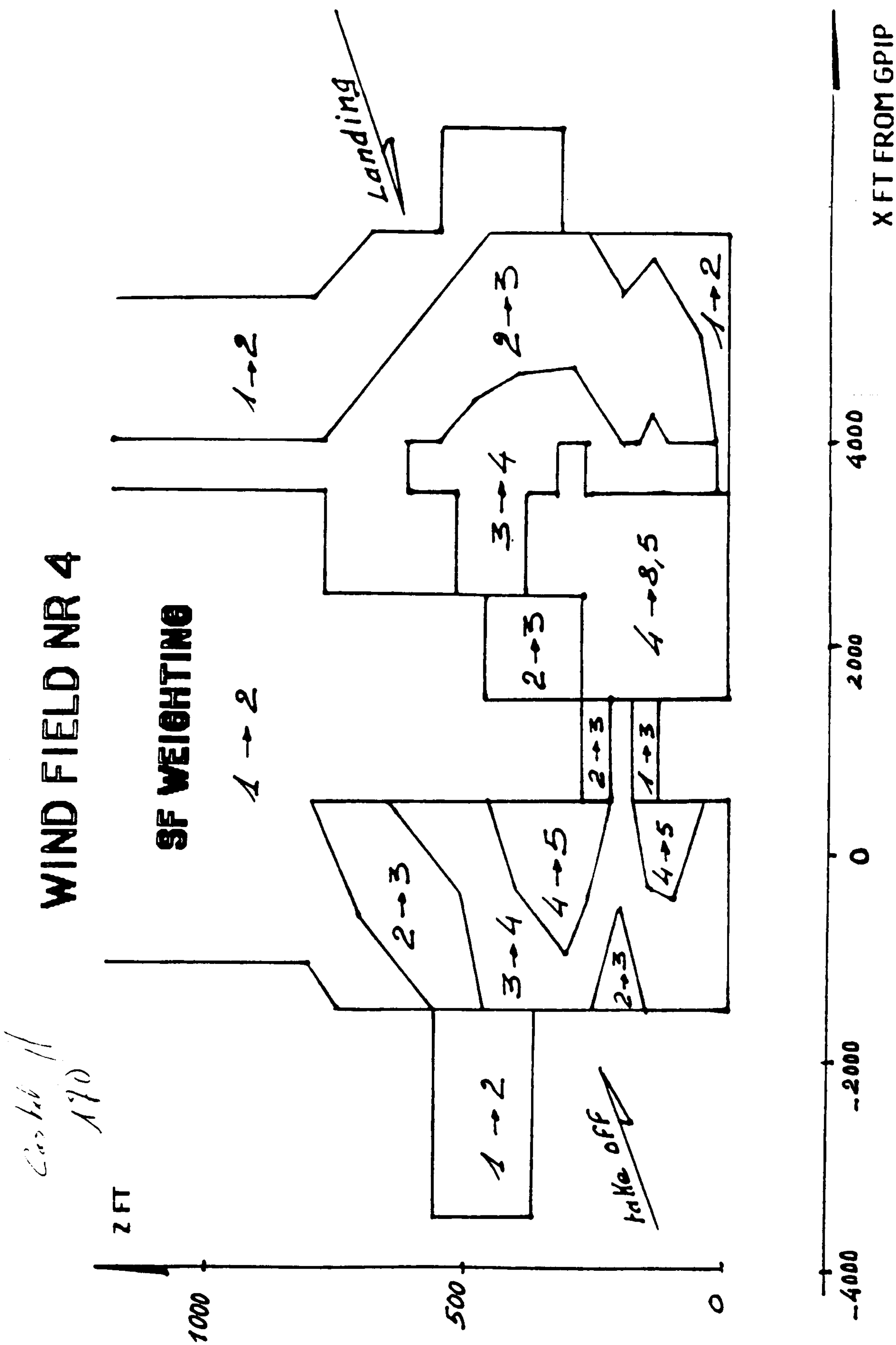
SF is in Kt/s

SF IN TAKE OFF CASES



SF IN LANDING CASES





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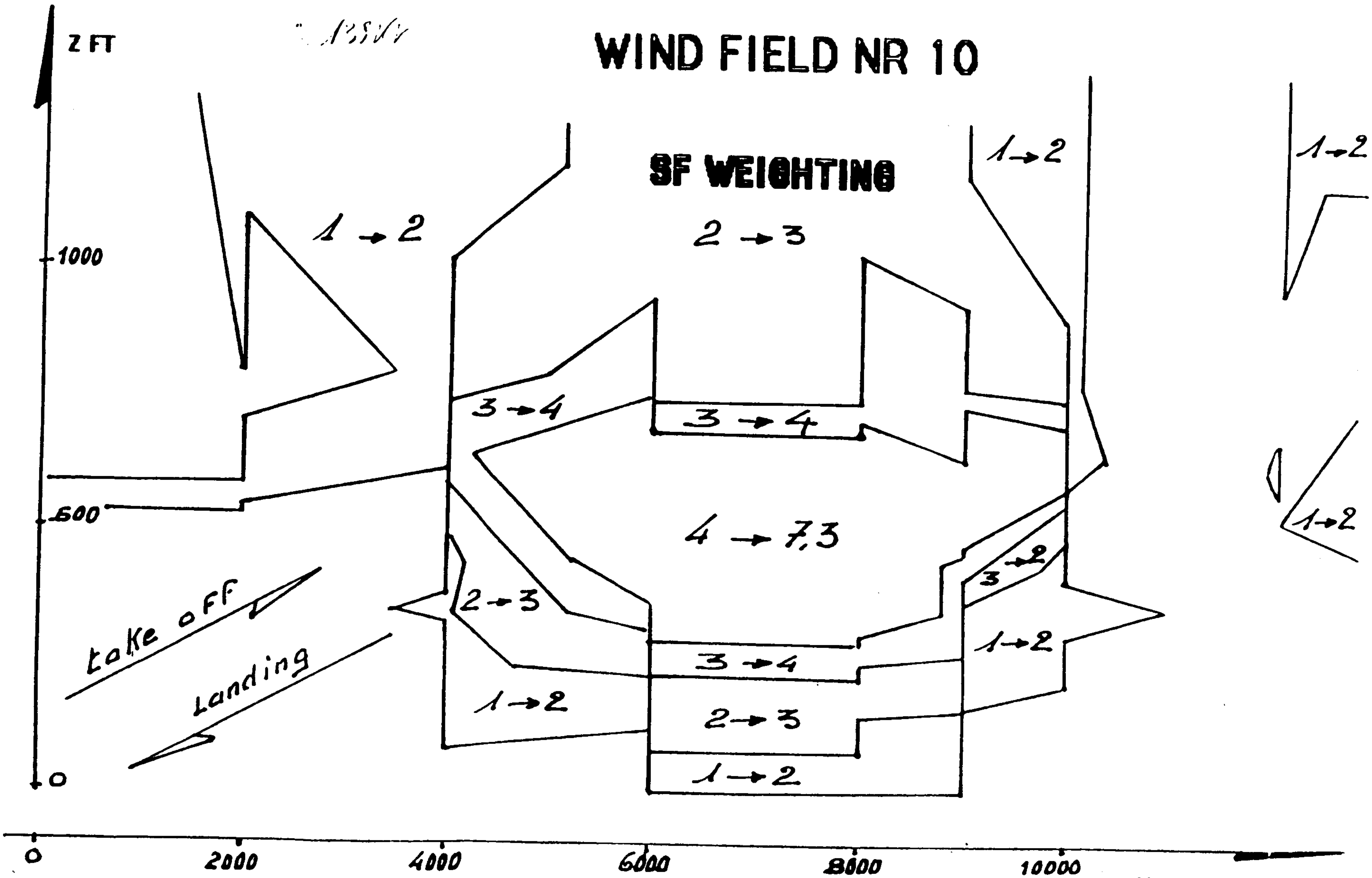
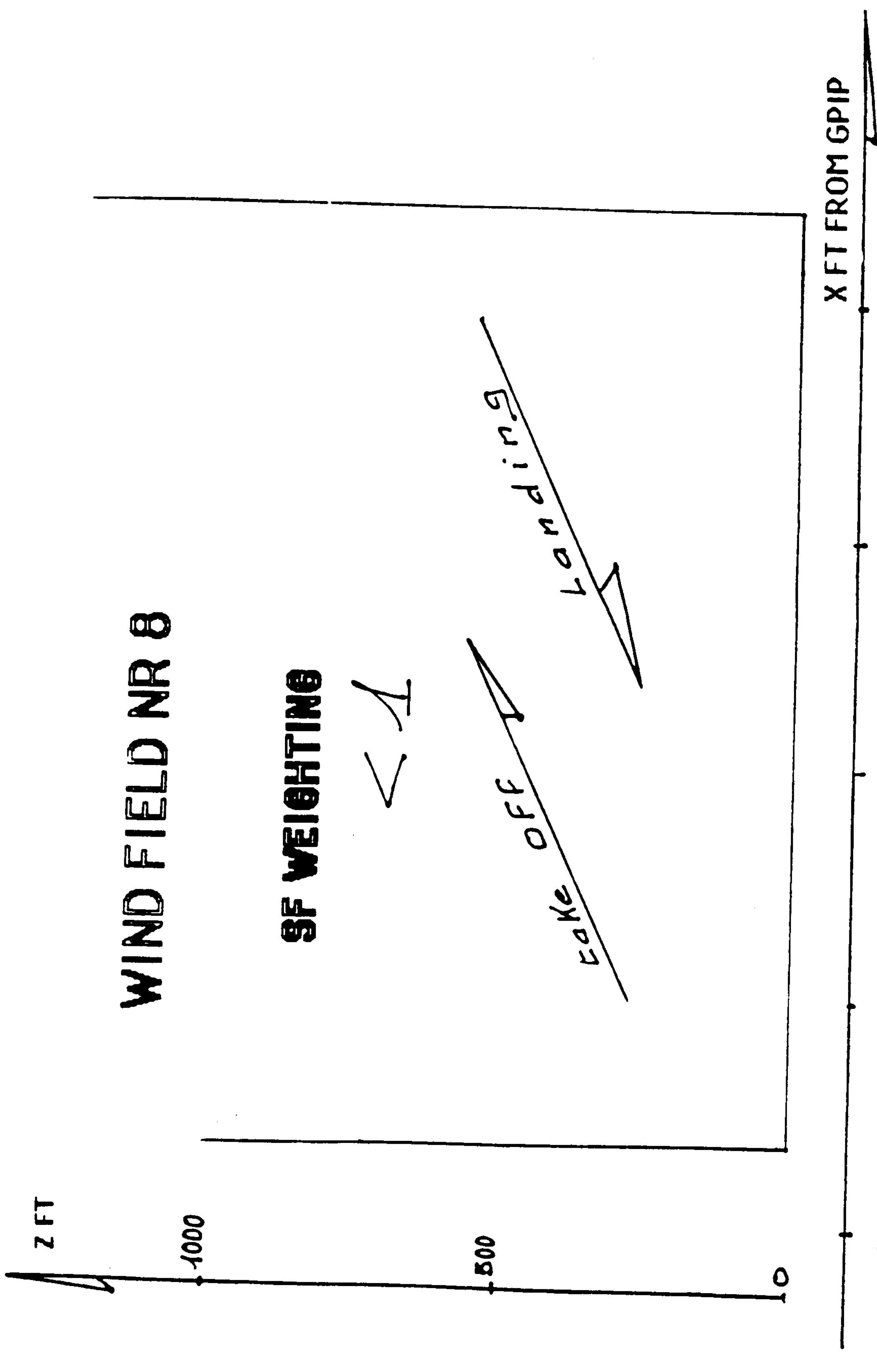
WIND FIELD NR 10




WIND FIELD NR 8
SF WEIGHTING
< 1
take off
Landing
Z FT
1000
500
0
X FT FROM GPIP
-4000
-2000
0
2000
4000

AC 120-41 Wind Fields

		4	6	7	8	9	10
T. OFF	UAL 209 ORD $P \approx 10^{-6}$	+	+	−	−	−	≃
	CO 426 DEN $P \approx 10^{-6}$	≃	≃	−	−	−	−
	PA 759 MSY $P \simeq 10^{-6}$	+	+	−	−	−	+
Landing	EA 66 JFK $P \simeq 10^{-6}$	+	≃	≃ −	−	−	+
	DAL 191 DFW $P < 10^{-6}$	−	−	−	−	−	−
	EA 69 ATL $P > 10^{-6}$	+	+	≃	−	+	+
	TWA 524 LGA $P \simeq 10^{-6}$	+	≃	−	−	−	+

+ more severe

− Less severe

≃ equivalent

$P(W.F)$?

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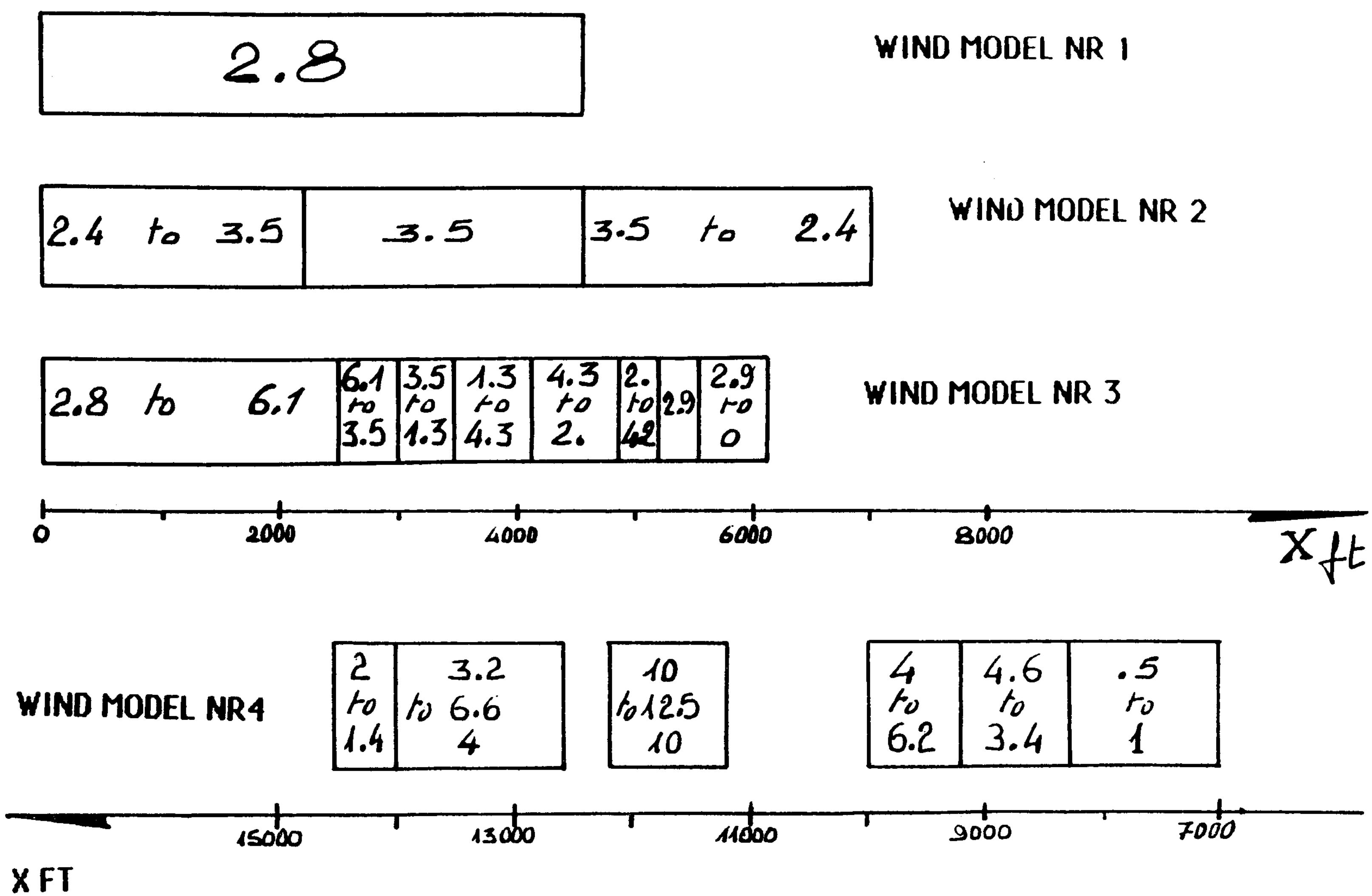
SF IN WINDSHEAR TRAINING AID



AC 120-41

WINDSHEAR TRAINING AID

	WM 1	WM 2	WM 3	WM 4
UAL 209 ORD 10^{-6}	≃	+	+	
CO 426 DEN 10^{-6}	−	−	−	
PA 759 MSY 10^{-6}	≃	+	+	
EA 66 JFK 10^{-6}				+
DAL 191 DFW $<10^{-6}$				−
EA 69 ATL $>10^{-6}$				+
TWA 524 LGA 10^{-6}				+
Wind Field Nr 4 10^{-6}	−	−	−	+
" Nr 6 10^{-6}	−	≃	−	+
" Nr 7 $>10^{-6}$	+	+	+	+
" Nr 8 $>10^{-6}$	+	+	+	+
" Nr 9 $>10^{-6}$	+	+	+	+
" Nr 10 10^{-6}	−	−	−	−

\+ more severe — less severe

$$WSF = \int_{X_{start}}^{X_{stop}} SF \, dx \quad \text{in } Kt/s \times ft$$

$$PSF = \frac{WSF}{|X_{stop} - X_{start}|} \quad \text{in } Kt/s$$

	UAL 209 ORD	14000	2.7
	CO 426 DEN	25000	4
	PA 759 MSY	12000	2.7
Windshear training aid	Wind Model Nr 1	12000	2.8
	Wind Model Nr 2	22000	3.1
	Wind Model Nr 3	22000	3.5
	Wind Model Nr 4	27000	3.7
	DAL 191 DFW	32000	4.1
	EA 66 JFK	7000	3.8
	EA 693 ATL	8000	1.6
	TWA 524 LGA	9000	4.2
AC 120.41	Wind Field Nr 4	28000 32000	3.2 3.8
	Wind Field Nr 6	24000 27000	4 4.5
	Wind Field Nr 10	26000 28000	4.3 4.6

in windshear training aid wind models $K_W = 1$.

take off speed = 170 Kt Landing speed = 135 Kt

WS Warning System Targets

Performance

- Detect 10^{-6} or $< 10^{-6}$ cases

- If no detection show the good behaviour of the aircraft

Nuisances

- Warning due to Active Failure
  AC 25 XX

- Lack of Warning due to Latent Failure
  AC 25 XX

- due to performance
  10^{-6} (Landing case)

Wind Shear Warning

The Aerospatiale Approach

- Compare shear and vertical wind intensity with AC energy and safe minimal energy
- Sensitize energy thresholds when short period head wind increases
- Desensitize energy thresholds in constant wind if thresholds are sensitized
- Means angle of attack (measured or estimated (V,Weight,CLaoa,Nz...)) ground speed,true air speed,vertical speed,pitch attitude,f/s position ,altitude

PATENT PENDING

PATENT PENDING

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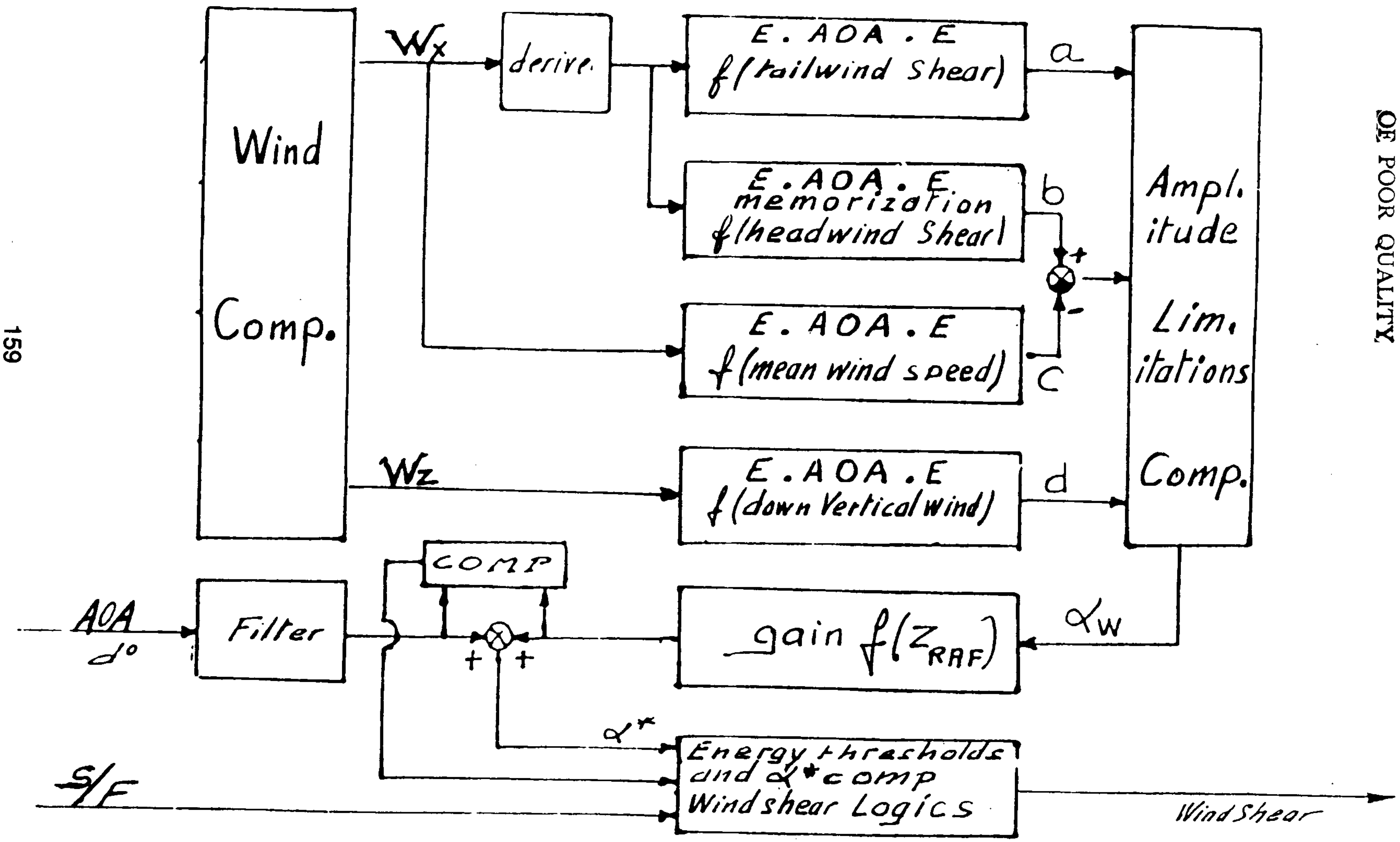
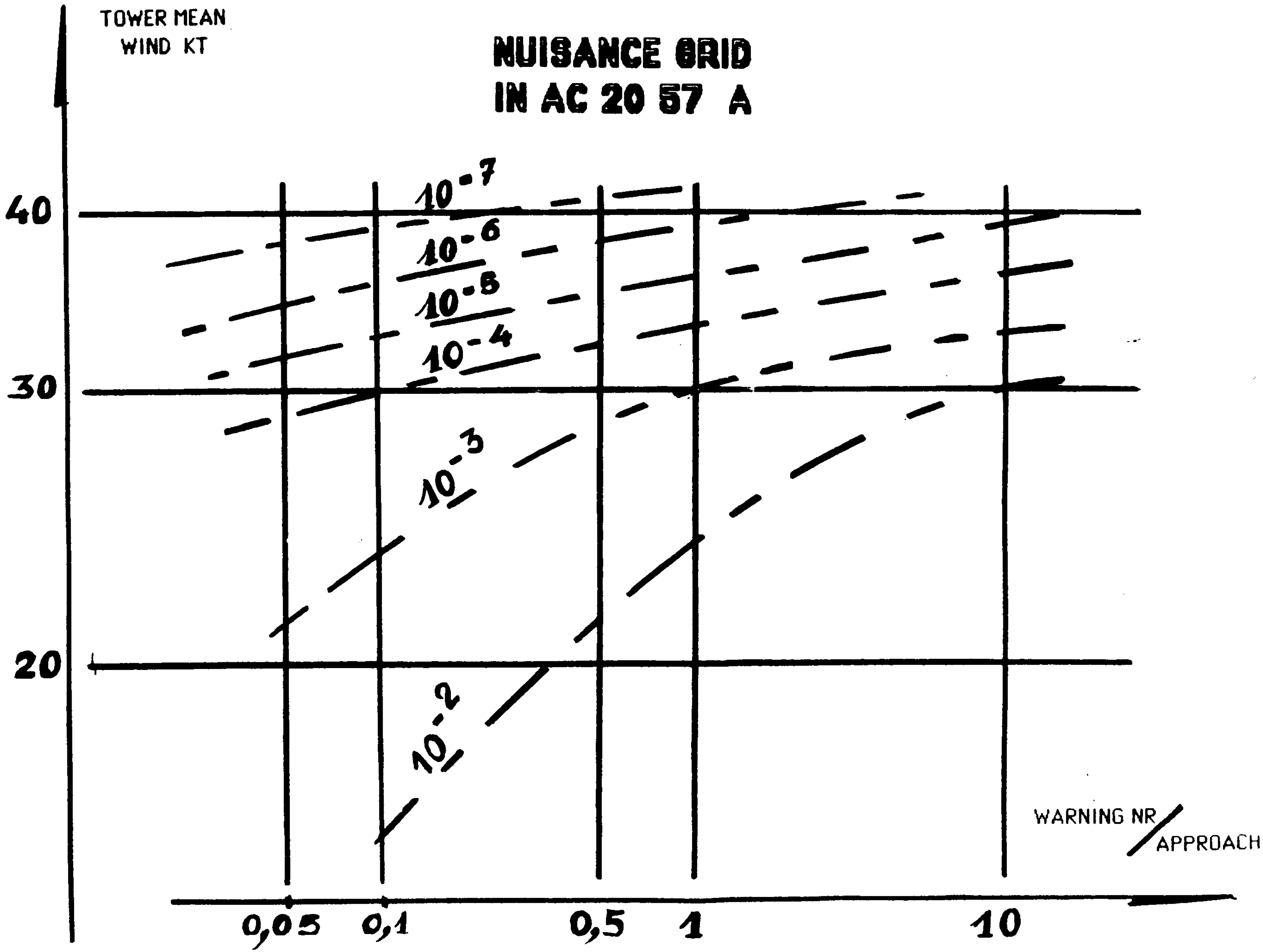
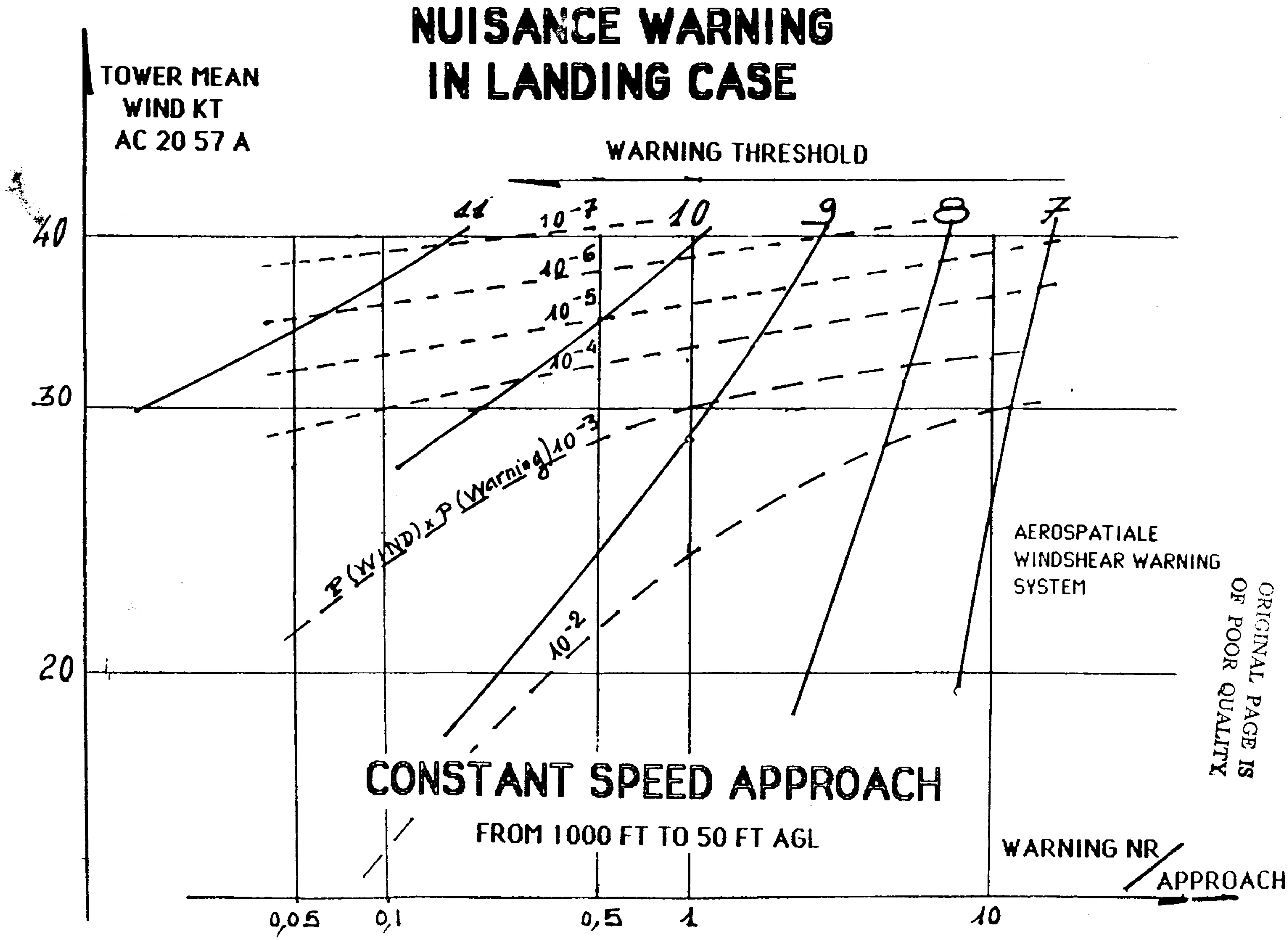
E°AOA°E = EQUIVALENT AOA ESTIMATE



AEROSPATIALE WINSHEAR WARNING COMPUTATION PRINCIPLE

NUISANCE GRID IN AC 20 57 A





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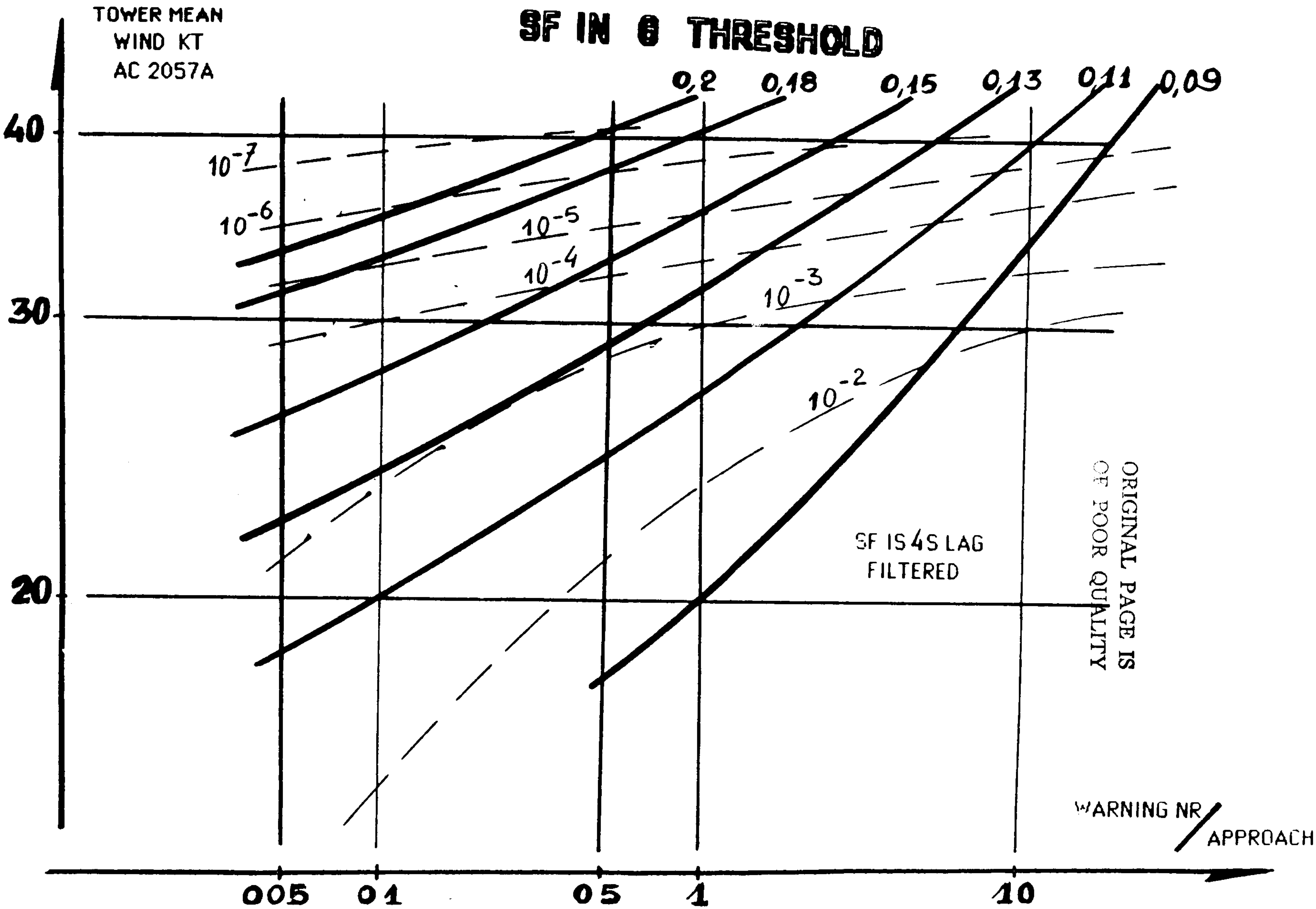

SF IN 6 THRESHOLD
TOWER MEAN
WIND KT
AC 2057A
0,2
0,18
0,15
0,13
0,11
0,09
40
30
20
10^{-7}
10^{-6}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
SF IS 4S LAG
FILTERED
WARNING NR / APPROACH
005
01
05
1
10

QUESTIONS AND ANSWERS

KIOUMARS NAJMABADI (Boeing) - I would like to know if the alert criteria is based on energy rate of change or is it based on energy margin?

J.L. BONAFE (Aerospatiale) - Both. Just a moment. [Pointing to viewgraph] The minimal energy is defined by the threshold you have here. That is right. But, you increase your energy taking your angle of attack, considering the derivative of the horizontal shear, and the vertical shear. So you increase your energy estimate by the shear estimate. You don't compare only the energy threshold and the incidence estimate. It is a, sort of, rate increase in energy. Okay?

KIOUMARS NAJMABADI (Boeing) - So what you are saying is you are estimating your energy loss based on your energy rate of loss and then you are comparing that with your margin, am I correct?

J. L. BONAFE (Aerospatiale) - Yes. This is the way it is implemented.

N88-17621

Windshear Detection
Effect Of
Static Air Temperature Bias

Howard Glover

Sundstrand Data Control, Inc.
REDMOND, WASHINGTON 98073-9701
unit of Sundstrand Corporation

Reactive Windshear Detection

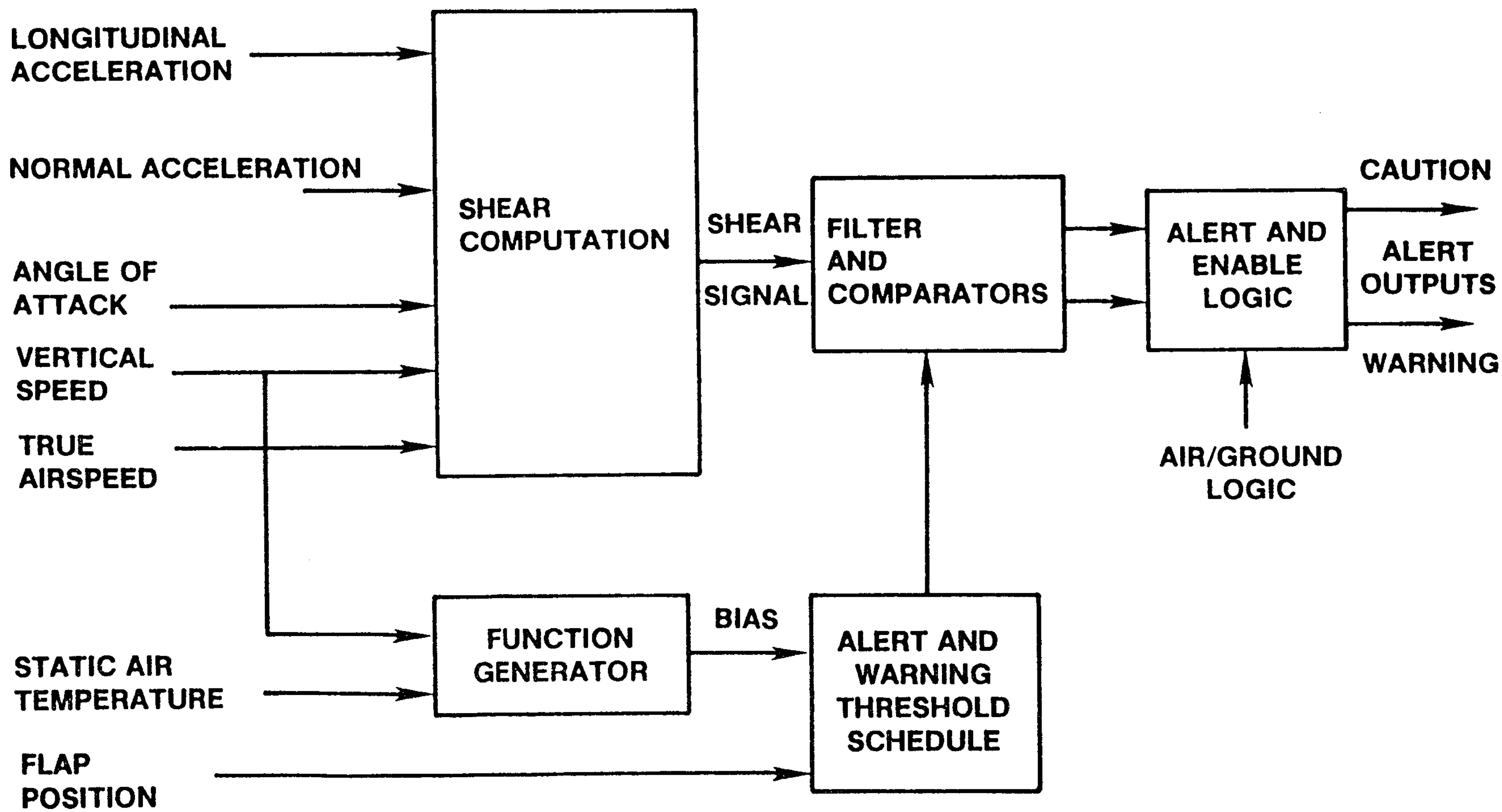
DETECTION TECHNIQUES:

- Aircraft Response To Windshear
- Atmospheric Parameters
- Combination Of Above

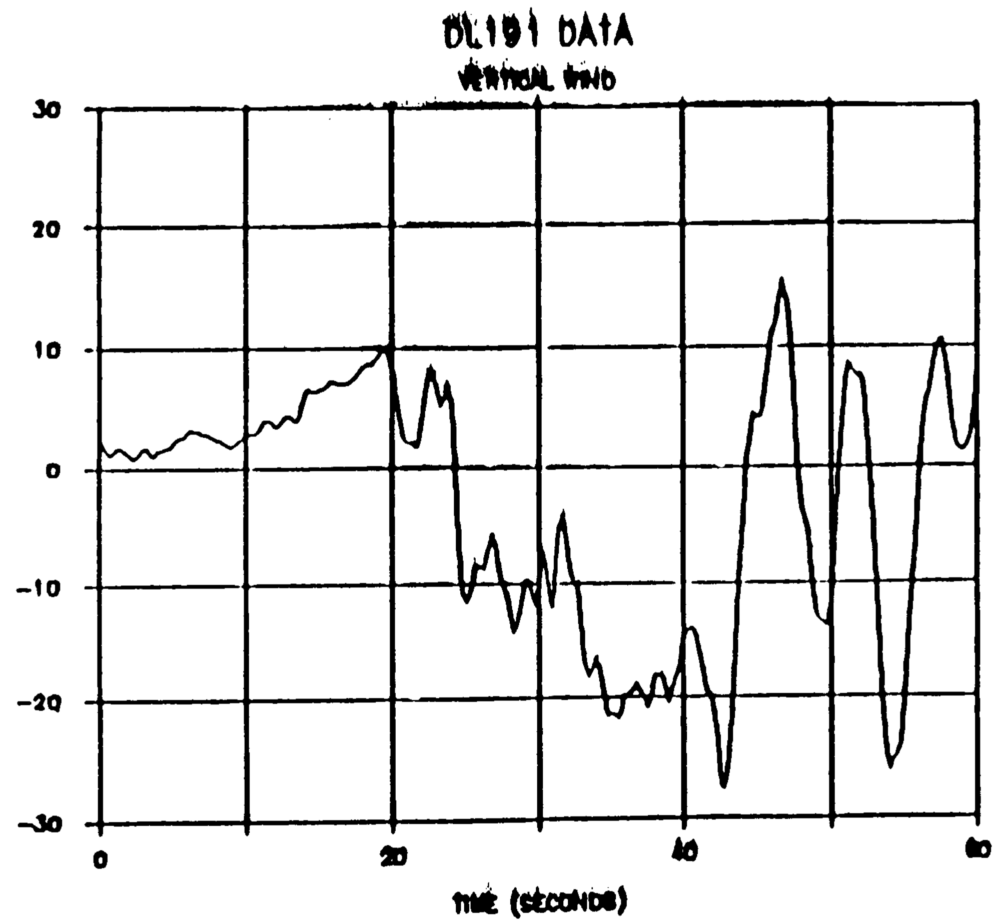
PERFORMANCE CRITERIA:

- Alerts In Time For Successful Escape
- No Unwanted Alerts

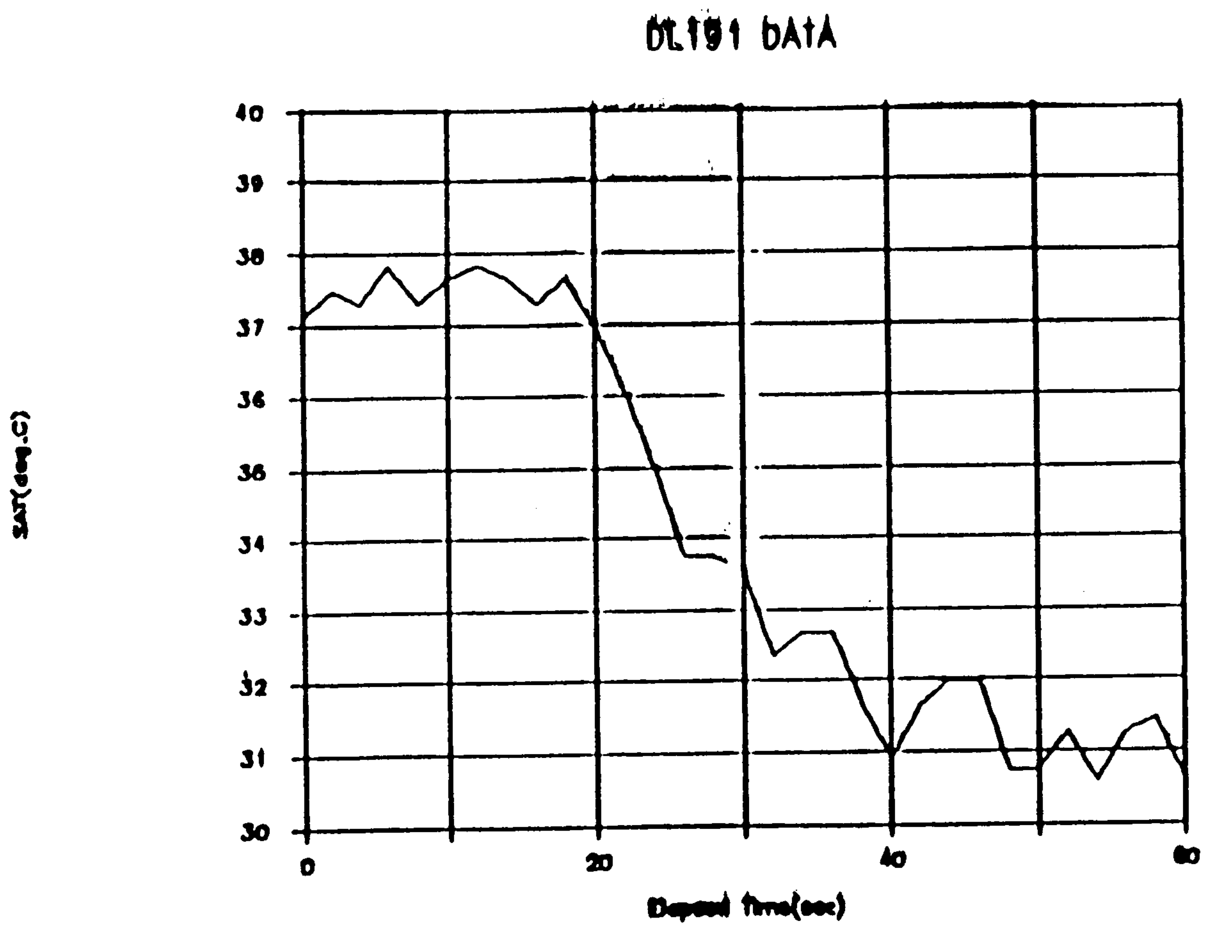
Sundstrand Windshear Detection Algorithm
BLOCK DIAGRAM



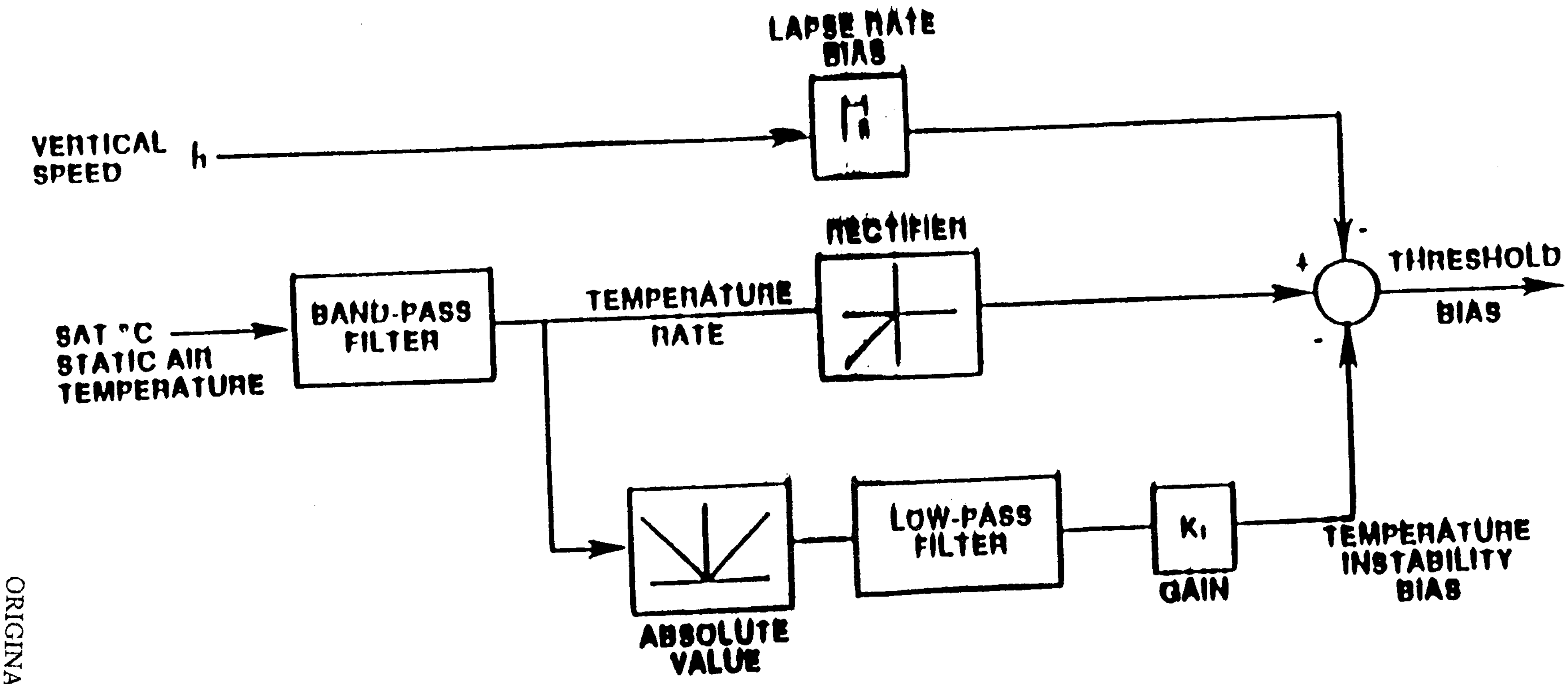
DL191 Vertical Winds



DL191 Temperature Data



Atmospheric Temperature Bias Function



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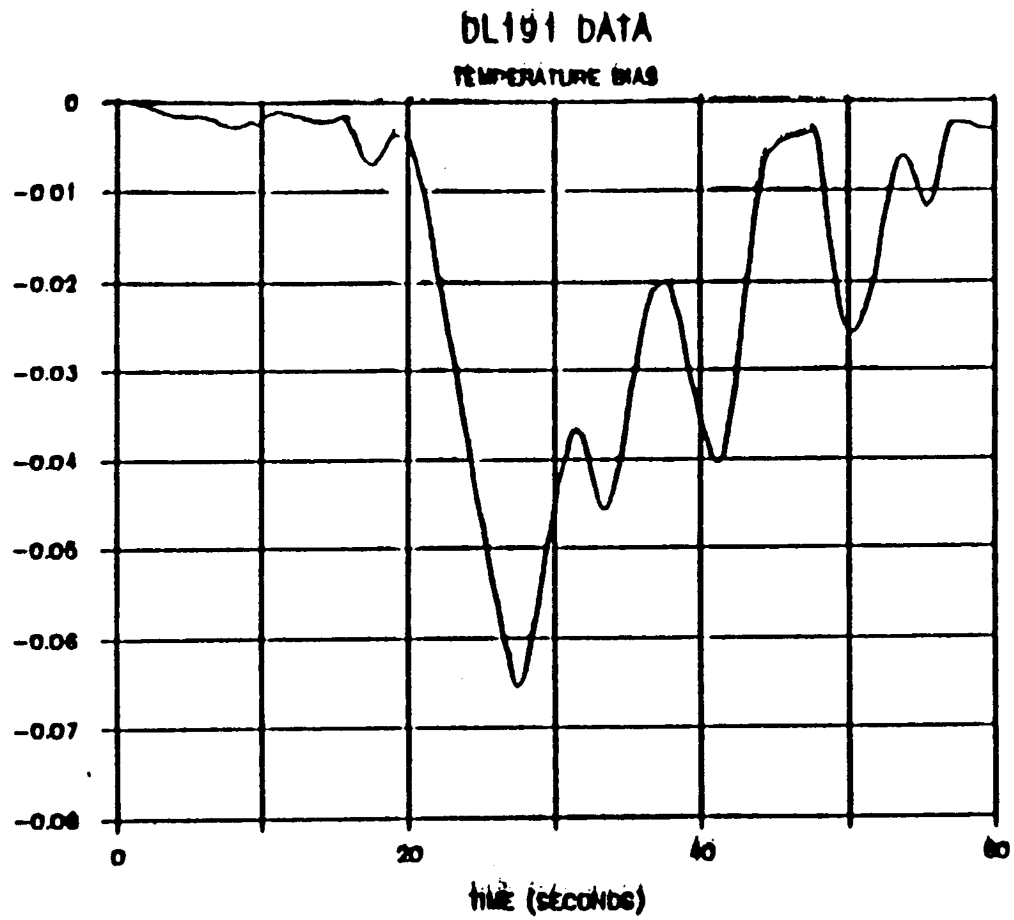
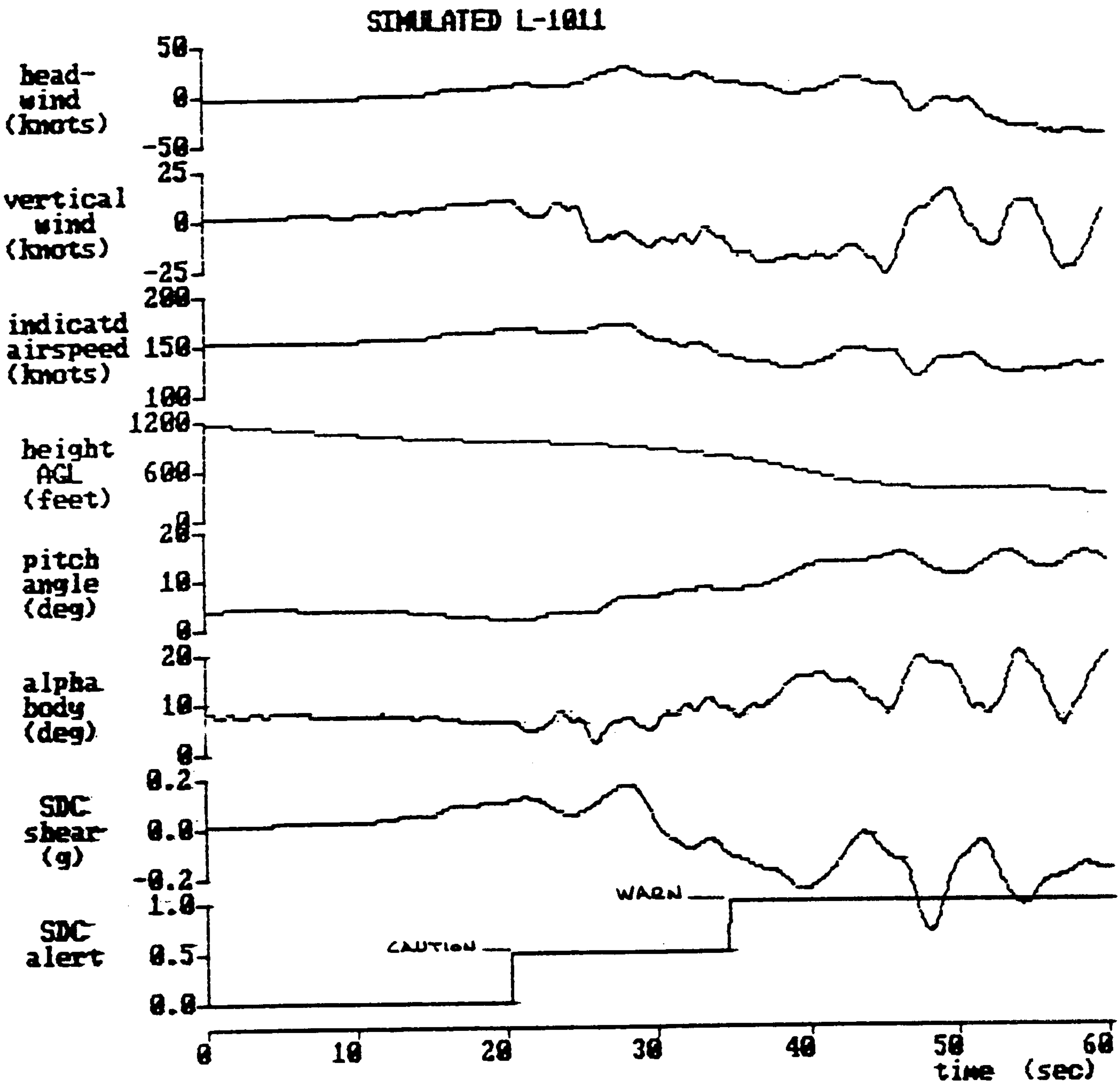
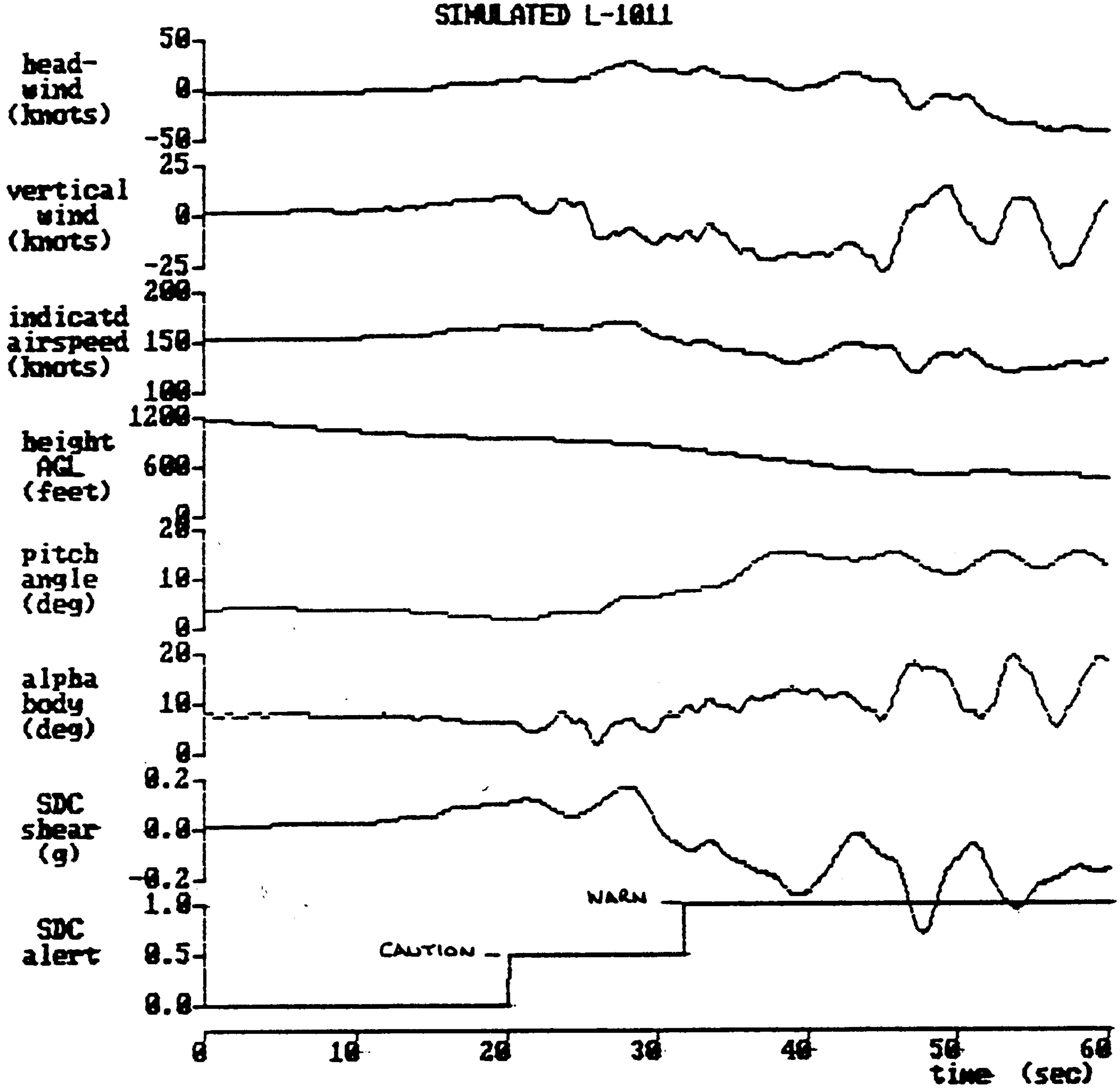
Temperature Bias Output





Simulation Without

Temperature Bias



Simulation With

Temperature Bias

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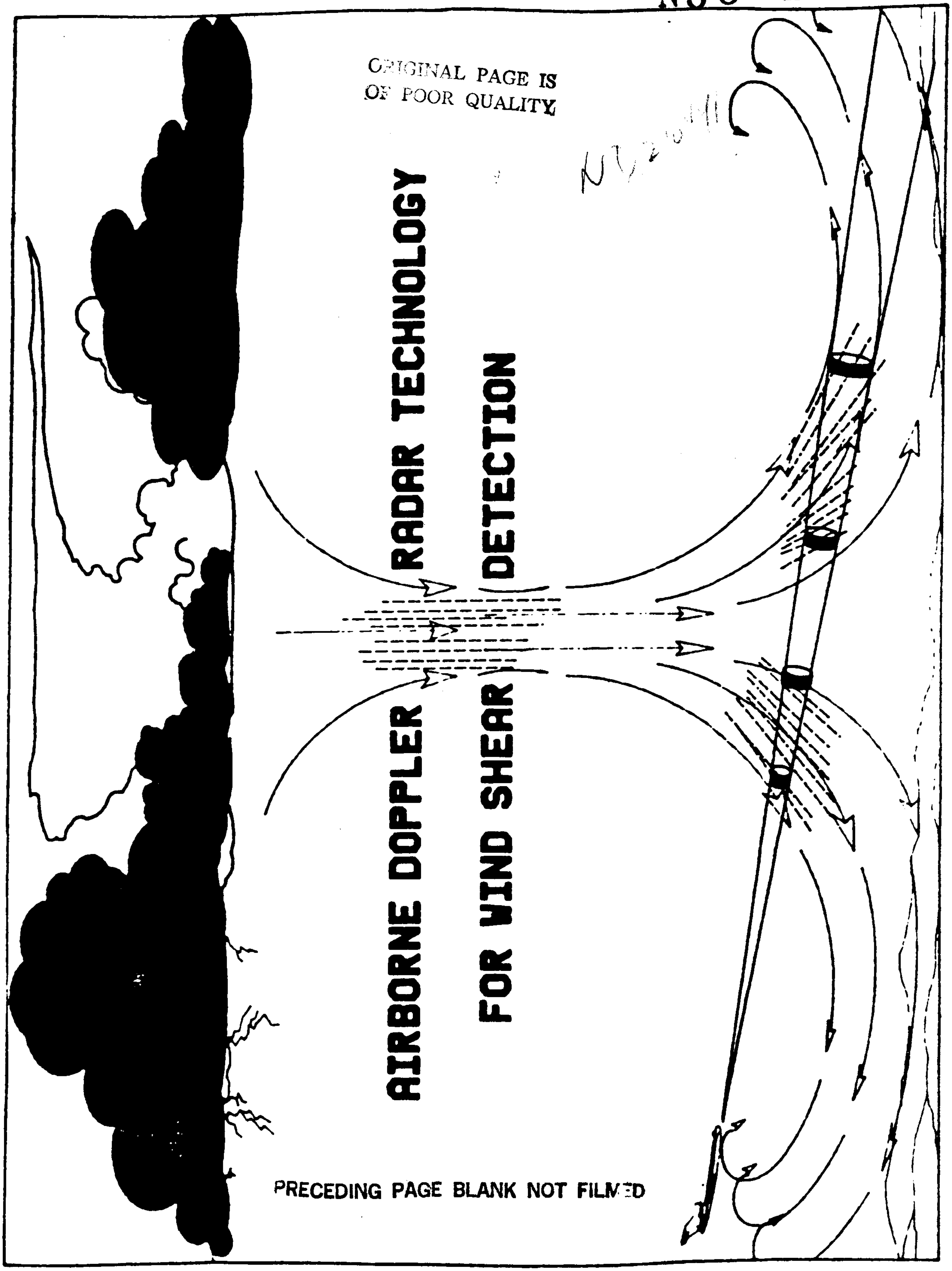
Conclusions

- Using Data From Dallas Accident:
  - Ratio Of Wanted/Unwanted Warnings Improved By Using Temperature Bias
- Need More Data
  - Variation Of Static Air Temperature During Normal Airline Takeoffs And Landings
  - Temperature Data For Windshear Related Incidents And Accidents
- Encourage Airline/Industry Data Collecting Program

JIM EVANS (MIT Lincoln Lab) - In the back of the handout that you will get tomorrow that Mark's talk, will be some of the TDWR results. You know there have been a lot of people who have been looking at mesonet data associated with microburst, surface sensors where they do get delta T versus velocity. I would say that it is far from a clear picture that you can always count on temperature drops. There was a little hint of that in Fred's discussion today. You know, at one point he showed a curve that showed a big thing but on the other hand there were some other situations where you wouldn't get much of a temperature change and in fact, I would say that this mesonet data, shows some temperature decrease, but it is certainly not enough that I would run around arguing that you could clearly reduce your threshold by the amount you've assumed under that circumstance. I think in the case of the planes, I am not quite sure you get data out of a plane when a plane crashes but that is a very small number of events and probably doesn't reflect the total situation.

HOWARD GLOVER (Sundstrand) - What we also need however, is data in turbulence but not severe wind shear. Boeing conducted a survey using just that kind of approach, but they were measuring essentially the F factor and at that time data on temperature wasn't gathered. Data on accelerations was, also rates of change of energy. We need something like that to leave gust turbulence in, or to disprove the usefulness of a feature like this.


AIRBORNE DOPPLER RADAR TECHNOLOGY
FOR WIND SHEAR DETECTION

OBJECTIVES OF THE AIRBORNE DOPPLER RADAR TECHNOLOGY DEVELOPMENT PROGRAM

- Quantify Physical Influences and Required Performance Bounds for Useful Airborne Doppler Radar Detection of Low Altitude Wind Shear.

- Develop Analysis Tools Which Can Provide a Basis for the Evaluation and Analysis of Prototype Airborne Radar Designs that can lead to Eventual Certification.

- Design/Procure Appropriate Experimental Hardware and Structure an Experimental Flight Program with wide Government/Industry Support to Evaluate and Verify Airborne Detection and Measurement Techniques.

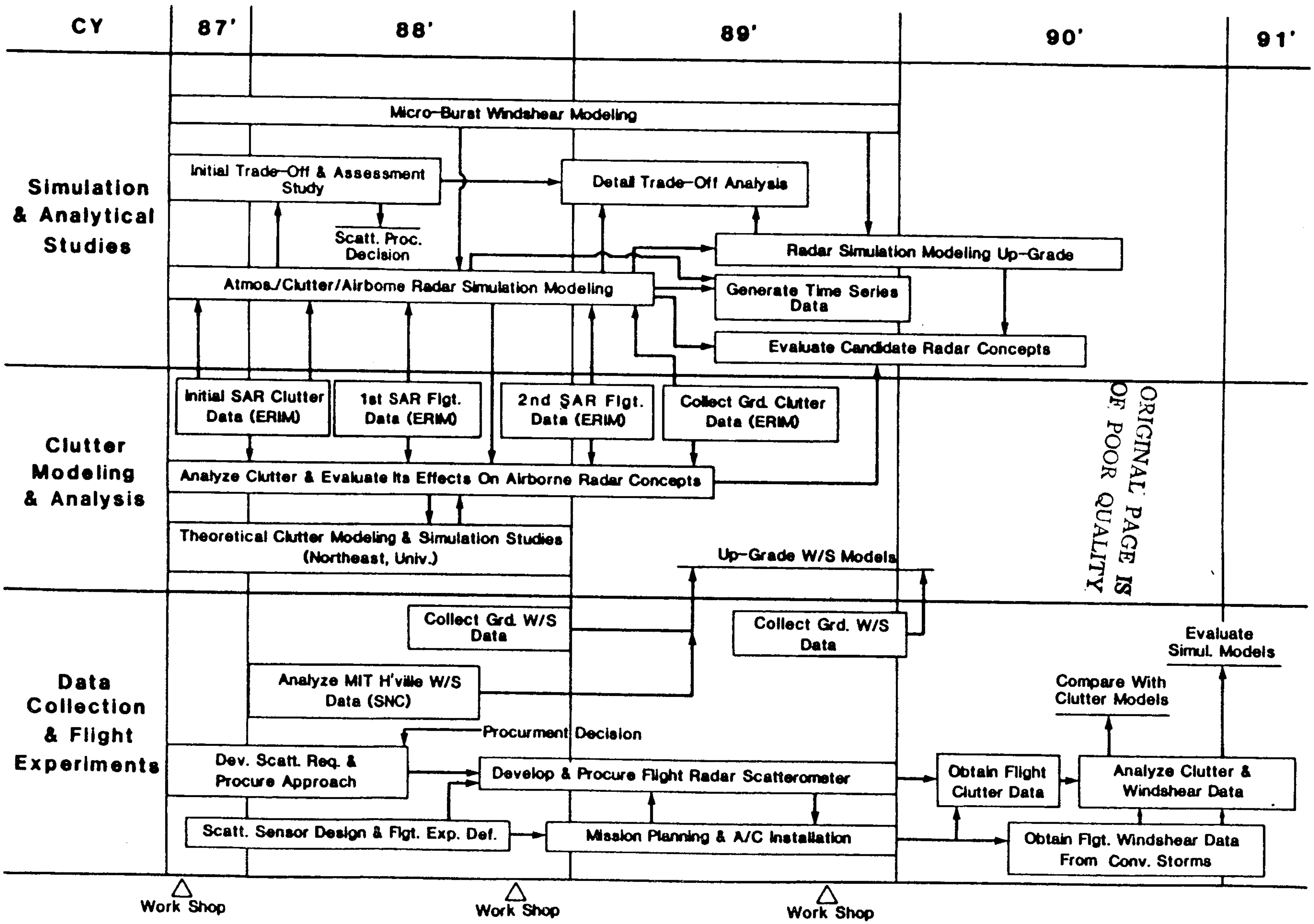
TECHNICAL APPROACH

- SIMULATION AND ANALYTICAL STUDIES
  - –Develop Atmos./Clutter/Airborne Radar Simulation Computer Programs.
  - –Conduct Parametric Trade–Off Studies
  - –Generate Simulated Time Series Radar Data For Industry Applications
  - –Evaluate Candidate Radar Concepts
- CLUTTER MODELING AND ANALYSIS
  - –Generate Clutter Backscatter Maps for use in the Radar Simulation Program
  - –Obtain Actual Synthetic Aperture Radar (SAR) Clutter Data for use in the Backscatter Maps
  - –Using the SAR Clutter Map Data Conduct Studies to Determine the Effects of Clutter on the Performance of Radar Concepts
  - –Adapt and Apply Theoretical Clutter Simulation Models to Aid in Understanding the Full Clutter Environment
- DATA COLLECTION AND FLIGHT EXPERIMENTATION
  - –Collect and Analyze Ground Based Radar Windshear Data
  - –Develop an Airborne Radar Scatterometer Instrument
  - –Conduct Flight Experiments to Collect Airport Clutter Data and Windshear Data From Convective Storms. Use Data to Evaluate and Up–Grade the Atmos./Clutter/Airborne Radar Simulation Program.

STATUS

- INITIAL VERSION OF ATMOS./CLUTTER/AIRBORNE SIMULATION PROGRAM DEVELOPED
  - New Microburst Windfield & Clutter Map
  - Simulates Various Radar Characteristics
  - Incorporates Various Processing Techniques
  - Computes Various Radar Parameters
- VARIOUS DOPPLER RADAR SIGNAL/CLUTTER SPECTRUM ANALYSIS PERFORMED
- CONTRACT AWARDED TO ENVIRONMENTAL RESEARCH INSTITUTE OF MICH. (ERIM) FOR CLUTTER DATA
  - Survey Inventory of Existing SAR Data
  - Analyze & Process SAR Data & Provide Digital Images & Tapes of Backscatter Data
  - Conduct Ground & Flight Clutter Data Collection Using SAR
- NORTHEASTERN UNIV. GRANT UNDERWAY
  - Develop Theoretical Doppler Radar Clutter Simulation Program
  - Conduct Clutter Simulation Studies During Take-Off & Landing
- PRELIMINARY DESIGN OF EXPERIMENTAL RADAR SCATTEROMETER

AIRBORNE WINDSHEAR RADAR TECHNOLOGY PROGRAM



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N88-17623

Presented at
First Combined Manufacturers' and Technology
Airborne Wind Shear Review Meeting
October 22-23, 1987

RADAR BACKSCATTER FROM AIRPORTS AND SURROUNDING AREAS

Robert G. Onstott
Environmental Research Institute of Michigan
Advanced Concepts Division
Radar Science Laboratory
P.O. Box 8618
Ann Arbor, MI 48107
(313)994-1200

The description of the clutter environment encountered during runway approaches is important in the development of aircraft instrumentation to detect microbursts or severe low altitude windshear. The purpose of the effort described here is to provide a description of ground clutter at and near airports. Realistic clutter scenes will be assembled using high-resolution synthetic aperture radar (SAR) data for incorporation into the NASA LaRC Microburst Simulation Model.

The Environmental Research Institute of Michigan (ERIM) has assembled an extensive inventory of SAR data. The archive has been examined for data collected of airports at an X-band frequency, at angles near grazing, and from which accurate radar scattering coefficients may be extracted (i.e. data has been recorded digitally and includes calibration target arrays).

The Willow Run Airport located near Detroit, Michigan has been overflown many times over the last 15 years and will serve initially as the principle airport site. The first clutter scene has been assembled. These data were obtained on December 17, 1984. The depression angle is about 22 degrees and the antenna transmit-receive polarization is Vertical-Vertical (VV). Analysis has begun by identifying potential contributors to the clutter background at and near the airport. The range of cross sections in a 6 km x 12 km region about the airport is being examined. This will be further broken down into the various scatters and into categories of like scattering properties.

RS-87-087-1

RADAR BACKSCATTER FROM AIRPORTS AND SURROUNDING AREAS

Robert G. Onstott
Radar Science Laboratory
Advanced Concepts Division
Environmental Research Institute of Michigan

22 October 1987

PURPOSE

Describe Ground-Clutter Environment At and Near Airports

APPROACH

I. Examine Existing Synthetic Aperture Radar (SAR) Data Archive

II. Supplement with New SAR Data

III. Supplement with Surface-Based Scatterometer Data

RADAR PARAMETERS

Frequency = X-Band

Polarizations = Like and Cross

Angles = Near Grazing

STATUS

- Work Began 15 September 1987
- Kick-Off Meeting at LARC
- Data Archive Examined
- First Airport-SAR Image Created
- Clutter Analysis has been Started

DATA ARCHIVE

Have Selected Sites According To

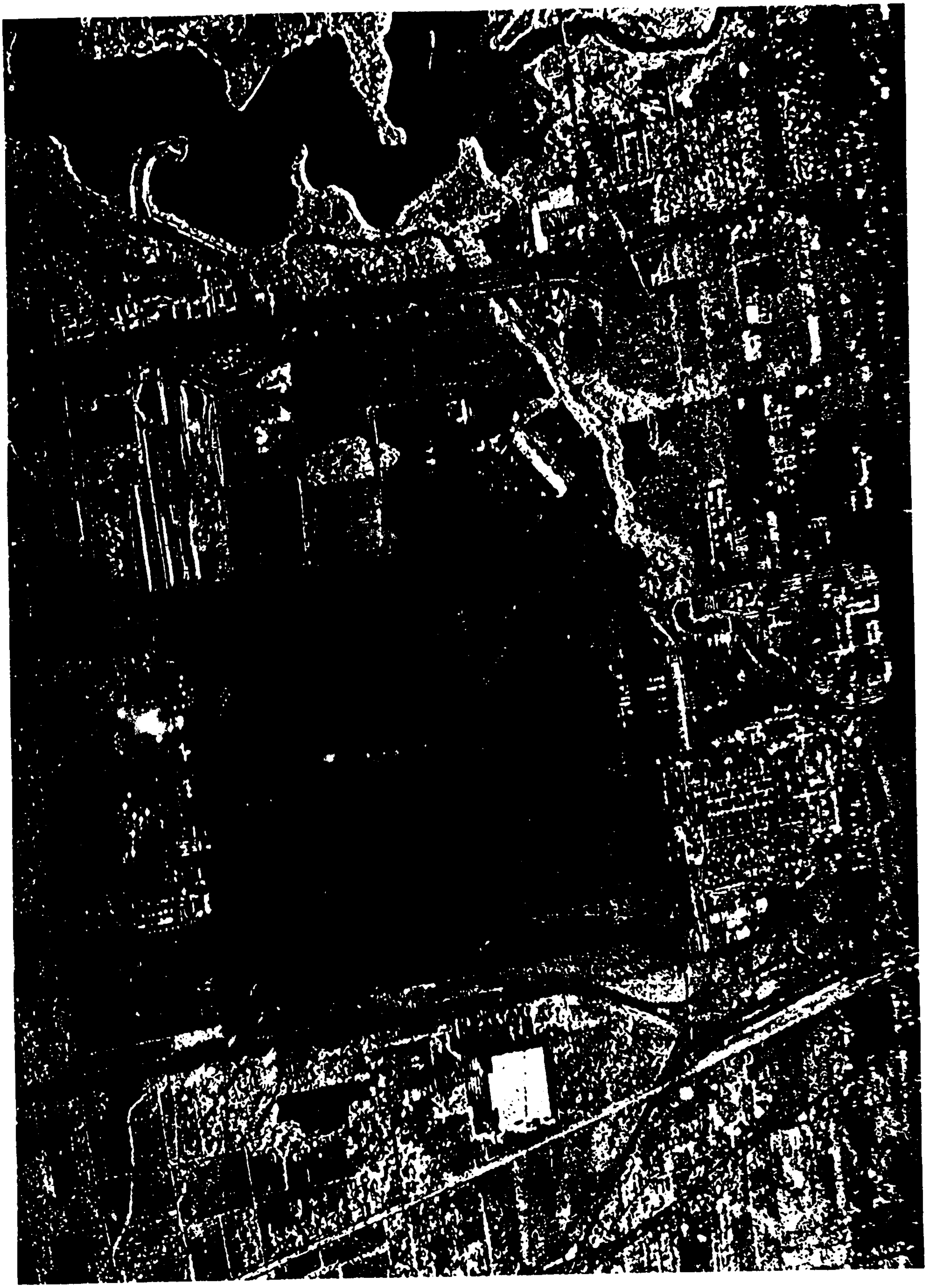
- Airports
- Digitally Recorded Data
- X-Band Frequency
- Calibration Targets are Present

Possible Airport Sites

Willow Run, Detroit, Michigan (principal site)
Peconic River Airport
Victoria, British Columbia

Radar Parameters

Angle = 10° to 20° (grazing)
Polarization = VV, VH, HV, HH



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CLUTTER SCENES

Airport:

- Instrumentation
  - Anemometer
  - VOR
  - Glide Slope
  - Beacons
  - Antennas
  - Towers
- Buildings
- Runways
- Grass Covered Fields
- Aircraft Parked, Taxiing & Landing
- Ground Vehicles Parked and Moving
- Trees
- Fences

CLUTTER SCENES
(Continued)

Surrounding Areas:

- Vehicles Traveling on Adjacent Highways
- Urban, Residential, Commercial and Industrial
- Trees, Woodlands and Forest
- Fences
- Trains
- Lakes, Rivers and Shoreline
- Mountains
- Farmland and Crops

C-3

RS-87-087-7

CLUTTER ANALYSIS

(1) Inventory Clutter Scenes

(2) Describe Statistically

- Mean
- Probability Distribution

(3) Examine Sensitivity to Radar Parameters

- Depression Angle
- Aspect Angle
- Polarization

N88-17624

RADAR RETURNS FROM GROUND CLUTTER IN VICINITY OF AIRPORTS

RESEARCH GRANT - NASA - LANGLEY
RESEARCH CENTER
NORTHEASTERN UNIVERSITY, BOSTON, MASS.

PRINCIPAL INVESTIGATOR: H.R. RAEMER
CO INVESTIGATORS: R. RAHGAVAN
A. BHATTACHARYA
GRADUATE RESEARCH ASSISTANTS: Z. XU
S. BHATIA

OBJECTIVE OF PROJECT

TO DEVELOP A DYNAMIC SIMULATION OF THE RECEIVED SIGNALS FROM NATURAL AND MAN-MADE GROUND FEATURES IN THE VICINITY OF AIRPORTS. THE SIMULATION IS RUN DURING LANDING AND TAKEOFF STAGES OF A FLIGHT. MODELLING OF CLUTTER BASED ON MOST UP - TO - DATE THEORIES AND RESULTS AVAILABLE

NOTEWORTHY FEATURES OF SIMULATION - I

(1) COHERENT SUMMATION OF COMPLEX VECTOR FIELDS OF SCATTERED WAVE, IMPLYING THAT:

- (A) RELATIVE PHASE BETWEEN SCATTERING CELLS IS ACCOUNTED FOR
- (B) POLARIZATION OF SCATTERED FIELDS IS ACCOUNTED FOR

(2) VELOCITIES OF RADAR AND SCATTERING CELLS ARE COMPUTED - DOPPLER SHIFT IS DETERMINED FOR RETURN FROM EACH SCATTERING CELL

NOTEWORTHY FEATURES OF SIMULATION - II

(3) MODELLING OF COMPLEX ANTENNA PATTERN

(A) IN TRANSMITTING MODE-GENERATE Θ AND Ø COMPONENTS OF COMPLEX RADIATED (ELECTRIC) FIELDS FROM X AND Y COMPONENTS OF COMPLEX APERTURE (ELECTRIC) FIELD

(B) IN RECEIVING MODE-GENERATE X AND Y COMPONENTS OF COMPLEX APERTURE (ELECTRIC) FIELD FROM Θ AND Ø COMPONENTS OF INCOMING COMPLEX (ELECTRIC) FIELD

(4) MODELLING OF TIME FUNCTIONS

(A) TRAJECTORIES OF RADAR AND MOVING CLUTTER SOURCES, UNDULATING SURFACES (E.G. WATER SURFACES), ANTENNA SCANNING PATTERN

(5) EM COMPUTATIONS PERFORMED IN FREQUENCY SPACE-CAN BE FT'D BACK TO TIME DOMAIN

NOTEWORTHY FEATURES OF SIMULATION - III

(5) MULTIPATH EFFECTS

TWO AND THREE-BOUNCE PROCESSES CONTRIBUTING
TO RECEIVED RADAR SIGNAL ARE ACCOUNTED FOR

(6) BLOCKAGE AND SHADOWING

TOTAL AND PARTIAL BLOCKAGE OF CELLS BY OTHER
CELLS IS ACCOUNTED FOR
FOR SINGLE BOUNCE CASE, OCCURS AT LOW GRAZING
ANGLES.
AFFECTS MULTIPLE BOUNCE CASES AT ALL GRAZING
ANGLES

(7) OUTPUTS AVAILABLE

(A) AVERAGE POWER IN RECEIVED SIGNAL

(B) CORRELATION FUNCTIONS AND SPECTRA

(C) AMPLITUDE PROBABILITY DISTRIBUTIONS

(D) EFFECTS OF RECEIVER FILTERING ON (A), (B) OR (C)

GROUND - CLUTTER DATABASES

A PREPARED FROM AIRPORT OBSTRUCTION CHARTS OBTAINED FROM NASA - LANGLEY

B AIRPORTS ARE: JFK, LA GUARDIA, LOGAN, WILLOW-RUN, MIAMI, DENVER, NEW ORLEANS, DALLAS, SAN DIEGO, TUCSON, BOEING(SEATTLE)

C <u>TYPICAL CLUTTER SOURCES</u>:

SEA WATER SURFACES (HARBORS, E.G. JFK, LA GUARDIA, LOGAN)
FRESH WATER SURFACES (LAKES OR RIVERS, E.G. WILLOW-RUN, DENVER)
PAVEMENT SURFACES (ROADS, RUNWAYS, ALL AIRPORTS)
HILLY TERRAIN (CLIFFS, E.G. BOEING)
SNOW COVERED TERRAIN (ALL AIRPORTS IN WINTER EXCEPT MIAMI, NEW ORLEANS, TUCSON, SAN DIEGO)
TOWERS, ANTENNAS, BUILDINGS (NEARLY ALL AIRPORTS)
SURROUNDING URBAN STRUCTURES (ALL AIRPORTS NEAR CITY, E.G. LOGAN, LA GUARDIA, JFK)

DEVELOPMENT OF ALGORITHMS FOR TERRAIN FEATURES

(1) MODELLING - WAVE APPROACH

(A) RIGOROUS FORMULATION BASED ON MAXWELL EQUATIONS

(B) ACCURATELY ACCOUNTS FOR POLARIZATION - BOTH CO-POL AND CROSS-POL RETURNS

(C) DISADVANTAGES - SOLUTIONS DIFFICULT AND CPU-TIME INTENSIVE; APPROXIMATIONS REQUIRED (E.G. 1ST AND 2ND ORDER BORN)

(2) RADIATIVE TRANSFER THEORY

(A) PURELY ENERGY - PHASE SUPPRESSED

(B) EASILY ACCOUNTS FOR MULTIPLE SCATTERING

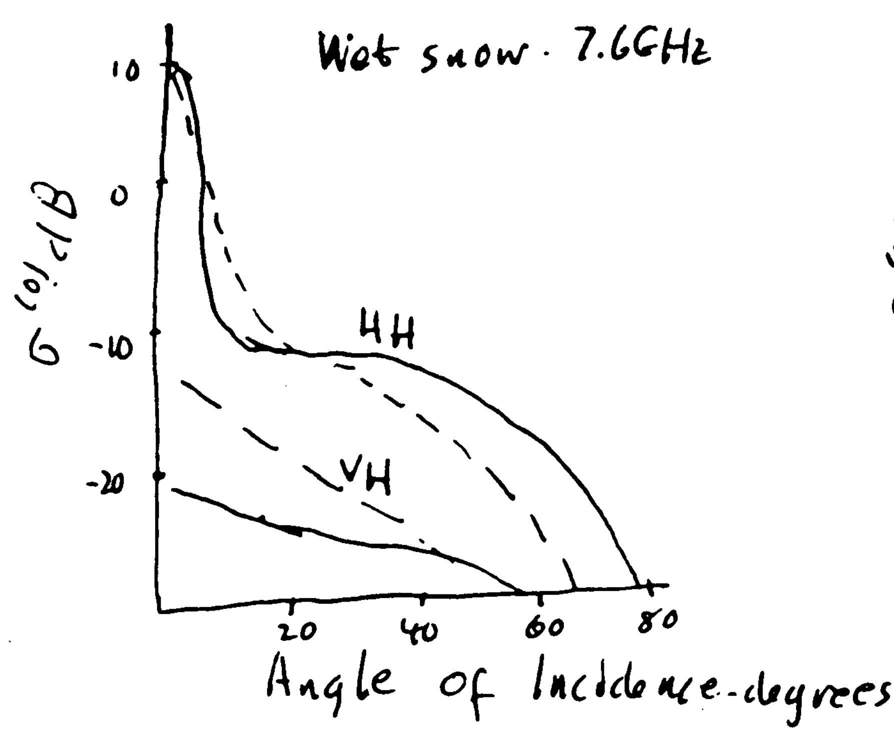
(C) FASTER BUT LESS ACCURATE

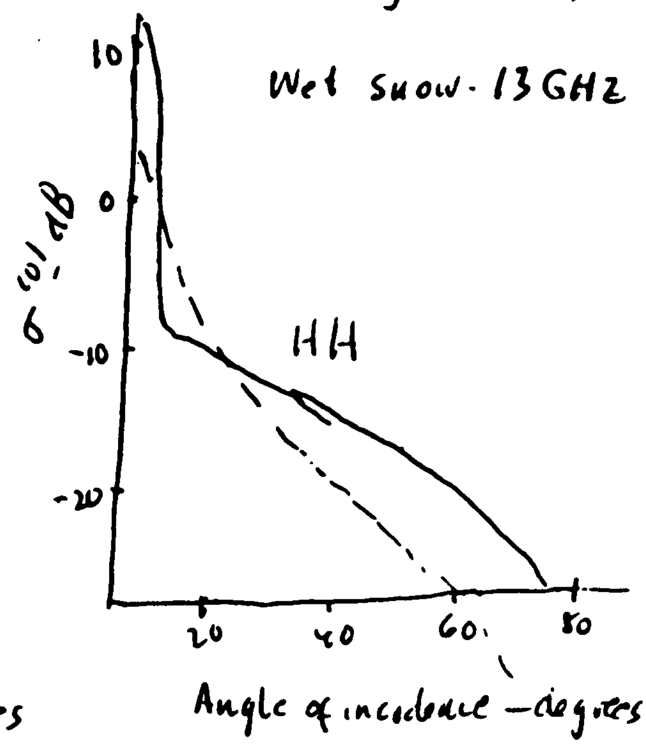
(3) DISCRETE SCATTERERS - SHORT OR LONG WAVE APPROXIMATIONS; EXACT SOLUTIONS FOR SIMPLE GEOMETRIES

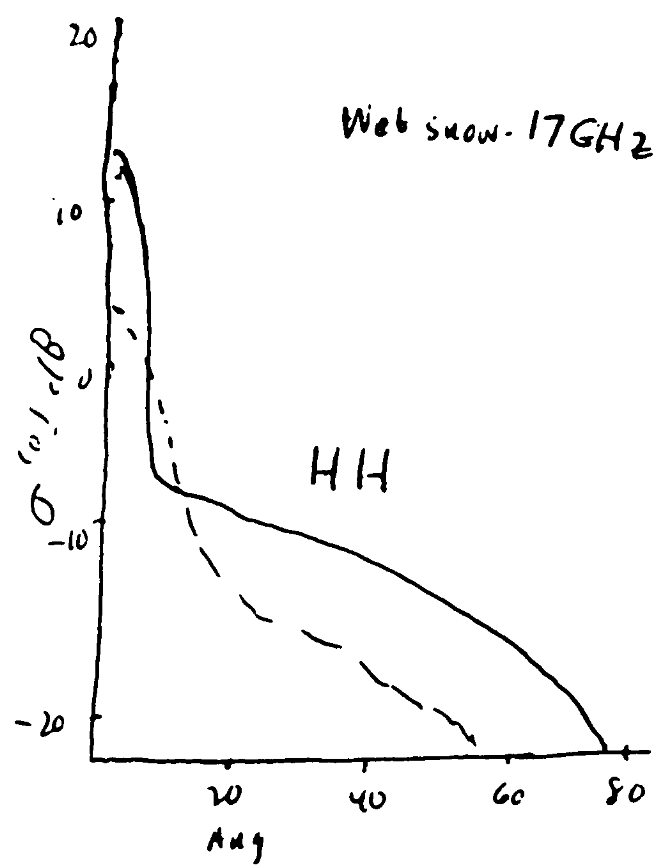
(4) SURFACE SCATTERING - TWO-SCALE MODEL WITH RANDOM SURFACE VARIATIONS

Wave theory results - cont'd

(U. Kansas Group - Stiles and Ulaby (1980))







In each case

——— Theory

- - - - Experiment

Typical wave theory results

(MIT μwave Remote Sensing Group - J. A. Kong et al). Backscatter cross sections - copol and crosspol

Grass - 35 GHz, 82° incidence

	σ_{HH}	$\sigma_{VH} = \sigma_{HV}$	σ_{VV}
Theory	−15.4	−23.6	−15.6
Exper.	−15.0	−23.2	−16.2

Trees 35 GHz, 82° incidence

	σ_{HH}	$\sigma_{VH} = \sigma_{HV}$	σ_{VV}
Theory	−13.1	−26.7	−13.1
Exper	−13.0	−25.2	−12.6

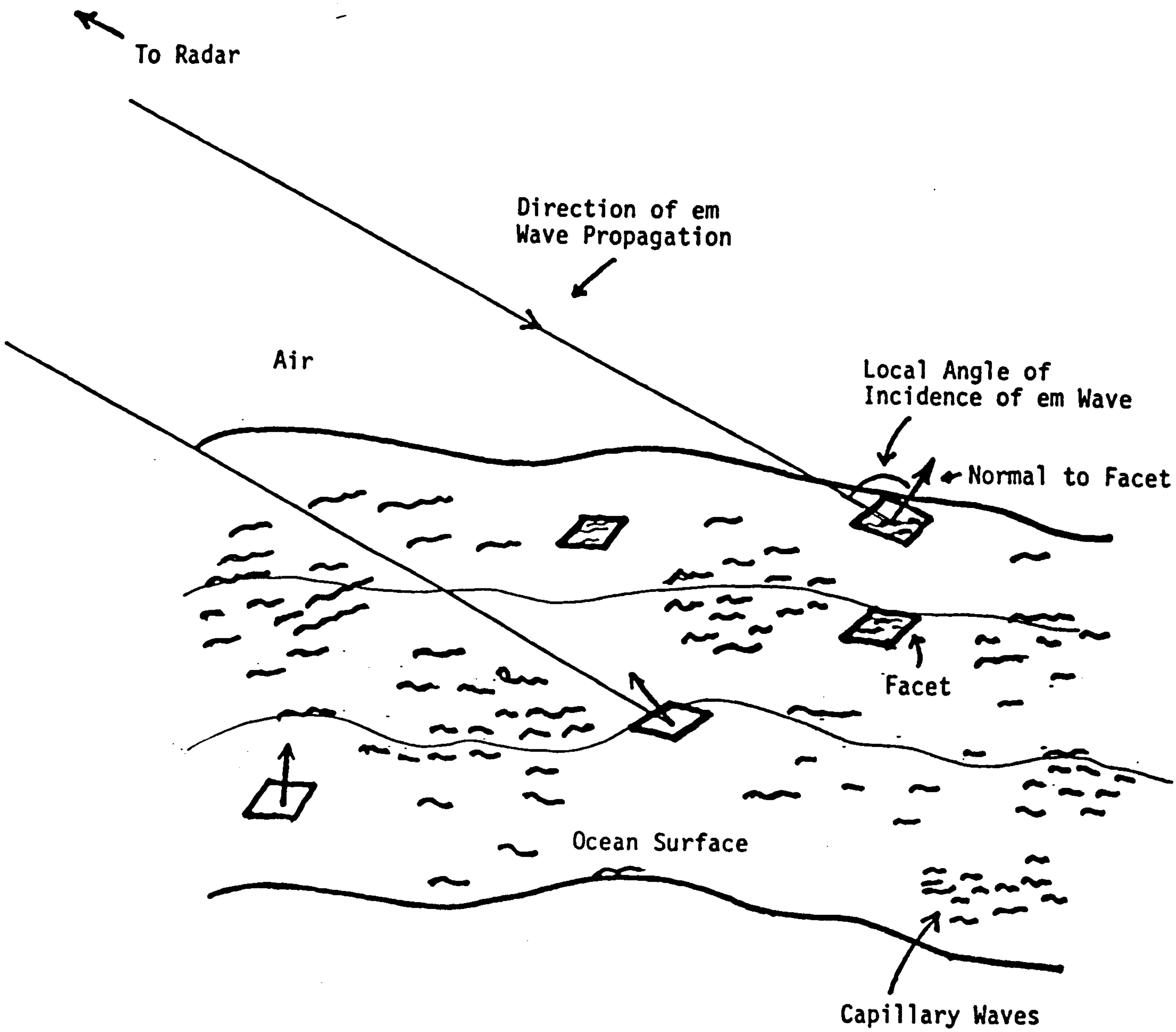


Fig. 2 Geometry of em wave scattering from ocean surface.

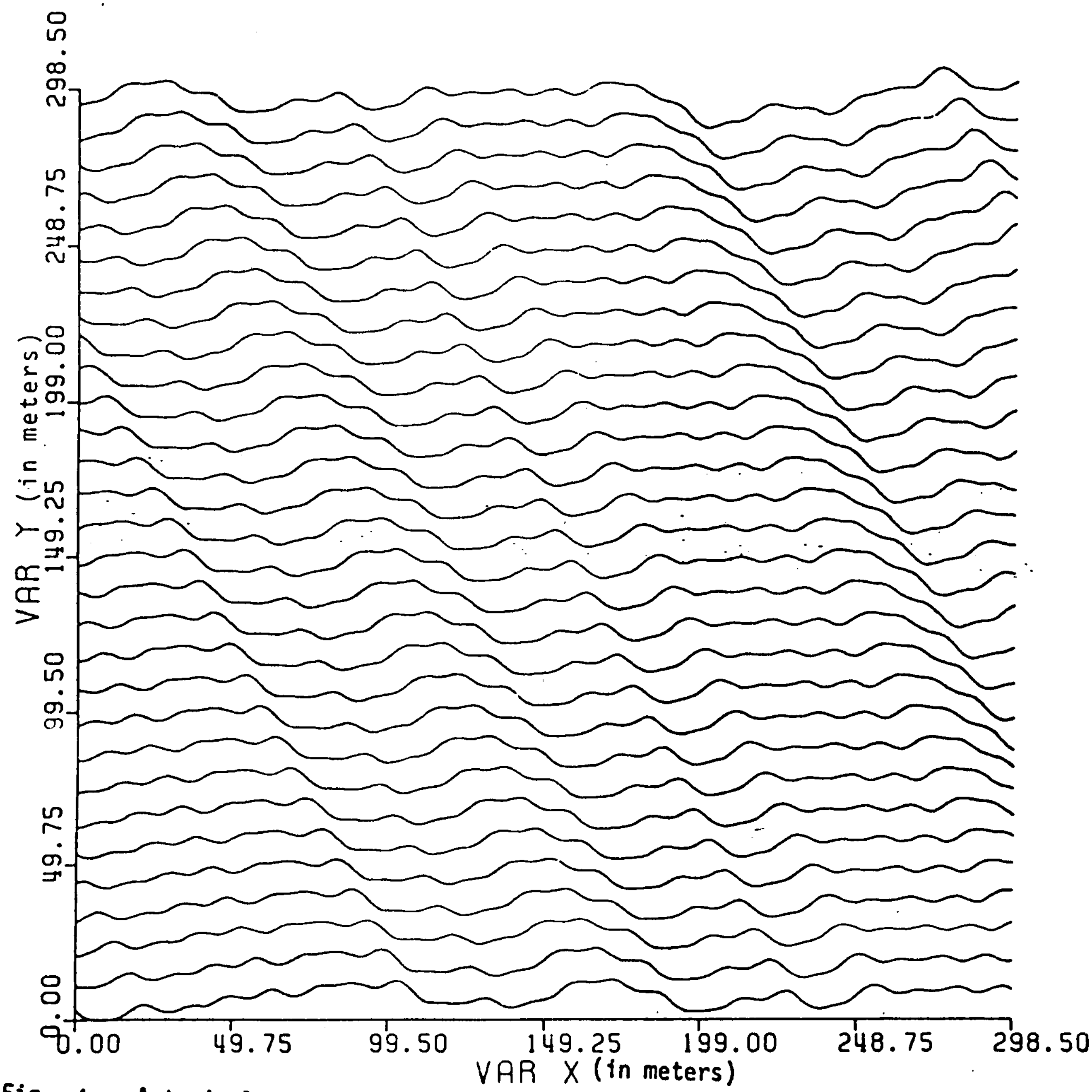


Fig. 4 A typical gravity wave height profile generated by the computer for a wind speed of 20 knots directed at a 45^o angle with respect to the x-axis. The x and y axes in the plot represent two orthagonal directions on the mean ocean surface. A different scale is used for the height of the gravity waves.

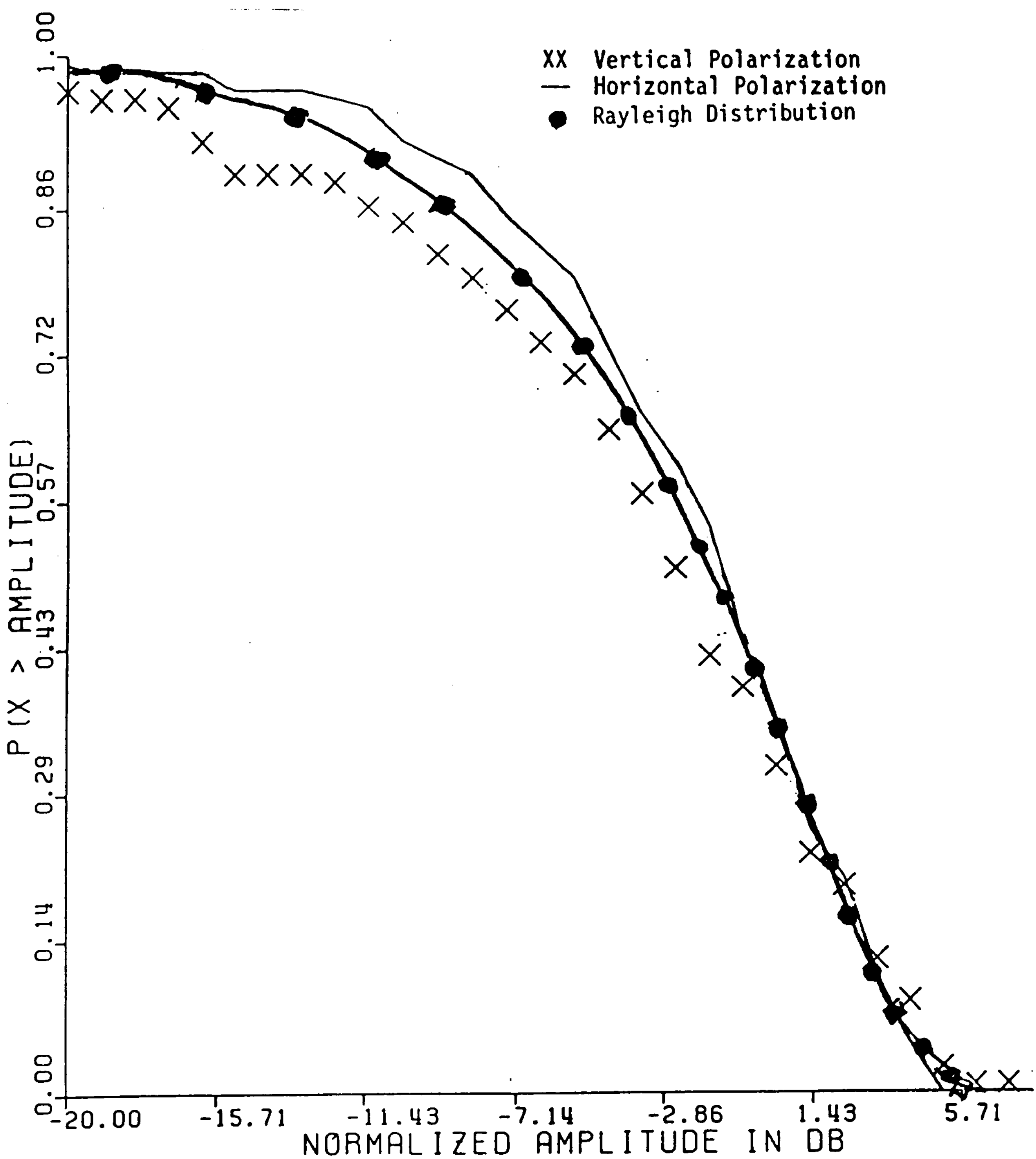


Fig. 6 & 7 The probability distribution of the backscattered signal envelope, (the angle of incidence of em wave is 70°; wind speed is 5 knots and is directed along the x-axis). The ordinate gives the probability that the backscattered signal envelope will exceed the abscissa.

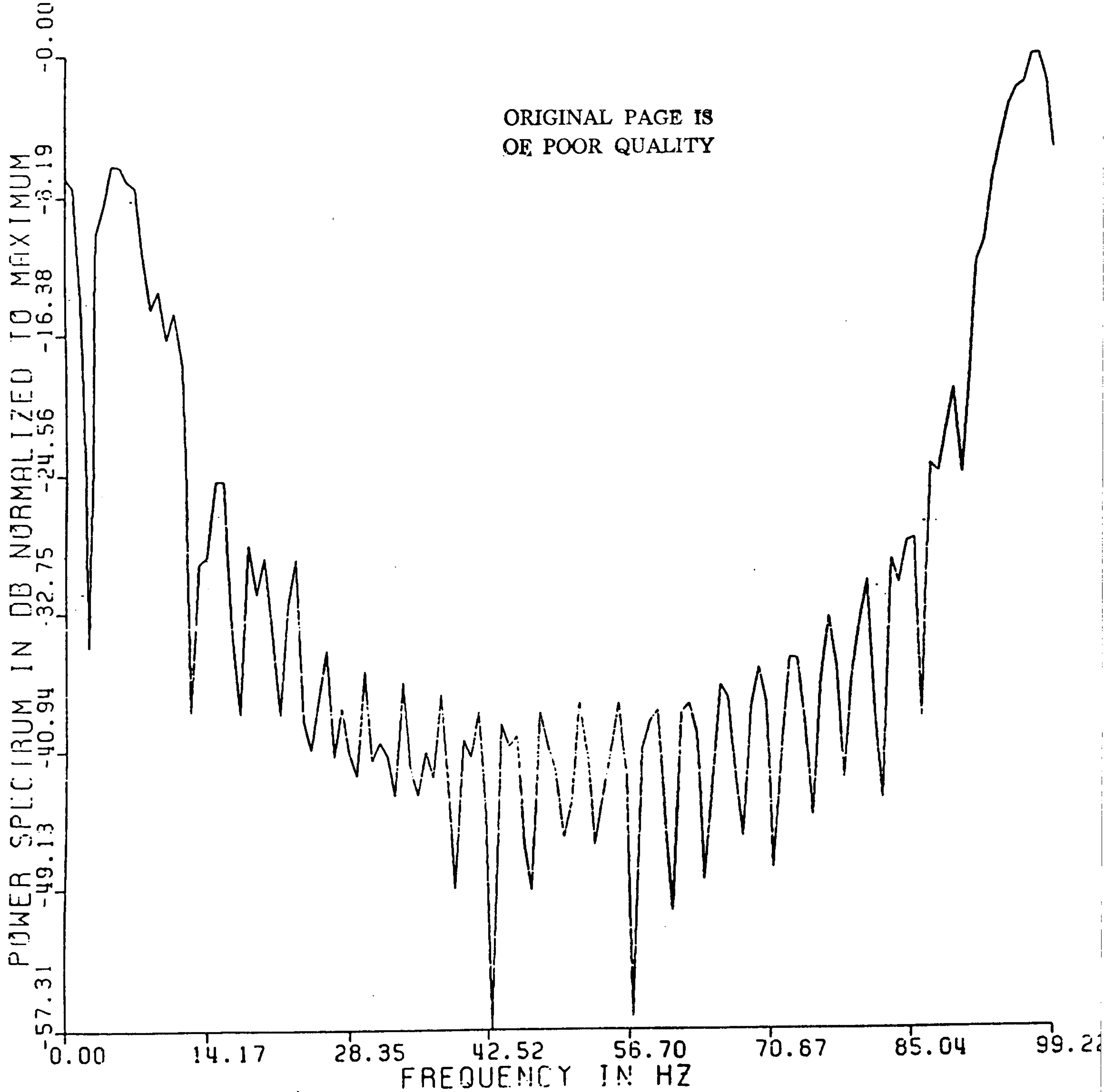
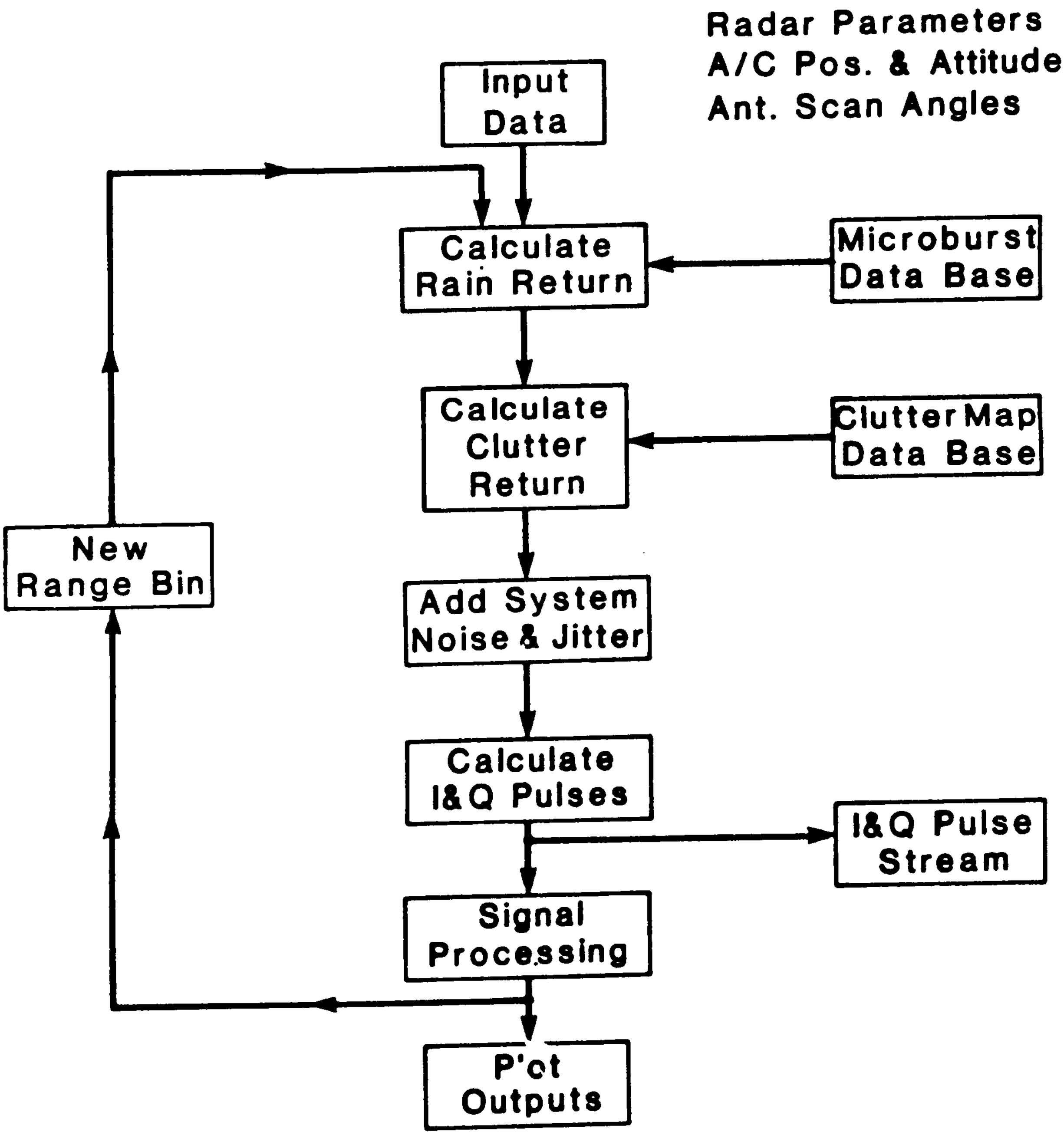


Fig. 5 A typical doppler spectrum of the backscattered field. (Angle of incidence of microwave (x-band) is 70°; wind speed = 20 knots, wind direction is 45° from the x axis; the incident and scattered fields are vertically polarized.)

WIND SHEAR RADAR SIMULATION

Charles L. Britt, Ph.D
Research Triangle Institute

RADAR SIMULATION



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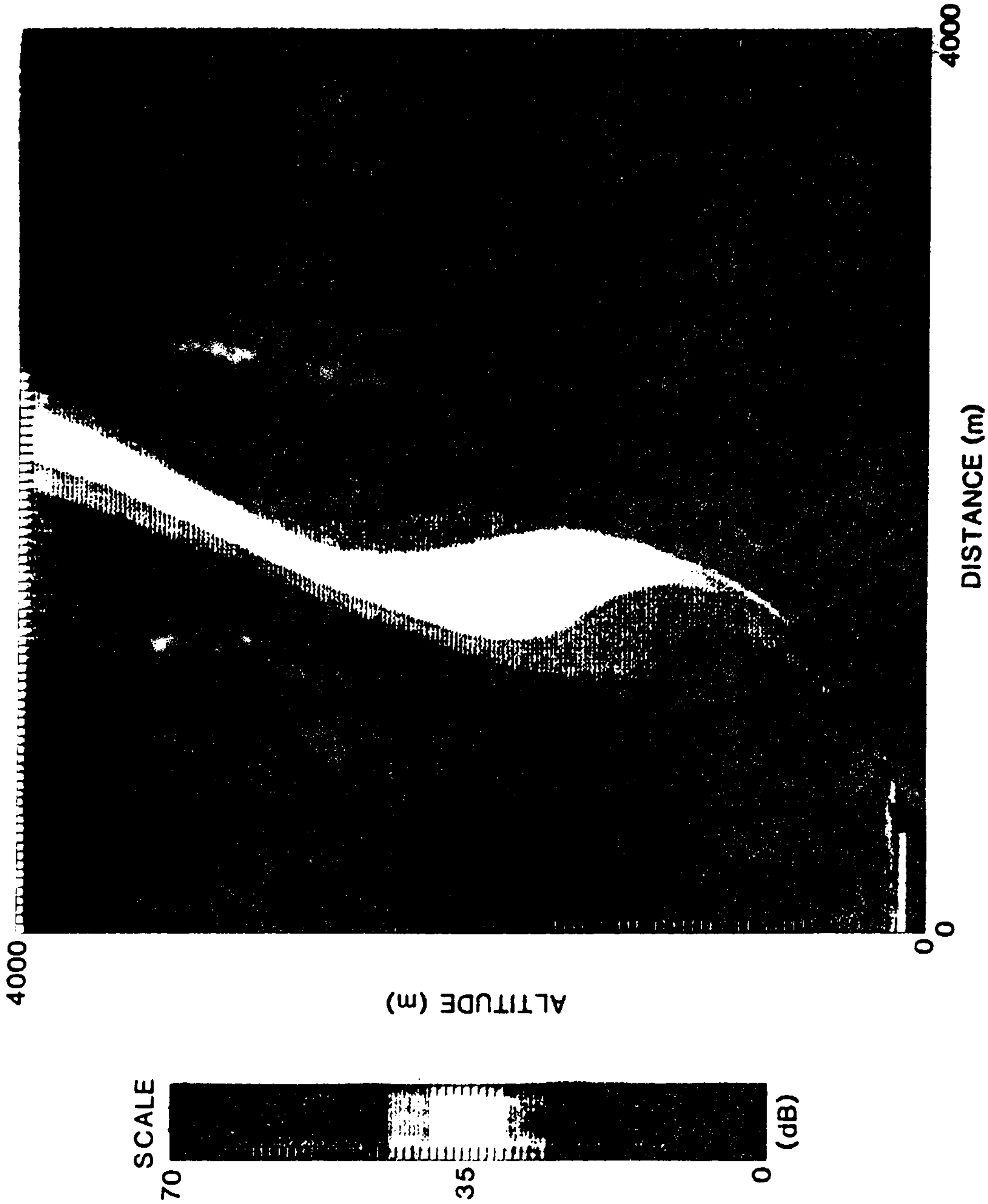
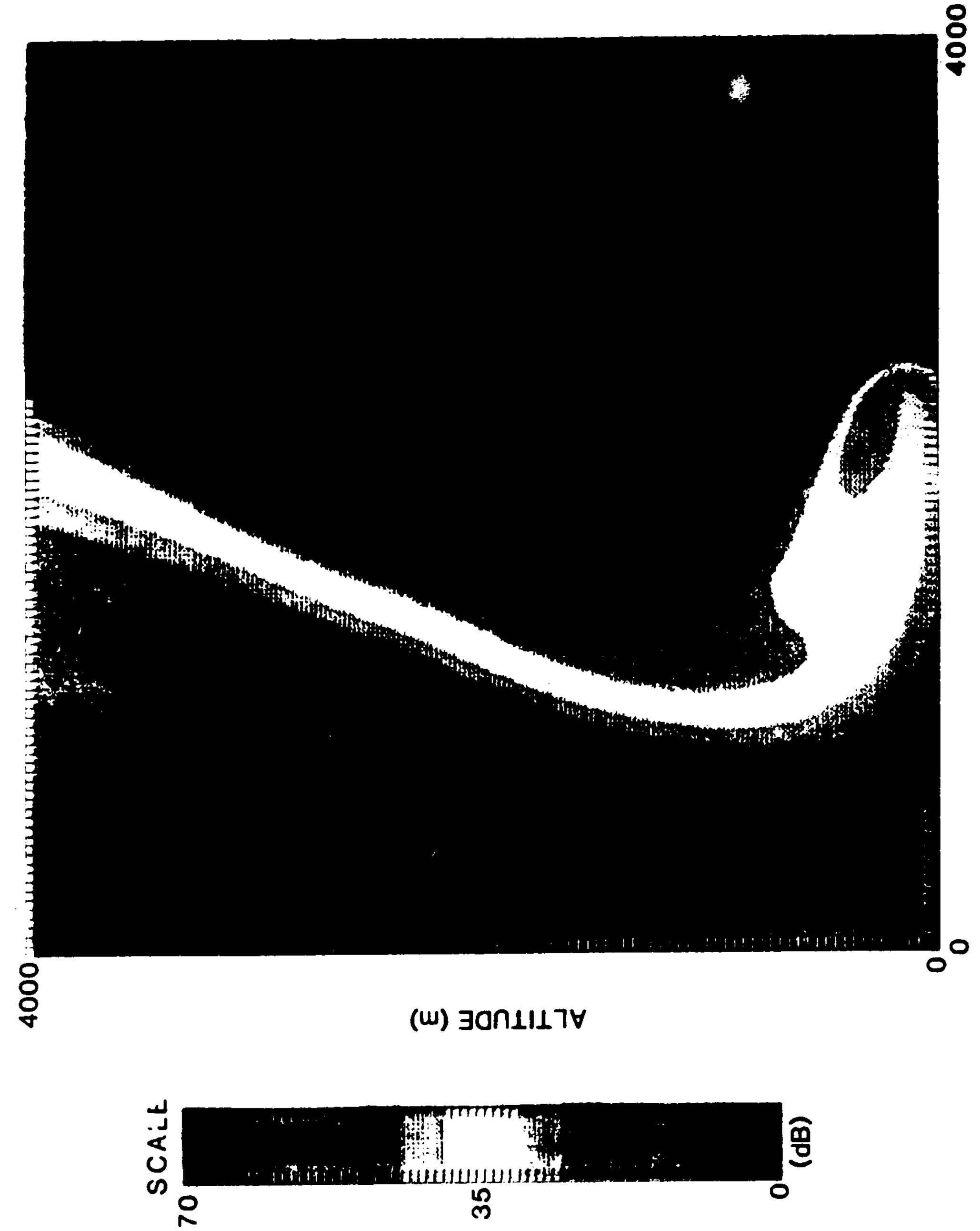
MICROBURST MODEL

RADAR REFLECTIVITY (A9)



MICROBURST MODEL

RADAR REFLECTIVITY (A11)



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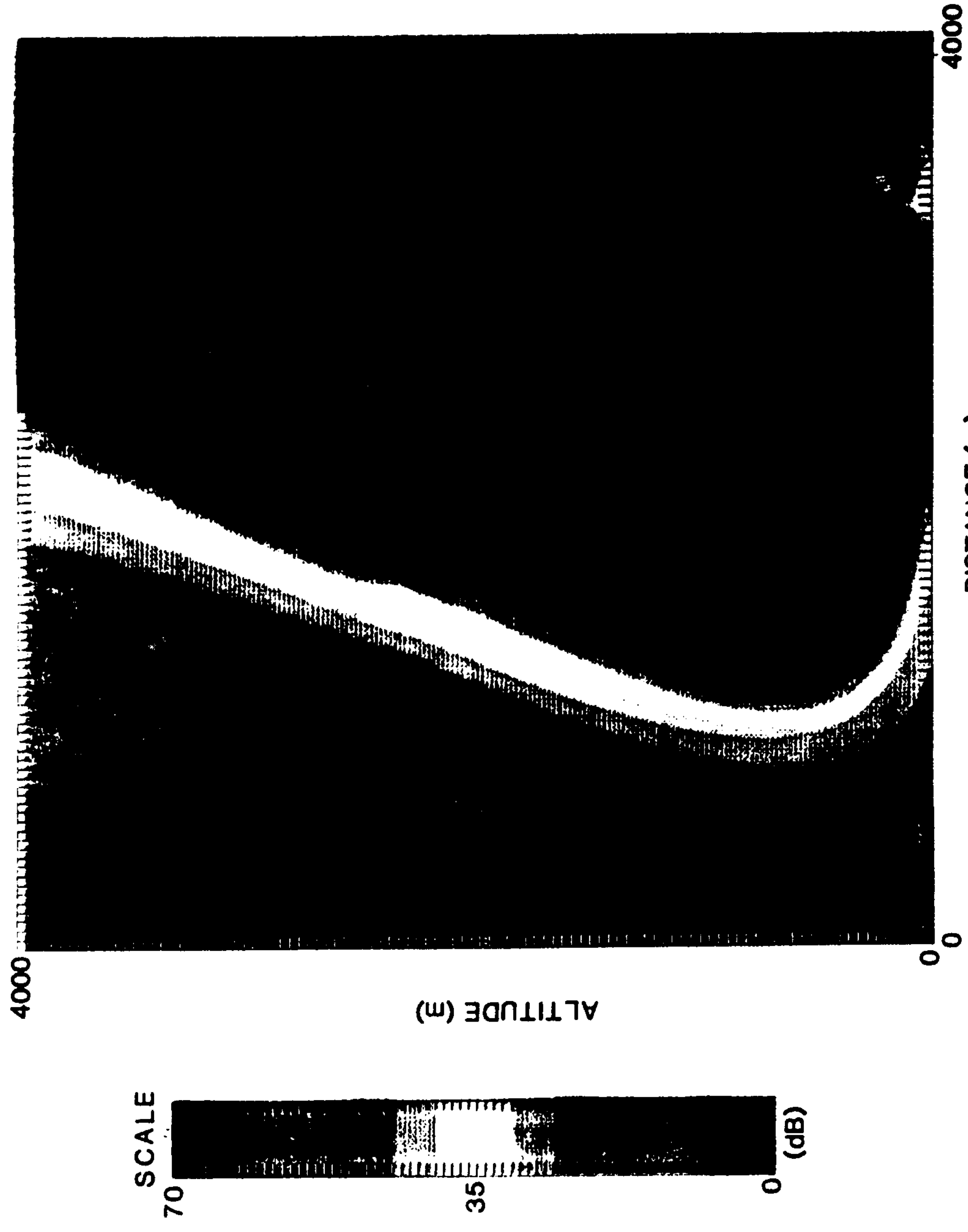
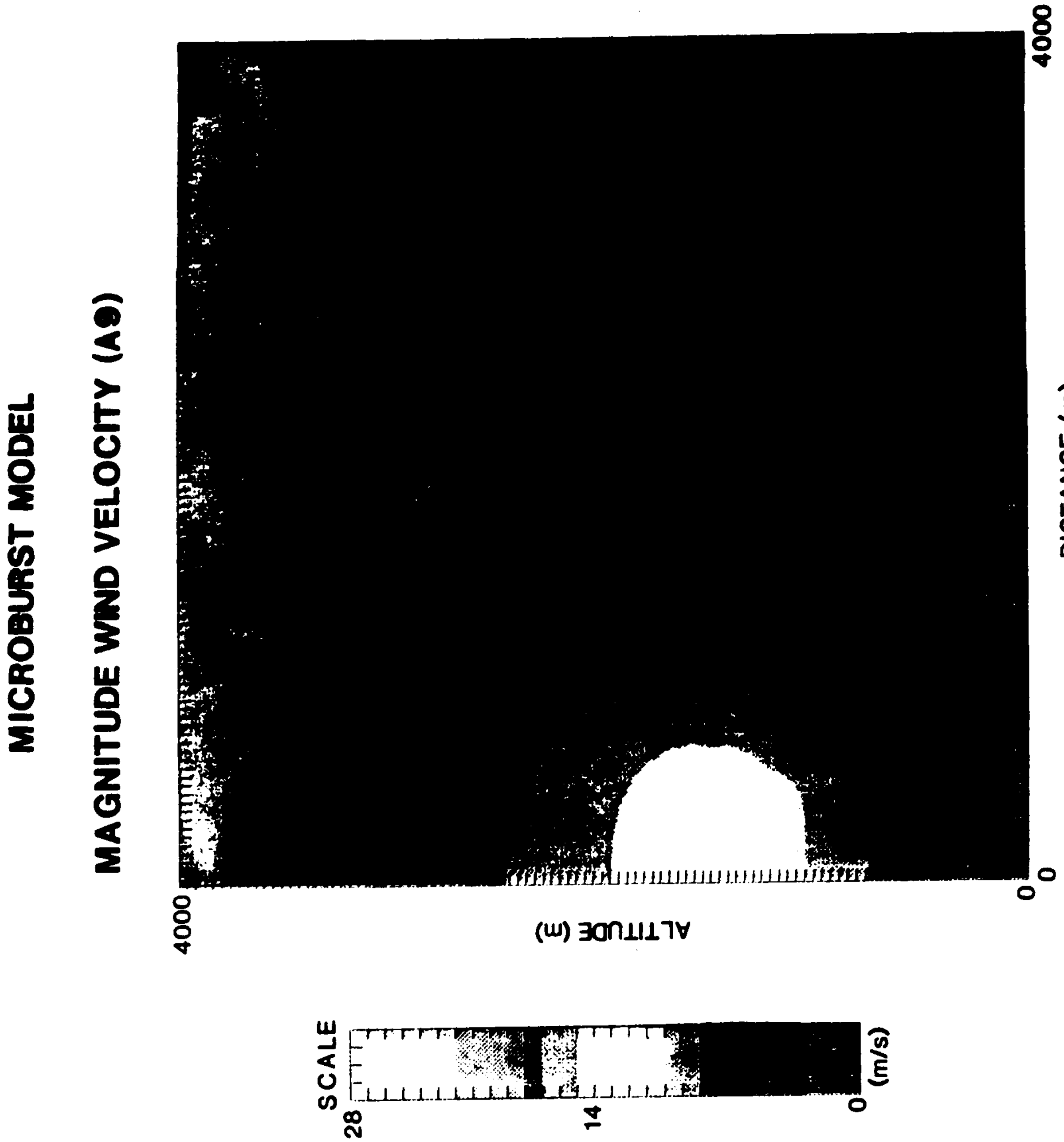
MICROBURST MODEL

RADAR REFLECTIVITY (A13)





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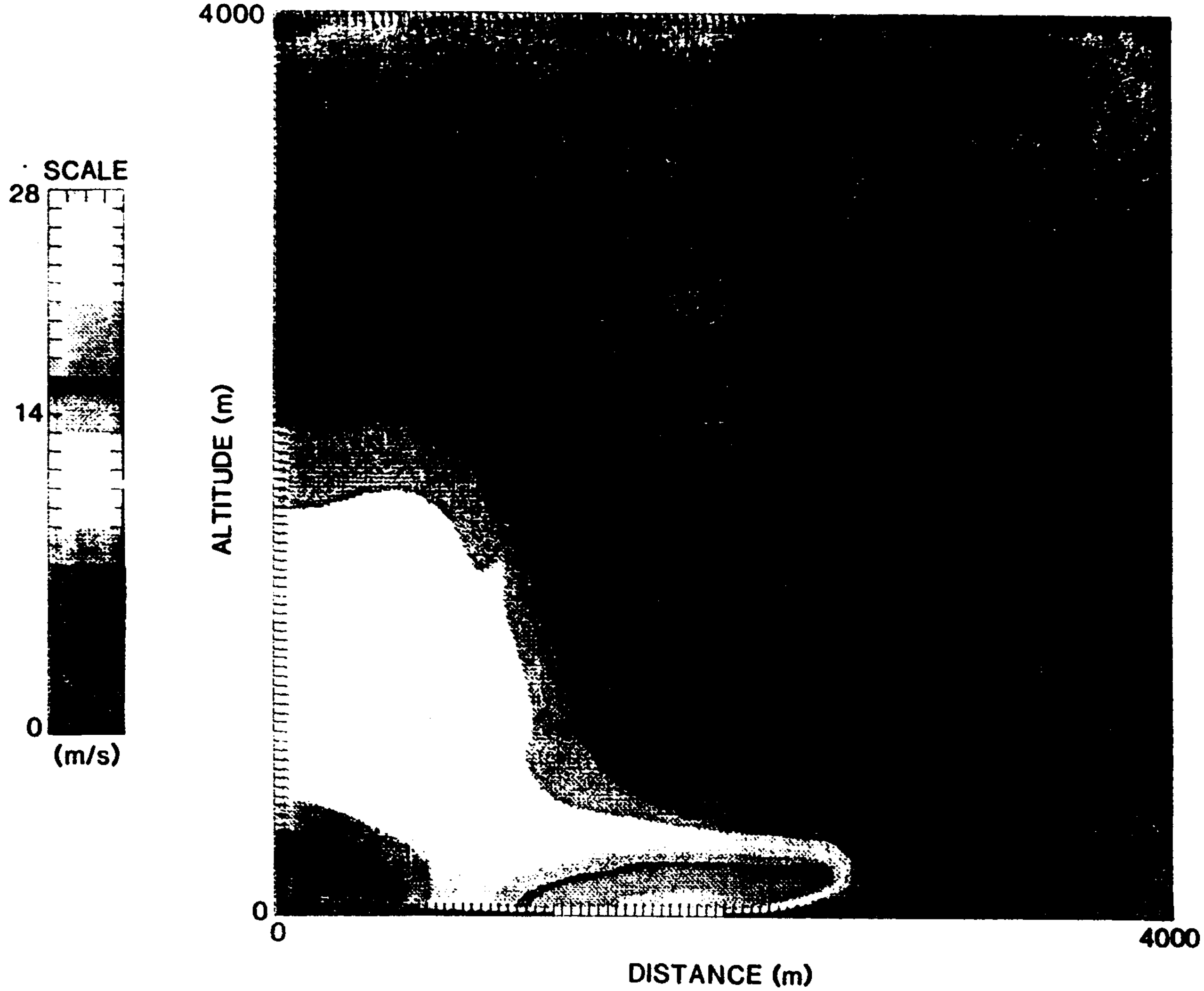
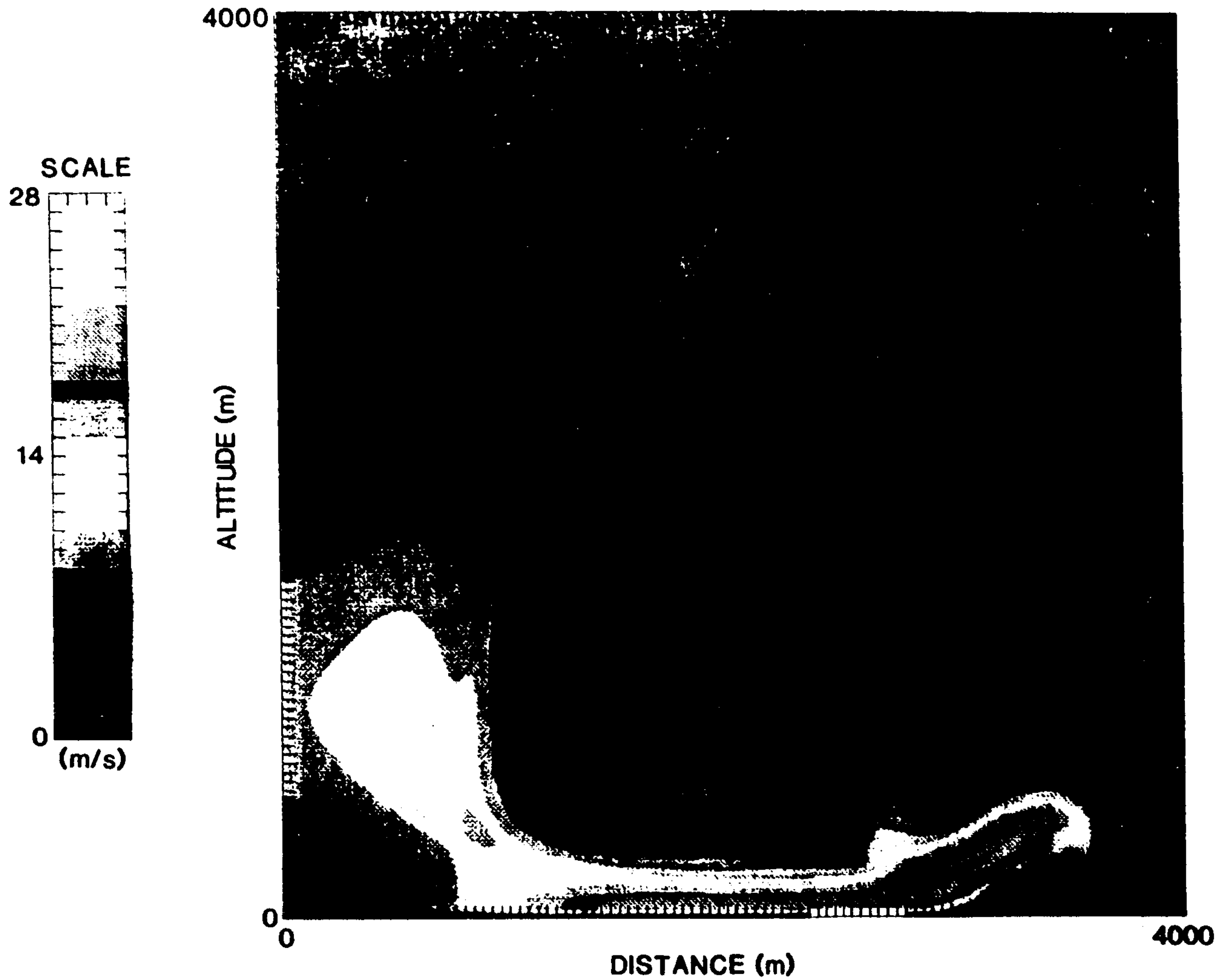
MICROBURST MODEL

MAGNITUDE WIND VELOCITY (A11)



MICROBURST MODEL

MAGNITUDE WIND VELOCITY (A13)



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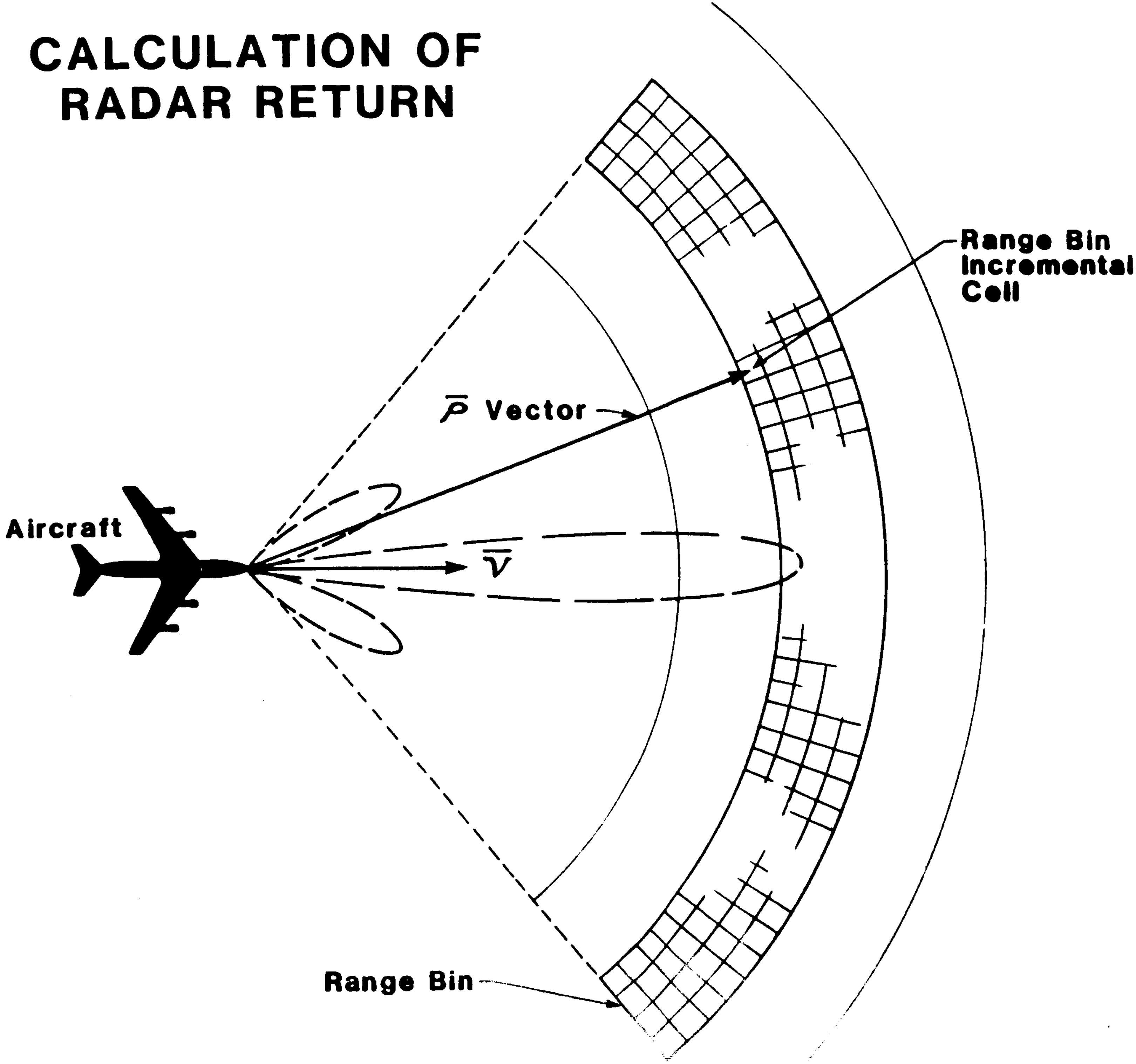
35°

10°

1 mi

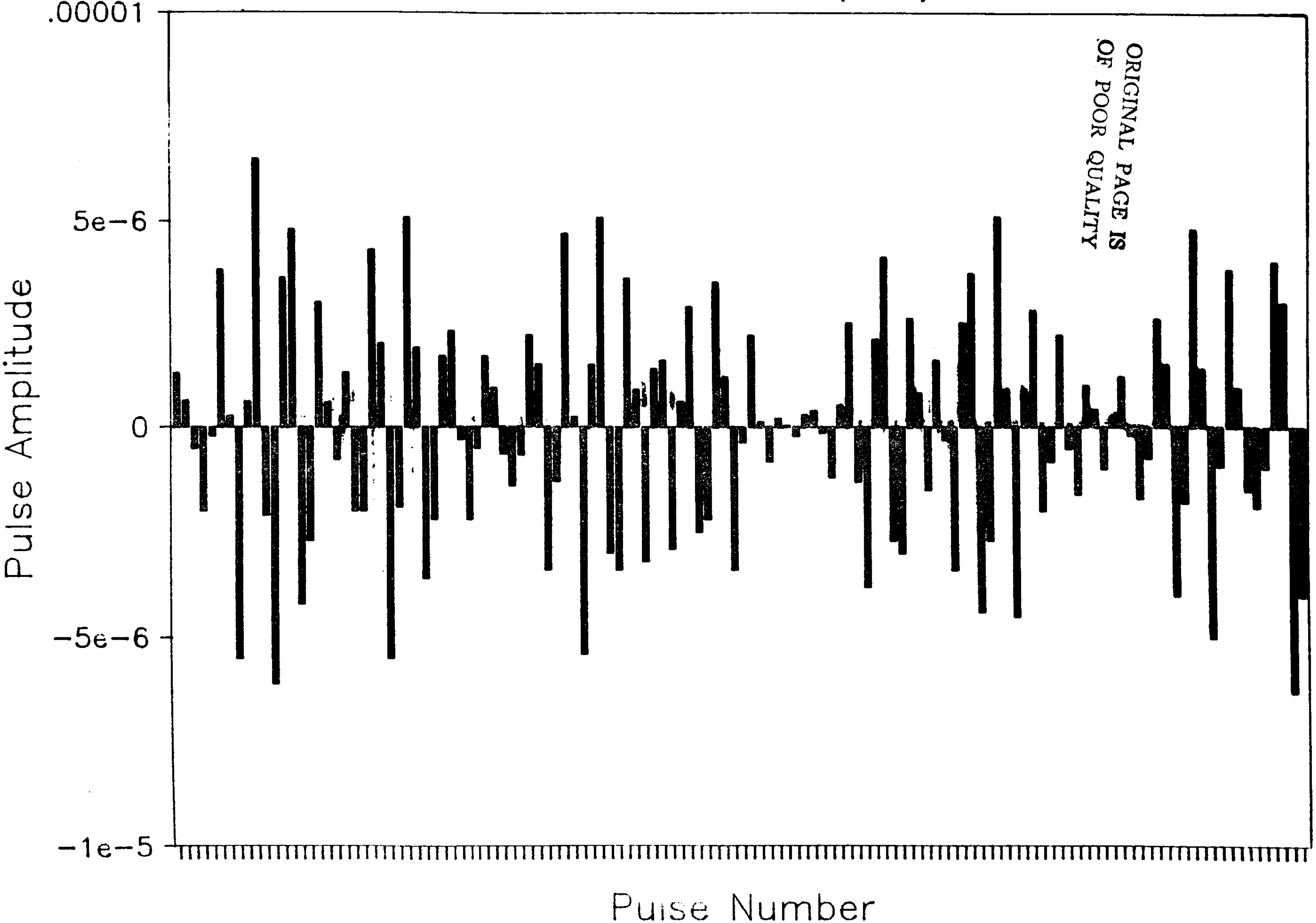
LOOK ANGLE

CALCULATION OF RADAR RETURN



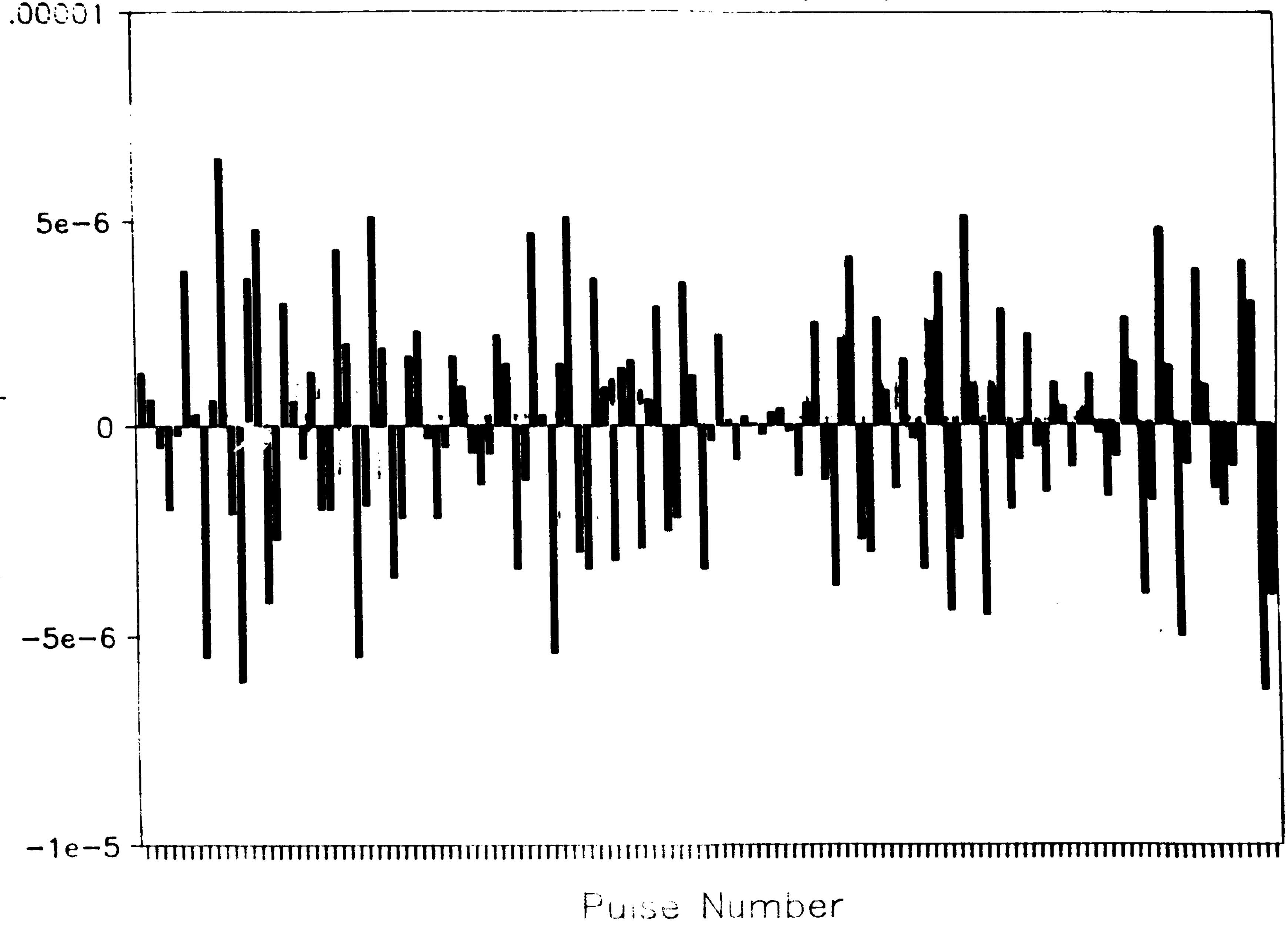
EXAMPLE OF RADAR PULSE OUTPUT

Quadrature Pulses (128)



EXAMPLE OF RADAR PULSE OUTPUT

Quadrature Pulses (128)



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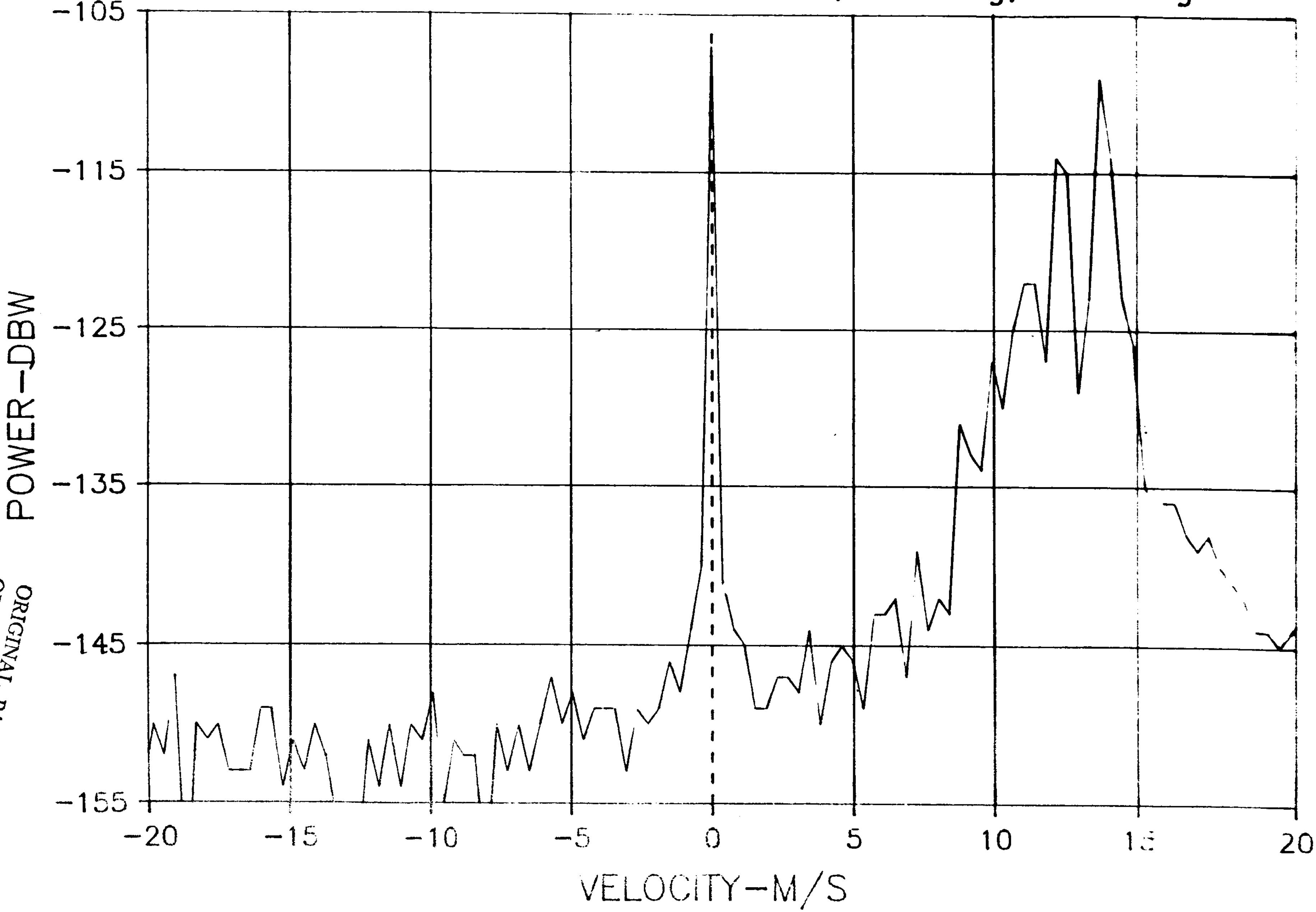
POWER SPECTRUM—MICROBURST A1 1

VEL=140kts,RG=10km,RGBIN=9km,EL=0deg,AZ=0deg



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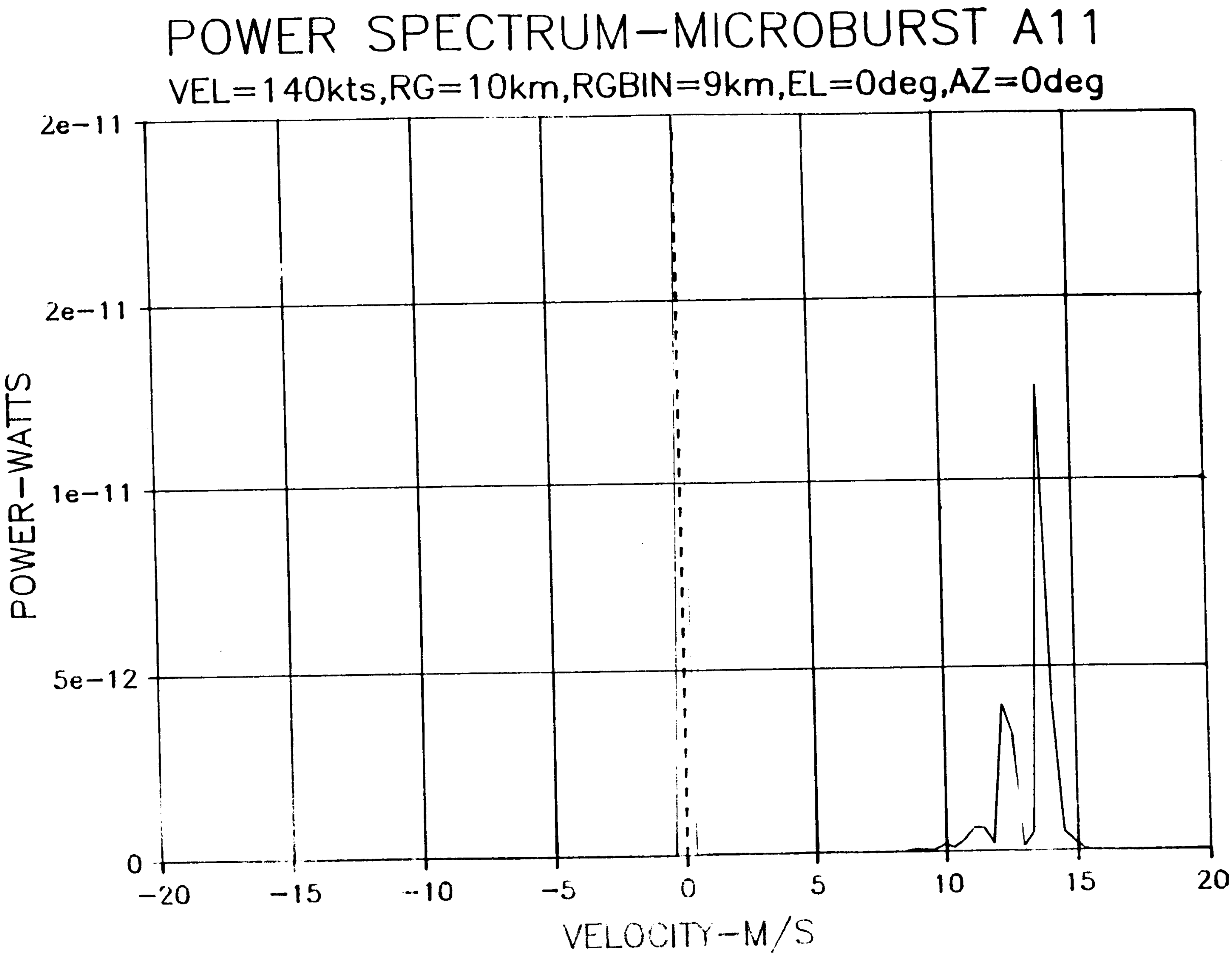
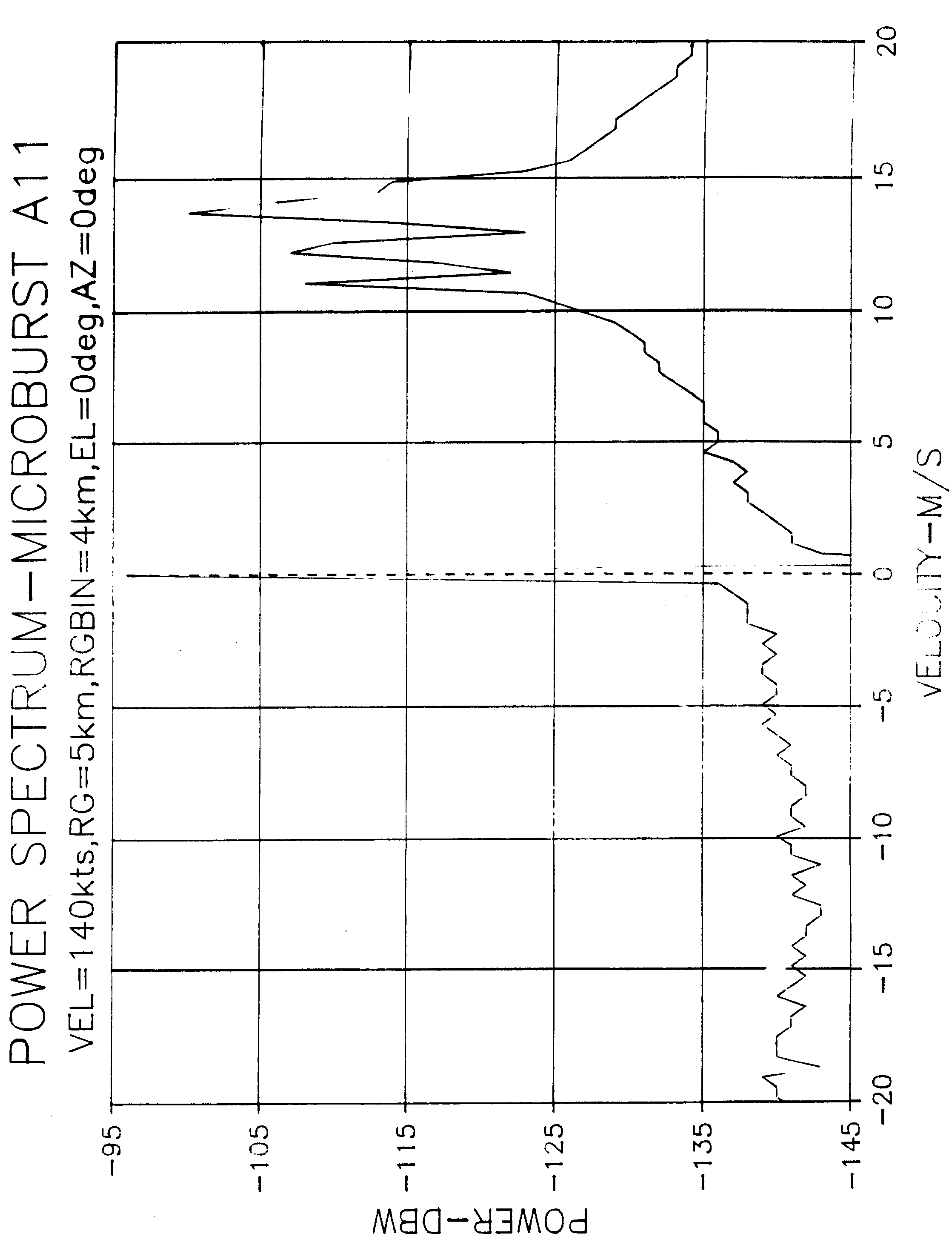
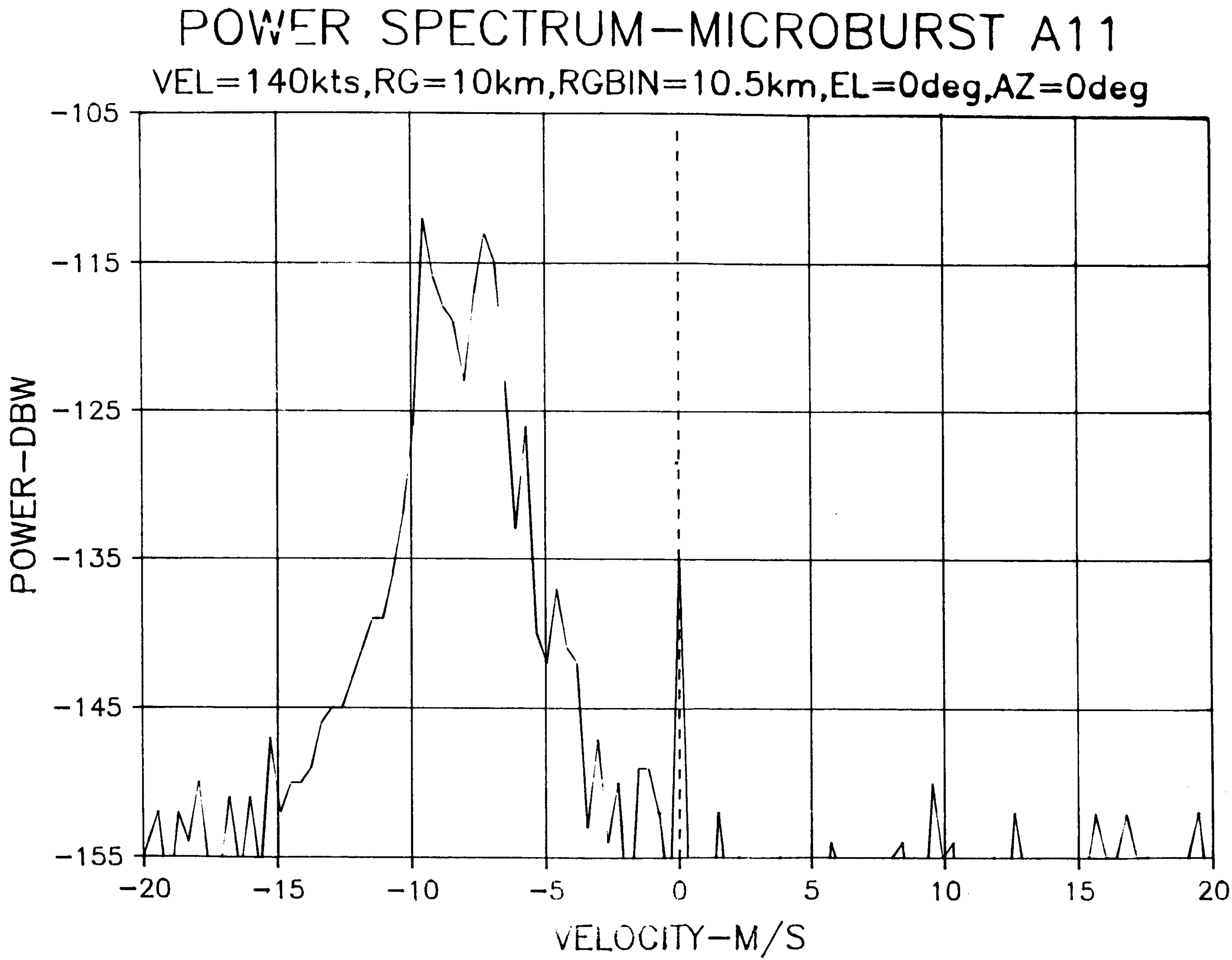
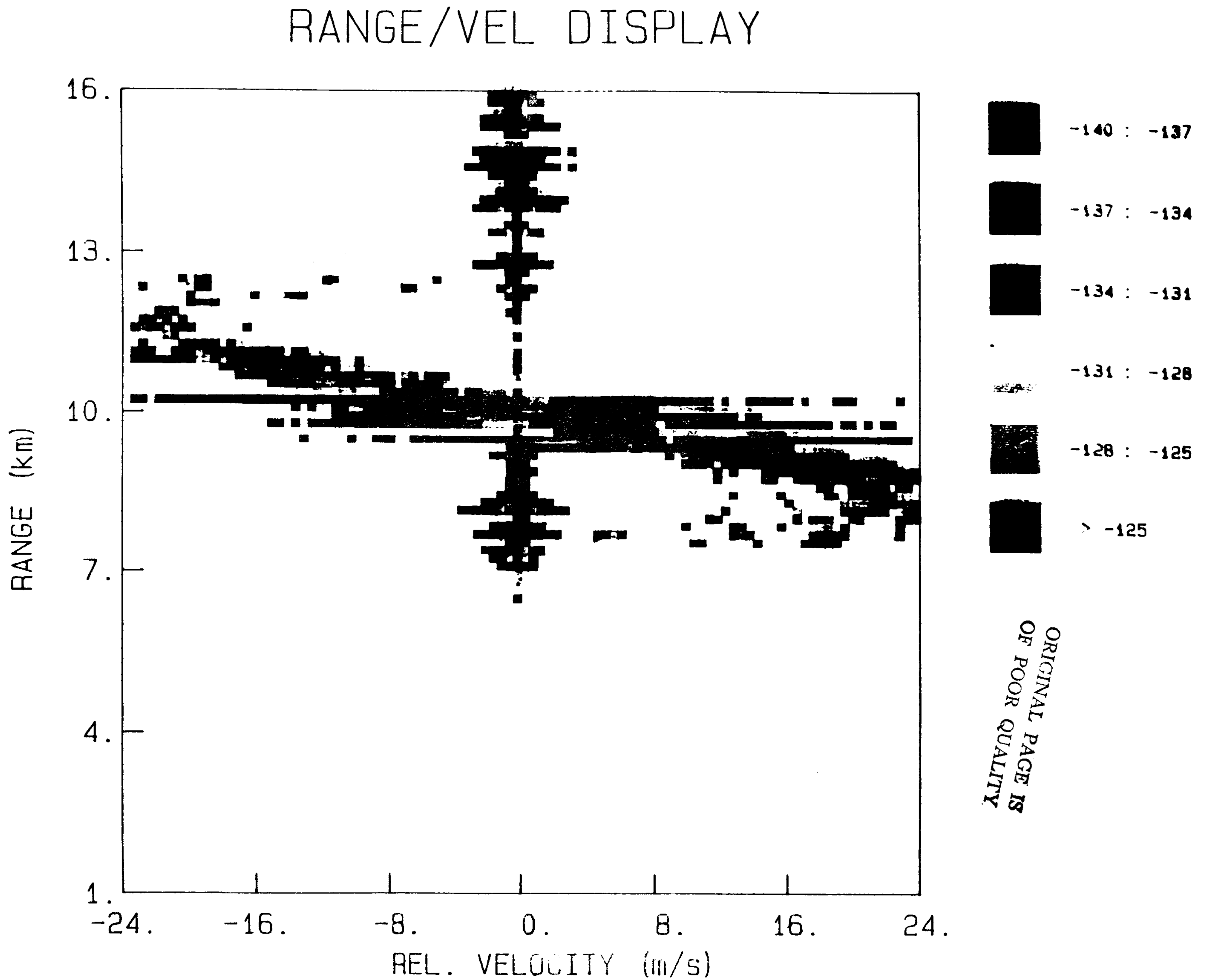
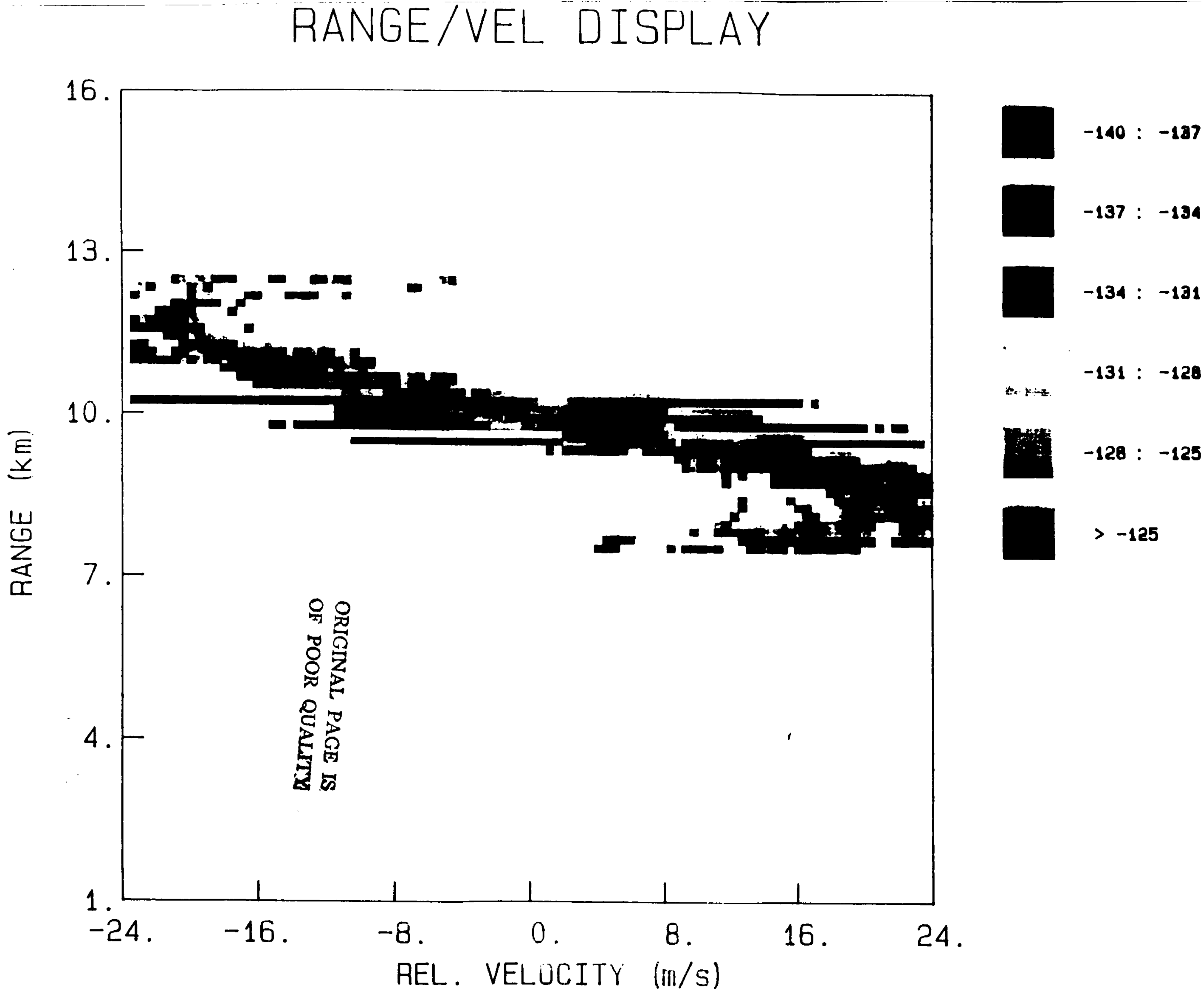

POWER SPECTRUM—MICROBURST A11
VEL=140kts,RG=10km,RGBIN=9km,EL=0deg,AZ=0deg
POWER—WATTS
2e−11
2e−11
1e−11
5e−12
0
−20
−15
−10
−5
0
5
10
15
20
VELOCITY—M/S



POWER SPECTRUM – MICROBURST A11
VEL=140kts,RG=5km,RGBIN=4km,EL=0deg,AZ=0deg
POWER–DBW
-95
-105
-115
-125
-135
-145
VELOCITY–M/S
-20
-15
-10
-5
0
5
10
15
20


POWER SPECTRUM—MICROBURST A11
VEL=140kts,RG=10km,RGBIN=10.5km,EL=0deg,AZ=0deg
-105
-115
-125
-135
-145
-155
POWER—DBW
-20
-15
-10
-5
0
5
10
15
20
VELOCITY—M/S


RANGE/VEL DISPLAY
16.
13.
10.
7.
4.
1.
RANGE (km)
-24.
-16.
-8.
0.
8.
16.
24.
REL. VELOCITY (m/s)
-140 : -137
-137 : -134
-134 : -131
-131 : -128
-128 : -125
> -125



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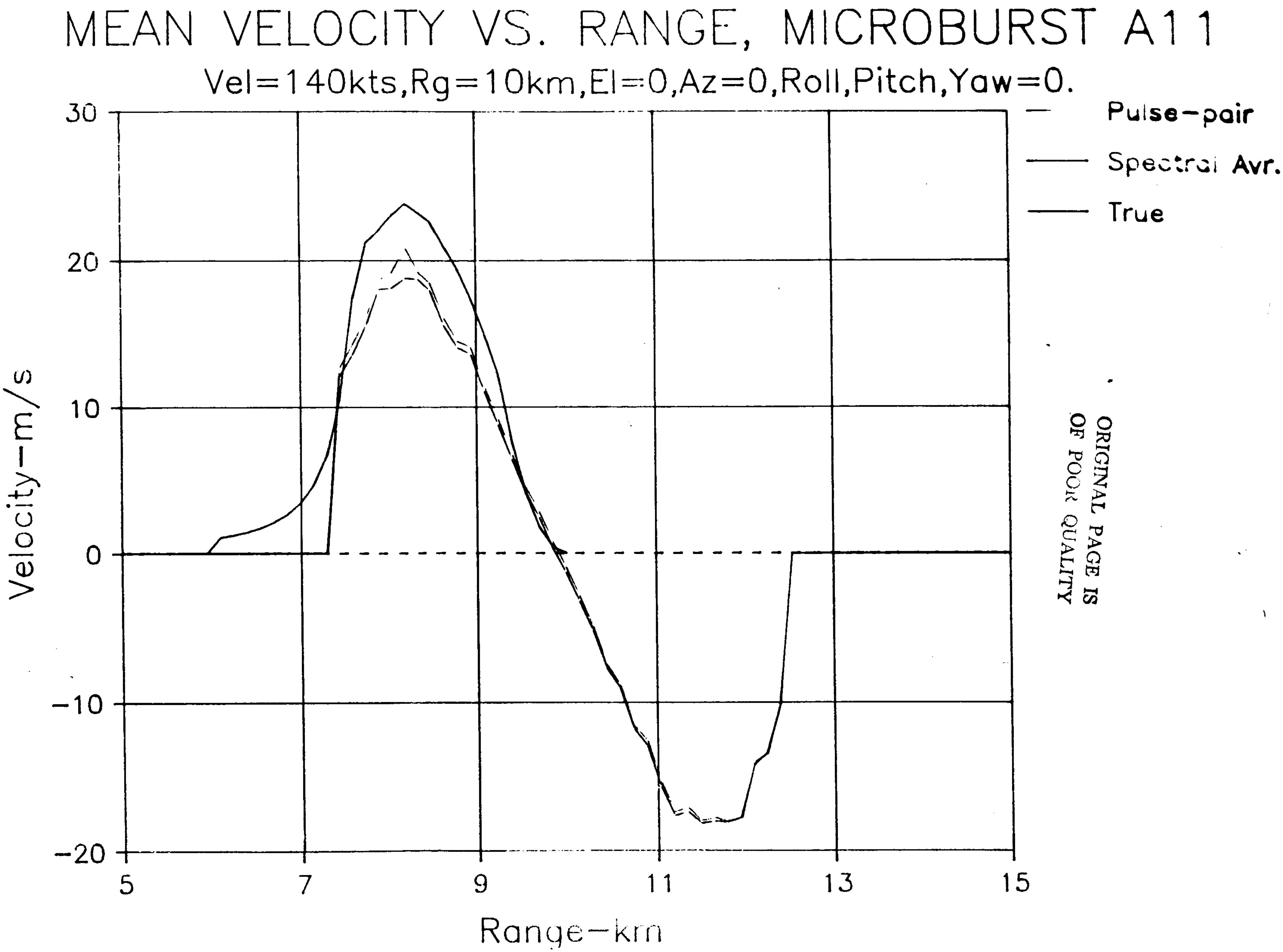

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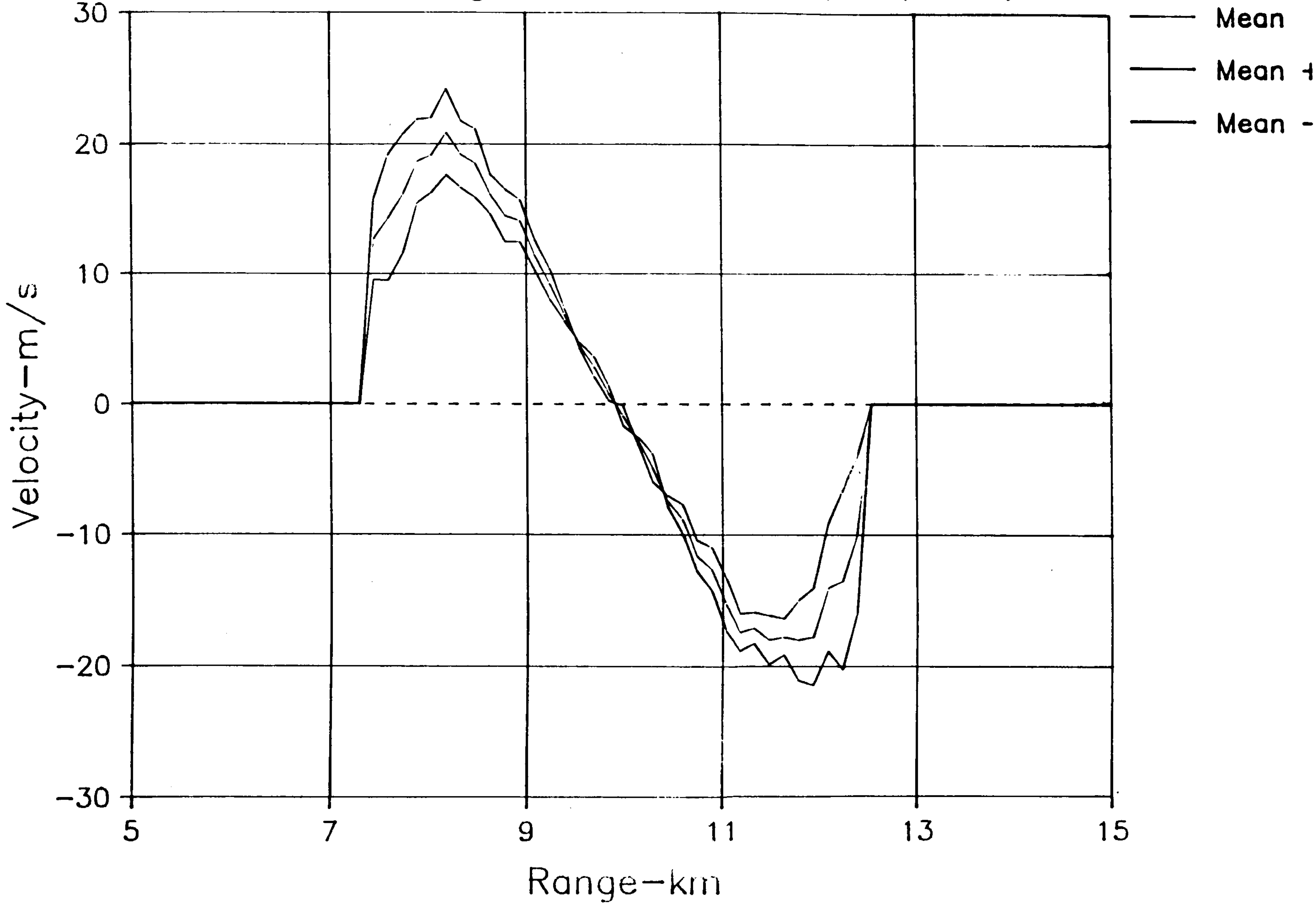
MEAN VELOCITY AND SPECTRUM WIDTH (PPP)

Vel=140kts,Rg=10km,El=0,Az=0,Roll,Pitch,Yaw=0.



SIMULATION PLANS

- **PARAMETER STUDIES**

  Radar Power, PRF, Pulse Width, # Pulses, Frequency, Pulse Jitter, Noise Figure, Polarization, Antenna Size & Illumination, Scan Angles & Rates, STC & AGC Techniques, Quantization, Etc...

- **TECHNIQUE & ALGORITHM EVALUATION**

  Clutter Suppression
  Mean & Peak Velocity Estimation
  Spectral Width Estimation
  Hazard Estimation
  Direct Shear Measurements
  Alarm Algorithms

- **DISPLAY GENERATION**

  Static
  Dynamic

- **PERFORMANCE EVALUATION** (With Various Microburst & Clutter Models or Real Data)

  Detection Or Display of Hazard
  False Alarms
  Missed Alarms

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QUESTIONS AND ANSWERS

RUSS TARG (Lockheed R&D) - I have a general question about signal to noise ratio. Everybody working in forward looking remote sensors is concerned about signal to noise ratio. I would like an idea of the magnitude of the clutter to signal that you are dealing with and the corollary to that would be in half the microbursts that we study at least, they are full of water and the other half they are so called dry microbursts. How is the algorithm you're developing deal with the so called dry microbursts and what are the general signal to noise situation with regard to clutter to return in the two kinds of microbursts you are studying?

CHARLES BRITT (Research Triangle Inst.) - Let me point out again that we are not to the point of coming out with signal to clutter ratios and signal to noise ratios, we are still developing the simulation and we haven't got good clutter data. I will make that point again. Maybe in a couple of weeks, when we get some reasonable clutter data we will be able to answer some of these questions, but I would not say now. I would generally say that clutter data is considerably more than the signal. Does that answer the question?

RUSSELL TARG (Lockheed) - It really didn't answer the questions. The last time we had a meeting here, six months ago, people were talking about 60 to 70 db clutter greater than signal. I wondered if any algorithms were developed? I know you are working on that to try and do something to filter out the clutter and obviously what you are working on 50-60 db seems like quite a deficit, particularly in the favorable case where you are looking at a wet microburst. We are having to look at both wet and dry and I know that there is a huge difference in the return that you get from wet or dry microbursts. And I wondered if the microwave approach you are looking at deals, at all, with the reduced signal that you get from the dry case?

CHARLES BRITT (Research Triangle Inst.) - Yes. The signal level comes from the microburst model that is generated by Doctor Proctor. He has generated a high level of dbz level initially. I understand he is developing one at a low dbz level which we will work with. There will be a threshold where we can't see. That is what we will find out.

E. BRACALENTE (NASA LaRC) - That 60 or 70 db number you saw was based on this model. We scanned that radar image, digitized it and then put in a calibration where the backscatter sigma zero ran from -5 db to -40 or -50 db depending on the ground target. And that was the basis. We haven't really got involved in algorithm development yet. We'll not until we get some real data and really know what we've got. But obviously there are techniques that can be applied. A lot of filtering schemes will be looked at.

1

In response to Russell Targs's second question. The clutter-to-signal (CSR) ratios mentioned at the previous meeting were in the 50 to 60 db range relative to a 0 dbz signal reflectivity. This is for the antenna pointed down along the glide slope and a range gate 5 Km from the a/c, where the main beam touches the ground. At shorter range gates, under 3 Km, the CSR falls below 30 db. With a 20 dbz or greater signal, typical of wet micro-burst, the CSR for the worst case will be below 40 db, and for the shorter ranges below 10 db. These CSR are within a range that present day radar and filtering designs could handle. For the dry microbust, where the reflectivity is below 10 dbz proper antenna pointing, range limiting, higher powers and higher frequencies may have to be employed. These trade-offs will be assessed to determine the performance and limitations of Doppler radars.

PAT ADAMSON (Turbulence Prediction) - At any point have you addressed the asymmetric cases for an airborne radar? It seems to me that that is a problem. I don't see it in any of the stuff that has been put up.

CHARLES BRITT (RTI) - We haven't yet. The data bases we have are symmetrical. The first thing to do is move those off center and then look at those and then we will get into the asymmetric cases.

E. BRACALENTE (NASA LaRC) - We just started looking at that and that is the first model we've got to work with and we will be looking at all the different cases. Wet, dry, symmetrical, etc. But we are trying to get the model for the simulation program developed to the point where we can start looking at all this.

JIM EVANS (MIT Lincoln Lab) - Let me make a couple of comments. The question of what the reflectivities are to microburst, I would represent, you don't need a simulation model. There have been enough field measurements run in wet and dry environments so that if you don't know what the dbz levels are by now your model will never tell you anything different. Because people have been measuring them now for 5-6-7 years and there are probably over 1000 microbursts that have been measured. And I dare say that anybody who claims that a simulation model is going to improve on the thousands of measured events is crazy. It is very simple to go through and compute the signal to noise ratio at X band for the presumed operation. And

----

1. E. BRACALENTE has asked that the following comments be added.

I'm hoping somebody has done--I'm sure John Chisholm has done and could share that result. If you plug in a typical sigma zero without getting into great exotic behavior ERIM's existing data base isn't applicable because, the crazy angles of incidence are really things like 3 degrees and below. And the sigma zero go up radically. The case you gave, the grazing angle and the scenario you have pointed out, is 3 degrees, not 10 degrees. Anybody who has ever looked at airborne data knows the cross sections go up very fast as the grazing angles gets down near 0 and below 5 degrees in particular. My rough guess is if it can't work in an urban environment people are never going to buy it. Almost every airport I can imagine has at least one approach or two that are over an urban environment and I mean houses and so on. Just look out next time you go into a major airport. So forget all the other stuff, if you can't work over an urban environment you probably don't have a viable system.

E. BRACALENTE (NASA LaRC) - That is exactly what we are doing. The data from ERIM that we are going to be getting, is at 3 degrees.

2

In response to Jim Evans' first comment. The purpose of the microbust simulation model is not to answer the question of what reflectivities or windspeeds are in a microbust, or to improve on the thousands of measured events, but to provide a high resolution spatiallly distributed data base of windspeeds and reflectivities representative of a typical microburst. These models can then be used by e aerodynamicist to evaluate its effects on a/c performance, and by sensor developers to evaluate sensor design trade-offs and performance. --- Generally, sigma zero does not go up as the grazing angle decreases. In fact for most targets such as runways, grass, water, farm lands, and forests the sigma zero decreases significantly with decreasing grazing angle. For urban environments sigma zero tends to be more constant as a function of grazing angle, with a mean value around -10db, and decreases slightly with decreasing grazing angle. Only when the grazing angle approaches 0 to 1 degree does sigma zero sometimes increase due to multipath scattering and specular reflection from the flat sides of buildings. These extremely low grazing angles will not occur in the range gates that would be processed in an airborne radar. -- It has never been suggested that an airborne radar is being developed to work only in non-urban area around airports. It is because of the urban environment around most airports that we're obtaining the ERIM SAR data at low grazing angles. This data will help us evaluate the severity of the urban clutter and to investigate radar configurations that may be able to work within this

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2. E. BRACALENTE has asked that the following comments be added.

environment.

JIM EVANS - Okay. Let me make a comment. If you take a -10 db sigma zero (which isn't a reasonable guess) and you work out the math for 10 kilometers, you are going to find your clutter is probably 70 or 80 db above your signal. That is just the way the numbers work out, and I think John Chisholm will verify that. At 10 kilometers I don't think you have a viable system. Not if you take the simulation model and you believe that the microburst are only 2 or 300 meters thick and you believe that you have to function over an urban environment, I don't think you are even in the ball park. And I'll make that as a simple challenge and you can plug it into the sigma zero numbers and carry them out, John Chisholm has done that and I'm sure has drawn the same conclusion.

[3] In response to Jim Evans's second comment. I think you will find that the numbers you have given are significantly in error. Specifically, for an a/c at 10 Km from touchdown and an altitude of 525 meters, using a 3 deg. beamwidth antenna looking down the glide slope (-3 deg.) at a 20 dbz reflectivity (a reasonable number for a wet microburst) and a ground backscatter sigma zero of -10 db (a reasonable estimate for urban clutter) the clutter will be about 45 db above the signal, not 70-80 db. (Which agrees approximately with the numbers John Chisholm computed. See his comment which follows.) At the 5 km range gate, which provides adequate warning time to the pilot, the clutter is about 26 db above the signal. At shorter ranges and with proper antenna pointing management the clutter levels can be reduced significantly further. These lower clutter-to-signal ratios are well within the limits that present day processors and radar designs can handle.

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3. E. BRACALANTE has asked that the following comments be added.

N88-17626

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LIDAR WINDSHEAR DETECTION AND AVOIDANCE: PERFORMANCE AND TECHNICAL ASSESSMENT

SUPPORTED BY

NASA/FAA
INTEGRATED WINDSHEAR PROGRAM

RUSSELL TARG

RESEARCH & DEVELOPMENT DIVISION
LOCKHEED MISSILES & SPACE COMPANY, INC.

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AGENDA

PROGRAM SUMMARY OF TASKS

DESCRIPTION OF SUB-CONTRACTED TASKS

WINDSHEAR DETECTION AND AVOIDANCE REQUIREMENTS

RESULTS SUMMARY: CONCEPT FORMULATION/PERFORMANCE ANALYSIS

SENSOR FUNCTIONS

CO_2 LIDAR OPTIONS – STI

RF WAVEGUIDE LASERS – UTRC

SOLID-STATE LIDAR OPTIONS – LIGHTWAVE ELECTRONICS

CONCEPT PERFORMANCE/SIMULATION ANALYSIS – CTI

CONCLUSIONS

LIDAR WIND-SHEAR DETECTION AND AVOIDANCE: PERFORMANCE AND TECHNICAL ASSESSMENT

PROGRAM SUMMARY

OBJECTIVE: THIS STUDY EVALUATES COMPETING LIDARS FOR USE IN AN AIRBORNE FORWARD-LOOKING SYSTEM TO ENABLE AIRCRAFT TO AVOID THE HAZARDS OF LOW-ALTITUDE WIND SHEAR

LIDAR-SENSOR REQUIREMENTS ANALYSIS: DERIVE THE REQUIREMENTS FOR AN AIRBORNE LIDAR TO REMOTELY SENSE POTENTIALLY HAZARDOUS WIND CONDITIONS USING THE RECONSTRUCTED, TEMPORALLY VARYING WIND FIELDS SURROUNDING THE DELTA 191 FLIGHT AT DFW IN AUGUST 1985.

SENSOR CONCEPT FORMULATION: CONCEIVE LIDAR SYSTEM CONCEPTS FROM A STATE-OF-THE-ART TECHNOLOGY BASE. IDENTIFY THE MOST PROMISING TYPE OF CO_2 AND SOLID-STATE LASERS. IDENTIFY THE DESIGN TRADE-OFFS FOR THE CRITICAL COMPONENTS OF THIS SYSTEM.

CONCEPT PERFORMANCE/SIMULATION ANALYSIS: PARAMETRICALLY CALCULATE THE SIGNAL-TO-NOISE RATIO AND WIND-VELOCITY ACCURACY CONSIDERING SUCH PARAMETERS AS PULSE ENERGY, PULSE LENGTH, p.r.f., DETECTION BANDWIDTH, AND ENVIRONMENTAL FACTORS.

CONCEPT EVALUATION: EVALUATE LIDAR CONCEPTS WITH RESPECT TO WIND-DETECTION PERFORMANCE IN THE PRESENCE OF VARIOUS TYPES OF WEATHER. SELECT THE CONCEPT THAT BEST FULFILLS THE REQUIREMENTS AND CAN BE DEVELOPED FOR COMMERCIAL APPLICATION WITHIN 4 YEARS.

FORWARD–LOOKING AIRBORNE LIDAR WIND–SHEAR DETECTION: GENERAL REQUIREMENTS

- MEASURE HEADWIND AND VERTICAL COMPONENTS OF WIND VELOCITY FROM AIRCRAFT OUT TO 3 km
- EMPHASIZE AVOIDANCE RATHER THAN RECOVERY
- RESPOND IN REAL TIME WITH LOW NUISANCE-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

RDD

TENTATIVE TECHNICAL REQUIREMENTS

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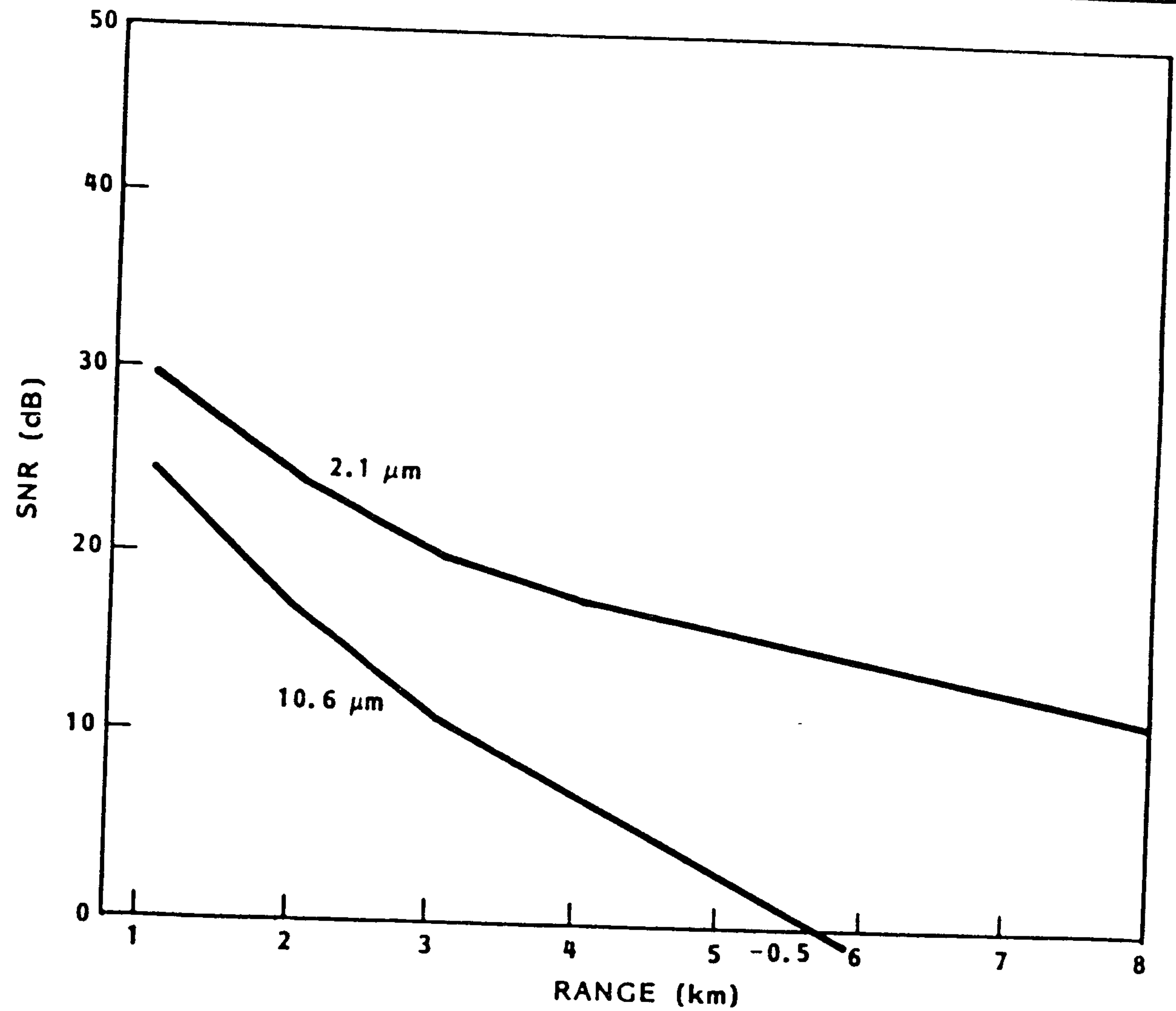
• SENSING RANGE	1 TO 3 km
• RANGE RESOLUTION	0.3 km
• VELOCITY RESOLUTION	APPROXIMATELY 1 m/s
• ADVANCE WARNING TIME	15 TO 30 s

STARTING PARAMETERS FOR LIDAR COMPARISON

PARAMETERS	LIDAR SYSTEM	
	Ho:YAG (2.1 μm)	CO_2 (10.6 μm)
SEA-LEVEL BACKSCATTER COEFF. $\left(\frac{1}{m \cdot sr}\right)$	5.5×10^{-7} (KENT)	5×10^{-8} (VAUGHAN)
EFFICIENCY ($\eta_T = \eta_o \eta_c \eta_q$)	0.1	0.03
ATTENUATION (dB/km)	0.1	1.0
PULSE ENERGY (mJ)	5	5
BANDWIDTH (MHz)	10	2
PULSE LENGTH (μs)	0.5	0.5
MIRROR DIAMETER (cm)	15	15

COMPARISON OF 2.1-μm AND 10.6-μm LIDARS: SINGLE-SHOT SIGNAL-TO-NOISE RATIO VERSUS RANGE IN CLEAR WEATHER



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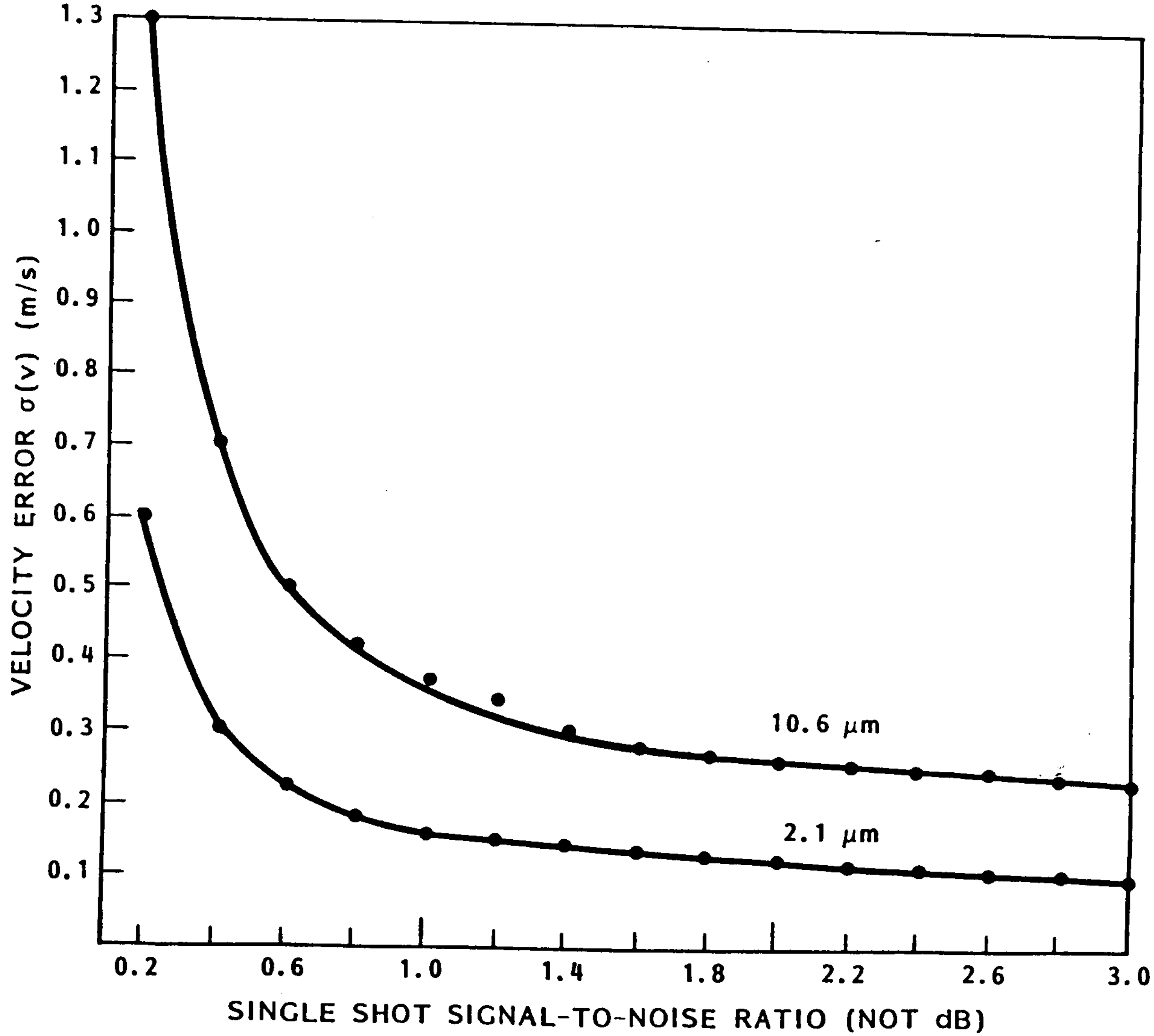
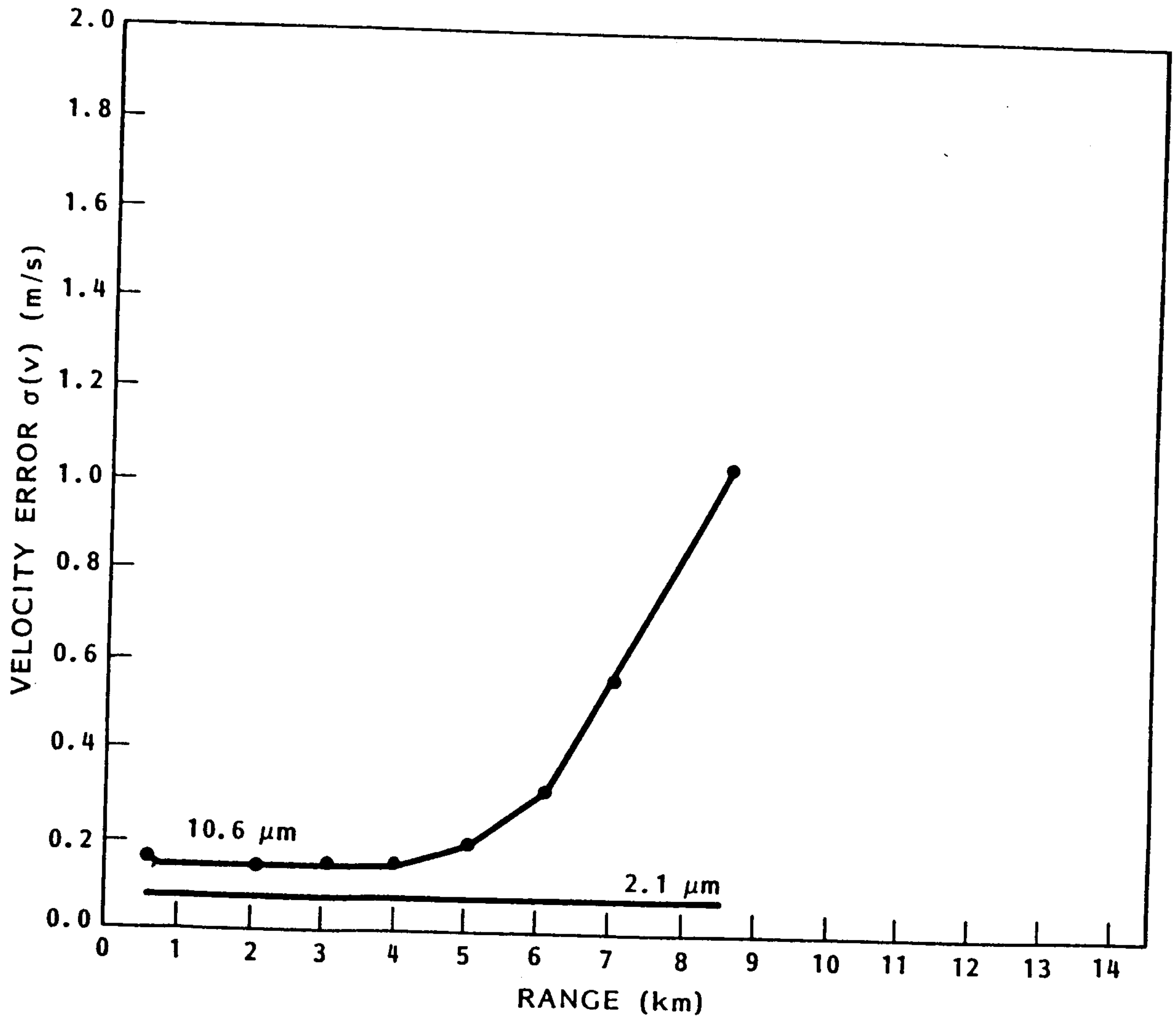
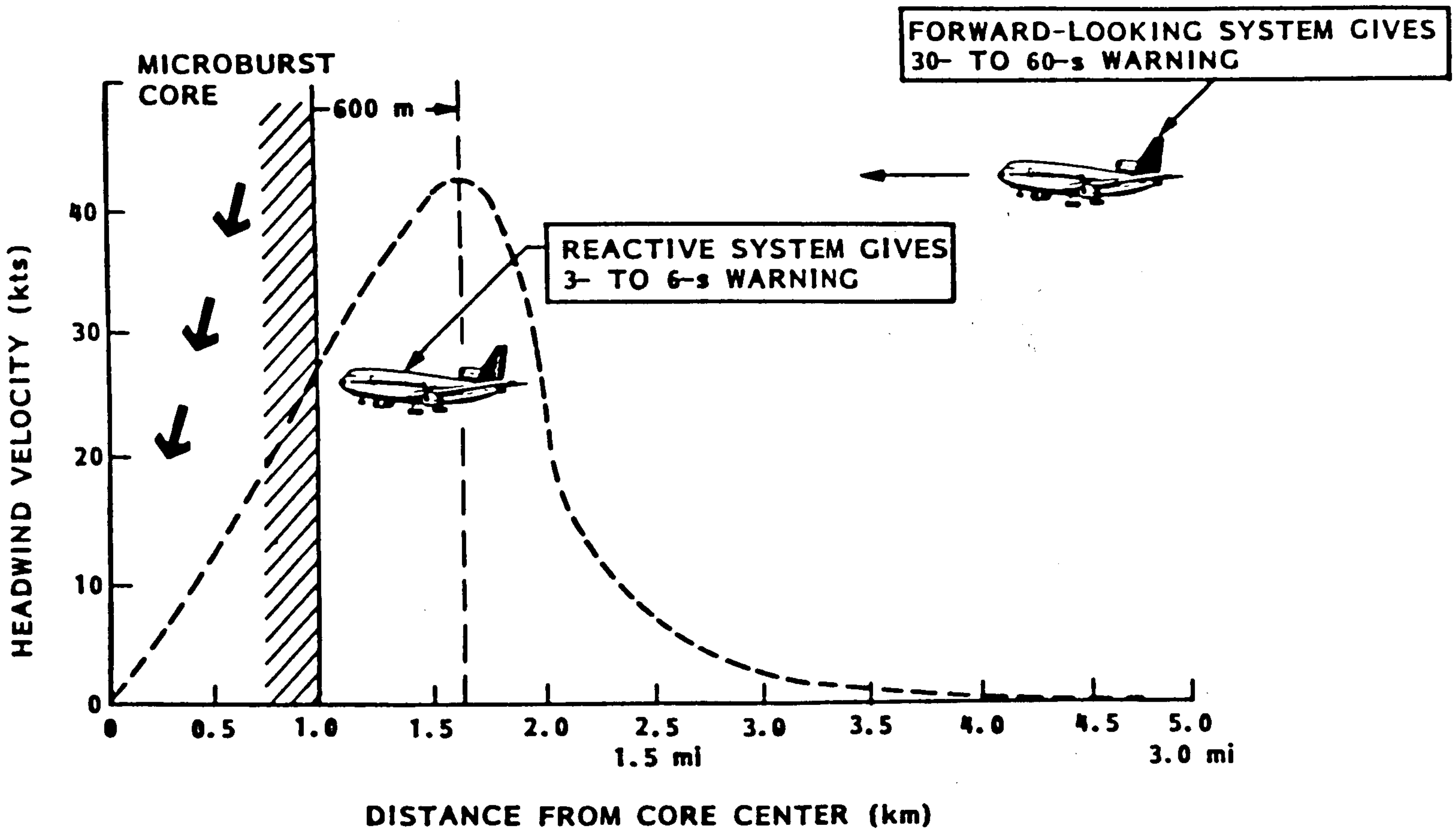
COMPARISON OF 2.1-μm AND 10.6-μm LIDARS: VELOCITY ERROR AS A FUNCTION OF SINGLE-SHOT SNR (PULSE PAIR ALGORITHM, Zrnic)



COMPARISON OF 2.1-µm AND 10.6 µm LIDARS: VELOCITY ERROR VERSUS RANGE IN CLEAR WEATHER (100 PULSES)

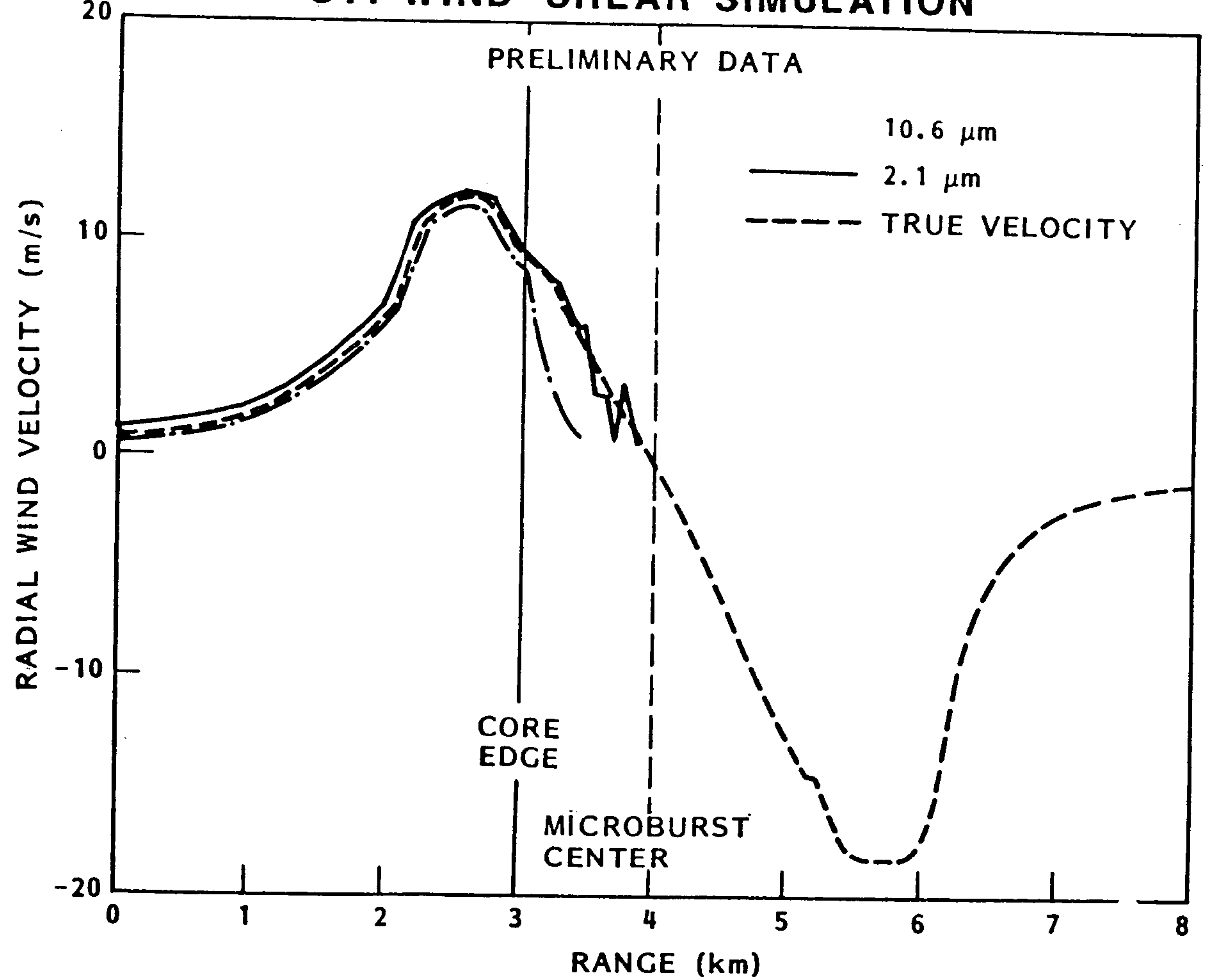


RELATIVE PERFORMANCE OF FORWARD-LOOKING AND REACTIVE SYSTEMS FOR THE DALLAS/FORT WORTH MICROBURST



COMPARISON OF 2.1-μm AND 10.6-μm LIDARS: SIMULATED AND TRUE VELOCITY VERSUS RANGE (D/FW MICROBURST)

CTI WIND-SHEAR SIMULATION



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WIND-SHEAR DISPLAY

DISPLAY SHOULD INCLUDE WIND-VELOCITY INFORMATION, BOTH RADIAL AND VERTICAL. CHANGES IN $\dot{w}_x$ AND THE VALUE OF w_h SHOULD BE DISPLAYED AT RANGES OF 1, 1.5, AND 2 mi.

THE ONBOARD WIND-SHEAR DETECTOR MUST BE GIVEN THE AIRCRAFT'S ATTITUDE AND AIR SPEED TO UPDATE OF ITS CALCULATION OF THE HAZARD INDEX F.

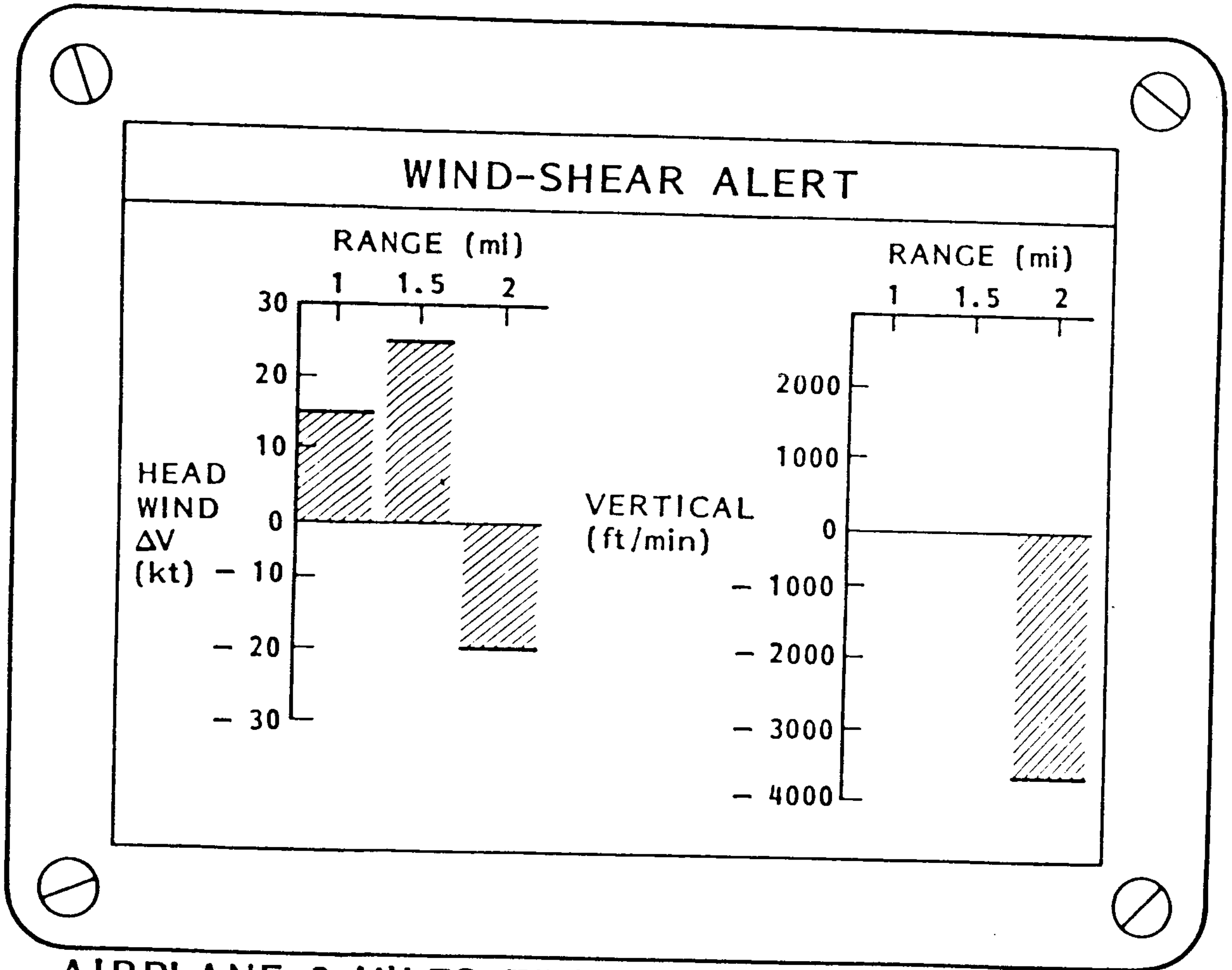
$$\boxed{F = \dot{w}_x/g - w_h/V}$$

WHERE

w_x = d/dt OF THE RADIAL WIND
w_h = VERTICAL WIND
V = THE AIRCRAFT'S AIR SPEED
g = THE ACCELERATION DUE TO GRAVITY (20 knots/s)

A MEASURED $\dot{w}_x$ OF 2 knots/s FOR 7.5 s INDICATES A POTENTIAL 15-knot LOSS OF AIR SPEED. SUCH A MEASUREMENT, OR A VERTICAL WIND OF 1500 ft/min, WOULD SOUND A WIND-SHEAR ALARM.

AIRCRAFT INSTRUMENT DISPLAY FOR AUGUST 1985 DELTA 191 APPROACH TO DALLAS/FORT WORTH



AIRPLANE 2 MILES FROM CORE EDGE
SHOWING HAZARDOUS MICROBURST

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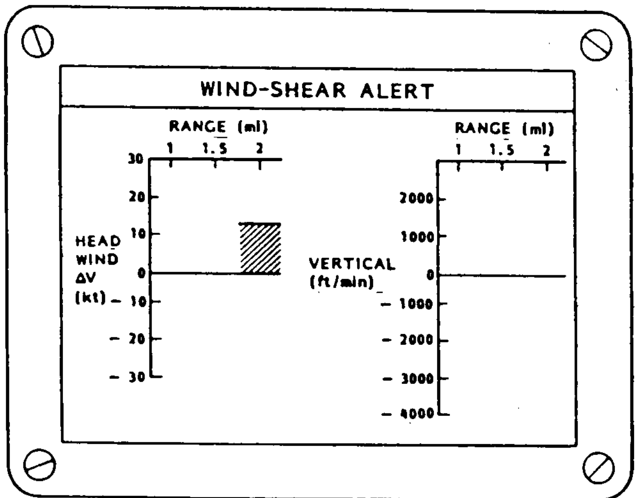
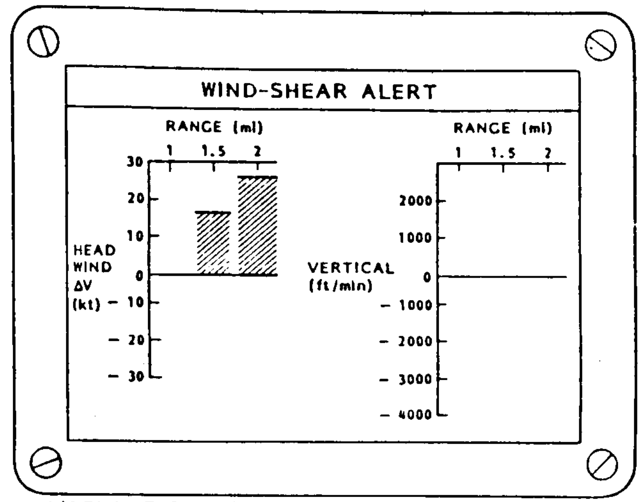
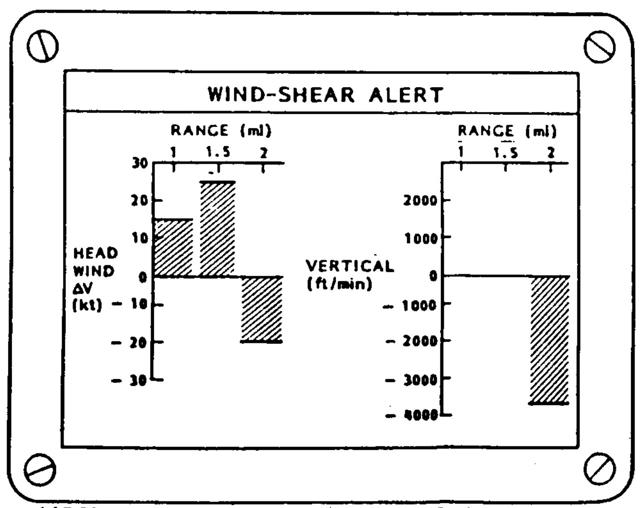
ALTOS DISPLAY FOR APPROACH TO DALLAS/FORT WORTH MICROBURST



AIRPLANE 3 MILES FROM CORE EDGE



AIRPLANE 2.5 MILES FROM CORE EDGE



AIRPLANE 2 MILES FROM CORE EDGE
SHOWING HAZARDOUS MICROBURST

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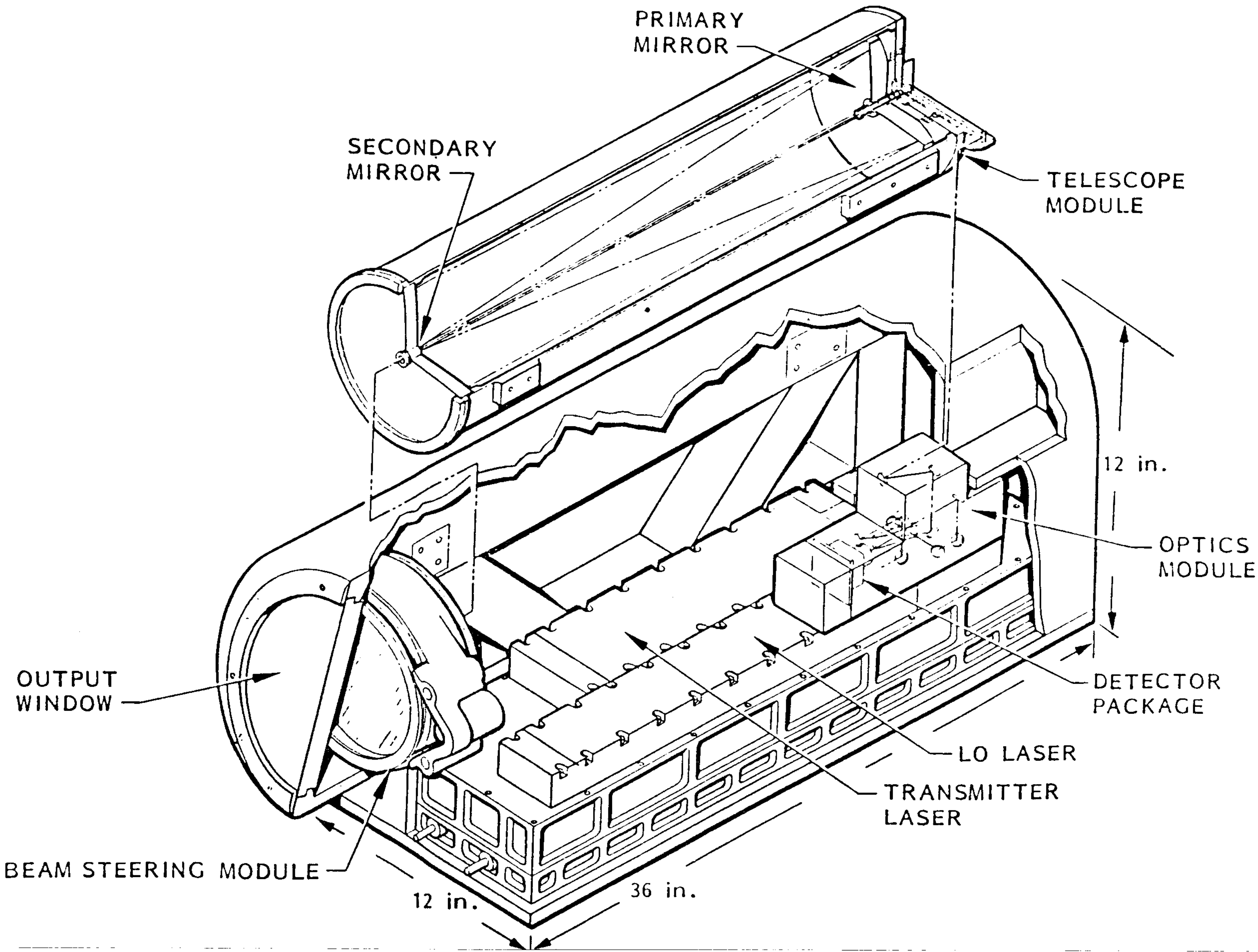
OPTO-MECHANICAL DESIGN



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PRELIMINARY RESULTS

- BOTH Ho:YAG AND CO_2 LIDAR SYSTEMS APPEAR ABLE TO MEET PRELIMINARY WINDSHEAR WARNING REQUIREMENTS AS DETERMINED BY SIMULATIONS OF THE 1985 DALLAS/FORT WORTH MICROBURST EVENT.
- Ho:YAG (2.1-μm) LIDAR POTENTIALLY HAS SUPERIOR PERFORMANCE TO THE CO_2 (10.6-μm) LIDAR TECHNOLOGY FOR LONG-RANGE DETECTION OF THE INTERIOR STRUCTURE OF A MICROBURST – Ho:YAG HAS BETTER TRANSMISSION IN CLEAR AND WET WEATHER AND A HIGHER BACKSCATTER COEFFICIENT.
- Q-SWITCHED, PULSED CO_2 LIDAR BRASSBOARD CAN BE READY FOR FLIGHT TEST WITHIN 18 MONTHS USING STATE-OF-THE-ART TECHNOLOGY.
- Ho:YAG BRASSBOARD IS NOT READY FOR FLIGHT TESTING AT THIS TIME BECAUSE OF UNAVAILABILITY OF LASER WITH REQUIRED PERFORMANCE.
- CONSIDERABLE FURTHER DEVELOPMENT IS NEEDED FOR Ho:YAG PULSED LASERS BECAUSE OF QUESTIONS ABOUT PERFORMANCE EFFICIENCY AND FREQUENCY STABILITY OF ROOM-TEMPERATURE Q-SWITCHED Ho:YAG LASER.
- QUESTIONS REMAIN REGARDING THE BEST APPROACH TO BEAM SCANNING IN A STRONGLY INHOMOGENEOUS WIND FIELD.
- TECHNOLOGY ASSESSMENT SHOWS THAT CO_2 TECHNOLOGY IS CONSIDERABLY MORE MATURE THAN SOLID-STATE TECHNOLOGY. Ho:YAG STILL REQUIRES AN ESTIMATED 5 YEARS OF CONCENTRATED RESEARCH AND DEVELOPMENT.

RDD Lockheed

LIDAR WINDSHEAR DETECTION AND AVOIDANCE: PERFORMANCE AND TECHNICAL ASSESSMENT

MIDTERM PROGRAM REVIEW

OCTOBER 7–8, 1987
NASA LANGLEY RESEARCH CENTER

RUSSELL TARG

RESEARCH & DEVELOPMENT DIVISION
LOCKHEED MISSILES & SPACE COMPANY, INC.

RJDD

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- TECHNOLOGY ASSESSMENT SHOWS THAT CO_2 TECHNOLOGY IS CONSIDERABLY MORE MATURE THAN SOLID-STATE TECHNOLOGY, BY 10 YEARS OR MORE.

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LIDAR WINDSHEAR DETECTION AND AVOIDANCE: PERFORMANCE AND TECHNICAL ASSESSMENT

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RF WAVEGUIDE LASERS – UTRC

SOLID-STATE LIDAR OPTIONS – LIGHTWAVE ELECTRONICS

CONCEPT PERFORMANCE/SIMULATION ANALYSIS – CTI

CONCLUSIONS

N88-17627

AIRBORNE DOPPLER LIDAR DETECTION OF WIND SHEAR

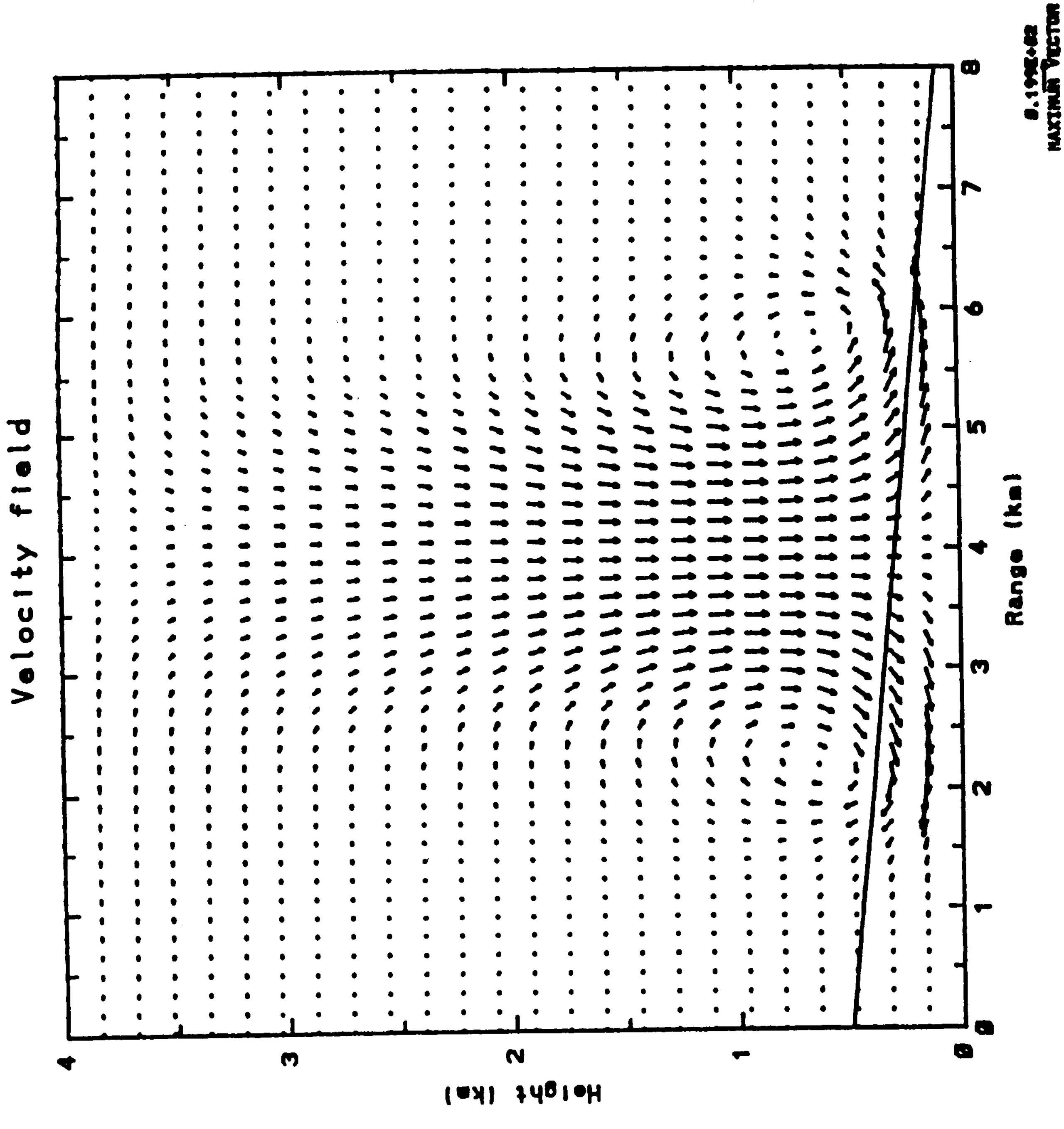
RESULTS OF PERFORMANCE ANALYSIS

NASA LaRC/LOCKHEED PO#SEPAK 8630A

OCTOBER 22-23, 1987

COHERENT TECHNOLOGIES, INC.

R. MILTON HUFFAKER


Velocity field
Height (km)
Range (km)
0
1
2
3
4
5
6
7
8

AIRBORNE WIND SHEAR

LIDAR COMPUTER SIMULATION

* READ INPUT PARAMETERS

* SET UP MEASUREMENT GEOMETRY

  Z, θ, Φ, ΔR

* REALIZATION LOOP

* SHOT LOOP

* RANGE GATE LOOP

* CALCULATE α (AFGL HITRAN)
  INTERPOLATE β, C_n^2

* CALCULATE E {RECEIVED POWER}

* MULTIPLY BY SRF
  SPECKLE, REFRACTIVE TURBULENCE, PHASE FRONT MISMATCH

* INCOHERENT SAMPLE LOOP
  IF $C\tau/2 < \Delta R$) (USE SAME R FOR ALL)

* APPLY EXPONENTIAL FLUCTUATION TO E {POWER} X SRF
  SPECKLE DOMINATED PDF

* CALCULATE WIDE AND NARROWBAND SNR
  $B_w = 4\ V_{max}/\lambda;\ B_n = 1/\tau$

* INTERPOLATE TRUE RADIAL VELOCITY FROM MICROBURST, V_r

* CALCULATE ESTIMATED VELOCITY $\hat{V}_r$
  CONVOLVE V_r WITH GAUSSIAN TEMPORAL PULSE

* CALCULATE VELOCITY WIDTH
  SECOND MOMENT

* CALCULATE CRAMER-RAO E {VEL. ERROR} = σ_V
  USE SNR_W AND VEL. WIDTH

* CHECK IF $\sigma_V < V_{max}$ THRESHOLD?
  IF NO, THROW ESTIMATE AWAY

* IF YES, GENERATE A GAUSSIAN R.V. V_E
  MEAN = 0, STD DEV = σ_V

* CALCULATE $V_m = \hat{V}_r + V_E$

* COMPLETE INCOHERENT SAMPLE LOOP

* CALCULATE MEDIAN V_m and snr
  (IF EVEN NUMBER, AVE. TWO IN MIDDLE)

* COMPLETE RANGE GATE LOOP

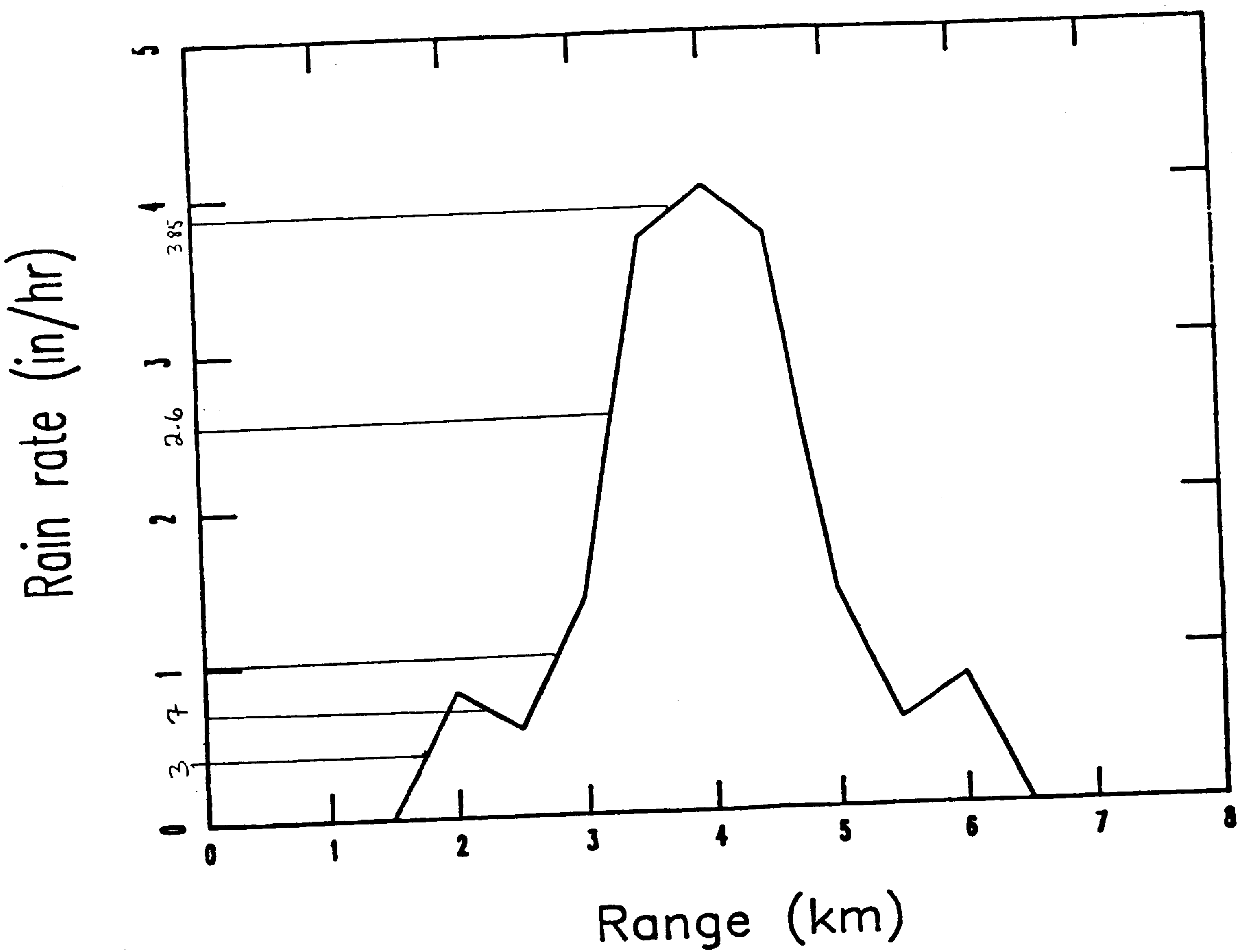
* COMPLETE SHOT LOOP

* CALCULATE $\overline{SNR}_n$, $\overline{V}_m$, $\overline{V}_E$, $\sigma_{V_E} / \sqrt{NSHOT}$

* COMPLETE REALIZATION LOOP

* CALCULATE $\sigma_{\overline{V}_E}$

CTI Wind Shear Simulation



AIRBORNE WINDSHEAR LIDAR BASE CASE PARAMETERS
(CO_2 LASER)

ATMOSPHERIC PARAMETERS

LaRC PROVIDED MICROBURST FIELDS

NO RAIN, HAIL, CLOUDS

MID-LATITUDE SUMMER MODEL ATMOSPHERE

AEROSOL BACKSCATTER COEFFICIENT $\beta = 5 \times 10^{-8}$ ($m^{-1} \cdot sr^{-1}$)

MODIFIED NOAA-WPL-37 C_n^2 PROFILE

LASER PARAMETERS

WAVELENGTH [CO_2 10P(20)] $\lambda = 10.591\ \mu m$

PULSE ENERGY = 5 mJ

OVERALL OPTICAL EFFICIENCY = .1

PULSE DURATION = 2 μs

300 m RANGE RESOLUTION

10 PULSES AVERAGED

15 cm TELESCOPE DIAMETER (e^{-2} INTENSITY)

3 km FOCAL RANGE

AIRCRAFT POSITION AND LIDAR ANGLE PARAMETERS

4 km TO CENTER OF MICROBURST (ON-AXIS)

500 m HEIGHT ABOVE GROUND LEVEL

-3^0 LIDAR ELEVATION POINTING ANGLE

AIRBORNE WINDSHEAR LIDAR BASE CASE PARAMETERS
(Ho:YAG LASER)

ATMOSPHERIC PARAMETERS

LaRC PROVIDED MICROBURST WIND FIELD

NO RAIN, HAIL, CLOUDS

MID-LATITUDE SUMMER MODEL ATMOSPHERE

AEROSOL BACKSCATTER COEFFICIENT $\beta = 1.25 \times 10^{-6}$ $(m^{-1} \cdot sr^{-1})$

MODIFIELD NOAA-WPL-37 C_n^2 PROFILE

LASER PARAMETERS

WAVELENGTH [Ho:YAG] λ = 2.0913 μm

PULSE ENERGY = 5 mJ

OVERALL OPTICAL EFFICIENCY = .2

PULSE DURATION = .5μs (4 SAMPLES AVERAGED INCOHERENTLY OVER 2 μs)

300 m RANGE RESOLUTION

10 PULSES AVERAGED

15 cm TELESCOPE DIAMETER (e^{-2} INTENSITY)

3 km FOCAL RANGE

AIRCRAFT POSITION AND LIDAR ANGLE PARAMETERS

4 km TO CENTER OF MICROBURST

500 m HEIGHT ABOVE GROUND LEVEL

-3^0 LIDAR ELEVATION POINTING ANGLE

CO_2 SYSTEMATIC PARAMETRIC ANALYSIS

Step 1: OPTIMIZE PULSE DURATION/RANGE RESOLUTION:

.5 μs, 1 μs, 2 μs, 3 μs, 5 μs, 6 μs
(75m), (150m), (300m), (450m), (750m), (900m)

Step 2: EXAMINE NUMBER OF SHOTS: 1, 2, 5, 10, 50, 100

Step 3: EXAMINE FOCUSING: $f = 3$ km, $f = \infty$

Step 4: EXAMINE OPTICAL DIAMETER: D = 7.5 cm, 15 cm, 20 cm

Step 5: EXAMINE REFRACTIVE TURBULENCE EFFECTS: C_n^2, $C_n^2 \times 10$

Step 6: EXAMINE PULSE ENERGIES:

1μJ, 50μJ, .5mJ, 5mJ, 10mJ, 15mJ, 20mJ, 100mJ

Step 7: EXAMINE AEROSOL BACKSCATTER EFFECTS:

$\beta = 5 \times 10^{-8}$, 10^{-8}, 10^{-9}, 10^{-10}, 10^{-11} $(m^{-1} \cdot sr^{-1})$

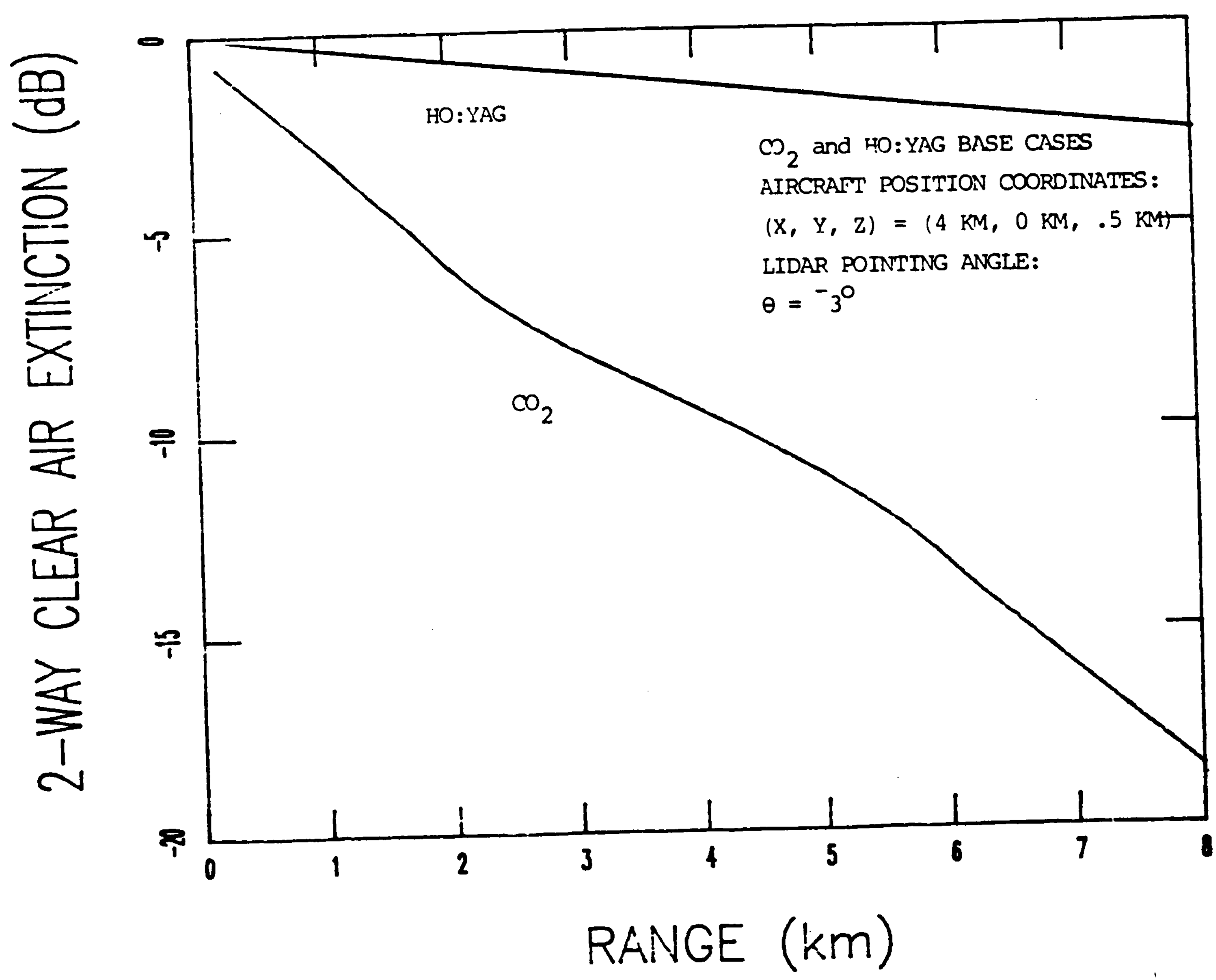
Step 8: EXAMINE WET MICROBURST

Step 9: EXAMINE AIRCRAFT POSITION: 4, 3, 2, 1 km FROM CENTER
TAKEOFF PROFILES
OFF-AXIS ENCOUNTERS

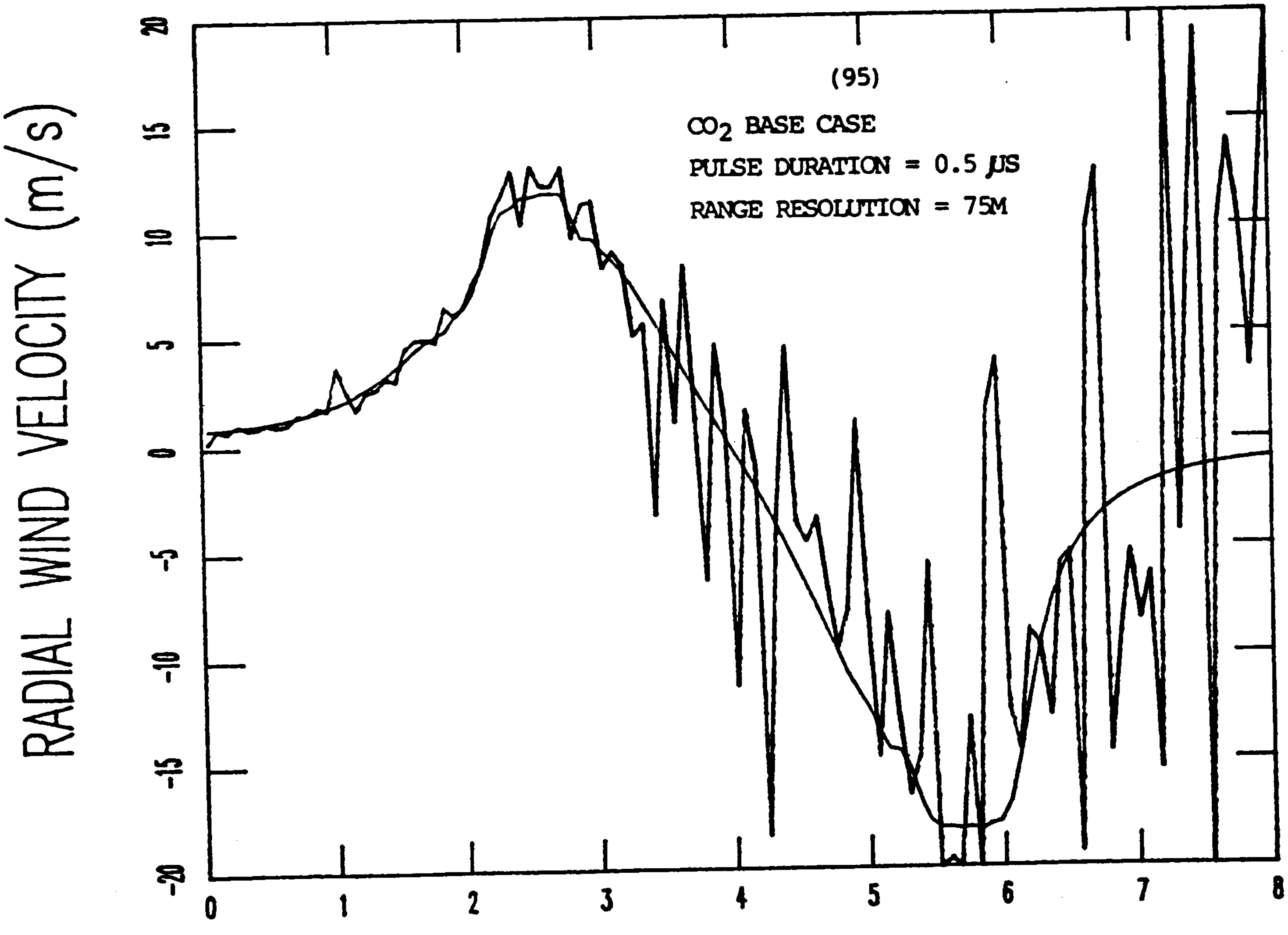
Step 10: EXAMINE AZIMUTHAL SCAN: ENCOMPASS ENTIRE WIND FIELD IN A 2-DIM PLANE AT 5^0 INCREMENTS

Step 11: MULTIPLE REALIZATIONS

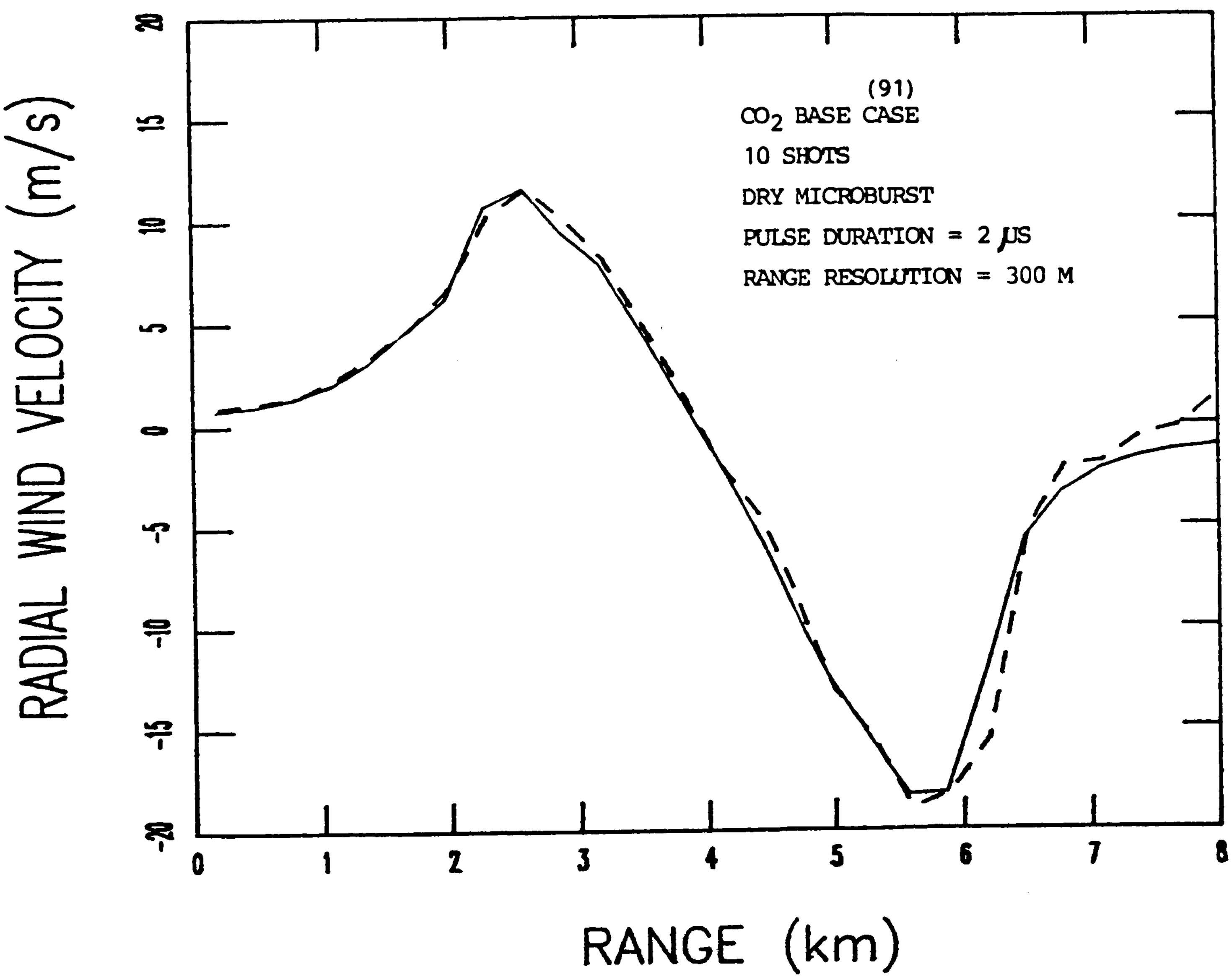
AIRBORNE WIND SHEAR LIDAR



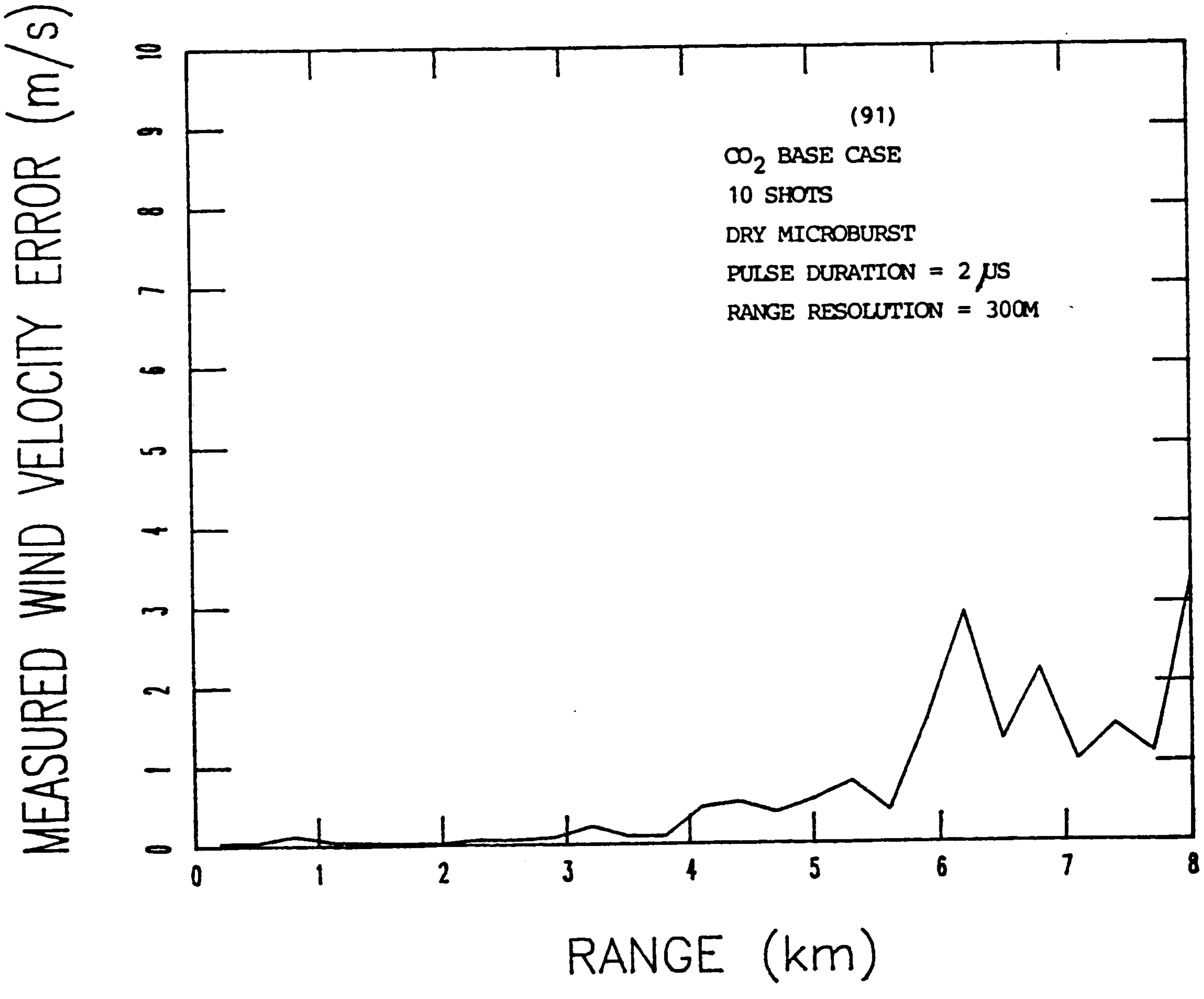
AIRBORNE WIND SHEAR LIDAR



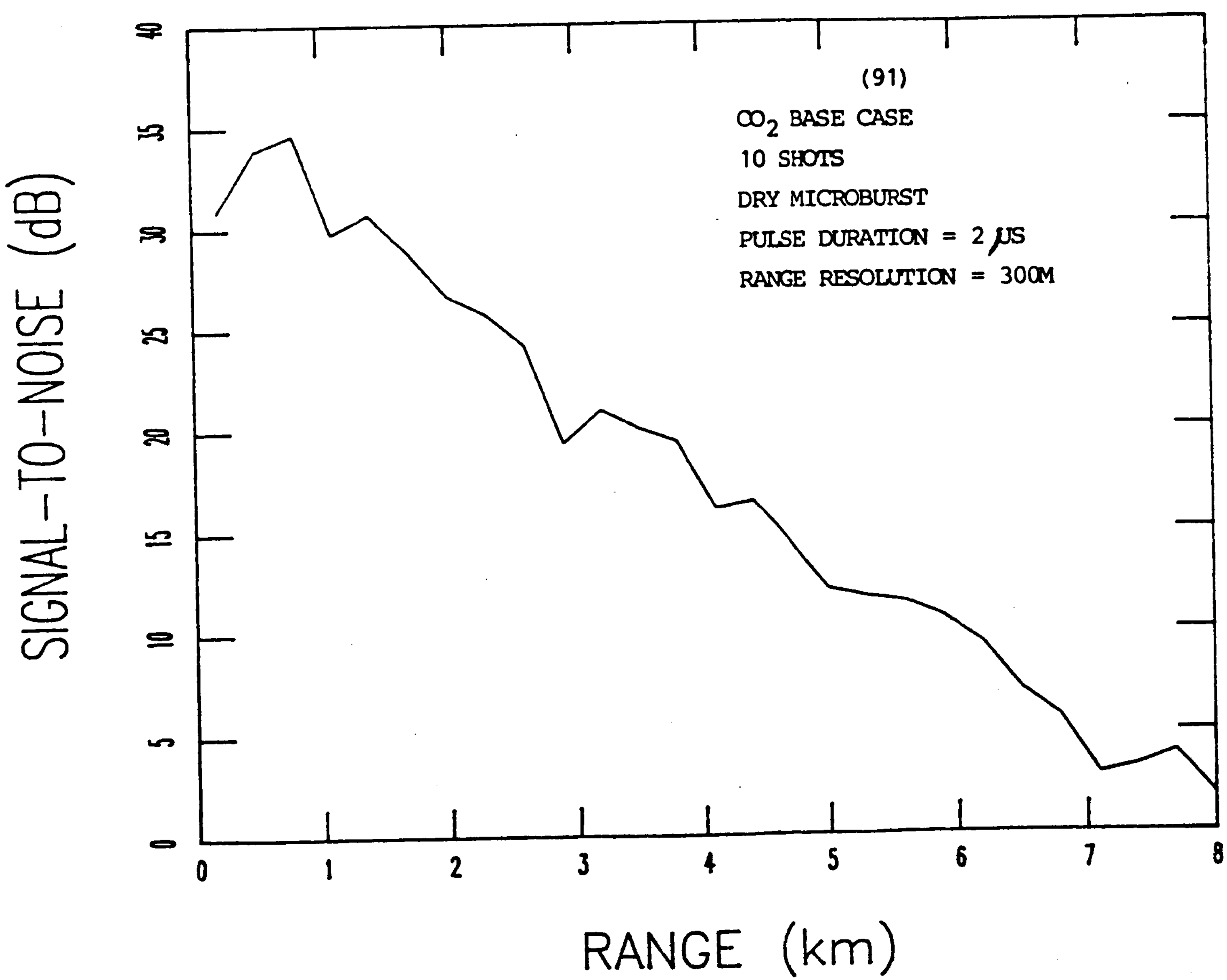
AIRBORNE WIND SHEAR LIDAR



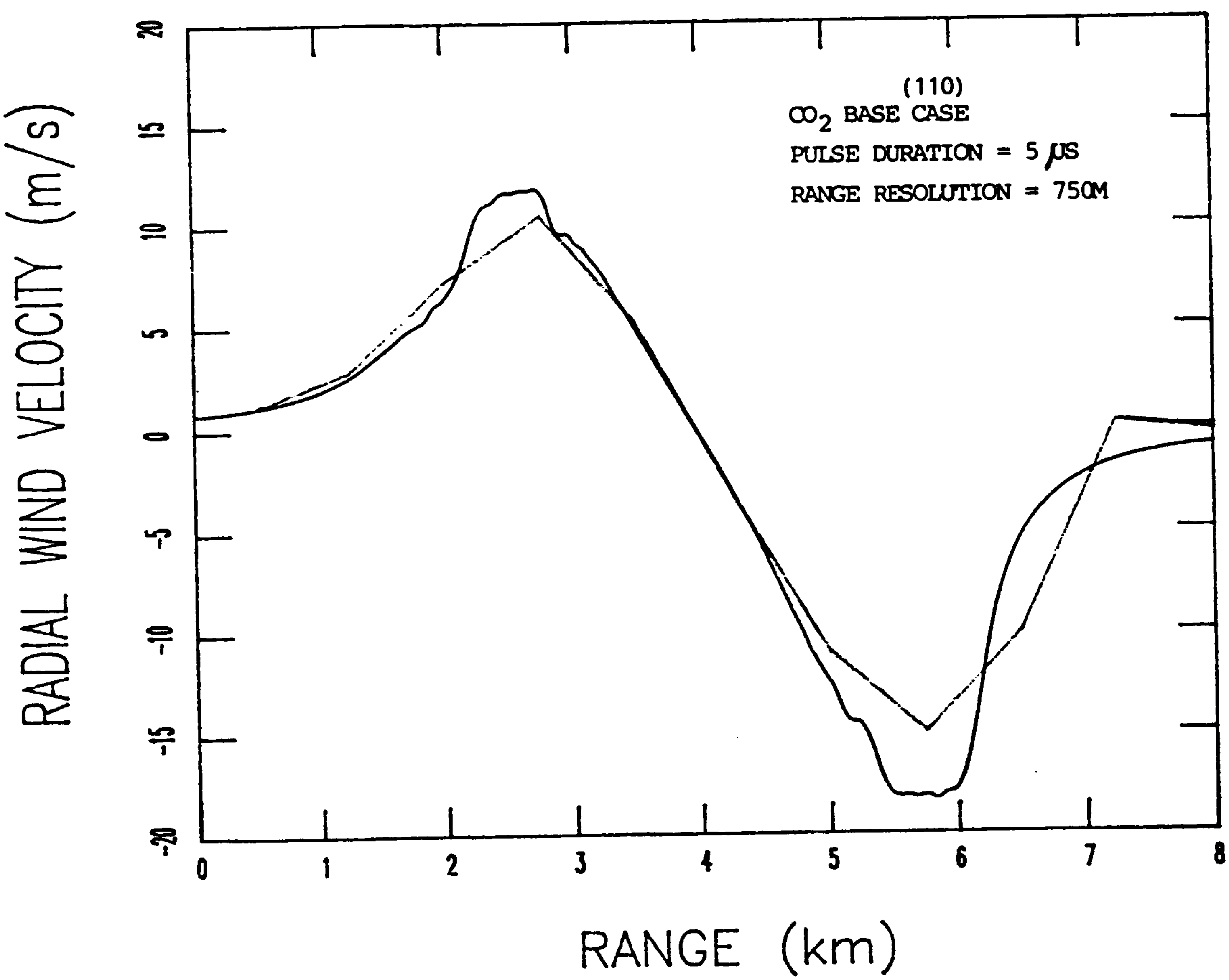
AIRBORNE WIND SHEAR LIDAR



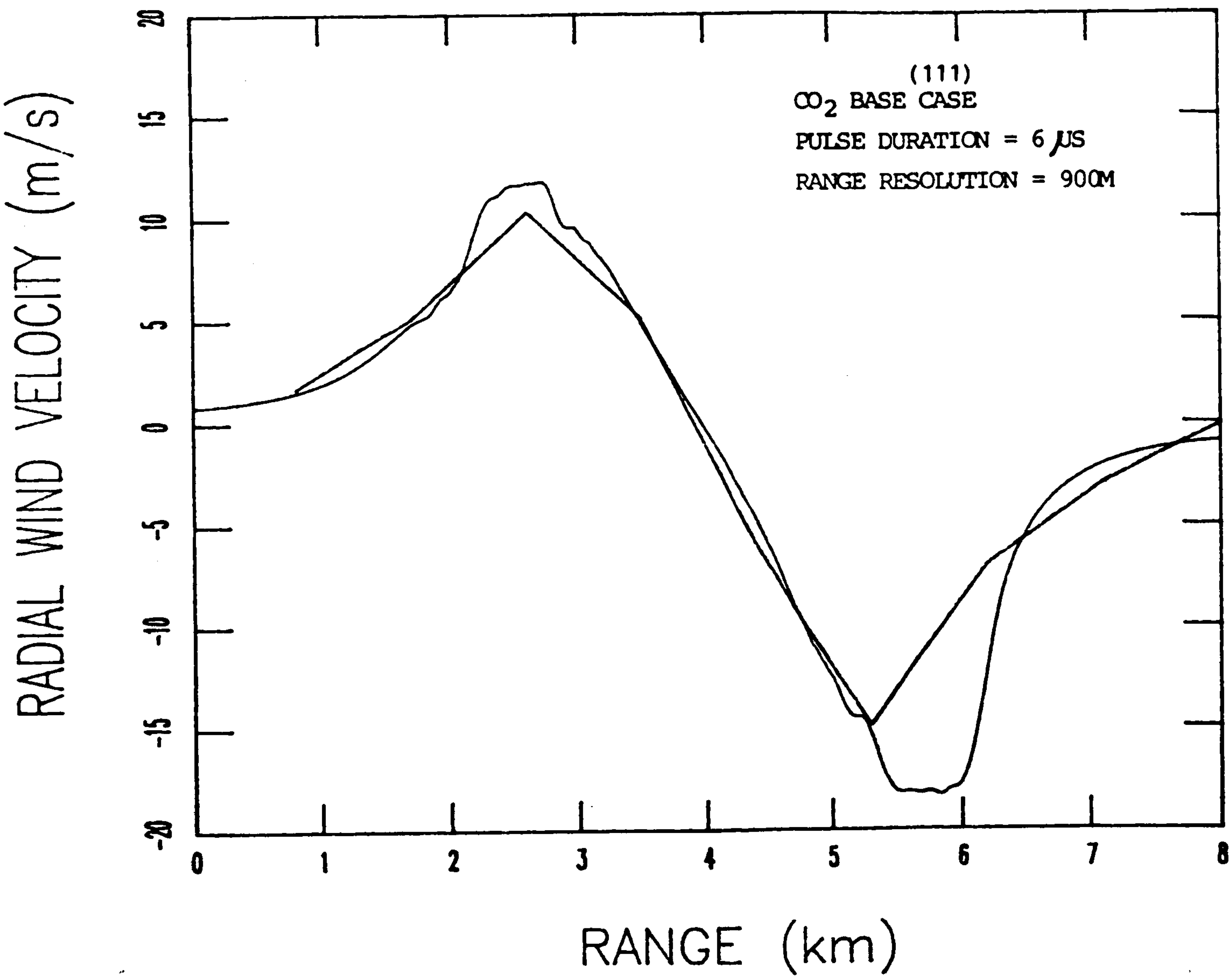
AIRBORNE WIND SHEAR LIDAR

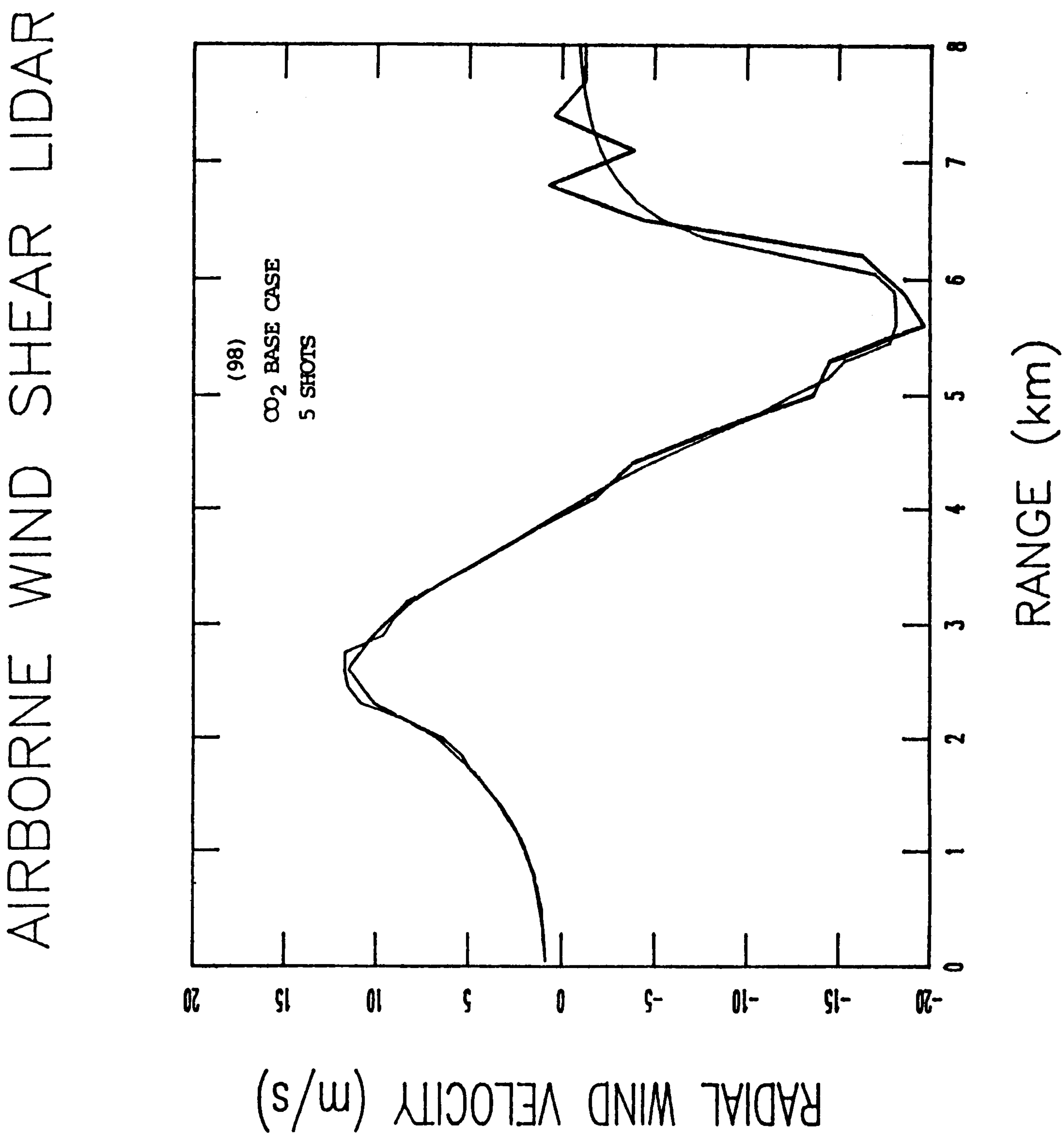


AIRBORNE WIND SHEAR LIDAR

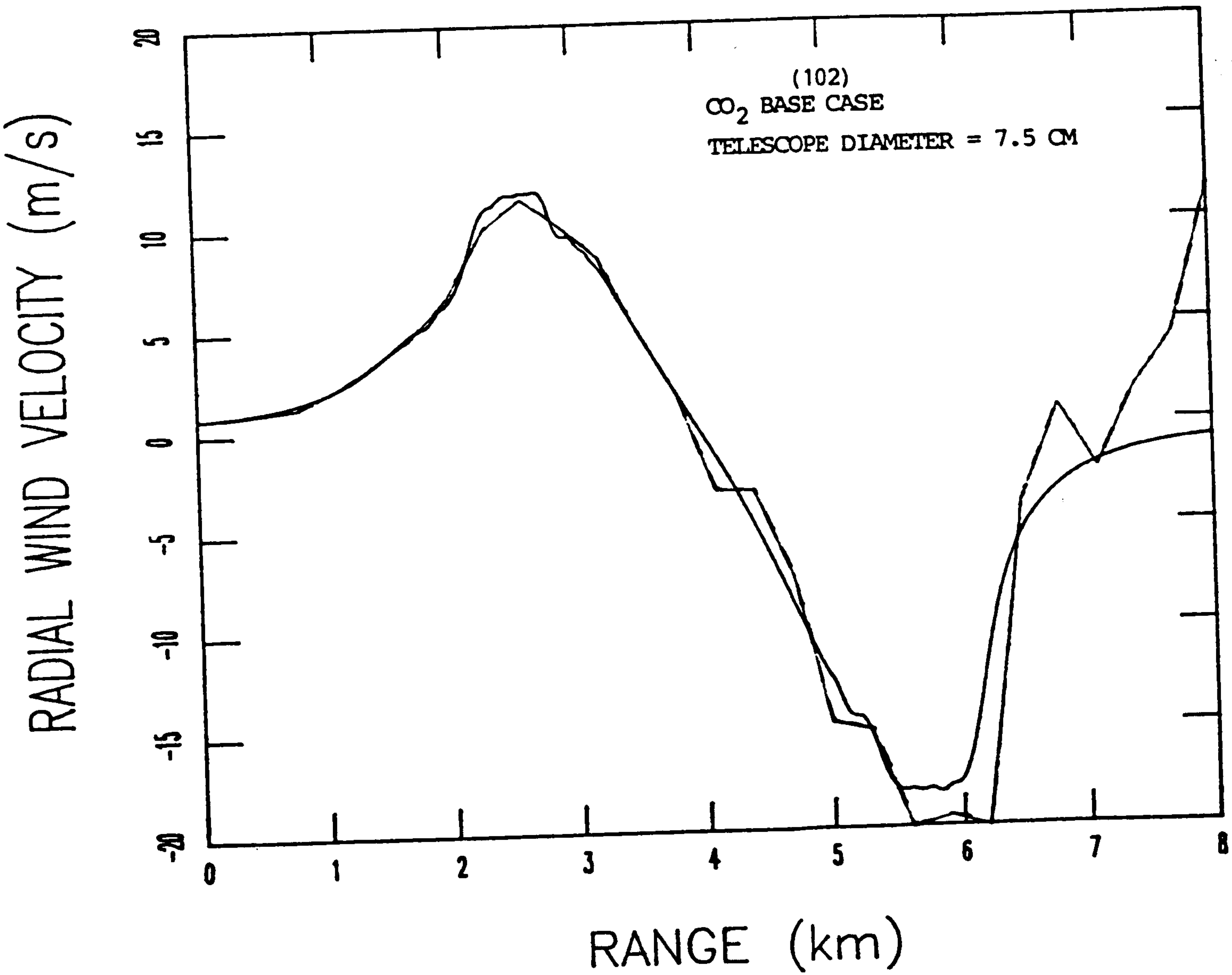


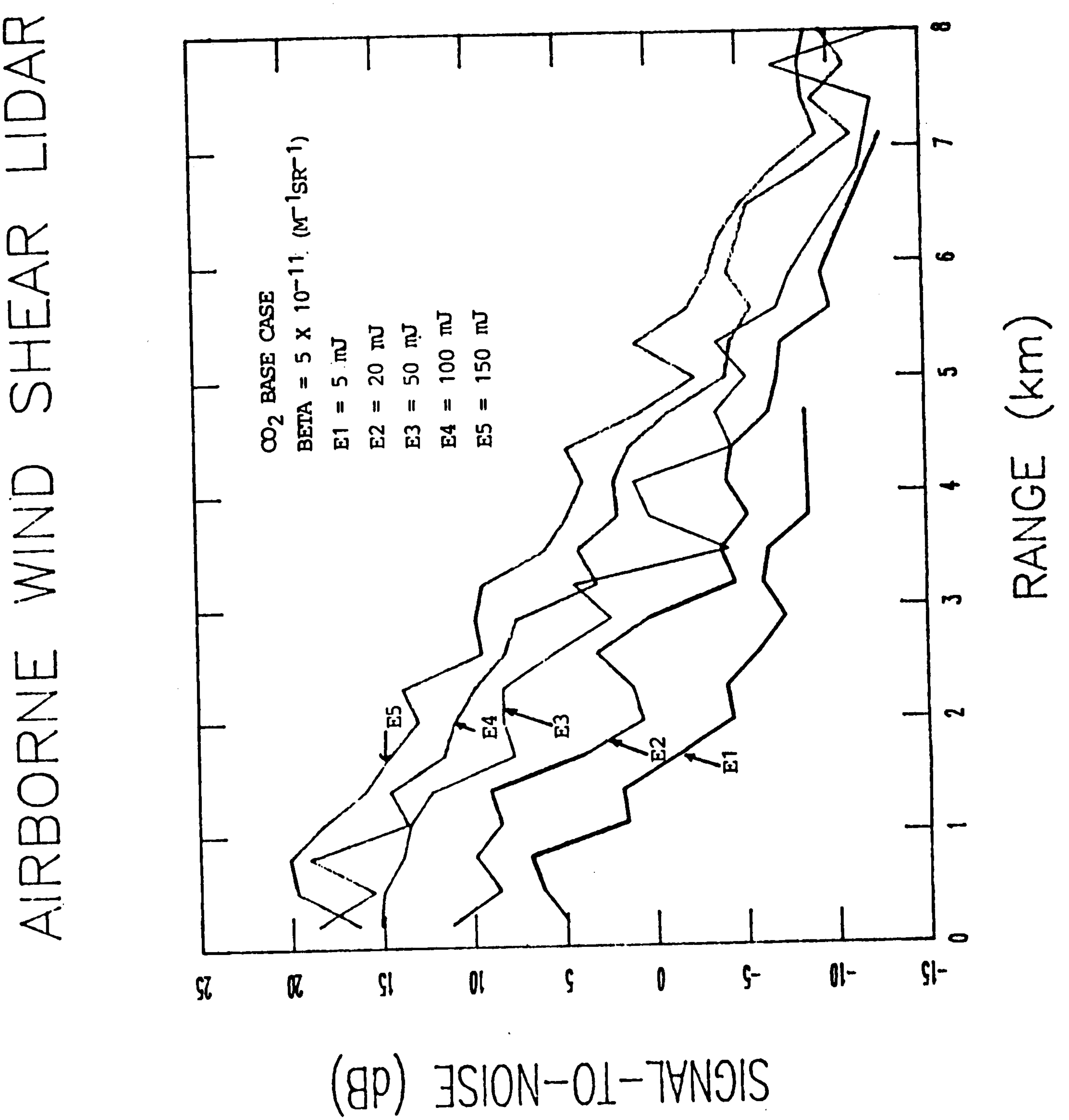
AIRBORNE WIND SHEAR LIDAR



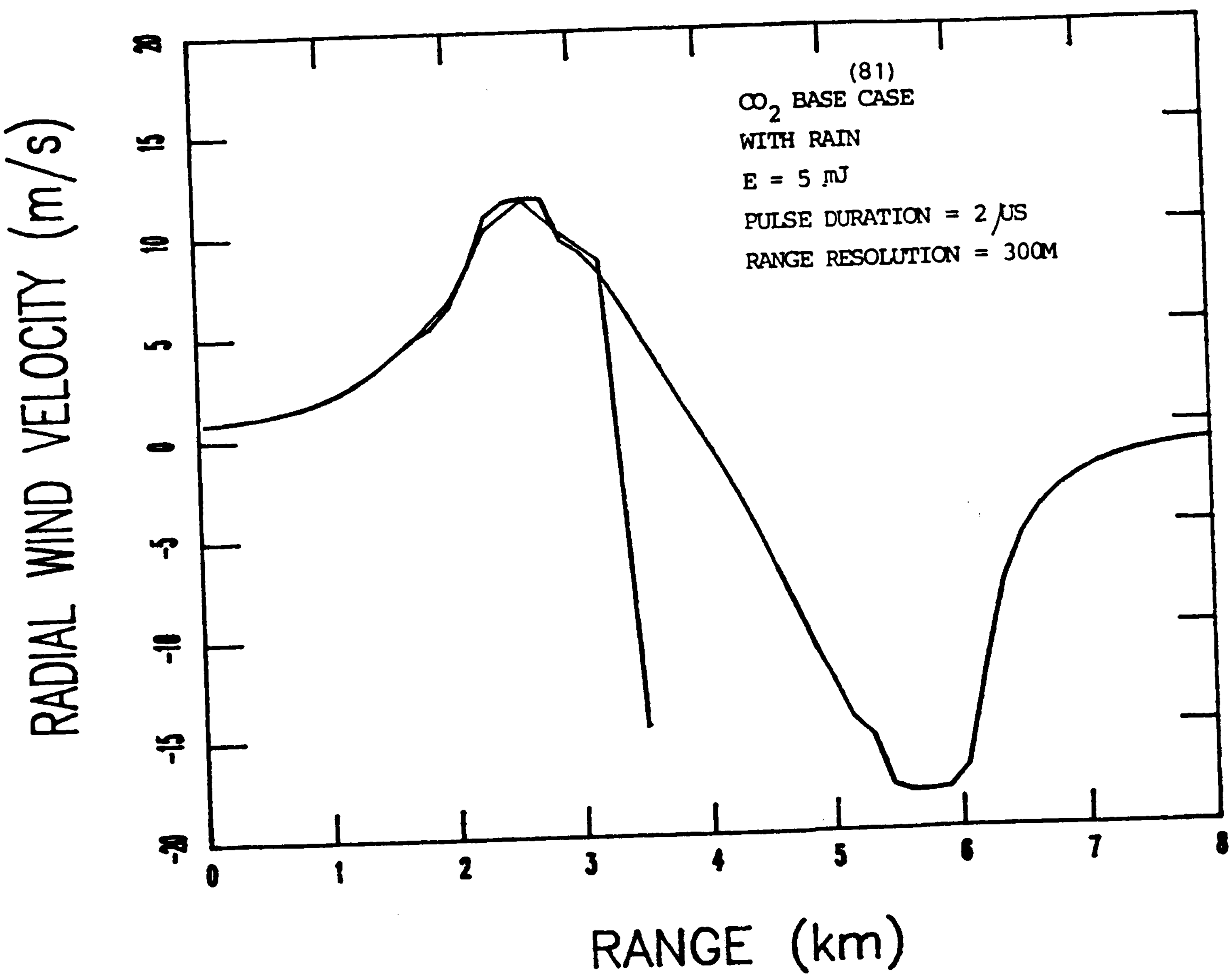

AIRBORNE WIND SHEAR LIDAR
(98)
CO2 BASE CASE
5 SHOTS
RADIAL WIND VELOCITY (m/s)
RANGE (km)
20
15
10
5
0
-5
-10
-15
-20
0
1
2
3
4
5
6
7
8

AIRBORNE WIND SHEAR LIDAR

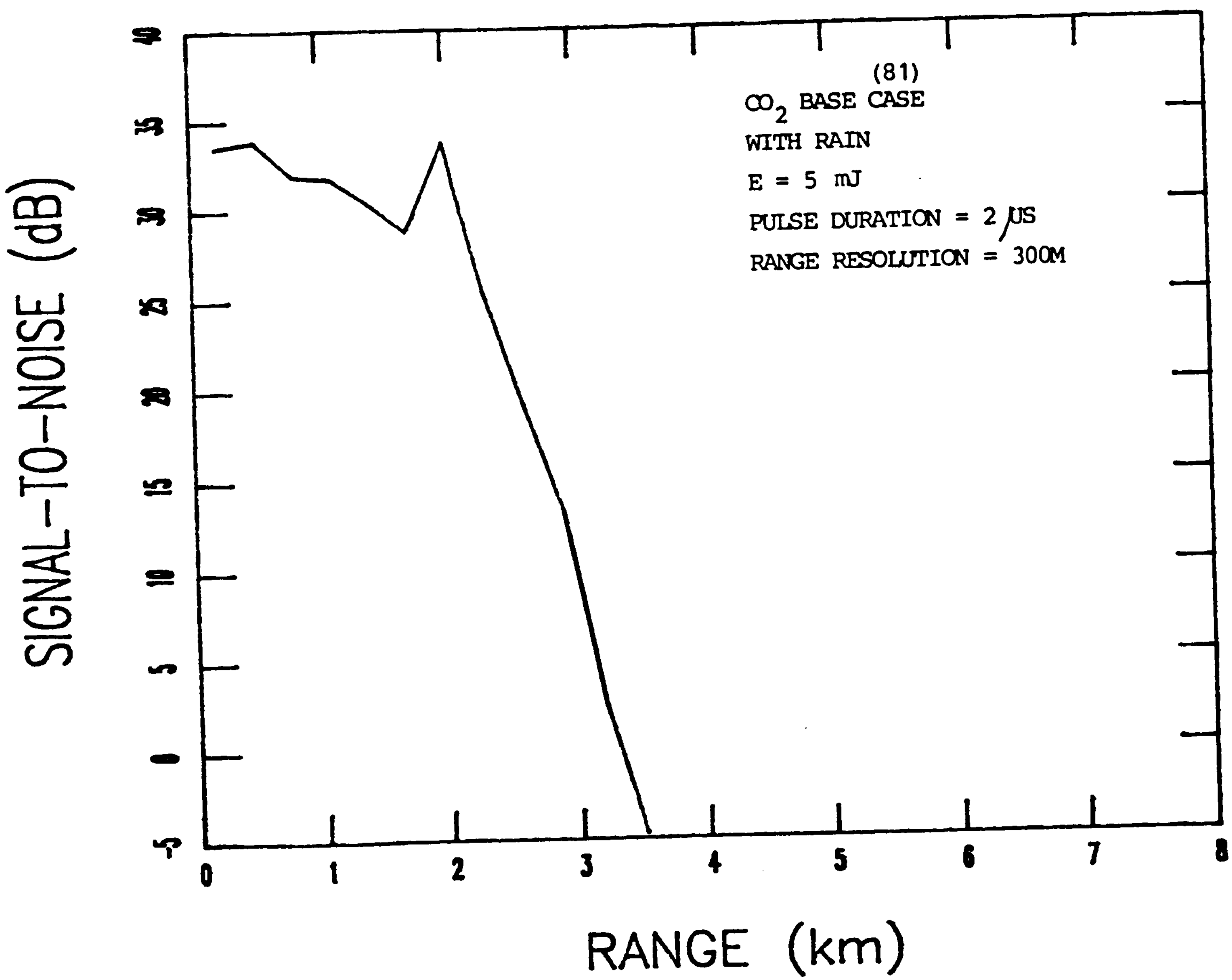



AIRBORNE WIND SHEAR LIDAR
CO_2 BASE CASE
BETA = 5 X 10^{-11} ($M^{-1}SR^{-1}$)
E1 = 5 mJ
E2 = 20 mJ
E3 = 50 mJ
E4 = 100 mJ
E5 = 150 mJ
E1
E2
E3
E4
E5
SIGNAL-TO-NOISE (dB)
25
20
15
10
5
0
-5
-10
-15
RANGE (km)
0
1
2
3
4
5
6
7
8

AIRBORNE WIND SHEAR LIDAR



AIRBORNE WIND SHEAR LIDAR



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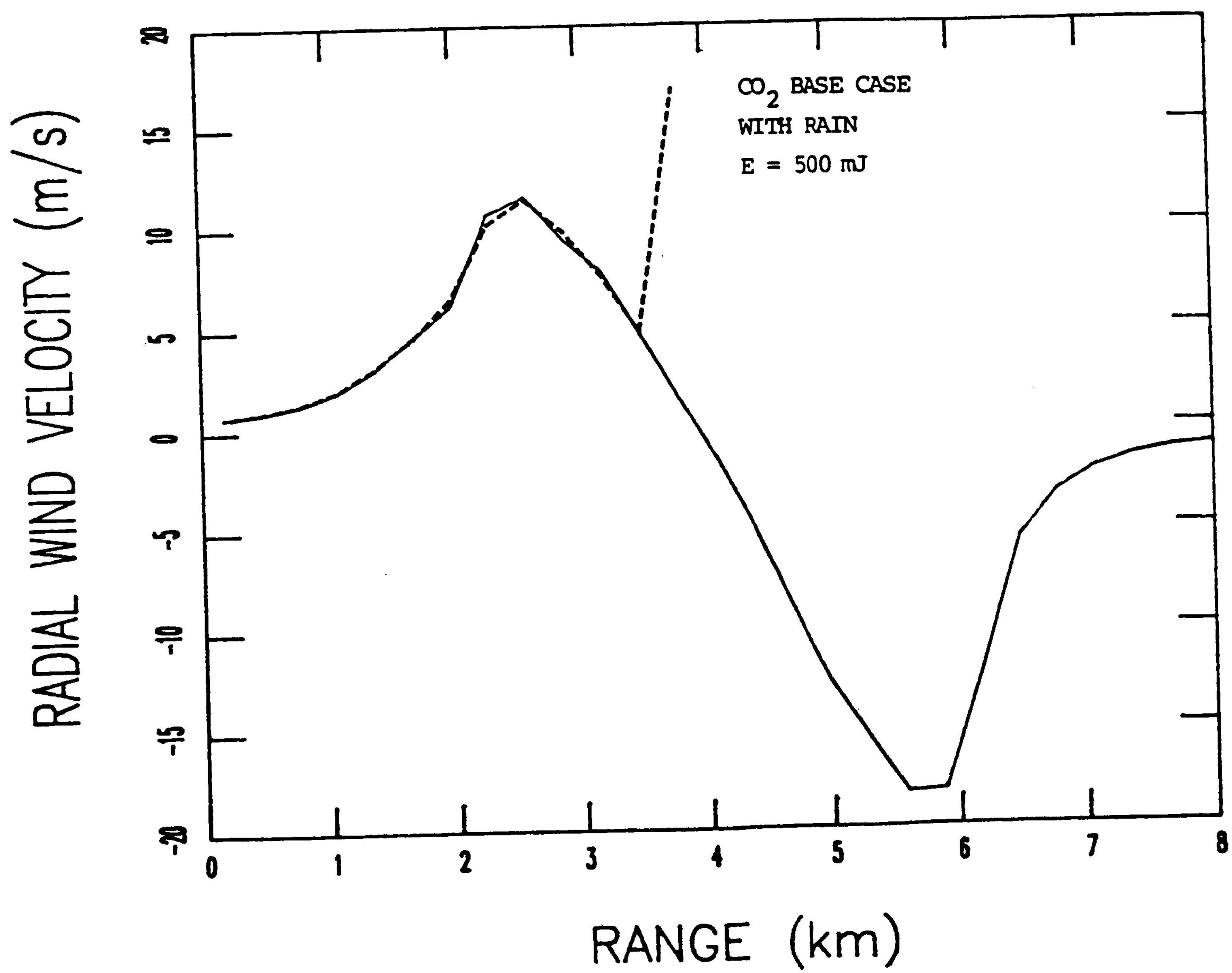
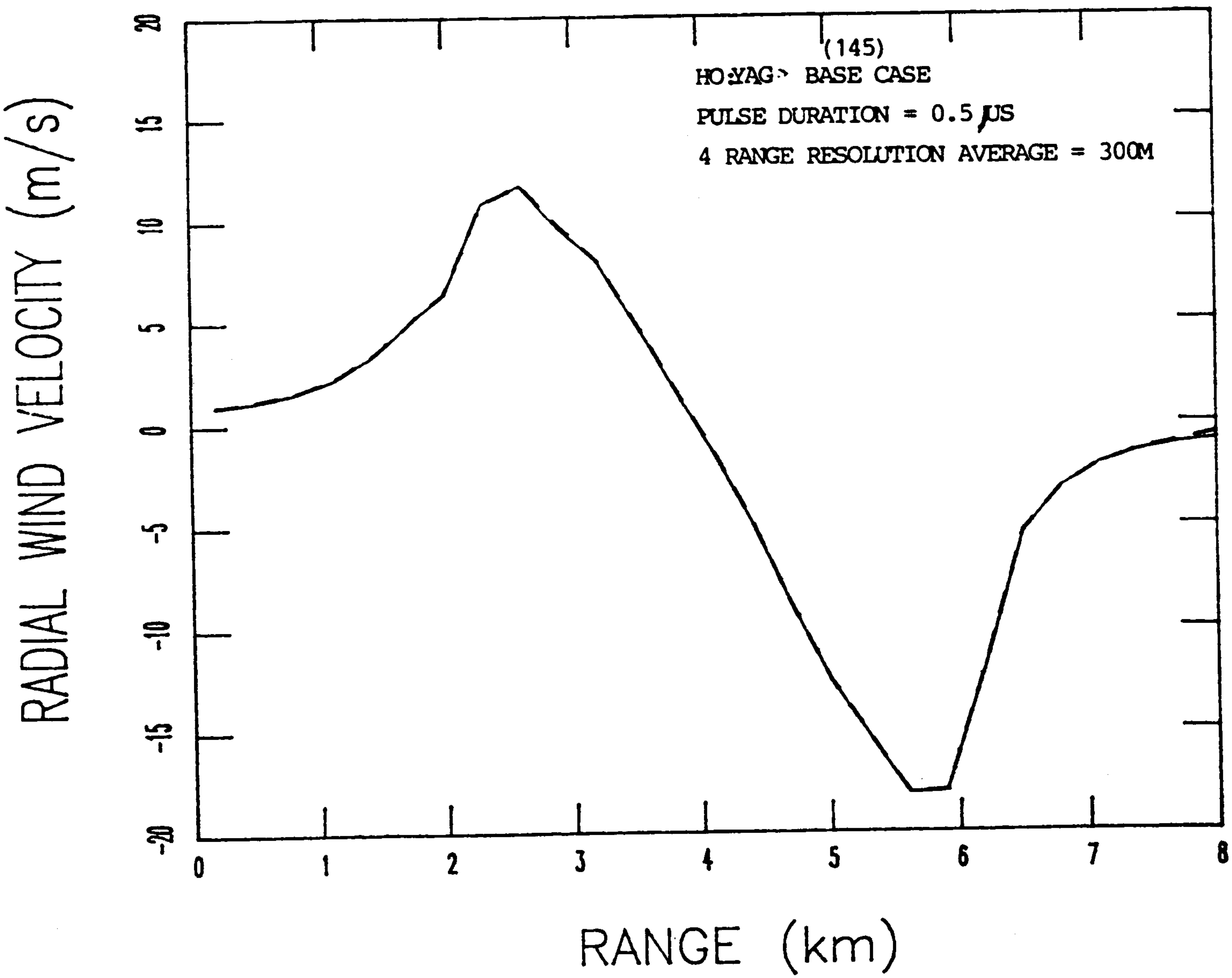
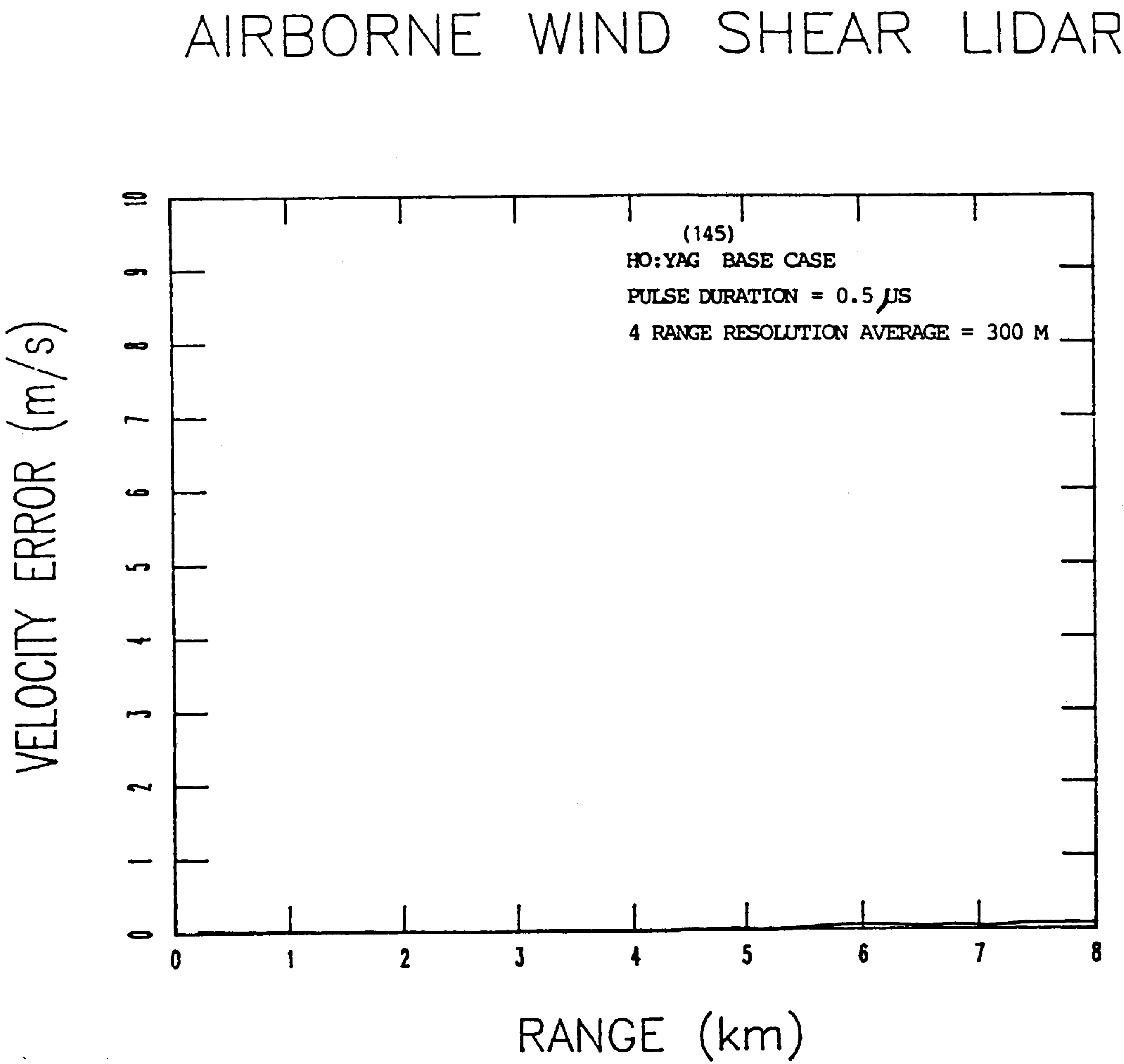
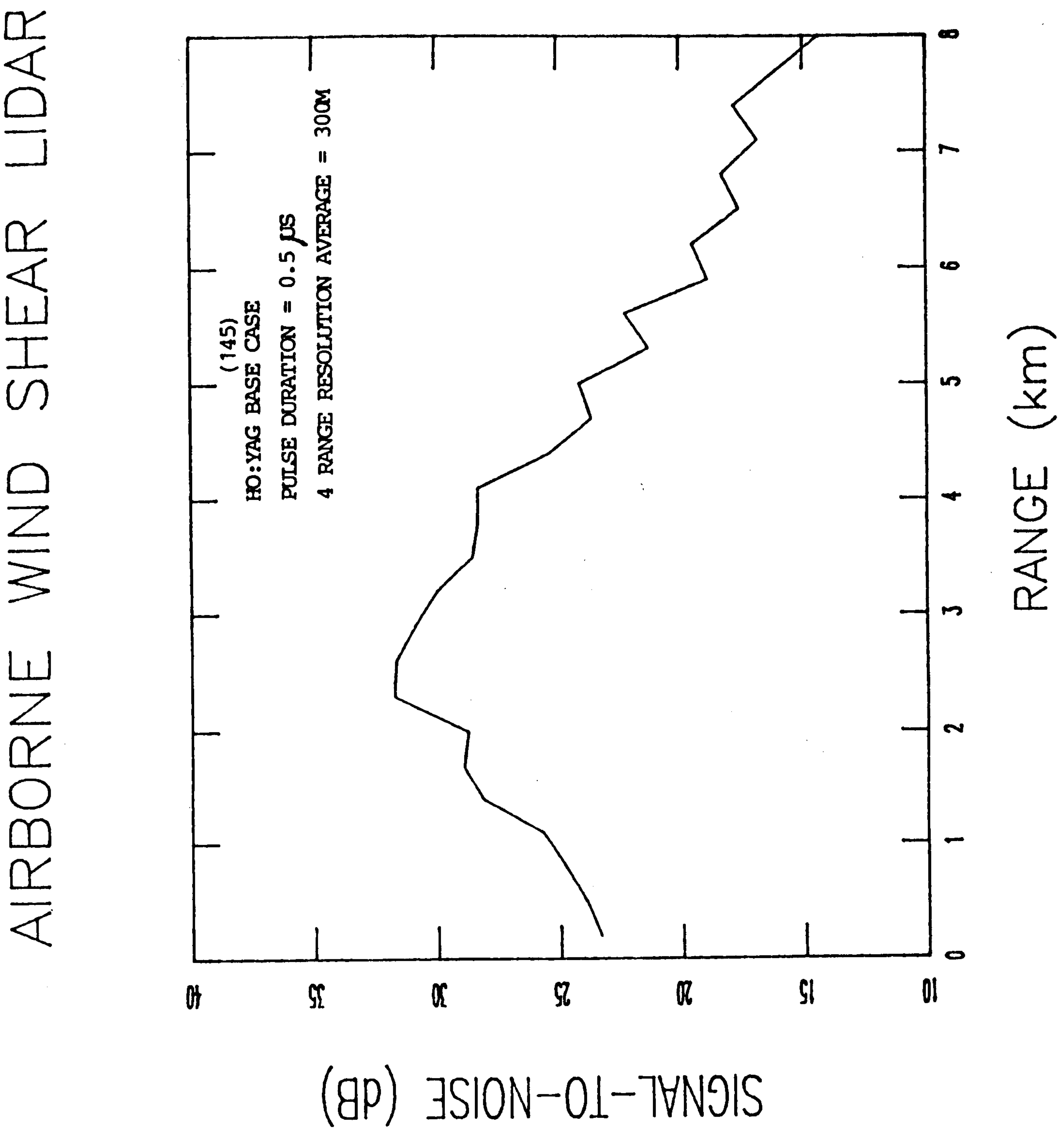


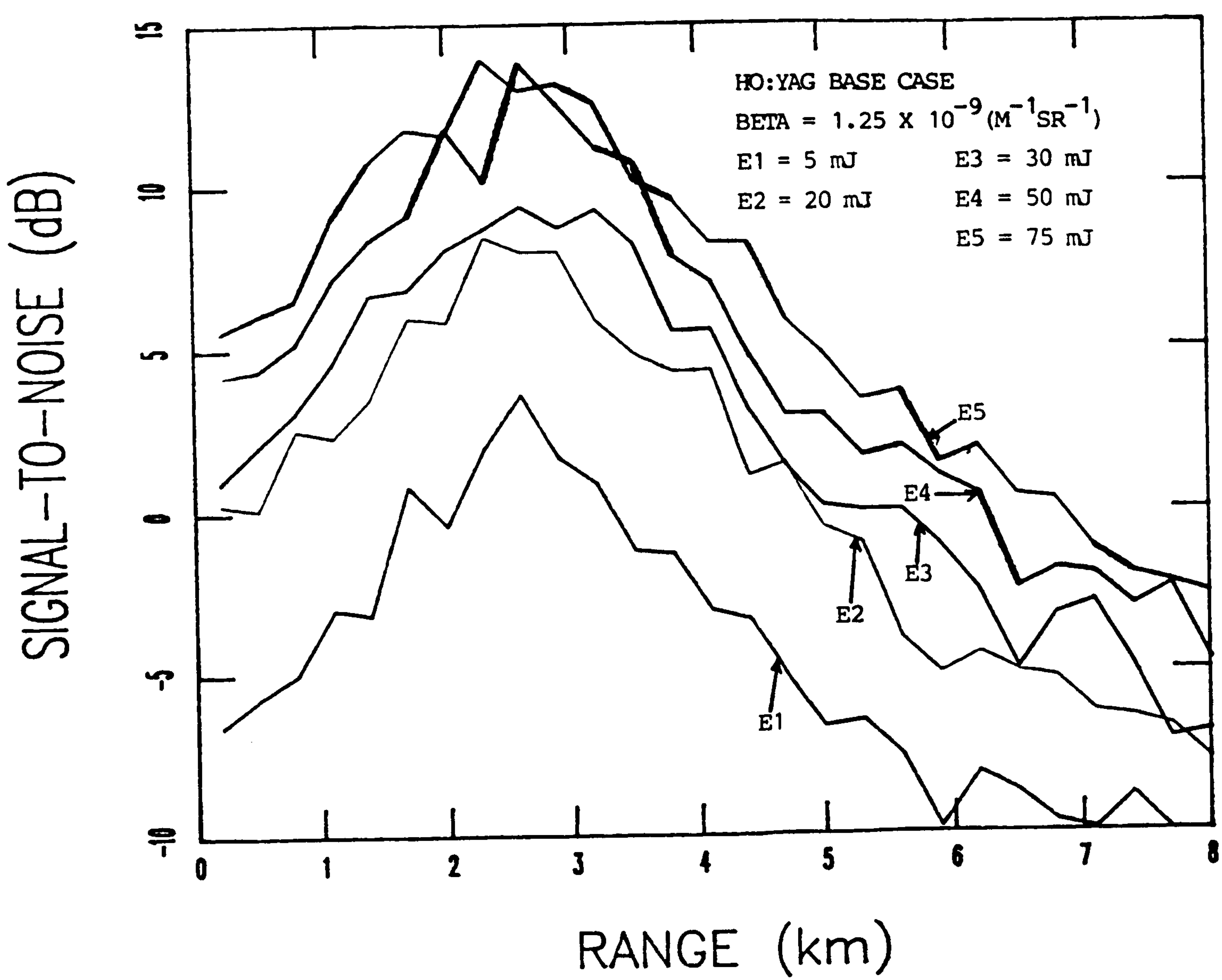
AIRBORNE WIND SHEAR LIDAR



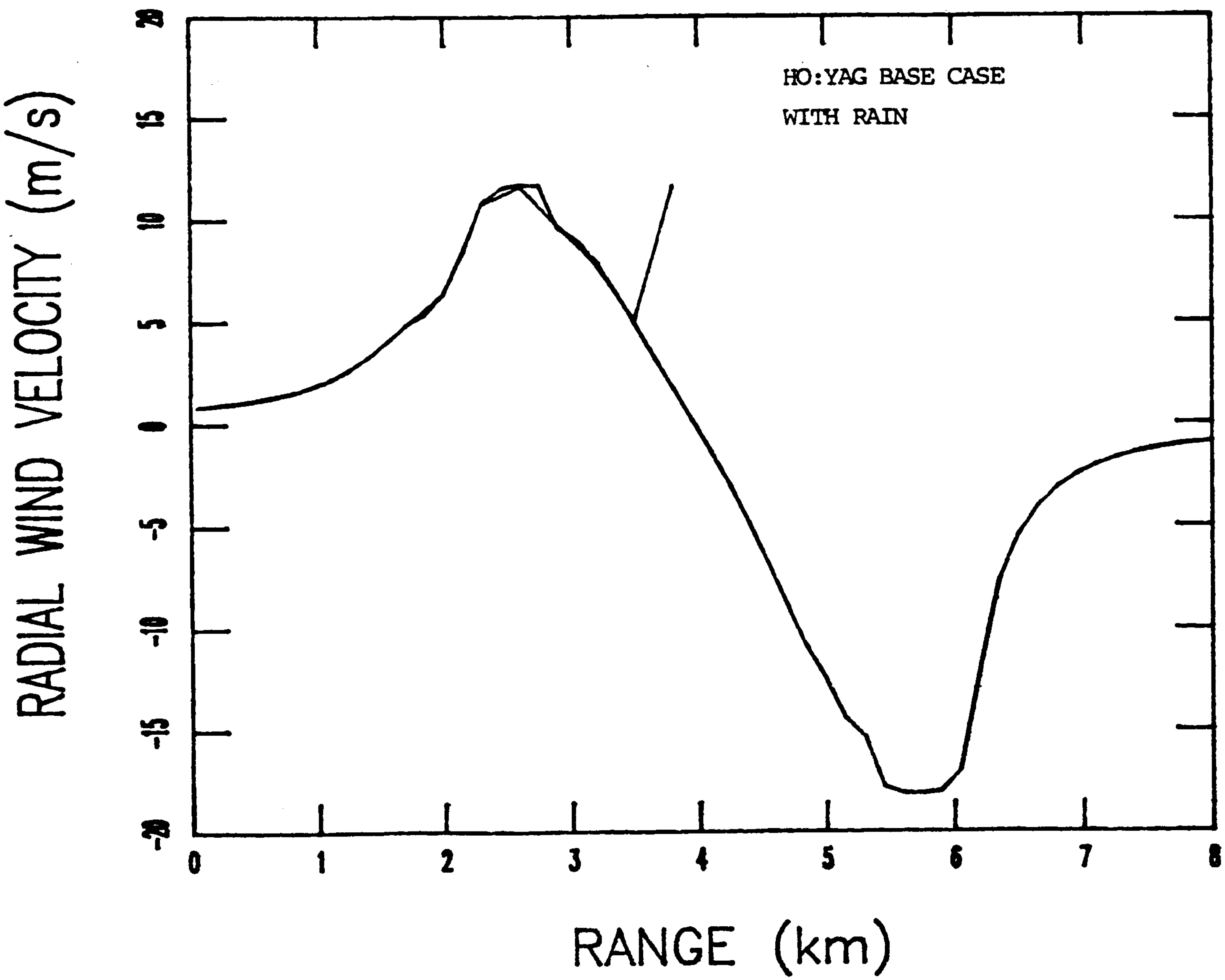

AIRBORNE WIND SHEAR LIDAR
(145)
HO:YAG BASE CASE
PULSE DURATION = 0.5 μS
4 RANGE RESOLUTION AVERAGE = 300 M
VELOCITY ERROR (m/s)
RANGE (km)
0
1
2
3
4
5
6
7
8
9
10


AIRBORNE WIND SHEAR LIDAR
(145)
HO:YAG BASE CASE
PULSE DURATION = 0.5 µS
4 RANGE RESOLUTION AVERAGE = 300M
RANGE (km)
SIGNAL-TO-NOISE (dB)
0
1
2
3
4
5
6
7
8
10
15
20
25
30
35
40

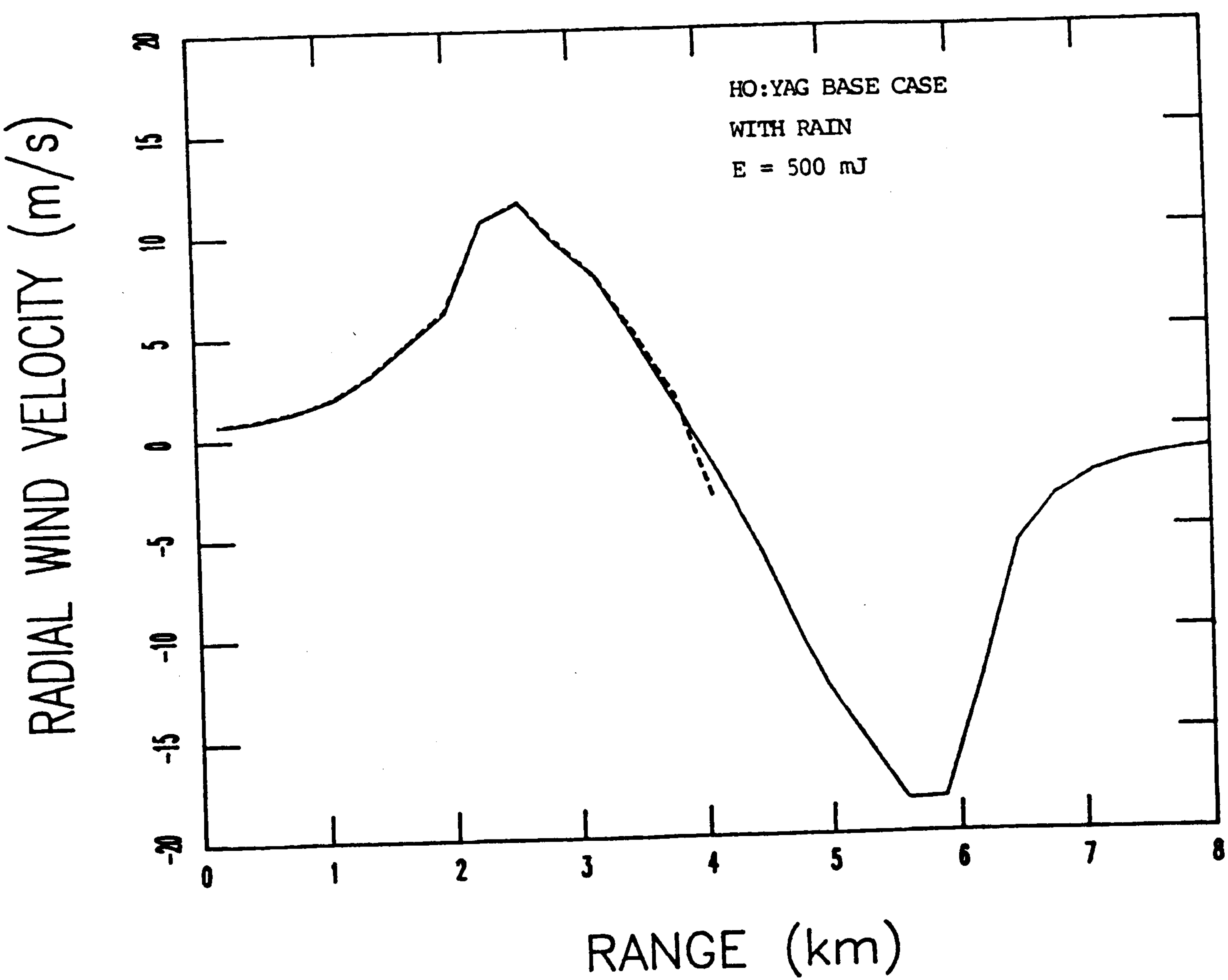
AIRBORNE WIND SHEAR LIDAR



AIRBORNE WIND SHEAR LIDAR



AIRBORNE WIND SHEAR LIDAR



SUMMARY OF PERFORMANCE

(LARC MICROBURST MODEL, 11:00 MIN.)

1. 20 MJ CO_2 LIDAR LINE-OF-SIGHT WIND VELOCITY ERROR <1 M/S TO 8 KM IN THE DRY MICROBURST TEST CASE.

2. 5 MJ Ho:YAG LIDAR LINE-OF-SIGHT WIND VELOCITY ERROR $<.5$ M/S TO 8 KM IN THE DRY MICROBURST TEST CASE.

3. 5 MJ CO_2 LIDAR PENETRATES TO WITHIN 1 KM OF WET MICROBURST CENTER.

4. 5 MJ Ho:YAG PENETRATES TO WITHIN .5 KM OF WET MICROBURST CENTER.

5. BOTH CO_2 (100 MJ) AND Ho:YAG (10 MJ) PERFORM WELL TO 3 KM OPERATING OUTSIDE THE BOUNDARY LAYER WHERE:
   BETA (CO_2) = $5 \times 10^{-11}\ M^{-1} \cdot SR^{-1}$
   BETA (Ho:YAG) = $1.25 \times 10^{-9}\ M^{-1} \cdot SR^{-1}$

6. LIDAR PERFORMANCE IN WET MICROBURST MODEL DOES NOT IMPROVE SIGNIFICANTLY WITH REASONABLE INCREASES IN LIDAR PARAMETERS.

CONCLUSIONS

1. BOTH CO_2 AND Ho:YAG ARE SHOWN FEASIBLE FOR AIRBORNE WIND SHEAR DETECTION FOR DRY MICROBURSTS WITH LIMITED PERFORMANCE IN WET MICROBURSTS.

2. Ho:YAG PERFORMS BETTER THAN CO_2 FOR A SET OF IDENTICAL LIDAR PARAMETERS.

3. THESE RESULTS ARE QUALIFIED BY THE LIMITED NUMBER OF TEST CASES.

N88-17628

A PRESENTATION TO
THE FIRST COMBINED MANUFACTURERS' AND
TECHNOLOGY AIRBORNE WIND SHEAR REVIEW
MEETING

INFRARED
LOW-LEVEL WIND SHEAR
WORK

PAT ADAMSON
OCTOBER 22, 1987

T5823435

TURBULENCE PREDICTION SYSTEMS
4876 STERLING DRIVE
BOULDER, CO 80301
(303) 443-8157

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Pat Adamson
Turbulence Prediction Systems
Boulder, Colorado

This presentation contains results of field experiments for detection of Clear Air Turbulence and Low Level Wind Shear utilizing an infrared airborne system. The hits, misses and nuisance alarms score and presented for the encounters. The infrared spatial resolution technique is explained and graphs are presented.

The popular index of aircraft hazard $\left(F = \frac{WX}{g} - \frac{VN}{AS}\right)$ is developed for a remote temperature sensor.

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THE PROBLEM

- WIND SHEAR
  - 1 accident per 5,000,000 T + L @A
  - 1 strong shear per 65,000 T + L @B
- SOURCES OF WIND SHEAR
  - downbursts
  - microbursts
- DURATION @C
  - severe winds - 2 to 4 minutes
  - life span - 5 to 15 minutes
- SIZE COLUMN @D
  - 4km or 2.5 miles
- EFFECTIVE DIAMETER OF OUTFLOW @C,D
  - > 2 x column diameter
- DIFFERENTIAL VELOCITY ACROSS BURST @C
  - > 56 knots average
- MICROBURSTS OFTEN HAS LATERAL MOTION

REFERENCE:

A R. Bowles NASA Langley; FAA/NASA Airborne Predictive Meeting; Feb 1987

B Uary-Durham NASA Langley; AIAA 22nd Aerospace Sciences Meeting; Jan 1984

C McCarthy-Serafin NCAR; Weatherwise; June 1984

D Fujita University of Chicago; THE DOWNBURST Microburst and Macroburst: 1985

TURBULENCE PREDICTION SYSTEMS

FAA WIND SHEAR PLAN

-EXCELLENT PROGRAM

- -TRAINING
- -GROUND SENSORS
- -AIRBORNE SENSORS

-SECTION 5.3

THE ELEMENTS THAT CAN IMPROVE THE FLIGHT CREW'S ABILITY TO RELIABLY DETECT AND AVOID HAZARDOUS WIND SHEAR INCLUDE:

THE DEVELOPMENT OF FORWARD-LOOKING WIND SHEAR SENSORS FOR AIRCRAFT.

THE IMPROVED UTILIZATION AND INTEGRATION OF PRESENT-POSITION SENSORS.

REFERENCE: "INTEGRATED FAA WIND SHEAR PROGRAM PLAN"; U.S. DEPARTMENT OF TRANSPORTATION; FEDERAL AVIATION ADMINISTRATION; APRIL 1987; DOT/FAA/DL-87/1; DOT/FAA/VS-87/1; DOT/FAA/AT-87/1.

TURBULENCE PREDICTION SYSTEMS

REMOTE SENSING TECHNIQUES FOR WIND VELOCITY ARE NO PANACEA

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-ALL REMOTE SENSORS INFER

TABLE 4 LISTS SOME ADVANTAGES AND DISADVANTAGES OF THE REMOTE-SENSING TECHNIQUES FOR WIND. IN GENERAL, LONG-RANGE MEASUREMENTS REQUIRE RADAR, AND SHORT-RANGE APPLICATIONS USE LIDAR OR SODAR DEPENDING ON WHETHER SPATIAL RESOLUTION OR LOW COST IS A PRIMARY CRITERION FOR SELECTION. FOR SOME REQUIREMENTS, SUCH AS A LOW-COST SENSOR FOR AIRCRAFT USE, THERE MAY NOT BE AT PRESENT A SUITABLE REMOTE-SENSING TECHNIQUE. (Emphasis added)

TABLE 4
Techniques for Velocity Measurement

	Advantages	Disadvantages
Sodar	Bistatic signal strength depends on turbulent microstructure Comparatively inexpensive	Flow tracers not uniformly distributed; i.e., sometimes only senses w in special layers Sensitive to noise from precipitation, high wind, and vehicles
Radar	Long range with appropriate tracers 3-D vector fields available with multiple sensors	Systems comparatively large and expensive Antenna side lobes limit usefulness close to the ground Clear-air targets nonconservative (e.g., temperature fluctuations) and require high transmitter power
Lidar	Very narrow beam widths Uses conservative tracers	Possible danger to eyes Beam attenuated by cloud and fog

REFERENCE: "A COMPARATIVE OVERVIEW OF ACTIVE REMOTE-SENSING TECHNIQUES"; BY R. L. SCHWIESOW; IN D. H. LENSCHOW, EDIT. PROBING THE ATMOSPHERIC BOUNDARY LAYER, 1986; AMERICAN METEOROLOGICAL SOCIETY; P. 135.

TURBULENCE PREDICTION SYSTEMS

AIRBORNE SENSORS ARE NEEDED

- ISLAND CONCEPT
  - AIRCRAFT CAN TAKE CARE OF ITSELF

MANY AIRPORTS WILL NEVER HAVE ENOUGH SOPHISTICATED EQUIPMENT

- CASPER, WYOMING
- GREENSBOROUGH, NORTH CAROLINA
- FARMINGTON, NEW MEXICO

INFORMATION HAS MINIMAL LINKAGE TO AIR CREW

TURBULENCE PREDICTION SYSTEMS

HISTORICAL CAT RESEARCH RESULTS

NASA LEAR - MOLETRON - 1979
NASA C-141A - BARNES - 1979
NASA CV 990 - ADAMSON - 1979

TEST PROTOCOL:

A HIT IF THE ALARM SOUNDS AND A SHEAR OF GREATER THAN 0.2 G ACCELERATION WAS ENCOUNTERED, OTHERWISE A MISS

RESEARCH RESULTS: ~ 700 HOURS

- WITH MOLECTRON/BARNES RADIOMMETER

247 ENCOUNTERS	84.62% HITS
MISSED ENCOUNTERS	15.38%
NUISANCE ALARMS	14.00%

- WITH ADAMSON RESEARCH INSTRUMENT

119 ENCOUNTERS	98.32% HITS
MISSED ENCOUNTERS	1.68%
NUISANCE ALARMS	8.51%

ADVANCE WARNING RESULTS: 700 HOURS

AVERAGE WARNING 4 MINUTES

REFERENCE: "FINAL STATISTICAL REPORT ON AVIATION SAFETY TECHNOLOGY (IN-FLIGHT DETECTION AND PREDICTION OF CLEAR AIR TURBULENCE)"; BY LOIS STEARNS AND VALERIE NOGAY, NOAA; FOR NASA AMES RESEARCH CENTER; DECEMBER 1, 1979.

TURBULENCE PREDICTION SYSTEMS

$$F = \underset{\text{horizontal component}}{\frac{\dot{wx}}{g}} - \underset{\text{vertical component}}{\frac{vw}{AS}}$$

Reference:

R.A. Greene, Safe Flight Instrument Corp; Journal of Aircraft; 12/79.

R. Bowles, NASA Langley; FAA/NASA Airborne Predictive Meeting; 2/24-25/87

Definitions:

$\dot{wx}$	=	kts/sec	-	horizontal wind rate
g	=	kts/sec	-	gravity
vw	=	kts	-	vertical wind velocity
AS	=	kts	-	air speed

Sign Convention:

$\dot{wx}$ = + kts/sec when tailwind
vw = - kts when downdraft

TURBULENCE PREDICTION SYSTEMS

SOUTHWEST 737-300 IN-SERVICE DATA

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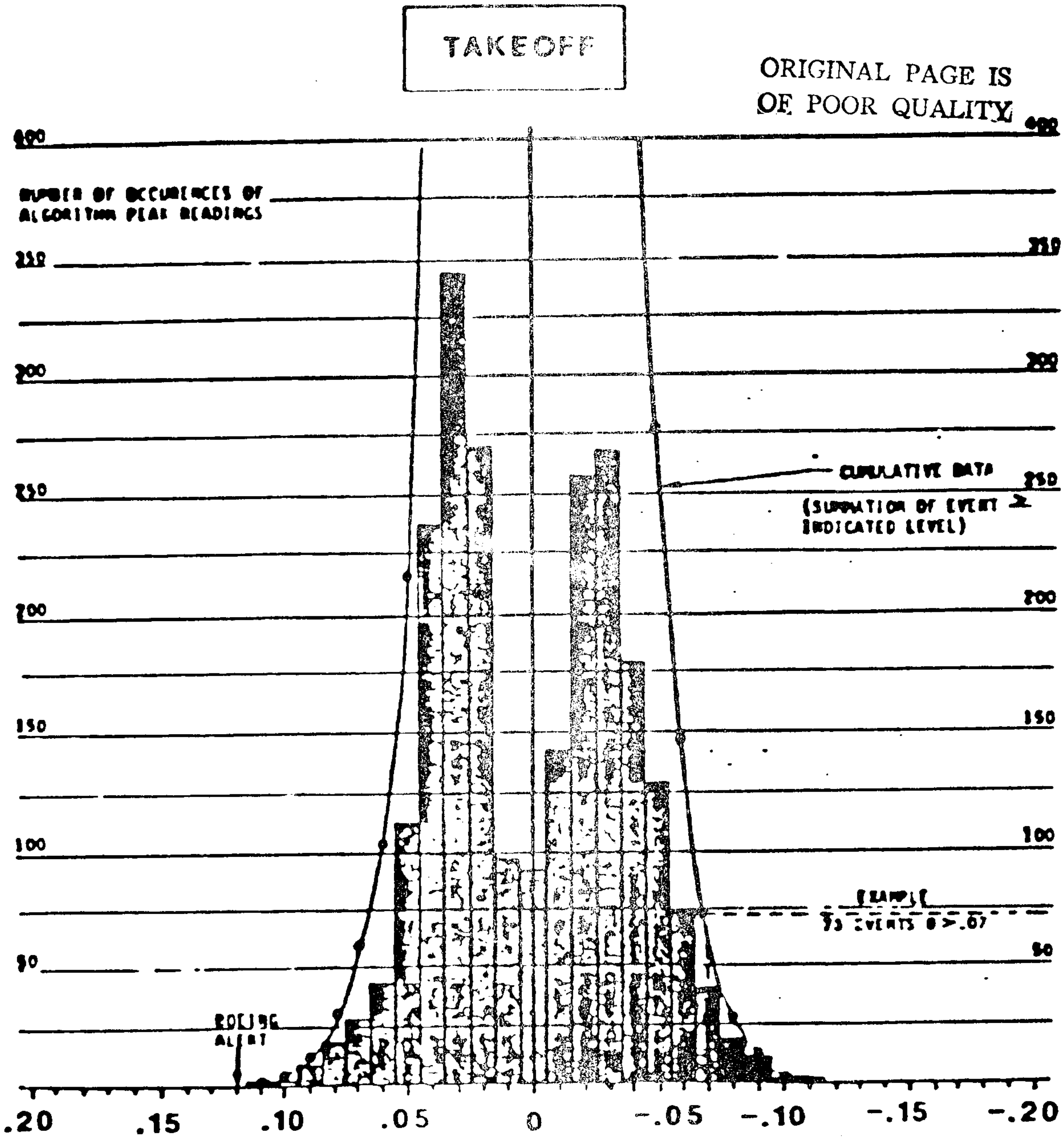
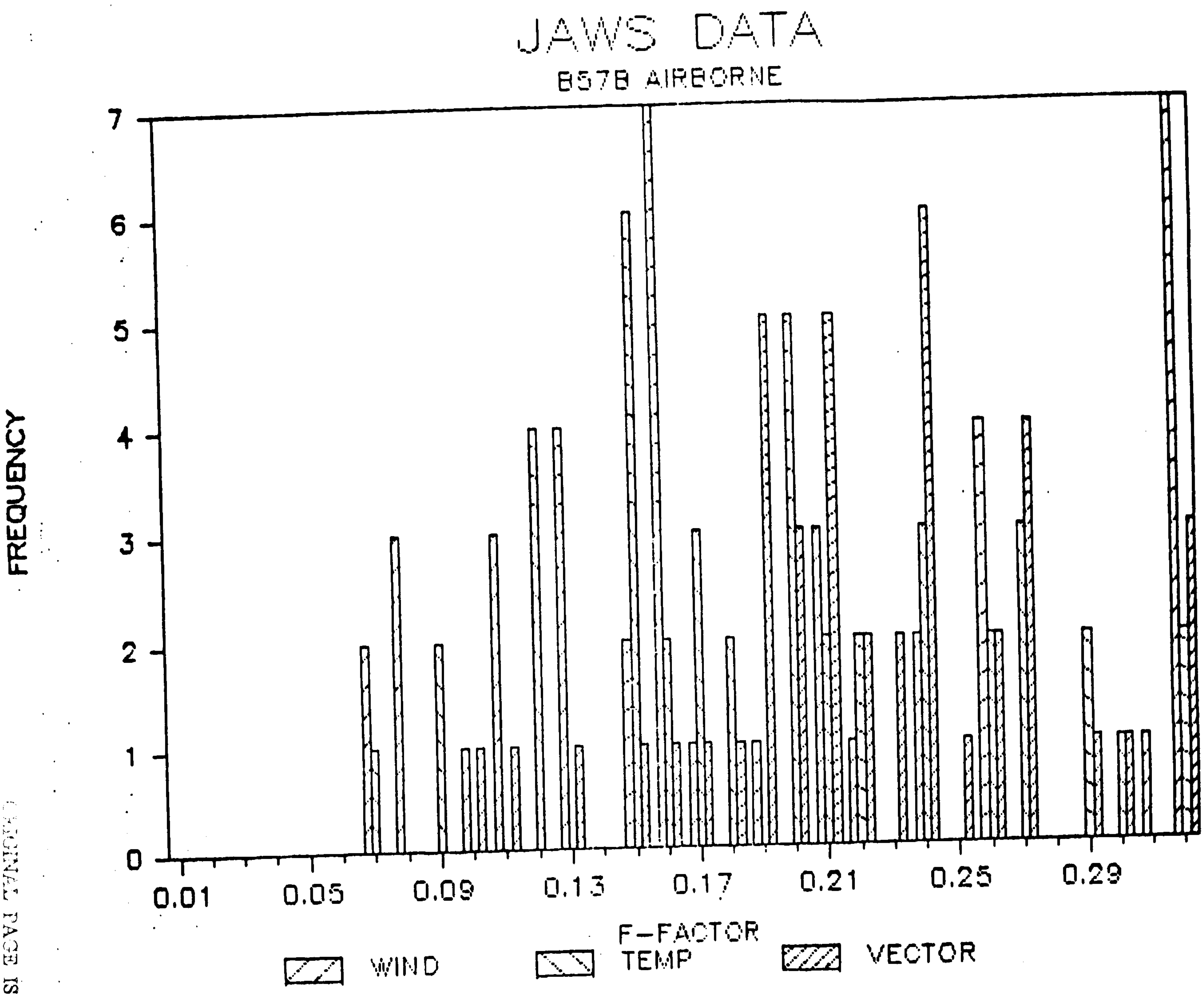


NO WIND SHEAR EVENTS REPORTED BY PILOTS

INDUSTRY REVIEW OF FORWARD LOOKING SENSOR TECHNOLOGY FOR DETECTION OF WIND SHEAR
NASA Langley Research Center 24-25 Feb. 1987, Roland L. Bowles



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HISTORICAL LLWS RESEARCH RESULTS

NASA LEAR - 1978 CALIFORNIA
NASA B57B - JAWS - 1982 DENVER, CO

TEST PROTOCOL:

A HIT IF THE ALARM SOUNDS AND A VERTICAL SHEAR GREATER THAN 0.1 SEC^{-1} (=10 KNOTS /100 FEET) WAS ENCOUNTERED, OTHERWISE A MISS
REFERENCE: SNYDER

RESEARCH RESULTS: ~ 300 HOURS

42 ENCOUNTERS	100.0% HITS
MISSED ENCOUNTERS	0
NUISANCE ALARMS	0

ADVANCE WARNING RESULTS:

MINIMUM WARNING	14 SECONDS
AVERAGE WARNING	46 SECONDS
MAXIMUM WARNING	68 SECONDS

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REFERENCE: "APPLICATION OF INFRARED RADIOMETERS FOR AIRBORNE DETECTION OF CLEAR AIR TURBULENCE AND LOW LEVEL WIND SHEAR"; BY P.M. KUHN; FINAL REPORT DECEMBER 31, 1982 - MARCH 31, 1985.

"ANALOG STUDY OF THE LONGITUDINAL RESPONSE OF A SWEPT-WIND TRANSPORT AIRPLANE TO WIND SHEAR AND SUSTAINED GUSTS DURING LANDING APPROACH"; BY C.T. SNYDER, NASA AMES RESEARCH CENTER; NASA TN D4477; 1968.

TURBULENCE PREDICTION SYSTEMS

HISTORICAL LLWS RAIN RESEARCH

NASA B57B - JAWS - 1982 DENVER, CO
CESSNA 207 - 1985 HUNTSVILLE, AL

TEST PROTOCOL:

A HIT IF THE ALARM SOUNDS AND A VERTICAL SHEAR OF GREATER THAN .15 SEC^{-1} (15 KNOTS /100 FEET) WAS ENCOUNTERED, OTHERWISE A MISS

A SUCCESSFUL PREDICTION REQUIRED AN ADVANCE WARNING OF GREATER THAN 40 SECONDS

RESEARCH RESULTS: 19 TRACTS FLOWN

8 ENCOUNTERS	75.0% HITS
MISSED ENCOUNTERS	25.0% (2<40S)
NUISANCE ALARMS	4

ADVANCE WARNING RESULTS:

MINIMUM WARNING	5 SECONDS
AVERAGE WARNING	32 SECONDS

REFERENCE: "AIRBORNE INFRARED WIND SHEAR DETECTOR PERFORMANCE IN RAIN OBSCURATION"; BY P.M. KUHN AND P.C. SINCLAIR, ARIS, INC.; PAPER PRESENTED AT AIAA MEETING JANUARY 18, 1987; RENO, NEVADA.

TURBULENCE PREDICTION SYSTEMS

INFRARED SENSING TECHNIQUE

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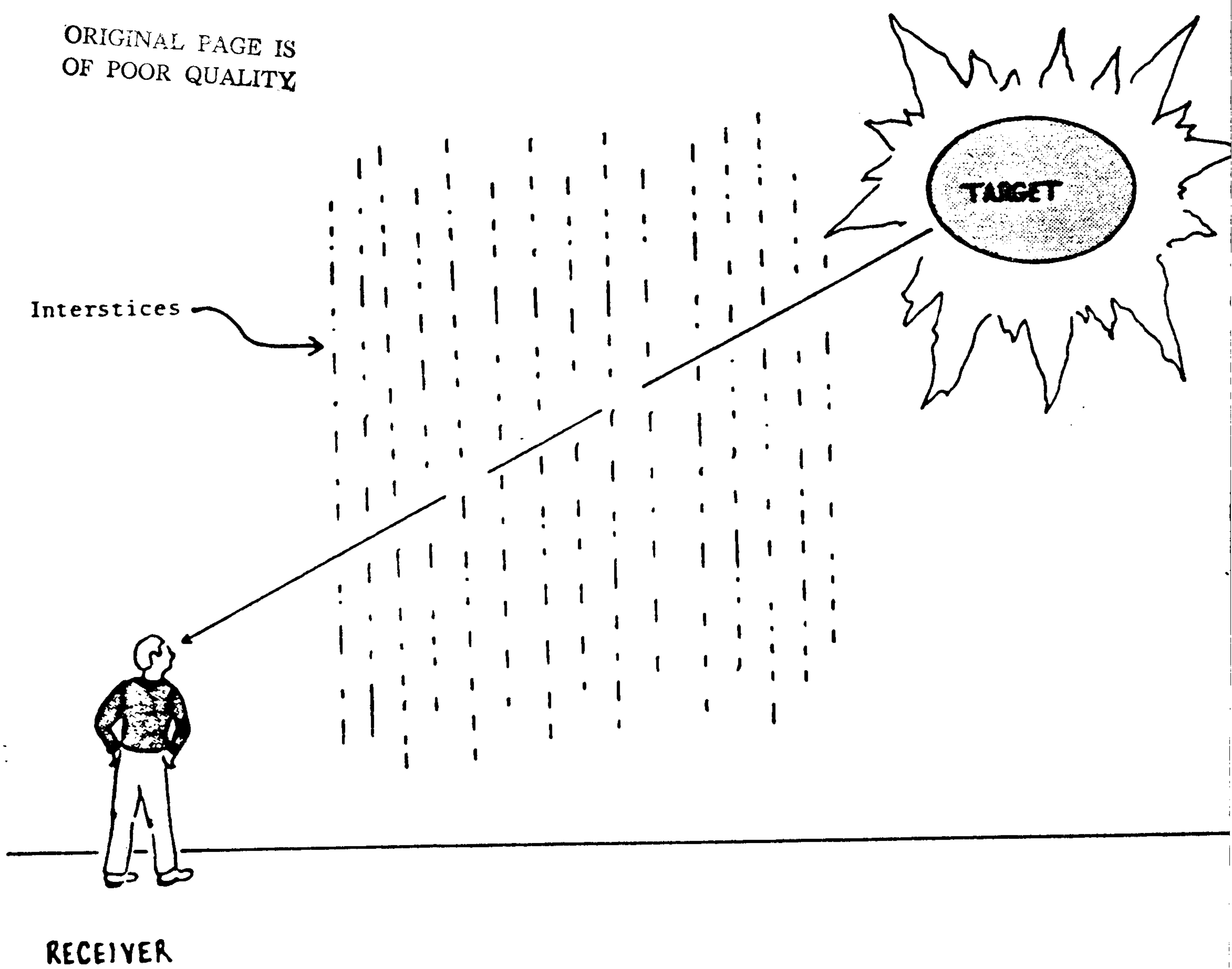
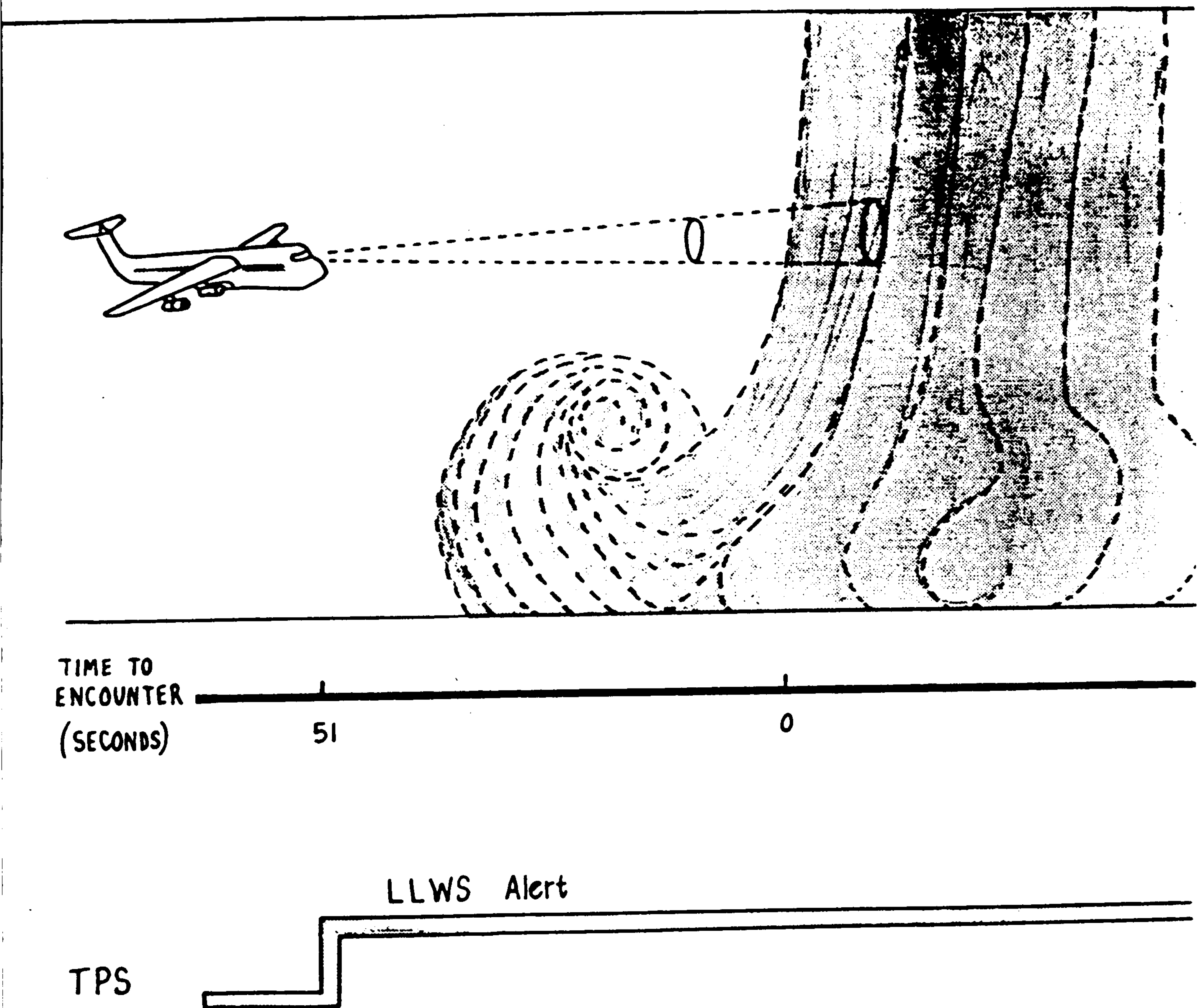
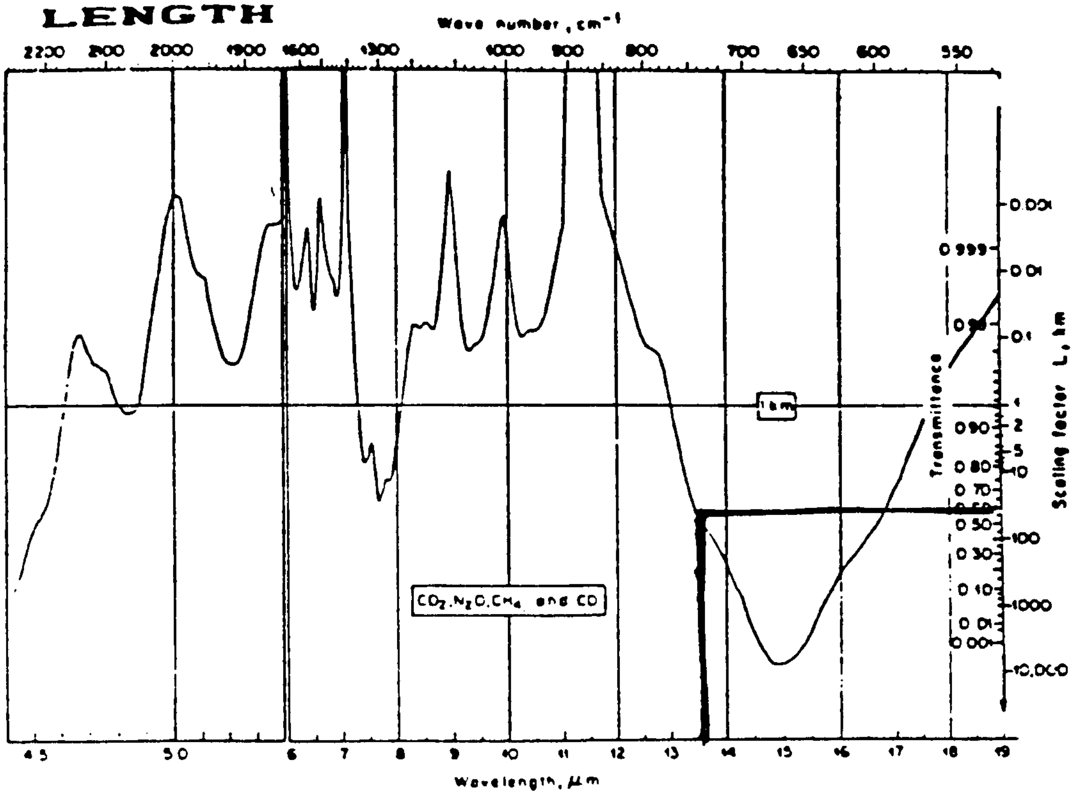




TPS's INFRARED LLWS ADVANCE WARNING DIAGRAM

UNIFORM DISTRIBUTED GASES

INFRARED IS ABSORBED BY THE UNIFORM DISTRIBUTED GASES AS A FUNCTION OF WAVE LENGTH



(b)

Fig. 17 *(Continued)*

NOTE: TRANSMITTANCE/KILOMETER

FOR EXAMPLE:

@ 13.5 MICRONS

TRANSMITTANCE = .60/KM

@ 5 KM

TRANSMITTANCE = (.60)^5 = 7.8%

REFERENCE: HANDBOOK OF OPTICS; WALTER G. DRISCOLL, EDITOR; McGRAW-HILL BOOK COMPANY; 1978; FIGURE 17, PAGE 14-43.

Radiative transfer Theory via the transfer equation (RTE) demonstrates that a "horizontally looking" infrared (IR) radiometer can easily detect temperature changes as small as 0.3C at a distance of 10 km. The IR pass band for such observations is the carbon dioxide (CO_2) band. In this instance we refer to transfer calculations in the 695 to 725 cm^{-1} pass band.

The RTE expresses the radiant emission received through a horizontal path in the atmosphere at an IR detector through a filter, $\phi(\nu)$, as

$$\vec{N} = -\int_{\nu}\int_{z} B(\nu,T)\phi(\nu)\,\frac{\partial\tau(u(CO_2))}{\partial z}\,dz\,dz), \qquad (2)$$

where N and B are radiance ($w\ cm^{-2} sr^{-1}$); ν is wave number (cm^{-1}); T is temperature (^oK); u is the optical mass of CO_2 ($g\ cm^{-2}$); z is distance (cm).

The filter function, $\phi(\nu)$, in equation (2) determines the IR pass band to which the CO_2 band low altitude wind shear radiometer responds. Since the CO_2 portion of the spectrum is broad, ranging from nominally 630 to 710 cm^{-1}, it is necessary to choose a passband of a width of 20 to 30 cm^{-1}, within the broad band which will provide a suitable range capability. The absorption (and emission) across the CO_2 band varies considerably thus allowing a greater or lesser horizontal atmospheric penetration. For example the CO_2 Q-branch centered near 667 cm^{-1} would permit a range of only a few meters.

Weighting functions are defined by

$$\frac{d\tau_{\Delta\nu}}{d\ln z} = \frac{-\bar{K}_{\Delta\nu} p\bar{q}\ z}{RT}\exp\frac{-1}{RT}\int_{o}^{z}\bar{K}_{\Delta\nu}\ p\bar{q}\ dz \qquad (3)$$

where τ is the atmospheric transmission (dimensionless); $\Delta\nu$ is the wave number interval (cm^{-1}); $\bar{K}_{\Delta\nu}$ is the CO_2 absorption coefficient ($cm^2 g^{-1}$); p is pressure (cgs); $\bar{q}$ is mass mixing ratio of CO_2 (dimensionless); R is the universal gas constant (cgs).

The weighting function describes the ranging characteristics of the filter, and thus the range of the radiometer. Figure 3 illustrates weighting or ranging functions for various center frequency passbands either 20 cm^{-1} wide for CO_2. The position of the peak of the weighting function defines the "look" distances or range of the instrument. As an example we employed the weighting function of Fig. 3 at a center frequency for the CO_2 filter of 685 cm^{-1} (20 cm^{-1} wide). We assumed a horizontal temperature constant at 288K in one instance and 286K from 1.0 to 1.6 km distance in the other calculation. The CO_2 mixing ratio (mass) was assumed 5.28×10^{-6} $w\ cm^{-2} sr^{-1}$. This corresponds to a temperature difference of 2K.

...onboard NASA's Learjet Laboratory is ± 0.3K. Hence it is feasible to determine downdraft temperature changes this small at distances of 10 km or more during glide path approach with a horizontally stabilized radiometer system.

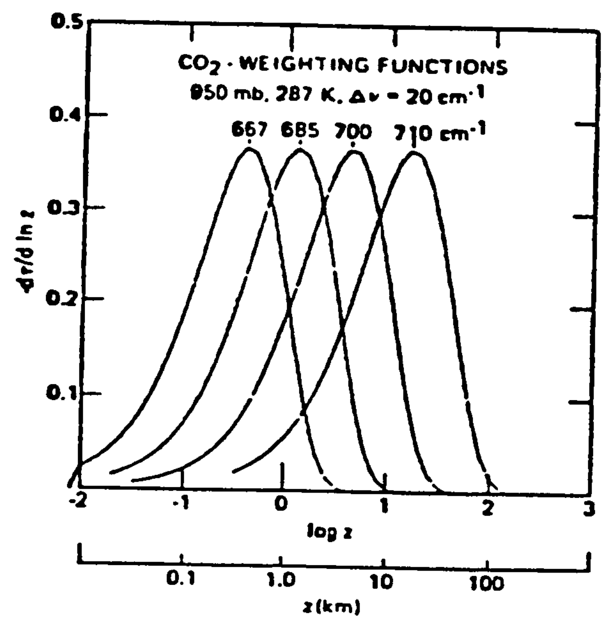


Figure 3. Carbon dioxide horizontal weighting functions centered at the indicated frequencies.

REFERENCES

Fawbush, E. J. and R. C. Miller (1954): A Basis for Forecasting Peak Wind Gusts in Non-Frontal Thunderstorms. Bulletin Amer. Met. Soc., 35, 14-19.

Foster, Donald S. (1958): Thunderstorm Gusts Compared with Computed Downdraft Speeds. Mon. Wea. Rev., 86, 91-94.

Fujita, T. T. (1976): Spearhead Echo and Downburst Near the Approach End of A John R. Kennedy Runway, New York City. SMRP Research Paper, 137, 51 pp.

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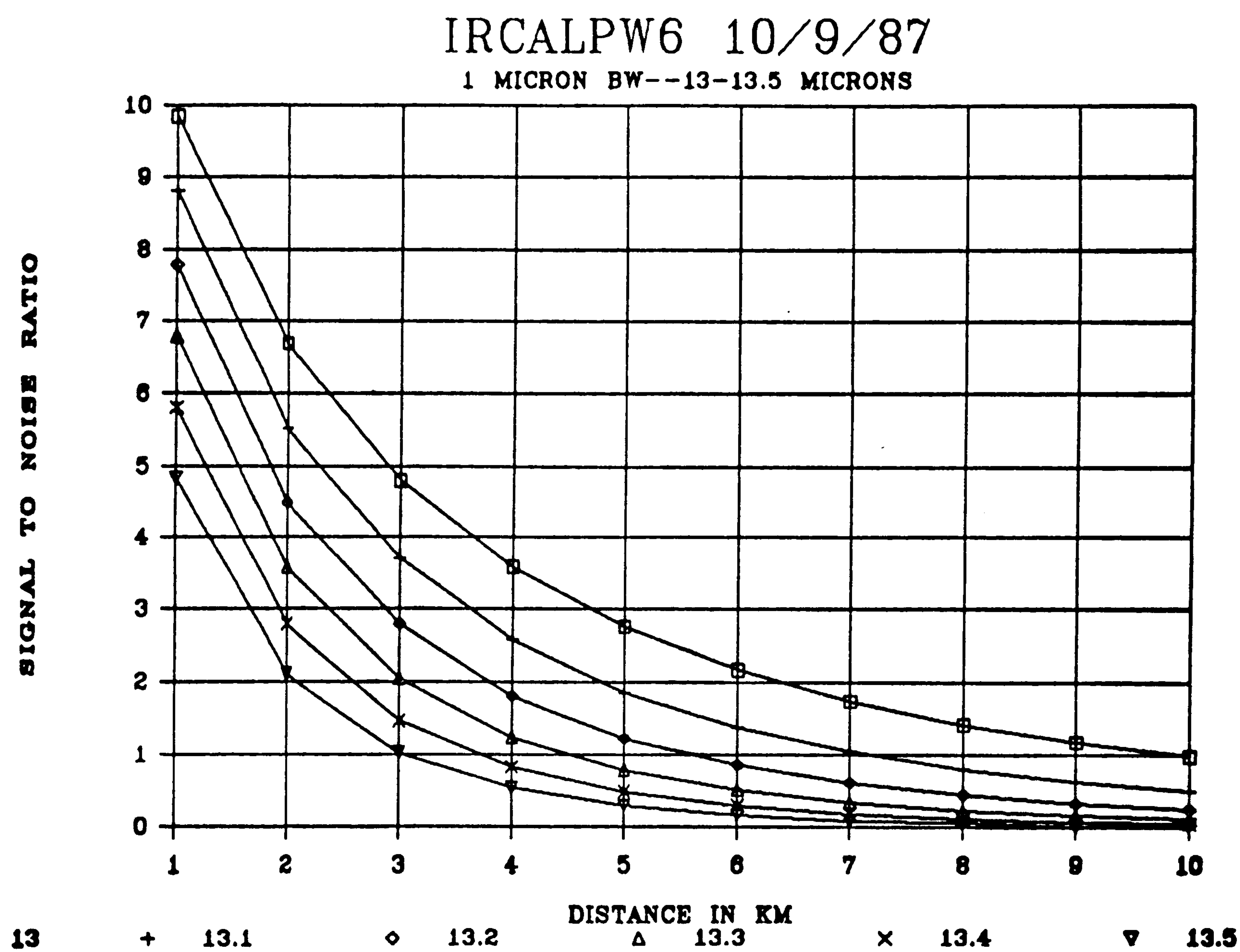
OF POOR QUALITY

Infrared Remote Sensing and Radiative Transfer in Wind Shear Detection. P.M. Kuhn, F. Caracena, I.G. Nolt, J.V. Radostitz. Reprint from Preprint Volume: 3rd Conference on Atmospheric Radiation June 28-30, 1978.


IRCALPW6 10/9/87
1 MICRON BW--13-13.5 MICRONS
SIGNAL TO NOISE RATIO
0
1
2
3
4
5
6
7
8
9
10
1
2
3
4
5
6
7
8
9
10
DISTANCE IN KM
13
+ 13.1
◇ 13.2
△ 13.3
× 13.4
▽ 13.5

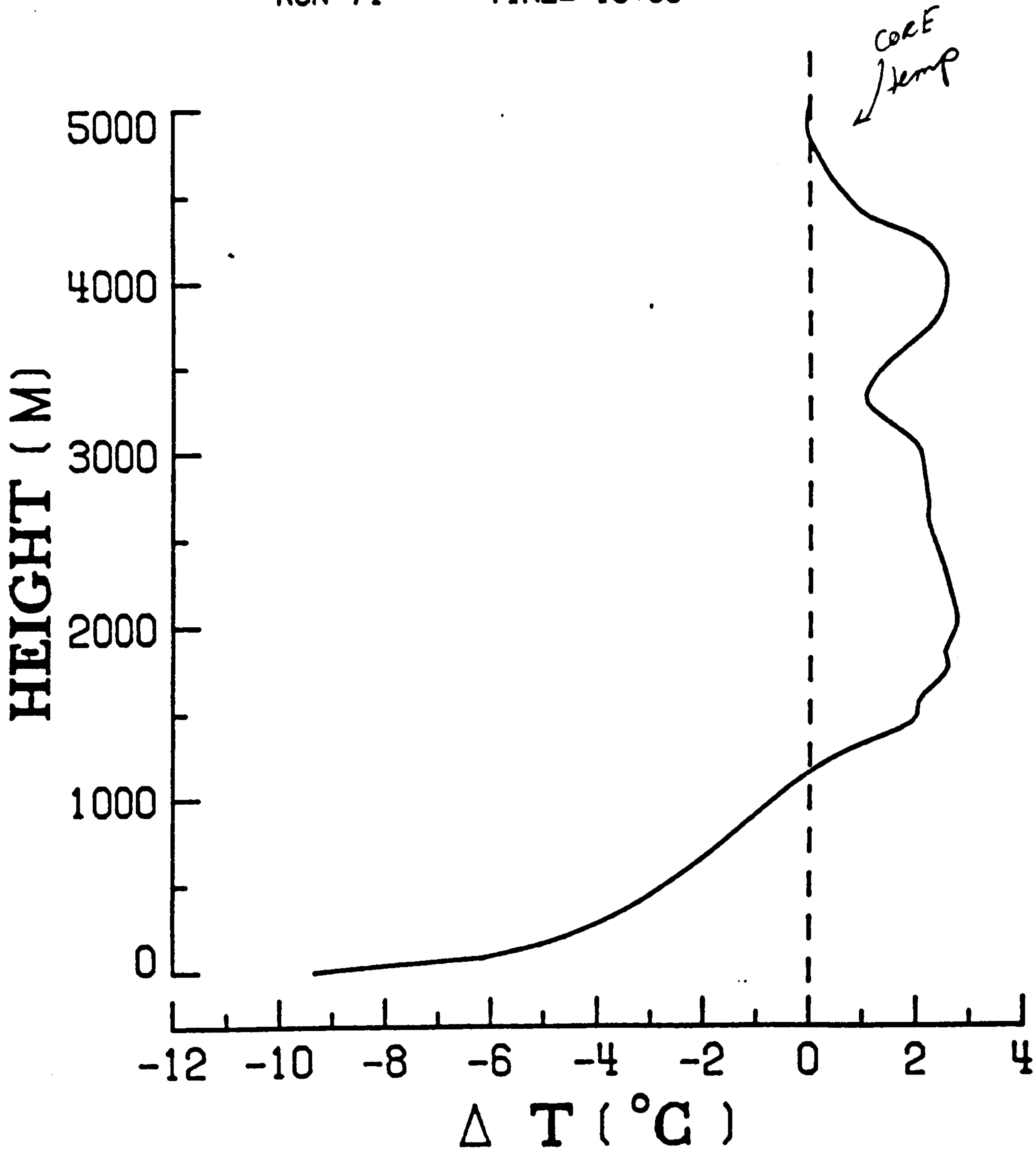
VALIDATION OF INFRARED WEIGHTING FUNCTION

IN 1979, RESEARCHER DR. PETER KUHN AND NASA TEST PILOT MR. GLEN STINNET FLEW THE NASA LEAR JET #705 OVER THE SANTA BARBARA CHANNEL ALTERNATING BETWEEN LAND (40° C) AND THE CHANNEL (15° C) TO VALIDATE THE WEIGHTING FUNCTION

THIS VALIDATION INVOLVED USING A BARNES PRT5 RADIOMETER AND INTERCHANGING 6 CO_2 FILTERS UNTIL THE WEIGHTING FUNCTION WAS VALIDATED

REFERENCE: PERSONAL CORRESPONDENCE DR. PETER KUHN; AUGUST 1987

RUN-74 TIME= 10.00



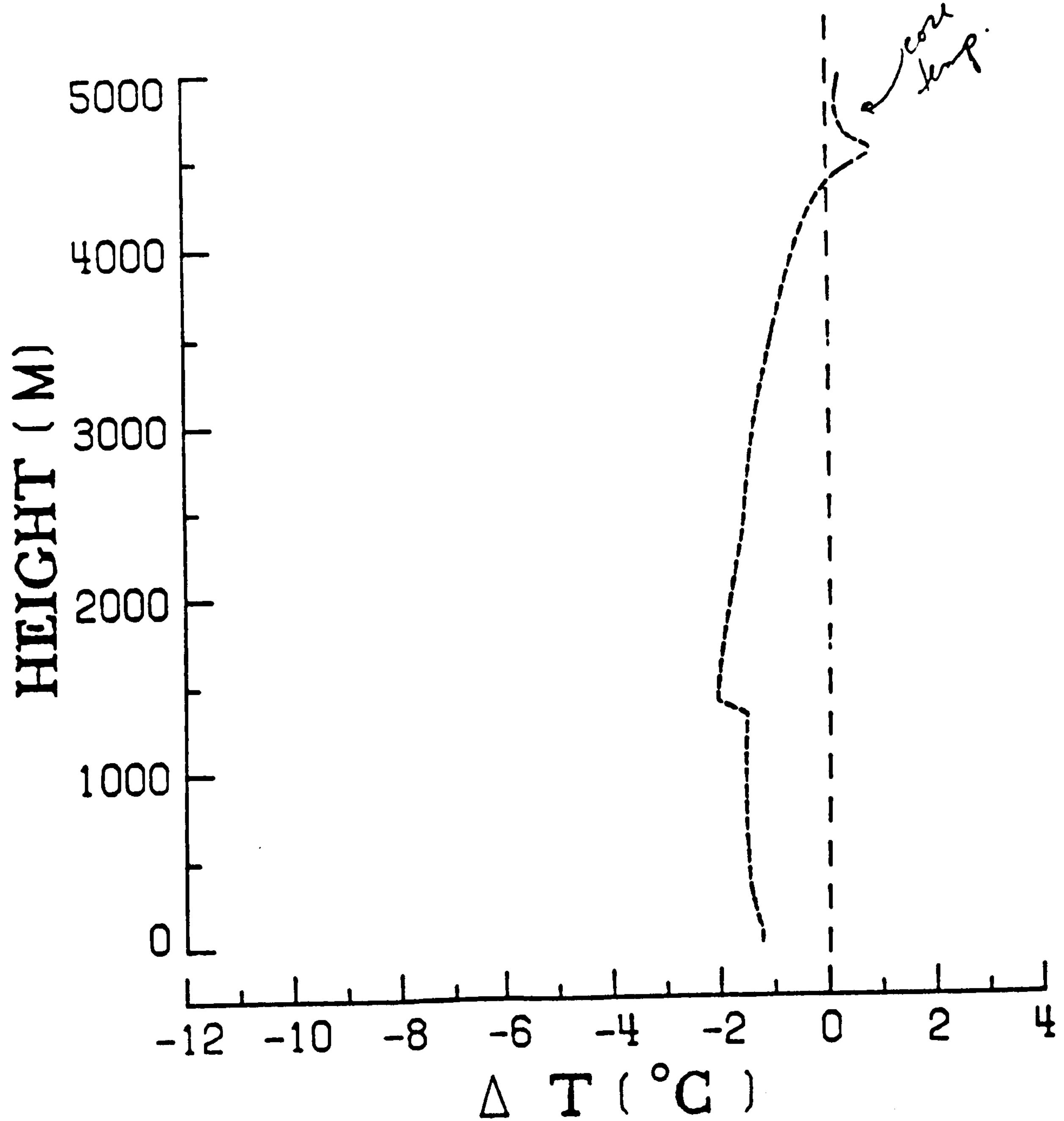
WET CASE 10/13/87

RECEIVED AT NASA
LANGLEY FROM
F. PROCTOR

SNOWDRIVEN CASE 10/13/87

RECEIVED AT NASA LANGLEY
FROM F. PROCTOR

RUN-10 TIME= 25.01



THE END PRODUCT OF AIRBORNE IR SENSOR

IS:

$$\frac{\Delta \Phi_e \quad \text{(change in radiant flux)}}{\Delta t \quad \text{(time)}}$$

FROM WHICH WE GET:

$$\frac{\Delta T \quad \text{(temperature)}}{\Delta t \quad \text{(time)}} \qquad \text{OR} \qquad \sum_{t_1}^{t_2} \Delta T$$

FROM THIS WE WILL CALCULATE A HAZARD INDEX WHICH APPLIES TO THE AIRCRAFT'S FLIGHT PATH.

TURBULENCE PREDICTION SYSTEMS

WIND SHEAR "HIT"

- HAZARD INDEX $F = \frac{\dot{W}_x}{g} - \frac{W_h}{V}$
- ALERT AND WARNING THRESHOLD DETERMINED BY MAX. PERMISSIBLE F IN RELATION TO AIRCRAFT PERFORMANCE CAPABILITY
- F IS A SENSED QUANTITY
- HAZARD INDEX APPLICABLE TO BOTH INSITU–SENSED INFORMATION AND REMOTE–SENSED WIND SHEAR

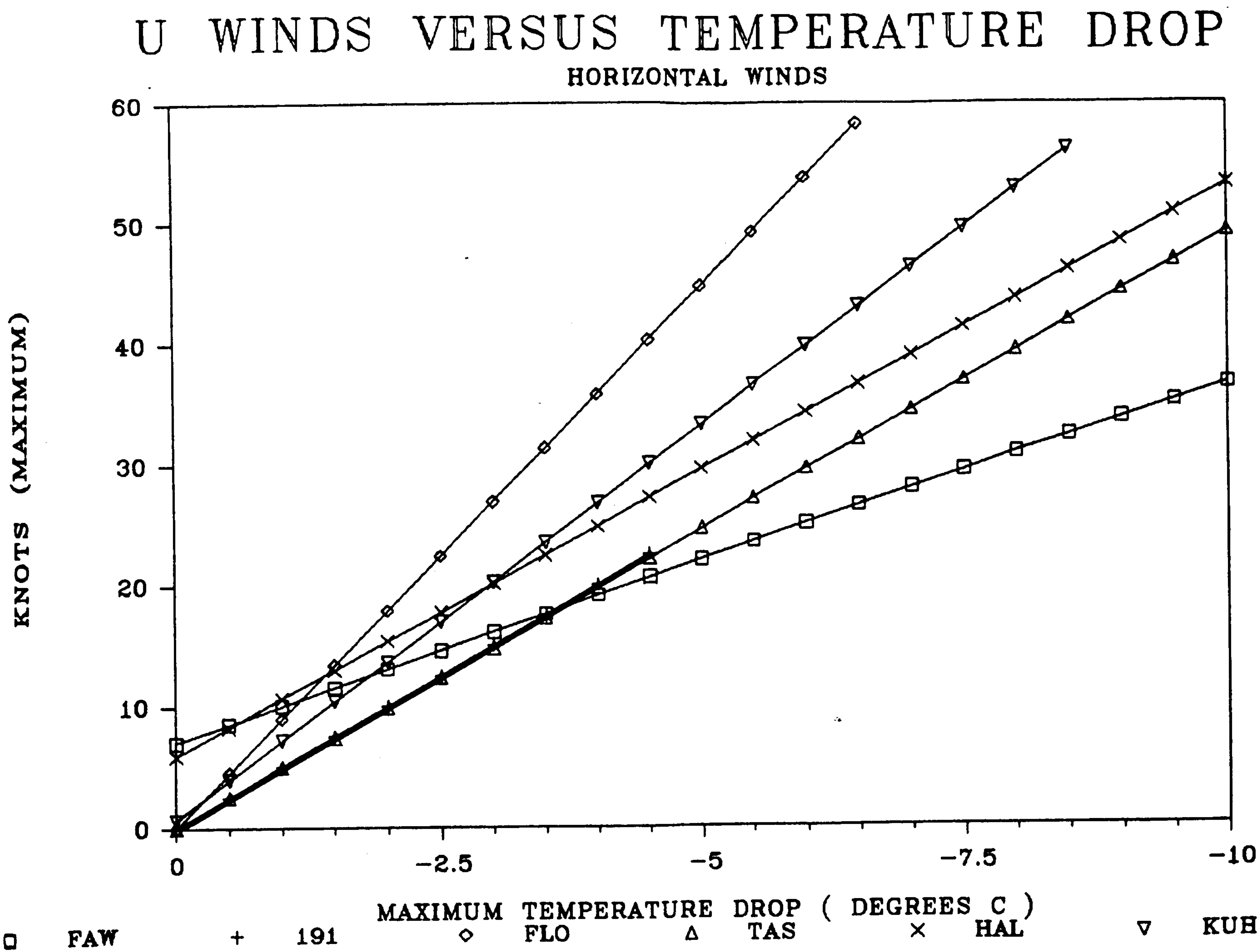
INDUSTRY REVIEW OF FORWARD LOOKING SENSOR TECHNOLOGY FOR DETECTION OF WIND SHEAR
NASA Langley Research Center 24-25 Feb. 1987, Rowland L. Bowles

F FACTOR

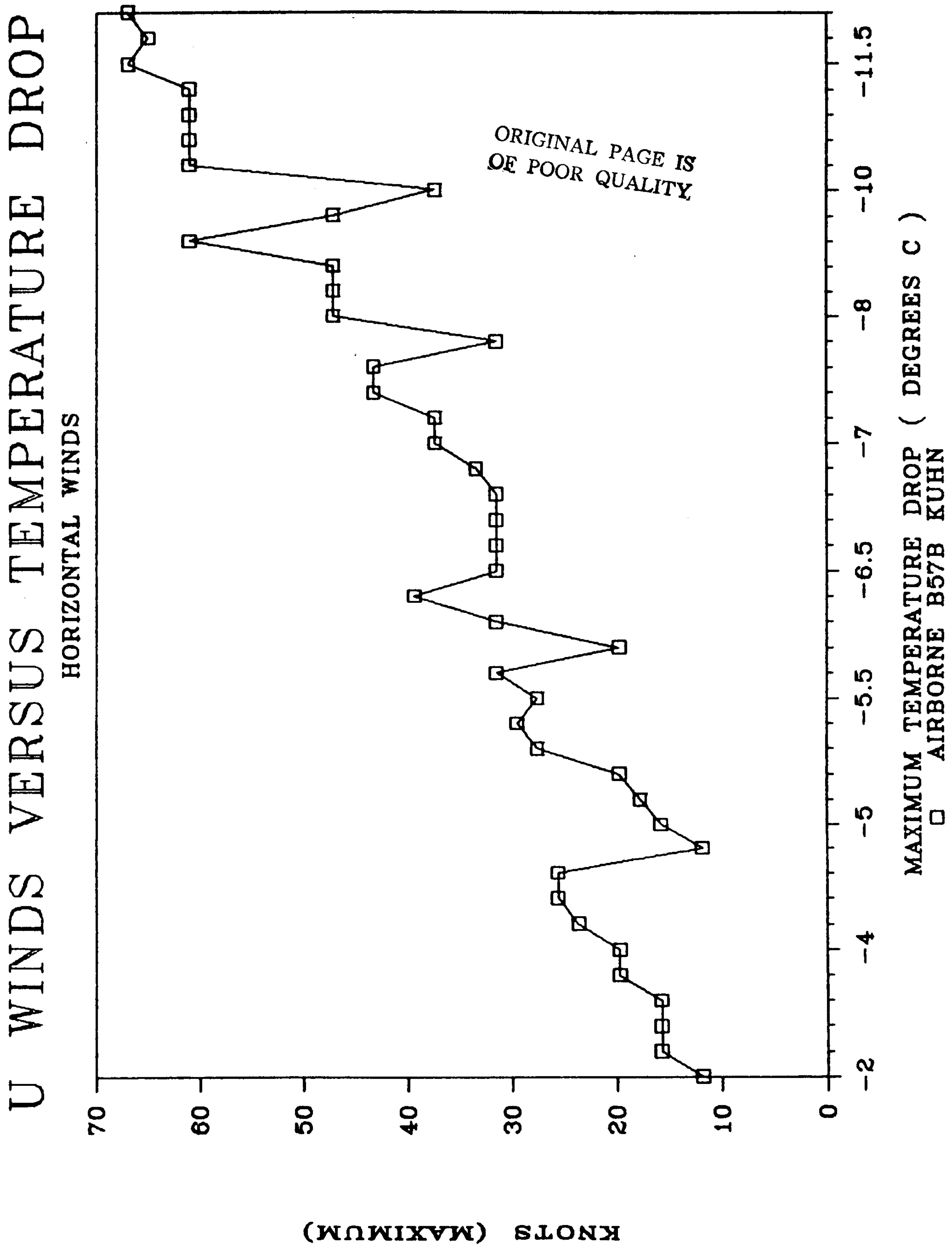
WE NEED TO ASSESS THE THREAT TO THE AIRCRAFT IN BOTH THE HORIZONTAL AND VERTICAL WIND COMPONENTS.

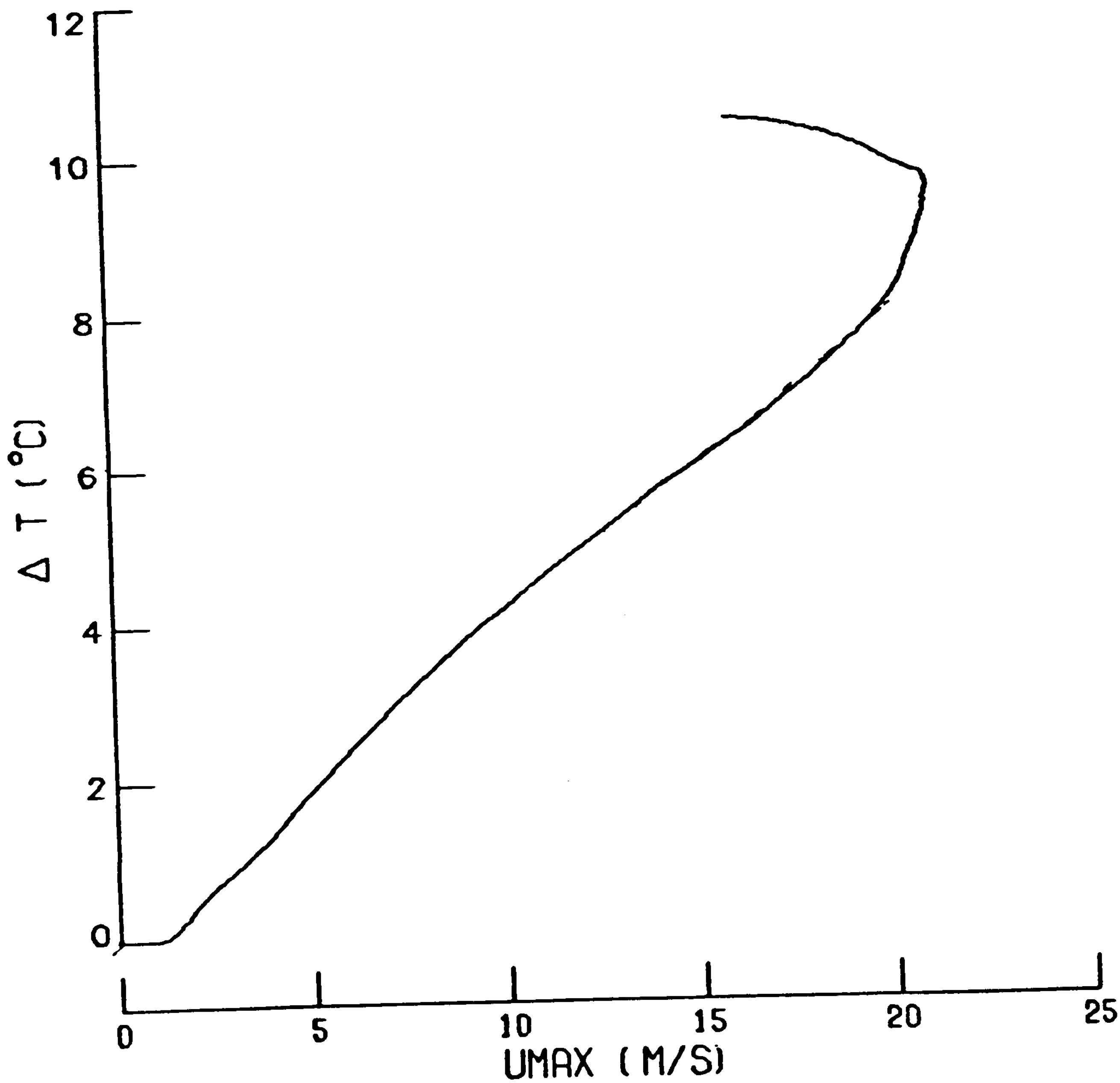
—HORIZONTAL CASE

THERE IS A GOOD EMPIRICAL RELATIONSHIP BETWEEN TEMPERATURE DROP AND HORIZONTAL WIND VELOCITY.



U WINDS VERSUS TEMPERATURE DROP
HORIZONTAL WINDS
KNOTS (MAXIMUM)
60
50
40
30
20
10
0
0
-2.5
-5
-7.5
-10
MAXIMUM TEMPERATURE DROP (DEGREES C)
FAW
191
FLO
TAS
HAL
KUH


U WINDS VERSUS TEMPERATURE DROP
HORIZONTAL WINDS
KNOTS (MAXIMUM)
MAXIMUM TEMPERATURE DROP (DEGREES C)
AIRBORNE B57B KUHN
70
60
50
40
30
20
10
0
-2
-4
-5
-5.5
-6.5
-7
-8
-10
-11.5



REFERENCE: F. PROCTOR/R. BOWLES, NASA LANGLEY RESEARCH CENTER

FROM THE NASA TASS MODEL THE RELATIONSHIP IS:

$$\Delta U_{m/s} \cong 2.5 * - \Delta T^{\circ}{}_{c}$$

SO TO GET HORIZONTAL PORTION OF F FACTOR

WE GET:

$$F_H = \frac{-\Delta T * 2.5}{g}$$

T IN DEG C
G IN m/s

WHICH THEN IS THE TEMPERATURE EQUIVALENT

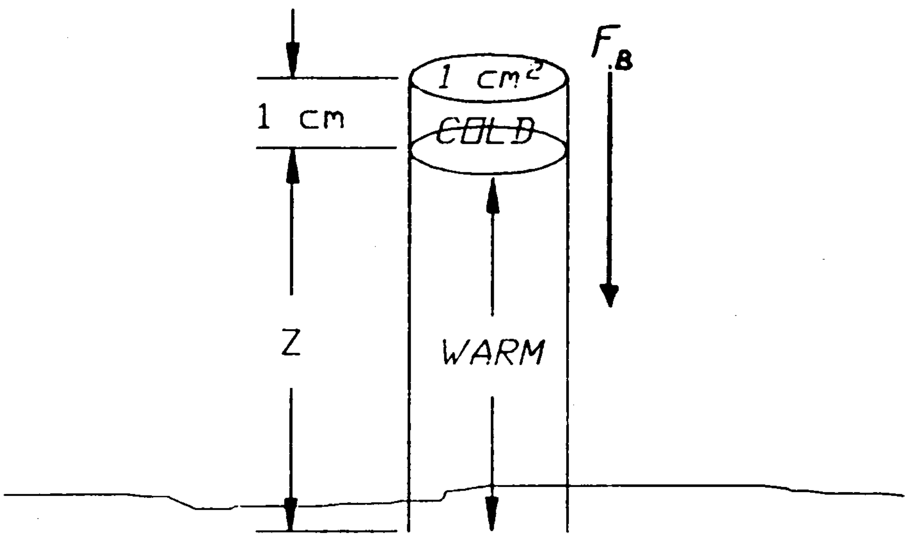
OF:

$$F_H = \frac{\dot{W}X}{g}$$

REFERENCE: "THE TERMINAL AREA SIMULATION SYSTEM"; BY FRED PROCTOR; REPORT NO. DOT/FAA/PM-86/50, I NASA CR-4046, VOLUME I: THEORETICAL FORMULATION; APRIL 1987.

-VERTICAL PORTION OF F FACTOR

NEGATIVE BUOYANCY HAS LONG BEEN RECOGNIZED AS THE MAJOR FORCING FACTOR IN DOWNBURSTS.



THE BUOYANT FORCE IS:

$$F_B = g * \frac{\Delta T^{\circ}}{T_m}$$

WHEN $\Delta T = T - T_m$

WHERE

T = TEMPERATURE OF AIR PARCEL

T_m = AMBIENT TEMPERATURE

FOSTER'S WORK ALLOWS US TO CALCULATE THE VERTICAL VELOCITY FROM THE TEMPERATURE DROP

$$W \int_{W_0}^{0} dW = \frac{g * \Delta T^{\circ}}{T_m} \int_{0}^{Z} (1 - z/Z)\, dz$$

WHICH REDUCES TO

$$W_{()}^{2} = -\frac{g * Z * \Delta T^{\circ}}{T_m}$$

AND

$$W_{()} = \sqrt{\frac{-g * Z * \Delta T^{\circ}}{T_m}}$$

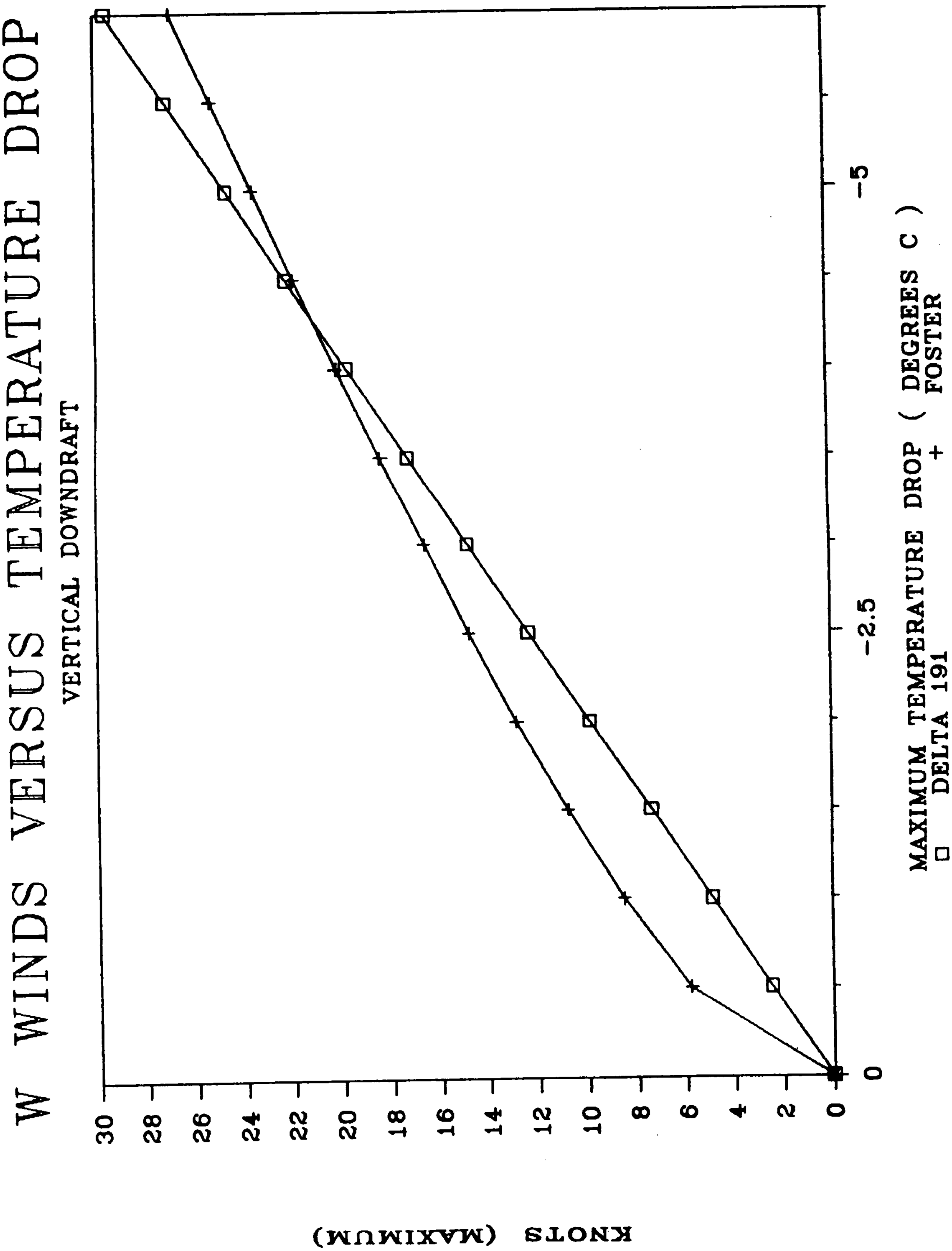
SEE PLOT OF FOSTER VS 191

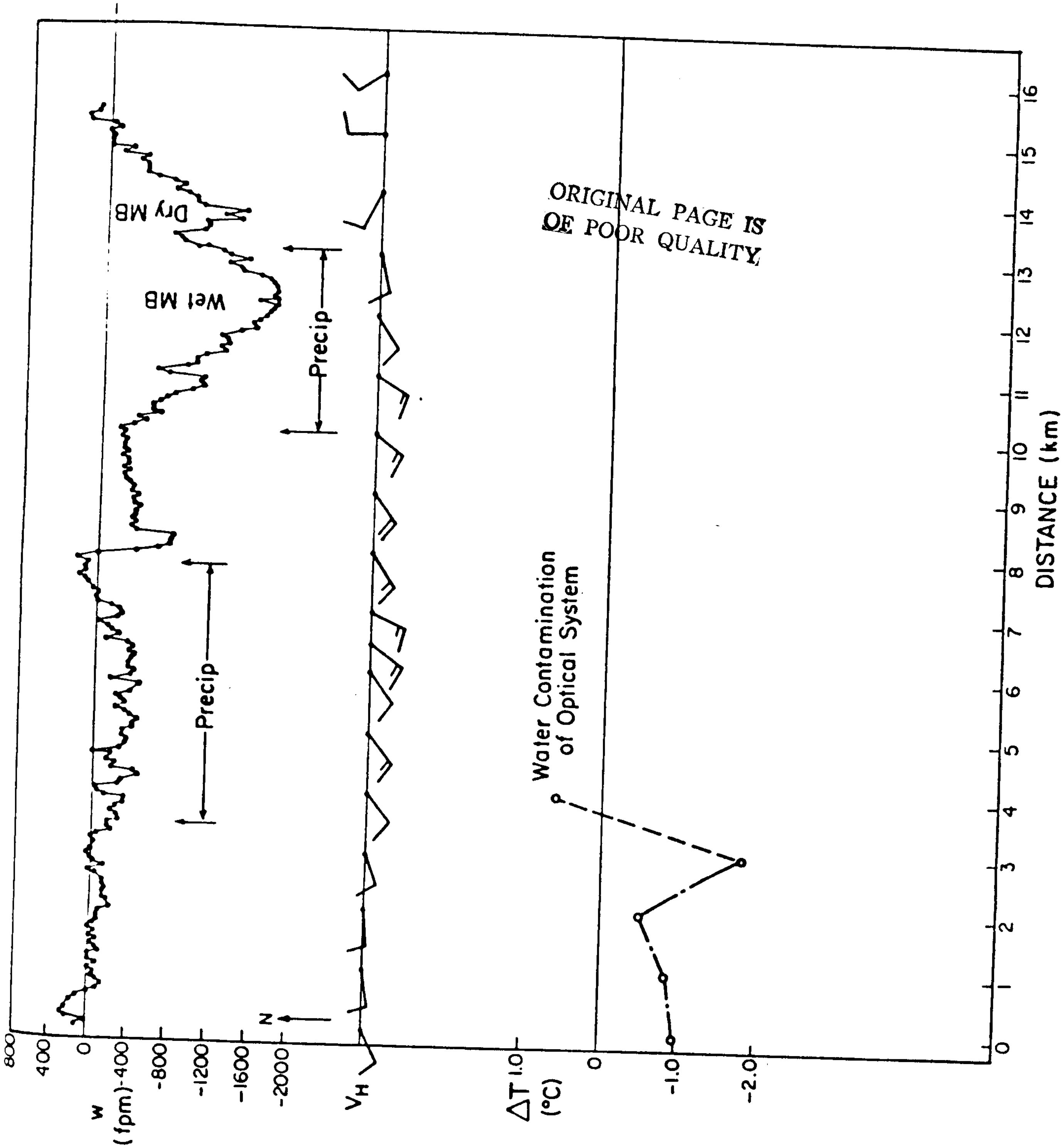
TEMPERATURE DROP RELATED TO VERTICAL WINDS

REFERENCE: "THUNDERSTORM GUSTS COMPARED WITH COMPUTED DOWNDRAFT SPEEDS"; BY DONALD FOSTER; MONTHLY WEATHER REVIEW, MARCH 1958, PP. 91-94.

REFERENCE: "A SHORT COURSE IN CLOUD PHYSICS"; BY R.R. ROGERS; 2ND EDITION; INTERNATIONAL SERIES IN NATURAL PHILOSOPHY VOLUME 96; 1979.

TURBULENCE PREDICTION SYSTEMS


W WINDS VERSUS TEMPERATURE DROP
VERTICAL DOWNDRAFT
KNOTS (MAXIMUM)
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
0
-2.5
-5
MAXIMUM TEMPERATURE DROP (DEGREES C)
□ DELTA 191
+ FOSTER



Sinclair, Kuhn
9/87

Figure 8

WE CAN THEN ASSUME SOME Z (ALTITUDE)

AND

$$Fv = \frac{\sqrt{\dfrac{-g * Z * \Delta T^{\bullet}}{Tm}}}{AIRSPEED}$$

WHICH IS THE TEMPERATURE EQUIVALENT OF

$$Fv = \frac{Vw}{As}$$

SO COMBINED HAZARD FACTOR AS A FUNCTION OF TEMPERATURE IS:

$$F = \frac{2.5 * -\Delta T}{g} + \frac{\sqrt{\dfrac{-g * Z * \Delta T^{\bullet}}{Tm}}}{AIRSPEED}$$

TURBULENCE PREDICTION SYSTEMS

CONCLUSIONS:

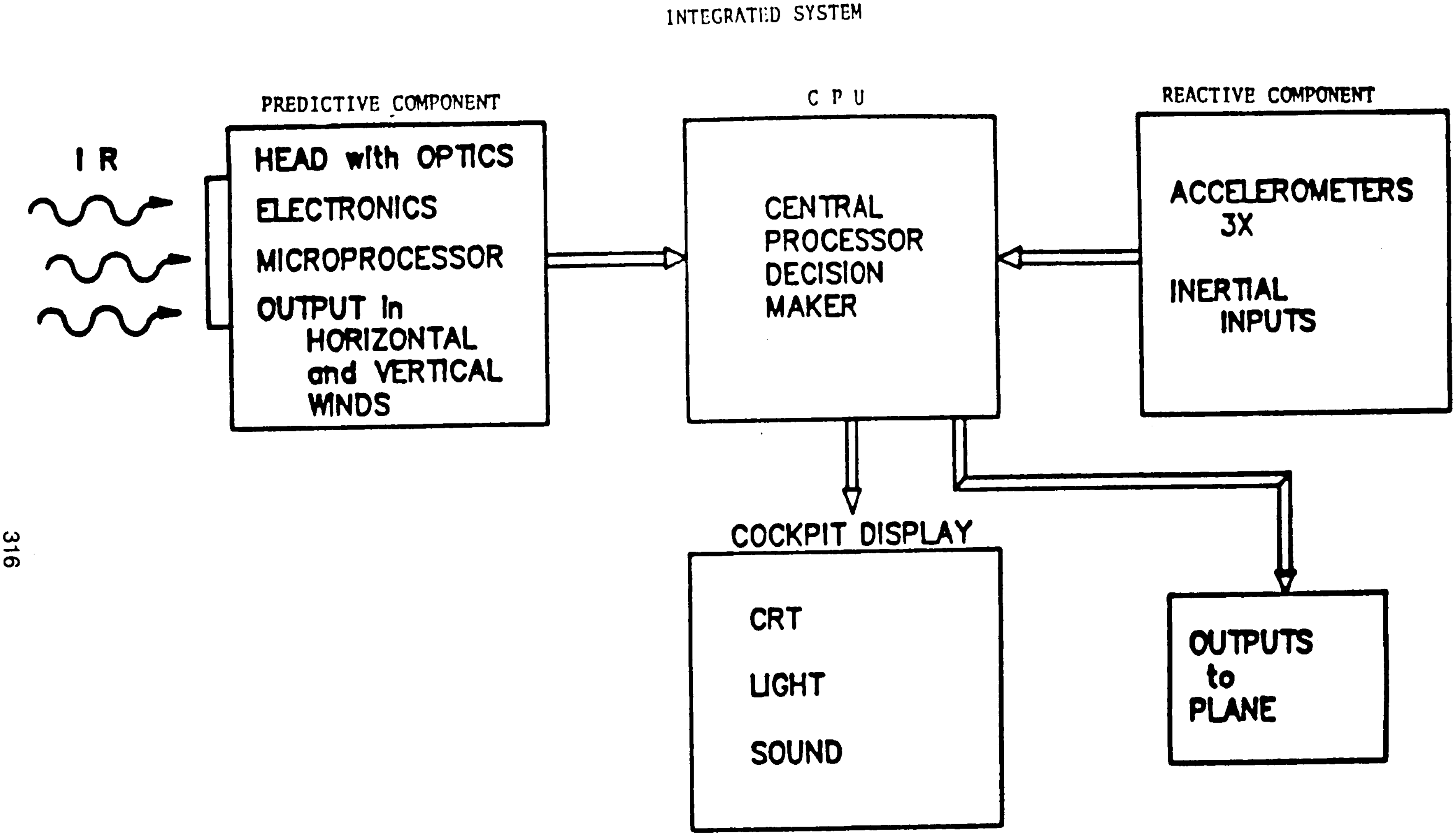
NOW WE HAVE COVERED BOTH ASPECTS OF CONCERN TO THE AIRCRAFT FROM THE

HORIZONTAL WIND RATE OF CHANGE AS A FUNCTION OF EMPIRICAL AND MODELLED WORK RELATED TO TEMPERATURE DROP.

VERTICAL WIND VELOCITY FROM A WELL ACCEPTED FORCING FACTOR RELATED TO TEMPERATURE DROP

THIS CALCULATED HAZARD INDEX HAS RELEVANCE TO THE IN SITU SYSTEMS PRESENTLY IN USE

TURBULENCE PREDICTION SYSTEMS



BLOCK DIAGRAM of
TURBULENCE PREDICTION SYSTEMS
ADVANCE WARNING SYSTEM

WHERE TO NOW:

THEORETICAL WORK IN PROGRESS

- NUISANCE ALARMS
  - COLD FRONTS
  - GUST FRONTS
  - SPECIAL CASES
    - SNOW DRIVEN WITH STABLE LAYER
    -

DEFINITION OF STANDARD TEMPERATURE NOISE FIELD

PROBABILITY OF NUISANCE ALARMS FOR INFRARED SYSTEM

PROBABILITY OF NUISANCE ALARMS FOR AN INTEGRATED SYSTEM

TURBULENCE PREDICTION SYSTEMS

OPERATIONAL ENVIRONMENT

WE HAVE OBTAINED WIDE-SCALE USER INTEREST TO ASSIST US IN EVALUATING OUR SYSTEM

WE ARE PROCEEDING WITH A PRIVATELY FUNDED IN-SERVICE EVALUATION OF OUR SYSTEM (12 MONTH PROGRAM)

QUESTIONS WE WANT TO ANSWER

WILL OUR OPERATIONAL SYSTEM PROVE AS RELIABLE AND ACCURATE AS THE RESEARCH INSTRUMENTS DID?

IF NO:

REEVALUATE INFRARED AS A VIABLE CANDIDATE

IF YES:

THE NATION WILL HAVE INCREASED AIR SAFETY NOW

TURBULENCE PREDICTION SYSTEMS

TPS IN-SERVICE EVALUATION

GOALS:

- PROVE TPS'S ADVANCE WARNING SYSTEM PERFORMS WELL IN AN OPERATIONAL SETTING

- HELP ESTABLISH INDUSTRY EVALUATION CRITERIA

- ASSIST IN OBTAINING FAA CERTIFICATION

TURBULENCE PREDICTION SYSTEMS

TPS'S FUTURE

GOAL: FAA CERTIFIED SYSTEM (1988)

METHOD: IN-SERVICE EVALUATION

- INDUSTRY PARTNERS
  * PIEDMONT AIRLINES - 4 SYSTEMS 1988
  * HONEYWELL/SPERRY CORPORATION

- TIMETABLE FOR ALL IN-SERVICE EVALUATIONS
  * 1988
  * EXPECTED AIR TIME

    12 SYSTEMS - 24,000 FLIGHT HRS

- POST ANALYSIS OF IN-SERVICE DATA
  * TPS (HONE ALGORITHMS AS WE LEARN)
  * INDUSTRY PARTNERS
  * FAA

TURBULENCE PREDICTION SYSTEMS

JIM EVANS (MIT Lincoln Labs) - Your program sounds like a good way to start trying to address some of the false alarms. On the other hand, one hopes they don't penetrate microburst very often. How are you working at trying to establish what the detection probability is for this combined system?

PAT ADAMSON (TPS) - One of the things we are going to do--and that was part of my last slide--Since the hazard index is applicable to both systems assuming that everybody did their math correctly, we will time tag the data. Part of our data gathering technique will be to look for shears or hazard index such that they may not be terribly hazardous to the aircraft. And it will look for a similar event to occur at some time after that in the reactive system. That is what we are hoping to do. If we get shears over the year that is bad or good, I don't know which.

JIM EVANS (MIT Lincoln Labs) - Again, I understand how you can do that comparison, what I meant was how will you? This plane could fly all summer and never see a microburst. How will you establish whether it detects microbursts or not, in this situation? Wouldn't you really have to have the same system and get a plane out and try to fly it around and try to fly it through microburst?

PAT ADAMSON (TPS) - Well, I don't think so. I mean, I think that has already been proven. I think for example, the report I just showed from Quinn and Sinclair was a completely equipped plane that the B57B was a completely equipped plane--I think they worked properly, it showed they worked in the optimum research section. I don't think we are every going to get proof that they work in the operational setting--nobody is going to take that chance.

N88-17629

FORWARD LOOKING WIND SHEAR DETECTION

STATUS REPORT 10/22/87

BACKGROUND

- INERTIAL AND INTEGRATED AVIONICS SYSTEMS
- ELECTRO-OPTICAL SURVEILLANCE SYSTEMS
- HUGHES AIRCRAFT SENSOR EXPERTISE

CURRENT OBJECTIVES

- ASSESS BASIC FEASIBILITY OF PASSIVE INFRARED (IR) INTEGRATED SYSTEMS SOLUTION TO EARLY DETECTION OF HAZARDOUS, LOW-ALTITUDE WIND SHEAR

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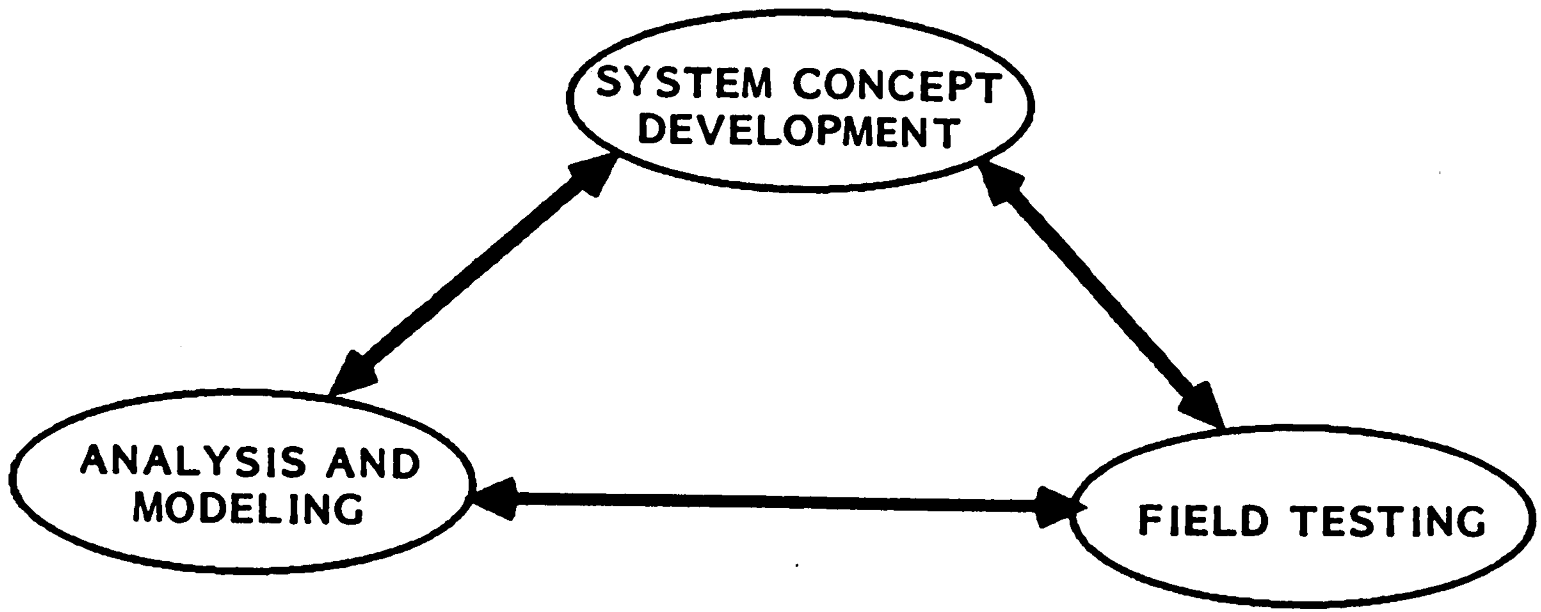
FEASIBILITY ASSESSMENT APPROACH



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SYSTEM CONCEPT DEVELOPMENT

PHILOSOPHY

- INTEGRATED SYSTEMS SOLUTION REQUIRED - NOT STANDALONE IR SENSOR.
- WIDE FIELD OF VIEW COVERAGE - MULTIPLE RESOLUTION ELEMENTS TO PERMIT MORE RAPID DETECTION, TARGET LOCATION & INTENSITY ASSESSMENT, AND NOISE REJECTION.
- MODELING OF ATMOSPHERE TO PROVIDE CALIBRATION OF PARAMETERS.
- ADAPTIVE THRESHOLD SENSITIVITY DEPENDENT ON ATMOSPHERIC CONDITIONS.

GOALS

- MINIMUM 20 SECONDS WARNING FOR MICROBURSTS.
- 60° (OR GREATER) HORIZONTAL FIELD OF VIEW.
- ASSESSMENT OF TARGET RANGE, HEADING & SEVERITY.
- STAGED LEVEL OF OPERATION & ALERTS.
  - SAFE
  - CAUTION
  - WARNING
- MINIMUM FALSE ALARM RATE
- RELIABLE, AFFORDABLE, MAINTAINABLE

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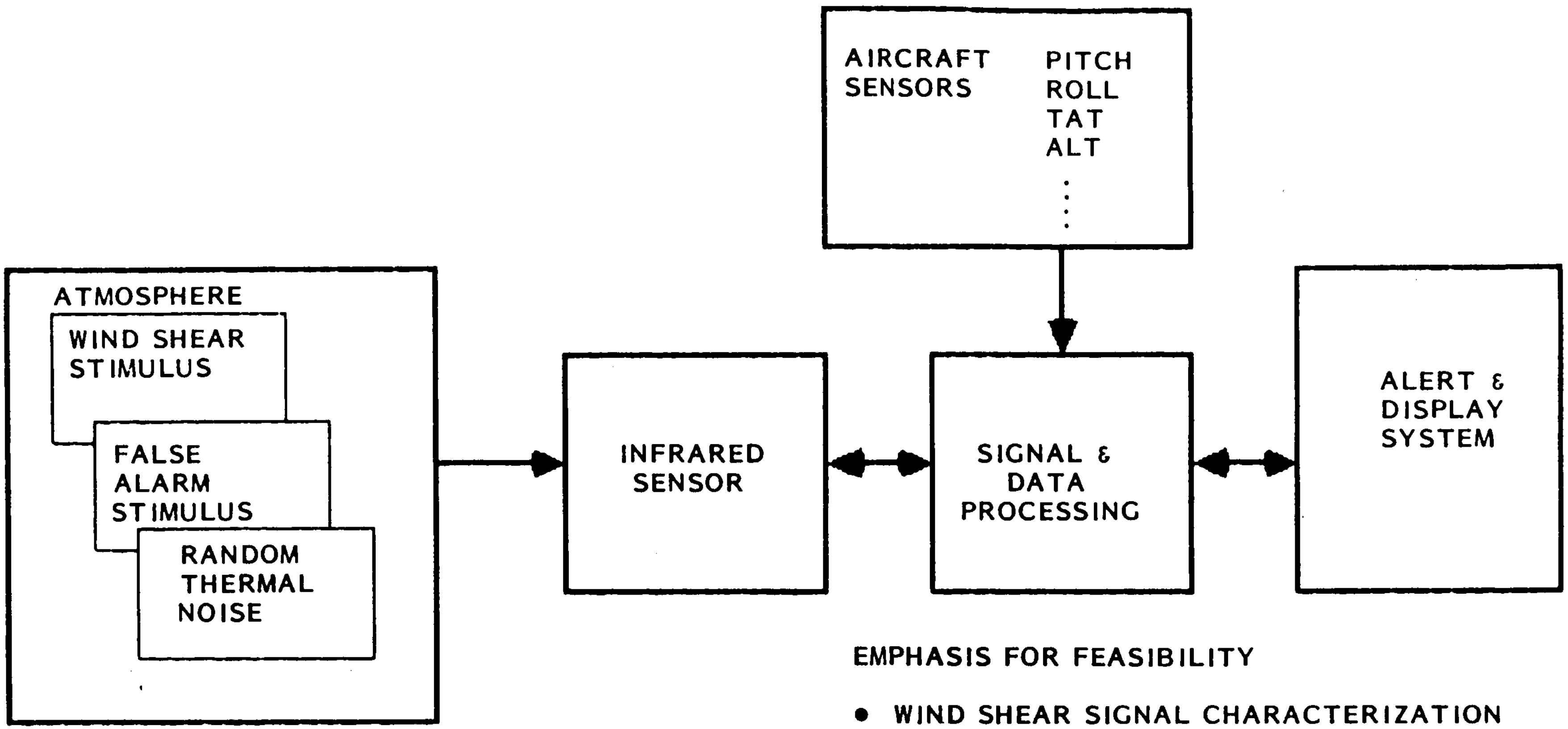
ANALYSIS/MODELING



EMPHASIS FOR FEASIBILITY

- WIND SHEAR SIGNAL CHARACTERIZATION
- FALSE ALARM DEFINITION
- RANDOM/BACKGROUND NOISE ASSESSMENT
- SENSOR REQUIREMENTS
- DISCRIMINATION ALGORITHMS

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ANALYSIS/MODELING

- SIGNAL CHARACTERIZATION

  SUBJECTS
  - HAZARD AND SCALE DEFINITION
  - THREAT INTENSITY
  - UNIQUE IR SIGNATURES/CUES
  - SIGNAL TO NOISE RATIOS
  - FEASIBLE OPERATING RANGES
  - RESOLUTION REQUIREMENTS
  - MICROBURST DRIVING FORCES
  - ATMOSPHERIC STABILITY INDICATORS

  SOURCES
  - EXISTING MICROBURST DATA
  - COMPUTER MODEL SIMULATIONS
  - SCIENTIFIC LITERATURE
  - ATMOSPHERIC EXPERTS
  - EXPERIMENTAL FIELD TESTS

- NOISE ENVIRONMENT AND POTENTIAL FALSE ALARM SOURCES
  - RANDOM TEMPERATURE FLUCTUATIONS (UNCORRELATED)
  - SPATIAL AND TEMPORAL TEMPERATURE FLUCTUATIONS
  - RAIN, DRIZZLE, FOG
  - CLOUDS AND ATMOSPHERIC HOLES BETWEEN CLOUDS
  - THERMAL PLUMES (HEAT ISLANDS)
  - FIELD OF VIEW STABILITY
  - STABILITY OF ABSORPTION AND SCATTERING
  - ENTRANCE WINDOW CONTAMINATION AND INTEGRITY
  - HARD TARGETS (AIRCRAFT/OBJECTS IN FOV)
  - TURBULENCE WAKES
  - SMOKE AND POLLUTANTS
  - INVERSIONS, DENSITY WAVES
  - SOLAR EFFECTS

ANALYSIS/MODELING (CONTINUED)

- SENSOR AND SIGNAL PROCESSING
  - OPERATING WAVELENGTHS
  - DETECTOR TYPES & CONFIGURATION
  - SCANNING MECHANISMS
  - STABILIZATION REQUIREMENTS
  - CALIBRATION TECHNIQUES
  - STIMULUS EVALUATION/CLASSIFICATION
  - FALSE ALARM DISCRIMINATION/MANAGEMENT
  - SENSITIVITY (SIGNAL TO NOISE ENVIRONMENT)
  - SIGNAL ENHANCEMENT/NOISE REJECTION
  - RANGE AND SEVERITY EVALUATION TECHNIQUES
  - ATMOSPHERIC DATA ASSESSMENT
  - INTEGRATION OF EXTERNAL SENSOR DATA
  - IMAGE CONSTRUCTION & PROCESSING
- AIRCRAFT AND OPERATOR INTERFACE
  - CONTROLS & ACTIVATION SEQUENCES
  - EXTERNAL INPUTS
  - WARNING & DISPLAY APPROACHES
  - SENSOR DATA SOURCES & PROCESSING

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FIELD TEST PROGRAM

OBJECTIVES

- TEST SENSING TECHNIQUES AND SIGNAL PROCESSING ALGORITHMS
- MEASURE AND EVALUATE BACKGROUND NOISE AND SPATIAL/ TEMPORAL VARIATIONS
- VERIFY SIGNAL CHARACTERISTICS/SIGNATURES
- INVESTIGATE PROPOSED WAVELENGTH RESPONSES AND STABILITY
- CHARACTERIZE DIFFERENT ATMOSPHERES (DRY, HUMID, MARINE, ETC.)

TEST CONFIGURATION AND LOCATIONS

- ARRAY OF FIVE SENSORS (THREE IMAGING, TWO RADIOMETRIC)
  - VISIBLE TV CAMERA WITH AUTO-IRIS
  - PYROELECTRIC VIDICON THERMAL IMAGING SYSTEM (8-20 MICRONS)
  - CRYOGENICALLY COOLED HgCdTe FLIR IMAGING SYSTEM (8-14 MICRONS)
  - DUAL PRT-5 RADIOMETERS WITH MULTIPLE BANDPASS FILTERS
- VIDEO AND DIGITAL RECORDING SYSTEMS WITH TIME CODE GENERATOR
- METEROLOGICAL DATA INPUTS
- DATA COLLECTED IN COLORADO, ALABAMA, AND FLORIDA

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PRELIMINARY RESULTS AND CONCLUSIONS

- BACKGROUND NOISE QUANTIFIED - APPEARS MANAGEABLE
- SIGNAL EFFECTS RECORDED - INCLUDING DRY MICROBURST
- NUMBER OF FALSE ALARMS SOURCES IDENTIFIED & ASSESSED
- PROPOSED OPERATING WAVELENGTHS, PROCESSING SCHEMES, & ALGORITHMS EVALUATED
- NO SHOW STOPPERS ENCOUNTERED
- FALSE ALARM DISCRIMINATION NOT TRIVIAL
- INTEGRATED SYSTEMS SOLUTION NECESSARY - NOT STANDALONE
- MORE QUANTITATIVE TESTING REQUIRED

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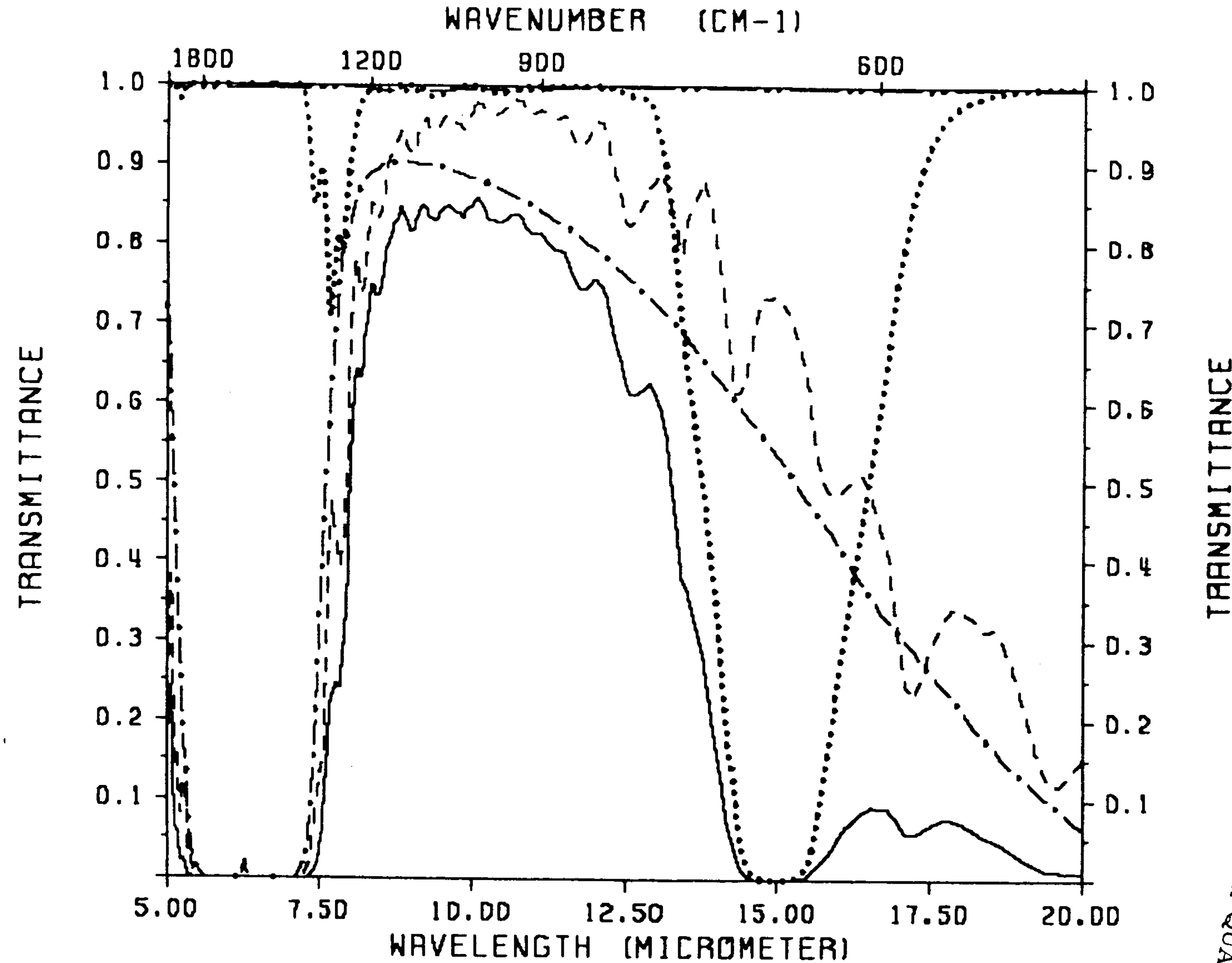
TYPICAL PC-TRAN MODEL OUTPUT



DENVER, 09/24/87, DRY ATMOSPHERE

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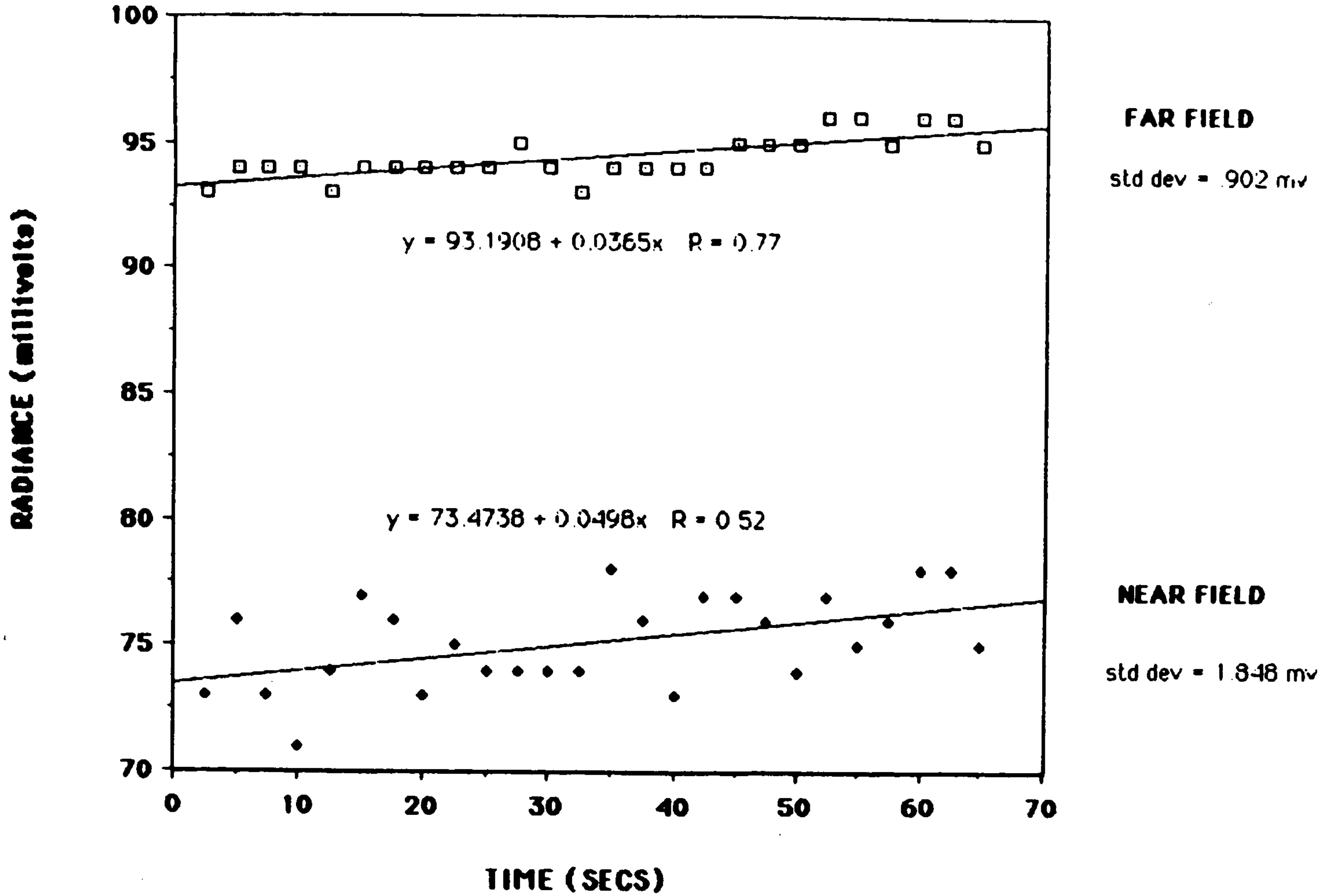
TYPICAL RADIANCE FLUCTUATIONS (NOISE) vs TIME



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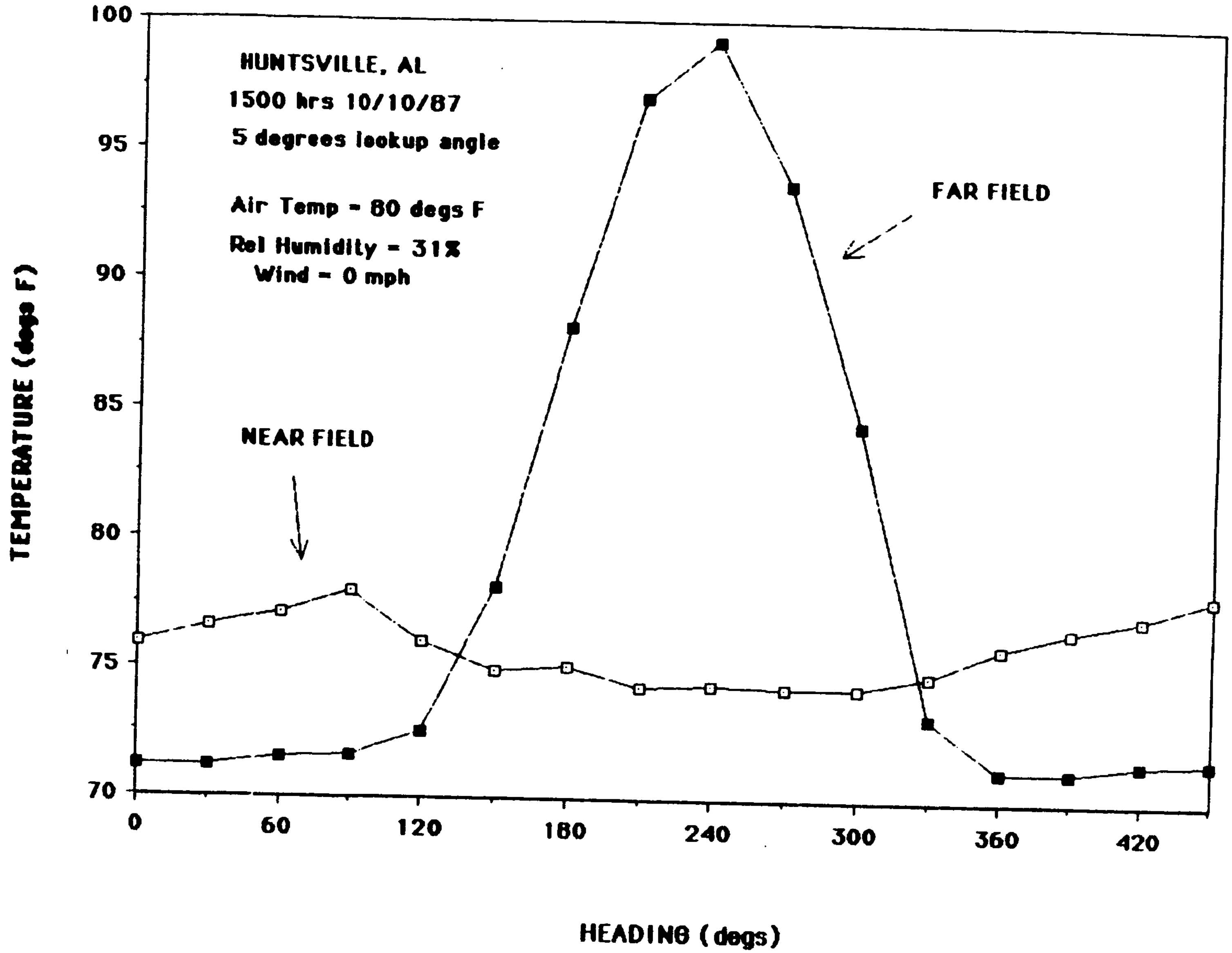
RADIOMETRIC TEMPERATURES vs AZIMUTH HEADINGS



Delco Systems

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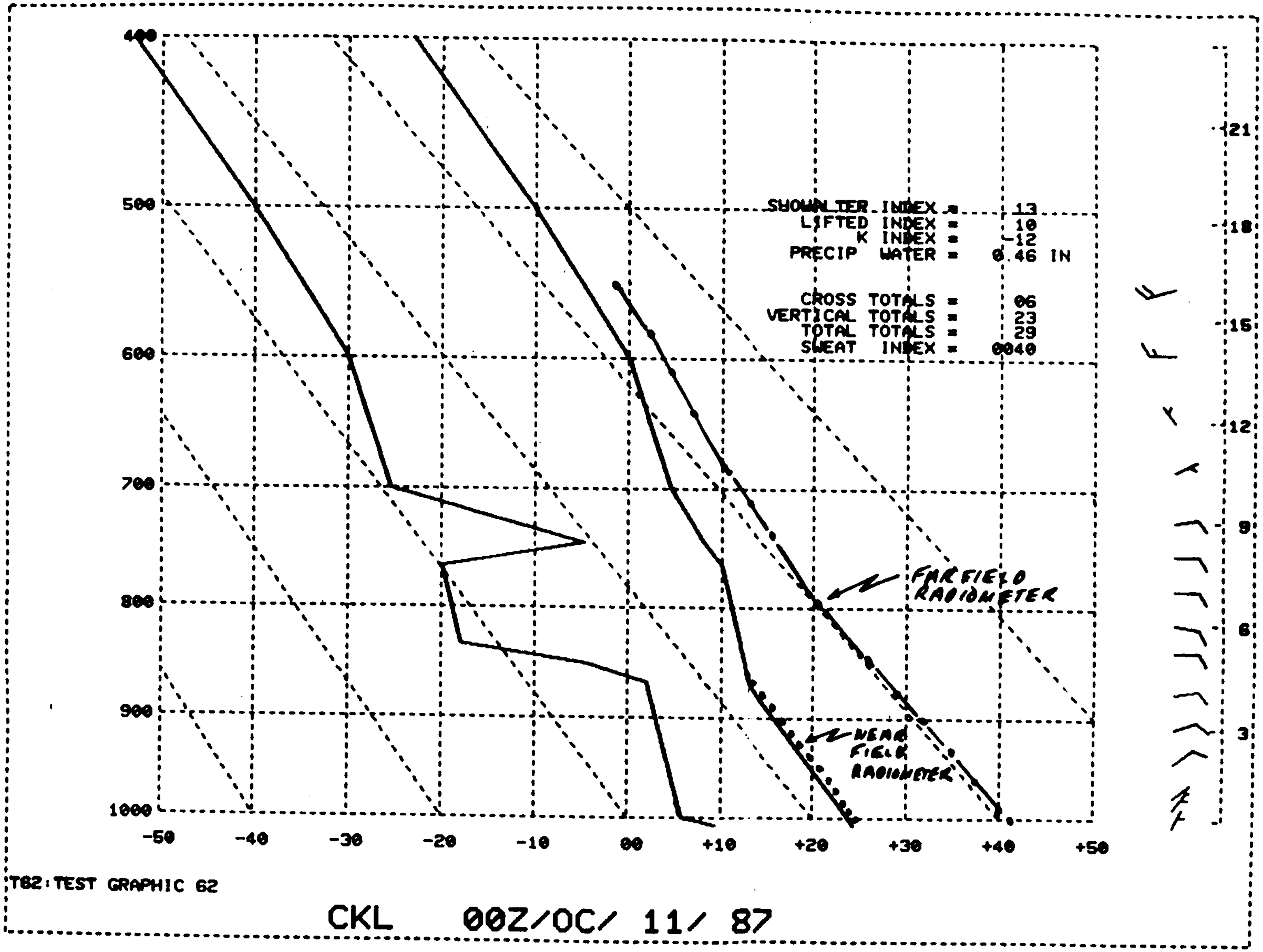
COMPARISON OF RADIOMETRIC TEMPERATURES WITH SOUNDING DATA 10/10/87



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N88-17630

SIMULATOR INVESTIGATION OF WIND SHEAR RECOVERY TECHNIQUES

DAVID A. HINTON

NASA - LaRC

OCTOBER 22, 1987

THIS RESEARCH REPRESENTS A PORTION OF THE WORK BEING PERFORMED FOR THE MASTER OF SCIENCE DEGREE WITH THE GEORGE WASHINGTON UNIVERSITY

OBJECTIVE

- DEVELOPMENT OF PRACTICAL FLIGHT PROCEDURES AND GUIDANCE FOR NEAR-OPTIMAL TRAJECTORIES DURING INADVERTENT WIND SHEAR ENCOUNTERS FOLLOWING TAKEOFF

APPROACH

- CONDUCT PRELIMINARY DEVELOPMENT OF CANDIDATE STRATEGIES USING BATCH SIMULATION OF POINT MASS AIRPLANE
- EVALUATE CANDIDATE GUIDANCE STRATEGIES IN PILOTED, REAL TIME, 6 D.O.F. SIMULATION

BATCH SIMULATION

- POINT-MASS B737-100 PERFORMANCE MODEL

- FLIGHT IN VERTICAL PLANE

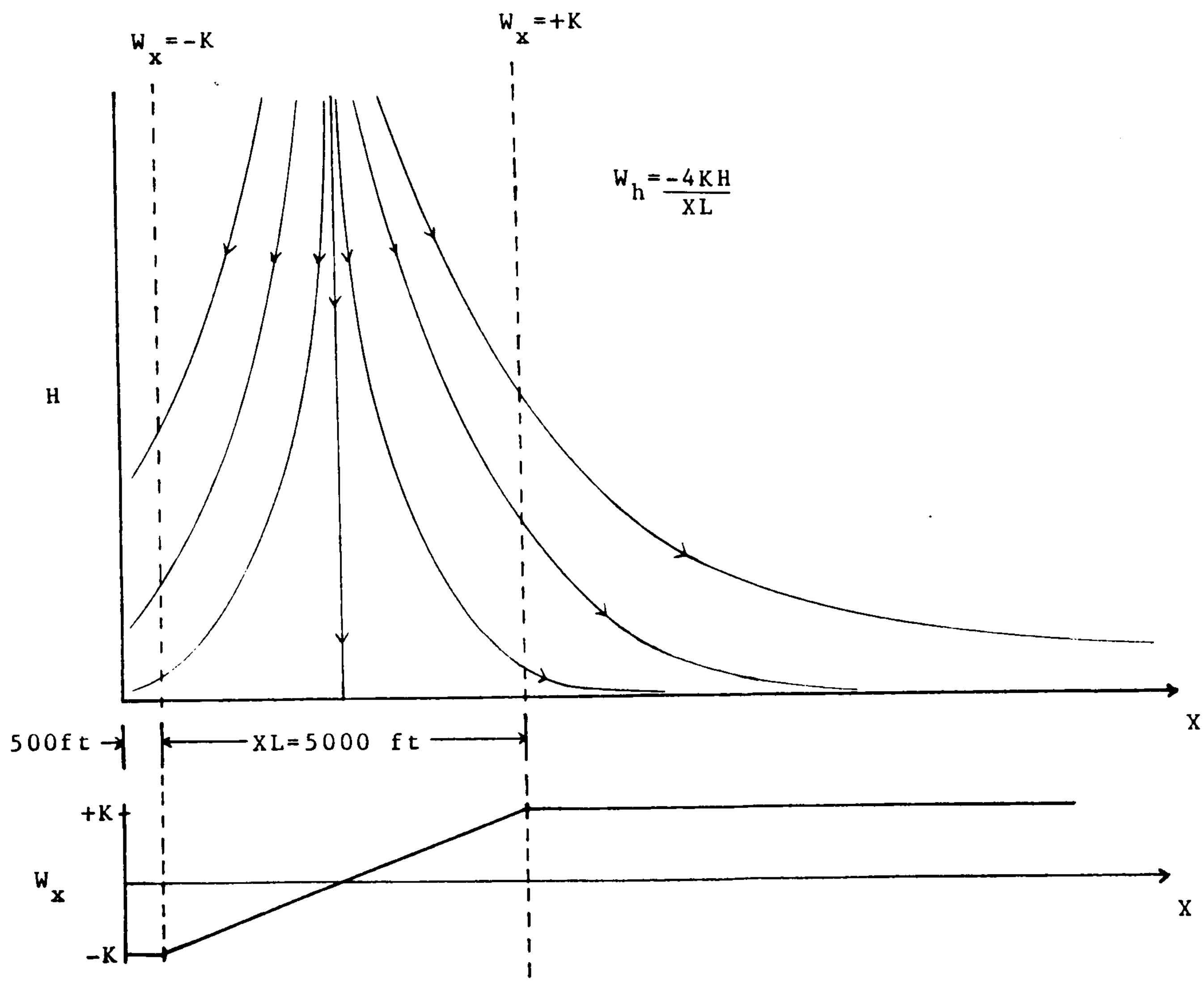
- POSITION-BASED ANALYTICAL WIND MODEL

- 3 GUIDANCE STRATEGIES DEVELOPED FOR REAL-TIME PHASE
    - o PITCH HOLD - FOR NONRETROFIT
    - o ACCELERATION - FOR RETROFIT TO NON-IRU AIRCRAFT
    - o FLIGHT PATH ANGLE - FOR RETROFIT TO IRU-EQUIPPED AIRCRAFT

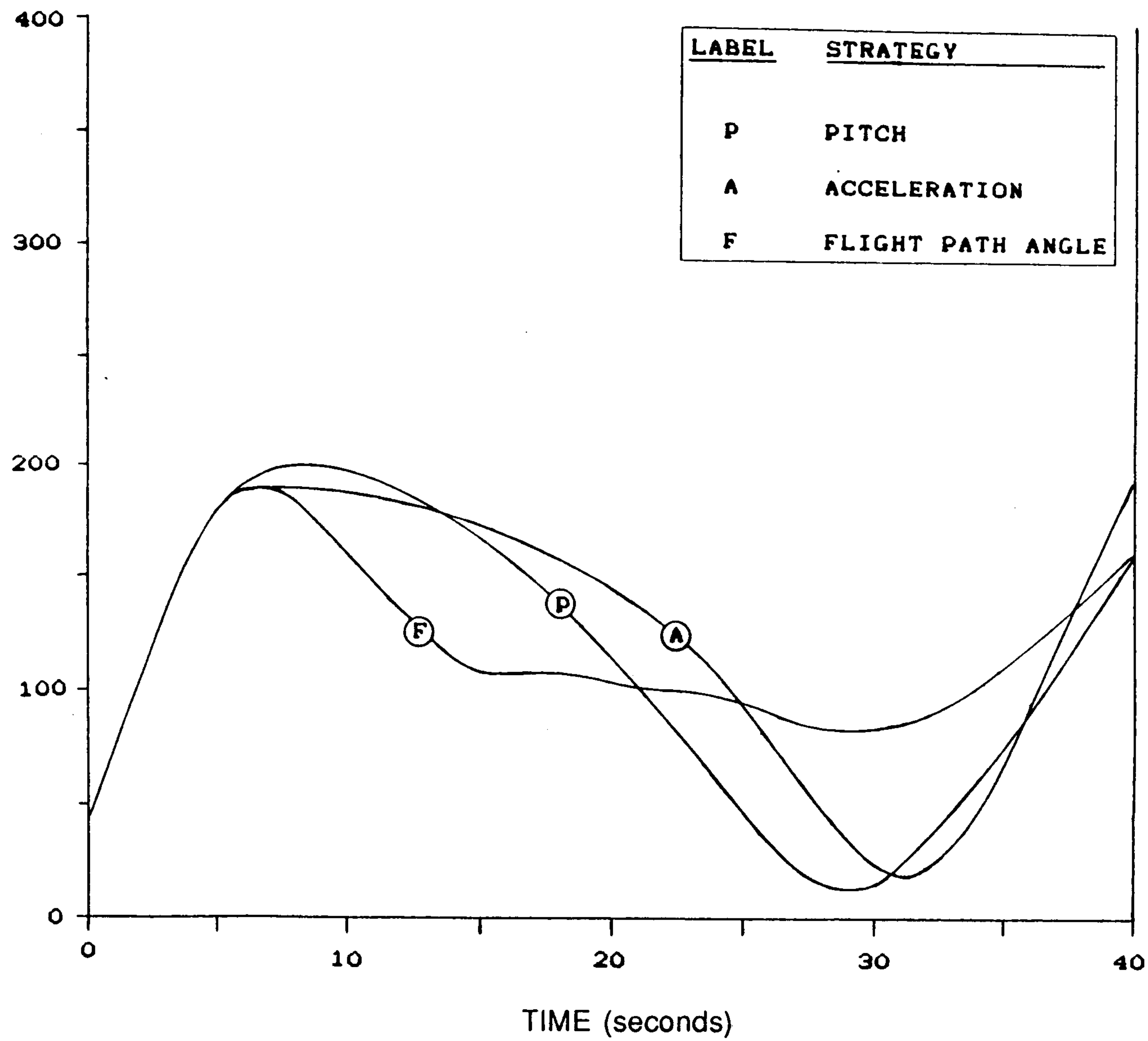
- BEST OVERALL RESULTS WITH FLIGHT PATH ANGLE STRATEGY

- LESSONS:
    - QUICKLY ARREST CLIMB IN TAKEOFF WIND SHEAR ENCOUNTER
    - USE MINIMUM FPA AND MAXIMUM KINETIC ENERGY THROUGH SHEAR
    - REACH LIMIT ANGLE OF ATTACK AT END OF SHEAR

SHEAR MODEL A



THREE GUIDANCE STRATEGIES



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REAL-TIME SIMULATION

- B737-100, 6 D.O.F. MOTION, OUTSIDE VISUAL SCENE

- CONVENTIONAL FLIGHT DECK

- THREE GUIDANCE OPTIONS, FROM BATCH SIMULATION

- TWO WIND SHEAR MODELS
    - SHEAR A, FROM BATCH STUDY, NONTURBULENT
    - SHEAR B, DFW-BASED TRAINING SHEAR, VORTEX TURBULENCE

- SHEAR ENCOUNTERED AT PRESET ALTITUDE FOLLOWING NORMAL TAKEOFF

- PERFECT INSITU SENSING ASSUMED, IMMEDIATE ALERT AND GUIDANCE AT SHEAR ENTRY

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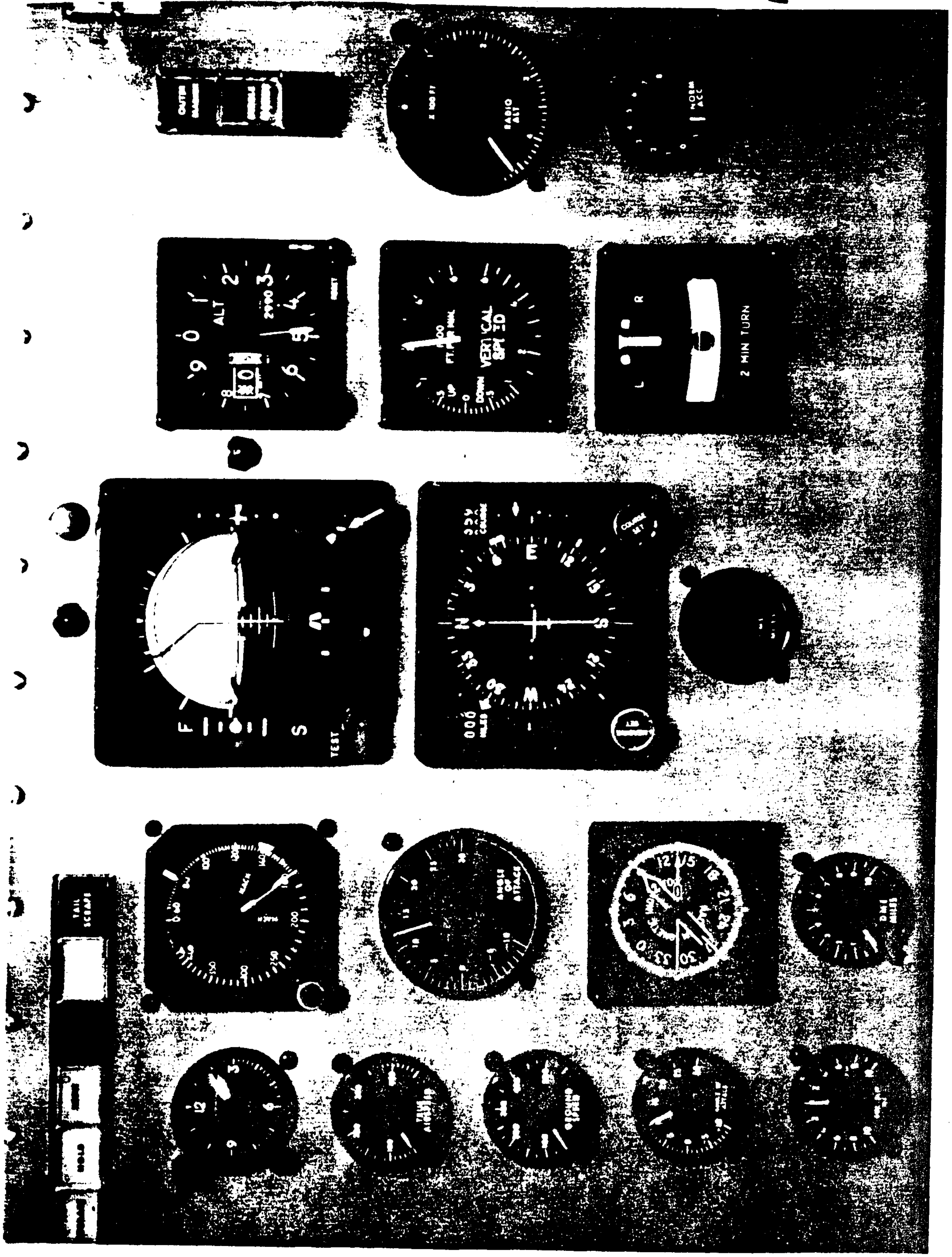

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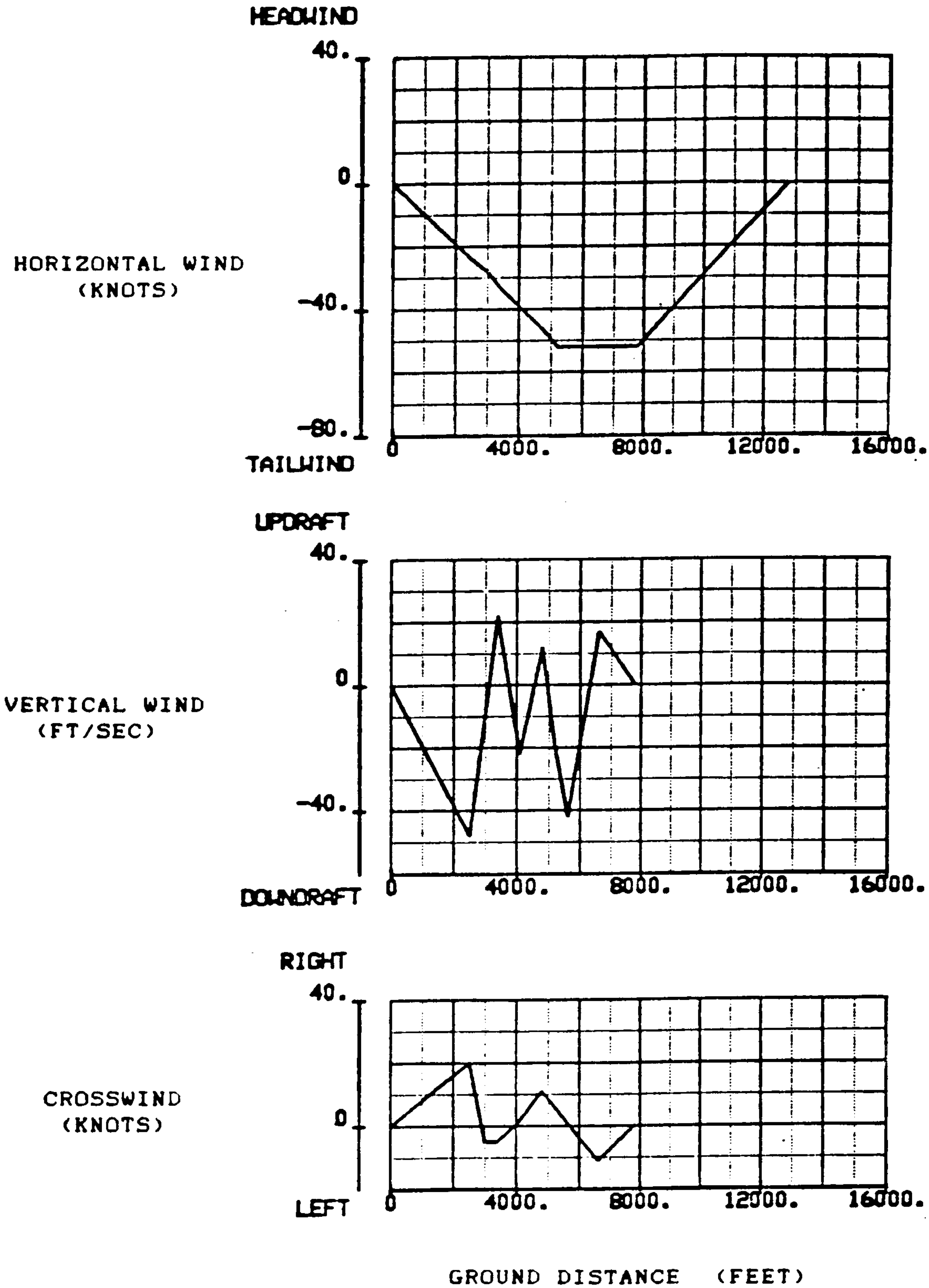
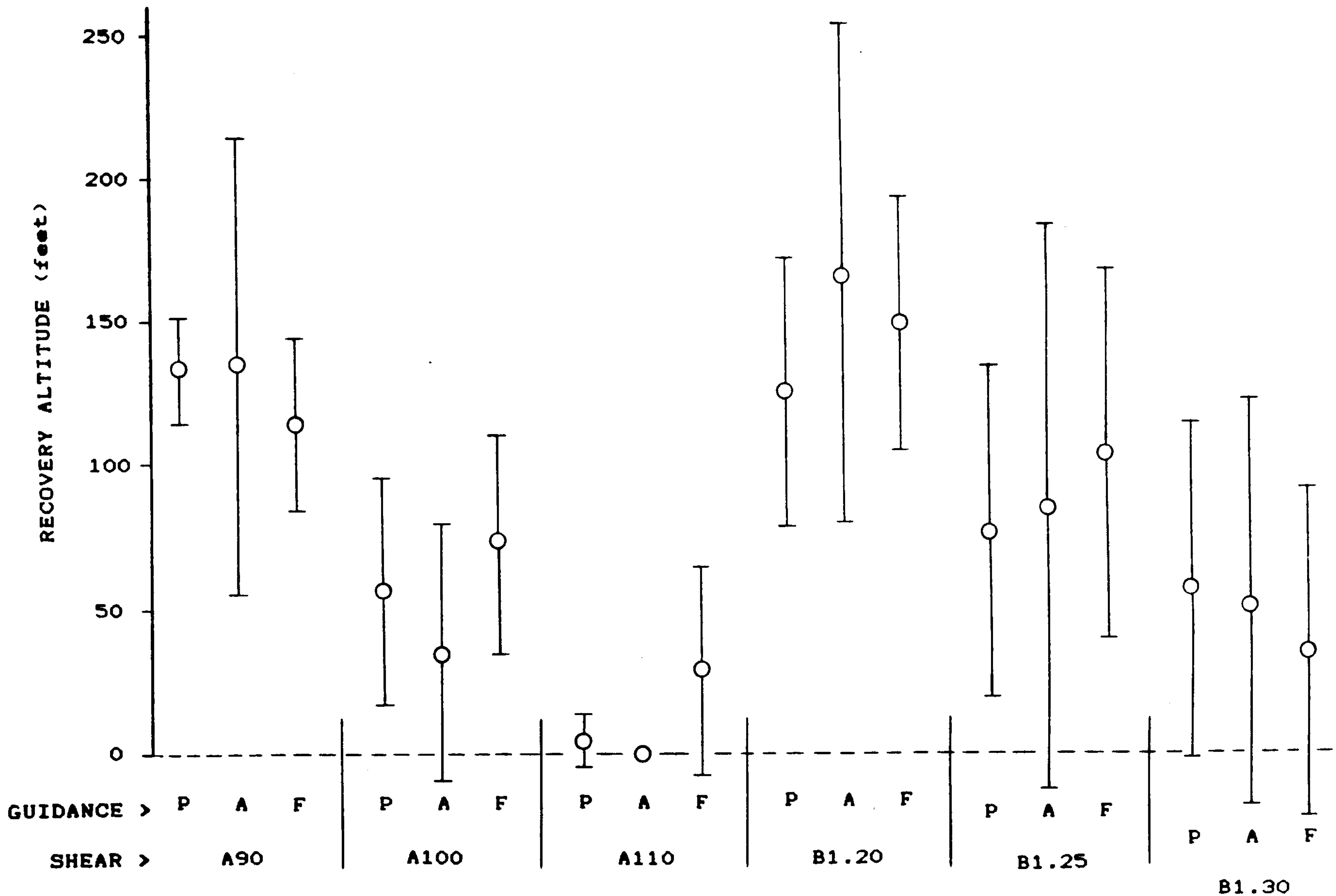
SHEAR MODEL B



REAL TIME MATRIX

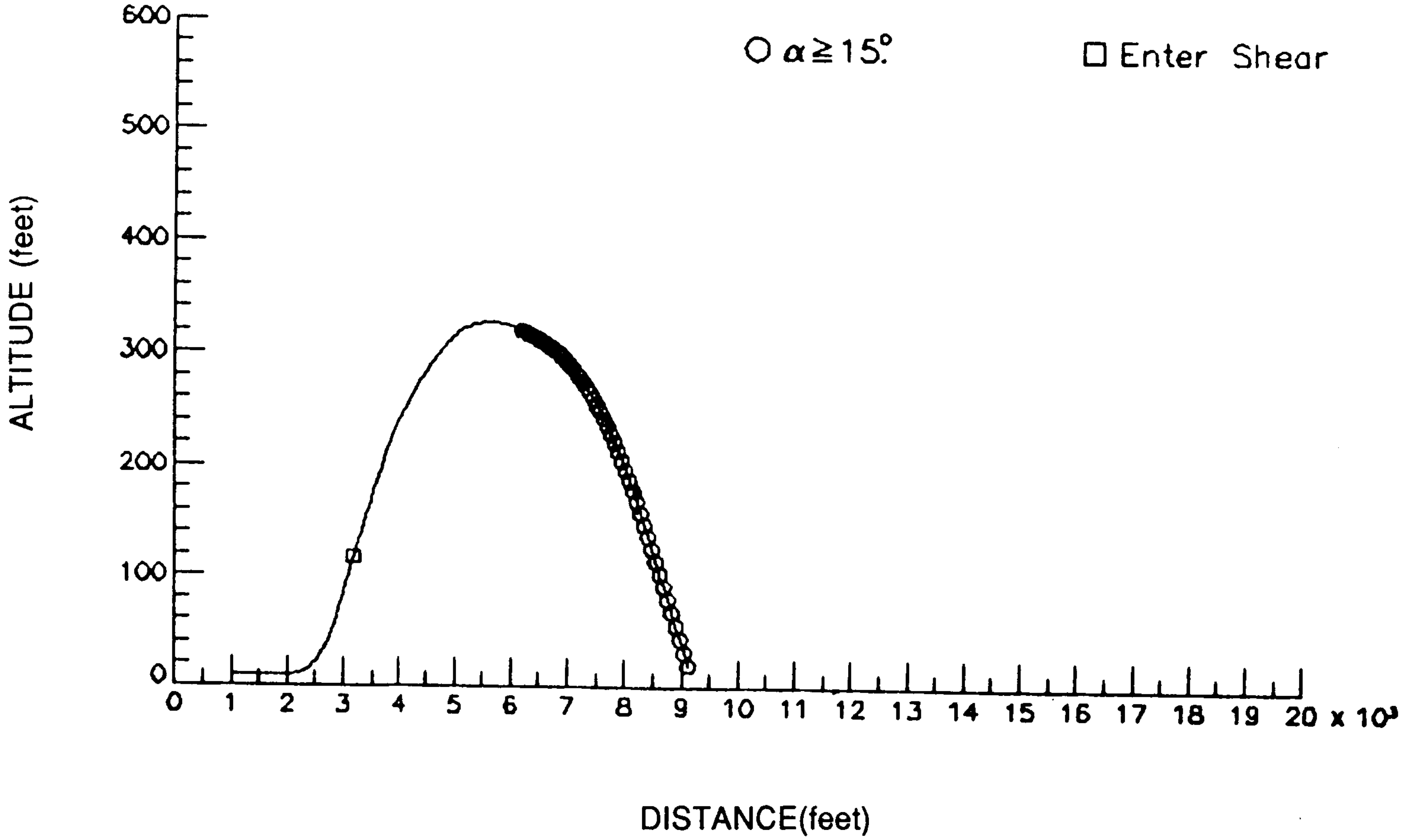
- 3 PILOTS
- 3 GUIDANCE STRATEGIES
- 7 SHEAR VARIATIONS
  - 3 LEVELS OF SHEAR A, ENTERED AT 100 FOOT ALTITUDE
  - 3 LEVELS OF SHEAR B, ENTERED AT 100 FOOT ALTITUDE
  - 1 LEVEL OF SHEAR A, ENTERED AT 20 FOOT ALTITUDE
- 21 CELLS, 4 REPETITIONS IN EACH CELL PER PILOT
- GUIDANCE OPTION CHANGED EVERY 6 RUNS, SHEAR WAS RANDOMLY VARIED

MEAN AND STANDARD DEVIATION OF RECOVERY ALTITUDE FOR GUIDANCE/SHEAR COMBINATIONS



EXAMPLE OF ACCELERATION GUIDANCE OPTION

SHEAR A100



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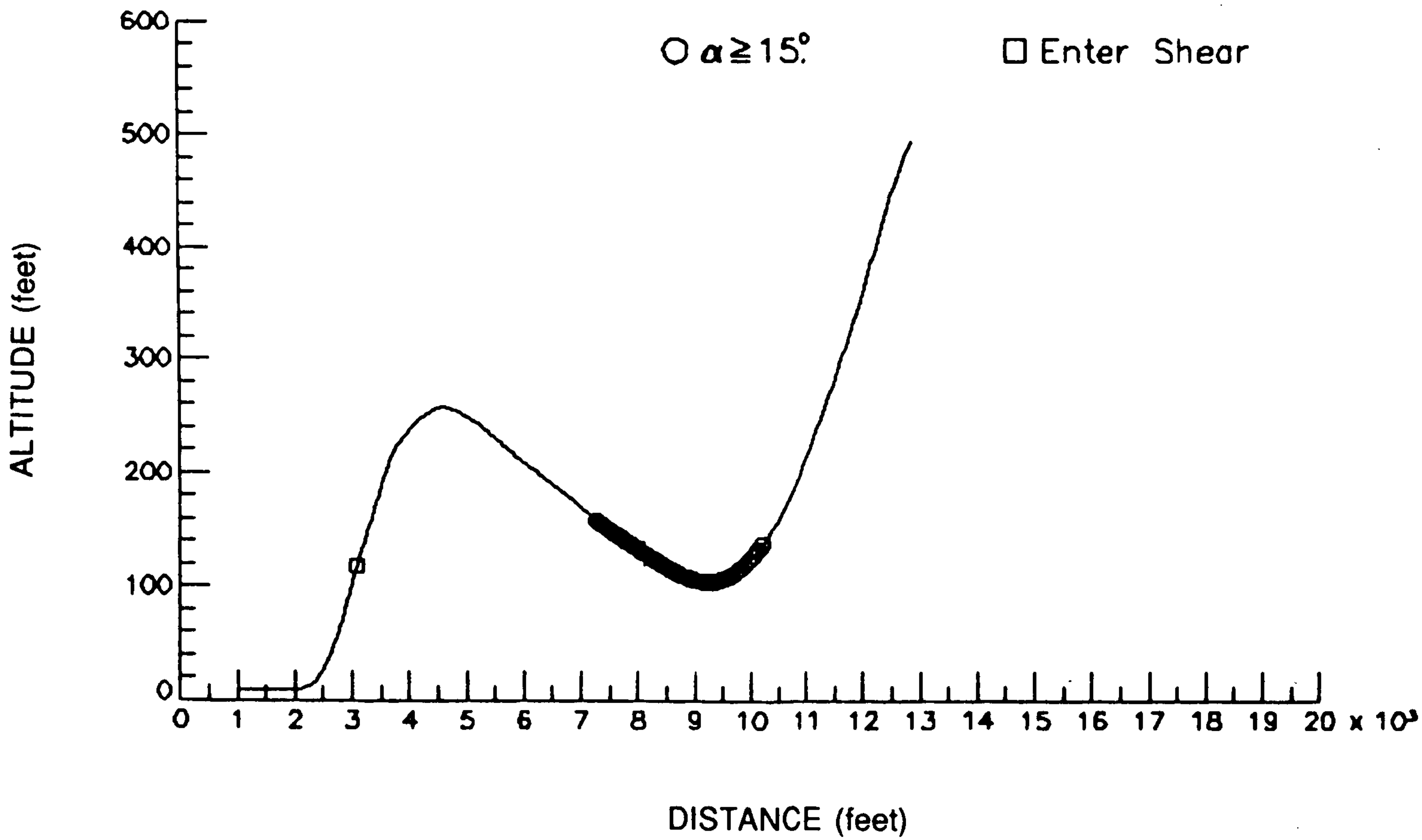
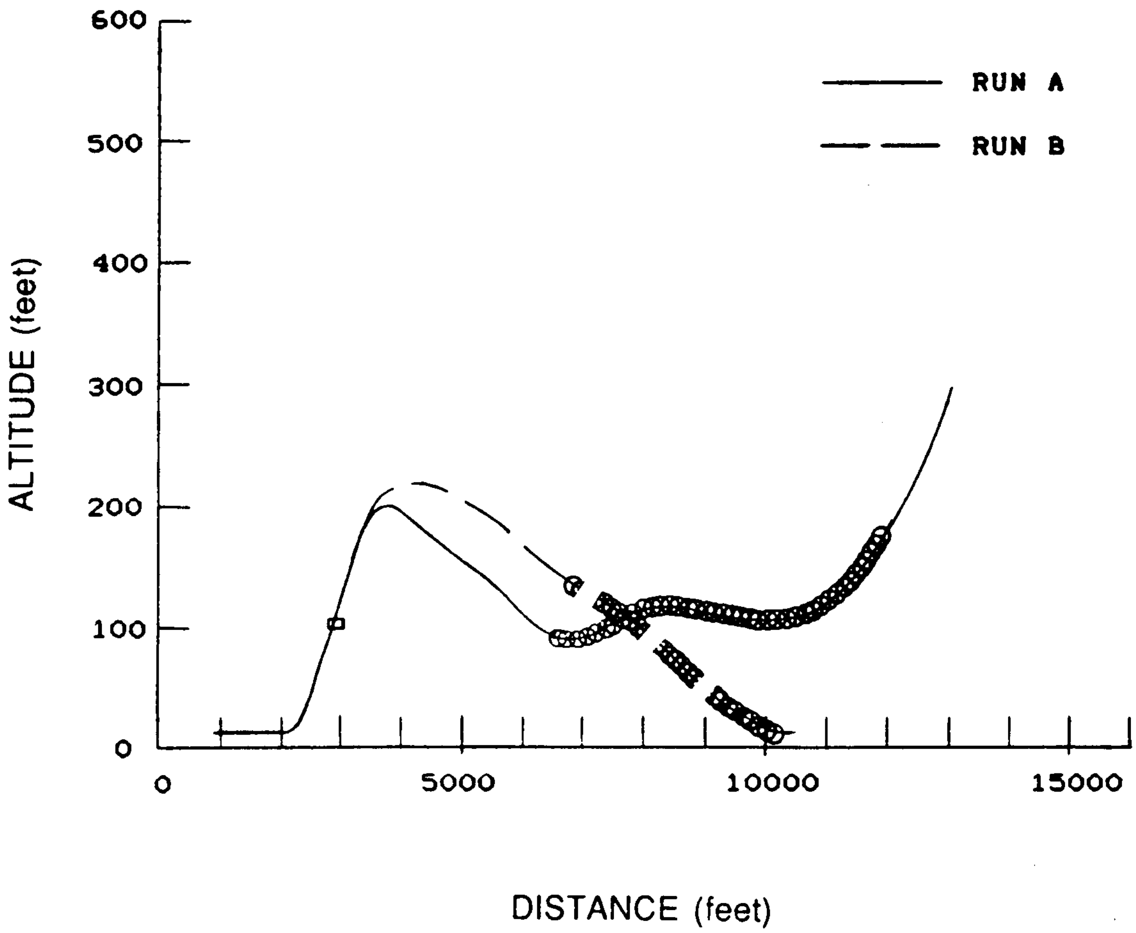
EXAMPLE OF FLIGHT PATH ANGLE GUIDANCE

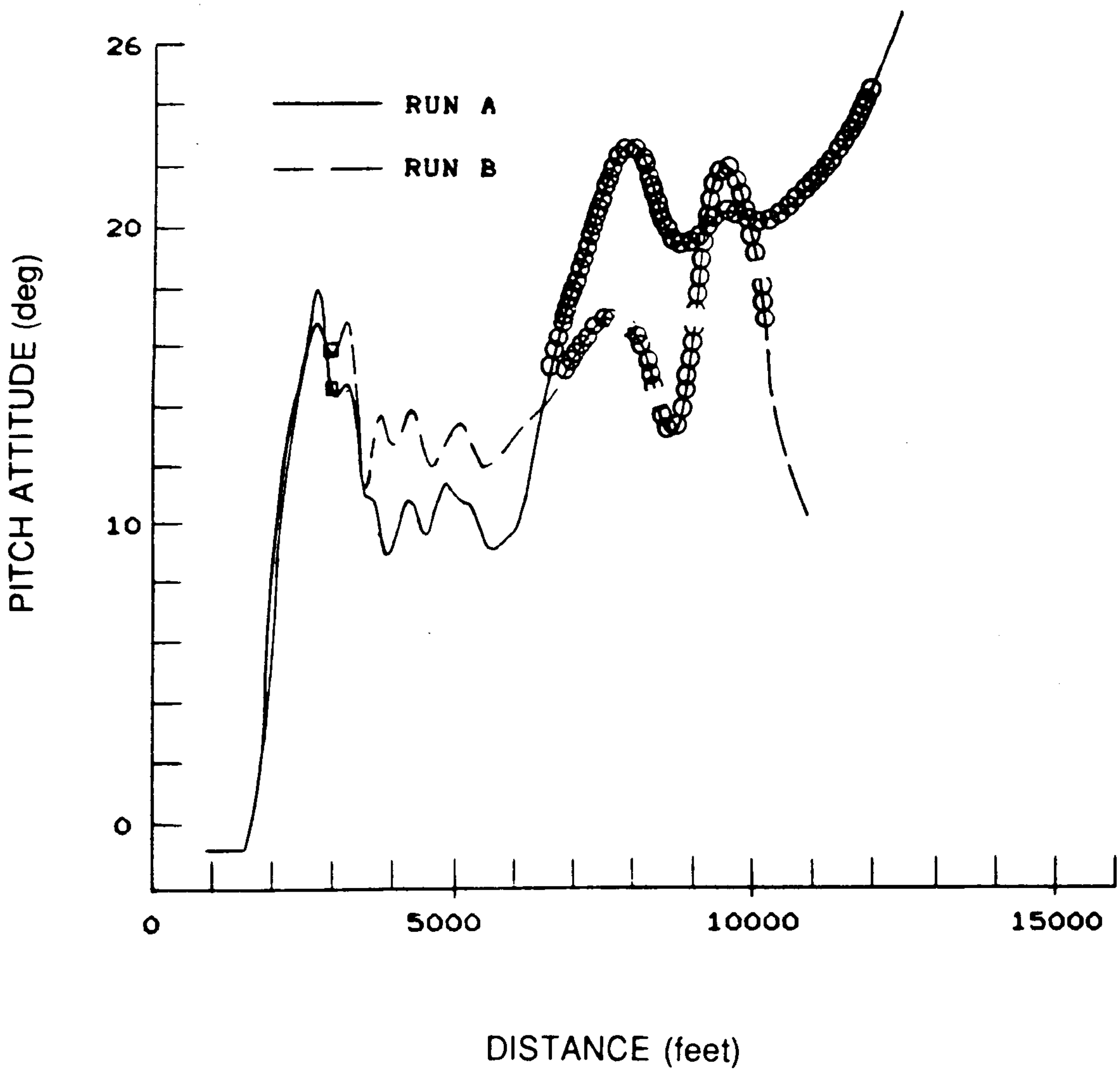
SHEAR A100



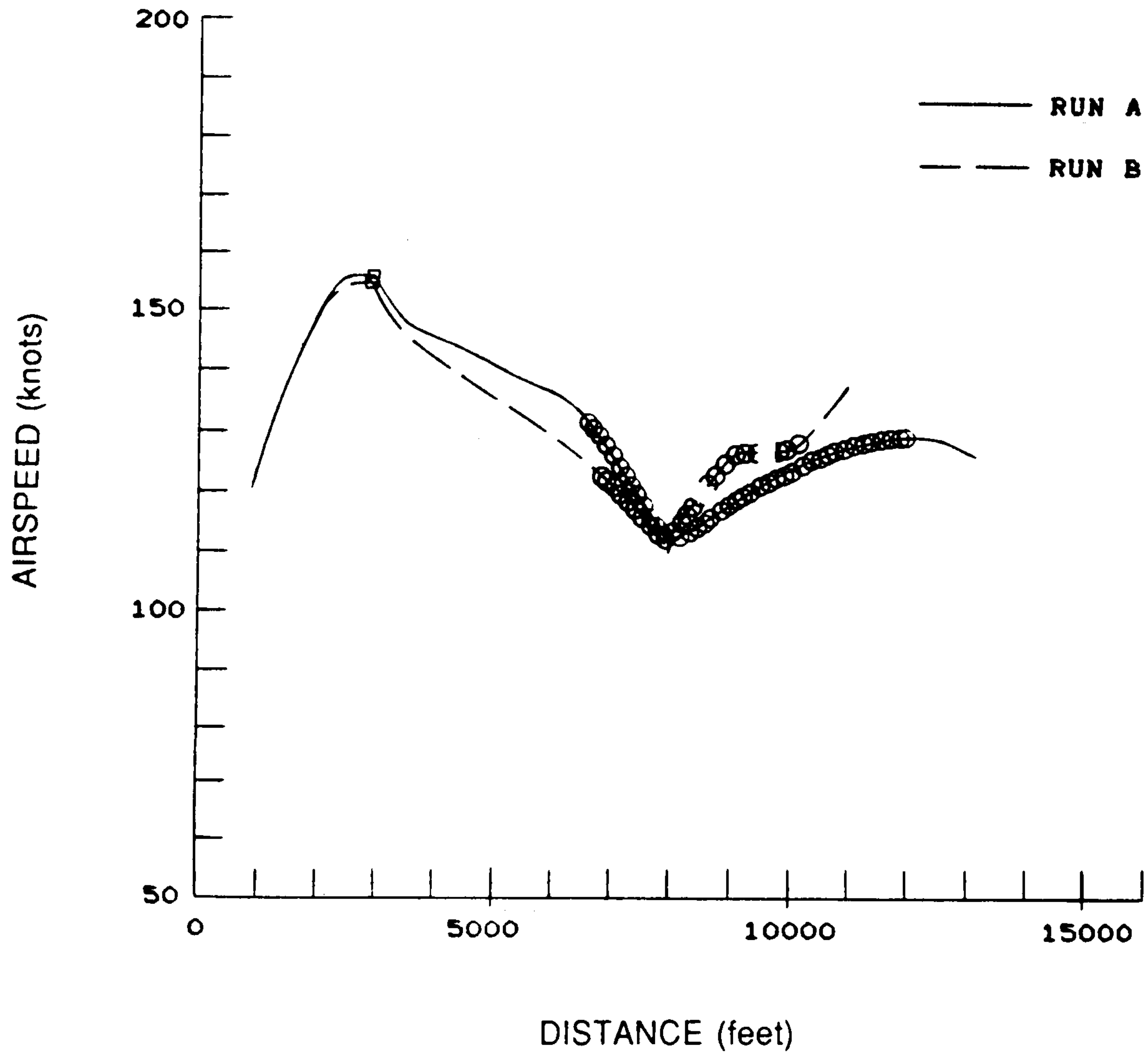
COMPARISON OF ALTITUDE PLOTS IN TWO RUNS WITH SHEAR A110 AND FLIGHT PATH ANGLE GUIDANCE



COMPARISON OF PITCH ATTITUDE IN TWO RUNS WITH SHEAR A110 AND FLIGHT PATH ANGLE GUIDANCE



COMPARISON OF AIRSPEED IN TWO RUNS WITH SHEAR A110 AND FLIGHT PATH ANGLE GUIDANCE

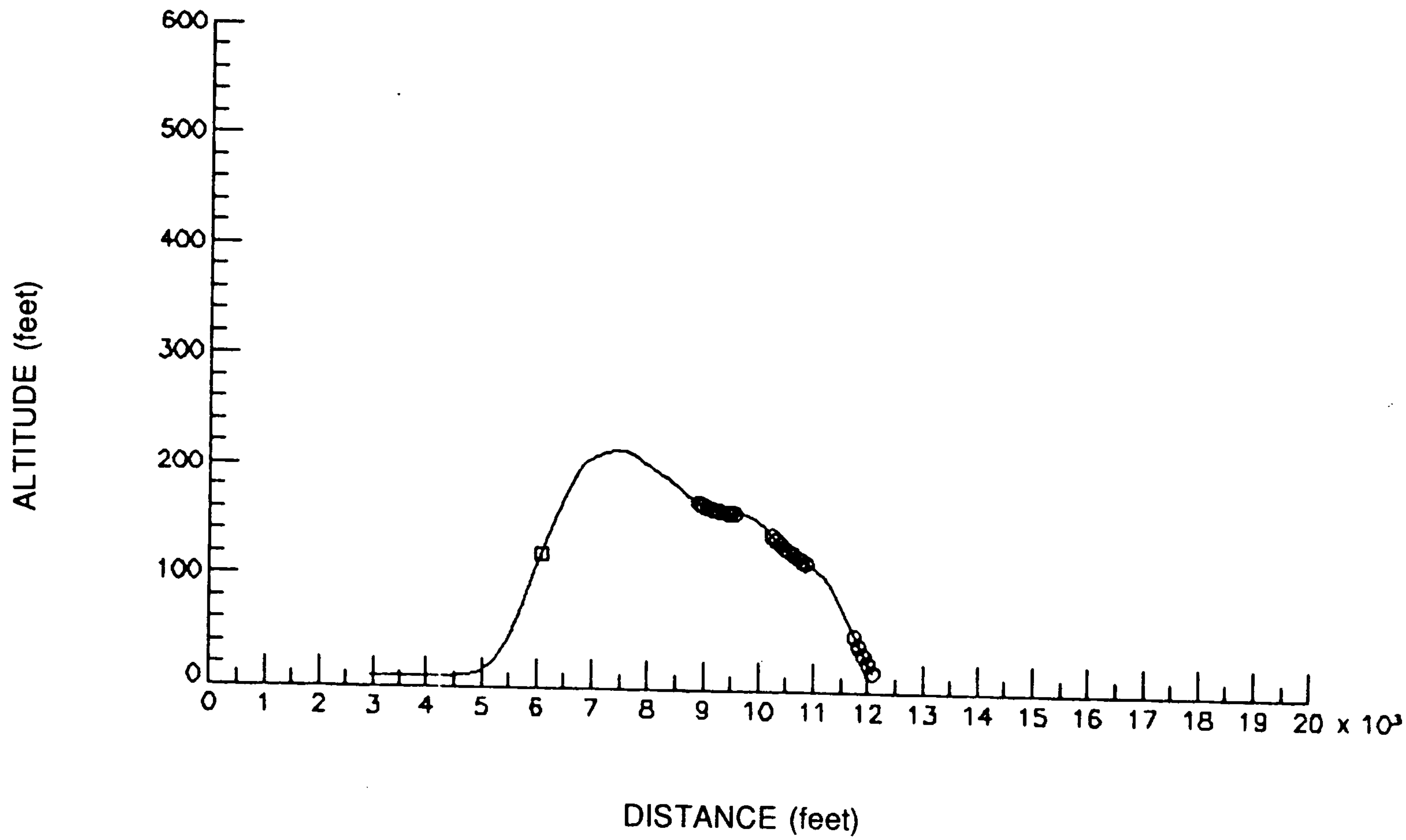


FACTORS INTRODUCED BY SHEAR B

- CONTROL PROBLEMS ASSOCIATED WITH VERTICAL WIND CHANGE
- AVERAGE RMS PITCH ERROR INCREASED FROM 2.45 DEG TO 3.87 DEG (SHEAR A TO B)
- LOWER ΔW_x VALUES CAN BE PENETRATED IN SHEAR B
- FREQUENCY OF W_h REVERSALS EXCITES PITCH OSCILLATION
- FINAL DOWNDRAFT OF SHEAR USUALLY CAUSED LARGE REDUCTION IN AOA AND FLIGHT PATH ANGLE
- POSSIBLE CHANGE IN OPTIMAL TRAJECTORY

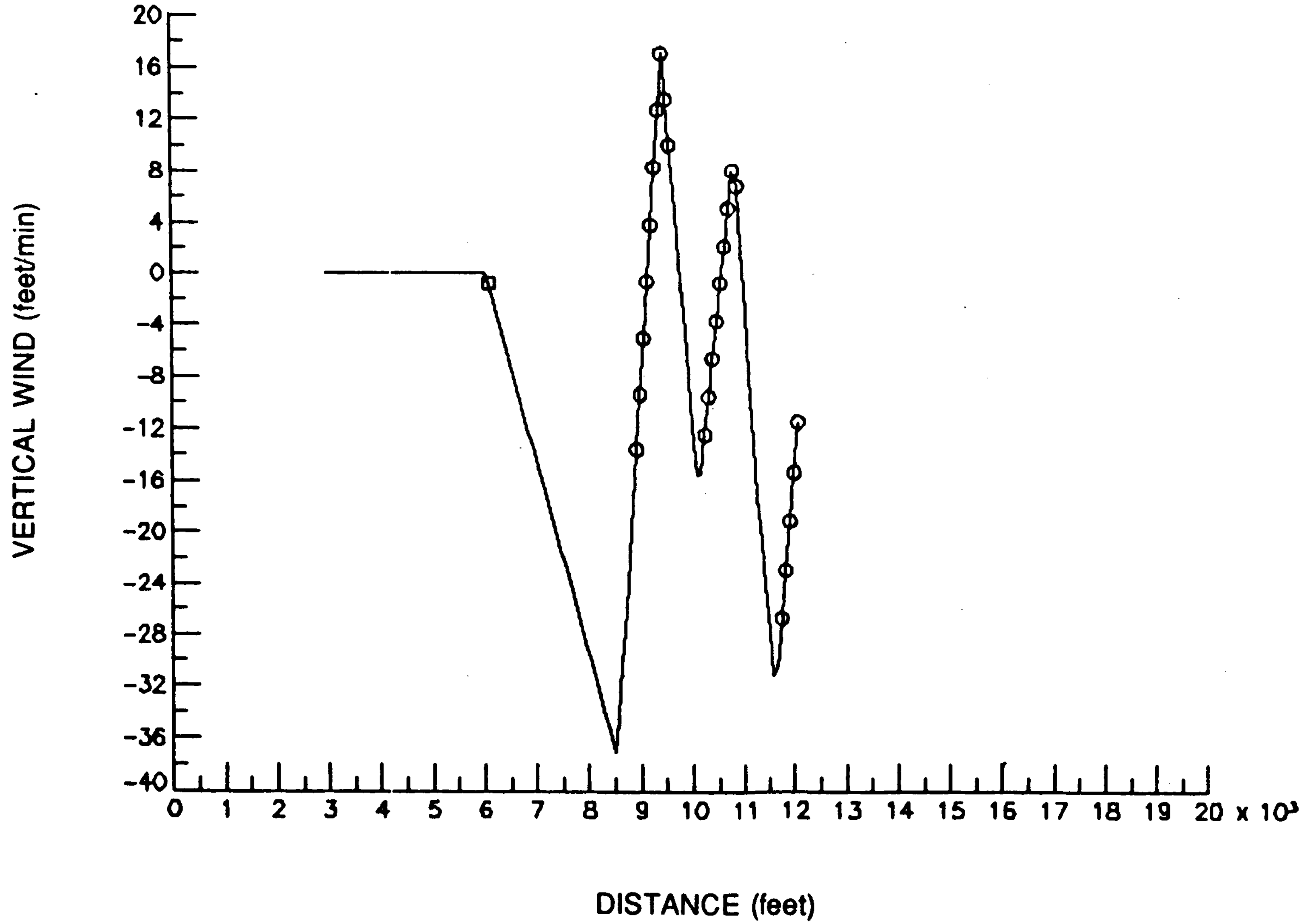
EXAMPLE OF FLIGHT THROUGH SHEAR B1.3

ALTITUDE

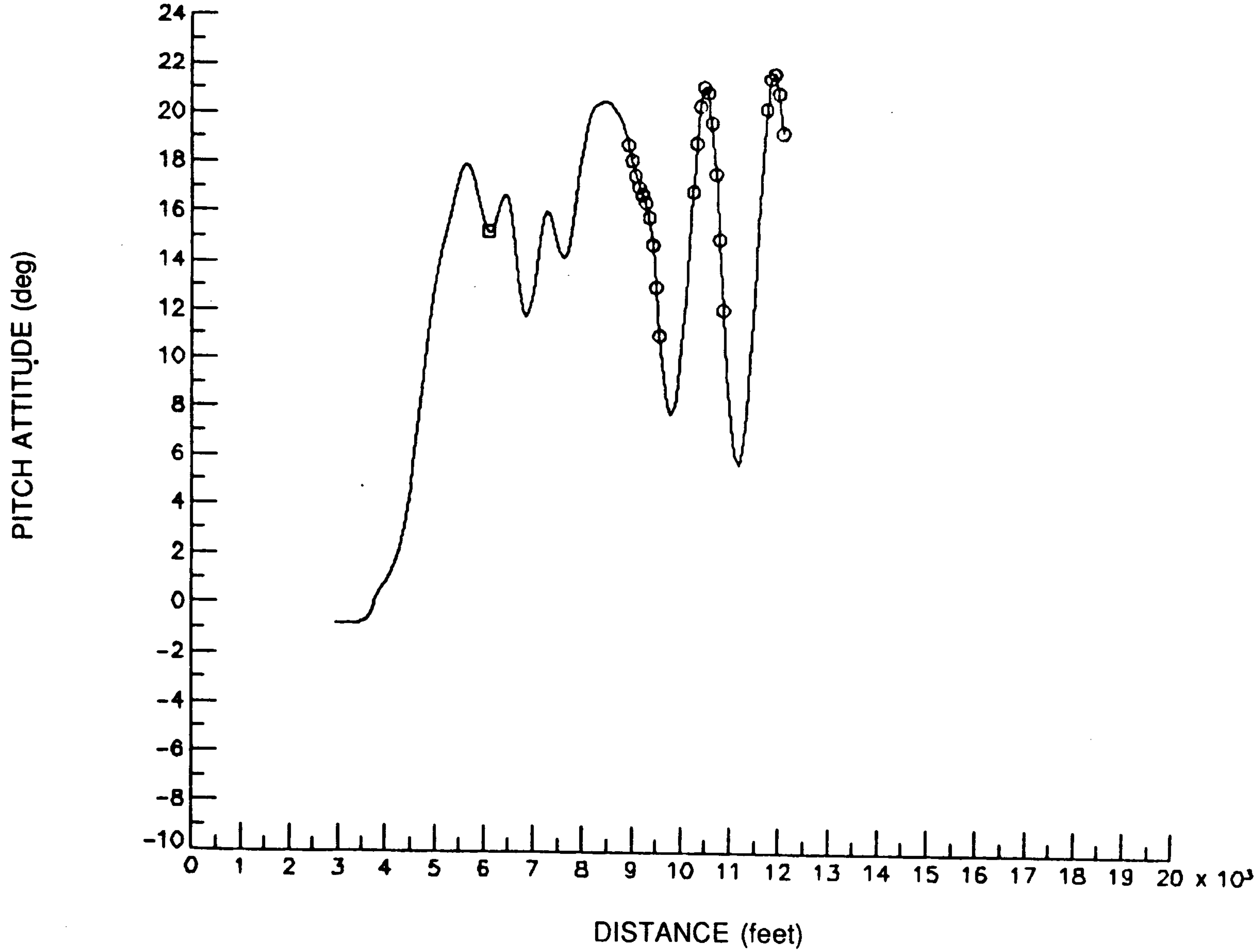


EXAMPLE OF FLIGHT THROUGH SHEAR B1.3

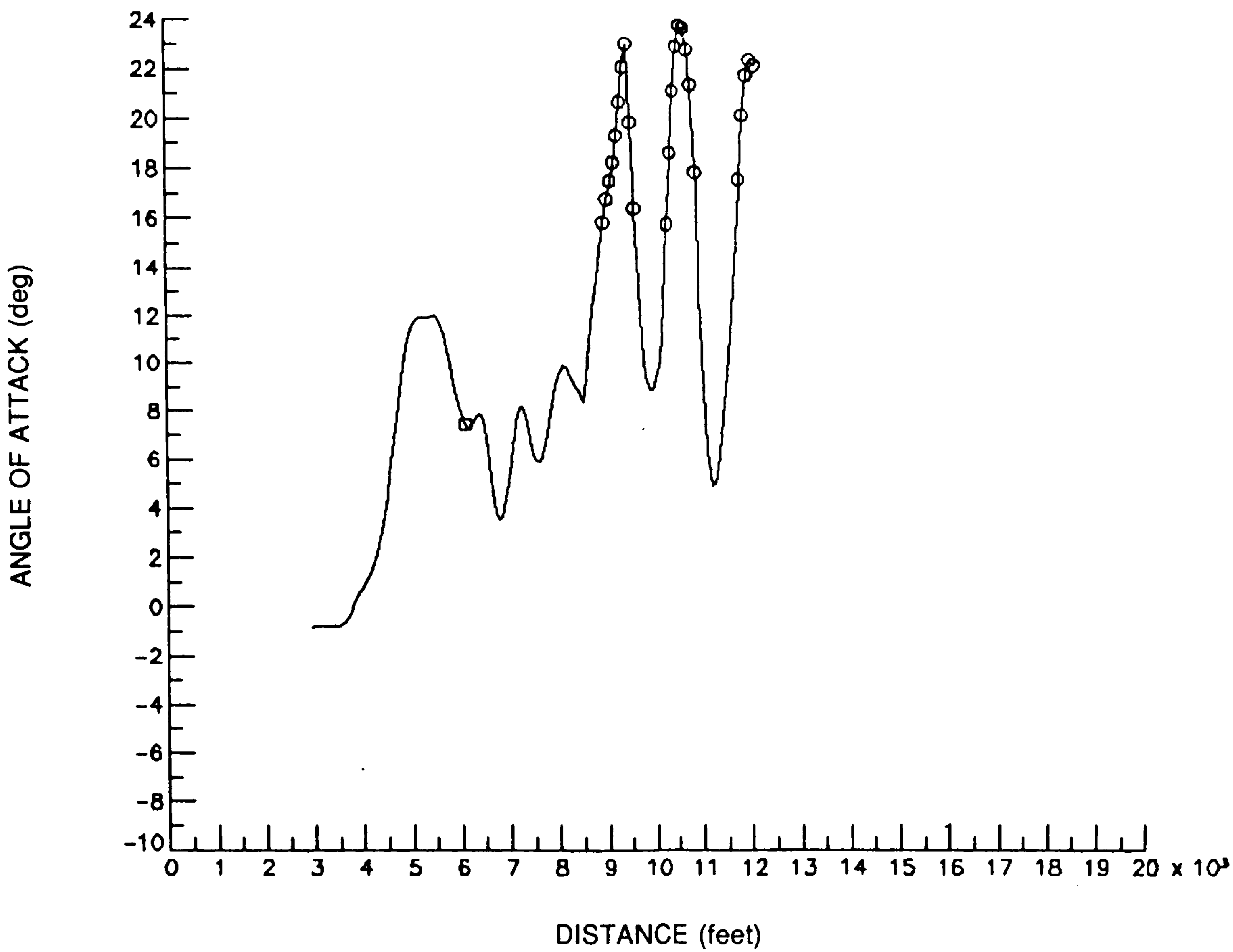
VERTICAL WIND



EXAMPLE OF FLIGHT THROUGH SHEAR B1.3
PITCH ATTITUDE

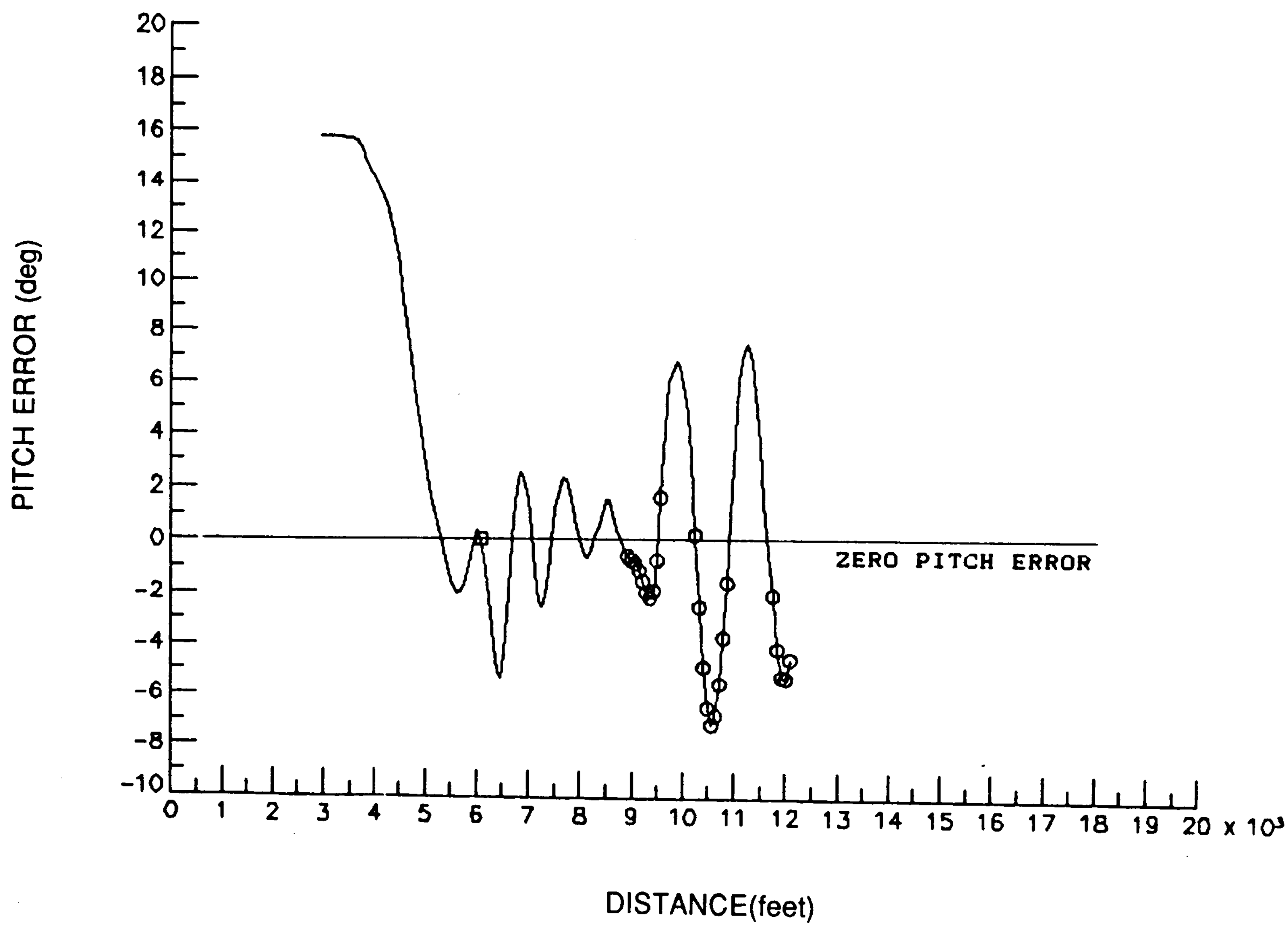


EXAMPLE OF FLIGHT THROUGH SHEAR B1.3
ANGLE OF ATTACK



EXAMPLE OF FLIGHT THROUGH SHEAR B1.3

PITCH ERROR



PILOT COMMENTS

- INITIALLY RELUCTANT TO REDUCE PITCH WHEN ENTERING SHEAR

- ACCELERATION GUIDANCE INITIALLY SEEMED MORE "NATURAL", LATER THE FLIGHT PATH ANGLE WAS PREFERRED

- ALERT AND AUTOMATIC FLIGHT DIRECTOR SWITCHING WAS ACCEPTABLE, LATERAL STEERING AND AOA GAGE WERE NOT USEFUL

- INTENTIONAL DESCENT BY "ALTITUDE-SMART" GUIDANCE WAS ACCEPTABLE

- PILOTS DEVIATED FROM GUIDANCE WHEN IT APPEARED TO BE LEADING THEM TO VERY LOW ALTITUDES

CONCLUSIONS

- MOST PROMISING GUIDANCE IS FLIGHT PATH ANGLE
- AIRSPEED DISTRIBUTION WAS IMPORTANT; BEST PERFORMANCE ACHIEVED BY INITIAL REDUCTION IN PITCH TO CONSERVE AIRSPEED, THEN TRADING OFF AIRSPEED AT END OF SHEAR
- ADDITIONAL FACTORS INTRODUCED BY VORTEX PENETRATION, MAY ALTER CHARACTERISTICS OF OPTIMAL RECOVERY
- AIRPLANE HAD LESS ΔW_x CAPABILITY IN VORTEX FLOW SHEAR MODEL THAN IN CLASSIC MICROBURST MODEL
- DIFFERENCE IN RECOVERY CAPABILITY BETWEEN GUIDANCE OPTIONS WAS SMALL COMPARED TO EXPERIMENTAL VARIATION BETWEEN RUNS
- ADDITIONAL RESEARCH NEEDED ON PRECISE HAZARD DEFINITION AND OPTIMAL TRAJECTORIES IN VORTEX ENCOUNTERS

SIMULATOR INVESTIGATION OF WIND SHEAR RECOVERY TECHNIQUES

An effort was conducted to develop techniques for flying "near optimal" trajectories, during inadvertent microburst encounters, when the microburst flow field ahead of the airplane is not known. Only the takeoff wind shear encounter case was considered. The research was done in two phases. In the first phase, a batch simulation, consisting of a simple point-mass performance model of a transport category airplane, was used to develop candidate wind shear escape strategies. A simple analytical wind shear model was used in the development. In the second phase, the strategies were evaluated in a real-time, piloted simulation. Both the simple analytical wind shear model and a second model, based on the vortex circulation encountered in the Dallas-Fort Worth accident, were used in the piloted simulation. The three guidance options tested were: pitch attitude hold, which commanded a constant recovery pitch; acceleration, which decelerated the airplane as a function of the instantaneous shear strength; and flight path angle, which produced a minimum altitude trajectory. All guidance options were presented to the pilot on an electromechanical flight director for manual tracking.

The results showed that the most promising guidance option is the flight path angle guidance, but that the experimental variation in recovery performance between runs was greater than the differences between guidance options. The distribution of airspeed loss across a wind shear was important. In a severe shear, a steady reduction in airspeed was less efficient than initially conserving kinetic energy, and trading it off near the end of the shear. The vortex circulation shear introduced additional factors into the recovery. There is evidence that the optimal recovery strategy may be slightly different in the vortex encounter than in a classic downburst model. The maximum horizontal wind change capability of the airplane was much less in the vortex shear model than in the simple analytical model. The pilots were initially reluctant to reduce pitch attitude close to the ground, upon entering the shear, but later observed and commented on the benefits of an initial pitch reduction.

KIOUMARS NAJMABADI (BOEING) - Earlier you showed the altitude profile of the three strategies when subjected to your analytical wind model where the horizontal wind is the same for all the strategies. But, any strategy which tries to climb will be penalized because your vertical wind is a function of altitude. Now did you compare, or do you have the same comparison for your B model?

DAVE HINTON (NASA LaRC) - Not directly. The reason is the B model is not implemented in the batch simulation. You're refering to this first chart, this one?

KIOUMARS NAJMABADI (BOEING) - That is right.

DAVE HINTON (NASA LaRC) - Okay. That particular simulation batch model does not have the vortex shear in there. The reason is, it is a very simple point airplane model and I can't hope to really duplicate all the effects. That is, the stability effects and control problems associated with shear B. Therefore, I didn't put that one in.

KIOUMARS NAJMABADI (BOEING) - The fact is that if you climb higher--I agree with you that the intensity of the down draft and all will increase--but at the same time I think that also the shear in the horizontal will decrease. If you look at the existing model.

DAVE HINTON (NASA LaRC) - I did run these same cases with no vertical wind present. The effect was not as large. But I saw that it was bad to climb there also. It was not just the effect of having the vertical wind stronger at altitude. Just giving up the airspeed is also bad.

PAUL CAMUS (Airbus Industrie) - I have two comments related to one of your viewgraphs. The comparison of altitude plots in two runs with flight path angle guidance, I notice that there is a large experimental variation in performance recovery between two runs with the same guidance. If you consider run A, a large pitch change demand is required to stop the altitude loss. And it seems to me that in the case of run B the pilot did not respond to the flight director commands.

DAVE HINTON (NASA LaRC) - He did not respond as quickly or as aggressively?

PAUL CAMUS (Airbus Industrie) - Yes.

DAVE HINTON (NASA LaRC) - That is correct. The pilots all temper the flight director somewhat with what they expect to do. And if there is a very large say--from 16 degrees to 10 degree pitch change--pilots may follow it very aggressively or not so aggressively.

PAUL CAMUS (Airbus Industrie) - Which means that it might be a problem of training, and the constant pitch might be the best anyhow.

DAVE HINTON (NASA LaRC) - There are a lot of issues that I didn't have time to get into. A lot of training issues were raised during the simulation study.

PAUL CAMUS (Airbus Industrie) - I have a second point. It seems that you accept a large flight path declination before you accept the deceleration of the plane. Therefore, during the initial phase you have to pitch down to track the air speed--Also a down draft at this moment.

DAVE HINTON (NASA LaRC) - In shear B that is precisely what happened. In shear B you'll notice we are climbing and then we change that over to a descent. At that same time the airplane has been hit with the first down draft, which was the strongest one, and because the down draft is helping the pilot to accomplish his objectives (in arresting the rate of climb) it wasn't even really noticed. The last down draft, which was not quite as strong, is usually the one that really hurt the aircraft.

PAUL CAMUS (Airbus Industrie) - Do you believe that a pilot would be prepared to accept a negative vertical speed in the initial phase when he has high kenetic energy?

DAVE HINTON (NASA LaRC) - Our pilots did seem to believe that it was acceptable to have smart guidance decending them towards the ground. The rate of decent in each of these cases was limited to about the same value you would see in the glide slope, about 600 feet per minute, so it was a very gentle decent. Again, it goes back to training, because initially the pilots did not like it. After flying about 30, 40 50 runs they began to see the advantages of doing that, and were more aggressive in pitching over. Obviously, you can not have every airline crew flying a hundred runs. So there is a definite training issue.

PAUL CAMUS (Airbus Industrie) - Thank you.

DICK BRAY (NASA Ames) - Dave, I want to sort of put this to you as a question. On your flight path control law going into shear B, the perfect following of that shear law would still require very rapid pitch of the aircraft at about that 6 second period wouldn't it?--Just to maintain? In other words that was a very demanding, very active pitch task produced by that law.

DAVE HINTON (NASA LaRC) - The pilots varied. They tried various gains, of course. Three pilots used for our research were test pilots here at NASA, not line pilots. They varied their gains and I did not see anything beyond the realm of what you could do in an operational environment. They did not feel it was beyond the realm. The guidance was presented to them in the form of--if I wanted them to go to 10 degrees of pitch--that is where I put the needle on the flight director. It is entirely up to the pilot to close the loop and get the airplane to that pitch attitude.

DICK BRAY (NASA Ames) - Okay. But just flying through that would, if he followed it perfectly, be a very, very active pitch.

DAVE HINTON (NASA LaRC) - Actually, the needle movement was limited to three degrees per second, so that is not beyond the realm. That was the limit on the pitch needle movement rate.

DICK BRAY (NASA Ames) - You wave a sort of nasty dynamic problem with that particular shear. I was wondering whether you ever considered flying to an air mass flight path instead of an inertial flight path.

DAVE HINTON (NASA LaRC) - We could do it either way, it would be a similar task.

DICK BRAY (NASA Ames) - Yeah, well there should be an awful lot less activity if you were deriving flight path, with angle of attack with the proper amount of lag on it. It should really stabilize the pitch command. You'll get an oscillation in the flight path but (paused)

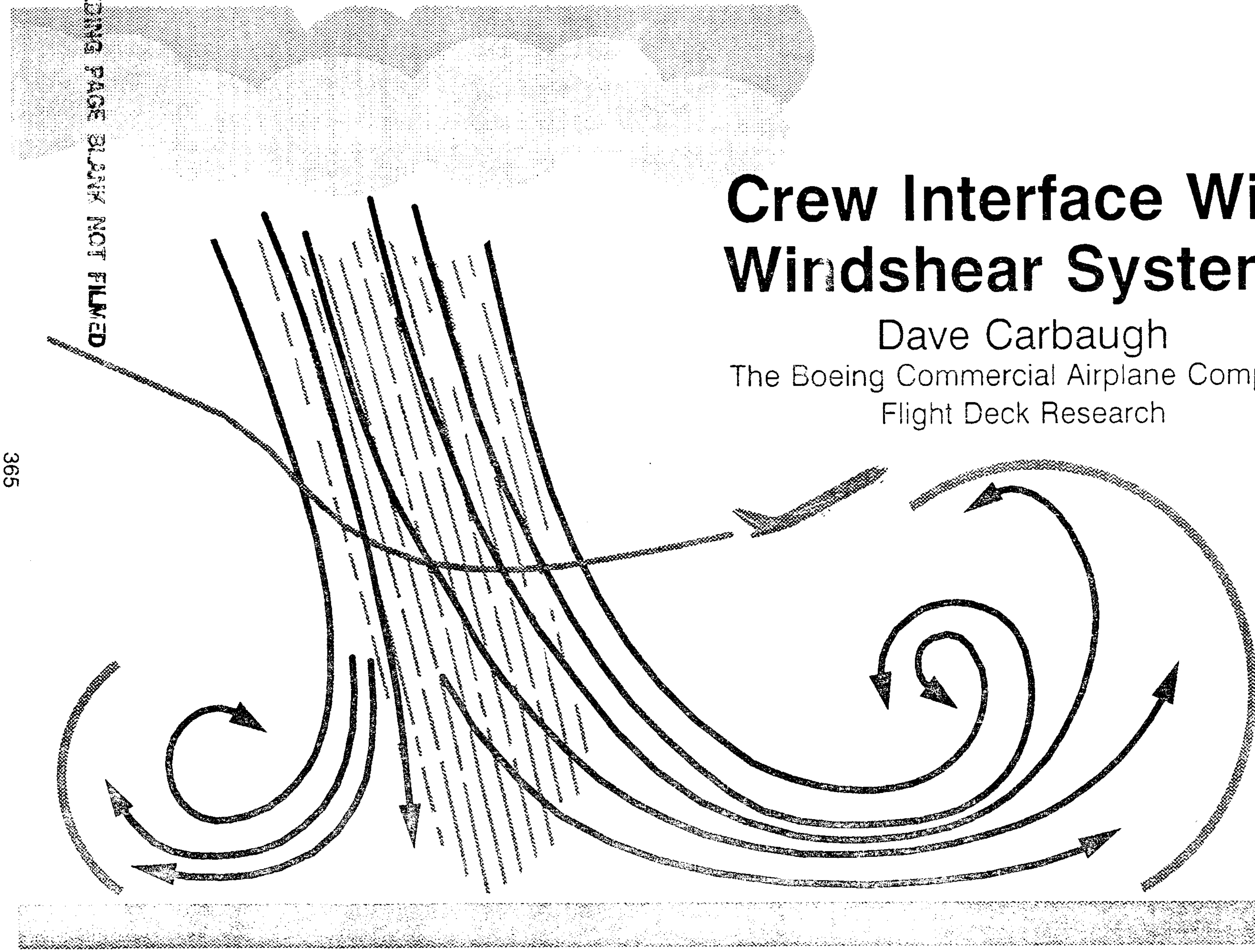
RALPH COKELEY (Lockheed) - Dave, I've got some concerns, and I don't question the validity of what you have shown us, but I want to point out to the rest of us that have not been in the piloting picture (and perhaps associated with some of the other studies), that at this moment we don't have a means of recognizing the shear instantaneously. And, for the next four years we are going to be doing it differently and training some 25000 pilots to do it differently. Up to that time our accident picture has been letting the nose drop too far and too late. So, the emphasis for the next four years is going to be not to let that happen inadvertently when you don't recognize it. So even assuming that this is valid, we've got some road-crossing, down the road, to change paths and change guidance strategies to make something like this work.

DAVE HINTON (NASA Ames) - That is true. That is very true.

N88-17631

Crew Interface With Windshear Systems

Dave Carbaugh
The Boeing Commercial Airplane Company
Flight Deck Research



Slide 1
Crew Interface with Windshear Systems

Dave Carbaugh is one of the investigators involved with Boeing Commercial Airplane Company's contract with NASA to conduct windshear studies. The Flight Deck Research Group is primarily a human factors group focusing on advanced commercial transport projects. Dave Carbaugh has a degree from the United States Air Force Academy in engineering mechanics and a masters in aviation management with a human factors emphasis from Arizona State University. In addition, he has over 5000 hours jet time and 2000 hours instructor time in various aircraft from the F-15 to 4-engine heavy jets.

Crew Interface With Windshear Systems

- NASA contract
- Flight deck research efforts
- Nuisance and alerts
- Research issues document

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Slide 2
Crew Interface with Windshear Systems

The topics to be presented at the First Combined Manufacturers' and Technology Airborne Wind Shear Review Meeting include:

1. A review is given of the areas within Boeing that are presently working on the NASA contract to conduct windshear studies.

2. A synopsis is given of the work in particular that Boeing Flight Deck Research is conducting.

3. A short review of nuisance and alerts is given in light of upcoming forward-look technology.

4. Finally, an explanation is given of the research issues document that was distributed to the meeting attendants.

NASA/FAA Airborne Windshear Program Elements

- Hazard characterization
  - Windshear physics/modeling
  - Heavy rain aerodynamics
  - Impact on flight characteristics
- Sensor technology
  - INSITU
  - Airborne Doppler radar/lidar
  - Sensor fusion
- Flight management systems
  - System performance requirements
  - Guidance/display concepts
  - Pilot factor/procedures

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Slide 3

NASA/FAA Airborne Windshear Program Elements

Boeing is working in three areas on the present NASA windshear contract. These areas include hazard characterization, sensor technology, and flight management systems. These areas mirror areas of the NASA/FAA Airborne windshear program. In the area of hazard characterization, Boeing is studying windshear physics modeling and improvements to windshear models presently used. Future work will look at heavy rain aerodynamics and the impact of microbursts on flight characteristics. In another area, Boeing will assist NASA in the evaluation of windshear advanced technology to include forward-look sensors and sensor fusion. The last area is in flight management systems which is handle by the Flight Deck Research group. We will look at system performance requirements, guidance and display concepts, and pilot factors and procedures.

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Slide 4
Goal

The long term goal of the Flight Deck Research groups' effort is to provide industry with a data base of crew information requirements, crew performance requirements, and display design guidelines for use in development and manufacturing of certifiable airborne windshear systems.

Goal

To provide industry with a data base of crew information requirements, crew performance requirements, and display design guidelines for use in development and manufacturing of certifiable airborne windshear systems.

B1259.07

Slide 5
Objectives

The way we are going to meet this goal is to accomplish these objectives:

1. We will establish the information requirements needed by flightcrews in order to avoid hazardous windshear conditions.

2. We will develop candidate formats of how the information needed by the crews will be displayed on flight deck.

3. We will develop operational and functional requirements for integration of reactive and forward-looking windshear sensor information as received by the flightcrew.

4. We will develop the procedures and criteria necessary to demonstrate that flightcrews are performing correctly to the windshear information displayed to them.

5. We will evaluate candidate crew interface requirements to determine recommended guidelines.

Objectives

- Establish information requirements needed by flightcrews to avoid hazardous windshear
- Develop candidate formats of how that information should be presented to the flightcrew
- Develop operational and functional requirements for integration of reactive and predictive sensor information
- Develop the procedures and criteria needed to demonstrate crew performance using windshear systems
- Evaluate candidate crew interface concepts

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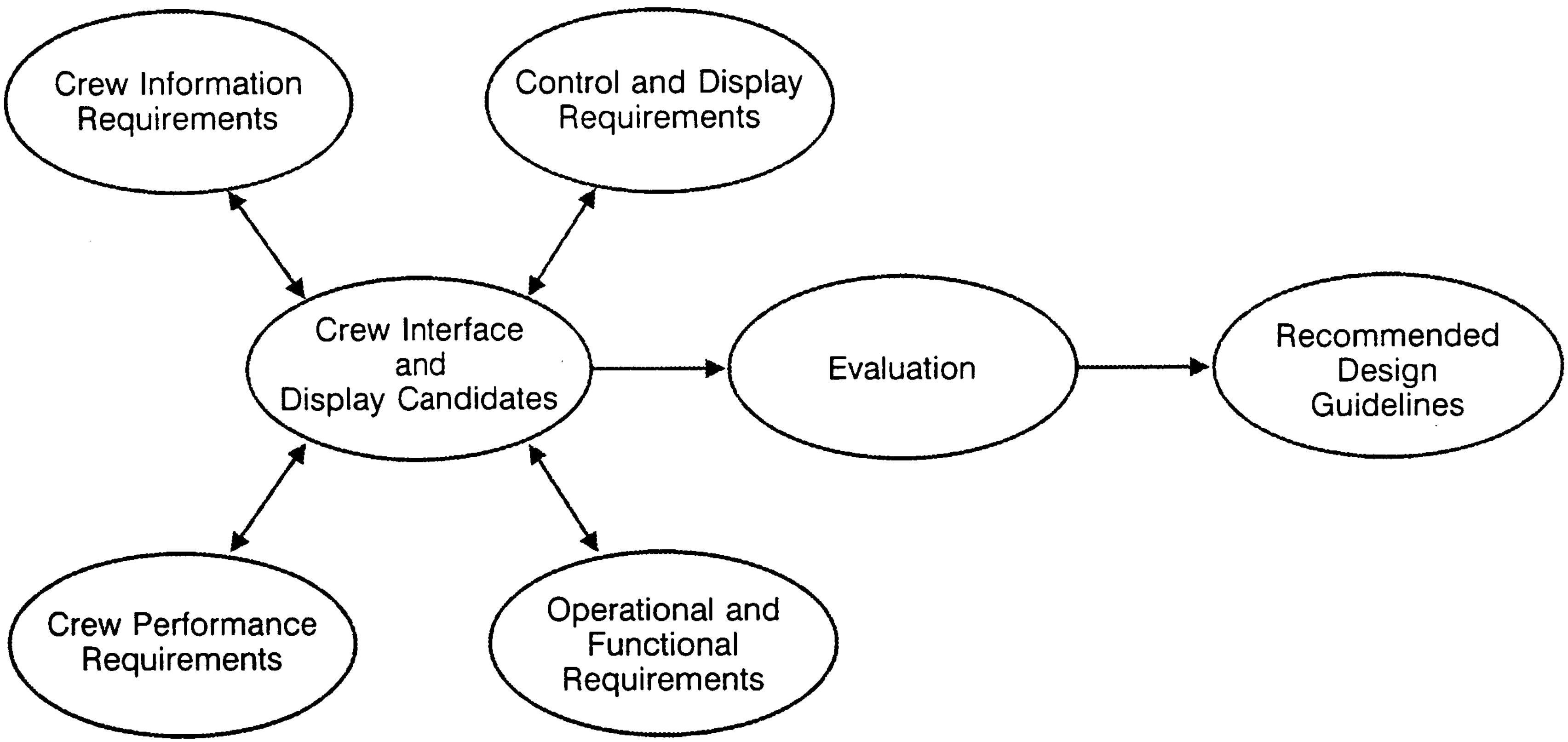
Slide 6

Crew Interface with Windshear Systems Program Approach

The crew interface with windshear systems program approach will be to take all four areas of interest(crew information requirements, crew performance requirements, operational and functional requirements, and control and display requirements) and develop candidate crew interfaces and displays. These candidates will then be evaluated in the laboratory, simulator, and in aircraft. The results of these evaluations will be used to recommend design guidelines for advanced windshear detection systems.

Crew Interface With Windshear Systems Program Approach



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Slide 7
Tasking of Present Contract - May 1988

This slide represents the tasking of Boeing Flight Deck Research efforts to complete the present NASA contract. The highlights of this tasking are the program plan, establishment of preliminary information requirements, and categorization of windshear alerts.

Tasking of Present Contract - May 1988

- Develop plan for defining crew interface with integrated windshear alerting system
  - First-year plan
  - Follow-on plan
- Perform a study to analyze pilot factor data
  - Survey
  - Review literature
  - Define requirements for additional data
  - Establish preliminary information requirements
  - Categorize windshear alerts
  - Review associated standards

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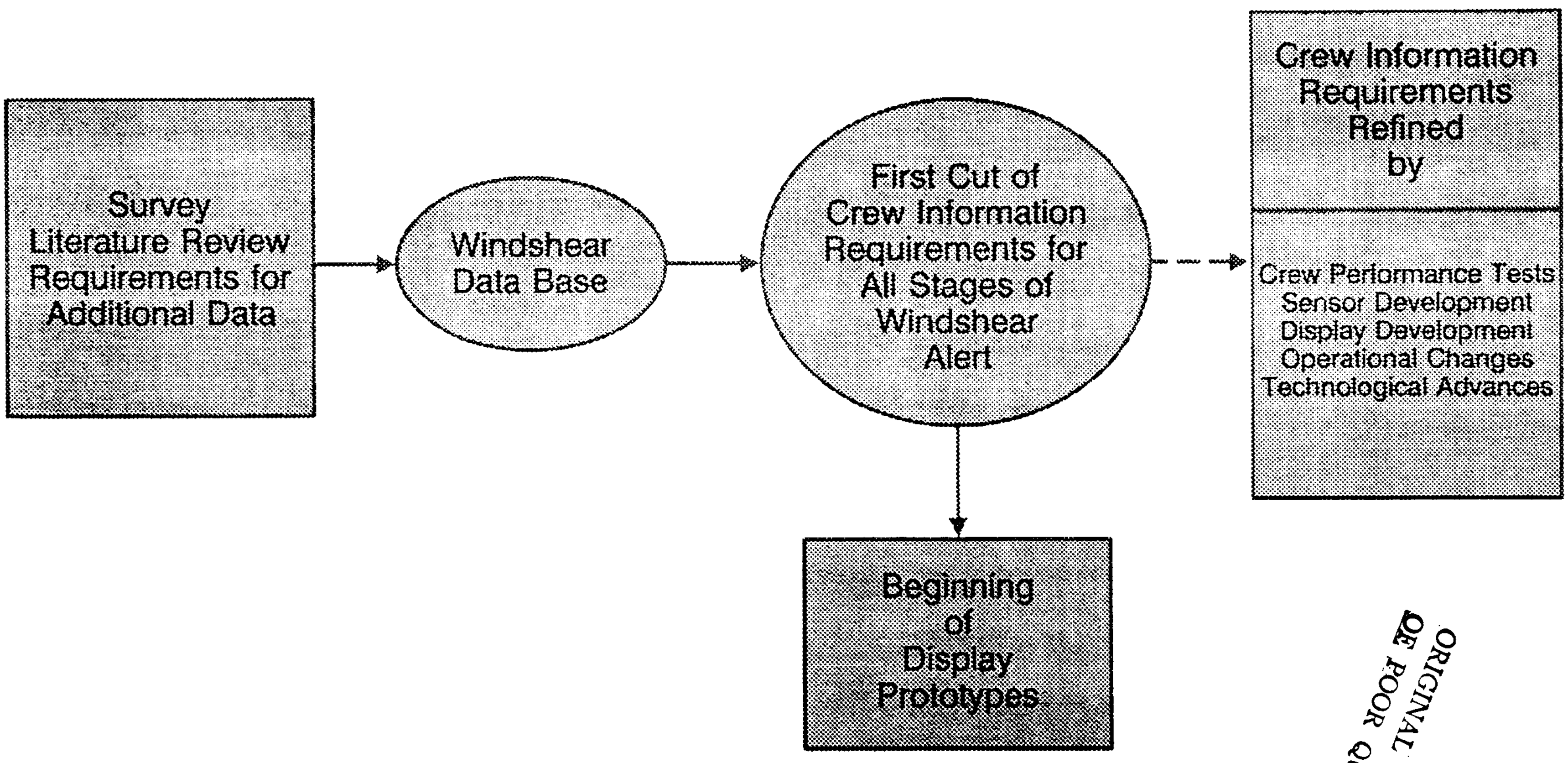
Slide 8
Establish Preliminary Crew Information Requirements

This slide represents how our group intends to determine the crew information requirements. The use of a survey of crew information issues will help determine critical areas of understanding and required research. A literature review will be conducted and the requirements for additional data will be understood. The survey, literature review, and requirements for additional data will help establish a windshear data base from which a first cut of crew information requirements can be made. Display development can begin once this first cut of information requirements is performed. The crew information requirements will be refined by crew performance testing, sensor development, display development, operational changes, and technological advances.

Establish Preliminary Crew Information Requirements



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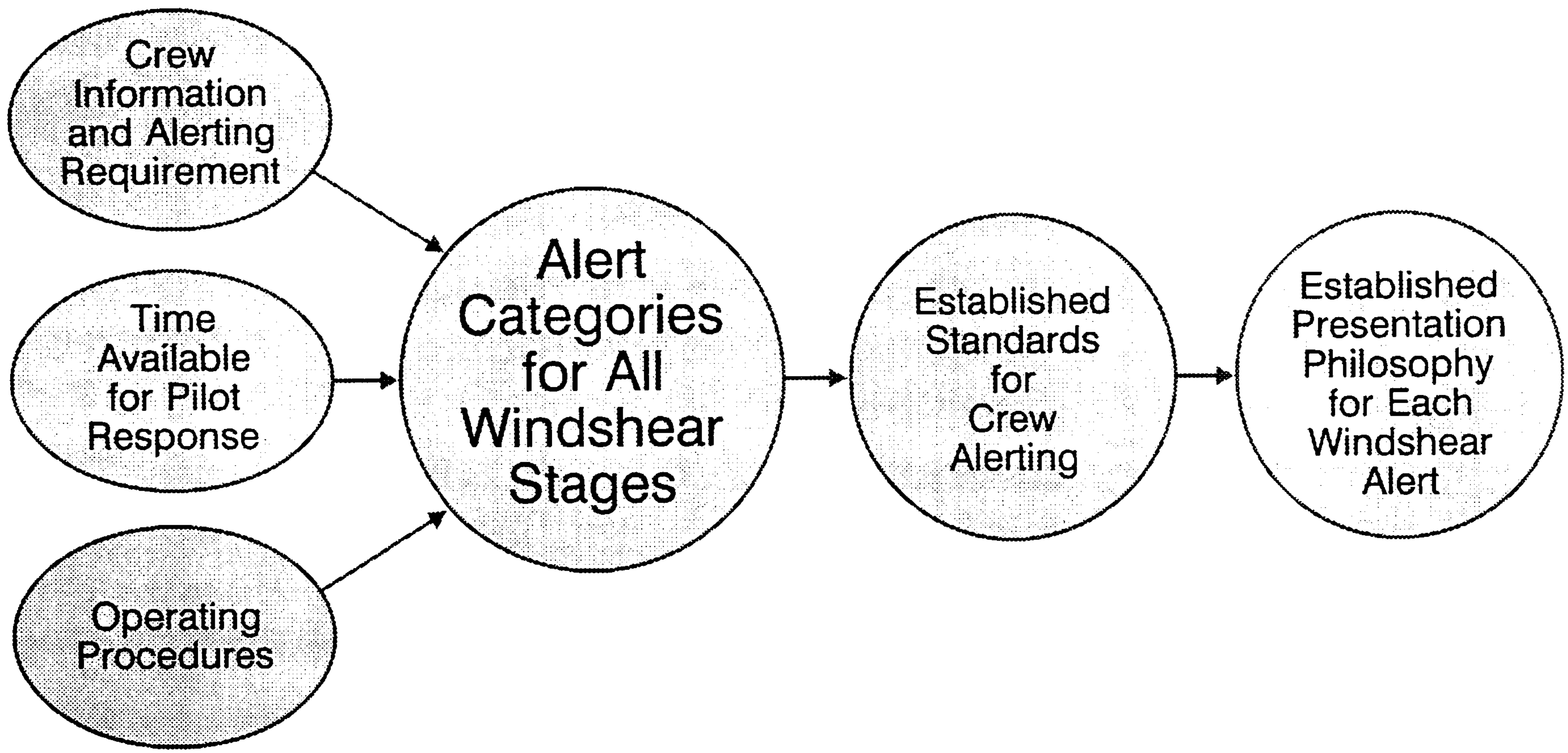
Slide 9
Categories of Windshear Alerts

This slide represents our groups method for determining the categorization of windshear alerts. Alert categories for all windshear stages will be determined by understanding crew information and alerting requirements, the time available for the pilot to respond, and crew operational procedures. Once alert categories are established then we will use the established standards for crew alerting and determine the established presentation philosophy for each of the windshear alerts. For example, if a windshear were detected at a range of 5 minutes then perhaps an alert category of advisory would be established. The established standards for crew alerting would then be used and the display would probably just be in a message form in the malfunction/message display area.

Categories of Windshear Alerts



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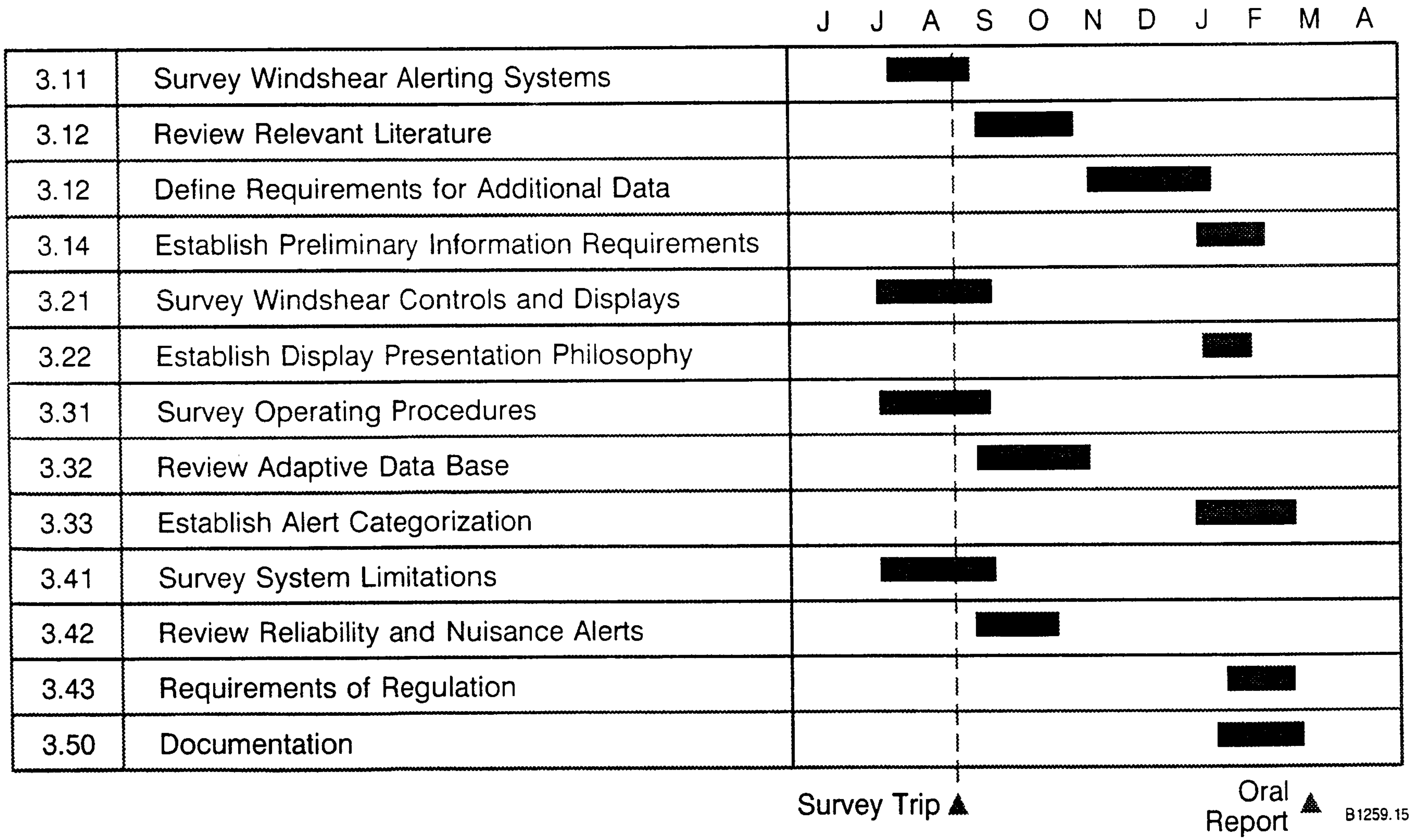
Slide 10
First-Year Program Schedule

This slide represents the timing of the events required to complete the first year of Flight Deck Research groups' present windshear contract with NASA. Highlights of this schedule include the preliminary information requirements in January of 1988 and the alert categorization in February of 1988.

First-Year Program Schedule



Slide 11
A Look at Alerting

It is very important to look at alerting and nuisance when considering forward-look technology windshear systems. These systems must be design with the special requirements of the crew, the decision making force, in mind. These systems may be executive or advisory in nature. Advisory systems are those systems that provide the crew with guidance which they follow only when, in the crew's judgment, they have some other reason to believe that they should carry out the indicated action. Executive systems are those systems that provide the crew with guidance that is mandatory unless, in the crew's judgment, they have reason to believe that they shouldn't carry out the indicated action.

A Look at Alerting

Advisory systems

Systems that provide the crew with guidance which they follow only when, in the crew's judgment, they have some other reason to believe that they should carry out the indicated action

Executive systems

Systems that provide the crew with guidance that is mandatory unless, in the crew's judgment they have reason to believe that they shouldn't carry out the indicated action.

Slide 12
Types of Alerts Crews Receive

There are four basic types of alerts crews can receive. Time critical alerts are those which the time to respond is extremely limited and the response to the alert is the most important action the crew can take at that specific time. A warning alert is an emergency operational or aircraft system condition that requires <u>immediate</u> corrective or compensatory <u>action</u> by the crew. A caution alert is an abnormal operational or aircraft system condition that requires <u>immediate</u> crew awareness and <u>subsequent</u> corrective or compensatory crew action. Lastly, an advisory alert is an operational or aircraft system condition that <u>requires</u> crew awareness and <u>may</u> require crew action.

Types of Alerts Crews Receive

- Time critical warning
- Warning alert
- Caution alert
- Advisory alert

B1259.33

Slide 13
Looking at the "Nuisance" Problem

There are three types of alerts that generally fall under the "nuisance" problem category.

1. Missed Alerts - Alerts not given but threat to aircraft exists

Example - The aircraft enters a dangerous microburst with no warning. The missed alert rate should obviously be held very low.

2. False Alerts - An alert caused by false indication or system malfunction given when no threat exists

Example - The aircraft receives a windshear warning on a calm day when clearly no windshear exists. The false alert rate should be quite low so as to not destroy crew confidence.

3. Nuisance alert - Wind change or microburst is actually detected but does not develop or represent a threat

Example - The windshear alert is given for a microburst 3 miles removed from the intended flight path or for a microburst that exists 2 miles past the departure end of the runway when an aircraft is crossing the threshold for landing. This nuisance rate should be at a rate acceptable to the crews and is probably at a "to be determined" rate.

Looking at the "Nuisance" Problem

- Missed alert

  Alert not given but threat to aircraft exists

- False alert

  An alert caused by false indication or system malfunction given when no threat exists

- Nuisance alert

  Wind change or microburst actually detected but does not develop or represent a threat

B1259.31

Slide 14
Windshear Issues Document

All participants at the First Combined Manufacturers' and Technology Airborne Wind Shear Review Meeting should have received a windshear issues document. The purpose of this survey document is to help determine the priority of research on crew information issues involving advanced windshear detection equipment. The responses to this survey will help identify crew information issues and those issues of a critical nature that need to researched in the near term. The future use of this document will be the incorporation of the issues into an R-bases software data base for easy access by industry and government. This readily accessed data base will allow the information exchange necessary to help industry develop windshear systems with the crew's needs understood.

Windshear Issues Document

- Purpose
  - Priority of research
  - Identify issues
- Future
  - Provide ready-access
  - Information exchange

B1259.34

Slide 15
Issues Document Limitations

The survey of crew information issues was developed with several limitations imposed. These limitations include: forward-look orientation, no involvement in FAA regulatory changes, not sensor specific, reactive devices are incorporated as part of an overall advanced windshear system, involvement to be centered around the man-machine interface, and the scope limited to airborne systems.

Issues Document Limitations

- Forward-look orientated
- No involvement in FAA regulatory changes
- Not sensor specific
- Reactive devices are incorporated as part of system
- Involve with man-machine interface
- Limit ground-based involvement

B1259.35

Slide 16
Conclusion

This presentation stated how Boeing is involved in a NASA contract to conduct windshear studies, in particular the Flight Deck Research Groups' effort. A review was given of the importance of understanding nuisance and alerting when related to the development of forward-look technology. Finally, the crew information issues document was presented and the importance of identifying key issues stressed.

- Boeing invlovement
- Nuisance and alerts
- Research issues document

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P 411

A Survey to Help Determine the Priority of Research on Crew Information Issues Involving Advanced Windshear Detection Equipment

I. Introduction:

This survey is part of a program to determine the focus and priority of research efforts involving advanced windshear detection. The flight crew has many information sources available to cope with dangerous windshear situations. These information sources are expanding with the probability that look-ahead sensors may be added to present windshear detection capabilities. Understanding what information the crew needs becomes increasingly important as flight crews seek, with the aid of advanced sensors, to avoid entering hazardous windshear conditions. The introduction of look-ahead sensors as a natural next step in windshear detection reveals crew information issues that need to be resolved. We must determine how much data and information the crew needs and the integrated presentation concepts, which consider pilot workload, that should be adopted. The resolution of these issues will assist in the development and implementation of improved windshear detection equipment.

II. Purpose:

This survey document is a compilation of crew information issues to obtain opinions relating to hazardous windshear avoidance. The results of this survey will be used to determine the priority and focus of future research involving the crew interface with advanced windshear detection systems. It is intended that this document eventually will be a living report of the crew information issues involving advanced windshear detection systems. It will be updated to reflect research activities as they effect the issues.

III. Objectives:

The objectives of this issues document are to help mature future windshear systems by:

* Documenting identified crew information issues associated with advanced windshear detection systems

* To provide requirements for research activities to address the issues raised

* To sample opinions and provide a sampling document for identifying issues of human engineering concern dealing with windshear detection systems

IV. Scope:

The scope of this survey document is limited to advanced windshear detection system crew interface and information issues, problems, and requirements for implementation.

Identified issues will be addressed by NASA, FAA, and Boeing Flight Deck Research for possible research funding and issue resolution. Please feel free to add any additional issues you feel are important and the appropriate rating that issue should receive. Return the completed crew information issues survey to:

Dave Carbaugh
Flight Deck Research
Boeing Commercial Airplane Company
P.O. Box 3707, MS 66-25
Seattle, Washington 98124-2207
Phone: 206-237-7286

Please return your survey by 1 December 1987 and indicate if you would like to receive a copy of the results.

Your time and thoughtful responses to this survey will be greatly appreciated.

Survey Definitions and Limitations

Definition of issue ratings:

On the next page starts a list of crew information issues involving advanced windshear detection systems. This list is by no means complete. Please rate each of the issues into the following four categories.

CRITICAL

* Issue resolution required prior to industry-wide implementation of look-ahead advanced windshear detection systems

SERIOUS

* Should be resolved prior to industry-wide implementation of look-ahead advanced windshear detection systems

DESIRABLE

* A resolution of an issue could be expected to improve the physical and/or operational man-machine interface

No Opinion

* Issue not applicable or unclear

The limitations of this survey are:

* The focus of this survey is on the incorporation of forward-look technology on airborne platforms (although ground information will form a factor in the crew decision making process, our focus is on airborne systems)

* Issues should be involved with the man-machine interface (from the instrument panel to the pilots and back)

* Issues should not directly require FAA procedural changes

* Issues should not be sensor specific

* Present day reactive sensors are considered to be non throw-away technology that would be incorporated as part of any advanced windshear system

Crew Information Issue List

Name________________

Organization____________________

Ratings- C=Critical
S=Serious
D=Desirable
N=No Opinion

In the area of displays.....

Ratings and Comments

1. What is the benefit to crews to have look-ahead capable windshear systems identify non-critical shears (those shears with thresholds below present alerting levels)?

2. Would crews benefit from actual or derived look-ahead wind velocities being actually displayed to the flight crew?

3. How far in front of the aircraft does the crew need to receive windshear information to make avoidance decisions?

4. How far displaced from the centerline of the flight path do pilots need to see windshear information for safe takeoff and approach?

5. At what points, given a look-ahead sensor detecting hazardous windshear during an approach or takeoff, would crews benefit from guidance commands for conducting escape maneuvers?

6. What would be the benefits to crews to have forward-look windshear information displayed in a three-dimensional manner?

7. Can windshear look-ahead warnings and information be integrated into present day electronic and conventional flight deck displays?

8. What would be the benefits to crews to have microburst movement information displayed using look-ahead windshear systems?

Name__________________

Organization______________________

Ratings and Comments

9. What would be the benefits to crews to have look-ahead raw wind information(as compared to relative wind/energy information) displayed by forward-look devices?

In the area of controls......

10. What benefits can be gained by crews by being able to control the look-ahead field of view for takeoff or approach to avoid hazardous windshear?

11. What are the benefits to crews to have crew selectable look-ahead parameters(field of view, range of view, look-down angle,etc)?

12. What are the optimal crew operating procedures for use of look-ahead windshear information?

13. To what extent will pilot control of windshear system parameters make the look-ahead windshear system more acceptable to flight crews?

In the area of alerting and crew interface...

14. What benefits can be gained by crews if look-ahead capable windshear systems alert on energy increasing shears?

15. What benefits do crews gain from being aware of total magnitude wind changes even if the rate of change of the shear is not dangerous?

16. What windshear system nuisance alert rate is acceptable to crews using look-ahead capable windshear systems?

("Nuisance" means shear exists but is not a factor to the crew because of location of shear or changing intensity of shear. "Acceptable" means crews react to the alert in a safe manner.)

Name____________________

Organization____________________________

Ratings and Comments

17. What look-ahead capable windshear system missed (system fails to detect shear) alert rate is acceptable to crews?

18. What look-ahead capable windshear system false (system error - shear does not exist) alert rate is acceptable to crews?

19. Do crews react to look-ahead windshear warning alerts in an executive manner or in an advisory manner?

("executive" means crews are required to follow guidance unless they have reason to believe that they shouldn't. "Advisory" means crews follow guidance only if they have some other reason to believe that they should.)

20. What benefits would crews have if reactive windshear systems alerting thresholds are rescheduled by look-ahead sensor information?

21. At what altitude does the crew no longer need windshear alerting or look-ahead information for takeoff and approach?

22. What would be the benefits to crews, given look-ahead information, of "avoidance" maneuvers in other than the vertical plane?

23. What level of interaction between forward-look displays and present day color weather radar displays produces the greatest crew awareness of the windshear hazard?

24. What are the benefits to crews if alerted on positive (energy increasing) shears of the same magnitude as negative shear alerts detected by look-ahead sensors?

25. How do crews react and perform given windshear alerts on an aircraft that normally carries a look-ahead system and a reactive system and one of these systems are known to be inoperative?

Name________________
Organization________________

Ratings and Comments

26. What would be the benefits to crews to use voice in look-ahead situations for crew alerting?

27. What are the effects on pilot performance given a look-ahead windshear alert in instrument conditions as compared to a clear air dry microburst situation?

28. What are the tradeoffs in crew capability and reaction to either warning alerts given by forward-look devices or caution alerts given by forward-look devices as related to the distance to the windshear hazard?

29. What are the effects of the increased response time available to the crew with look-ahead windshear detection equipment?

30. What is the effect on response time and accuracy to a reactive system when look-ahead information is used as a precursor to the reactive alert?

31. What is the influence of achievable precision of look-ahead sensors on total effectiveness of the windshear detection system?

32. What are the benefits to crews of various update rate capabilities of look-ahead sensors?

33. What are the benefits to crews in the tradeoffs of increased accuracy as compared to range capability of look-ahead sensors?

OTHERS..

OPENING REMARKS
Herb Schlickenmaier
Friday, October 23, 1987

Why are we here? For two reasons. One is to provide an opportunity to transfer the ongoing results from the NASA/FAA airborne program to you, the technical community. The second reason is to pose problems of current concern to the combined group. Up until now, we have met in two distinct groups. The **Manufacturers' Review Group** has met three times. Our topics have ranged from the first public presentation of the **Bowles(F)-Factor,** a fundamental definition of the effect of wind shear on the aircraft, as well as providing a forum for open discussion of the FAA's AC 25-xx. The **Forward-Look Technology Review Group** has met once. At that review, we were able to discuss the three top contenders for forward-look technology, namely: infrared, lidar and microwave radar. Further, the meeting centered not only on these sensors, but around a common definition of the hazard and discussion of how a forward-look device could be used on the flight deck. A thread between both of these groups has been the definition of the wind shear hazard.

At this first meeting of the combined review groups, I see a unique opportunity for cross-fertilization. Although the two groups work to address different aspects of the wind shear threat, we speak the same language: a common knowledge of the effect of wind shear on aircraft performance. Now the opportunity exists for the manufacturers to review the very latest in forward-look technology concepts. Now the foundation is laid for the technologists to gain from the experience of the manufacturers' development and certification programs. Forward-look and reactive devices are no longer competing concepts, they are allies in combating a common threat to aviation safety.

Yesterday you heard the technical essence of the national airborne program. Today we will go into some of the related areas: a review of the **FAA Windshear Training** program; a quick look at what has been going on in the **Ground Sensors** arena; an early look at a **Terminal Information System**-related project at Ames Research Center; a status report on various **Airborne** certification and regulatory efforts and a discussion of how we might extend our knowledge and experience to the general aviation community; and, finally, insight into the massive effort required to establish a national wind shear **Meteorological Characterization** data base, by examining the FAA Technical Center's experience with their atmospheric data bases.

The agenda is full. The work is not yet complete. Both with the dialog that we have established and our common goal fixed, we can expect nothing less than success.

Windshear Training Kit

Two Binders

Volume 1

- Windshear Management Overview
- Windshear Pilot Guide
- Example Windshear Training Program

Volume 2

- Substantiating Data

Videos

- A Windshear Avoided
- Windshear: What the Crew Can Do

Slides

- 90 35mm companion to 'Example Windshear Training Program'

Letter from the Administrator

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- 121 Operators
- Scheduled-135 Operators
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- Regions and Centers
- Special Interest Groups for further distribution

BCAC, DAC and Lock-Cal

- European customers in London, May 1987
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Steps

1 - Windshear Weather Evaluation
2 - Precautions
3 - Recovery - Windshear Escape Manuever
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STATUS OF FAA TERMINAL DOPPLER WEATHER RADAR PROGRAMS

MARK W. MERRITT
MIT LINCOLN LABORATORY

23 OCTOBER 1987

PROGRAM STATUS/SCHEDULES

- MICROBURST/GUST FRONT PHENOMENOLOGY AND DATA
- MEMPHIS (TN)/HUNTSVILLE (AL)
- DENVER (CO)

MICROBURST DETECTION ALGORITHM STATUS

1988 TEST PLANS

FAA GOALS FOR TDWR PERFORMANCE

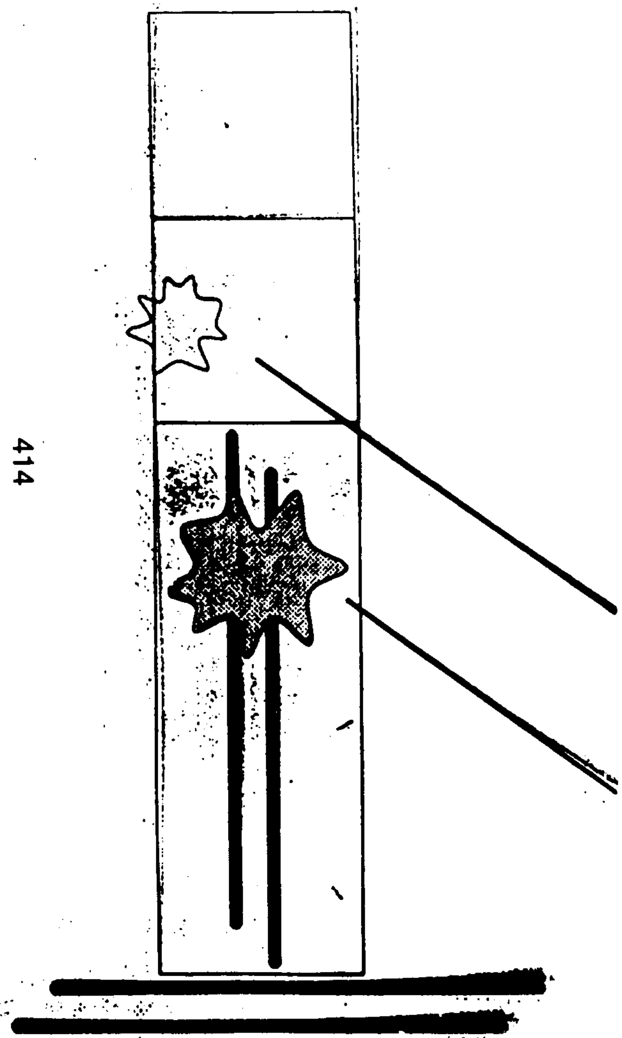
MICROBURST

- $>$ 90% PROBABILITY OF DETECTION
- $<$ 10% PROBABILITY OF FALSE ALARM
- ONE MINUTE ADVANCE WARNING
- $\pm$ 5 KNOTS (OR 20%) ACCURACY ON STRENGTH

GUST FRONT

- 20 MINUTE ADVANCE WARNING
- VERY LOW FALSE ALARM RATE

MICROBURST DETECTION OUTPUT PRODUCTS



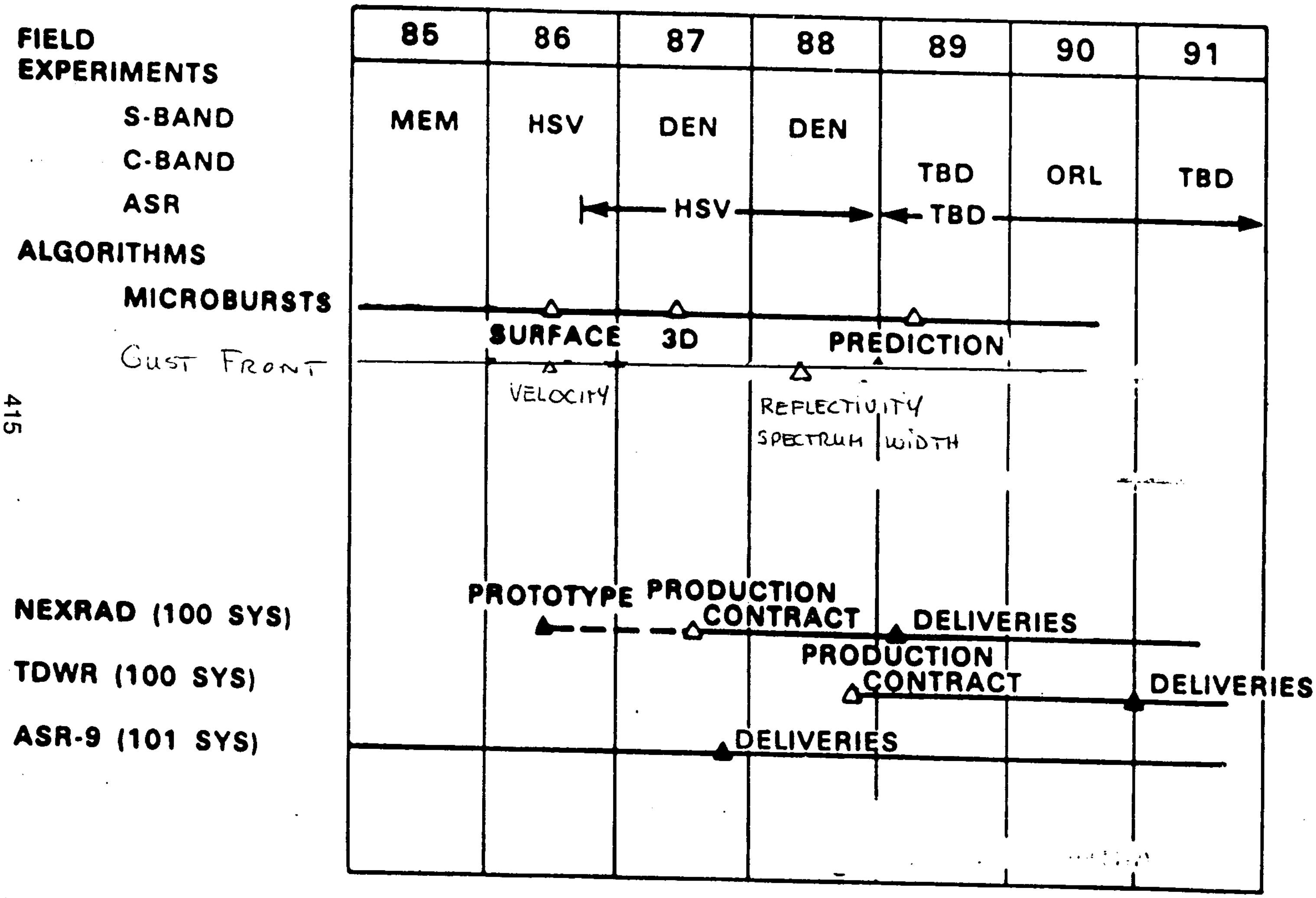
IDENTIFICATION
QUANTIFICATION
LOCATION
TREND

'MICROBURST, 15 KNOT LOSS, 1 MILE FINAL, INCREASING'

'MICROBURST, 30 KNOT LOSS, ON THE RUNWAY, DECREASING'

desired output for users.

LINCOLN WEATHER RADAR PROGRAMS



88077-2

DOPPLER WEATHER RADAR PROGRAM MAJOR ELEMENTS

- TESTBED RADARS FOR DATA ACQUISITION AND FEASIBILITY DEMONSTRATION
- EXECUTION OF MAJOR MEASUREMENT AND PRODUCT DEMONSTRATION PROGRAMS IN VARIOUS REGIONS
- ANALYSIS OF DATA AND DEVELOPMENT OF HAZARD DETECTION ALGORITHMS

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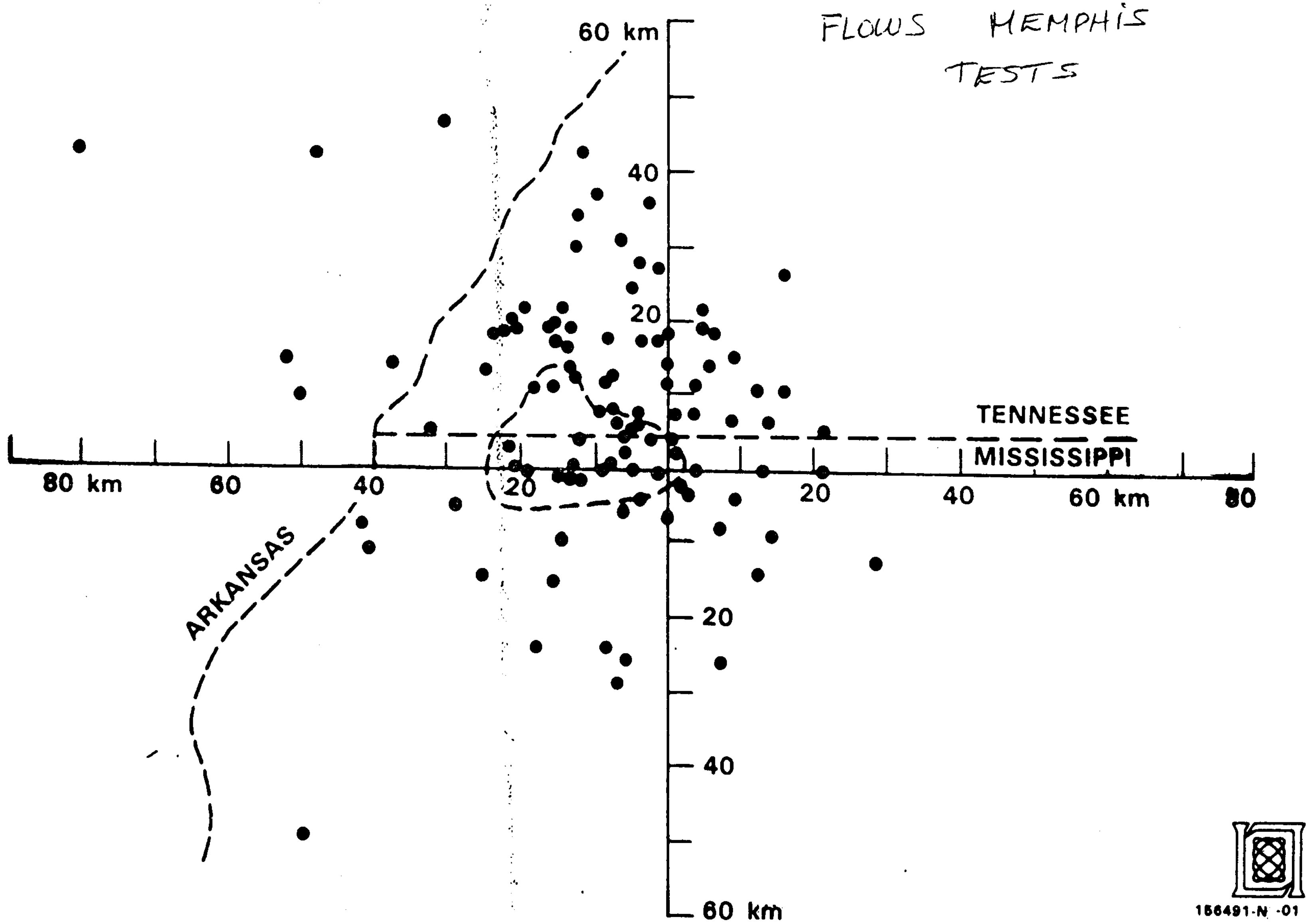
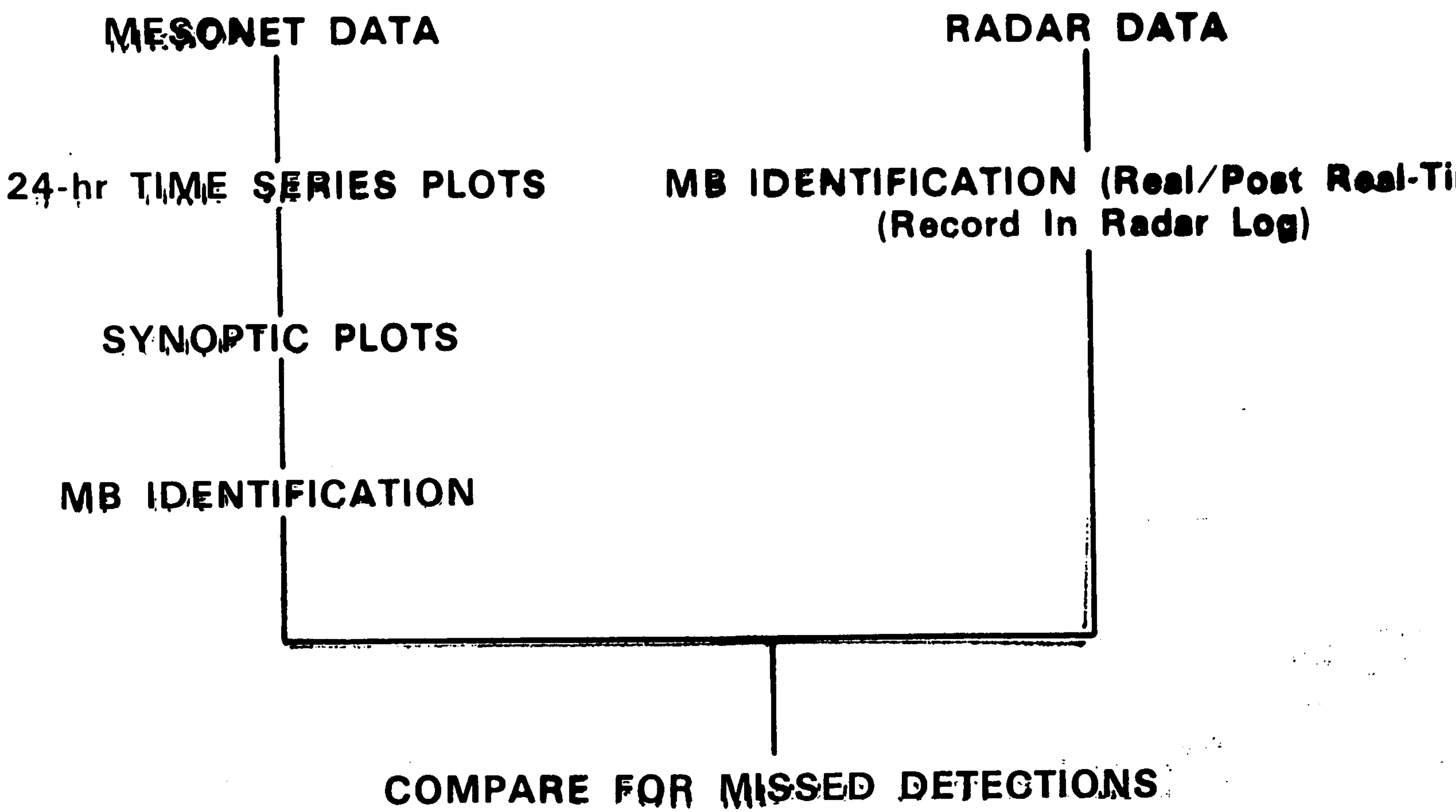
LOCATIONS OF WINDSHEAR EVENTS RECORDED IN RADAR LOG (April-November 1985)

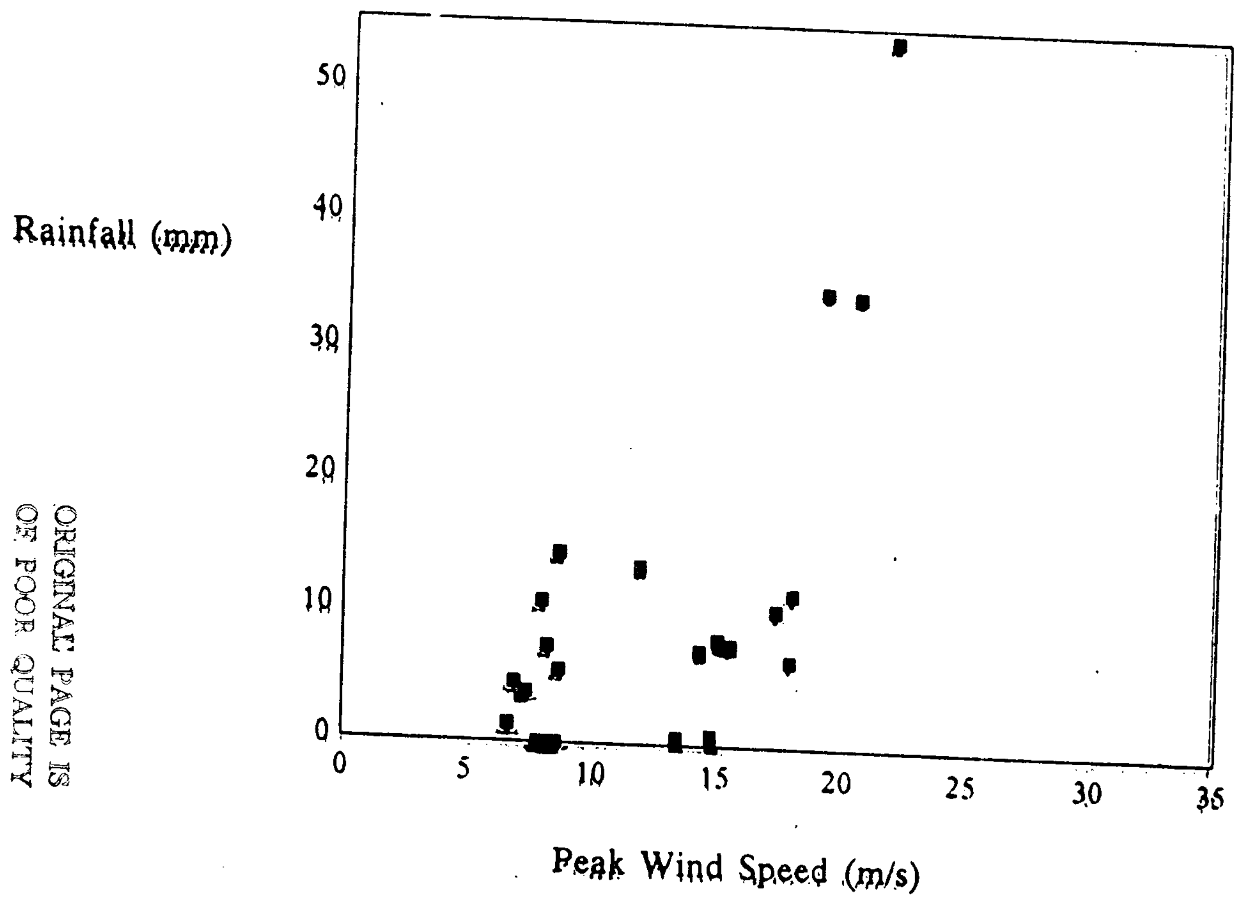
FLOWS MEMPHIS TESTS



RADAR/MESONET COMPARISON



FLOWS MESONET
TOTAL RAINFALL vs PEAK WIND SPEED IN MICROBURSTS



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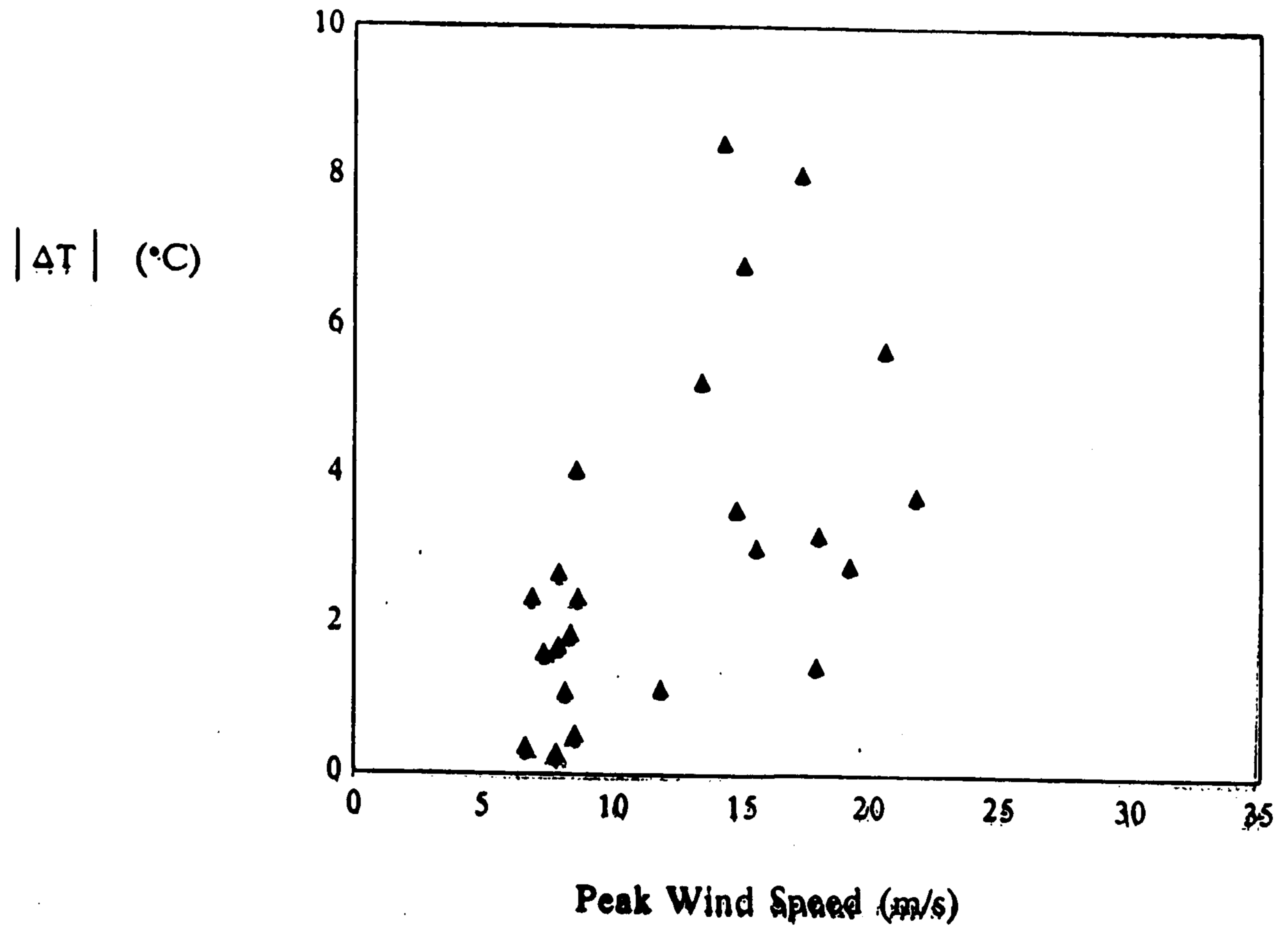
FLOWS MESONET

CHANGE IN TEMPERATURE vs PEAK WIND SPEED IN MICROBURS



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		6. Performing Organization Code
7. Author(s) R.E. Rinehart, J.T. DiStefano, and M.M. Wolfson		8. Performing Organization Report No. ATC-141
9. Performing Organization Name and Address Lincoln Laboratory, MIT P.O. Box 73 Lexington, MA 02173-0073		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. DTFA-01-80-Y-10546
12. Sponsoring Agency Name and Address Department of Transportation Federal Aviation Administration Systems Research and Development Service Washington, DC 20591		13. Type of Report and Period Covered Project Report
		14. Sponsoring Agency Code

15. Supplementary Notes

The work reported in this document was performed at Lincoln Laboratory, a center for research operated by Massachusetts Institute of Technology, under Air Force Contract F19628-85-C-0002.

16. Abstract

During 1984 and 1985 M.I.T. Lincoln Laboratory, under the sponsorship of the Federal Aviation Administration (FAA) conducted a measurement program in the Memphis, Tennessee, area to study low-level wind shear events and other weather phenomena that are potentially hazardous to aircraft operations, with particular emphasis on those issues related to the Terminal Doppler Weather Radar (TDWR). The principal sensor for the measurement program was the S-band FAA-Lincoln Laboratory Testbed Doppler Weather Radar (FL2) which incorporates many of the functional features of the TDWR. Both FL2 and a C-band Doppler Weather Radar operated by the University of No h Dakota (UND) obtained reflectivity, mean velocity and spectrum width measurements with a radar geometry and scan sequences to facilitate determining the surface outflow features of microbursts at the anticipated TDWR ranges. A 30-station network of automatic weather stations (mesonet) collected 1-min averages of temperature, humidity, pressure, wind speed and direction, and total rainfall, plus the peak wind speed during each minute; this system operated from about March through November 1984 and 1985. Finally, the UND Citation aircraft operated two 3-week periods during 1985, collecting thermodynamical, kinematical and microphysical data within and around selected storms in the area as well as providing *in situ* truth for locations and intensity of turbulence.

This report describes the principal initial results from the Memphis operations, stressing the results from 1985 when the FL2 radar was fully operational. These results are compared to those from previous studies of wind-shear programs, e.g., NIMROD near Chicago, JAWS and CLAWS near Denver. During 1985, 102 microbursts were identified in real time along with 81 gust fronts. One of the dominant results is that most microbursts in the mid-south are wet; that is, they are accompanied by significant rainfall. This is in contrast, for example, to the results from Denver where more than half of all microbursts have little or no appreciable rain reaching the ground. Aside from this major difference, microbursts near Memphis were similar to those found elsewhere in the country in terms of wind shear magnitude. The report also gives more representative results from the aircraft operations and discusses the effectiveness of the groun ' clutter filters used on the FL2 radar.

17. Key Words mesonet, Doppler radar, microburst, wind shear, gust front, Terminal Doppler Weather Radar, NEXRAD, turbulence, clutter suppression, Low-Altitude Wind Shear, aviation weather hazards	18. Distribution Statement Document is available to the public through the National Technical Information Service, Springfield, VA 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	198	

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6c. ADDRESS (City, State, and Zip Code) P.O. Box 73 Lexington, MA 02173-0073	7b. ADDRESS (City, State, and Zip Code) Hanscom AFB, MA 01731
8a. NAME OF FUNDING/SPONSORING ORGANIZATION Department of Transportation Federal Aviation Administration Systems Research and Development Service 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER F19628-85-C-0002
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11. TITLE (Include Security Classification)

Study of Microburst Detection Performance During 1985 in Memphis, TN

12. PERSONAL AUTHOR(S)

John T. DiStefano

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Project Report	FROM ______ TO ______	1987, August 5	40

16. SUPPLEMENTARY NOTATION

None

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	low-level wind shear; microburst; Doppler weather radar; surface anemometers; mesonet; microburst outflow detection algorithm; radar/mesonet comparison; missed detections

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

This report focuses on the detectability of microbursts using pulse Doppler weather radars and surface anemometers. The data used for this study were collected in the Memphis, TN area during the FLOWS* project of 1985. The methods used for declaring a microburst from both Doppler radar and surface anemometer data are described.

The main objective of this report was to identify the results that were generated by comparing the 1985 radar detected microbursts (which impacted the surface anemometer system) with the surface mesonet detected microbursts. In so doing, the issue of missed microburst detections, for which there occurred two (both by the radar), is identified. Possible reasons as to why these two microbursts were not detected are discussed in detail.

*FAA/Lincoln Laboratory Observational Weather Studies

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☐ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL Maj. Thomas J. Alpert, USAF	22b. TELEPHONE (Include Area Code) (617) 863-5500, x-2330 22c. OFFICE SYMBOL ESD/TML

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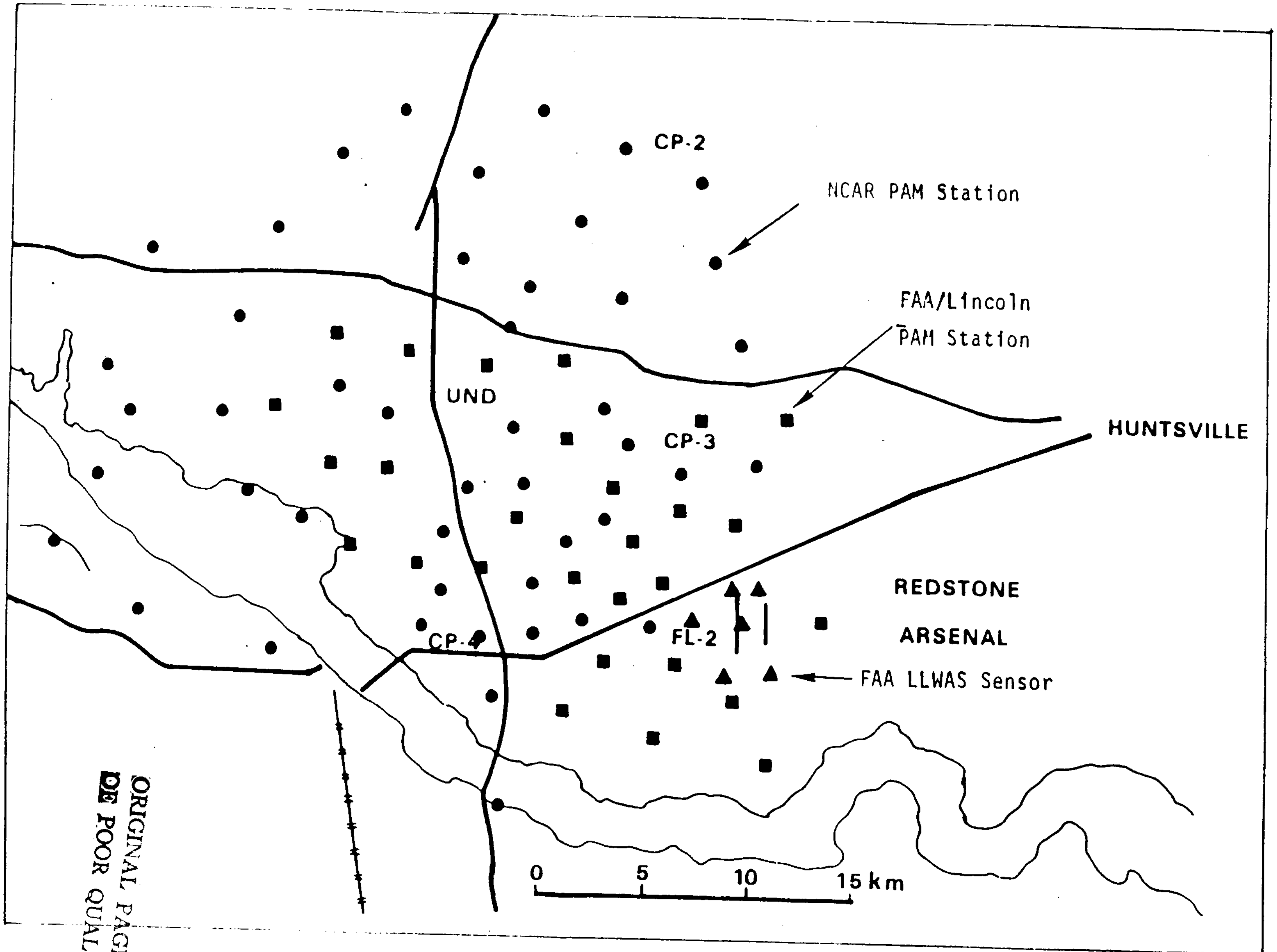
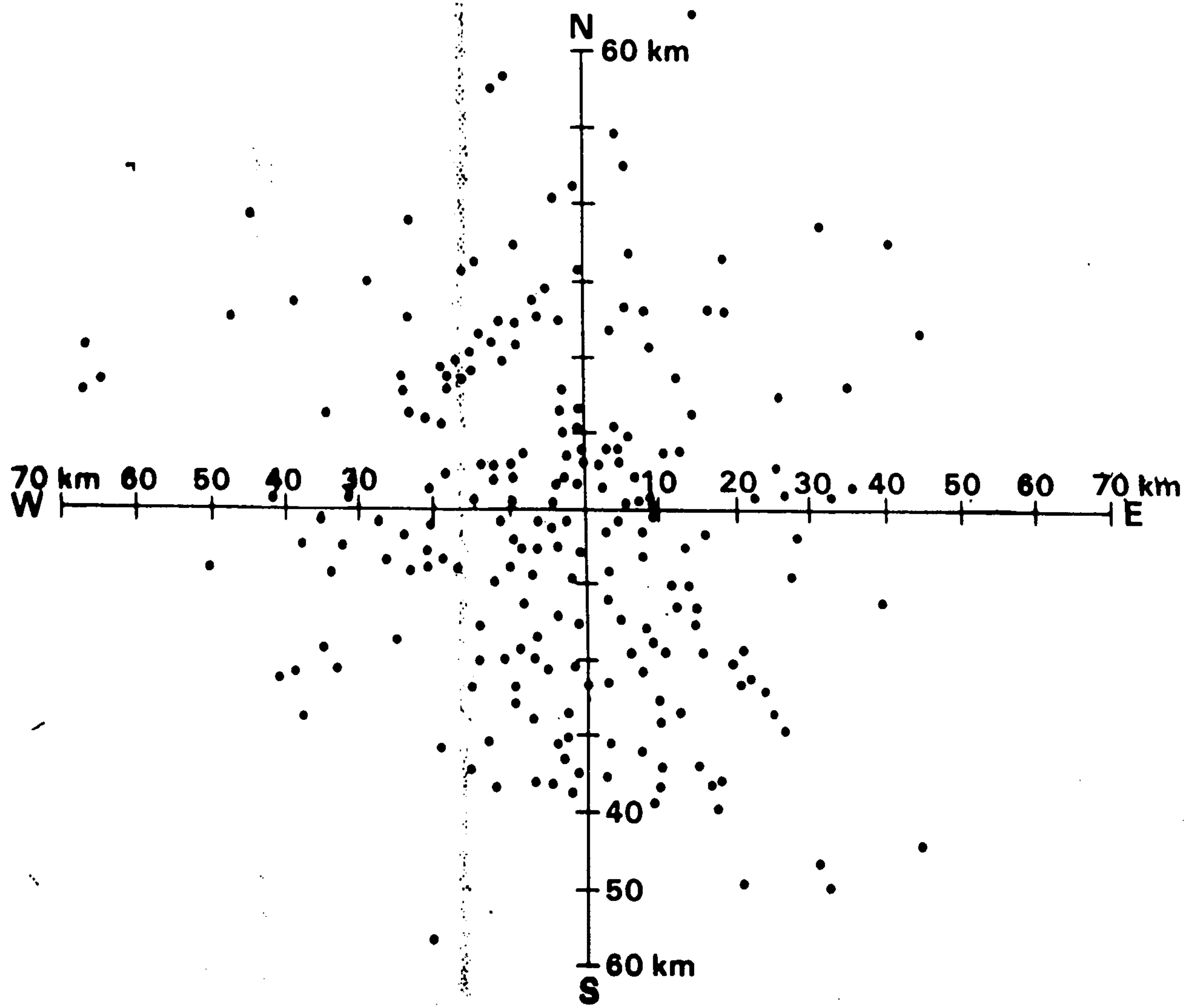
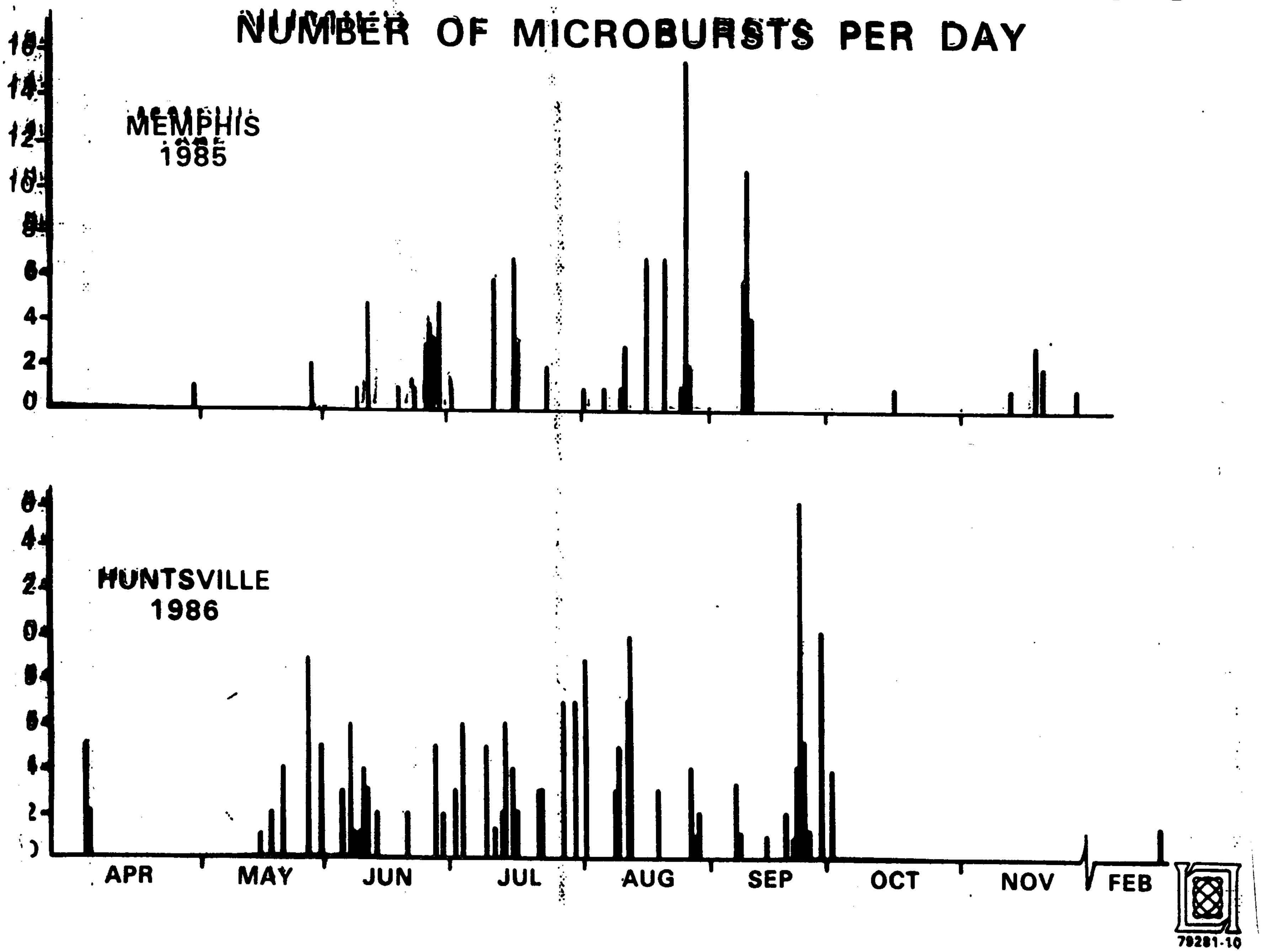


FAA/Lincoln Laboratory and MIST Systems at Huntsville, AL.

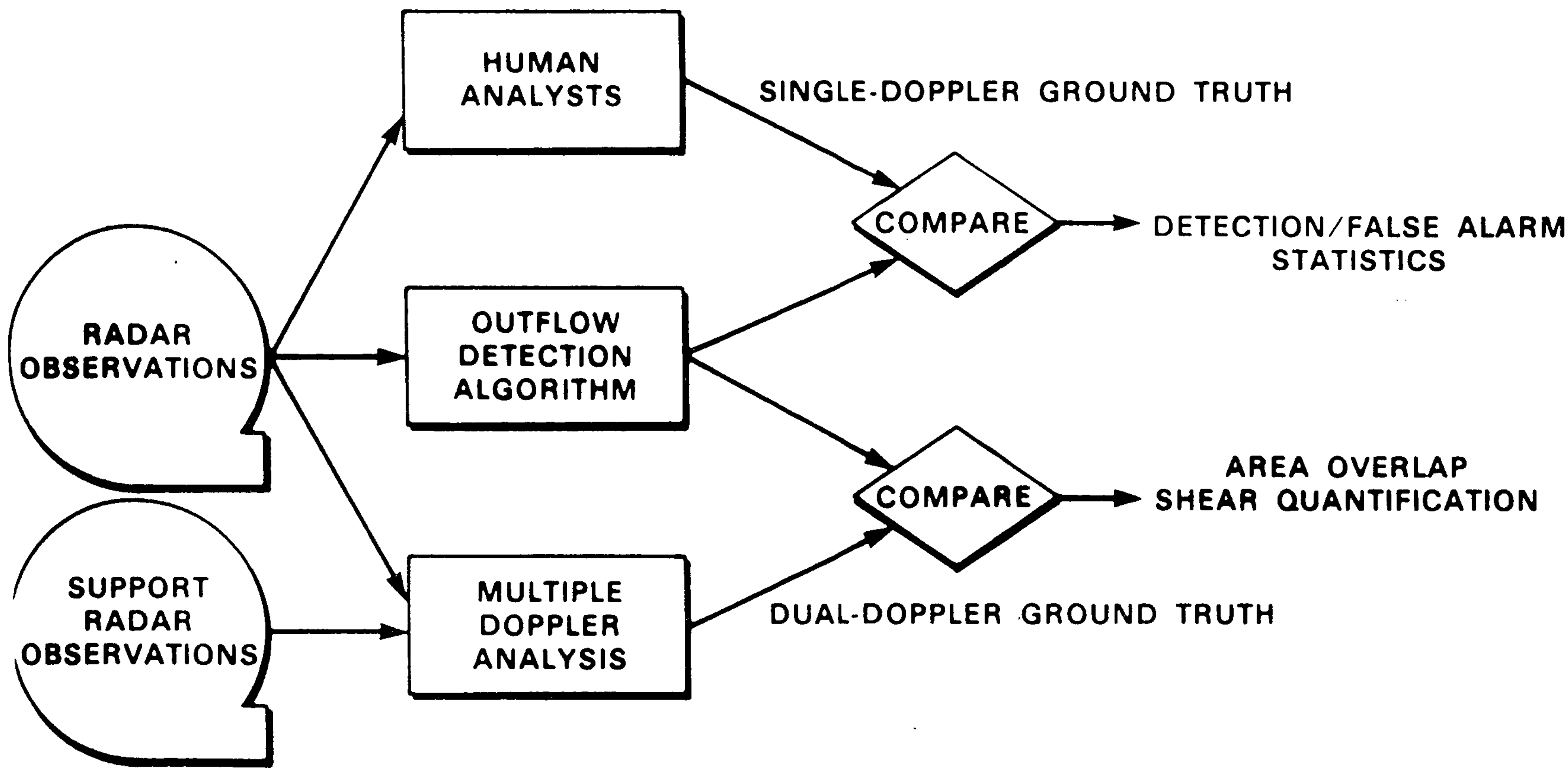
1986 MICROBURST LOCATIONS
HUNTSVILLE, ALABAMA



TEMPORAL DISTRIBUTION OF MICROBURSTS



ALGORITHM SCORING PROCEDURE



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1986 GROUND TRUTH DATABASE (10/7/87)

DATE	TAPES	DATA AVAILABLE(UT)	TRUTH TYPE	TRUTH PERIOD(UT)	WEATHER SYNOPSIS	TRUTH GRADE	TRUTHER	SCCS VERSION
JUNE 7	A-F	1625-2150(5.4)	Surface	1651-1749(1.0)		A	LL	2.3
JULY 1	A-I	1102-1425(3.3) 1732-2339(6.1)	Surface	1734-1940(2.1)		A	LL	2.3
JULY 6	A-E	1804-2228(4.4)	Precursors	2043-2121(0.7)		C	LL	2.3
JULY 11	A-E	0012-0107(0.9) 1205-1234(0.5) 1618-2245(5.5)	Precursors	0012-0034(0.3)		C	LL	2.3
			Precursors	1720-2042(3.3)		C	LL	
JULY 24	A-D	1733-2033(3.0)	Surface & Precursors	1756-1935(1.7)		B	NCAR	2.3
JULY 25	A-H	1448-2258(8.2)	Surface & Precursors	1853-2216(3.3)		A	NCAR	2.3
JULY 31	A-F	1637-2055(4.3)	Surface & Precursors	1741-1923(1.7)		A	NCAR	2.3
AUG 7	A-G	1802-0022(6.3)	Precursors	2109-2200(0.9)		C	LL	2.3
AUG 24	A-G	1749-2211(4.3)	Surface & Precursors	1845-2011(1.5)		A	LL	2.4
SEPT 5	A-D	0023-0147(1.4) 2044-2100(0.3)	Surface	2045-2058(0.2)		A	LL	2.3
SEPT 20	A-B	1708-2159(4.9)	Precursors	2113-2131(1.3)		C	LL	2.3
SEPT 21	A-H	1722-2201(4.7)	Surface & Precursors	1832-2046(2.2)		A	LL	2.3
SEPT 22	A-E	1923-0006(4.7)	Surface	2121-2354(2.5)		B	LL	2.3
SEPT 26	A-F	1638-2107(4.5)	Surface	1733-1945(2.2)		A	LL	2.3

Table D.2 Institutions* Responsible for Data Collection, Checking and Archival

Data Type	Data Collection	Data Checking	Generation of Level IIB Data	Data Archival
PAM-II surface mesonet	NCAR	NCAR, UC, UCLA, MSFC	NCAR	NCAR, NASA, UC
NASA surface mesonet	MSFC/UAH	MSFC/UAH	MSFC	MSFC
FAA surface mesonet	~~FAA~~ LL	~~FAA~~ LL	~~FAA~~ LL	~~FAA~~ LL
Raingage network	MSFC, TVA	MSFC	MSFC	MSFC
LLF network	MSFC	MSFC	MSFC	MSFC
Rawinsonde network	MSFC/UAH	MSFC/UAH	MSFC	MSFC
Special NWS rawinsonde	NWS	MSFC	MSFC	MSFC
U-2, ER-2 aircraft	MSFC, GSFC	MSFC, GSFC	MSFC, GSFC	MSFC, GSFC
T-28 aircraft	SDSMT	SDSMT	SDSMT	SDSMT, MSFC
P-3 aircraft	NOAA	NOAA, UC, MSFC	NOAA	NOAA, UC, MSFC
UND Citation	UND	UND	UND	UND
FAA Convair 580	FAA	FAA	FAA	FAA
CSU Cessna	CSU	CSU	CSU	CSU
BNA RADAP	NWS, MSFC	MSFC	MSFC, NOAA	MSFC
CP-2	NCAR	NCAR, CSU, PSU, MSFC	NCAR	NCAR, MSFC
CP-3, CP-4	NCAR	NCAR, UCLA, UC, FSU	NCAR	NCAR
FL-2	LL	LL	LL	LL
UND	UND	UND	UND	UND
Satellite image products	UND	UND	UND	UND
Derived satellite soundings	UW	UW, MSFC, GSFC	UW	UW, MSFC
Derived satellite winds		MSFC, UW	MSFC, UW	MSFC

*MSFC-NASA Marshall Space Flight Center, GSFC-Goddard Space Flight Center, NOAA-National Oceanic and Atmospheric Administration, NCAR-National Center for Atmospheric Research, FAA-Federal Aviation Administration, UC-University of Chicago, UCLA-University of California in Los Angeles, PSU-Penn State, CSU-Colorado State, SDSMT-South Dakota School of Mines and Technology, FSU-Florida State, UW-University of Wisconsin, LL-Lincoln Laboratory.

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4. TITLE AND SUBTITLE SPACE/COHMEX DATA INVENTORY DOCUMENT		5. REPORT DATE August 1987
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*Atmospheric Science and Remote Sensing Laboratory, Johnson Research Center, University of Alabama in Huntsville, Huntsville, AL 35899

16. ABSTRACT

During the period June through July 1986, NASA conducted the Satellite Precipitation and Cloud Experiment (SPACE) in the central Tennessee, northern Alabama, and northeastern Mississippi area. In addition to SPACE, the MIcroburst and Servere Thunderstorm (MIST) Program, sponsored by the National Science Foundation, and the FAA-Lincoln Laboratory Operational Weather Study (FLOWS), sponsored by the Federal Aviation Administration, operated concurrently under the acronym of COHMEX (COoperative Huntsville Meteorological EXperiment). The COHMEX field program incorporated measurements from remote sensors flown on high altitude aircraft (ER-2 and U-2), Doppler and conventional radars, rawinsondes, satellites, cloud physics research aircraft, and various surface observational systems.

This document contains a brief description of the field program and a daily data collection summary. Chapter 2 summarizes the program instrumentation and facilities, and includes sample selected data products. Chapter 3 provides a meteorological summary, operations overview, and an inventory of the data collected for each day of the field program. The purpose of this document is to provide the researcher and scientist with a tool to select data sets for case studies and instrument evaluation.

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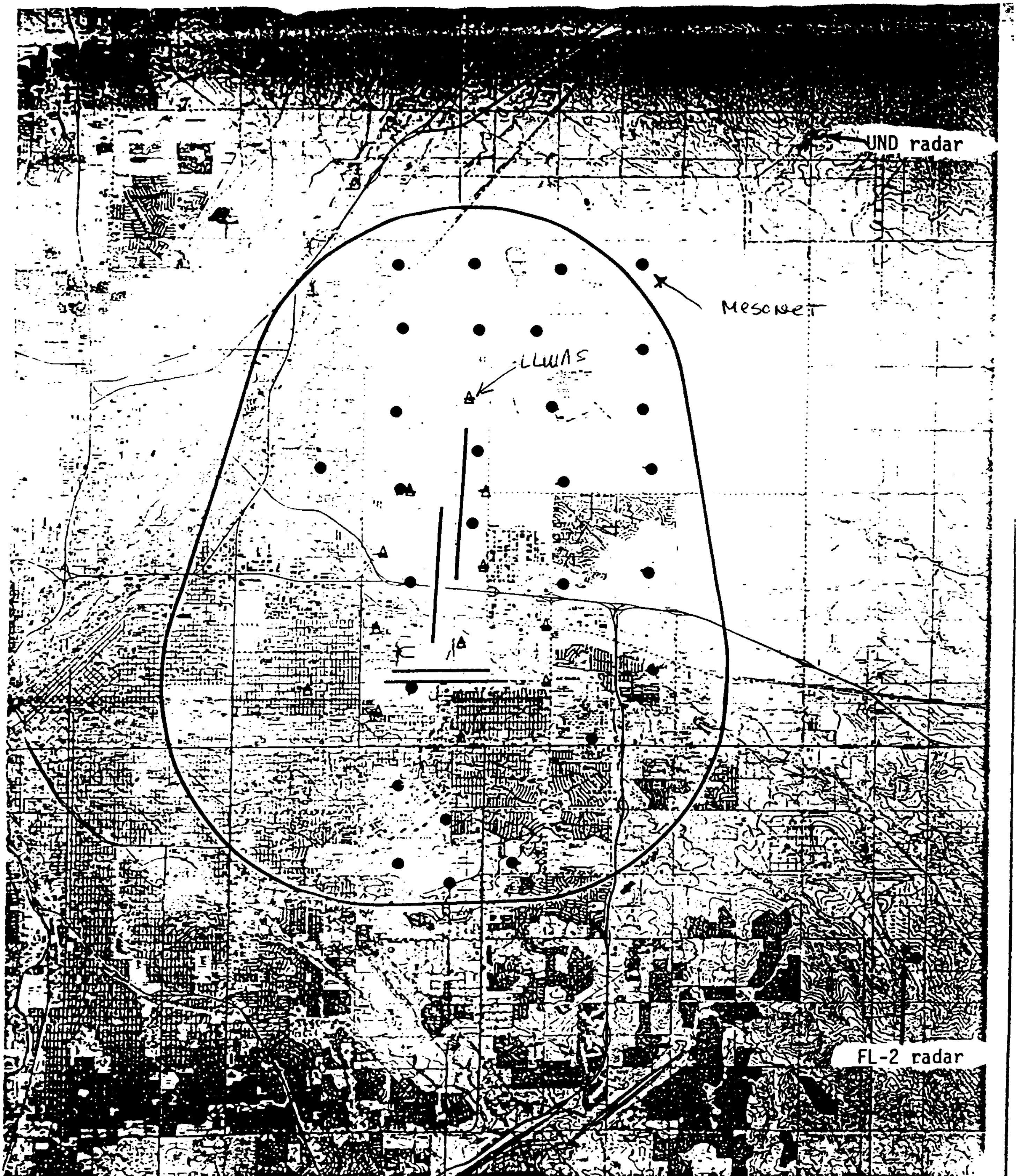
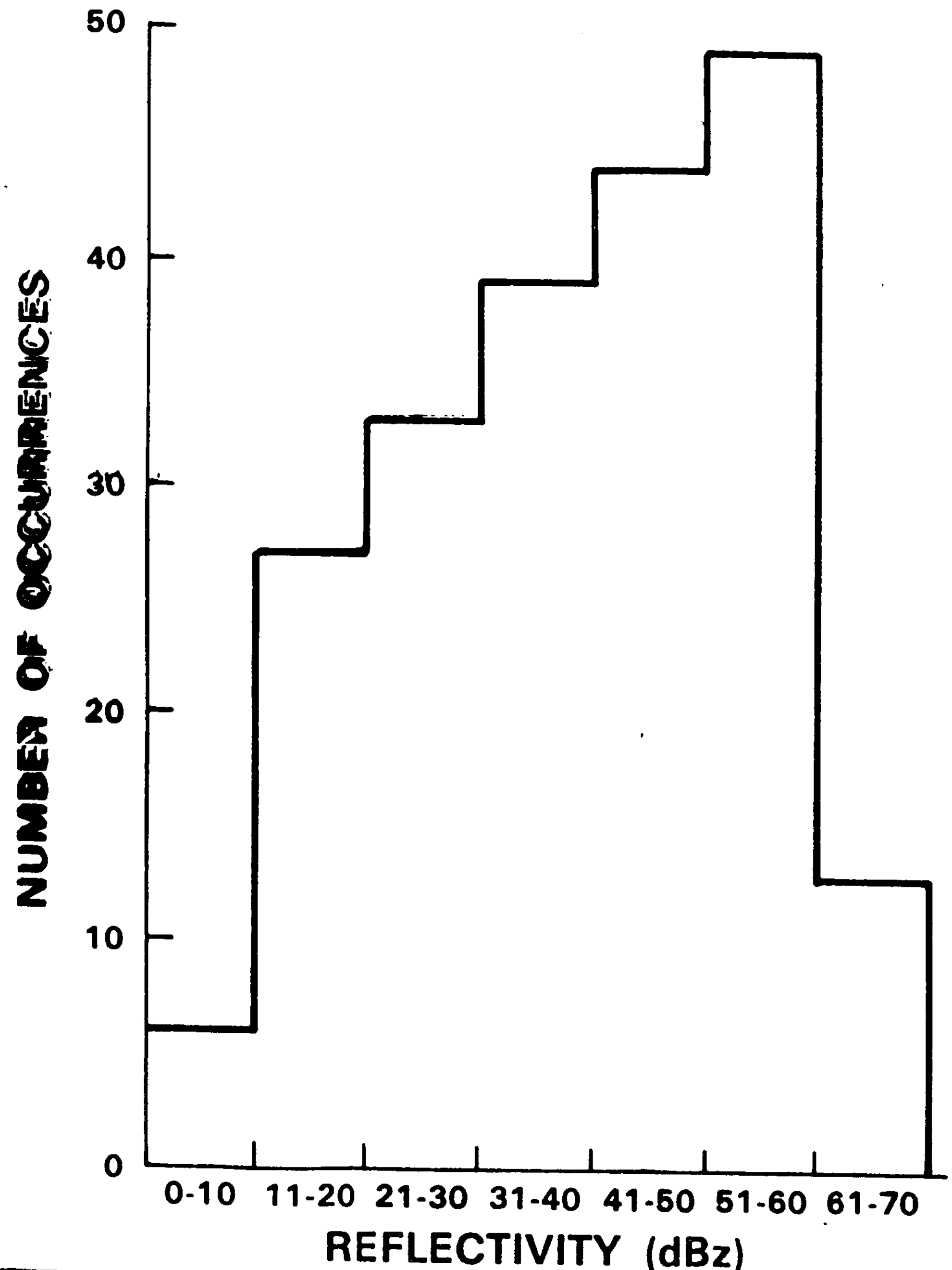


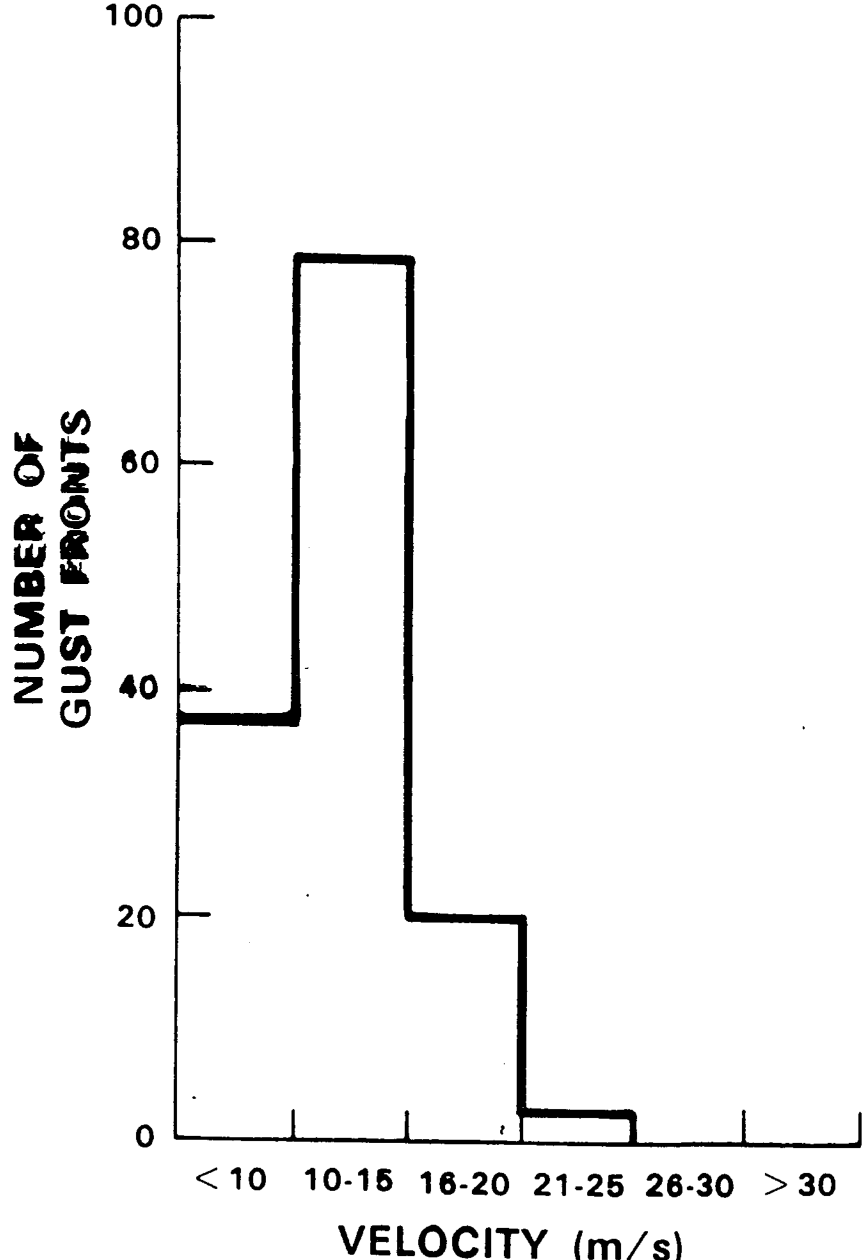
● surface weather stations Δ Low-Level Wind Shear System anemometers

Terminal Weather Sensors Near Stapleton Airport for FAA 1987 Wind Shear Measurement Programs

1987 DENVER MICROBURST REFLECTIVITIES



1987 DENVER GUST FRONT WIND SHEARS



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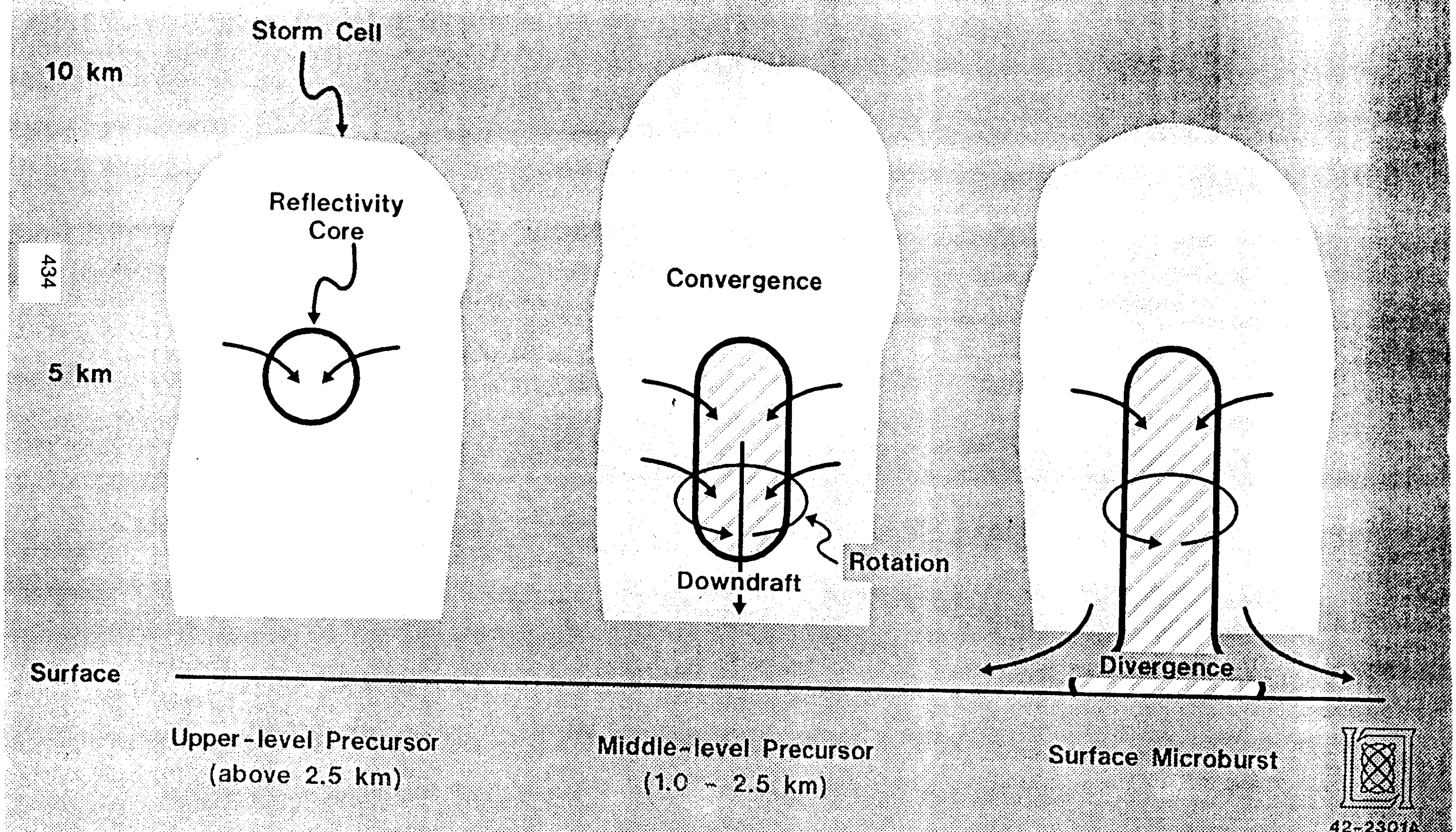
1987 GROUND TRUTH DATABASE (10/7/87)

DATE	TAPES	DATA AVAILABLE(UT)	TRUTH TYPE	TRUTH PERIOD(UT)	WEATHER SYNOPSIS	TRUTH GRADE	TRUTHER	SCCS VERSION
MAY 23	A-E	2037-2344(3.1)	Surface	2100-2218(1.3)	TRW's	A	LL	1.6
MAY 28	A-D	2051-0048(4.0)	Surface	2149-0026(2.6)	TRW's	B	NCAR	1.8
MAY 30	A-C	2323-0205(2.7)	Surface	2346-0206(2.3)	Wet TRW's	B	NCAR	1.8
JUNE 7	A-D	2138-0238(5.0)	Surface	2323-0157(2.5)	High Refl., Line	A	LL	1.10
JUNE 10	A-D	1901-0017(5.2)	Surface	1919-2322(4.0)	Dry, Line	A	LL	1.10
JUNE 14	A-E	1933-0058(5.4)	Surface & Precursors	1953-0057(5.0)	Hot, TRW's	B	LL	1.6
JUNE 17	A-D	2103-0036(3.5)	Surface	2124-2333(2.1)	Weak TRW's	B	LL	1.1
JUNE 18	A-F	1934-0123(5.9)	Surface	2147-2327(1.7)	Supercell TRW	B	NCAR	1.5
JUNE 21	A-E	1759-0100(7.0)	Surface	1941-0045(5.0)	Dry MB's	B	LL	1.1
JULY 9	A-D	2051-0220(5.5)	Surface & Precursors	2342-0014(0.5)	Warm, TRW's	C	LL	1.1
AUG 25	A-I	1919-0047(5.5)	Surface	2309-0033(1.5)	Wet, Line	B	LL	1.1
SEPT 2	A-G	1722-0039(7.3)	Surface	2223-2310(0.9)	Line TRW's	B	LL	1.2

MICROBURST ALGORITHM FEATURES



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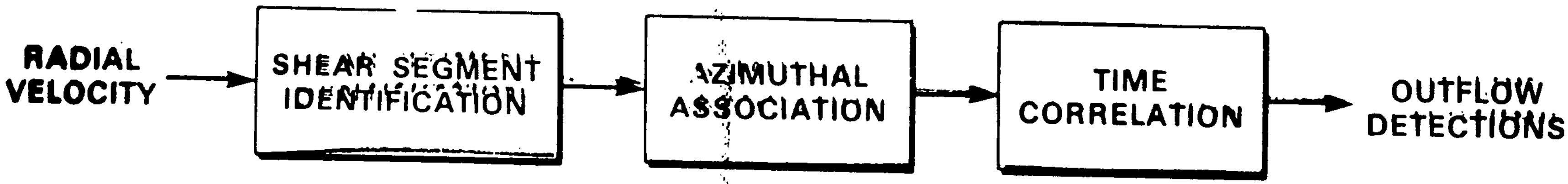
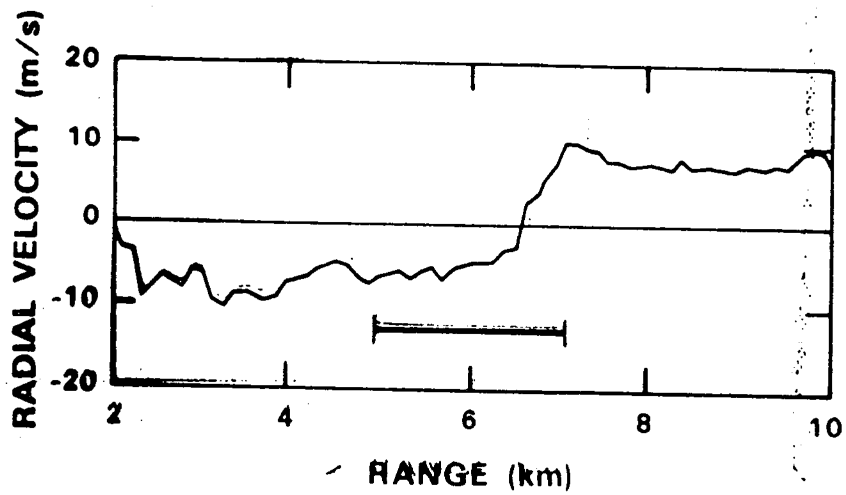
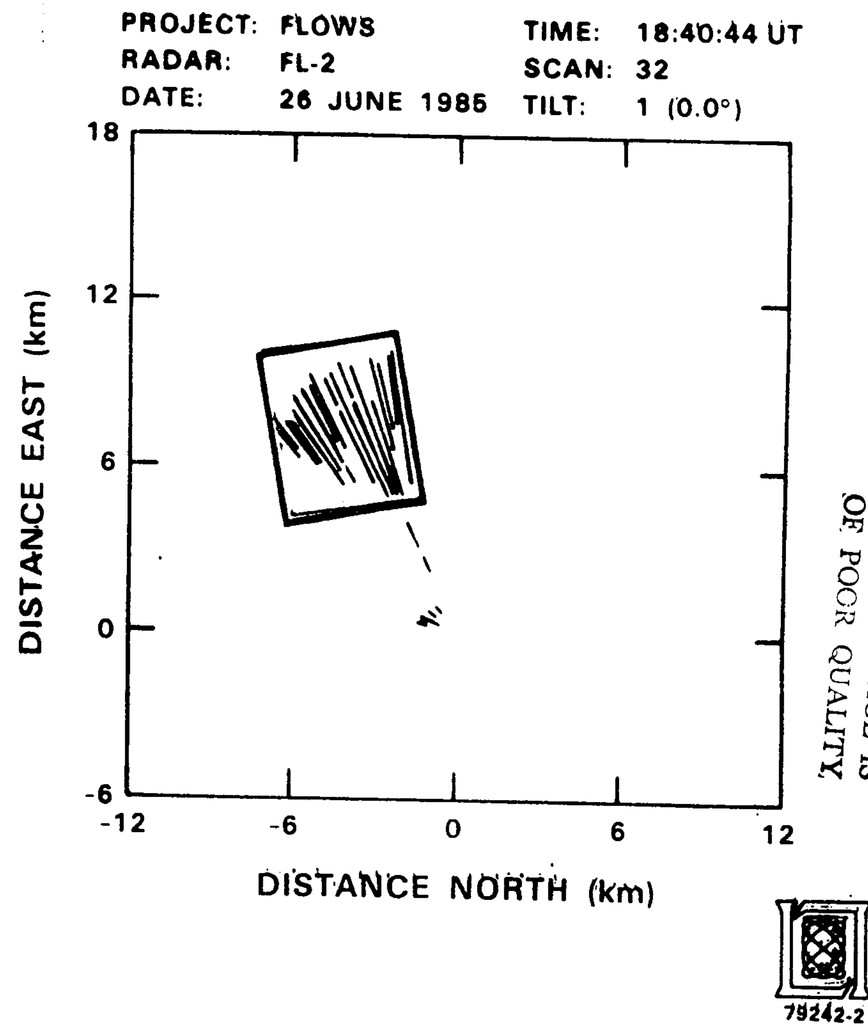
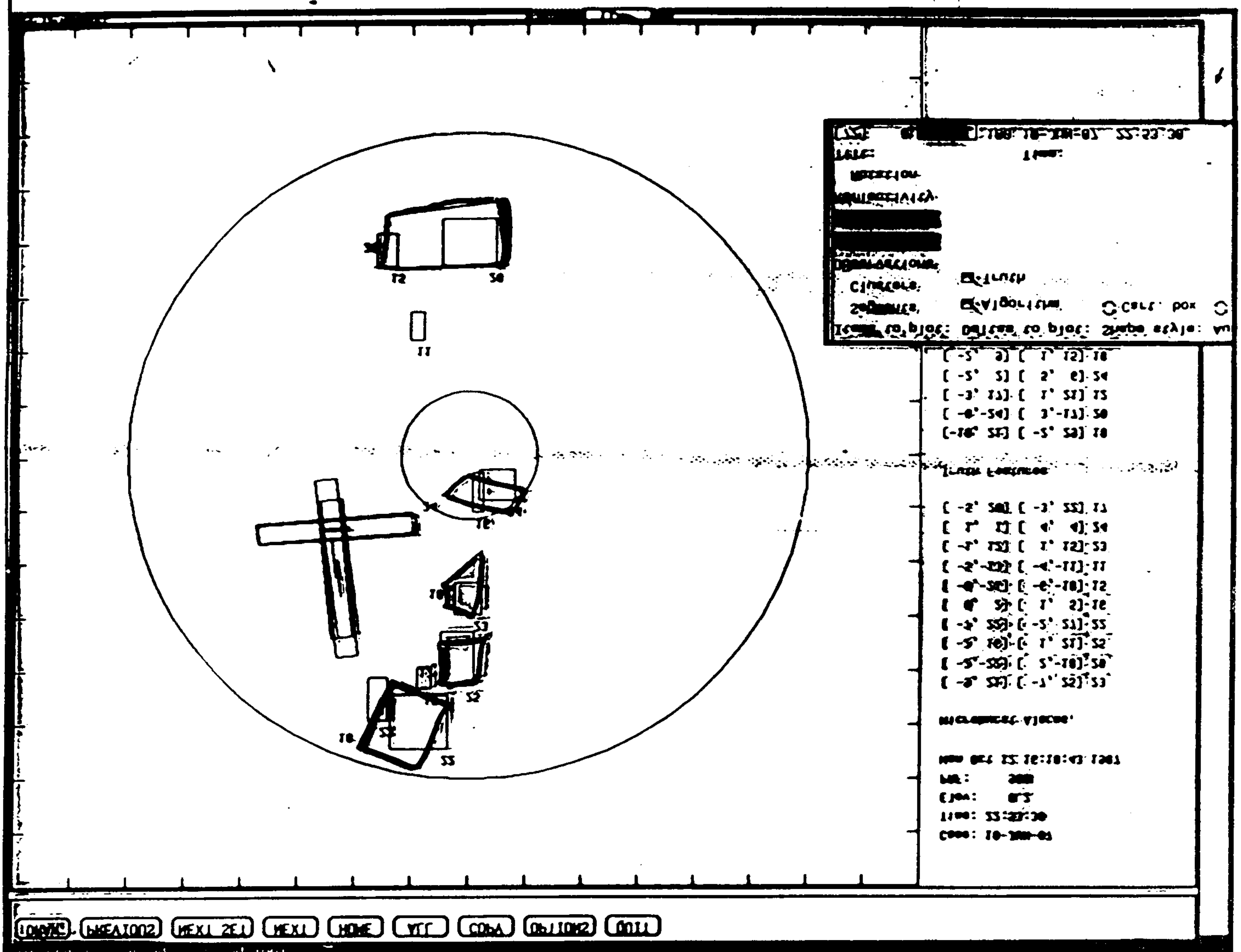
OUTFLOW DETECTION ALGORITHM









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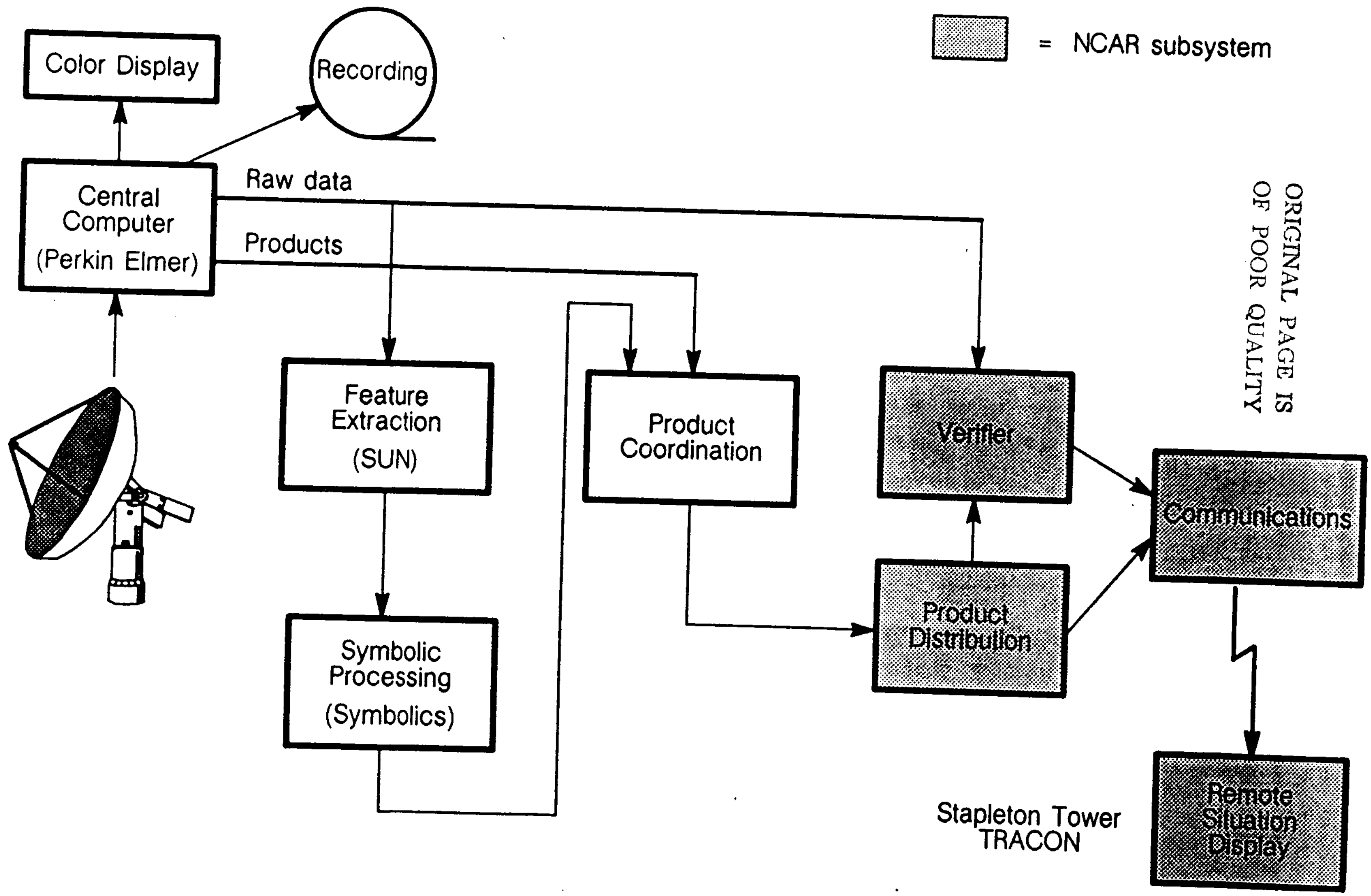
CONFIGURATION FOR REAL-TIME DEMONSTRATION



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24 June 1987
INFORMATION PACKAGE
FAA Doppler Weather Radar Tests
Denver, CO

Introduction

The Federal Aviation Administration (FAA) will be conducting an experimental measurement program using pulse Doppler weather radars during 1987 around Stapleton International Airport, Denver, CO to obtain information on low altitude wind shear phenomena and other terminal aviation weather hazards. The objective of the FAA measurement program for 1987 is to develop and validate techniques for the automatic detection of phenomena such as microbursts and gust fronts, turbulence and heavy rain. The results of this development program will be incorporated into the hardware and/or software components of the Next Generation Weather Radar (NEXRAD) and the Terminal Doppler Weather Radar (TDWR) systems which are being procured by the FAA.

A principal objective of the program is to develop techniques for detecting low-altitude wind shear* events which are potentially hazardous to aircraft taking off or landing at an airport. A particularly dangerous wind shear situation occurs when a microburst, or downburst, from a storm spreads out horizontally on reaching the ground as illustrated in Figure 1. When an aircraft encounters such a wind situation, there is often a rapid change from a headwind, which increases the lift of the airplane, to a tail wind, which reduces the lift of the airplane. In extreme cases, the sudden loss of lift from the tail wind can cause the airplane to crash. Encounters with wind shear events may have contributed to as many as 25 aircraft accidents worldwide over the past 10 years, resulting in over 500 fatalities.

Wind shear events can be caused by a number of meteorological situations. Thunderstorms often produce strong outflows and downdrafts which can spread out upon hitting the surface. Large thunderstorms are capable of producing long duration outflows, the leading edge of which are called "gust fronts." Gust fronts can extend several miles away from the rain area and last for periods as long as an hour or more.

Small storms and even relatively innocuous looking clouds are capable of producing small but intense downdrafts which can be just as hazardous (if not more so!) than those of their larger cousins. The smaller storms produce what has been termed "microbursts" by some scientists. These microbursts are often only a mile or two in diameter and last for as little as 5 minutes. Nevertheless, if a microburst were to occur near an airport while an aircraft is taking off or landing, an accident could result.

*The term wind shear is used to describe situations in which the wind encountered by an aircraft changes rapidly along the flight path. Not all wind shears are hazardous.

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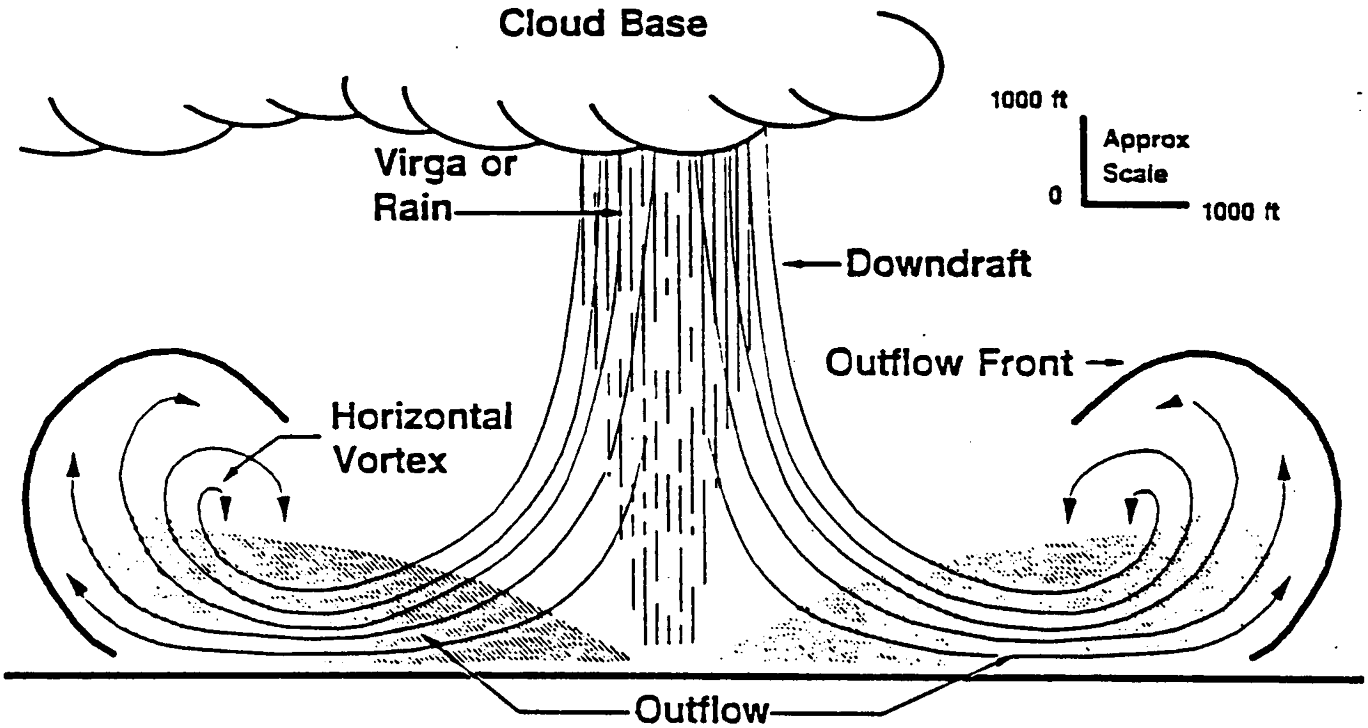


Figure 1. Symmetric Microburst. An Airplane Transiting the Microburst Would Experience Equal Headwinds and Tailwinds.

Low-altitude wind shear measurement and detection programs have been conducted at a number of locations (Chicago, Denver, Memphis (TN), and Huntsville (AL)) over the past few years. Denver was the site for:

1. The Joint Airport Weather Studies (JAWS) project, a study of the basic physics of microbursts conducted during the summer of 1982, and

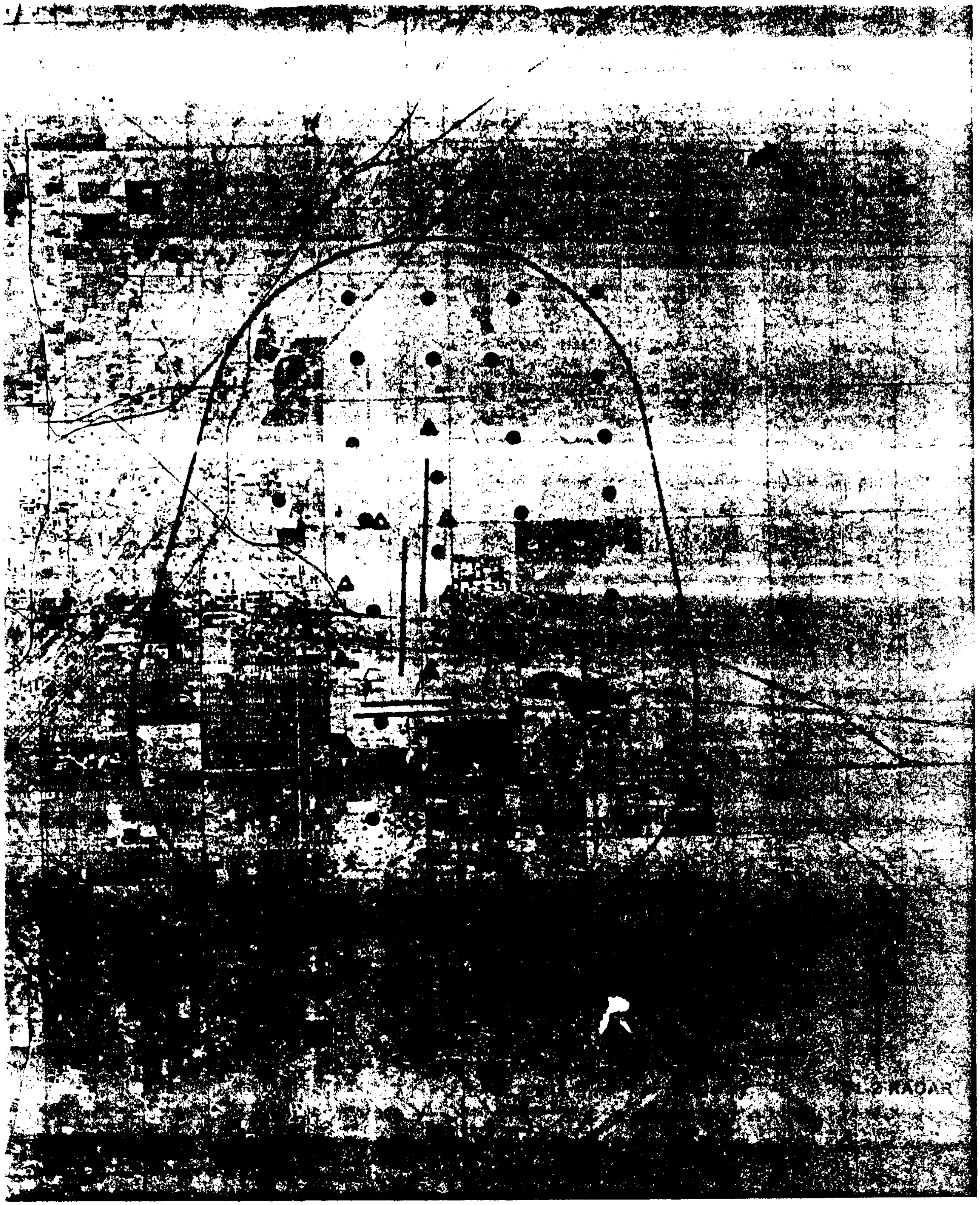
2. The Classify, Locate and Avoid Wind Shear (CLAWS) project, in which real time wind shear warnings were provided to the FAA control tower at Stapleton Airport during a 45-day period in the summer of 1984. The warnings were produced manually by research meteorologists from the National Center for Atmospheric Research (NCAR) who monitored data from a research Doppler weather radar. The warnings were provided to controllers who then informed pilots of hazardous weather events. CLAWS demonstrated that properly interpreted Doppler weather radars could provide operationally useful warnings of low-altitude wind shear.

The Denver Area Measurement Program

The measurement program in 1987 focuses on transitioning the scientific and operational knowledge gained in the previous measurement programs to a fully automated wind shear detection system.

Figure 2 shows the locations of the various ground weather sensing systems being used in the 1987 measurement program. The FAA test-bed Doppler weather radar developed and operated by the Lincoln Laboratory of the Massachusetts Institute of Technology (MIT) for the FAA will be the primary data collection tool for the measurement program. This S-band radar (designated by the letters FL-2 in Fig. 2 and shown in Fig. 3) uses a 28-ft. diameter antenna and a powerful signal processing system to record, process and display the Doppler measurements. This radar utilizes certain advanced digital processing techniques (e.g., digital clutter suppression filters and automatic choice of signal waveforms) which will be required in the systems the FAA is procuring. The FL-2 radar will be located on the Buckley Air National Guard airbase approximately 10 miles southeast of Stapleton Airport.

The second Doppler radar used in the 1987 testing will be a C-band system operated by the University of North Dakota (UND). This radar, located approximately 8 miles northeast of Stapleton (designated UND in Fig. 2), will provide additional confirmation of wind shear events near Stapleton as well as enable the FAA to determine the effects of wavelength on the measured reflectivity of wind shear events.



● SURFACE WEATHER STATIONS △ LOW-LEVEL WIND SHEAR SYSTEM ANEMOMETERS

Figure 2. Terminal Weather Sensors near Stapleton Airport for FAA 1987 Wind Shear Measurement Programs.

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A network of 30 automatic weather stations (denoted by circles in Fig. 2) located in open areas is collecting data on temperature, humidity, pressure, wind speed and direction and rainfall, 24 hours a day. Data are averaged over 1-minute intervals and transmitted from each of the stations to the GOES-East geostationary satellite every half hour. The data are downlinked and provided to the project scientists by telephone line or computer tape for analysis or display. The wind data from the weather stations are used to validate the wind shear detection performance of the Doppler radars while the other weather station data are used to accomplish meteorological analyses of the wind shear events.

Additional information on the surface wind characteristics during wind shear events will be provided by data from the 12 FAA Low-Level Windshear Alert System (LLWAS) anemometers located about Stapleton (which are designated by triangles in Fig. 2).

UND is also operating its Citation jet aircraft equipped with instruments to measure the winds, temperature and humidity conditions near storms as well as the numbers and sizes of cloud droplets and raindrops encountered within storms. The Citation aircraft will furnish the data on the upper air environment associated with wind shear as well as direct measurements of turbulence to confirm the accuracy of Doppler radar-based turbulence detection algorithms.

The development and validation of algorithms to automatically determine the location and intensity of hazardous low altitude wind shear phenomena is a principal objective of the 1987 program. In June 1987, real time testing of the microburst outflow detection algorithm and the gust front detection algorithm will commence at the FAA test-bed radar site.

These algorithms, based on experimental programs and data analyses over the past few years by researchers at NCAR, NSSL, Lincoln Laboratory, and the University of Chicago will operate in real time on the FL-2 data processing system with the algorithm outputs being displayed on a color display workstation.

Researchers from NCAR, Lincoln Laboratory, and the National Severe Storms Laboratory (NSSL) will perform an initial evaluation of wind shear events and the algorithm performance in real time. A more detailed assessment of the weather phenomenology encountered and the algorithm performance (using data from the UND radar and surface weather sensors as well as FL-2 data) will be accomplished in post-measurement analyses.

The algorithms to be tested in 1987 have demonstrated operationally useful performance on wind shear events measured by the FL-2 system in 1985 near Memphis, TN and in 1986 near Huntsville, AL. The microburst events encountered in the humid southeast portion of the U.S. were typically accompanied by heavy rain. By contrast, many Denver area microbursts are associated with much lighter precipitation producing storms. Thus, it is

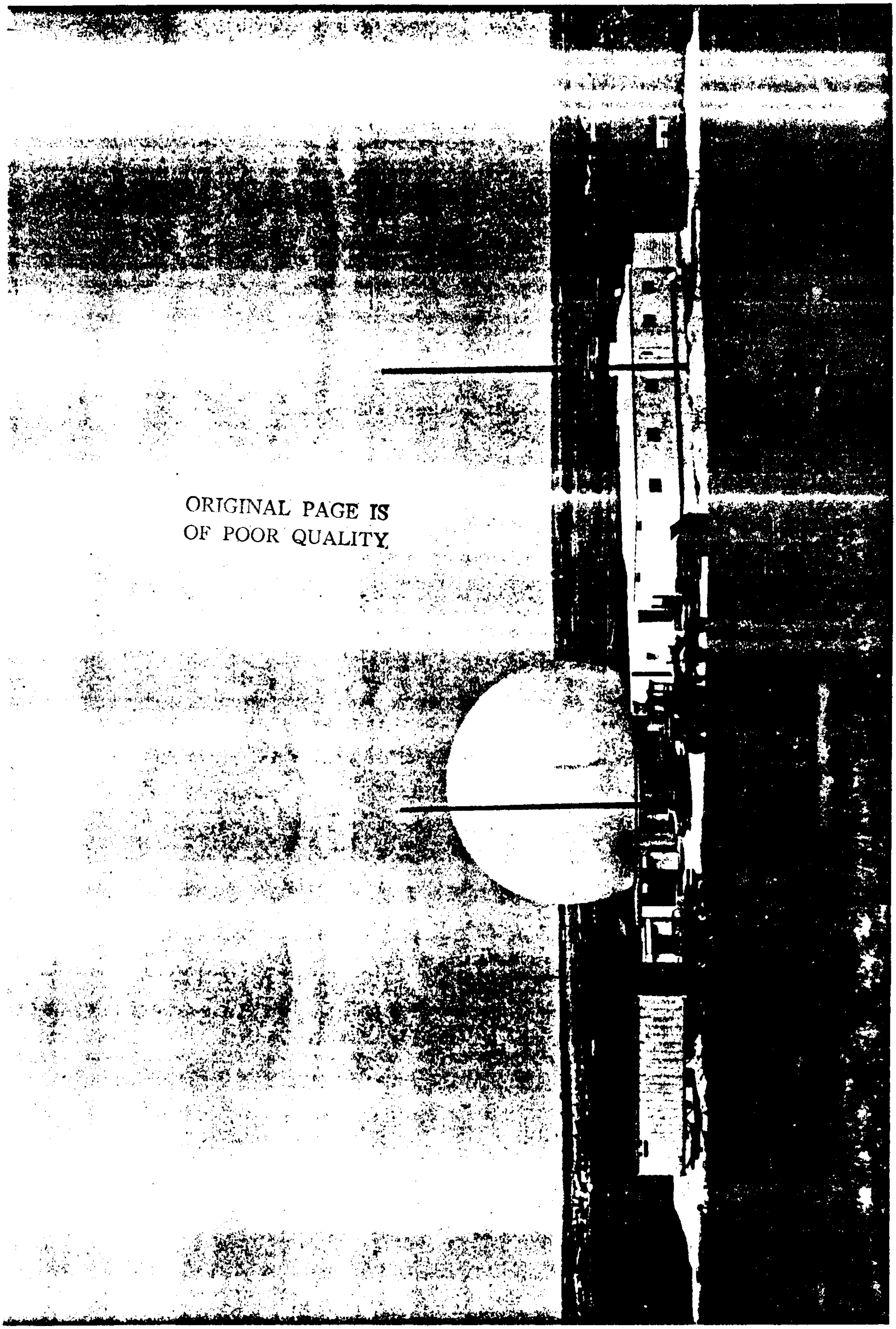

Figure 3. FAA testbed Doppler Weather Radar at Buckley ANG Airbase (Aurora, CO).

necessary to demonstrate that the algorithms have adequate performance on Denver wind shear events before the automated wind shear detection products can be provided to the air traffic controllers at Stapleton.

If an operationally useful detection capability is achieved against the Denver area windshear events measured in 1987, the FAA plans to conduct a full operational demonstration during 1988 in which automatically generated hazardous weather warnings will be provided to controllers for transmission to pilots.

Additionally, the 1987 program will explore the possibility of future enhancements to the near term automated products. A group of researchers from NCAR will review the FL-2 data in real time to determine whether expert radar meteorologists can reliably predict the imminent (e.g., 5-10 minutes) occurrence of microbursts and/or the development of thunderstorms.

FAA Weather Radar Procurement

The Federal Aviation Administration is participating in 3 weather radar programs. These are the Next Generation Weather Radar (NEXRAD), terminal NEXRAD, and Terminal Doppler Weather Radar (TDWR). The NEXRAD Program is a joint effort of the FAA, the National Weather Service, and the Air Force to develop and procure a national network of weather radars.

The terminal NEXRAD Program involves the use of 17 NEXRAD units reconfigured for terminal operations and installed near major airports such as Denver Stapleton, Dallas-Fort Worth, and Chicago. These radars will be operated for an interim period until the TDWR is available after which the terminal NEXRAD systems will be reconfigured as standard NEXRAD systems and relocated to Alaska, Hawaii, and the Caribbean.

The TDWR systems being procured by the FAA will provide pilots and controllers with an indication of wind shear and other hazardous weather conditions. These systems will be installed at major airports beginning about 1992.

The Denver test program supports all of these activities.

Details on the scope and time schedule of the FAA weather radar program can be obtained from Mr. Donald Turnbull [telephone (202) 267-8429].

Additional information on the Lincoln Laboratory, NSSL, and NCAR participation in the above measurement program can be obtained from Drs. James Evans [(617) 863-5500 X814-433], Dusan Zrnic' [(405) 366-0403] and Cleon Biter [(303) 497-8937], respectively.

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American Meteorological Society

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Recognizing Low-Altitude Wind Shear Hazards from Doppler Weather Radar: An Artificial Intelligence Approach*

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(Manuscript received 23 April 1986, in final form 12 December 1986)

ABSTRACT

This paper describes an artificial intelligence-based approach for automated recognition of wind shear hazards. The design of a prototype system for recognizing low-altitude wind shear events from Doppler radar displays is presented. This system, called WX1, consists of a conventional expert system augmented by a specialized capability for processing radar images. The radar image processing component of the system employs numerical and computer vision techniques to extract features from radar data. The expert system carries out symbolic reasoning on these features using a set of heuristic rules expressing meteorological knowledge about wind shear recognition. Results are provided demonstrating the ability of the system to recognize microburst and gust front wind shear events.

1. Introduction

Considerable attention has recently focused on the problem of detecting low-altitude wind shear hazards. It is known that wind shear poses a substantial hazard to aircraft, particularly on take-offs and landings (National Academy of Sciences, 1983). Wind shear is reported to have caused major air crashes in 1975 and 1982 (Fujita, 1985), and is strongly suspected to be the cause of a more recent crash at Dallas in August, 1985 (Fujita, 1986).

Because of the concern for aircraft safety posed by low-altitude wind shear, it has been proposed to install Doppler weather radars at major airport areas to detect these events (Federal Aviation Administration, 1984). Research projects such as JAWS (Joint Airport Weather Study) at Denver in 1982 demonstrated the detectability of microburst events by Doppler radar (Wilson et al., 1984). The CLAWS (Classify, Locate and Avoid Wind Shear) project in the summer of 1984 showed that microbursts and gust fronts can be recognized in real-time by skilled radar meteorologists using single-Doppler weather radar displays (McCarthy and Wilson, 1985).

However, it is clear that the operational use of Doppler radar to support air traffic control (ATC) functions will require an automated wind shear recognition capa⁻ ''ity. First, not enough radar meteorc' ogists exist t, monitor wind shear hazards at all ·o-tential radar sites. Second, the task cannot be delegated to air traffic controllers because of the meteorological expertise required and the increase in workload that would be imposed.

The objective of the work reported here is to explore the use of artificial intelligence techniques in weather radar interpretation. Specifically, the goal of the project is to develop a system which mimics the performance of a meteorologist in recognizing low-altitude wind shear hazards from Doppler radar displays. The WX1 design employs techniques from artificial intelligence and computer vision to achieve this aim. The rationale for this approach will now be briefly explored.

2. Expert systems and radar meteorology

Expert systems have gained much attention recently as a technique for capturing the performance of human experts in specialized fields of knowledge. Areas in which expert systems have been developed include such varied applications as mass spectrogram analysis, disease diagnosis, speech understanding, geological data analysis, and computer configuration (Hayes-Roth et al., 1983).

The assumption behind these applications is that a body of specialized knowledge is possessed by the human expert. Expert systems attempt to capture this knowledge in an explicit form and employ mechanisms to apply this knowledge to solve problems in the domain of expertise. Using this approach, expert systems have been able to successfully perform tasks which previously could only be carried out by human specialists. Moreover, expert systems have in some cases been able to attain levels of performance equaling that of humans (Buchanan and Shortliffe, 1984).

Given the growing application of expert systems in

* This work was supported by the System Engineering Service of the Federal Aviation Administration (FAA) under Interagency Agreement DTFA01-83-Y-10579. The information presented does not necessarily reflect the official view or policy of the FAA.

many fields, it is natural to ask how this technology might be applied to meteorology. In particular, the present project grew out of the question of whether an expert system could be built to recognize wind shear hazards from Doppler radar data. In order to answer this question, it is necessary to examine the nature of the task that a radar meteorologist is asked to carry out in recognizing a wind shear hazard such as a microburst.

First of all, it should be recognized that the radar meteorologist's task has a large visual processing component. A typical weather radar display consists of a series of color-coded images representing such products as reflectivity and radial velocity. The meteorologist must be able to recognize patterns in these images in order to recognize a wind shear hazard. To do this, the radar meteorologist makes heavy use of the image processing capabilities of the human visual system. These capabilities include the ability to discern regions, edges, gradients, peaks and so forth.

Second, the interpretation task also involves the use of specialized knowledge. What appears as a collection of meaningless colored blobs on a screen to the naive observer is perceived as a microburst, gust front, storm cell or other phenomenon by the radar meteorologist. The specialized knowledge of the expert also allows such artifacts as second trip echoes, velocity folding and clutter to be rejected. In fact, recognizing these artifacts is an important part of the interpretation process.

The radar expert also uses meteorological knowledge to guide processing in an adaptive fashion. For example, the divergent outflow signature of a microburst might initially be quite weak. However, the meteorologist may have some indication that a microburst is about to occur, such as the observation of a descending reflectivity core. In this case, the meteorologist is able to recognize this weak divergence as a microburst indicator and therefore provide an early warning.

3. The WX1 system

It can be seen from the foregoing discussion that a system which attempts to emulate the performance of a radar meteorologist requires an approach which combines symbolic reasoning with visual processing. The basic problem confronting such a system is to refine the massive detail of the input radar data into an abstract representation of meteorological phenomena.

A conceptual view of this refinement process is shown in Fig. 1. The pyramid shape of the diagram indicates that information is represented in increasingly abstract and less detailed form as the processing proceeds. At the lowest level of the pyramid is the radar data comprising literally millions of bytes of information. This mass of data is abstracted by the application of pattern recognition algorithms into a set of image features numbering perhaps in the thousands.

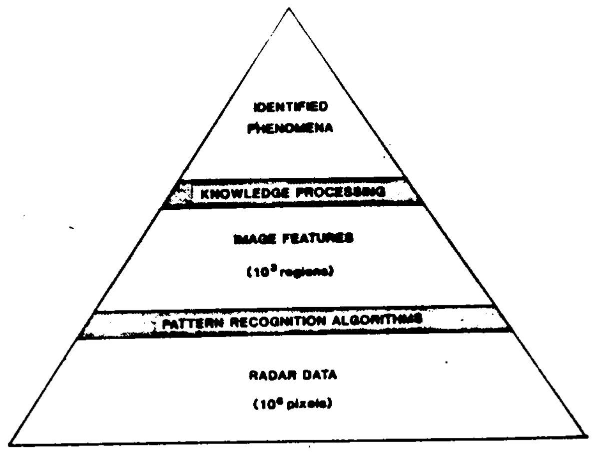

FIG. 1. Conceptual view of system processing.

These image features are then refined by knowledge-processing operations into a handful of identified phenomena at the top level, such as microbursts, gust fronts, storm cells and so forth.

a. Approach

The AI approach employed in the WX1 system can be contrasted with conventional techniques in two main areas. First, WX1 is broad-based. It relies on multiple sources of information and on multiple lines of reasoning. Second, WX1 is knowledge-based. It employs knowledge about wind shear structure, and about radar artifacts which can lead to false alarms.

The WX1 system employs multiple sources of information to identify wind shear hazards. For example, WX1 uses both Doppler velocity and reflectivity data to recognize gust fronts, instead of relying on a single radar product. In one case, the gust front might be most apparent as a shear line in the velocity field; in another case, the gust front might be more apparent as a reflectivity thin-line. Furthermore, WX1 can use results from one information source to guide processing for the other sources.

WX1 does not depend on a single algorithm to interpret a given information source. Rather, it uses multiple pattern recognition algorithms to extract features from the radar data. For example, it uses two different algorithms to extract shear features from the Doppler velocity product. Neither algorithm works in all cases, but by using them together the system can detect some shears that it would otherwise miss.

WX1 performs knowledge-based classification and interpretation of wind shear hazards. WX1 contains structural models which relate meteorological phenomena to features extracted from the radar data. In addition to modeling these phenomena, the system also contains models for radar artifacts which could lead to false alarms. For example, an apparent shear line will

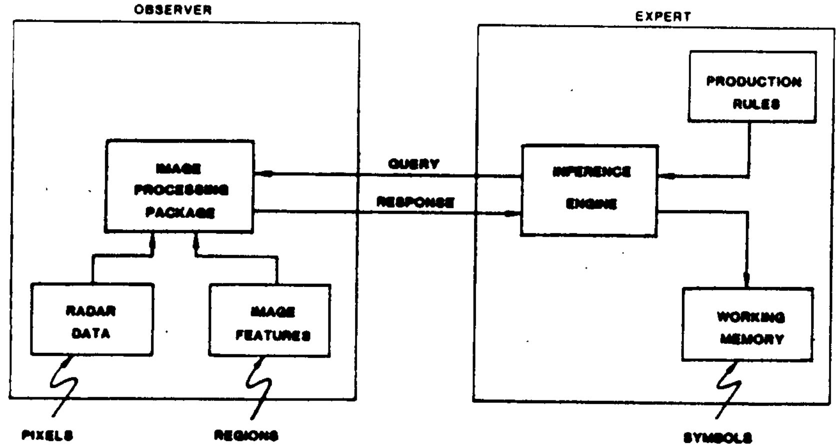

FIG. 2. WX1 System Design.

be rejected if WX1 determines that it matches the model for second-trip echoes.

b. System design

The WX1 system design consists of two major elements, as shown in Fig. 2. The radar image processing element contains the numerical and image processing capabilities of the system; the expert element contains the system's meteorological knowledge and symbolic reasoning capability. The two elements communicate with each other by exchanging messages, with the expert generating queries and the observer producing reponses.

The radar image processing element performs operations on two databases. The first of these is a radar database containing the input data in Cartesian resampled form. This radar data includes primary radar products, such as reflectivity, radial velocity and spectrum width, and derived products such as radial and azimuthal shear.

The feature database contains the image features which have been extracted from the radar data. It also contains higher-level features which have been created from the product-level features. At the top level, it contains abstract features such as a microburst recognized over several successive volume scans.

The expert system element consists of production rules, a working memory and an inference engine. The working memory contains a set of facts which represent symbolically the contents of the radar and feature databases. For example, suppose that V1 is a Doppler velocity field, and that F1 and F2 are features extracted from that field, as shown in Fig. 3. Thus, V1 is an element of the radar database, and F1 and F2 are elements of the feature database. The working memory contains facts which represent these elements in symbolic form, such as the fact indicating F1 is a positive velocity feature.

The inference engine performs the task of matching these facts to the condition part of rules. When a match occurs, the inference engine performs any required tests

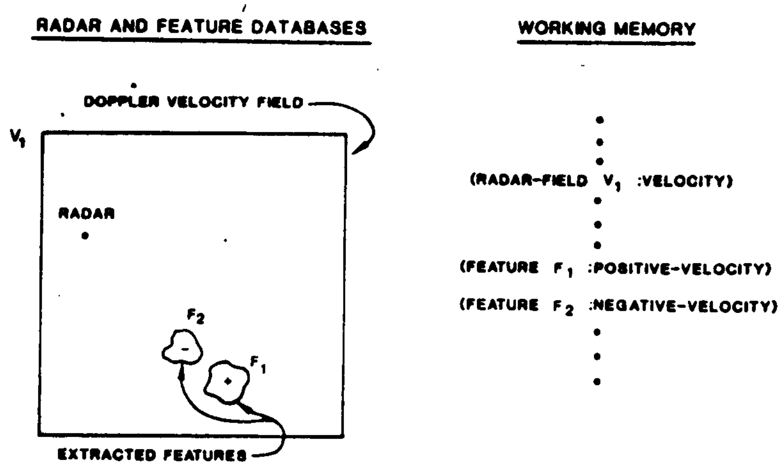

FIG. 3. Representation of extracted features as facts in working memory.

on those facts by sending queries to the radar image processing element. If all the tests are satisfied, the action part of the rule is then carried out. Typical actions consist of asking the radar image processing element to create a higher-level feature and to add that feature as a fact to the working memory.

The partitioning of the system design into expert system and radar image processing components allows WX1 to perform symbolic reasoning while retaining a powerful capability for processing radar images. The advantage of this approach is that it allows the details of the radar data and image features to be hidden from the expert system. Thus, a particular image feature is known to the expert system as a region of a particular type, such as a positive velocity feature. The size, shape and other properties of a given feature are not known directly by the expert system, but can be determined by sending queries to the radar image processing subsystem.

c. *System configuration*

The WX1 system is currently implemented on a Symbolics 3670 Lisp machine with 4MB memory capacity and 474MB of disk storage. The hardware includes a monochrome console display, a high-resolution color display for radar images and a nine-track magnetic tape drive for data input.

The software for the WX1 system currently consists of approximately 15 000 lines of Lisp code. Of this total, about 10 000 lines or two-thirds are devoted to image processing operations. The remainder consists of the expert system shell and two rulesets, one for microburst recognition and the other for gust front recognition. At present, the microburst ruleset contains about 150 rules and the gust front ruleset about 200 rules.

The expert system is implemented in YAPS (Yet Another Production System), a production rule language similar to OPS5 (Allen, 1982). The image processing component is implemented with extensive use of the Flavors object-oriented programming system (Weinreb et al., 1983).

4. Radar image processing

The radar image processing component of the system performs numerical and computer vision operations on radar images. These operations include processing the input radar data, extracting image features and performing various computations on features.

a. *Input data processing*

The input radar fields are currently converted from polar to Cartesian-sampled form by off-line processing prior to entry into the system. A number of numerical operations can be carried out by the WX1 system on the input radar data. One type of processing is to modify the radar data by such operations as filtering to reduce noise, masking out regions and applying thresholds to the data. Another class of operations is to compute derived products such as radial and azimuthal shear.

b. *Feature extraction*

Feature extraction involves three steps: pixel classification, connected-region determination and feature instantiation. Pixel classification is based on an a priori assignment of pixel values to classes. For example, pixels in a radial velocity field are classified as positive (>2.5 m s^{-1}) or negative (<2.5 m s^{-1}). The result of this process are point maps of the classes for each field. The connected regions for each point map are then determined, resulting in a list of regions for each class.

c. *Feature processing*

Three types of operations can be carried out on features. The first type of operation is to answer a query about the properties of a particular feature. These properties include 1) location (centroid, range to radar, azimuth, altitude); 2) shape (length, width, height, elongatedness, compactness); and 3) numeric value (maximum, minimum, average).

The next type of operation involves determining relationships between features. The response to these queries can be either numeric or logical. An example of a numeric result is to compute the distance between two features, e.g., the distance between the centroids of features F1 and F2 in kilometers. An example of a logical result would be to compute whether features on adjacent elevation scans overlap; in this case the result of the operation would be a true/false response.

The third type of operation is to create higher-level features from lower-level features. A higher-level feature is created by the image processing package when the expert element finds that there is a reason to group features together. For instance, when the expert element determines that features F1 and F2 constitute a velocity couplet signature, it asks the image processing element to create a velocity couplet feature from F1 and F2. This higher-level feature can also respond to queries about its properties and its relationship to other features.

5. Knowledge processing

The function of WX1's expert system is to examine and classify the results derived from lower-level pattern recognition algorithms. The expert system contains symbolic models of weather phenomena to be recognized. The low-level features extracted from the radar data are compared against these models to determine the most likely classification of each feature.

This section will describe the nature of the meteorological knowledge used in the system. An example of how rules are used to recognize wind shear phenomena is provided. Next, a mechanism for quantifying the degree of certainty about the interpretation of features is discussed. This mechanism for reasoning about uncertainty allows evidence from multiple sources to be combined and selection of the most likely interpretation from a set of competing hypotheses. Finally the control strategy used in the system is described.

a. *Meteorological knowledge*

The WX1 system ruleset contains several types of knowledge. One type of knowledge defines the weather phenomena and radar artifacts which the system can recognize. A second type of knowledge relates these phenomena to radar image features. Other knowledge defines the relationships between different weather phenomena and the evolution of these phenomena in time.

As an illustration of the first type of knowledge, consider Table 1, which shows the various radar meteorology phenomena recognized by the WX1 system. These phenomena are divided into "storm" and "shear" classes. The "storm" class contains two possible types of phenomena: "storm event" and "storm artifact". The storm event subclass is further subdivided into different types of events, including single-cell, squall-line and super-cell. The storm artifact subclass includes several types of spurious signatures that must be differentiated from actual storms, including clutter, range ring (a data recording artifact) and range folding.

The second type of knowledge expresses structural models which connect meteorological phenomena to radar observables. For example, Fig. 4 shows a model, based on Fujita (1985), of a particular type of surface microburst. In this model, a surface microburst consists of a surface divergence, a middle-level rotation and an upper-level convergence. Each of these phenomena, in turn, is linked to radar signatures. For example, a surface divergence is recognizable from a velocity couplet, a positive radial shear or both signatures.

Another type of knowledge defines the relationships between different meteorological phenomena. These relationships are important in distinguishing between real phenomena and radar artifacts. For example, the presence of a nearby storm can be used to help confirm the existence of a gust front. Similarly, the presence of a shear line associated with a gust front can be used to predict the existence of a reflectivity thin-line.

A final type of knowledge describes the time evolution of meteorological phenomena. For example, a microburst begins with activity at or above cloud level, descends to middle level and finally reaches the surface. Thus, the presence of precursors at middle or upper levels can be used to increase the confidence in a surface divergence signature. Likewise, if a microburst is recognized in a particular radar scan, then the confidence in that recognition should be higher if the microburst was recognized in the same location on a previous radar scan.

TABLE 1. Classification hierarchy for knowledge base.

- Storm
  - Storm event
    - Single-cell
    - Squall-line
    - Super-cell
  - Storm artifact
    - Clutter
    - Range ring*
    - Range folding
- Shear
  - Shear event
    - Linear gust front
      - Gust front
      - Inflow-outflow line
    - Ring gust front
    - Downburst
      - Microburst
      - Macroburst
    - Divergent line
    - Mesocyclone
  - Shear artifact
    - Velocity folding
    - Range folding
    - False zeros†
    - Bad radial*
    - High noise

* Data recording artifact.
† Velocity zeros induced by clutter.

b. *Use of rules*

As an example of how rules are used in the system, consider the problem of detecting a velocity couplet signature indicating a surface outflow for a microburst. A rule to recognize velocity couplets might then appear (in pseudo-English form) as follows:

(rule recognize-velocity-couplet

if	FP is a candidate positive-velocity feature FN is a candidate negative-velocity feature
test	distance between FP and FN $\leqslant$ 4.0 km velocity difference between FP, FN $\geqslant$ 10 m s^{-1}
then	create velocity couplet feature from FP, FN add velocity couplet fact to working memory).

This rule assumes that the velocity features are previously evaluated by other rules to produce a set of candidate or likely features on the basis of size, shape, maximum value and other tests.

For the case shown in Fig. 3, the variables FP and

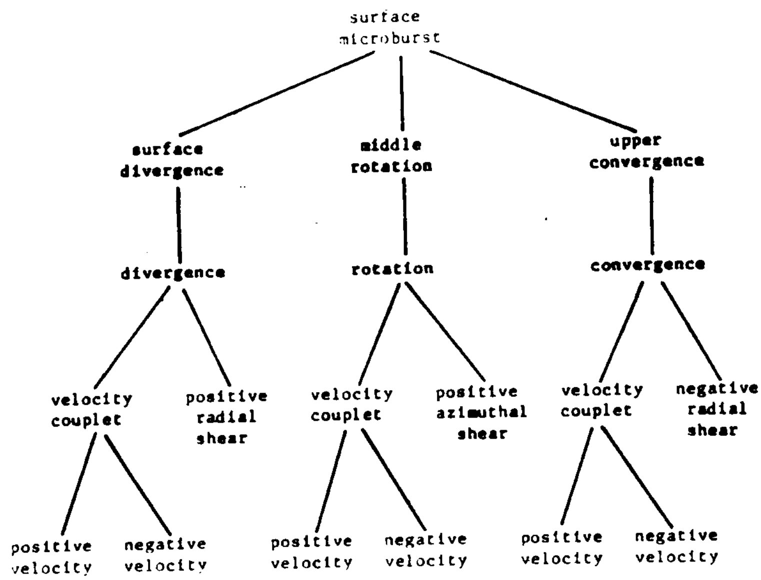

FIG. 4. Model of a microburst wind shear hazard.

FN would be matched up against features F1 and F2, in the "if" part of the rule. The "test" part of the rule invokes the computation of the distance from F1 to F2, and then checks that the result is less than 4.0 km. It also checks that the difference in velocity between the two features is greater than 10 m s^{-1}.

If these conditions are fulfilled, then the action part of the rule is carried out. For this rule, the actions are to create a velocity couplet feature from F1 and F2, and add the corresponding fact to working memory. This new fact can then trigger another rule which decides, based on its orientation, that the velocity couplet represents a divergence. A new fact would then be added to the working memory representing this divergence feature.

It can be seen that other rules can recognize rotation and convergence signatures, and add the corresponding facts to working memory. These signatures are further classified as surface divergence, middle-level rotation and upper-level convergence. These signatures can then be combined by a rule to recognize the surface microburst.

c. *Reasoning with uncertainty*

In order to quantify the degree of certainty to which a given feature represents a particular meteorological phenomenon, each feature has one or more quantities associated with it called *confidence factors* (CFs). A CF indicates the degree to which the feature is believed to represent a certain type of wind shear hazard or radar artifact.

A CF is a number ranging from −1 to +1. A positive CF indicates belief in a hypothesis, while a negative CF indicates disbelief. CFs from multiple lines of evidence can be combined to produce a net belief or disbelief. Given two pieces of evidence, E1 and E2, with associated confidence factors, CF(E1) and CF(E2), then

$$CF(E1, E2) = CF(E1) + CF(E2)[1 - CF(E1)] \quad (1)$$

assuming both CFs are positive. For example, if CF(E1) = 0.2 and CF(E2) = 0.5, then CF(E1, E2) = [0.2 + 0.5][0.8] = 0.6. (Note: positive and negative CFs can be combined using a more general version of Eq. (1), as detailed in Buchanan & Shortliffe, 1984). Positive CFs accumulate in a fashion which asymptotically approaches +1, indicating increasing certainty as more evidence is added.

The CFs are used in two ways in the WX1 system. The first way is to combine evidence from multiple sources to increase belief in a given hypothesis. The second way is to select the most likely interpretation of a feature from a set of competing hypotheses. Examples of these uses will now be provided.

As an example of evidence accumulation, consider the following hypothetical example in microburst recognition. Suppose that there are two confidence factors associated with a surface divergence (outflow) feature. The first CF is the result of a velocity differential test and is denoted CF(DV); the second CF is determined by whether a precursor signature was recognized on the previous volume scan and is denoted CF(PC). Suppose that these CFs are defined by

$$CF(DV) = \begin{cases} 0.2, & 5 < DV < 10 \text{ m s}^{-1} \\ 0.6, & 10 < DV < 20 \text{ m s}^{-1} \end{cases}$$

$$CF(PC) = \begin{cases} 0.0, & \text{no precursor on previous volume scan} \\ 0.5, & \text{precursor on previous volume scan} \end{cases}$$

and that CF(MB) = CF(DV, PC) represents the confidence factor for the feature representing a microburst.

Now consider two cases. In case 1, the velocity differential DV is 12 m s^{-1} and there is no precursor on the previous volume scan. For this case, CF(DV) = 0.6 and CF(PC) = 0.0, so CF(MB) = 0.6. In case 2, the velocity differential is only 8 m s^{-1}, but a precursor was present on the previous scan. For this case, CF(DV) = 0.2 and CF(PC) = 0.5, so CF(MB) = 0.6 as before. Thus, if a CF(MB) of 0.6 is viewed as a definite microburst indication, it can be seen that the feature can be declared as a wind shear hazard in both cases.

A further extension of this approach allows the system to consider multiple hypotheses while carrying out the wind shear recognition task. The system assigns a confidence factor to each hypothesis and then selects the hypothesis with the highest CF. For example, the system may hypothesize that a given shear feature represents a gust front, velocity aliasing, ground clutter or weak signal. Suppose that the system assigns the following confidence factors while searching for gust fronts in a given tilt:

$$\begin{aligned} &CF\ (\text{gust front}) &&= 0.6 \\ &CF\ (\text{aliasing}) &&= 0.2 \\ &CF\ (\text{second trip}) &&= 0.3 \\ &CF\ (\text{weak signal}) &&= 0.1 \end{aligned}$$

In this case, the system would select the gust front hypothesis as most likely for this shear feature.

It should be noted that the performance of the WX1 system is relatively insensitive to small changes in the values assigned to the CFs. In fact, the system tends to resist attempts to fine tune the CF values. This behavior is due to the system combining many sources of evidence to arrive at conclusions, and also because it invokes additional rules and feedback operations to resolve uncertain features. Improved system performance is achieved by adding more knowledge to the system, rather than by attempting to tune the CF values.

d. Control

The WX1 uses a combination of bottom-up (data-driven) and top-down (goal-driven) control. The basic control strategy in YAPS is forward-chaining or data-driven, i.e., reasoning from premises to conclusions. However, WX1 also makes heavy use of goals to provide a hierarchical processing structure. This hierarchy reflects the natural organization of the radar data into datasets, volumes, tilts and fields. The goal structure ensures, for example, that all fields (reflectivity, velocity, radial shear, etc.) are processed for a given tilt before going on the next tilt.

The interpretation process proceeds basically in a bottom-up fashion, assembling lower-level features into higher-level ones (i.e., combining surface divergence, middle-level rotation and upper-level convergence features into a microburst feature). However, the system does generate goals in a top-down fashion in some cases. For example, if a gust front was detected from a shear line, then the system will generate a goal to look for a thin-line in that region using a special algorithm that would not normally be applied. Also, if a gust front was located on the previous volume scan, the system will look for the gust front in that area first on the next scan.

6. Results

Rulesets are currently being developed to recognize two types of low-altitude wind shear hazard: microbursts and gust fronts. This section will describe the characteristics of these hazards, their associated single-Doppler radar signatures, and some current recognition results.

a. Microburst recognition

A microburst is a small-scale, short-lived event characterized by a strong downdraft which induces a hazardous outflow of winds at the surface. Figure 5 shows an aircraft encountering a microburst while landing. The combination of downdraft and loss of airspeed while passing through a microburst can cause excessive altitude loss and result in a crash.

Microbursts are defined to be less than 4 km in initial horizontal outflow extent and to last 5 to 10 min. For a typical microburst observed in the Joint Airport Weather Study (JAWS) project, the surface differential velocity typically increased from 12 m s^{-1} (25 kt) to a maximum of 24 m s^{-1} (50 kt) in this time interval (Wilson et al., 1984).

Figure 6 shows the characteristic single-Doppler radar signatures associated with these flow fields. The model of Fig. 4 discussed previously shows the connection between these radar signatures and a microburst model proposed by Fujita (1985). In this model, a microburst is characterized by a surface divergence, middle-altitude (~1.5 km AGL) rotation and upper-level (~2.5 km AGL) convergence. The ruleset includes other microburst models, such as a surface divergence accompanied by a high reflectivity rain core.

Figure 7 shows an example of a JAWS microburst which occurred 13 km east of Stapleton Airport on 14 July 1982. The microburst began at about 1433 MDT and reached peak intensity ten min later (Stevenson, 1984), at about the time the data of Fig. 7 were collected. Radial velocity data are shown for scans at the

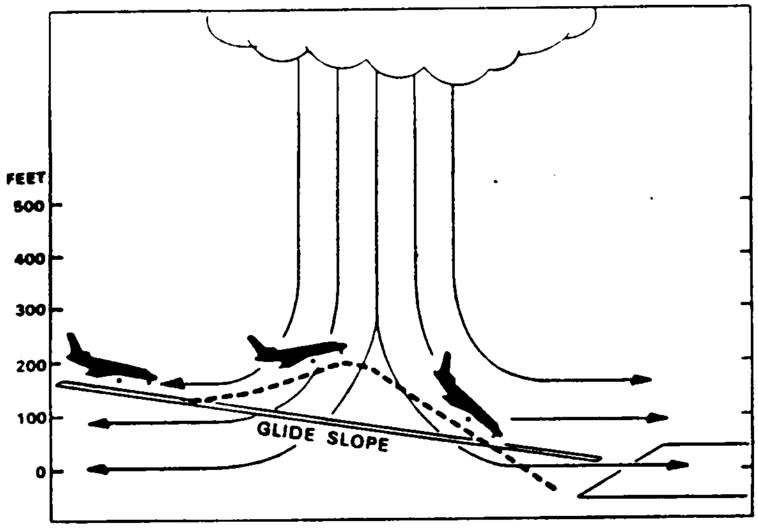

FIG. 5. Aircraft encounter with a microburst.

surface (tilt 1, upper panel) and at 2.1° elevation angle (tilt 2, lower panel). The cursors show the location of a surface divergence signature in tilt 1 and a middle-altitude rotation signature in tilt 2. The images are 256 by 256 pixels at a resolution of 0.25 km per pixel.

The first step in the microburst recognition processing is to extract features from the input radar fields. For tilt 1, the velocity and radial shear fields are extracted, while for tilt 2, the velocity and azimuthal shear fields are extracted. Different fields are extracted for the two tilts because the system is looking for surface divergence signatures in the first tilt and for middle-altitude rotation signatures in the second. Upper-altitude data were not available in this case, so there was no attempt to perform extraction for convergence signatures.

The ruleset evaluates the extracted features, promoting likely features to candidate status, and labeling the others as weak. The candidate features for each field are shown in Fig. 8. Initially, the features in the velocity couplet signature are labeled as weak due to their small size. However, these features are promoted to candidate status on the basis of their overlap with one of the radial shear signatures. The velocity couplet is then recognized as a surface divergence.

The candidate features for tilt 2 are examined in a similar fashion. A middle-altitude rotation is identified from one of the azimuthal shear features, but the cor-

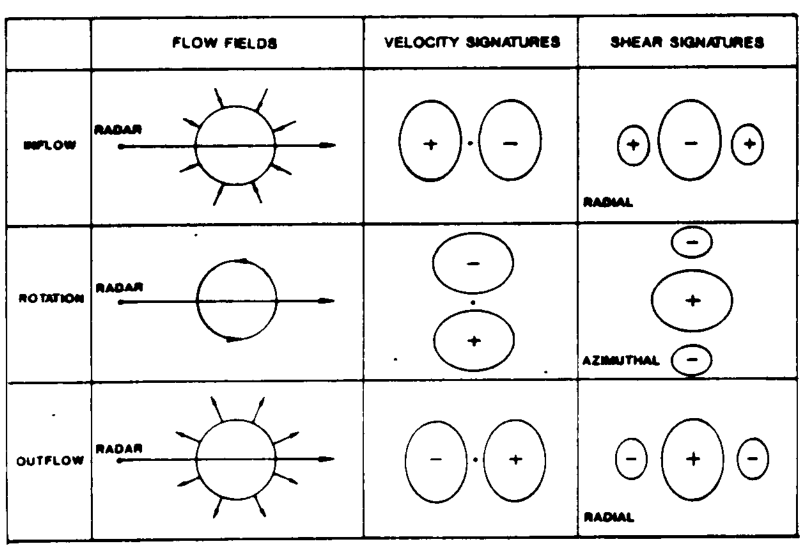

FIG. 6. Single-Doppler radar signatures of a microburst.

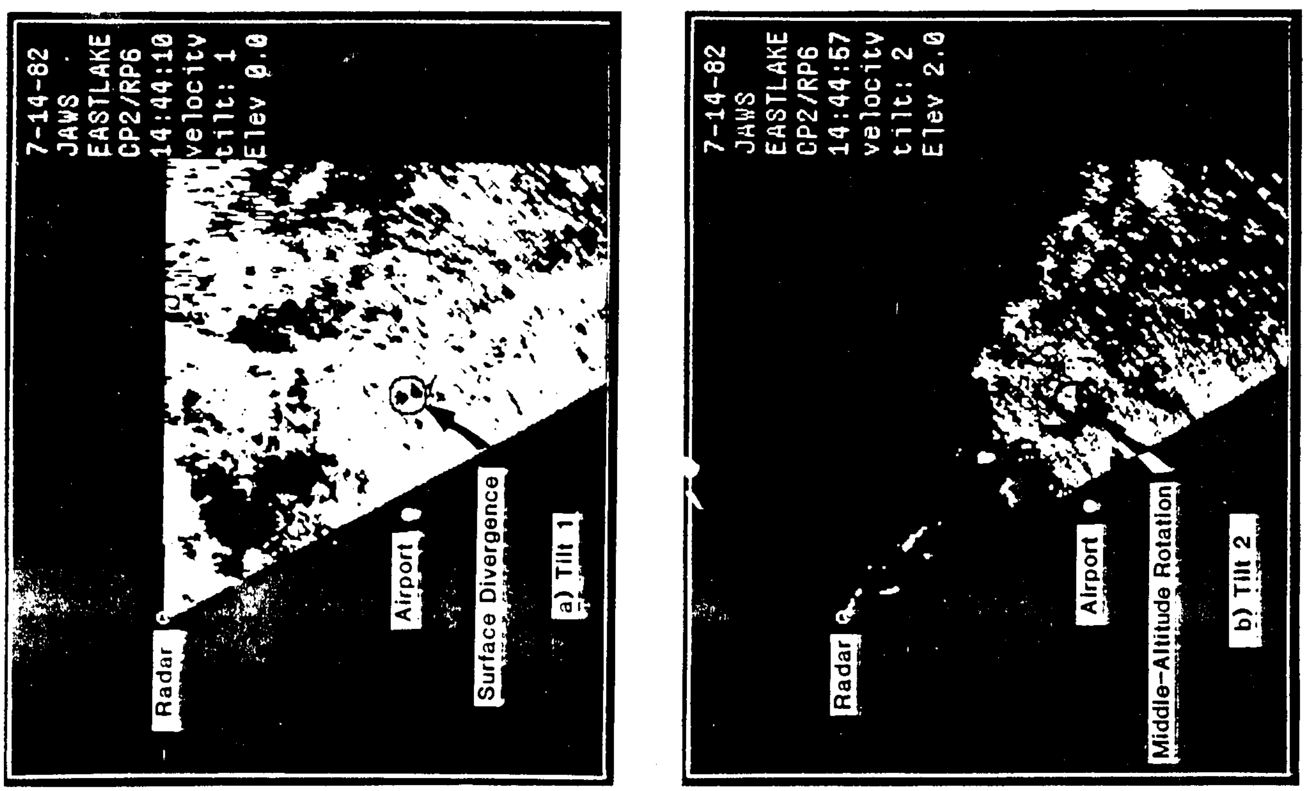

FIG. 7. Radar data for Denver microburst on 14 July 1982.

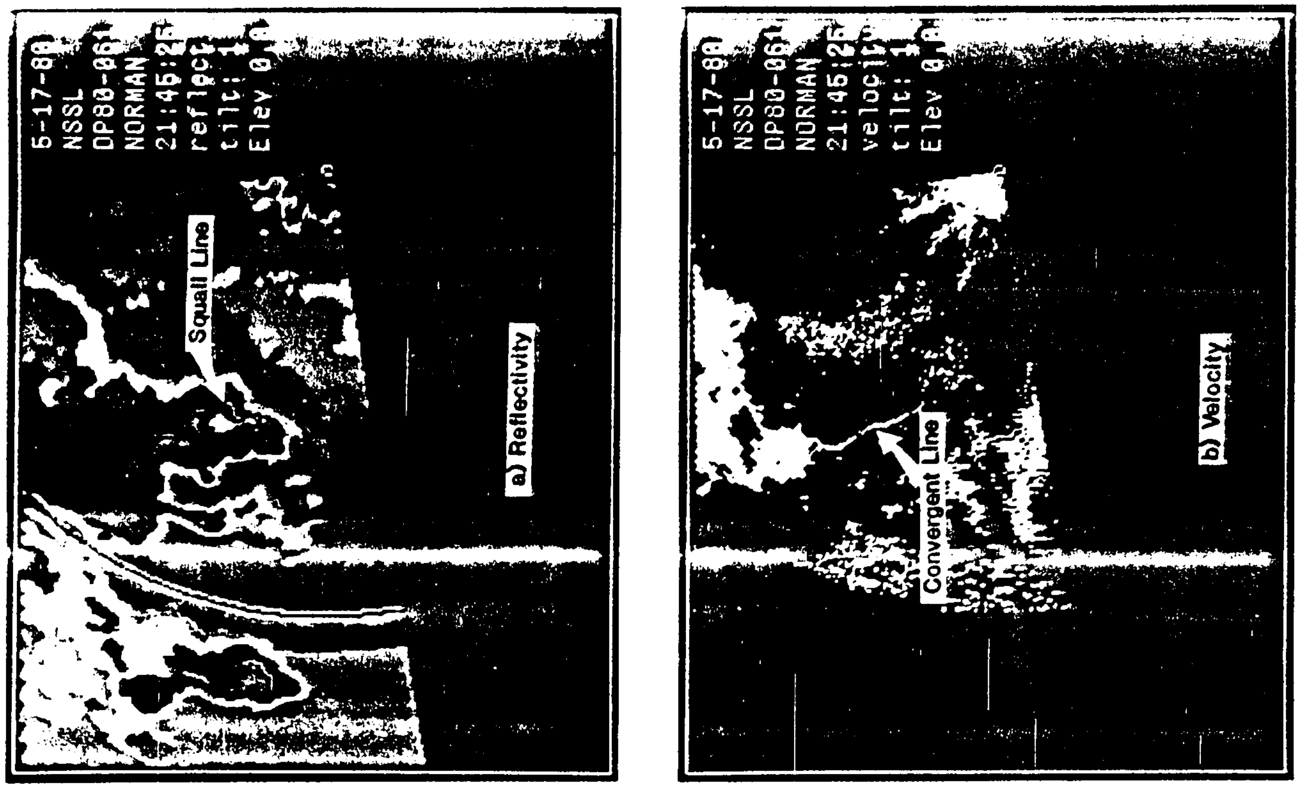

FIG. 14. Radar data for Oklahoma gust front on 18 May 1980.

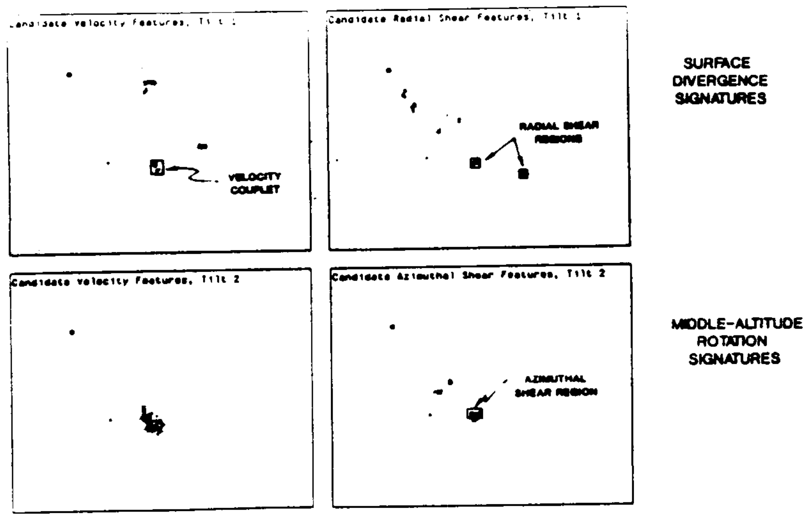

FIG. 8. Surface and middle-altitude microburst signatures.

responding velocity couplet signature is not recognized because the positive velocity feature is too large. However, the system then determines that the middle-altitude rotation overlaps the surface divergence, and therefore declares that a microburst has been detected. This result is indicated in Fig. 9, showing the overlap of the surface divergence and middle-altitude rotation features.

This example illustrates the ability of the system to combine evidence from multiple sources. In this case, a surface divergence signature was recognized from both velocity couplet and radial shear signatures. The resulting combined surface divergence signature is of higher reliability than either signature individually. The capability of the system to merge these signatures increases the robustness and reliability of the microburst recognition process.

Figure 10 summarizes the results of processing seven volume scans of JAWS data for 14 July 1982 lasting fourteen min from 1431 to 1445 MDT. Two microbursts were detected during this interval, the first during 1431–1434 and the second during 1442–1445. Each microburst was recognized for two volume scans, as indicated by the centroids plotted in the figure.

The microburst ruleset has been run on a set of 25 Denver microburst cases covering 77 volume scans of radar data. Quantitative evaluation of these results is currently in progress.

b. *Gust front recognition*

A gust front is the leading edge of a cool air mass that has recently descended from a thunderstorm or convective cloud (National Academy of Sciences,

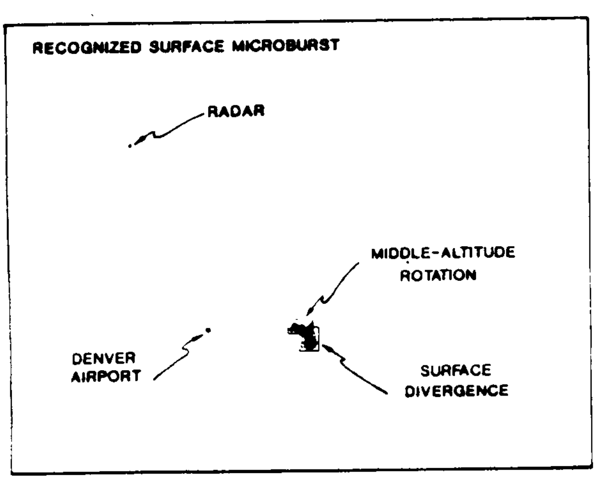

FIG. 9. Recognized surface microburst.

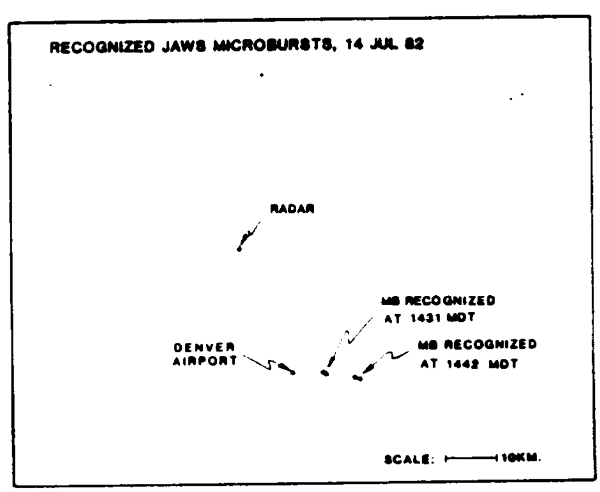

FIG. 10. Recognized JAWS microbursts.

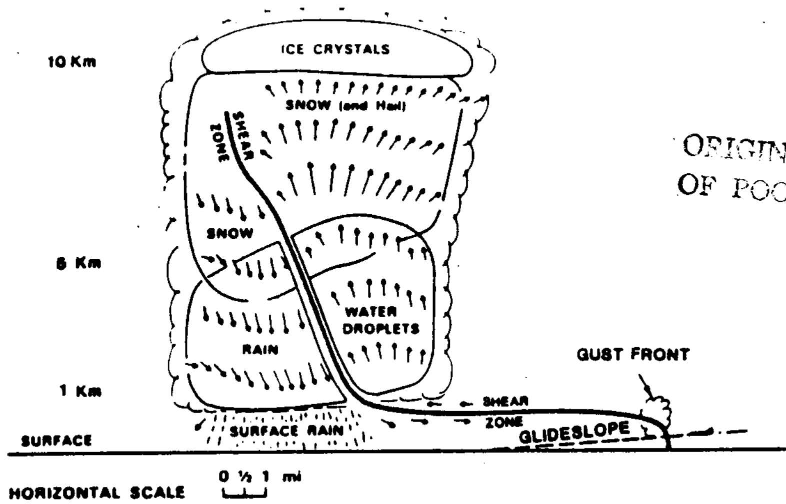

FIG. 11. Aircraft encounter with a gust front.

1983). This air mass spreads out at the surface and is often found many kilometers away from the parent storm, as shown in Fig. 11. Although gust fronts pose less of a threat to aircraft than microbursts, an aircraft passing through one can experience turbulence and buffeting. Also, the ability to detect gust fronts is useful in predicting wind shifts that cause active runway changes (McCarthy and Wilson, 1985).

As shown in Fig. 12, a gust front is characterized by a region of cold air outflow converging with a warm air inflow. This convergence creates a long, thin line of negative radial shear (decrease in radial velocity with increasing radial distance), independent of whether the gust front is moving towards or away from the radar.

The gust front ruleset initially looks for shear regions that have a high probability of representing a gust front. These regions are declared to be high confidence features on the basis of such evidence as proper shape and size and high correlation with shear regions in adjacent tilts. These high confidence features are then used as islands of reliability to guide the processing of regions with weaker evidential support.

An example of this process is illustrated schematically in Fig. 13. In tilt 1, the line of shear is long and unbroken, and thus it is labeled as a high confidence shear region. In tilt 2, however, the line of shear is split into two regions due to noise, missing data, or imperfect feature extraction. The resulting segments are therefore assigned as candidate or lower confidence regions. But because these two segments overlap a high confidence

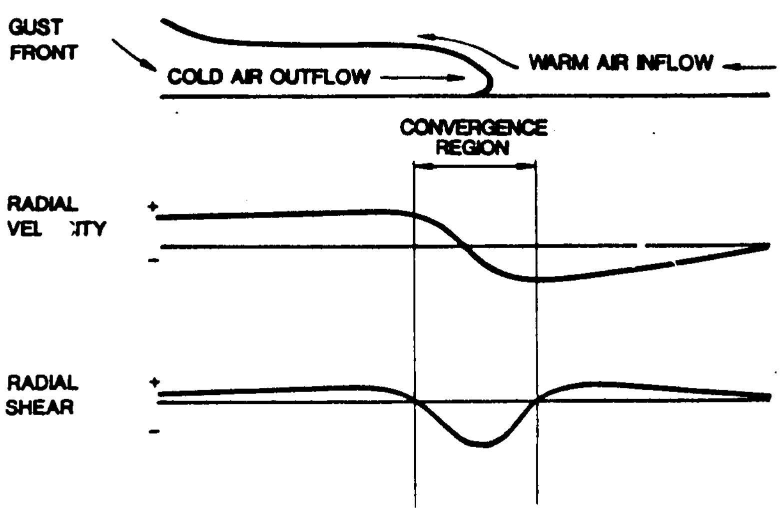

FIG. 12. Gust front convergence signatures.

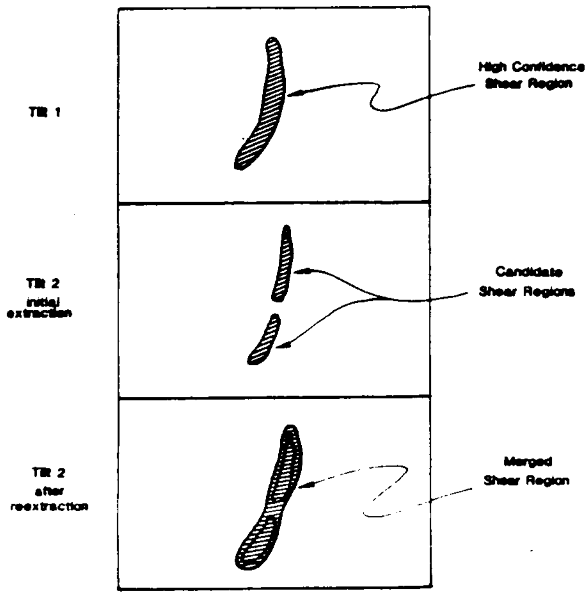

FIG. 13. Use of evidential support to guide gust front processing.

region on an adjacent tilt, the expert system directs the radar image processing element to grow (enlarge), the two regions and examine them again. In this case, the two regions now touch and are merged into a single region which can now be assigned high confidence.

When one or more shear features in a tilt are recognized as representing a gust front, WX1 assembles them together into a convergent line signature. This convergent line signature can be combined with other recognized features, such as a reflectivity thin line, to form a gust front signature. If shear line signatures in adjacent tilts overlap sufficiently, they are assembled to form a gust front signature for that volume scan. Gust front signatures from successive volume scans can in turn be combined to yield the recognition of a gust front over a time sequence of radar observations.

To illustrate this process, consider the radar data of Fig. 14. These data were gathered by the National Severe Storms Laboratory (NSSL) at Norman, Oklahoma and contain a large convective storm moving eastward. The dataset includes four volume scans covering a 15 min period, plus one additional volume scan 52 min later. The figure shows the surface elevation scan for the first volume. A squall line is seen in the reflectivity field (upper panel) and a line of convergence is seen in the velocity field (lower panel). The scale is 1 km per pixel for these 256 by 256 pixel images.

Figure 15 shows the gust front features detected by the system for the first four volume scans. Note in particular that the gust front feature for volume 2 is broken into two distinct parts. Nonetheless, the ruleset recognizes these two segments as representing a single gust front shear line. Furthermore, it is able to recognize that these features recognized in successive volume scans represent a single gust front moving westward.

Figure 16 shows ability of the system to predict the location of the gust front line. The gust front features for the first four volume scans are plotted at the left side of the figure, with a rectangle indicating the cen-

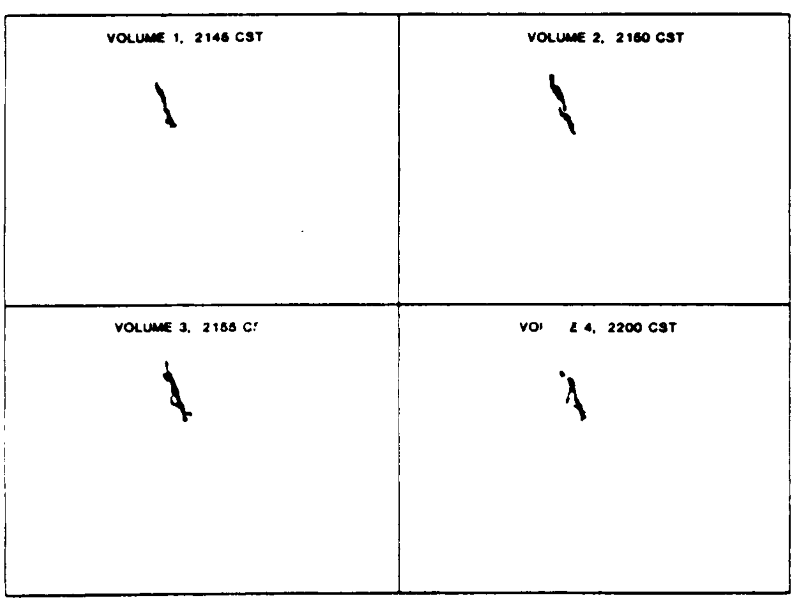

FIG. 15. Gust front signatures, 2145–2200 CST.

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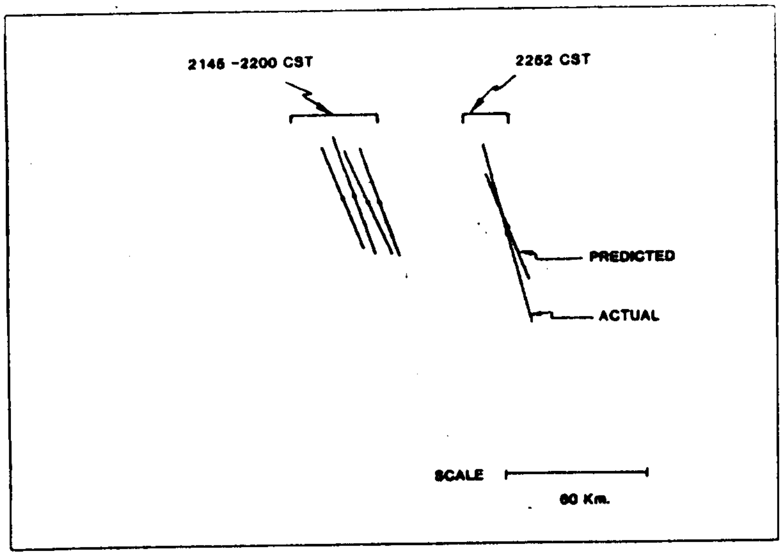

FIG. 16. Gust front tracking and prediction.

troid of each feature and a line indicating its orientation and approximate length. At the right side of the figure are the predicted location of the gust front 52 min later and the actual location of the gust front at that time as determined by the system.

7. Summary

This paper has presented work on the development of an artificial intelligence-based system for recognizing low-altitude wind shear hazards from Doppler radar data. The approach employed by the WX1 system is to use expert system and computer vision techniques to emulate the symbolic reasoning and visual processing capabilities of a radar meteorologist. A rule-based expert system employs heuristic rules to capture meteorological knowledge, and reasons symbolically about radar image features represented as facts in its working memory. The expert system invokes numerical and image processing operations on features by sending messages to WX1's radar image processing component.

The basic mode of operation in the WX1 system is to build up an interpretation of the radar data by performing successive stages of abstraction. The input radar data are converted to a set of regions by an initial feature extraction step. These product level features are combined to form more abstract features, leading ultimately to the recognition of wind shear hazards. This process is directed by a set of recognition rules which express expert knowledge about radar meteorology, including weather phenomena and radar data artifacts. This knowledge includes structural models linking weather phenomena to radar image features.

The system design includes a means for inexact reasoning about features using confidence factors. Confidence factors are used to accumulate evidence and to resolve multiple competing hypotheses. The use of CFs allows the system to constrain the search for wind shear signatures to a set of likely candidates. It also allows the system to process these features in an adaptive fashion using past history and contextual cues.

Rulesets are currently being refined for recognizing microburst and gust front wind shear hazards. The initial results presented demonstrate the ability of the system to recognize these hazards. Work in progress includes a quantitative assessment of the system performance, including probability of detection and false alarm rate.

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Automated Detection of Microburst Windshear for Terminal Doppler Weather Radar*

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ABSTRACT

An image analysis method is presented for use in detecting strong windshear events, called microbursts, in Doppler weather radar images. This technique has been developed for use in a completely automated surveillance system being procured by the Federal Aviation Administration (FAA) for the protection of airport terminal areas. The detection system must distill the rapidly evolving radar imagery into brief textual warning messages in real time, with high reliability.

1. INTRODUCTION

The term "microburst" refers to the divergent windshear formed when a strong downdraft impacts the Earth's surface. Such downdrafts often occur within convective storms, and are also found in virga shafts where no rain reaches the ground. This form of low-altitude windshear has come into focus in the last decade as a serious hazard to aviation, and has been blamed for several major aircraft accidents. The FAA is currently procuring a capable Terminal Doppler Weather Radar (TDWR) system, to be placed near major airports for the detection of these windshear hazards.

The problem of detecting microburst windshear events using surface-based Doppler radar is addressed in this paper. The characteristics of the phenomena to be detected, and of the sensor to be used, differentiate this problem from more classical computer vision and image processing applications. The lack of man-made edges and the amorphous time-varying shape and size of the windshear regions render most well-known edge detection and object tracking techniques ineffective. To overcome these difficulties, an ad hoc scale-independent shear detection method is used to locate the hazard regions, which are then tracked as distributed events, not individual point targets.

The subsequent sections of this paper discuss the Doppler radar signature of microburst events, the details of the detection procedure being used to identify these signatures, and the performance results obtained to date.

2. MICROBURSTS AND THEIR SIGNATURE IN DOPPLER RADAR DATA

The physical phenomena related to a microburst are depicted in Figure 1. The strong downdraft which creates the surface divergence defining the microburst will often exhibit convergence and rotation at middle and upper altitudes. This downdraft is also typically associated with a storm cell, which is observed as a region of locally strong reflectivity [1].

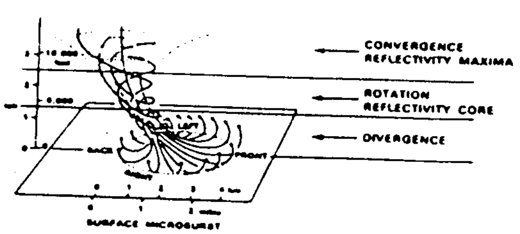

Figure 1: Radar signatures associated with microburst-related phenomena.

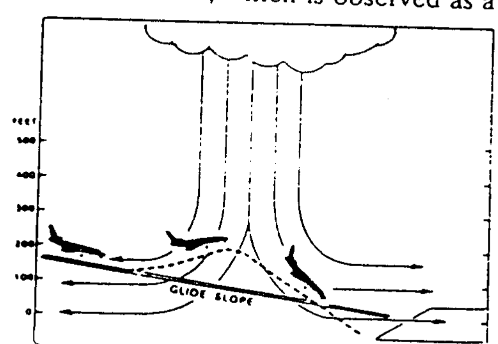

Figure 2: Schematic diagram of an aircraft encounter with a microburst outflow.

* The work described here was sponsored by the Federal Aviation Administration. The United States Government assumes no liability for its contents or use thereof.

The surface divergence formed by the downdraft is the primary characteristic of the microburst, and the strength of this outflow determines the degree of hazard which the microburst presents to penetrating aircraft. As shown in Figure 2, as an aircraft encounters a microburst when landing, the outflow is first manifest as an increase in headwind which lifts the aircraft above the desired glide slope path. As the aircraft passes through the outflow center, the strong downdraft and sudden tailwind dramatically reduce the lift force of the craft, causing it to lose altitude rapidly. If the aircraft has inadequate reserve thrust to compensate for this loss of lift, ground impact may result short of the runway.

Since the surface divergence is the primary feature of the microburst, and the actual source of the hazard to aircraft, the focus in this paper shall be on the detection of this divergence region, independent of the remaining radar observables shown in Figure 1. While this approach was initially chosen to minimize the computation requirements and complexity of the detection process, the resulting algorithm has also been shown to perform quite well. Work on a more advanced detection process, utilizing the additional microburst features aloft, is presented in [2].

The primary quantities measured by Doppler weather radar are reflectivity and (radial) velocity. The reflectivity measurement is related to the number and size of the radar scatterers (particularly raindrops) in the radar sample volume (typically 1 degree in azimuth and 120 meters in range). The velocity measurement indicates the mean of the radial component of the scatterer velocities. The images of these quantities (which are sampled on a polar, not Cartesian, grid) provide the basic precipitation and windfield information used by radar meteorologists to locate and characterize storm cells, and related windshear hazards.

The color images shown in Figure 3 illustrate the radar reflectivity and radial velocity images for each of two typical microbursts. The first case (Figure 3a) is from data collected on 1 July 1986 using the FL2 Doppler radar in Huntsville, AL. An angular wedge of data was collected to the North of the radar (located at the vertex of the wedge), where air-mass thunderstorms and showers were present. Several strong reflectivity cells are present, and are producing divergent outflows of varying strengths. The two regions outlined in red are the output of the microburst outflow detection algorithm. The leftmost region is a microburst at the peak of its outflow strength, while the smaller outflow to the right is a microburst which is just impacting the ground; the strength of the outflow for this microburst will increase with time. The second case (Figure 3b) is taken from 25 July 1986, and shows a strong isolated storm cell producing a clear microburst divergence signature, located roughly 20 km southeast of the radar. These examples indicate the amorphous nature of the microburst surface images, and the variation in size, strength, and shape typical of these features.

Figure 4 shows the range-velocity profile for the outflow from Figure 3a, for each of four adjacent radials from the radar. Each plot shows the radial velocity as a function of range, and the line segments above each plot denote the segment of the radial where the detection algorithm found divergent shear. These plots illustrate the general character of the shear signature, and its variability from radial to radial. On the two center

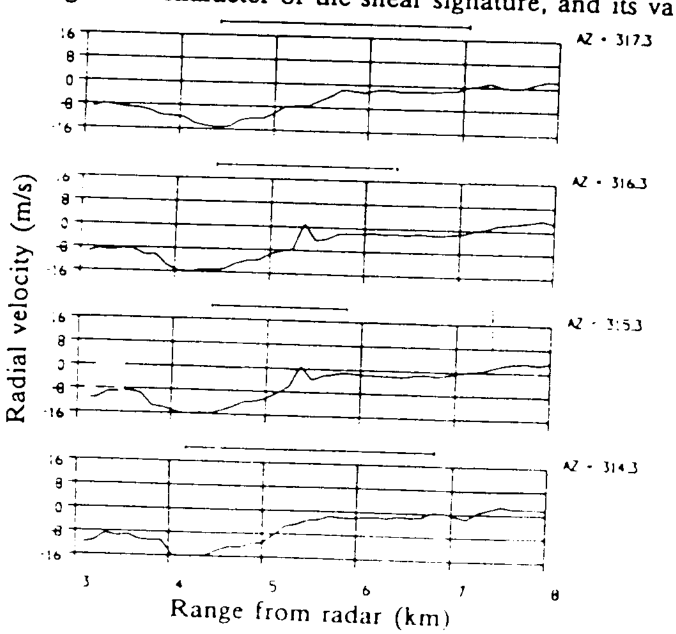

Figure 4: Range-velocity profiles for 1 July 1986 case. Each plot shows the radial velocity as a function of range from the radar, for four adjacent radials of the radar. The line segments above each plot indicate the divergent shear segments identified by the microburst detection algorithm.

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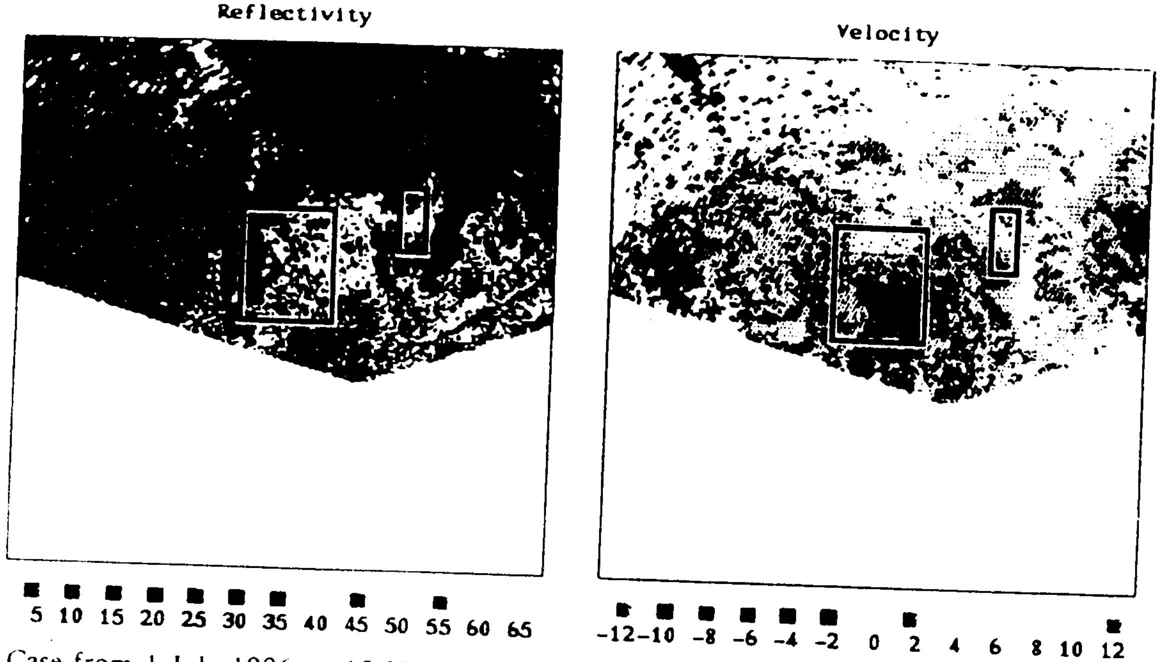
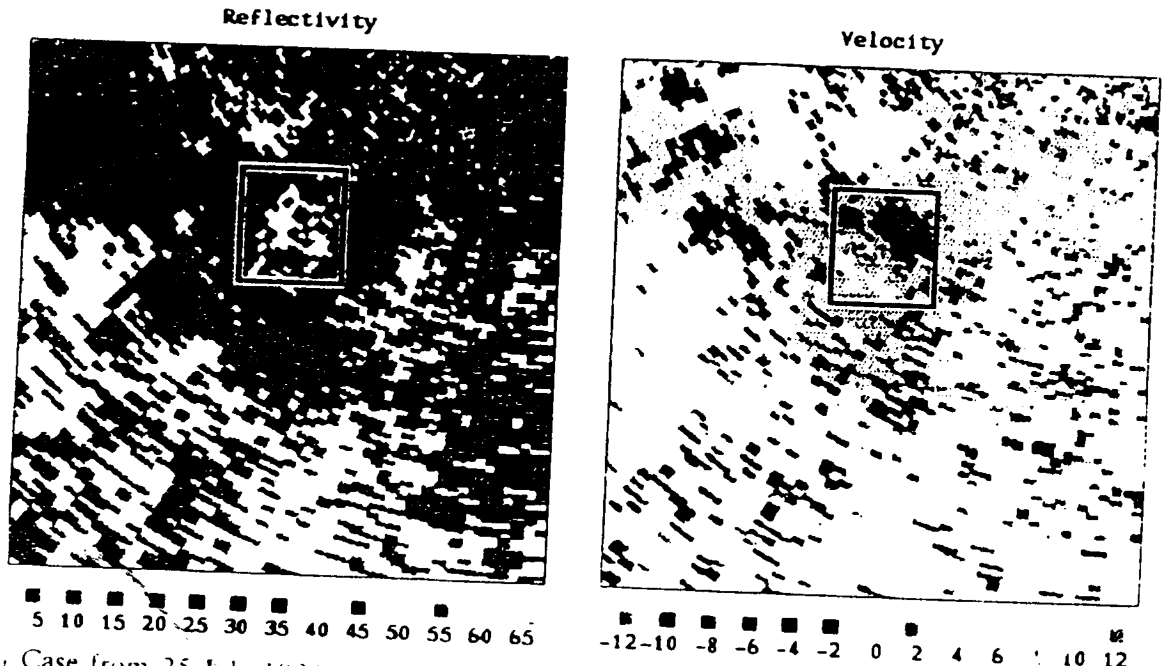


(a) Case from 1 July 1986, at 18:27:02 UT. Radar is located at vertex of data collection sector.



(b) Case from 25 July 1986, at 20:12:41 UT. Radar is located 20 km northeast of microburst

Figure 3: Radar images for typical microbursts. Images on left are radar reflectivity, in units of dBz (30 dBz is light rain, 50 dBz is extremely heavy rain or hail). Images on right are radial velocity, in units of m/s where negative velocities indicate motion towards the radar. Each image depicts an area 26 km-square. The regions outlined in red are microburst algorithm alarms, where strong divergent shear have been dete[illegible]. Both cases were observed with the FL2 radar, while it was located in Huntsville, AL.

radials (azimuth angles 315.3 and 316.3), a single point anomaly is seen at roughly 5.3 km range. At this range, the velocity measurement has been biased by the power returned from a localized clutter source (i.e., birds, aircraft, buildings, etc), and has disturbed the smooth shear pattern. As explained below, the shear detection process incorporates specific tests to avoid being distracted by such localized disturbances.

3. Algorithm Description

The microburst surface outflow detection algorithm is composed of three basic stages, illustrated in Figure 5. The first stage attempts to locate regions of divergent shear along individual radials of velocity measurements (as shown in Figure 4), resulting in linear segments of detected shear. The second stage associates these segments in azimuth, joining together overlapping segments found on adjacent radials. The result of the second stage is a set of two-dimensional regions of shear. These regions are then correlated from radar scan to scan in the third stage, to produce time histories for each region. Shear regions which exhibit adequate time continuity and sufficient outflow strength are then declared as microbursts.

Figure 5: Microburst outflow detection algorithm block diagram

Shear Segment Detection

The divergent shear segment detection process is the fundamental element in the algorithm; the remaining stages serve primarily to filter out those segments and regions which are not of adequate significance to generate microburst alarms. The job of the shear segment detector is to identify the characteristic divergence patterns, such as those in Figure 4. The most straightforward approach to detecting this pattern would be the use of a local linear operator such as the one-dimensional gradient: $\Delta = f(x+n) - f(x-n)$, the output of which would be thresholded against a specific gradient level. This approach would then detect segments with consistent shear above the threshold level.

The simple gradient operator has several well-known difficulties, particularly its sensitivity to noise and spurious data values. The use of smoothing and outlier rejection pre-filters may be used to reduce the noise level, at the cost of some blurring of the gradient information in the data. Another difficulty with this approach is the implicit spatial scale involved in choosing the parameter 'n', which must be chosen to match the scale of the shear. Since microburst outflows are typically small (< 1 km diameter) when they first impact the surface, and grow to much larger diameters as they intensify, no single scale will be optimal over the full duration of the microburst lifetime. Multi-scale techniques could potentially be used to overcome such problems, by merging the outputs of several gradient operators of different scales applied to the signal.

In an effort to avoid the complication associated with scale-specific gradient operators, a scale-independent technique has been employed for the shear segment detection. This method was adapted from the pattern search algorithm developed by Zrnic and Gal-Chen [3] for the detection of divergence at storm tops. The resulting shear identification method is tailored to find runs of velocity measurements which are 'generally increasing' with range, and includes several specific conditions designed to cope with data anomalies typical of weather radar observations.

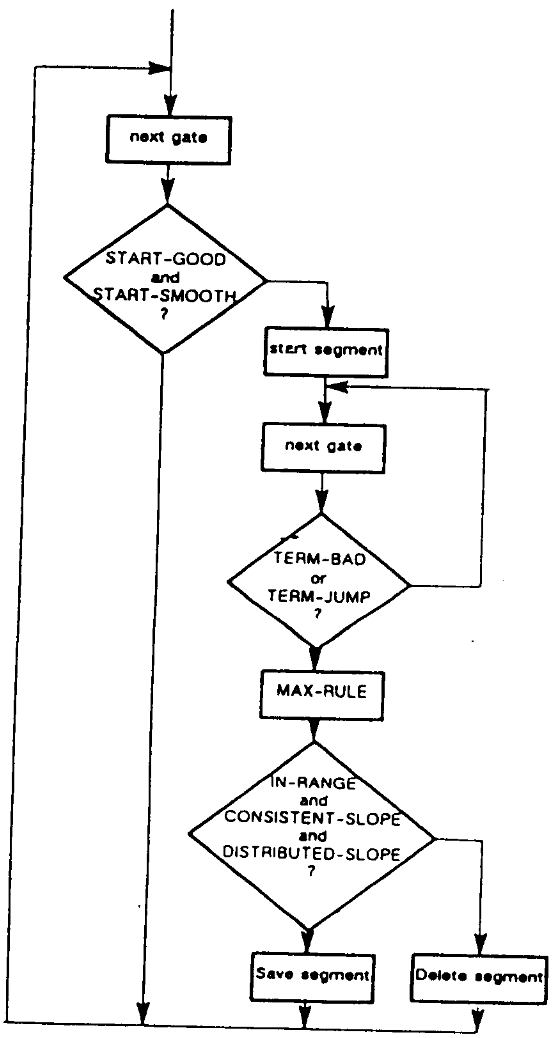
The shear segment detection process, detailed in Figure 6, consists of sliding a window along a radial of velocity measurements, applying a detailed set of segment start/stop tests to locate sections corresponding to significant divergent shear. The criteria used to determine whether to start or stop a segment at the current sample point are both based on the notion of a 'window' of sample points (typically a span of 4 sample points, or 0.48 km actual distance) ahead of the current sample point. The basic detection process proceeds as shown in Figure 6(a), by sliding the window out in range until the start-of-segment criteria (START-GOOD and START-SMOOTH, as described in Figure 6(b)) are satisfied. At this point, a new segment is started, and the window is advanced in search of the end of the segment.

To expedite the search for the end of the segment, and to reduce the chance of ending the segment prematurely, not all sample points are considered in this search. After the starting point has been located, subsequent sample points are chosen for consideration based on the NEXT-GATE rule, which attempts to move from point to point in a consistently increasing trend, but avoids getting 'caught' on large 'spikes' in the data. At each subsequent point chosen by this rule, the sample points in the window following it are tested for the end–of–segment criteria (TERM–BAD or TERM–JUMP), which end the segment when either a decreasing trend or an unrealistically large increase is found.

Once the end of a segment has been detected, the ending point of the segment is adjusted so that it lies at a local maxima. This adjustment is accomplished by incrementally moving the ending point back (towards the starting point) one sample point at a time until the MAX–RULE criteria is satisfied. At this point a segment has been found, and the endpoints both correspond to local extrema. An additional set of tests are now applied, to determine if the segment thus located exhibits the basic characteristics of a 'generally increasing' run of values. Each of the three validation tests (IN–RANGE, CONSISTENT–SLOPE, and DISTRIBUTED–SLOPE) must be satisfied by the segment for it to be considered for subsequent processing.

Azimuthal Association

The second stage in the outflow detection process is the association of the shear segments in azimuth. The goal of this step is to merge the shear segments from the previous step into 'clusters' of adjacent segments. This merging is accomplished by considering each pair of segments found on a radar scan, and tagging them as belonging to the same cluster if they overlap in range and lie on adjacent, or next–to–adjacent, radials of the radar (typically spaced 1 degree apart in azimuth). The sets of segments connected by this single–linkage clustering scheme are then denoted as two–dimensional shear regions. Several characteristics are computed



(a)

[START–GOOD]
None of the sample points in the window are either
i) 'bad' (i.e., a valid velocity measurement was not possible because of low signal power) or,
ii) have a velocity less than that at point X

[START–SMOOTH]
The velocity values at points X, X+1, and X+2 are monotonically increasing.

[NEXT–RULE]
From a given sample point X, choose as the next sample point that point Y such that the difference between the velocity measurement at Y and at X is both non–negative and less than 50% greater than the minimum non–negative difference to all points in the window

[TERM–BAD]
More than 3/4 of the of the sample points in the window are either
i) 'bad' (i.e., a valid velocity measurement was not possible because of low signal power) or,
ii) have a velocity less than that at point X

[TERM–JUMP]
The difference between the velocity at the current sample point and that point in the window with the smallest velocity value greater than that at the current point exceeds 15 m/s.

[MAX–RULE]
The velocity value at the current sample point is greater than or equal to the value at the previous sample point (toward the starting point), or both values are 'bad' measurements.

[IN–RANGE]
No more than 1/8 of the sample points in the segment may have a velocity value which is either less than the velocity value at the starting point of the segment or greater than that at the ending point

[CONSISTENT–SLOPE]
The running mean of the velocity values, calculated over 4 consecutive sample points, must be monotonically increasing over the ent length of the segment

[DISTRIBUTED–SLOPE]
The ratio of velocity differences: {velocity(Y)–velocity(X)} / {velocity(Y–1)–velocity(X+1)}, where sample points X and Y are the starting and ending points of the segment, respectively, must be at least 0.6.

(b)

Figure 6: Flowchart (a) and test criteria (b) for divergent shear segment identification stage of the microburst outflow detection algorithm

for each region, including the number of segments, total area, and the maximum velocity difference across any shear segment in the region. These characteristics are used by the third stage to judge the significance of the shear feature for alarm generation.

Time Correlation

The final stage of the algorithm processing attempts to associate the two-dimensional shear regions in time, across successive scans of the radar. The algorithm compares each cluster found on the current scan with all those found on recent previous surface scans (where 'recent' means the lesser of: two scans, or two minutes, in the past). Each previous cluster is then tested for spatial overlap with the current cluster. In the usual case, where all the previous clusters which overlap the current cluster belong to a single existing microburst, the current cluster is tagged as also belonging to that microburst. If the overlapping clusters belong to multiple microbursts (i.e., microbursts which are closely spaced together), the current cluster is tagged as belonging to the microburst for the previous cluster which 'best' overlaps the current cluster. If the best overlapping previous cluster is not already tagged as part of a microburst, and the current cluster passes the size and strength thresholds, then a new microburst is declared.

By performing such an association, it is possible to identify situations where a previously-detected single microburst is now detected as two separate clusters (e.g., because the shear detection step may have missed some actual shear segments). In such cases, these clusters are merged together, to provide a more consistent output product. A second benefit is the ability to filter out those detected shear regions which do not persist in time. Observation of the performance of the shear detection and clustering stages have indicated that most false alarms are not persistent, while actual microburst hazards are typically observed on several consecutive scans. By requiring multiple detections of a shear region before declaring an alarm, the false alarm rate is reduced considerably. This time filtering rarely causes actual microbursts to be missed, since shear regions below the microburst intensity threshold are usually observed prior to the outflow reaching an operationally significant strength.

4. Performance Assessment

The performance of the microburst outflow detection algorithm has been evaluated through an extensive data collection and analysis program. This program was designed to compare the microburst alarms generated by the algorithm when applied to actual weather radar data with the detailed analysis of those cases performed by experienced radar meteorologists.

The role of the human analyst is to examine the raw radar measurements, in an offline (not real-time) environment, searching for microbursts. The location, extent, and strength of all identified microbursts are then documented for each surface scan of the radar (roughly once per minute). This database of microburst 'ground truth' may then be compared to the algorithm alarm output to determine detections, misses, and false alarms. This manual analysis is an extremely time consuming task, and the evaluation described below is the result of several man-years of combined effort from scientists at Lincoln Laboratory and from the National Center for Atmospheric Research (NCAR).

To achieve uniformity in the ground truth database, which involved efforts from numerous analysts in the program, a commonly agreed definition of a microburst was needed. For the development and evaluation of the detection algorithm, a microburst is defined as a divergent outflow region which exhibits a wind speed difference of at least 10 m/s over a distance of no more than 4 km. Note that the velocity difference may extend beyond the 4 km scale, so long as the required 10 m/s difference exists within some 4 km sub-region. A microburst is considered 'ended' when the velocity difference (over a 4 km scale) drops (and remains) below 10 m/s for a period of at least two minutes.

Rules for scoring against ground truth

To evaluate the performance of the algorithm, two basic quantities are desired: the Probability of Detection (POD) and the Probability of False Alarm (PFA). The POD is defined as the ratio of the number of events detected by the algorithm to the total number of events. The PFA is the ratio of the number of false alarms to the total number of alarms.

These definitions relate performance to three fundamental concepts: an *event*, a *detection*, and a *false alarm*. In this application, an event is defined as a single observation of an actual microburst by the radar, on a low-elevation angle scan. Each actual microburst is typically observed on several sequential scans, and hence represents several events. Only those actual microbursts which fall within 30 km of the radar are considered in the scoring. An event is considered detected by the algorithm if the rectangle representing the event intersects any rectangle(s) representing a microburst alarm from the algorithm. A microburst alarm from the algorithm is considered a false alarm if it does not intersect any rectangle(s) representing actual microburst events. To provide an operationally realistic evaluation of the algorithm, certain alarms which would be strictly classified as 'false alarms' are tallied separately. Declarations which overlap actual events which appear on radar scans within two minutes (before or after the current scan) are not considered false alarms, nor are any declarations which appear in the immediate vicinity (within 2 km) of actual microbursts considered false alarms. Also excluded are algorithm declarations which can be clearly traced to defects in the data acquisition system (e.g., ground clutter residue), which are not representative of the specified TDWR radar platform.

Data cases used in the evaluation

The performance statistics presented below are based on the radar measurements made on the dates shown in Figure 7, using the FL2 Doppler weather radar [4]. During the data collection period from which these cases were selected, the FL2 radar was located in Huntsville, AL as part of the FLOWS '86 and COHMEX data collection programs [5]. It is important to note that all of the microburst events used in this performance evaluation were associated with strong precipitation (as were virtually all of those microbursts observed during the Huntsville data collection program). No 'dry' or 'virga' microbursts (those which have little or no precipitation reaching the ground) were available for this evaluation. The 1987 FLOWS data collection program is currently in progress in the Denver, CO area, where data on a better mix of both dry and wet microbursts are being collected. The performance analysis results for the Denver microburst collection are not yet available.

Date	Microbursts	Surface scans	Time period (hrs)
June 7	5	40	1.7
July 1	7	75	2.2
July 25	12	67	3.8
July 31	6	144	2.2
Sept 26	8	100	3.7
Totals:	38	426	13.6

Figure 7: Cases used for performance evaluation. All cases taken from 1986 data colected with FL2 radar, in Huntsville, AL

Performance statistics

For each of the days listed in Figure 7, the outflow algorithm outputs were compared to the ground truth information, and both detection and false alarms were tallied on each surface radar scan. The results of this comparison are shown in Figure 8, broken down into several outflow strength categories. Although the minimum outflow strength required for a microburst has been set at 10 m/s, a category for shears below 10 m/s is present in the chart. This category is needed for those events which temporarily drop below the 10 m/s threshold (for at most 2 minutes) before intensifying, and are hence accepted by the definition as a single continuous microburst.

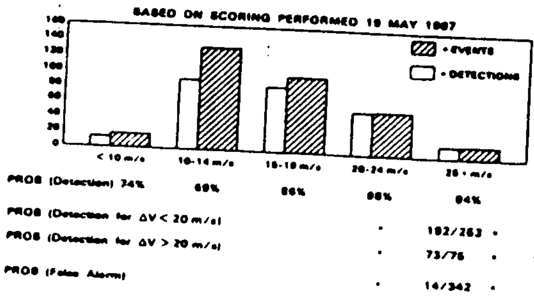


Figure 8: Microburst detection algorithm performance statistics

The figure clearly indicates that the detection performance improves with the strength of the outflow, and that strong outflows (above 20 m/s velocity change) are almost always detected. The weaker shears are detected with lower probability, due in part to the fact that the algorithm often underestimates the true strength of the outflow, so that weak events fall beneath the detection threshold of 10 m/s.

Note that the statistics presented in Figure 8 indicate how well microbursts were detected on a scan-by-scan basis, and not on an event-by-event basis. The outflow detection algorithm rarely misses a microburst over its entire lifetime; of the 38 microbursts used for the statistics presented here, only 3 were entirely missed by the algorithm (92% detection rate). These events were very weak (averaging velocity difference of 13 m/s) and lasted for only a few minutes each.

5. Future Work

The development and operational evaluation of microburst detection techniques is a major component of both the Weather Radar program at Lincoln Laboratory, and the Research Applications Program at NCAR. Considerable work remains to be done before the algorithm performance is adequately tuned and evaluated. The primary goals for near-term improvements to the microburst detection algorithm include:

1) a complete examination of the algorithm performance against a larger set of single-Doppler ground truth cases, plus more detailed case studies using dual-Doppler and surface wind station measurements,

2) the application of a clutter residue editing map prior to the detection algorithm processing, to determine the ability of such a map to reduce the algorithm false alarms from clutter-biased measurements,

3) several enhancements to the outflow detection process to reduce the number of false detections, to better measure the wind speed change through the outflow, and to improve the time continuity of the algorithm output [to provide a product more comprehensible to the end-user].

Additional research into microburst forcing mechanisms and precursors, as well as aircraft response to microburst wind shears, will surely result in an ongoing cycle of development and refinement of the automated detection techniques, to keep pace with meteorological understanding of the microburst phenomena.

6. Acknowledgments

The work described in this paper is the result of the cumulative effort of numerous people over the last several years. In particular, the 1986 microburst ground truth analysis performed by: Mark Isaminger, Charles Curtiss, and Nat Fischer, from Lincoln Laboratory, and Cathy Kessinger and Rita Roberts of NCAR, was vital to the algorithm development and evaluation reported here.

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TECHNICAL REPORT STANDARD TITLE PAGE

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16. Abstract

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In this report, we use pencil-beam Doppler weather radar data, combined with on-airport ground clutter measurements, to analyze the performance of the six-level weather channel in the next generation airport surveillance radar, the ASR-9. A key tool was a computer procedure that used these data to simulate the output of the ASR-9's weather channel, including effects of the radar's fan-shaped elevation beams, short coherent processing intervals and ground clutter filters. Our initial analysis indicates that: (a) the combination of high-pass Doppler filters and spatial/temporal smoothing should normally prevent ground clutter from having a significant effect on the controllers' weather display; (b) the spatial/temporal smoothing processor will result in weather contours that are statistically stable on a scan-to-scan basis, reinforcing controller confidence in the validity of the data; (c) relative to the coarse resolution imposed by use of the NWS levels, accurate two-dimensional parameterizations of storm reflectivity can be estimated. Our assessment indicates that the ASR-9's weather reflectivity maps should be reliable. The radar will be widely deployed at significant air terminals, and will provide a combination of high update rate and large volumetric coverage not available from other sensors. These attributes should lead to the ASR-9 becoming an important component of the Federal Aviation Agency's modernized weather nowcasting system.

17. Key Words		18. Distribution Statement
airport surveillance radar	ground clutter	Document is available to the public through the National Technical Information Service, Springfield, VA 22161.
ASR-9	spatial and temporal smoothing	
weather channel	computer simulation	
precipitation reflectivity	reflectivity estimate accuracy	
fan-beam	beamfilling compensations	

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CHARACTERISTICS OF MICROBURSTS OBSERVED IN THE CONTINENTAL U.S.*

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1. INTRODUCTION

The topic of microbursts is explored in this paper through a historical perspective and review of the studies that have been performed since Fujita (1976) first introduced the concept. Taken as a whole, this body of work actually *defines* microbursts, and begins to take some of the initial steps toward their understanding. However, a number of dynamically distinct phenomena that give rise to strong surface outflows are being referred to as microbursts. The recent emphasis within the scientific and aviation communities on understanding microbursts makes it particularly important to categorize these various phenomena according to their meteorological nature and true aviation hazard potential. This paper takes some of the first steps toward this categorization, and emphasizes some of the differences in storms that can be expected in different climatological regimes.

2. HISTORICAL PERSPECTIVE

The word "downburst" was introduced by Fujita and Byers (1977) to describe the meteorological event which caused the crash of Eastern Flight 66 at JFK airport in New York on 24 June 1975, in which a thunderstorm downdraft became hazardous to the operation of jet aircraft (Fig. 1). If a downdraft has a speed of at least 12 ft/s at an altitude of 300 ft agl (comparable to that of a jet transport following the usual 3° glideslope on final approach) and a spatial extent of 0.5 mi or larger (large enough to have a noticeable effect on the aircraft (Fujita and Caracena, 1977)), then it qualifies as a downburst. Later the term "microburst" was created to distinguish small downbursts (0.8 - 4.0 km) from larger ones (Fujita, 1978, 1979).

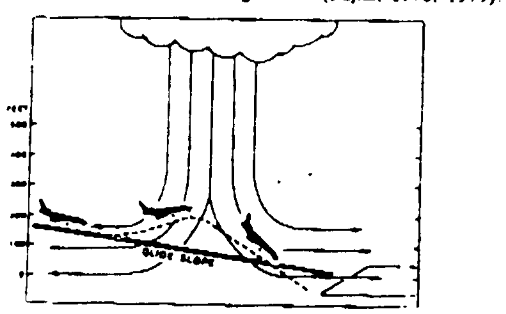

Fig. 1 Schematic drawing of an aircraft encounter with a microburst. Notice that the increased headwind lifts the plane above its intended glideslope while the increased tailwind causes the plane to fall below its intended glideslope.

The introduction to the meteorological community of the concept of the downburst met with some controversy and resistance. As Fujita (1985) notes, most meteorologists believed "that a downdraft, no matter how strong it may be inside or beneath the cloud, should weaken to an insignificant speed long before reaching the surface." Many scientists also wondered what the difference was, if any, between the downburst and the well known thunderstorm downdraft. Fujita (1979) thought they were essentially the same but, following the clear precedent in meteorology for establishing new terminology for extreme meteorological phenomena that are known to be dangerous, chose a term more forceful than even the "downrush" introduced by Fawbush and Miller (1954), and defined it according to its potential hazard to aircraft. Confusion still exists over what exactly the term describes; it will be made clear through the review of observational studies in the next section that several possibly dynamically distinct phenomena can qualify.

Despite rejection of the "downburst", there was great concern in the meteorological community and especially at the National Severe Storms Laboratory (NSSL) with preventing aircraft accidents such as the one mentioned above at JFK airport. However, it appeared to some scientists that the very wind shear related aircraft accidents attributed by Fujita to downbursts were actually caused by aircraft penetration of larger scale gustfronts. Part of this argument was based on detailed dual and triple-Doppler radar analyses of tornadic storms in Oklahoma in which no small scale downdrafts were found (Brandes, 1977; Ray, 1978). The evidence available to these researchers suggested that "straight-line" downburst winds might well be those experienced along the leading edge of advancing gust fronts. An anemometer-based wind shear detection system was designed and installed at airports (the Low Level Wind Shear Alert System (LLWAS); Goff, 1980) based on NSSL recommendations. Fujita (1980, 1981a) went to great lengths in his early papers to explain the differences between downbursts and gustfronts, especially with regard to the wind shear hazard they posed for aviation. A general skepticism that nothing new was being documented remained.

However, Fujita remained convinced that unusually strong, small scale downdrafts not only existed but posed a very real threat to aviation. He obtained scientific support and facilities, including Doppler radars, instrumented aircraft, and mesonet stations, for project NIMROD (Northern Illinois Meteorological Research on Downbursts; with Srivastava) near Chicago in 1978 (Fujita, 1979), project JAWS (Joint Airport Weather Studies; with McCarthy and Wilson) near Denver in 1982 (McCarthy *et al.*, 1982), and most recently, project MIST (Microbursts and Severe Thunderstorms; with Wakimoto) near Huntsville in 1986 (Dodge *et al.*, 1986).

After both NIMROD and JAWS, the downburst was redefined to encompass newly observed phenomena. After NIMROD the downburst was redefined as "an outburst of damaging winds on or near the ground" (Fujita and Wakimoto, 1981) where "damaging winds" referred to winds of at least 18 m/s; microbursts were simply wind events of this magnitude on a smaller scale. During JAWS, many more microbursts were found and the emphasis was accordingly shifted. The microburst was redefined as having a "differential Doppler velocity across the divergence center greater than or equal to 10 m/s and the initial distance between maximum approaching and receding centers less than or equal to 4 km" (Wilson *et al.*, 1984)**. This definition now encompasses weaker but still highly divergent meteorological phenomena.

A major impetus was added to the meteorological investigation of microbursts when, after the crash of Pan American World Airways Flight 759 in July 1982 shortly after take-off at New Orleans International Airport in which all 149 persons on board and 8 persons on the ground died (Fujita, 1983; Caracena *et al.*, 1983a), a National Academy of Sciences Committee for the Study of Low-Altitude Wind Shear and Its Hazard to Aviation was formed under the sponsorship of the Federal Aviation Administration (FAA). The final report of that committee (National Research Council, 1983) states that "Some wind shears have been understood by meteorologists for a number of years. These include those found in gust fronts, warm and cold airmass fronts, [*etc.*]..." and that "most [of these] are predicable, sometimes hours in advance." They go on to note that "Scientists have recently begun to recognize the importance of storm downdrafts that are unusually small in horizontal cross sections and that are of short duration. Such downdrafts have been called microbursts." The meteorological community finally seemed convinced of both the hazard of low-altitude wind shear to aviation and the existence of microbursts (Kessler, 1985).

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CHARACTERISTICS OF MICROBURSTS OBSERVED IN THE CONTINENTAL U.S.*

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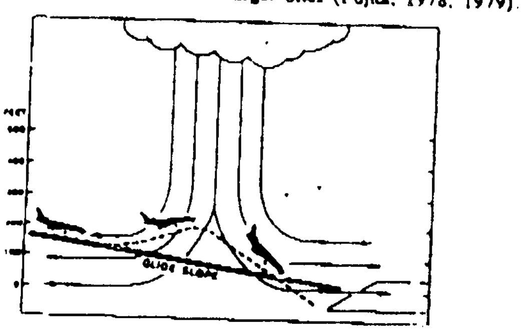

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automation and to provide information on low-altitude wind shear, turbulence, and rainfall intensity."

The MIT Lincoln Laboratory, under contract to the FAA, began in 1982 the development of an FAA pulse Doppler weather radar testbed to be used for the detection of hazardous aviation weather in enroute and terminal airspace (Evans and Johnson, 1984; Laird and Evans, 1982). The FAA supported the development of the Lincoln testbed (and the meteorological research on low-altitude wind shear in the JAWS project) under its newly commenced Terminal Doppler Weather Radar Program. The transportable radar (called FL-2) was moved to Memphis, TN in mid-1984 and operated during 1985 as part of the multi-year FLOWS (FAA-Lincoln Laboratory Operational Weather Studies) Project. The radar was moved again to Huntsville, AL in 1986 where the FLOWS Project joined with the MIST project in the Cooperative Huntsville Meteorological Experiment (COHMEX). Microbursts were indeed found and datasets with scanning strategies suitable for use in an automatic microburst detection system were collected. Most microbursts in Memphis and Huntsville were caused by the collapsing phase downdrafts of isolated, air-mass thunderstorms, and were accompanied by very heavy rain. These storms appear to be very similar to those that have caused a large number of aircraft accidents (see *e.g.*, Fujita, 1985).

Since the National Academy of Sciences Committee made its recommendations, another aircraft accident occurred that has been attributed to microburst wind shear. This was the crash of Delta 191 at Dallas/Ft. Worth in August 1985 (Fujita, 1986; Caracena *et al.*, 1986). Efforts are now underway within the scientific and engineering communities to refine techniques for automated aviation-hazardous weather detection with the Terminal Doppler Weather Radars (Evans and Turnbull, 1985; Zorpette, 1986). The FL-2 radar has been moved to Denver where, during the 1987 microburst season, many excellent datasets with 1-min. surface update rates and coverage of upper level storm sturcture were gathered. Lincoln Laboratory, NSSL, and NCAR will be demonstrating the feasibility of providing real-time low-altitude wind shear information to air traffic controllers at Denver's Stapleton airport in the summer of 1988. The microburst detections will be generated by automated algorithms developed at MIT Lincoln Laboratory that operate on the FL-2 Doppler weather radar data (Merritt, 1987; Campbell, 1988).

3 OBSERVATIONAL STUDIES OF MICROBURSTS

In this section, a number of studies pertaining to microbursts (those performed before 1987) are reviewed and summarized. The review is divided into categories primarily to differentiate between essentially different phenomena that give rise to microbursts; however, it is shown that some categories are not distinct.

3.1 Spearhead echoes

The parent storm responsible for the outflow in which the Eastern airlines flight crashed at JFK in 1975 was determined to be a type of isolated multicell storm, roughly 30 km long, which occurred on a day with numerous scattered cells of various sizes. The echo took on a "spearhead" shape in the low resolution radar PPI films (Fig. 2).

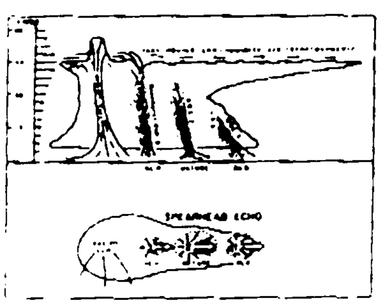

Fig. 2. A model of a spearhead echo from Fujita and Byers (1977).

Unusual surface convergence both from old thunderstorm outflows and a weak sea breeze front enhanced the growth of new cells. Although the encountered outflow was first classified as a downburst, a revised study showed that a number of smaller microbursts were present (Fujita, 1985). A more detailed discussion of this type of storm is presented in section 3.6.

3.2 Bow echoes and downbursts

After further observational work a more general type of echo with which downbursts were associated was identified by Fujita (1978) as the "bow" echo which then takes the shape of a spearhead echo during the strong downburst stage and which sometimes develops a "weak echo channel" at low levels in the area of strongest winds (Fig. 3). Tornadoes sometimes develop on the cyclonic shear side of the area of high winds or in the rotating head (Smith and Partacz, 1985). The maximum echo top becomes displaced ahead of the strong reflectivity gradient along the leading edge of the bow at low levels (Przybylinski and Gery, 1983). Satellite analyses have shown general cloud top warming in advance of the downburst formation, indicating collapse of the cells (*e.g.*, Fujita and Wakimoto, 1981). Fujita (1979) also notes that a hole may appear at the edge of the echo at high levels (5 km); in general this reflectivity notch is observed on the upshear side of the storm system, *i.e.*, the side upon which the environmental winds are impinging at upper levels.

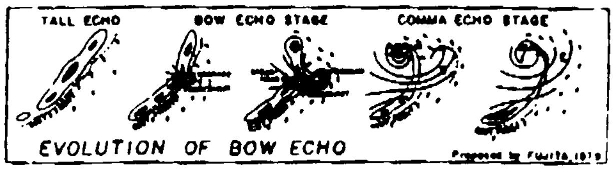

Fig. 3. Evolution of bow echo proposed by Fujita (1981b). In this model a bow echo is produced by a downburst thunderstorm as the downflow cascades down to the ground. Finally the horizontal flow of a weakening downburst induces a mesoscale circulation which distorts the initial line echo into a comma-shaped echo with a rotating head.

The bow shaped echo is generally part of a synoptic scale squall line (Wolfson, 1983; DiStefano, 1983), part of a mesoscale linear echo configuration or cluster (Fujita and Wakimoto, 1981; Forbes and Wakimoto, 1983; Knupp and Jorgensen, 1985; Cooley, 1986), or a combination of supercell and weaker storms (Caracena, 1978; Schmidt and Cotton, 1985). Similar storm reflectivity patterns have been called "line echo wave patterns" or LEWPs by Nolen (1959) and Hamilton (1970). A resurrected term "derecho*" (Hinrichs, 1888) has been used by those with operational experience to describe some four different types of severe weather producing mesoscale convective systems exhibiting bow echo characteristics (Johns and Hirt, 1983; Przybylinski and DeCaire, 1985); these storms all have either one large or numerous smaller channels of weak echo behind the main cells. Eilts and Doviak (1987) note that Oklahoma downbursts often have asymmetric surface wind shear patterns which make their strength difficult to estimate with single Doppler radars.

Knupp and Jorgensen (1985) studied a downburst-producing bow echo storm that developed in southeastern Kansas in an environment characterized by "moderately low" wind shear, abundant moisture up to 850 mb, and a nearly dry adiabatic lapse rate up to 600 mb. The authors analyzed P-3 aircraft data, including airborne Doppler radar data taken near the weak echo region of the bow just after damaging surface winds had occurred. They concluded that negative buoyancy created by melting and evaporation in the lowest 2-3 km of the storm caused pressure reductions of up to 1.6 mb over the large stratiform rain region behind the bow, as air parcels were accelerated downward. Schmidt and Cotton (1985) show, for a similar storm, a strong inflow from the rear of the storm directly into the vertex of the "bow" at 5 km, apparently in response to this type of large scale downdraft. This large scale downdraft generated a strong low-level outflow which reached damaging speeds when convective scale downdrafts of only moderate intensity were superimposed.

A study of synoptic and mesoscale factors associated with downburst producing thunderstorms by Forbes *et al.* (1980) showed that a marked low-level (850 mb) jet was always present as was a jet streak at the 300 mb level, implying the possible importance of a coupling of the two and the possibility that the flux of momentum from these levels to the surface could at least partially account for the high speed outflow winds. They also found that stability indices were generally indicative of considerable thunderstorm potential, that the precipitable water content of the atmosphere was high, and that the 1000-500 mb mean relative humidity was typically moderate. The downbursts studied were often accompanied by tornadoes but it was not determined if the environmental conditions which tend to promote the two types of storms differ.

Damage surveys by, *e.g.*, Forbes and Wakimoto (1983), Fujita (1978), and Fujita and Wakimoto (1981) revealed that small microbursts and tornadoes, twisting downbursts, and other rotational and divergent wind patterns coincidentally occurred. This led Wolfson (1983) to hypothesize that a small scale occlusion downdraft, dynamically induced by low pressure associated with the strong rotation at low levels, was forcing a smaller scale microburst within a larger scale thunderstorm outflow, and that *this* superposition caused the damaging surface winds. The small scale downdraft was thought to be essen-

*"Derecho" is Spanish for "straight" and is used to describe straight line winds just as "tornado" is used to describe rotational winds.

tially the same as the occlusion downdraft found by Klemp and Rotunno (1983) in a high resolution numerical model of the tornadic region in a supercell storm.

In summary, these organized downburst storms occur throughout the Continental US at times of the year when synoptic scale instabilities dominate the weather patterns (typically through the central part of the country during spring and fall; farther north during early and late summer). They develop in environments characterized by moderate vertical shear of the horizontal wind, instability or conditional instability, and abundant moisture. In the cases analyzed, a layer of dry air was present at midlevels. These bow echo storms generally are part of a larger mesoscale or synoptic scale storm complex or frontal line storm, have high radar reflectivity levels (at least 50 dBZ), produce downbursts that are quite large (typically 20 km or more across), and often contain embedded microbursts and tornadoes. With some confidence it can be stated that the large scale downdraft is driven by the cooling due to evaporation and melting as dry environmental air enters the storm from behind in a region of stratiform rain with small, readily evaporated precipitation particles, and that this process leads to the formation of the weak echo regions behind the bow. The downward flux of horizontal momentum from midlevels is also important in accounting for the high surface wind speeds in some cases. The smaller embedded microbursts may be produced in a variety of ways. In general, these storms are long lived with fairly predictable paths, and apparently threatening enough that aircraft rarely if ever try to fly through them. Thus while these storms are inherently very hazardous to aviation, the hazardous regions are predictable and avoidable using the currently available meteorological information.

3.3 Bow echoes and microbursts

Care must be taken when categorizing storms according to their radar echo appearance. Elmore (1986) discusses the evolution of a microburst associated with a bow-shaped, low reflectivity echo (34 dBZ maximum) that occurred near Denver. In which the reflectivity notch was observed to develop on the *downshear* side of the storm coincident with anticyclonic rotation. This storm, roughly 8 km in horizontal extent, was very different from those described in the previous section. Elmore notes that this storm was tilted significantly downwind (and downshear) throughout its lifetime, and suggests that the observed anticyclonic circulation might have been part of a von Karmann vortex pair in which the cyclonic half was somehow attenuated in the environment characterized by anticyclonic shear.

Knupp and Cotton (1985a), through analysis of a numerically simulated convective cloud (15 km diameter), have come up with a more convincing explanation. They show that weak, tilted updrafts allow precipitation to descend to lower levels where downdrafts are produced, and that the flow around the updraft at midlevels systematically transports precipitation to this downshear region (Fig. 4; see also

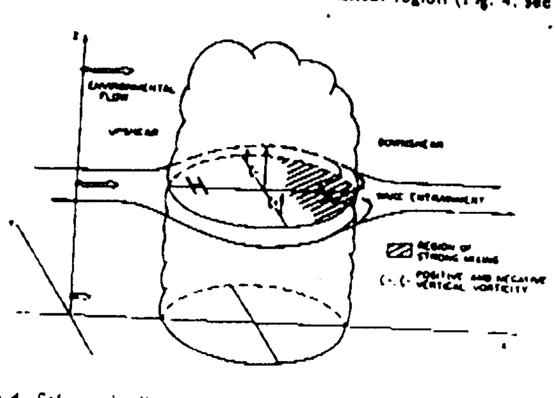

Fig.4 Schematic diagram illustrating wake entrainment within the downshear flank of a convective cloud. The symbols H and L represent high- and low-pressure perturbations. These perturbations, along with the vertical vorticity patterns, are produced by cloud vertical motion interacting with environmental flow increasing with height in this case. From Knupp and Cotton (1985b).

Heymsfield, *et al.*, 1978). They also note that the equivalent potential temperature values in the downshear region were quickly reduced as the downdraft matured, and that "this process provides a method by which surface precipitation may nearly coincide with developing downdrafts and low-valued equivalent potential temperature air..." Although no dramatic vorticity developed in the wake region of the model cloud, it is quite plausible that vertical stretching in a similarly created downdraft concentrated the ambient anticyclonic vorticity in Elmore's observed bow echo and microburst. This type of "bow echo", then, actually belongs in the following category (section 3.4).

3.4 Shallow, high-based cumulonimbus clouds

Since the JAWS project in 1982, a great deal of attention has been given to microbursts which originate from benign-looking, high-based (-4 km agl), shallow (-2 km deep) stratocumulus or cumulus congestus clouds. These clouds often have glaciated tops and lack the rapidly rising convective towers, thunder, and lightning of typical lower-based cumulonimbus clouds (Wakimoto, 1985), although some small convective turrets can occasionally be seen (Hjelmfelt *et al.*, 1986). Virga is commonly visible below cloud base (giving rise to the term *virga microbursts*) but often little or no rain reaches the ground (Fujita and Wakimoto, 1983b). Braham (1952) briefly mentioned this phenomenon, and Krumm (1954) characterized the "dry thunderstorm over the plateau area of the United States" with, in retrospect, amazing accuracy. Brown *et al.* (1982) also documented this type of storm, and noted that its damaging outflow could qualify as a downburst. They also predicted what the JAWS investigators were soon to discover, that this type of storm is much more common than was generally recognized at the time.

Attempts to generalize the characteristics of the environment in which this type of microburst forms, primarily for forecasting purposes, have been quite successful. Caracena, *et al.* (1983b) and Wakimoto (1985) found that a deep, dry subcloud layer (dew point depression greater than 30°C) with a nearly dry adiabatic lapse rate was common, and that a moist layer around the 500 mb level nearly always occurred. Winds typically had a strong westerly component, and increased with height. Using a simple rule that the dew point depression at 700 mb be greater than 8°C and that it be less that 8°C at 500 mb, Caracena, *et al.* (1983b) were able to correctly classify 26 of 30 days on which dry microbursts occurred.

Radar and flow characteristics of this type of storm have been documented by Wilson, *et al.* (1984), Fujita and Wakimoto (1983a), Roberts and Wilson (1984), Hjelmfelt (1984), Mueller and Hildebrand (1985), Fujita (1985), Elmore (1986), and summarized by Kessinger, *et al.* (1986). Statistical results of surface mesonet measurements of JAWS microbursts have been summarized by Bedard and LeFebvre (1986). These microbursts all formed between 1300 and 1900 MDT with 75% occurring between 1400 and 1700 MDT. Reflectivity values were always less that 30 dBZ at 500 m agl. The evolution of the surface flow field typical of nearly all microbursts observed during JAWS is schematically illustrated in Figure 5. The

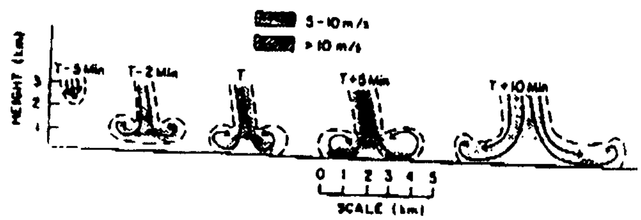

Fig. 5. Vertical cross section of the evolution of the microburst wind field based on JAWS data. T is the time of initial divergence at the surface. The shading refers to the vector wind speeds. From Wilson et. al. (1984).

horizontal vortex roll at the periphery of the downdraft (T-2 Min in Fig. 5) led Fujita and Wakimoto (1983a) to define the "mid-air" microburst; Roberts and Wilson (1984) showed that this divergence aloft primarily occurred for the low reflectivity virga microbursts.

Observations based on all microbursts in JAWS (approximately half were associated with virga or light rain) show that there is no correlation between radar reflectivity or surface rainfall rate and the subsequent strength of the outflow (McCarthy, *et al.*, 1983; Fujita and Wakimoto, 1983b). Rainfall rates never exceeded 3 inches per hour, and only on 6 days was the rainfall rate associated with microbursts above 1 inch per hour. The strong surface outflow typically lasted from 2-5 minutes with outflow speeds between 10 and 20 m/s. Fujita (1985) also found that the surface temperature was just as likely to rise as to fall, by as much as 3°C; Kessinger, *et al.* (1986) found a 1-2°C surface temperature drop and no rain for the one case they discuss.

Brown, *et al.* (1982) hypothesize that the combination of the deep dry subcloud layer allowing negatively buoyant air near cloud base to descend to the surface without losing all of its negative buoyancy (and to accelerate over a great distance), and the weak updrafts producing small precipitation particles which evaporate and melt more rapidly than the larger particles formed in more vigorous convection, allows the very strong downdrafts to form.

Srivastava (1985), using a simple one-dimensional time-dependent model of an evaporatively driven downdraft, systematically considered the various factors that could influence the ultimate strength of the downdraft. He found that intense downdrafts were favored when the lapse rate was close to dry adiabatic, when the rainwater mixing ratio near cloud base (origin of the downdraft) was high, and when the downdraft radius was at least 1 km. Srivastava also confirmed that "a given rainwater content distributed in smaller drops is generally a more efficient producer of cooling and intense downdrafts", but did find that under some circumstances larger drops, with their greater terminal fall velocities, were able to produce a deeper, stronger downdraft by spreading the cooling over a greater depth. He also noted that the relative humidity of the environment, in the idealized but not too far from realistic case of no mixing, affects the downdraft only indirectly by affecting its buoyancy. Thus a virtually warmer (more humid) atmosphere would actually be *more* conducive to strong downdrafts.

Krueger and Wakimoto (1985) used a two dimensional axisymmetric numerical cloud model to simulate the dry microburst life cycle. Their results basically agreed with those of Srivastava (1985) but since they included a lower boundary, the attained downward velocities were lower, as expected. They found that the vertical velocity decreased appreciably as the radius of the initial rainwater region was increased but that the subsequent surface outflow velocity increased only slightly. This result is more generally applicable to any isolated downdraft; the cylindrical geometry and mass continuity alone determine that the ratio of the outflow speed to the downflow speed is a linear function of the initial radius of the rainwater region ($U/W \sim R/2$). Although it was not discussed, the numerical model output data presented by the authors did fall along a straight line ($U/W \sim R/3 + 0.75$, where R is in km).

Krueger, *et al.* (1986) used this same model to study the role of ice-phase microphysics in determining the downdraft and outflow strength of dry microbursts. They performed experiments in which the precipitation dropped at the top of the model consisted of either rain, graupel, or snow at each of three cloud base precipitation rates with identical radial distributions. They found that the more precipitation, the stronger the downdrafts and surface outflows, and that these variations were much larger than those attributable to the different forms of precipitation with the same concentration. However, for a given precipitation rate, rain generally produced the strongest downdraft and graupel produced the coldest, strongest surface outflow. The ratio of the outflow to the downflow speed was always smallest for rain and largest for graupel. This emphasizes the importance of the vertical distribution of negative buoyancy on the ratio of maximum outflow speed to maximum downflow speed for storms of equal horizontal scales.

Mahoney (1983) developed an evaporation model to estimate the subcloud cooling rates in JAWS microbursts using aircraft-measured hydrometeor spectra (Rodi, *et al.*, 1983) and ambient relative humidity values. He found a maximum in the cooling rate just below cloud base where high concentrations of small ice particles were present. Using equivalent potential temperature as a tracer, he found that the air in the downdraft was originating at the base of the cumulus cloud, and not from within or from the top of the cloud. He, too, concluded that strong downdrafts occurred with a deep, dry adiabatic subcloud layer and a large concentration of small particles, but for *low* relative humidity values. It may be that with higher atmospheric relative humidity values, different forms of convection arise. Rodi, *et al.* (1986) used a similar model to compute the maximum cooling rates resulting from initial graupel particle densities of 0.1 and 0.9 g/cm^3, with a typically observed size spectrum, and found them to be very different. Although the vertical equation of motion was not solved, they too concluded that knowledge of the precipitation rate or particle density is crucial to the understanding of downdraft magnitudes.

Compensating convergence must develop at or above the downdraft initiation level to replace the descending air in the microburst. This downward motion and convergence will increase the vertical vorticity in the same region. Significant convergence, including sinking of the visible cloud into the downdraft region has been observed (Fujita, 1985), as has increased rotation coincident with the downdraft and reflectivity core (Fujita and Wakimoto, 1983a; Roberts and Wilson, 1984).

In summary, all observations and simulations indicate that downward acceleration from negative buoyancy, generated as precipitation with the typically observed distribution of small drops falls from cloud base into the deep, dry adiabatic subcloud layer and evaporates (and melts), can lead to the observed downdraft speeds in the microbursts originating from shallow, high-based cumulonimbus clouds. The conditions suitable for the formation of this type of microburst have mainly been observed in the high plains east of the Rocky Mtns. during the summer months, although they can certainly occur elsewhere*. It is probable that the downdrafts are originally initiated by precipitation loading within the elevated clouds. The small horizontal scale of the phenomenon has not been adequately explained, but it cannot be decoupled from the scale of the original updrafts, that is, the preferred scale of the instability that created the cumulus clouds in the first place.

Model results show that the narrowest downdrafts will be the most hazardous to aviation; not only will the vertical velocities be the strongest, but the outflow winds will be nearly as strong as those from larger storms while the horizontal scale is smaller. The actual hazard to aviation of this type of microburst has been assessed through observations of air traffic response by Stevenson (1984, 1985). He found that aircraft do fly through microbursts at Stapleton International Airport in Denver, and that pilot reports of encountered wind shear are used to warn subsequent flights. Because these microbursts occur only in the afternoon (daylight hours), and because they are often marked by virga below cloud base, pilots can sometimes avoid flying through them. The surface reflectivity values of these microbursts are low and, because they occur in an urban (high clutter level) environment, a Doppler radar with sophisticated ground clutter supression capability is required for their effective detection.

3.5 Microburst lines

The observation that microbursts occurred in "families" was first made by Fujita (1978) based on damage surveys. During JAWS, it was found that two or more microbursts could occur simultaneously, forming a line (Kessinger *et al.*, 1983). Hjelmfelt and Roberts (1985) define the microburst line as consisting of "two or more microbursts, at least twice as long as it is wide (between velocity maxima on either side of the line) and having a velocity differential in the cross-line direction meeting microburst criteria. A microburst line may be nearly homogeneous along its length or may be made up of distinct, discrete microbursts." A preliminary schematic of the basic microburst line structure is shown in Fig. 6.

Hjelmfelt and Roberts (1985) have found that microburst lines are produced from high-based shallow cloud lines. These original cloud lines may be initiated by surface convergence lines that develop daily over the Rocky mountains (Wilson and Schreiber, 1986), or perhaps in response to orographically forced Von Karman-like vortex streets that are set up parallel to the prevailing winds (Fujita, 1985; Peterson, 1985). The lines generally have embedded centers of divergence at the surface, coincident with local maxima in the radar reflectivity field. Whereas a single microburst might have a lifetime on the order of 15 minutes, the microburst line typically lasts for about an hour.

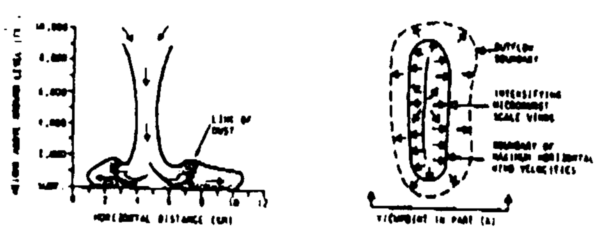

Fig. 6 Basic microburst line structure by Stevenson (1985).

Stevenson (1985) has shown that microburst lines have a severe impact on airport operations primarily because they are long-lived and propagate slowly (mean speed 1.3 m/s (Hjelmfelt and Roberts, 1985)); however, this also implies that they can be more easily predicted. Using a quasi-compressible three-dimensional numerical model, Anderson *et al.*, (1985) showed that merging microburst outflows may pose an even greater danger to aviation than solitary outflows for two reasons: the effective divergent outflow depth increases and thus so does the total amount of hazardous airspace, and the increased horizontal pressure gradients can lead to even stronger, more divergent outflows.

In summary, the strength of the microburst line outflow and the corresponding hazard to aviation can vary tremendously. Al-

*Wieler (personal communication) has observed microburst wind shear associated with a very low reflectivity storm near Boston, MA with the Raytheon Co. prototype NEXRAD Doppler weather radar.

though microbursts have been observed to form in groups or "families" in other parts of the country, the identification of the microburst line as a new storm type arose from observations of weather phenomena near the Rocky Mtns, suggesting orographic influences in the organization of this storm type. The primary concern for aviation appears to be the severe impact that a slow-moving large scale storm with embedded divergent outflows has on airport operations.

3.6 Airmass thunderstorms

One of the first parent cell types to be associated with microbursts was the isolated cumulonimbus cloud (Fig. 7). Although

Fig. 7 Conditions that might be expected in a thunderstorm cell in the mature stage. From Byers and Braham (1949)

called simply "thunderstorms" at the time, Byers and Braham (1949) measured very strong, small scale divergent surface outflows that would today be classified as microbursts (*e.g.*, "When the cold downdraft of a cell reaches the surface layers of the atmosphere, it spreads out in a fashion similar to that of a fluid jet striking a flat plate"). Based on the number of fatalities that have occurred in wind shear related accidents, these are the storms that produce the most hazardous forms of low-altitude wind shear. The research question then becomes how to distinguish in advance the thunderstorms that will produce violent outflows from those that will produce outflows of ordinary strength.

Airmass storms are common in areas of convective instability, high surface relative humidity, and little or no vertical wind shear, implying that they could occur in most any part of the country during the summer months. Dyer *et al.* (1976) present Doppler observations of a windstorm near Boston in which a "brief phenomenon" associated with heavy rain caused straight line wind damage "confined to a region less than 1.5 square miles in area". They also note that none of the characteristic severe storm radar signatures were present so radar operators failed to recognize the damage potential. A subsequent reexamination of the same case showed a disorganized multicell airmass storm with one large, tall cell and a weak echo region at the surface in the area of highest winds.

Caracena and Maier (1979) present an analysis of a dual microburst event that occurred in the FACE (Florida Area Cumulus Experiment) mesonet. The cell which produced the microbursts was, again, one of the tallest within a disorganized multicell line of storms, having been forced more vigorously at the surface in the convergence zone of two colliding outflow boundaries. The authors conclude, as have others since, that the spearhead shape taken on by the radar echo was attributable to the rapid growth of new cells on the advancing edge of the storm. The microbursts, lasting less than 5 minutes, were associated with heavy rain and embedded in a storm scale downdraft that continued for over 30 minutes. Careful analysis of the synoptic scale situation revealed 1) a broad area of enhanced positive vertical velocity ahead of a 500 mb meso-low, 2) the intrusion of air with low equivalent potential temperature between 400 and 500 mb, and 3) intensifying vertical wind shear, as north-northwesterly winds of 5-7.5 *m/s* at 500 mb overlaid boundary layer easterly winds of 5 m/s. Hourly photographs taken before the microbursts occurred showed that the towering cumuli tilted significantly downshear.

In trying to account for the observed 30 m/s surface outflow speeds, the authors found that a technique by Foster (1958), based on moist adiabatic descent of downdraft air consisting of a mixture of midlevel air and updraft air (equal proportions), predicted gusts of less than 19 m/s. They suggested that the additional source of negative buoyancy could come from: 1) the melting of large quantities of ice; an unusually large quantity may have formed since, with the extraordinary boundary layer forcing of the microburst cell, the precipitation core remained aloft with overshooting tops of 17 km for 45 minutes; 2) efficient entrainment of midlevel air of low equivalent potential temperature into the downdraft without mixing with updraft air, and/or 3) precipitation loading; however the observed precipitation rates were too low to completely account for the discrepancy.

The striking difference between probable downdraft speeds and observed outflow speeds has also been observed by Fujita (1984, 1986). Through analysis of a microburst that caused damage at Andrews AFB, through visual and multiple Doppler observations of JAWS microbursts, and through laboratory simulations with cold descending air currents, the presence of a well defined rotor at the leading edge of the microburst outflow was demonstrated. Wakimoto (1982) has also shown Doppler observations of a vortex roll at the leading edge of a downburst outflow. Waranauskas (1985) notes that "the lower pressure at the rotor core acts to accelerate the surface winds, thereby making the axial center and the microburst coincident on spatial and temporal scales". It is hypothesized by Fujita that in this way, through vortex tube stretching at the leading edge of an expanding outflow, a weak or moderate downdraft could produce strong surface winds that would appear in small patches along the outflow boundary as the vortex tube separated (Fig. 8).

Linden and Simpson (1985) used a laboratory model with aqueous salt solutions of two different densities to show the existence and increasing vorticity of both the primary vortex roll at the leading edge of the expanding outflow, and a secondary vortex (Figure 8). They suggest that the vortices are manifestations of Kelvin-Helmholtz instability; in two dimensional flows the K-H billows are restricted to the upper half of the current but in this three dimensional case "the billows temporarily occupy the full depth of the outflow". They also note that an already existing circulation in the descending air would further increase the intensity of the primary vortex.

Both Fujita (1986) and Linden and Simpson (1985) suggest that the embedded vortices in the outflow pose an additional wind shear threat to aviation, and that the recent microburst-related crash of Delta 191 at Dallas/Ft. Worth may have been caused by the downward motion on the backside of one of these vortices. One unknown

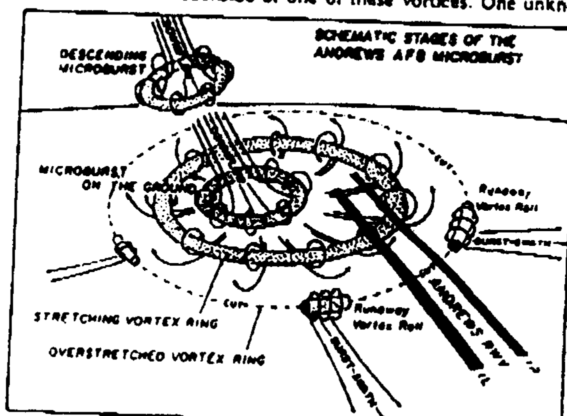

Fig. 8. Four stages of Andrews AFB microburst. They are: 1st Stage (DESCENDING) Midair microburst descends. 2nd Stage (CONTACT) Microburst hits the ground. 3rd Stage (MATURE) Stretching of the ring vortex intensifies the surface wind speeds. 4th Stage (BREAKUP) Runaway vortex rolls induce burst swaths. From Fujita (1984).

is how often and under what conditions these high speed horizontal vortex rolls will develop. In one microburst observed with RHIs taken with the FL-2 radar in Huntsville, AL (9/21/86), horizontal vortices were excited in a pre-existing outflow pool when the fresher outflow from a newly forming microburst impacted the surface (Fig. 9a). These smaller vortices rapidly dissipated (Fig. 9b) leaving the largest, fastest wave travelling outward at the head of the outflow current. The presence of this type of well developed leading outflow wave is the rule rather than the exception in microbursts observed in Memphis, TN and Huntsville, AL.

Some of the JAWS microbursts were associated with isolated, unsteady multicell airmass thunderstorms that produced very heavy rain, although commonly the cloud bases were quite high and the storms were fairly long-lived. One impressive storm that occurred on 30 June 1982 has received considerable attention (*e.g.*, Kessinger, *et al.*, 1983; Smith and Waranauskas, 1983; Weisman, *et al.*, 1983;

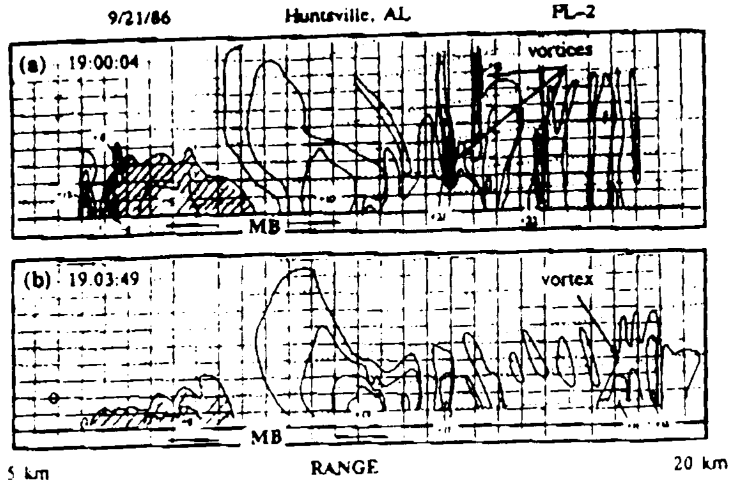

Fig. 9 RHI cross section through a microburst storm on 9/21/86. The background grid spaces are 0.1 km in the vertical and 0.5 km in the horizontal. The region shown is thus 1 km high by 15 km across, at a range of 5-20 km from FL-2 (the radar is at the left). Contours of Doppler velocity at 3 m/s intervals are shown. Numbers are Doppler velocities in m/s; negative velocities (hatched) represent flow toward the radar. The outflow is stronger away from the radar than toward because the microburst fell into a pre-existing outflow that was moving away from the radar.

a.) Contoured Doppler velocity from an RHI scan taken one minute after the microburst impacted the ground, at 19:00:04 GMT. Note the vortices set up in advance of, and at the leading edge of, the outflow.

b.) Contoured Doppler velocity from an RHI scan taken at 19:03:49. Notice that the outflow has become thinner (~ 200 m deep), broader, and has increased in speed; the highest speed winds were at the lowest sampled altitude. The transient vortices have dissipated leaving the microburst outflow itself and one vortex at the leading (outbound) edge of the outflow pool.

Kessinger, *et al.*, 1984; Parsons, *et al.*, 1985). It evolved in an environment characterized by low vertical wind shear and moderate instability, had a lifetime of about 80 minutes, produced 1 cm sized hail, and maintained a reflectivity core in excess of 50 dBZ at the surface. A number of microbursts occurred within the larger scale storm outflow.

One of the key radar-detectable precursors of the occurrence of the microburst outflow is the descending reflectivity core of a collapsing thunderstorm cell (Roberts and Wilson, 1984 and 1986). This evidence, together with the very high rainfall rates and radar reflectivity levels observed in these storms, has led many investigators to conclude that liquid water loading must play a primary role in forcing the intense downward vertical acceleration. Analyses by Wolfson *et al.* (1985) of mesonet data collected during the 1984 FLOWS project in Memphis, TN show significant correlation between surface rainfall, which was at times extremely heavy, and the strength of the peak microburst outflow winds (Fig. 10a).

In nearly every case, however, the outflow current was significantly colder, and had lower equivalent potential temperature (EPT) than the surface air it was displacing. This implies that evaporation, and to some degree melting, must have contributed to the negative buoyancy. The peak microburst outflow speeds are also significantly correlated with the temperature deficit and the EPT deficit of the outflow (Figs. 10b and 10c).

Burrows and Osborne (1986) investigated the role of precipitation loading in forcing a microburst that occurred during FLOWS 1985 in Memphis, TN using aircraft measured hydrometeor spectra, cloud liquid water content, and vertical velocity. They showed that in every pass through the storm "the strong downdrafts were found in close association with the areas of heavy precipitation loading", but the correlation between vertical velocity and liquid water content was by no means perfect (Fig. 11). At that altitude in the storm (660 m agl), the negative buoyancy contribution from a mean liquid water content of 6 g/m^3 was slightly less than that from the observed temperature deficit of 2.3°C (42% water loading and 58% temperature deficit).

Leech (1985) makes the point that even if dry air is entrained into the precipitation core at high levels, little evaporative cooling can occur since the air is so cold. In fact, as Proctor (1985) showed with results from a two-dimensional (axisymmetric) numerical model of a thunderstorm, the temperature deviation in the downdraft may actually be positive above the freezing level, since the cooling from the evaporation of hail is too small to compensate for the effects of compressional heating. As the core descends, the effects of evaporative cooling become much more important; these effects will be most important near the level of the minimum in equivalent potential temperature. As Srivastava (1985) has noted, when a given water mixing ratio l is completely evaporated, it will contribute roughly $10l$ to the negative buoyancy through the resulting temperature deficit.

At upper levels in the region of liquid and/or frozen water accumulation, precipitation loading is the dominant forcing mechanism in initiating the the collapse of the cell. However, cooling due to water phase changes during the descent of the core must play a significant role in the additional forcing that gives rise to the extraordinary outflow speeds of the few cells that produce microbursts (see Smith and Waranauskas (1985) for examples of visually impressive microbursts, with reflectivity levels over 60 dBZ, that produced only weak outflows). Thus the nature of the entrainment process of dry air into the downdraft is of great interest. It should be noted that significant evaporation may take place without altering the general appearance of the radar echo. The smallest drops will evaporate first and most efficiently, but they contribute relatively little to the reflectivity, which is proportional to the sixth power of the rain drop diameter. Also, the reduction in liquid water content associated with a reduction in radar reflectivity of 5 dBZ from 55 to 50 dBZ is almost 6 times as great as the reduction in liquid water content associated with a 5 dBZ reduction from 40 to 35 dBZ.

In summary, the air mass thunderstorms with the strongest collapsing phase downdrafts and subsequent outflows qualify as microbursts. In essentially every case, very heavy rainfall concentrated in an area of small horizontal extent, and large decreases in both temperature and equivalent potential temperature at the surface are observed. Often the convection from which microbursts arise is itself initiated by the convergence at the edge of older outflows, so the microburst surface flow pattern is often embedded in a larger scale

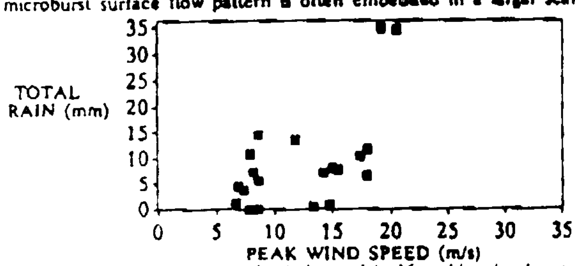

Fig. 10a Total rain vs. peak wind speed in Memphis microbursts.

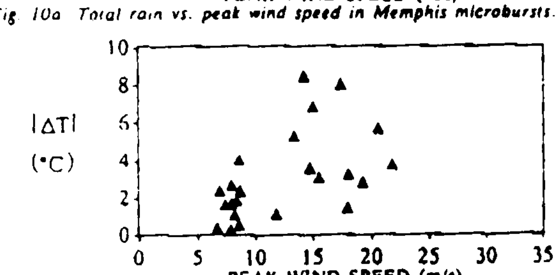

Fig. 10b Temp. drop vs. peak wind speed in Memphis microbursts.

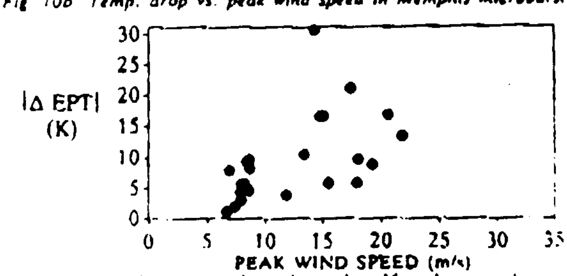

Fig. 10c EPT drop vs. peak wind speed in Memphis microbursts.

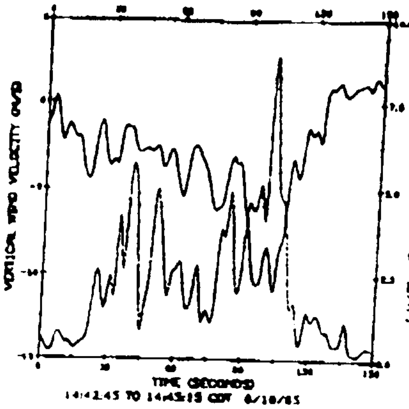

Fig. 11. Vertical velocity (solid line) and precipitation water content (dashed line) are plotted for one pass through the microburst storm on 10 August 1985 in Memphis, TN. Aircraft altitude was 0.66 km agl. From Burrows and Osborne (1986).

storm outflow. Thus, the convection is often but not always in the form of multicell storms, both "secondary" or discretely propagating as described above, or loosely organized with closer cell spacing in a line. Storms with overshooting tops have greater energy levels than other storms, and their cores contain more ice which can lead to greater generation of negative buoyancy as the downdrafts pass through the freezing level. Vortices at the leading edge and within the microburst outflow commonly occur and are associated with very strong surface winds.

Aircraft accidents attributed to microburst wind shear and accompanied by very heavy rain have lead to the greatest number of fatalities. The rain in some cases has been so heavy that it has been suggested that the aerodynamic performance of the aircraft deteriorates because of it, resulting in an overall loss of lift (Luers and Haines, 1981; Dunham *et al.*, 1985; Hansman and Craig, 1987). McCarthy *et al.* (1979) investigated the aircraft response to the Eastern 66 microburst at JFK, and found that the wind shear spectrum contained high energy at the aircraft's "phugoid" or resonant frequency. They believe that this resonance seriously deteriorated aircraft performance by giving rise to sudden oscillations in airspeed and height about the glideslope. Obviously, the high rate of occurrence of airmass storms, their highly divergent outflows, and the small, insignificant-looking size of the cells from which the microbursts form all add to the aviation hazard.

4. SUMMARY

Through the preceding review, it has been implied but not proven that a number of dynamically distinct phenomena give rise to strong surface outflows. At the largest scales, the organized downburst storms occur in association with mesoscale or synoptic scale linear radar echo configurations, in environments characterized by moderate vertical wind shear, and strong thunderstorm potential. The strength of the observed outflow is the result of both the strength of the vertical velocity and the downward flux of horizontal momentum, and may also be influenced by the nearly two-dimensional, linear storm geometry. Because these storms are large scale, long-lived, infrequent, and severe, aircraft have largely been vectored away from them successfully.

In environments with little wind shear, and similar conditional instability, isolated air mass thunderstorms form. In warm, humid conditions the strength of the outflow from these storms is determined by evaporative cooling, both in cloud and below cloud base, and by precipitation loading, especially at upper levels. As the outflow pool rapidly expands, strong straight-line microburst winds form in association with the leading edge vortex roll. This type of microburst-producing storm has proven to be the most hazardous for aviation for a number of reasons: the frequency with which they occur, the rapidity with which they develop, their small scale, the very strong outflows that they produce, their lack of translational motion, and also the fact that storms identical in appearance, at least visually and on conventional aircraft radar, are successfully flown through on a regular basis.

In between, to varying degrees, other forms of loosely organized multicell storms form. It is possible that these storms, with closely spaced echoes that merge to form a spearhead appearance on low resolution radar scopes, are similar to the microburst lines found near Denver; however, they form without any orographic organization. Strong forcing of the updraft can occur as the outflow from a nearby decaying cell triggers the enhanced growth of new cells. Cells that form later in the "chain" appear to grow faster and taller, perhaps because more humid air is entrained into their updrafts allowing for less diluted cores. These downdrafts and outflows will be correspondingly stronger, providing more forcing for the next cell, and so on. To the extent that these multicell storms are larger and longer lived than isolated storms, they are easier for air traffic to avoid; however their explosive growth makes them very unpredictable and airspace that was a safe distance away from such a storm complex one minute could be inundated with microburst wind shear the next.

The microbursts that arise from shallow, high-based cumulonimbus clouds can only occur in an environment with a deep, dry adiabatic mixed layer, with sufficient moisture aloft to sustain a downdraft all the way to the surface in the face of strong evaporation. Suitable conditions have mainly been observed in the high plains east of the Rocky Mtns. during the summer months. The surface reflectivity values of these microbursts are low and, because they occur in an urban (high clutter level) environment, a Doppler radar with sophisticated ground clutter supression capability is required for their effective detection.

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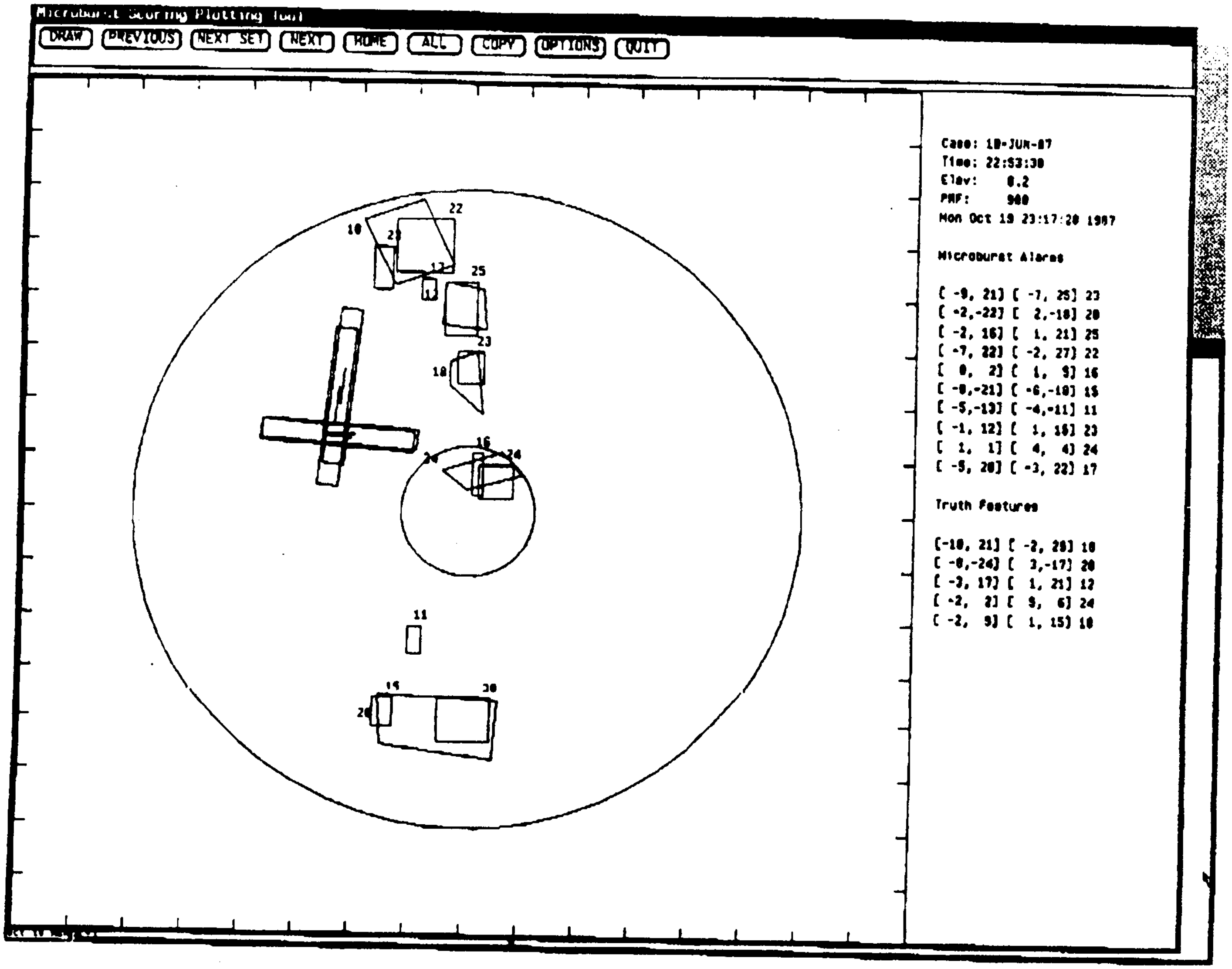

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QUESTIONS AND ANSWERS

ROLAND BOWLES (NASA LaRC) - You mentioned wind shear alarms several times. Could you tell me what alarm criteria you use, and does it factor in the effect that it be dependent on whether the radar is located on-airport or off-airport, and does it consider the fact that the divergence information may be in error by as much as a factor of six?

MARK MERRIT (MIT Lincoln Labs) - The simple answer is no to both of the questions. The processes as implemented to date obtains a measure of the divergence shear across the event based on the process I described, and a threshold to that. Of course prime continuity of that intensity applies a threshold criteria to that. It is independent of the location of the event with respect to the airport and is based primarily on measurement of the radial shear. With respect to the errors in the measurement of the shear, I presume you are reffering to assymmetry. The assymmetry problem has not yet been looked at carefully. The factor of 6 number is in fact not well supported. And this is the subject of considerable investigation at Lincoln as well. Observers have found looking at severe outflows that a line rotated through the center in different directions can find a factor of 6 difference in the velocity change across the event in different directions. That process does not correspond to the approach I described here measuring velocity of differences. (Which does not in fact look only through the center of the event.) In fact, the report recently issued by Mike Eilts at NSSL (National Severe Storms Laboratory) contains, there is now a program which is not well reported in the paper where in fact he took both approaches to the assessment of the assymmetry problem where he looked at different directions through a center point and one of the things he found was that the results of that kind of analysis (that is the ratio to maximum to minimum velocity difference seen through event) was extremely dependent on where that center point was chosen. What he also did was he examined various radar points offset the nominal distance from the event, synthesized what the radar view would be from those different directions and compared the velocity differences seen by the various radar positions. What he found in all cases was a substantial reduction to difference on the order of 2 to 1, 2 .5 to 1 maximum error. So the detection process does not in fact at this time take in account the assymmetry although the system we will be fielding next summer may well take into account the fact that one form of assymmetry causes the velocity couplet to be somewhat skewed at the surface and to rely not only on finding differences along radials from the radar but also being able to compare velocity differences with alignment somewhat skewed to the radial direction that we hope will help counter the assymmetry problem.

FRED PROCTOR (MESO, Inc.) - How do you distinguish between macrobursts and microbursts? A lot of what you have presented seem to look more like what I call macrobursts than microbursts.

MARK MERRIT (MIT Lincoln Labs) - The primary requirement here is that within a 4 kilometer region that we see a velocity change at 10 meters per second. That is the criteria developed by the TDWR LLWAS users group in the last couple of years.

FRED PROCTOR (MESO, Inc.) - Your definition of a microburst is a little different from that being used by other people. Usually a microburst is defined as having a horizontal distance between diverging outflow peaks of less than 4 km, and a velocity change between the peaks of at least 10 meters per second.

MARK MERRIT (MIT Lincoln Labs) - This is an issue again. There has been a group, Terminal Doppler Weather Radar Users' Group which has met a couple times under the organization of people from NCAR. There goal has been to try and work out issues like: At what point do you issue alarms; and what is the format of the resulting information presented to users? And this issue, of course, was discussed at length and this criteria which was developed which by no means is a consensus among the research community at all--the answer developed by that group which was based primarily on input from I believe Boeing and researchers at NCAR: Was this criteria of a specific velocity change within a 4 kilometer region? And you're right that is very different from what a lot of other people are using.

JOHN CHISHOLM (Sierra Nevada Corp.) - You mentioned that you are trying to use data at altitude. What is the status of that work?

MARK MERRIT (MIT Lincoln Labs) - There is an algorithm that has been reported (the copy of the first page of the paper in the handout), worked on at Lincoln to detect these features and notice, for example, that there is a core of reflectivity that is sinking towards the surface and is associated with rotation. That algorithm has been developed, tested extensively off-line (again these ground truth cases), and has been scored using the same scoring procedure and comes up with somewhat improved detection performance at this point. And that algorithm will be implemented in our demonstration system next summer.

JOHN CHISHOLM (Sierra Nevada Corp.) - Is it a useful algorithm. I mean how beneficial is it?

MARK MERRIT (MIT Lincoln Labs) - Well, if you are asking how much benefit you get by merging this information aloft in addition to looking at the surface velocity, we have two bases for experience. One is in Huntsville where we have predominantly heavy reflectivity -- heavy rain cases. In that situation we find that this 3-dimensional algorithm provides significantly better performance, particularly in its ability to reduce false alarms. In the Denver context, where we see a broader spectrum of intensity reflectivity in the reflectivity levels, we find that the added performance of this algorithm (given that the tuning of the algorithm to the Huntsville environment), is not as great. We are in the process now of refining the thresholds used in this algorithm on the Denver data and we will have a better idea of how much benefit it gives a little later.

JOHN CHISHOLM (Sierra Nevada Corp.) - In terms of your outflow algorithm, at what altitude is the data most useful? Right on the ground, 500 ft, 1000 ft?

MARK MERRIT (MIT Lincoln Labs) - The examination we've done on the surface outflow shows that the strongest winds are below 1000 ft. and we attempt to use information from an elevation angle scan which both clears clutter and maintains the maximum observation of those peak outflow winds. We are looking at the 4 to 600 ft. altitude region.

GARY BROWN (VPI) - Your algorithm for detecting at altitude: If you detect at altitude, do you have another way to determine what the magnitude of the down draft is resulting from that? Because that is a different aspect to the problem.

MARK MERRIT (MIT Lincoln Labs) - Yes. There is a feeling that one might be able to use, for example, the strength of the convergence aloft to the decent rate of the reflectivity core, to somehow get a handle on what the strength of the outflow is. There is research work going on in that direction. In particular, Marilyn Wolfson at Lincoln Lab is looking at that problem. It is not developed to the point where it is an actual operational capability yet. That capability has not been demonstrated to be feasible but there is a belief that there may be useful information there.

GARY BROWN (VPI) - Can I ask just one more? And that is, you've done a lot of work with the detection using the outflow, have you addressed the quantification problem yet?

MARK MERRIT (MIT Lincoln Labs) - Not in detail no. The detection process is evaluated using the information that has to date been primarily focusing on detectability, not so much on accuracy in terms of quantifying the strength.

C - 6

N88-17633

THE ADVANCED LOW-LEVEL WINDSHEAR ALERT SYSTEM

OPERATIONAL DEMONSTRATION RESULTS

SUMMER, 1987

DENVER STAPLETON INTERNATIONAL AIRPORT

BY

JAMES MOORE

ATMOSPHERIC TECHNOLOGY DIVISION

NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

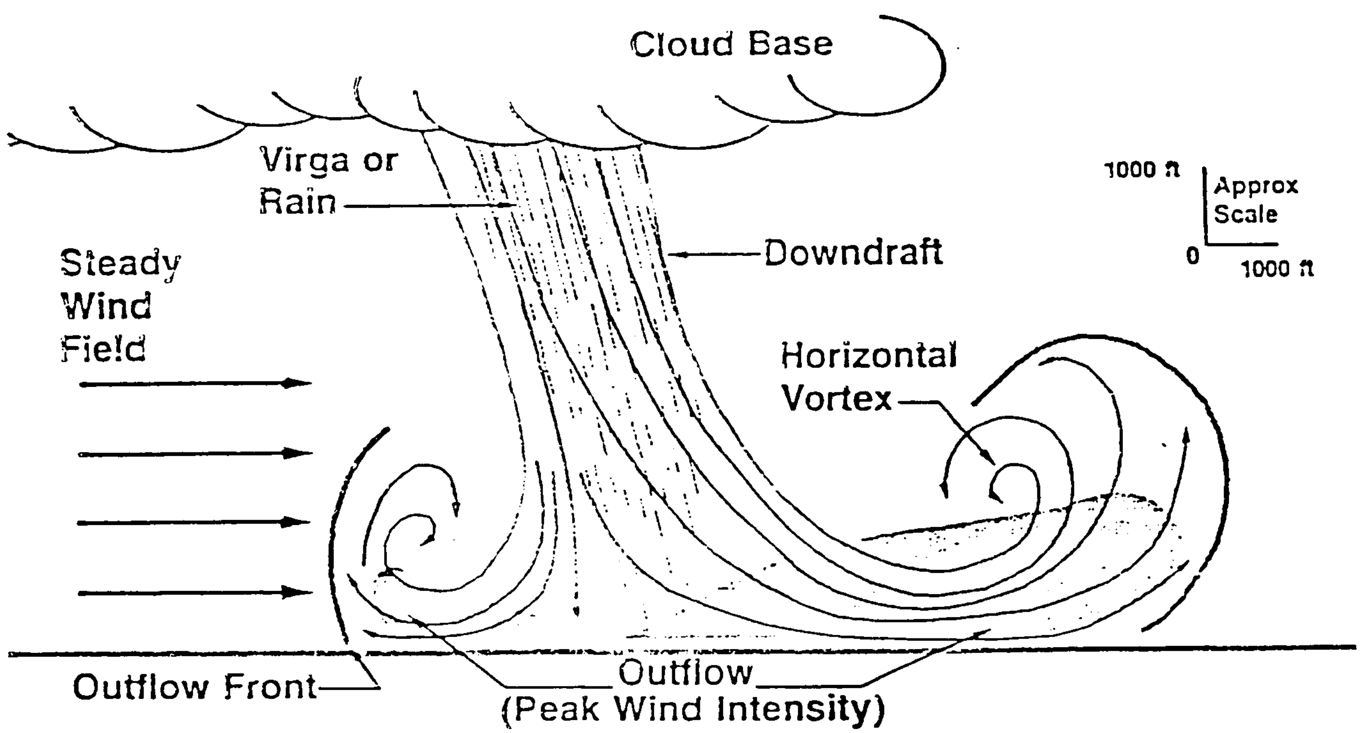
FOR THE

FIRST COMBINED MANUFACTURERS' AND TECHNOLOGY
AIRBORNE WIND SHEAR REVIEW MEETING

NASA LANGLEY RESEARCH CENTER

OCTOBER 22-23, 1987

DRAFT



	First Detection	Max Intensity
Max Velocity Differential	24 kn	47 kn
Distance	0.9 nmi	1.5 nmi

Time to Max Intensity → 6.4 min

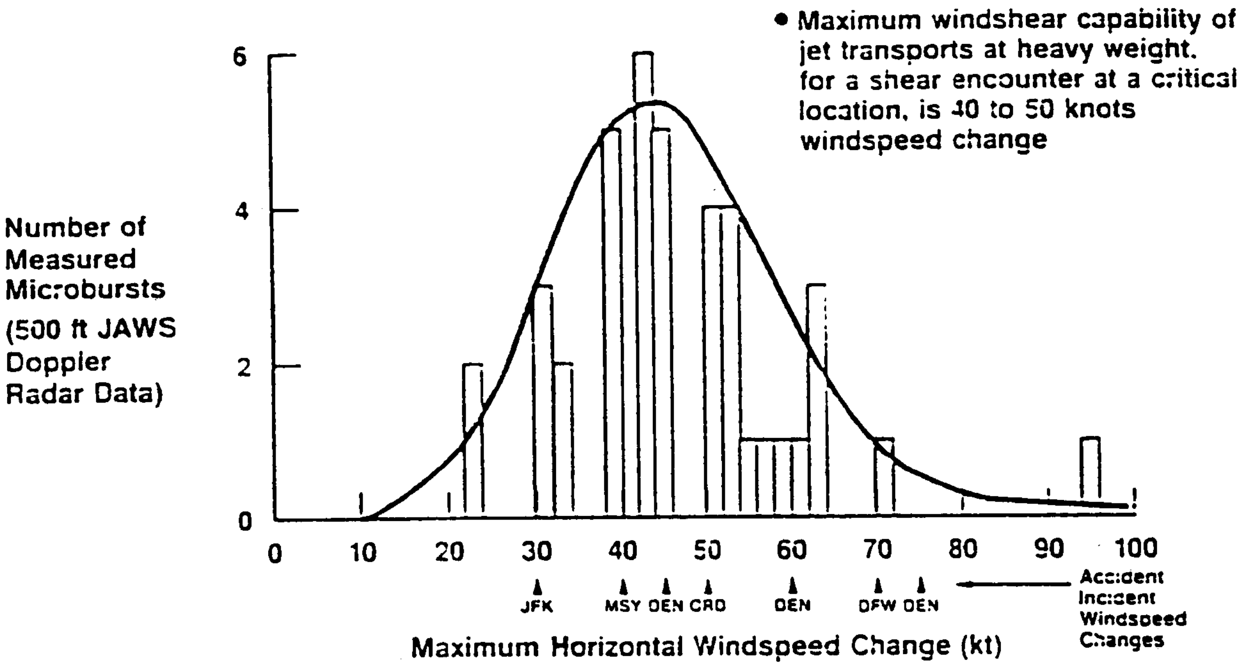


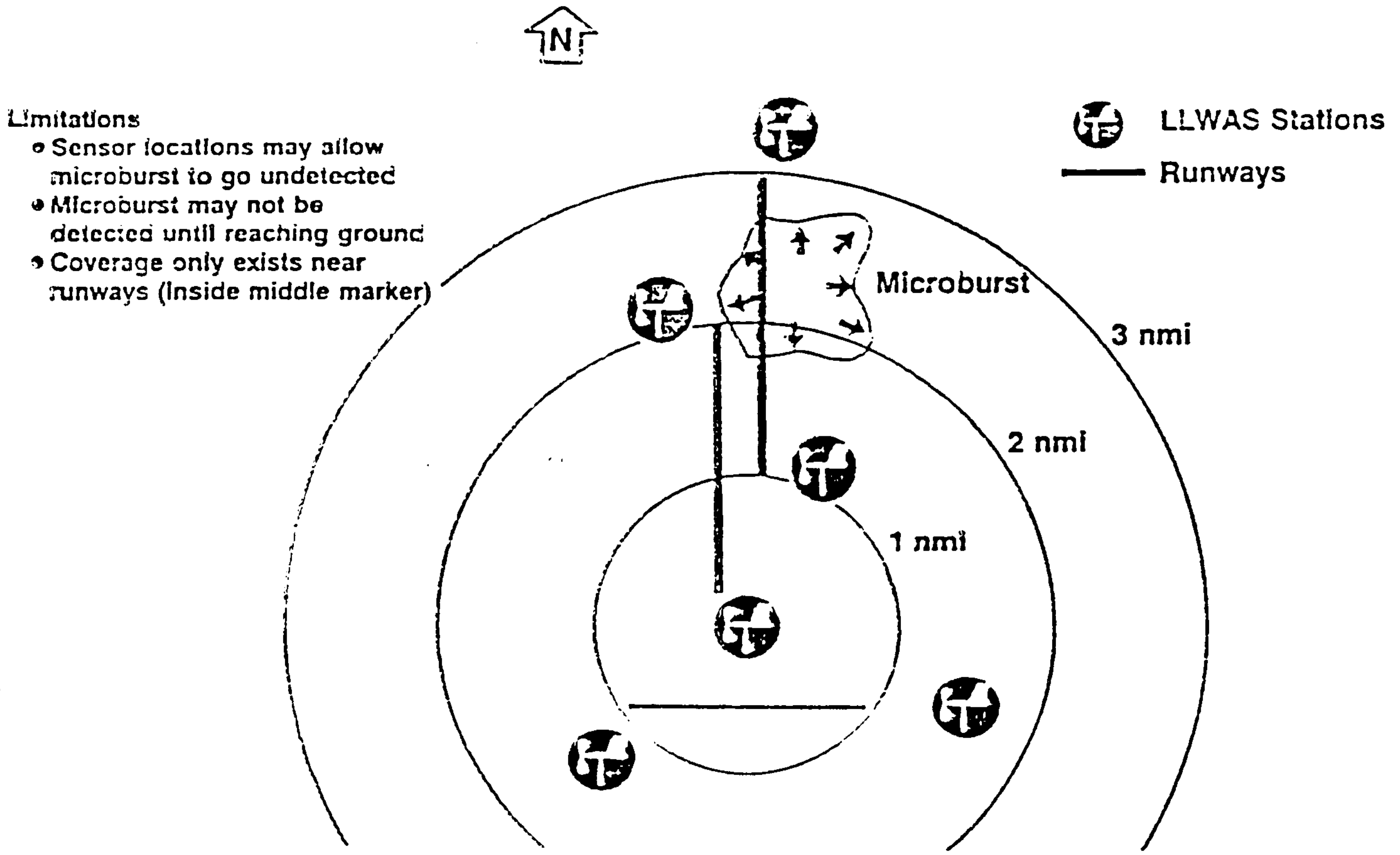
Figure 11. *Microburst frequency versus intensity. Accidents have occurred in windshears within performance capability of airplane. Some windshears cannot be escaped successfully!*

ENHANCED LOW-LEVEL WINDSHEAR ALERT SYSTEM (LLWAS)

ORIGINAL SIX-STATION:

- Spacing too crude to detect microbursts.
- Original six-station algorithm favored gust frontal wind shifts and generally did not detect microbursts.
- Format of old LLWAS message was confusing; confusion associated with this message listed as contributing cause of Pan Am Flight 759 in New Orleans.

DRAFT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Limitations
Sensor locations may allow microburst to go undetected
Microburst may not be detected until reaching ground
Coverage only exists near runways (Inside middle marker)
LLWAS Stations
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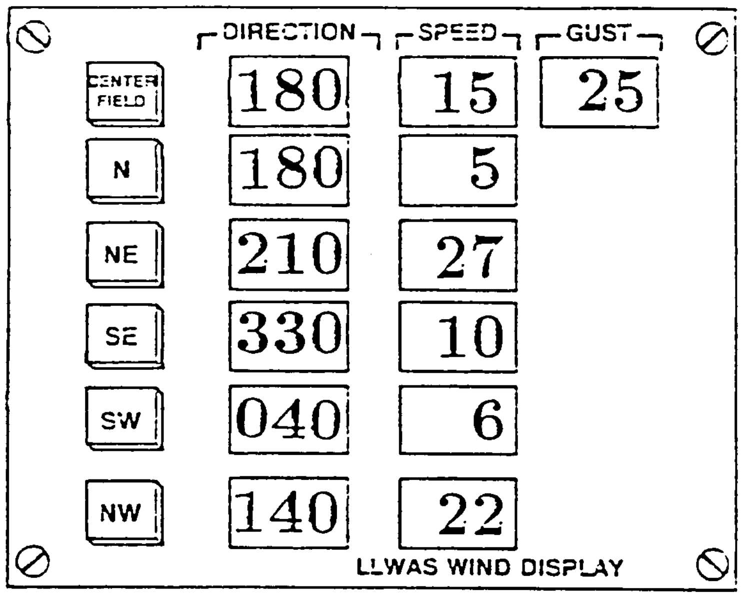
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LLWAS WIND DISPLAY

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ENHANCED LOW-LEVEL WINDSHEAR ALERT SYSTEM (LLWAS)

ENHANCED TWELVE-STATION:

- Spacing between stations cut in half. does considerably better job on detecting microbursts.
- Algorithms specifically identify *MICROBURST WIND SHEAR ALERT* as a first priority, then identifies all other wind shear events detected as *WIND SHEAR ALERT*.
- Format of enhanced system provides pilots with runway-oriented wind shear message:

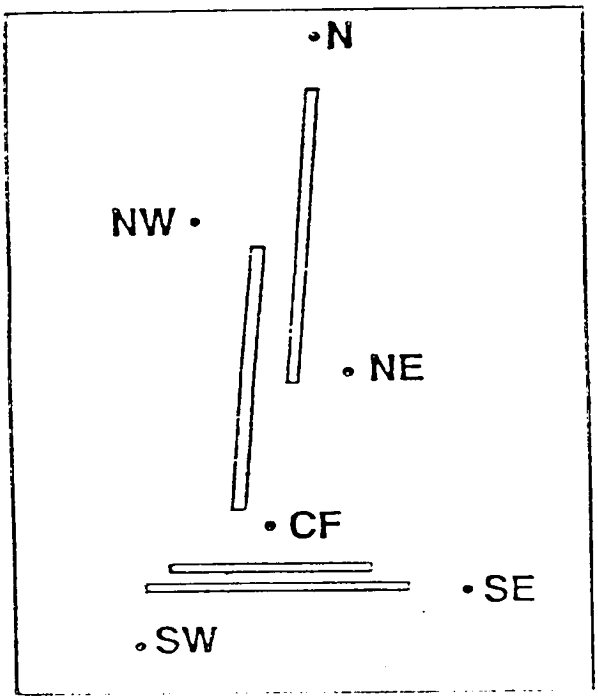
  UNITED FLIGHT 226, RUNWAY 26 LEFT, MICROBURST ALERT, 50 KNOT LOSS, ON THE RUNWAY

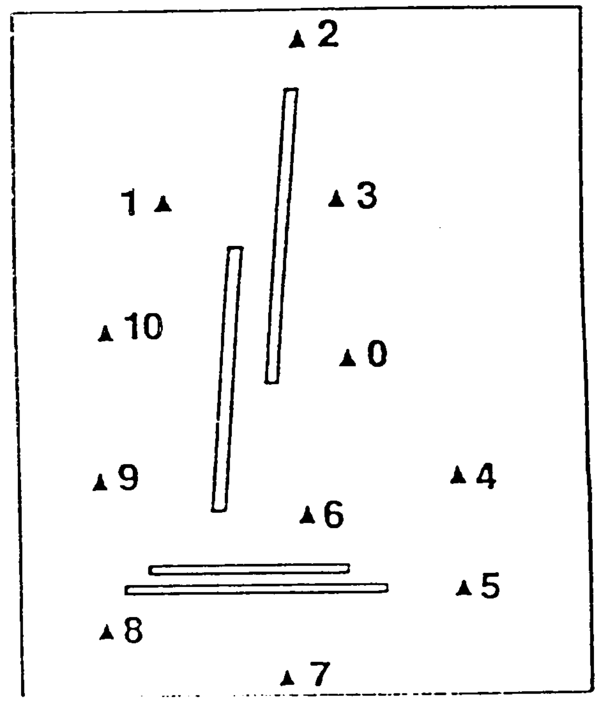
  DELTA FLIGHT 341, RUNWAY 17 RIGHT, WIND SHEAR ALERT, 15 KNOT GAIN, 1 MILE FINAL, THRESHOLD WIND 230 AT 22

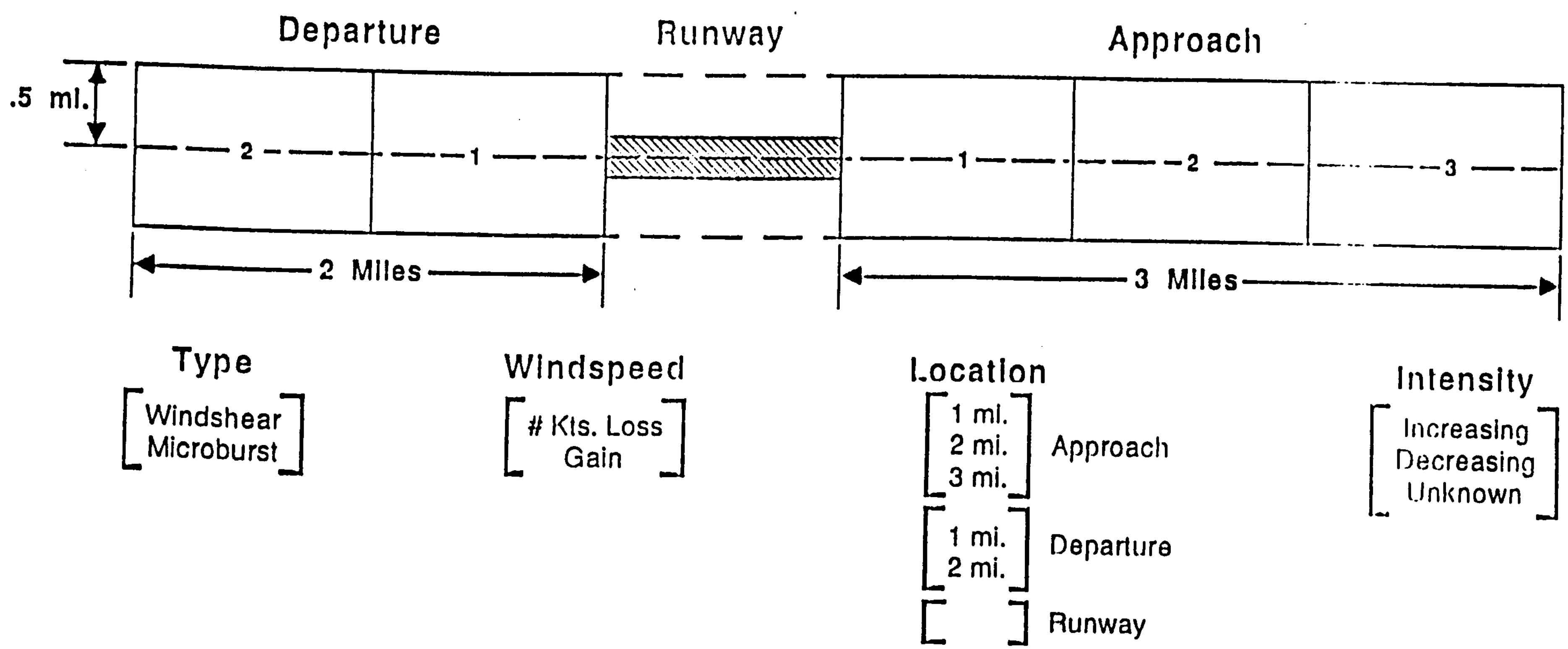
  CESSNA 9477 MIKE, RUNWAY 08 RIGHT, WIND SHEAR ALERT, 15 KNOT SHEAR, 1 MILE FINAL, THRESHOLD WIND 090 AT 15, WIND SHEAR OUTSIDE THE NETWORK

- We are testing a geographical situation map-type display in the tower, to appraise controller interest in such a display.

DRAFT



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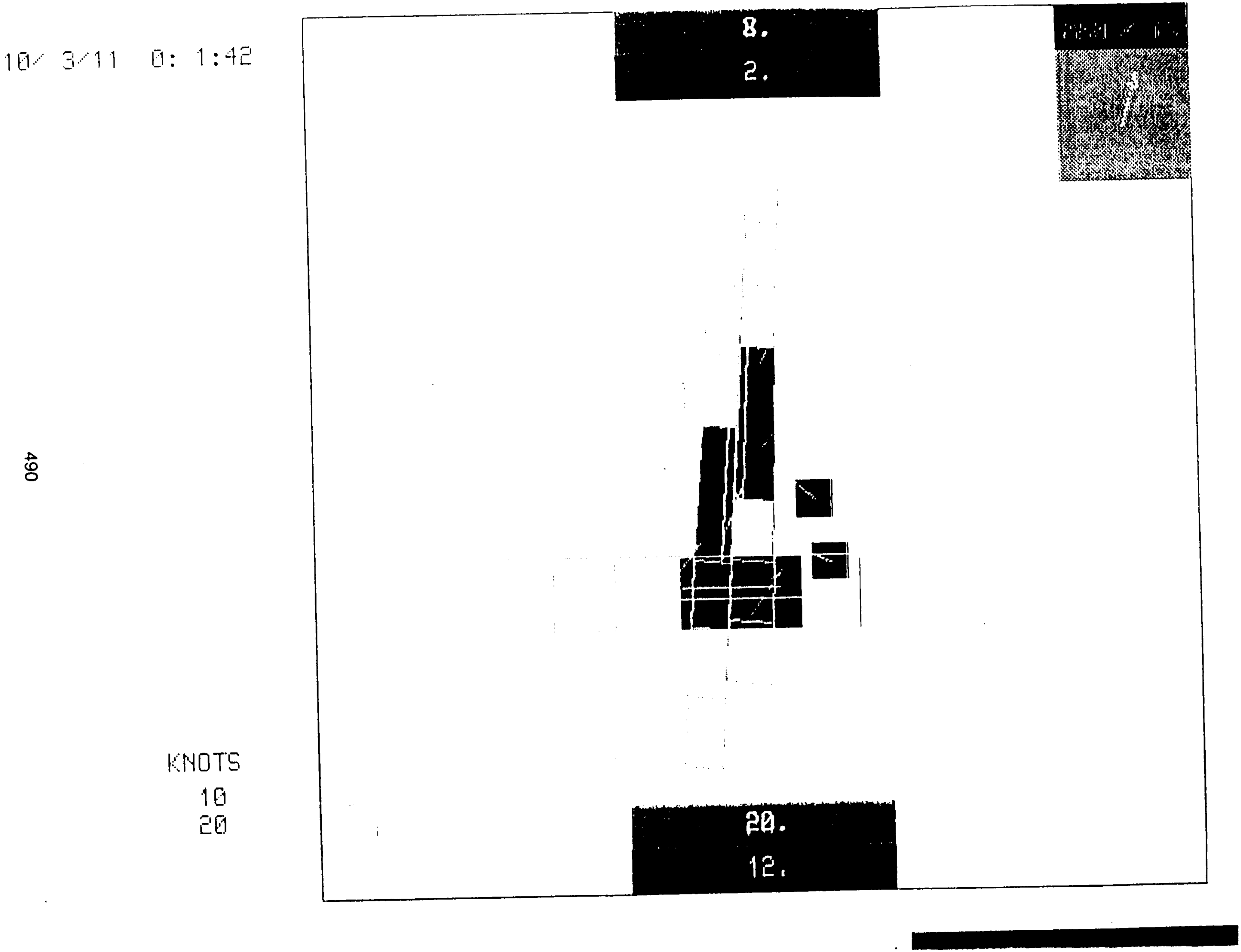
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MBA	26 D	045	15		RWY	35-
MBA	8 D	330	15	G 25	RWY	20-

	CF	190	16	G 25		
MBA	35 LD	160	22	G 30	RWY	50-
MBA	35 RD	180	5		RWY	25-
MBA	35 LA	030	23	G 30	1 MF	55-
	35 RA	180	10		3 MF	60-
MBA	17 LA	180	5		RWY	25-
MBA	17 RA	160	22	G 30	RWY	55-
	17 LD	180	10		RWY	60-
MBA	17 RD	030	23	G 30	RWY	55-

CF	280	6
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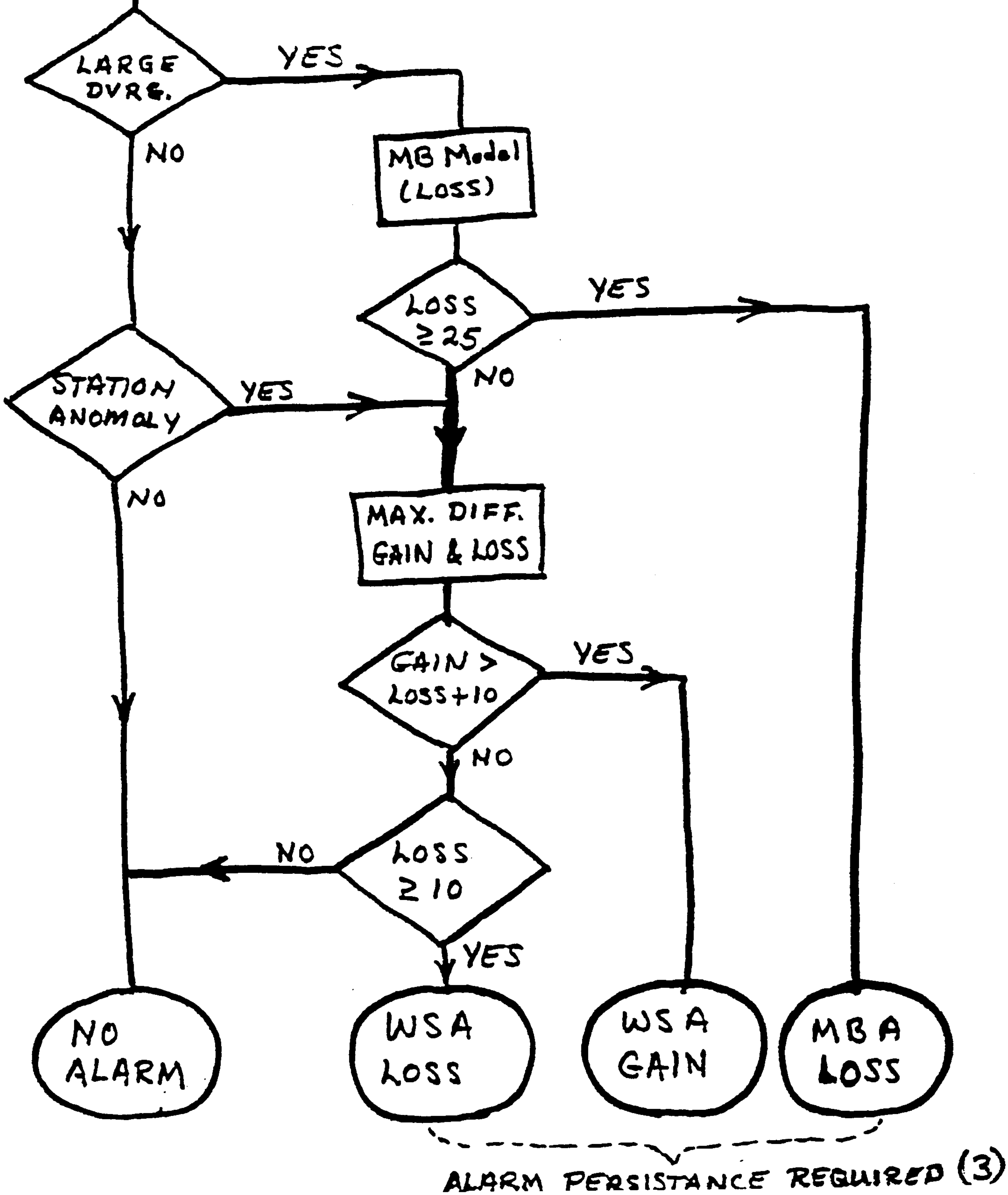
35 RD	290	4
35 LA	CALM	
35 RA	280	6
17 LA	290	4
17 RA	270	5
17 LD	280	6
17 RD	CALM	

ALARM LOGIC
(EACH 6-SEC POLL)



The Enhanced LLWAS issues three kinds of alarms:

MBA: Microburst Alarm (Loss $\geq$ 25)

WSA-: Wind Shear Alarm with LOSS

WSA+: Wind Shear Alarm with GAIN

We have compiled alarm statistics for the months of JUL AUG 1987 and have distinguished between the active afternoon and evening period and the more passive night and morning period. On average, we have found the following:

MONTHLY AVERAGES

	ACTIVE Min/10 Hrs		PASSIVE Min/14 Hrs		COMBINED Min/Day	
	JUL	AUG	JUL	AUG	JUL	AUG
MBA	1.6	.7	.8	.2	2.6	.9
WSA+	4.8	1.9	1.5	.1	6.5	2.0
WSA-	12.3	5.9	1.5	.2	14.3	6.1
Total Alarms	15.5	7.1	3.1	.3	18.2	7.4
CFA		11.2		1.3		12.5

SOME ACTIVE DAYS (min/10 HR)

	MBA	WSA+	WSA-	TOTAL	CFA
AUG 20 (2MB)	7.6	2.9	11.2	18.5	13.1
AUG 4 (THERM)	.5	3.9	5.5	9.0	37.1
AUG 5 (THERM)	3.3	.4	10.9	13.8	18.5

WHAT WE LEARNED FROM THE ADVANCED LLWAS OPERATIONAL DEMONSTRATION

MCCARTHY (OCTOBER 1987)

1. Alpha-numeric message quite successful from controller usage; several minor changes recommended that are being implemented.

2. Advanced LLWAS geographical situation display developed and fielded for NCAR tower meteorologist were successful; provided:

   Advanced LLWAS wind field over runway map in a manner that provided supervisory controller with means of "seeing" two-dimensional wind field at airport, on an approximately 5 n mi radius map overlay. In a non-alert status, this map provided limited ability for supervisor to reconfigure runways, based on prevailing wind situation (of course, wind shift prediction of TDWR would substantially improve this capability, after CLAWS results).

   Map-type display of wind shear alert information, that allowed supervisory controller to reconfigure approach/departures, depending on where alerts were occurring (i.e., if alerts were occurring only on N-S runways, controller would frequently use GSD to determine that E-W runways remained viable.

3. Preliminary Advanced LLWAS algorithm results (general impressions):

   Microburst detection alerted on approximately 25 knot differential (although alert threshold was divergence-dependent). Worked apparently well, except that very rare thermal that appeared divergent alerted system.

   Microburst detection always reported loss, based on a fit to a symmetric microburst model; likely misrepresented wind field on some occasions, presumably due to microburst asymmetries, or to semi-divergent winds imbedded in gust frontal structures.

   Wind shear alerts (station anomaly algorithm) worked very well, except that thermals occasionally fired the alarm; two types of WSAs occurred: wind speed loss, wind speed gain.

   No alarms were sounded if computed runway loss or gain did not exceed ten knots; this was a demonstration glitch - threshold should have been 15 knots. This would have eliminated some inappropriate alarms (alarms that presumably did not represent hazards).

   Some sheltering clearly caused some false alarms; this includes microburst and wind shear alarms.

4. Controller and Pilot feedback; still under review. Initial reactions suggest controllers wildly enthusiastic. All written pilot reaction favorable, but I have observed caution regarding accuracy of advanced LLWAS.

MCCARTHY'S GENERAL IMPRESSION OF ADVANCED LLWAS

1. Operational User Group display product concept very successful; estimate of runway effects, tailored to each runway direction, made quantum advance in terminal information content.

2. Non-alert status of advanced LLWAS provided excellent routine and very useful information to ATC; area supervisor will get advanced LLWAS alpha-numeric display in TRACON; is requesting GSD for supervisors in tower and TRACON.

3. Visual inspection of comparison between wind field seen on advanced LLWAS and alert message indicated at least qualitative and some quantitative agreement; somewhat but not always substantiated by pilots.

4. Advanced LLWAS concept should be cornerstone of TDWR operational display. In non-alert status, advanced LLWAS winds need to be displayed on TDWR 5 and 12? n mi GSD display, and on TDWR alpha-numeric display.

TERMINAL DOPPLER WEATHER RADAR (TDWR)

1987 TESTING:

- Running automatic microburst detection algorithms, off-line, to verify accuracy.
- Maintaining independent assessment of microburst presence; verification of all microbursts present.
- Over 200 microbursts identified within 30 km of Lincoln Lab radar since 18 May 1987!
- Goal is a 90% probability of microburst detection, and a 10% false alarm. Scoring is not yet complete, but results to date are very encouraging.
- Assuming 1987 scoring is satisfactory, plan to have full TDWR operational demonstration in 1988.

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SUMMARY OF TERMINAL DOPPLER WEATHER RADAR ACTIVITIES

SUMMER, 1987

MCCARTHY (10-19-87)

1. Over 300 microbursts identified within 30 km of MIT/Lincoln Lab radar!

2. Microburst surface divergence detection ground truthing provided POD greater than 90% and FAR less than 5 % (target was 90/10).

3. Microburst lines not well identified.

4. Gust front/wind shift detection/prediction not adequate.

ALGORITHM VERIFICATION

AND REFINEMENT PROCESS

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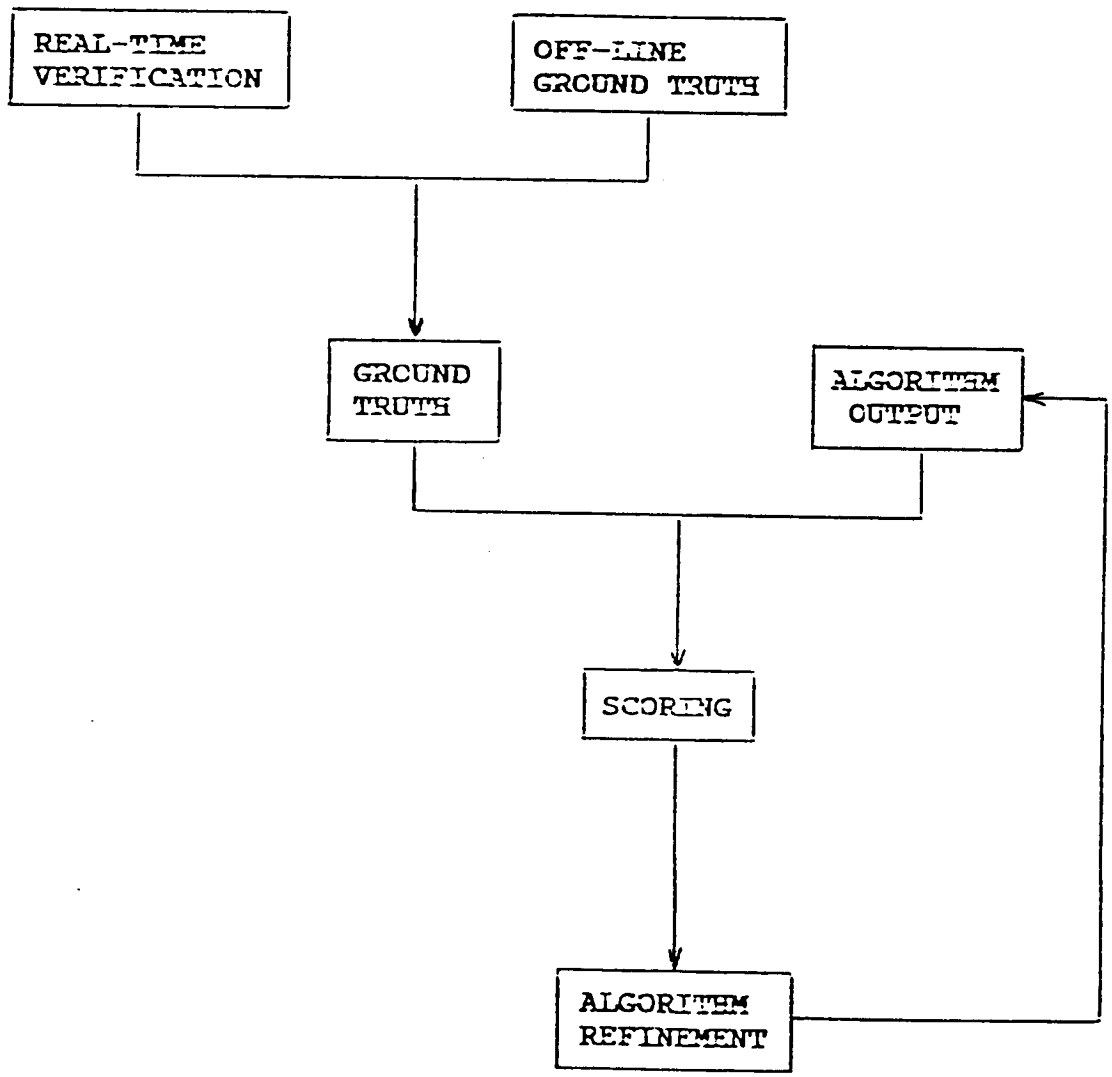


SINGLE-DOPPLER DATA: ASSESS THE FIDELITY OF THE ALGORITHM

DUAL-DOPPLER DATA: ASSESS THE FIDELITY OF THE SYSTEM

PLANS FOR SUMMER, 1988 OPERATIONAL DEMONSTRATION

1. Major RAP concentration on making microburst algorithm output user friendly and displayable to ATC, using model of Operational User Group as demonstrated with Advanced LLWAS; Cleon Biter and Wayne Sand have action here.

2. MIT/LL will concentrate on making 3-D microburst algorithm run faster in real time.

3. NSSL will concentrate on getting gust front/wind shift algorithm to work effectively.

4. RAP will concentrate on developing sophisticated NOWCASTING display system, utilizing Alliant/Symbolics/Pixar combination with Lutz/Barron/J. Wilson talents.

5. Summer, 1989 advanced operational demonstration is anticipated.

LOW-ALTITUDE WIND SHEAR RESEARCH AND DEVELOPMENT

THE MAJOR PLAYERS

<u>THE LLWAS SYSTEM:</u>

FEDERAL AVIATION ADMINISTRATION

NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

FAA TECHNICAL CENTER

FAIRCHILD-WESTON, INC.

CLIMATRONICS, INC.

MARTIN-MARIETTA CORP.

<u>THE TDWR PROGRAM:</u>

FEDERAL AVIATION ADMINISTRATION

MIT LINCOLN LABORATORY

NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

NATIONAL SEVERE STORMS LABORATORY

UNIVERSITY OF NORTH DAKOTA

MARTIN-MARIETTA CORP.

TRANSPORTATION SYSTEMS CENTER, DOT

QUESTIONS AND ANSWERS

RICK PAGE (FAA Tech Center) - Jim, just a point of clarification. The graphic display that was in the tower during the period of test in Denver -- I might want to point out to the audience -- was not part of the LLWAS system itself. That display is not part of the LLWAS.

JIM MOORE (NCAR) - If I didn't make that clear, the LLWAS display itself was a this and/or this [pointing to slide]. If there was an alert status, this type of a display would be there and if there was not an alert status there would be this type of a display. The situation display was a separate color graphic--it being used by people like myself and others to help evaluate the system. The issue, the thing though is that the supervisors especially were very interested in that display and did come over and look at that quite often during these events to see what was going on. Not only during the alert situations but during more normal scenarios where they were interested in just what the wind pattern was across the airport.

RICK PAGE (FAA Tech Center) - And another point of clarification, although that graphic display will be looked at in the future, it is not intended to be installed as part of the LLWAS system in the immediate future. I want to make that point clear.

JOHN CHISHOLM (Sierra Nevada Corp.) - Mark Merritt when he was discussing his doppler radar said he had sort of a scorecard or 95% probability 10% false alarms. If you did that for the old LLWAS what would the number be? And what would it be for the new LLWAS? My guess maybe is a ... (paused)

RICK PAGE (FAA Tech Center) - As a result of the summer test we are in the process right now of evaluating in a quick-look report those exact figures. What we did is take an event and we broke the event down into time slices and we evaluated, or are in the process of evaluating, the relationship between the old LLWAS and the new LLWAS. And we will have those figures within the next week or two. The report is in draft status now and that will be available to the community. So you might look for that.

JIM MOORE (NCAR) - In addition, I indicated that we had a doppler radar on the airport that was looking up the runway components as well. At NCAR we are trying to do some analysis with the new LLWAS and comparing that to doppler radar data to see how well we did.

JOHN CHISHOLM (Sierra Nevada Corp.) - One last question. Has anybody said in order to make LLWAS as good as a doppler radar I would have to put out so many anemometers and they would cost so much versus the cost of a TDWR. Is it 100 or 1000 or would it be 2,000,000 dollars versus 5,000,000. Does anybody have a crude number to that? I'm just sort of curious.

JIM MOORE (NCAR) - I don't know that a specific number has been addressed, I do know that there have been studies done with respect to what the spacing needs to be in order to cover a phenomenon like microburst. The number 12 seems to be some reasonable compromise. With respect to the resolution you would get with a doppler radar (which might be 150-200 meters versus what you are able to do here which is on the order of a kilometer), you have a ways to go. I'm not familiar with the exact number that would be required to make the match a true one.

TODD CERNI (OPHIR Corp.) - Just a comment on his question, you have to keep in mind that the surface base sensors don't measure quite the same thing as the remote sensors. That is, the LLWAS does not give you velocity along the glidescope. Okay? So the LLWAS may sound an alarm after the events pass through the glidescope and it's too late. This is part of the problem in the Dallas crash. Another problem with the Dallas crash is that the event was outside the airport property and the LLWAS sounded the alert after the event took place.

EMEDIO BRACALENTE (NASA LaRC) - Are these measurements made at 10 meters altitude? How high are they above the ground.

JIM MOORE (NCAR) - That's the standard height but there is some variation. In the Denver area, especially to the west of the airport there is the problem with a tree canopy very close to the end of the runway. So they actually had to run the tower up through the trees.

EMEDIO BRACALENTE (NASA LaRC) - Has there been any thought given to doing profiling to try to get winds at higher altitude by acoustic techniques or whatever that looks up, would that be useful information if that could be gathered?

JIM MOORE (NCAR) - Well there is a profiler in Denver for which data is provided to go back to several of the groups in Boulder. At that point it still is a point observation and if you have a microburst that is not right on the beam, you are never going to ... (paused)

EMEDIO BRACALENTE (NASA LaRC) - Well I was thinking at every LLWAS location to have a profile in addition to it.

JIM MOORE (NCAR) - That could get pretty pricey.

HERB SCHLICKENMAIER (FAA) - Well, if I can add--and Rick you can probably update this even more--there was some work looking into using acoustics, lasers, not as a profiler but as a replacement for 1000 ft. tall towers. As Jim was saying, with the practical day-to-day things that the LLWAS program has been dealing with for years, one of those practical problems is very very tall towers to get out of obstruction-type shear. Some consideration has been given to it at this point--some very preliminary tests have been going on. It is, in essence, to reproduce what an anemometer does, and also be able to program the height without all the mechanical constraints of a tower. I noticed there was about one more question to go.

BUD LAYNOR (NTSB) - Just in addressing the gentlemen's question on the TDWR comparison with the LLWAS, I thought maybe Mark might want to address some aspect of that. But it was our impression that the TDWR can also be used to look at the upper level convergence or the twisting of the core which would provide some lead-time predictive capability that the LLWAS is never going to provide. Even if you did go out beyond the field with the anemometers on the surface.

JIM MOORE (NCAR)- Well I think John's [Chisholm] question was only with reference to making a surface-similar type, the lowest level scan and what the comparison might be.

BUD LAYNOR (NTSB) - Well I agree, but I think that if the algorithm can be developed to give lead time it certainly is very important.

JIM MOORE (NCAR) - Yes, the predictive capabilities of the radar clearly outweigh whatever LLWAS ... (paused)

BUD LAYNOR (NTSB) - And the other question I'll ask Rick Page is: I don't understand why the FAA would be reluctant to put the CRT display in the towers as part of the LLWAS, or certainly as part of the TDWR when it comes along. If it is indeed as effective for the supervisor as it seemed to me as it was when I was out in the Denver tower.

RICK PAGE (FAA Tech Center) - I did not say we were reluctant to put it in. I just said that there were no immediate plans to put it in the tower. We will be looking at that particular display and other types of graphic representation of the data. It is just that that particular display (although it was in the Denver tower--and it was being looked at by the supervisors) for reconfiguration of runways was not part of the test, and the data that we acquired and the decisions we were making in relationship to the display itself did not include this particular display. That is why I made the distinction. The reports that we will be issuing will be based upon the CRT display.

N88-17634

INFORMATION TRANSFER IN THE NATIONAL AIRSPACE SYSTEM

Human Factors Research At NASA-ARC

Alfred T. Lee, Ph.D.
Aerospace Human Factors Research Division
NASA Ames Research Center
Moffett Field, CA

Alfred T. Lee
NASA Ames Research Center

Information Transfer in the NAS: An Overview of Human Factors Research at NASA-ARC

Although I had not planned on giving a formal talk on the issue, I will attempt to give an informal overview on the in-progress and planned work in the information transfer area specifically addressing the human factors issues in the current and future NAS. Information transfer is a general term which encompasses issues as to what kind of information is needed, when it is needed and in what form it should be presented to aircrews operating in today's and tomorrow's NAS. There are essentially two fundamental reasons for this effort. First, there is the mounting evidence that the existing system of transferring information concerning weather, traffic, etc. to the aircrew in an accurate and timely fashion is simply not adequate. The other reason is that plans for making changes to the existing system ought to be driven by the needs of aircrews (and controllers) and not simply by technology. This user-centered view of the implementation of elements of NASP will have to be supported by substantive data on how people will operate in this system if those of us in the human factors arena are to make a viable contribution to its design. The relevance, to the issue of windshear and other severe weather avoidance, of information transfer should be self-evident. Our focus from the human factors standpoint, in general, is long range, measured more in years than in months, so this work has a less direct relevance to these proceedings with respect to near-term regulatory implications. But Herb asked me to talk about this to give you an idea of what we are doing at Ames pertinent to windshear avoidance.

The first element of the program plan is look at the issue of information transfer in the current NAS operating environment, including problems associated with the transfer of weather information. Our chief source of information on these problems is the Aviation Safety Reporting Systems (ASRS) data base. A recent study of these problems for incidents reported during the calendar years 1985 and 1986 is due out this fall. A second study focusing strictly on weather related incidents is currently in progress.

The second are in the program deals with information transfer as it might occur in the next generation NAS, elements of which are described in the NAS plan (brown book). In this area the goal is to provide human factors guidelines for the design of the information transfer system in the NASP and to do so with as much specificity as possible. Task elements within this area include addressing the problem of managing information so the process of delivering the needed information to the flight deck at the appropriate time can be achieved. While previously the pilot served as the msanager of information on the flight deck, it is becoming increasingly apparent that the amount of information concerning traffic, weather, etc. can overload the crew. The evolution of new technology allows a substantial increase in the amount of information available but, no increase in the ability of aircrews to select, prioritize, and integrate that information. Our task is to provide some guidance in the design of such systems with respect to meeting the needs and limitations of the humans who will operate within it.

A third task, related to future information transfer system design, address the means by which that information will be displayed on the flight deck. Included in this task are design issues with regard to the type of information displayed, its formating, whether the information should be displayed visually or aurally, and other issues. Associated with the presentation of information is the access to that information, i.e., data entry and retrieval. Those familiar with the Flight 007 know that this is a potentially nontrivial issue particularly in highly automated operating environments.

The fourth task element is to develop appropriate decision-aiding technology. In future NAS we can expect the crew to have access to far more information in real-time than is currently available. Providing a means, by which, to aid aircrew decision-making, particularly in high workload terminal area operations, will utilmately enhance safety and efficiency. With specific regard to severe weather avoidance, the provision of displayed vectoring or waypoint information which may optimize not only safety but fuel efficiency, is within current technological capabilities. The integration of such decision-aiding components into the flight deck and defining the optimal human interface remain a challenge.

Although communications engineering is not the focus of the effort a brief discussion of this area seems in order. Much of this work rests on the assumption that conventional voice/VHF transmission will not be the principal means of information transfer. Rather digital datalink transmission will likely be the chief means by which information reaches the cockpit and is sent to ground or airborne/orbiting stations. This would presumably entail both Mode S, satellite, and conventional VHF or FM station subcarriers, some of which are already in use. Basically, the problem with some of these systmes is that they are slow with regard to communications baud rate. I have numbers on the Mode S system of 200-300 bits/sec. So one of the possible research areas is to look at the tradeoffs in terms of communications rate, particularly with the regard to the transmission of weather data at least as far as its impact on crew decision-making.

In general, our approach is looking at the area of information transfer is first, to use our existing data base (e.g., ASRS) in identifying current information transfer problems and recommending solutions. Secondly, to address human factors issues in proposed information transfer systems for the next NAS. The facilities at Ames Research Center will be employed in providing the data necessary to define guidelines for these systems. Both part systems and full mission simulators located at the Man Vehicle Systems Research Facility are being exploited in this effort.

INFORMATION TRANSFER

- OBJECTIVES

1. IDENTIFY HUMAN FACTORS ISSUES IN EXISTING INFORMATION TRANSFER SYSTEM AND RECOMMEND SOLUTIONS

2. PROVIDE HUMAN FACTORS GUIDELINES FOR THE DESIGN OF FUTURE INFORMATION TRANSFER TECHNOLOGY

   - INFORMATION MANAGEMENT
   - INFORMATION DISPLAY
   - DATA ENTRY AND RETRIEVAL
   - DECISION-AIDING

INFORMATION TRANSFER (CONT'D)

o APPROACH

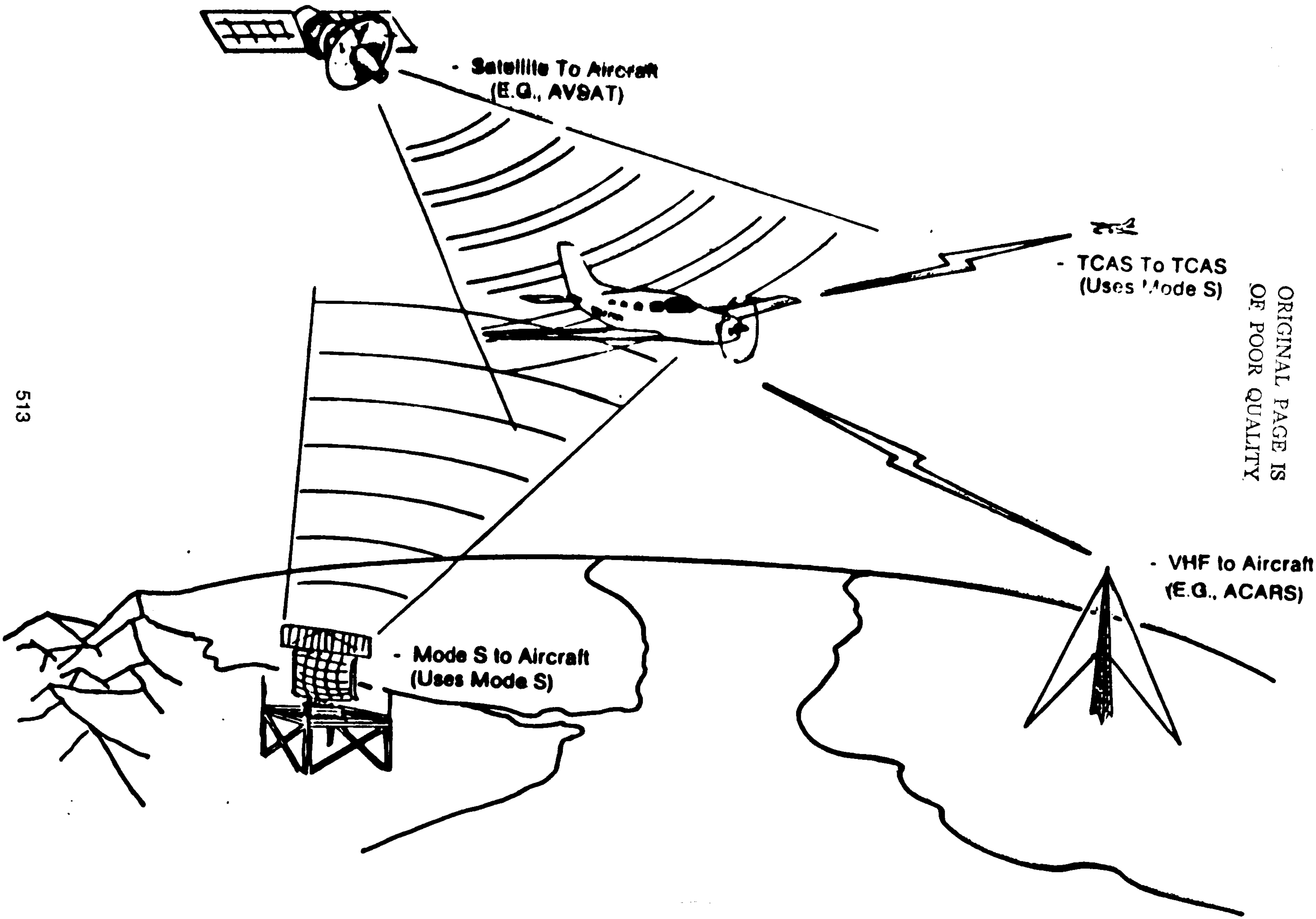
- INCIDENT, ACCIDENT DATABASE ANALYSES OF INFORMATION TRANSFER PROBLEMS

- REVIEW OF ANALOGOUS INFORMATION TRANSFER SYSTEMS

- PART SYSTEMS SIMULATION STUDIES (e.g., CDWI)

- FULL MISSION SIMULATION STUDIES

AIRCRAFT MULTI-DATA LINK ENVIRONMENT



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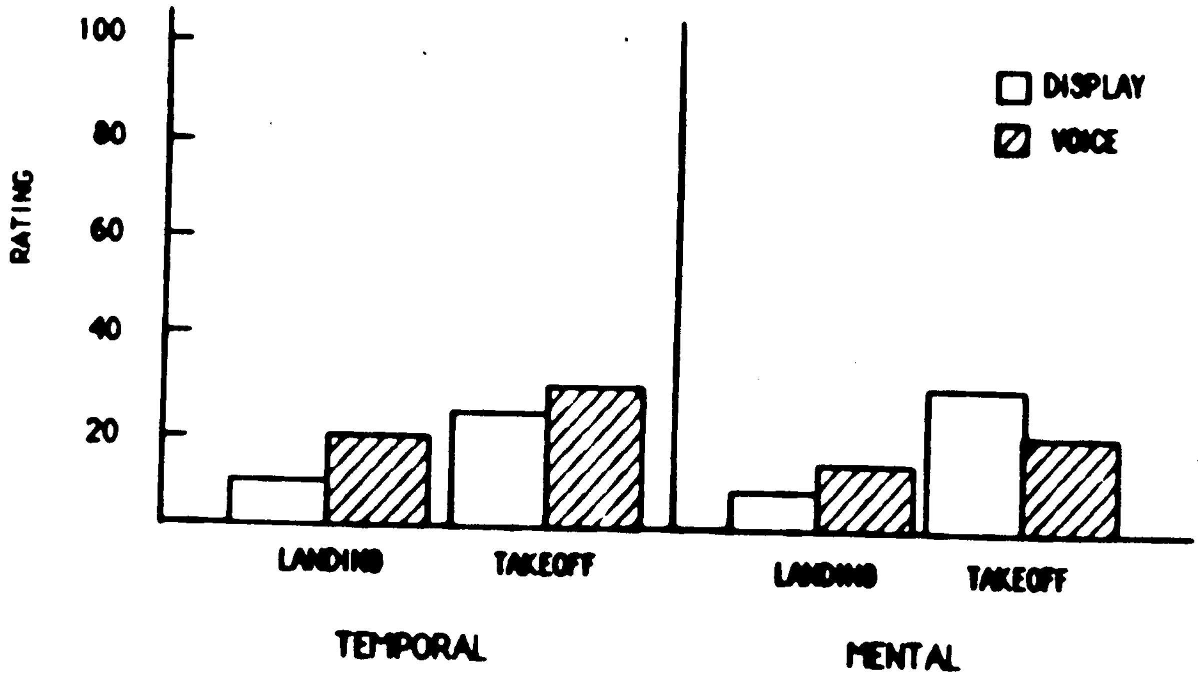
DISPLAY-BASED COMMUNICATIONS PROTOTYPE

- o GROUND-AIR-GROUND DATALINK SIMULATION (ca.1995)
- o ADVANCED AIR TRANSPORT AIRCRAFT
- o DIRECT COMPARISON OF CONVENTIONAL VOICE AND DISPLAY-BASED SYSTEM
- o MENU-DRIVEN, TOUCH PANEL CHARACTER DISPLAY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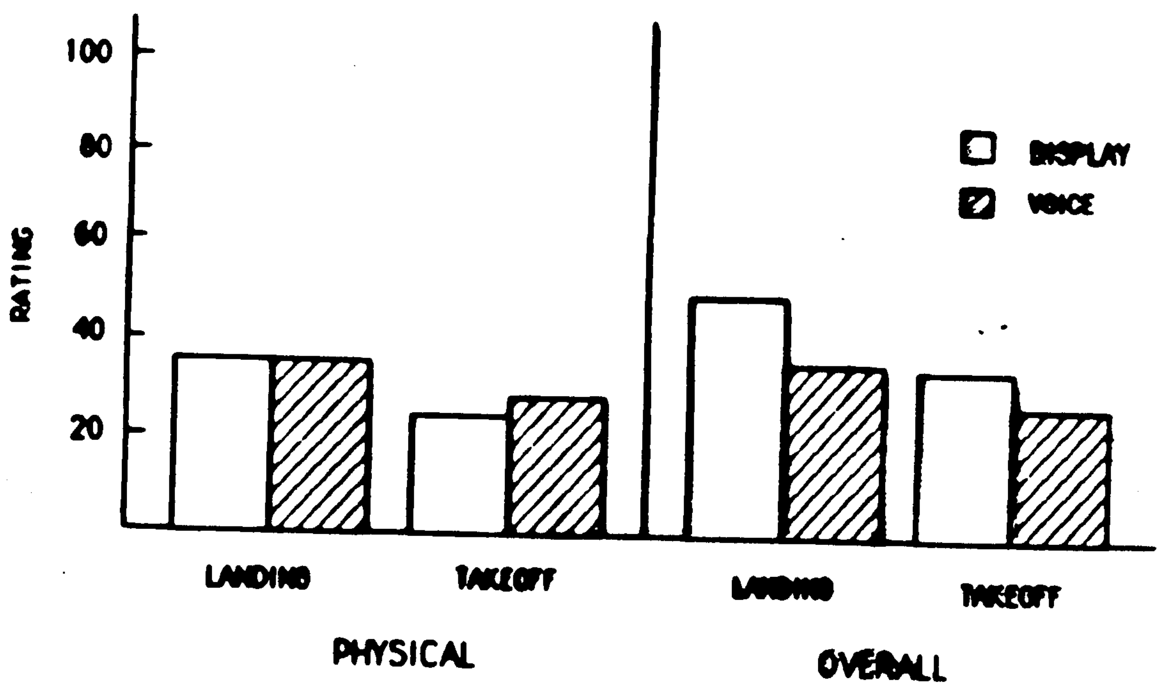
MENTAL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LANDING
TAKEOFF
PHYSICAL
OVERALL

N88-17635

ARE WINDSHEAR TRAINING AID RECOMMENDATIONS APPROPRIATE FOR OTHER THAN LARGE JET TRANSPORTS?

Pilot Procedures

Shear Models

R. S. BRAY
NASA-AMES
10/23/87

IS THE WSTA APPROPRIATE FOR:

GA Jets?	YES
Commuter and GA Turboprops?	?
GA Single-engine?	?

R. S. BRAY 2
NASA-AMES
10/23/87

PILOT PROCEDURES IN WINDSHEAR

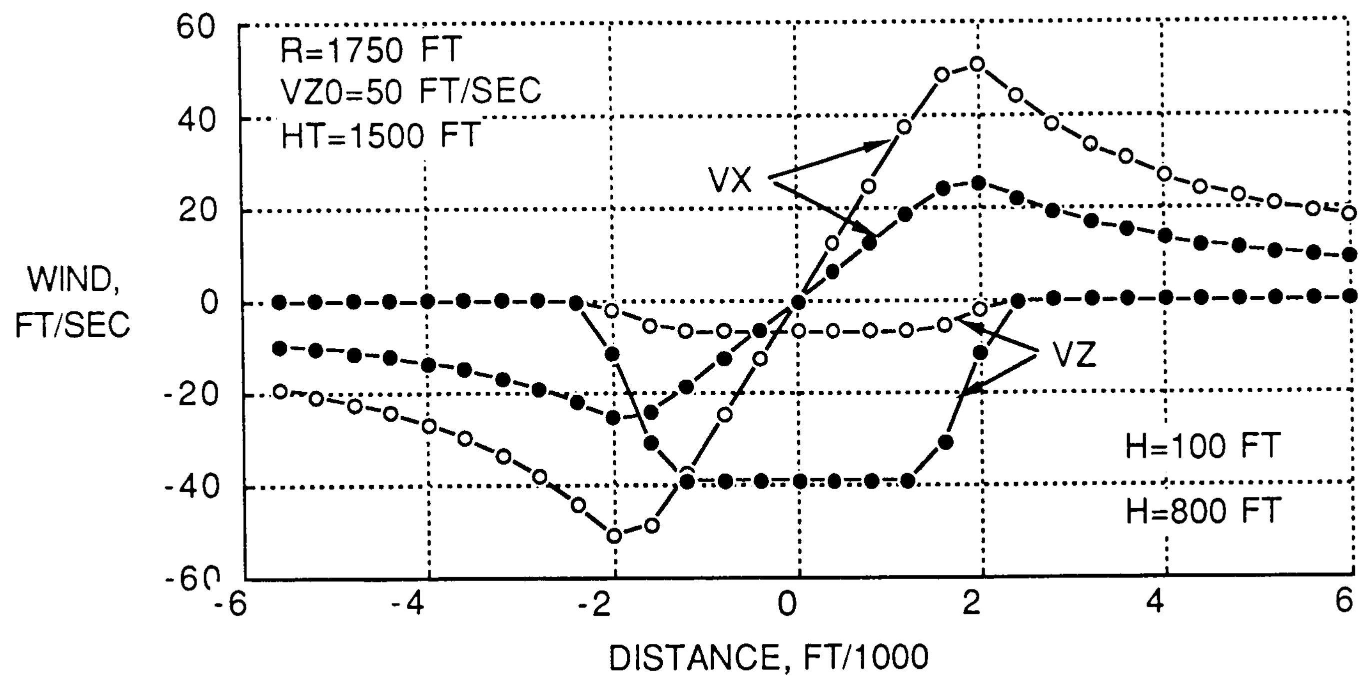
Proposal:

Pitch Target = Stall-warning Angle-of-Attack

727	15
L1011	17.5
Turboprop Twin	10-11

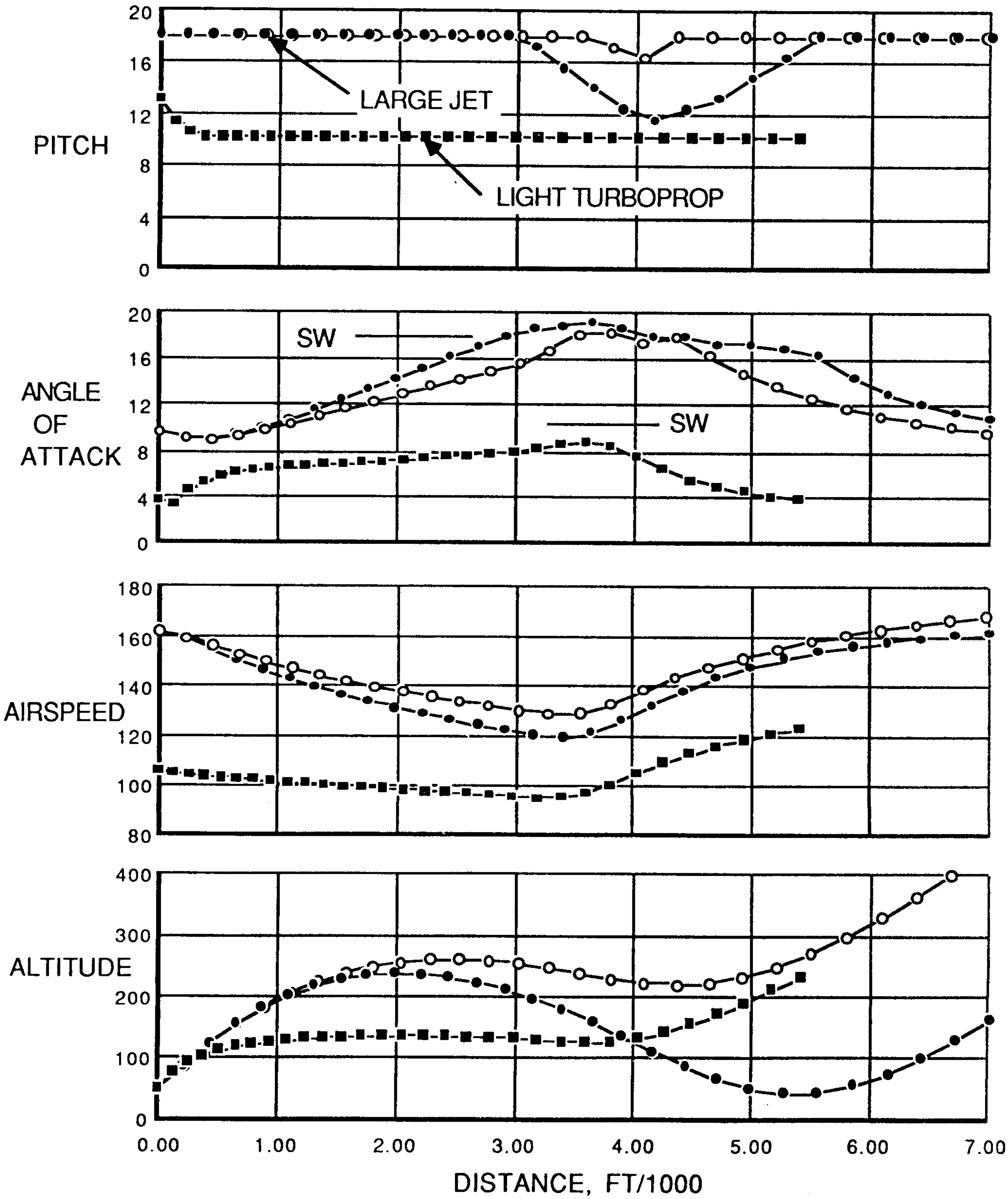
R. S. BRAY
NASA-AMES
10/23/87

TYPICAL WINDS IN EXAMPLE DOWNBURST



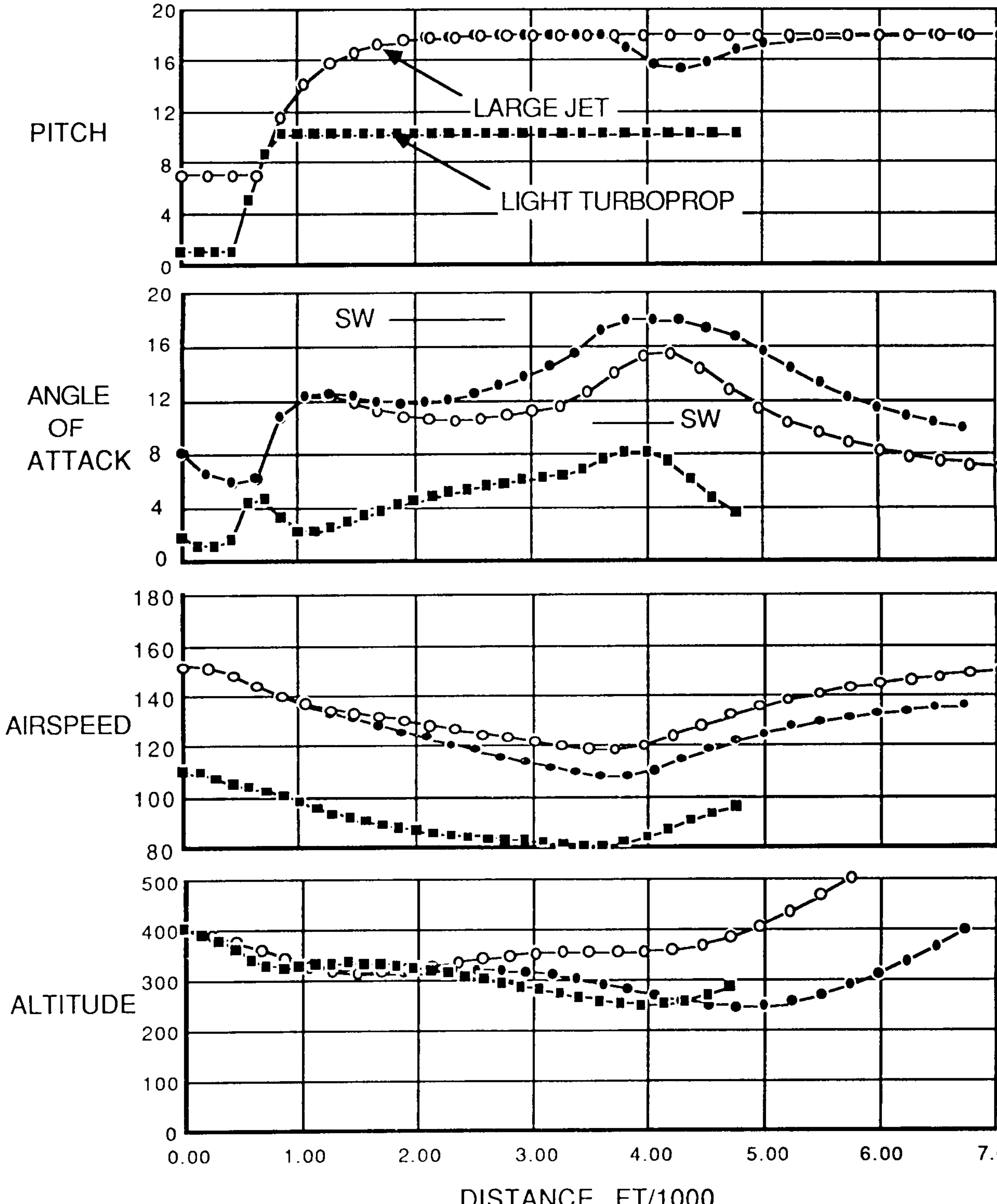
R.S.BRAY 4
NASA-AMES
10/23/87

DOWNBURST ENCOUNTER AT TAKEOFF; LARGE JET TRANSPORT AND LIGHT TURBOPROP TWIN



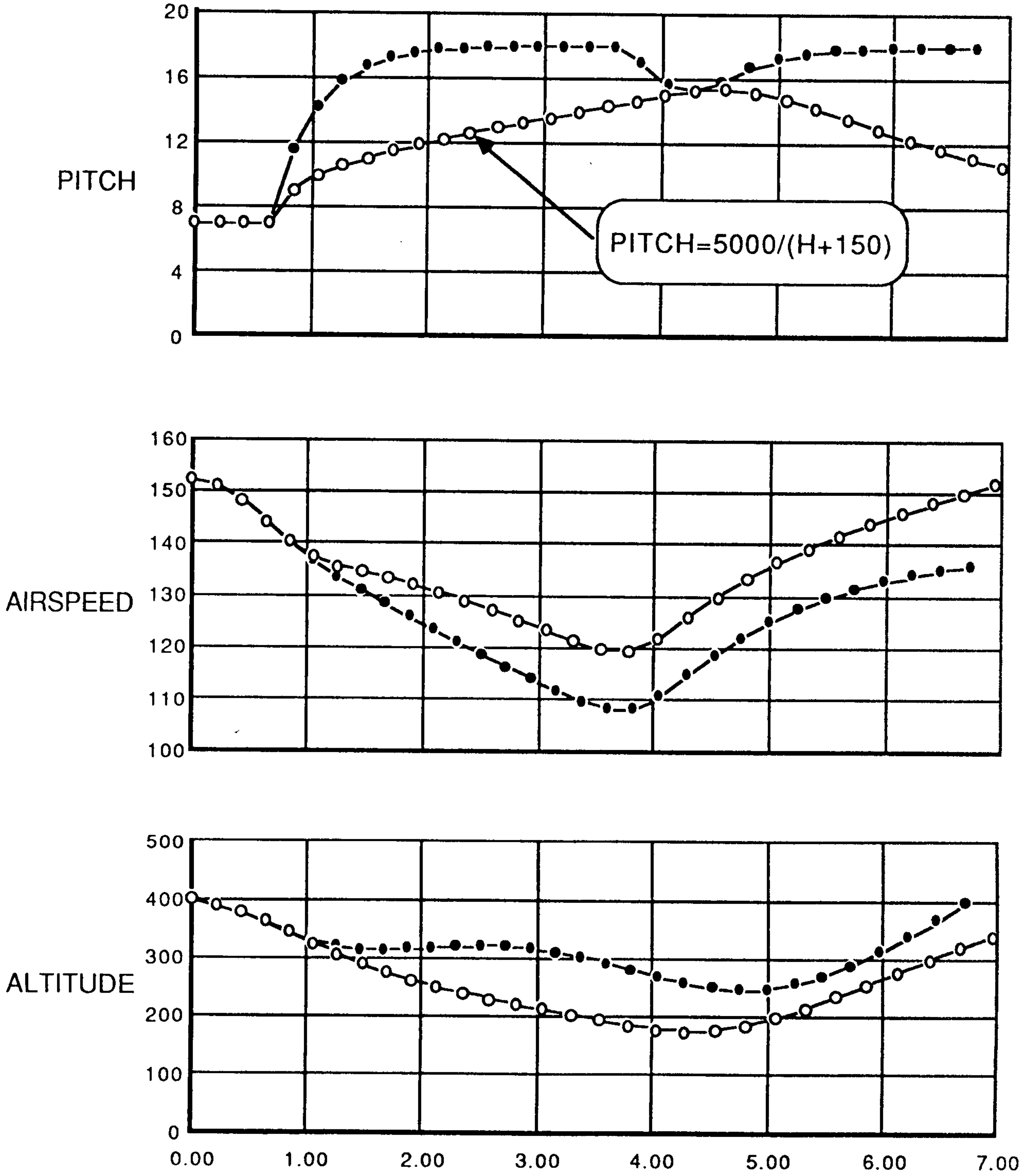
R.S.BRAY 5
NASA-AMES
10/23/87

DOWNBURST ENCOUNTER ON APPROACH; LARGE JET TRANSPORT AND LIGHT TURBOPROP TWIN



R.S.BRAY 6
NASA-AMES
10/23/87

A COMPARISON OF PITCH ALGORITHMS IN AN APPROACH ENCOUNTER WITH DOWNBURST SHEAR



R. S. BRAY 6A
NASA AMES
10/23/87

OBSERVATIONS:

The light turboprop appears no less tolerant of a downburst encounter than the large jet.

With selection of a pitch target, the WSTA applies.

R. S. BRAY
NASA-AMES
10/23/87

N88-17636

Airworthiness Considerations

Ray Stoer

FAA

Fi925368

6. AIRWORTHINESS CONSIDERATIONS.

a. Certification Program. This advisory circular provides guidance for the airworthiness approval of both "annunciation only" and "annunciation with guidance" airborne windshear warning systems as many of the system design aspects, functions, and characteristics are common. In either case, the scope of the applicant's program should be directed toward airworthiness approval through the Type Certificate (TC) or Supplemental Type Certificate (STC) process. In the case of systems with flight guidance which will ultimately be used on aircraft in air carrier service, the applicant is encouraged to undertake a certification program which will satisfy both the criteria contained herein, as well as that contained in AC 120-41, Criteria for Operational Approval of Airborne Windshear Alerting and Flight Guidance Systems. Many of the criteria outlined below in paragraph 6(d)(2) can also be satisfied in finding compliance with § 25.1301 of the FAR, if the certification program satisfies both operational and airworthiness criteria. A statement will be placed in the approved Airplane Flight Manual indicating compliance with AC 120-41, thereby providing for a more streamlined operational approval process for an air carrier under Parts 121 or 135 of the FAR.

b. Certification Plan. A comprehensive certification plan should be developed by the applicant. It should include how the applicant plans to comply with the applicable regulations and should provide a listing of the substantiating data and necessary tests. Also, a comprehensive system description and an estimated time schedule should be included. A well developed plan will be of significant value both to the applicant and the FAA.

c. System Criticality. Certain types of failure cases must be addressed in consideration of the potential hazard they may induce during the course of normal system operation. Advisory Circular 25.1309-1, System Design Analysis, provides criteria to correlate the depth of analysis required with the type of function the system performs (nonessential, essential, or critical). Also, failure conditions which result from improper accomplishment or loss of function are addressed. The criticality of certain system failure cases for windshear warning and systems with escape guidance are outlined in paragraphs (1) and (2) below. In the case of systems which provide escape guidance, there may be a number of complex system integrations with existing airplane systems and sensors; and the treatment of all the combinations possible is beyond the scope of this AC. In this case, AC 25.1309-1 states that the flight test pilot should: (1) determine the detectability of a failure condition, (2) determine the required subsequent pilot actions, and (3) make a judgment if satisfactory intervention can be expected of a properly trained crew. In addition, failure of the windshear warning system should not degrade the integrity of other essential or critical systems installed in the airplane. This includes common shared sensors.

(1) Windshear Warning. The system should be designed so that false warnings have a probability of occurrence on the order of 10^{-4} or less. This includes the failure of the system to annunciate a windshear warning as a result of a latent failure.

(2) Systems with Escape Guidance. In addition to the criteria of paragraph (1) above, the following system failure cases should be improbable in

accordance with AC 25.1309-1. (Consideration for out-of-production airplanes with early versions of unmonitored flight director computers and mechanical flight instruments is warranted, and those systems may have a probability of failure on the order of 10^{-3} or less.)

(i) Unannunciated failure of the system to provide the escape guidance function when commanded. Removal of flight director command bars constitutes adequate annunciation.

(ii) The display of escape guidance other than that evaluated and approved in accordance with § 25.1301 of the FAR (see paragraph d, Intended Function, below).

NOTE: The loss of windshear warning annunciation should not preclude or inhibit the presentation of the escape guidance information, as long as the guidance mode change annunciation remains valid and the annunciation is provided in a clear and unambiguous manner.

(3) Software Based Systems. The software should be developed to a minimum of level 2. An acceptable means for obtaining approval for the development of the software based system is to follow the design methodology contained in RTCA Document DO-178A, Software Considerations in Airborne Systems and Equipment Certification.

(4) Probability Analysis. The applicant should provide a quantitative probability analysis to support an engineering evaluation of the system failure cases listed above. For this purpose, an exposure time of 0.1 hour has been found acceptable by the FAA in the past. This criteria assumes that internal system tests verify proper system status immediately prior to the system being enabled. The probabiliy of the airplane encountering a severe windshear should be 1 (one) and the computed probabilities of occurrence should be expressed in failures per flight hour.

d. Intended Function. The major emphasis for showing compliance with § 25.1301 is centered around the aspects of establishing a windshear warning threshold that considers remaining airplane performance. For systems that include escape guidance provisions, a subjective evaluation of airplane performance is made to determine that the algorithms manage the available energy in such a manner as to enhance flight path control beyond that which would be normally expected without the use of the system. In addition, applicable system integration aspects are evaluated in order to determine that there are no adverse functional effects with the existing airplane systems and sensors that are integrated to the windshear warning system.

(1) Airborne Warning System. The applicant must demonstrate by analysis and simulation that the system warning threshold is appropriate for a given airplane/engine combination. Once this aspect has been demonstrated and approved by the FAA for a given windshear warning system, it need not be repeated for other airplane models if the applicant can show that the technology employed for this purpose is suitable. If applicable, system integration and the use of external airplane sensors on the same or new model types must be taken into account.

number of severe windshear encounters and conducted studies to determine the criticality of flight variables like airspeed, altitude, thrust-to-weight ratio, etc. This effort has resulted in the identification of a number of items that should be considered when establishing alert threshold, flight procedures, and training requirements.

(2) Warning Only System. The procedure added to the AFMS should contain the following basic elements:

(i) Aggressively apply maximum rated thrust, disengaging autothrottle if necessary.

(ii) Rotate smoothly at a normal rate to the go-around/takeoff pitch attitude and allow the airspeed to decrease, if necessary.

(iii) If the airplane is descending, increase pitch attitude smoothly and in small increments, bleeding airspeed as necessary to stop the descent.

(iv) Use stall warning onset as the upper limit of pitch attitude.

(v) Engine overboost should be avoided unless the airplane continues to descend and airplane safety is in doubt. When airplane safety has been assured, adjust thrust to maintain engine parameters within approved limits.

NOTE: Overboosting engines while at angles of attack near airplane stall warning may cause engine stall, surge, or flameout.

(vi) Do not retract flaps or landing gear until safe climb-out is assured.

(3) Warning with Escape Guidance System. In addition to providing the information and procedures peculiar to the new system, a statement should be made in the AFMS that in all cases of windshear warning, the escape guidance should be followed until the maneuver has been safely completed.

<u>QUESTIONS AND ANSWERS</u>

BOB IRELAND (United Airlines) - Ray, I've got one quick question for you. Could you bring up page 13 again that you had on the board before? There seems to have been an effort made on this page, and I applaud it, to recommend a manual recovery technique which is similar to that which comes out in the FAA training aid. The question I'm left with here is "(2)(ii)": "Rotates smoothly at normal rate to the normal go around take off pitch attitude." As you are well aware, the training aid does specify other target pitch attitudes, they are just fixed target pitch attitudes regardless of your gross weight or whatever else might affect takeoff pitch attitude. And I'm wondering why you chose to put something else there, when there is a warning on this airplane, as opposed to when there is not a warning? The FAA recommends just a fixed pitch attitude.

RAY STOER (FAA) - Because Bob, we are not trying to write the flight manual or get down to the details of a particular airplane type. What we are trying to do is say, "you should consider these basic elements." As we went through this with Herb and some of his people in our judgement, we felt that this was not inconsistent with the training aid. If you are trying to identify, perhaps, a specific airplane type then you might say--well that doesn't fit as well. Our intention here was to make some generic considerations which hopefully will bring to the attention of somebody writing the flight manual, the kinds of things that we would like to have considered. That was our intent.

BOB IRELAND (United Airlines) - I understand the intent. Would it, perhaps, be better to have said: "rotate to an appropriately determined pitch attitude," rather than a specific situation like that?

RAY STOER (FAA) - It may have been a better thing to do Bob.

BOB IRELAND (United Airlines) - Okay, I just wanted to understand your intent. I appreciate that.

RAY STOER (FAA) - Even with the change we made here [pointing to viewgraph] and I should point this out, that when we got into the overboost concern here and we made this new number 5 here [pointing to viewgraph], we coordinated this immediately with Herb, in fact we had a national telecom within the FAA on this power plant subject. We had Herb on because we wanted to be sure that whatever we did come up with was not going to be inconsistent with the wind shear training document. Or at least, if we were going to be inconsistent we wanted to understand that, right up front. That doesn't mean that if we don't find something is wrong we can't say it because we're inconsistent, but we wanted to identify that immediately. In our judgement, we are, from a generic standpoint, consistent with the wind shear training aid.

BOB IRELAND (United Airlines) - That's great. Just a comment on the engine section right there. I think that Ralph and I could tell you that many, many days and hours were expended in talking about engines in the training document as well. It was a very very difficult subject and I really like what you put there. I think it is a very good way to go.

RAY STOER (FAA) - Thank you. Our very first certification with the wind shear system was about 7 or 8 years ago and I had the pleasure of being on that with the United Airlines at the San Francisco Engineering Base on a 747. It was a "one-only" installation. It modified an existing Safe Flight SCAT (Speed Control and Autothrottle) system in the pitch axis computer to accommodate the wind shear escape guidance algorithms. United took the leadership in this field at that time when we hardly knew how to spell wind shear. And Safe Flight had so much patience with us in sitting down and almost training us to what they had. Again it relates back to the aspect that we have no resources but people. We don't have any facilities to go out and research things. We have to develop criteria concurrent with an existing program and depend upon the manufacturer of that equipment to teach and train us what he has. Our wind shear AC (advisory circular) over the past 4 years--formally when we had a team--and going back 7 and 8 years, has been a dynamic document. It started as a one-page of what we think we ought to be doing and has become a living document. And the reason that we are going ahead and printing it now--at last--is because we have a requirement within the government that if we have a rule-making project in process we have to have a means of complying.

DAN LABRIOLA (Tech AirServices) - For those of us on the training side - this is really a good point about the engine overboost and it seems it has really been a tough one because, we started out saying that you should never overboost the engine and you know max EPR's is what it was and we've been coming about on that. But if we are going to start differentiating airplanes; are you, or is someone, going to solicit and publish those aircraft for which we can't recommend pushing the throttle to the firewall.

RAY STOER (FAA) - Dan, I don't know the answer to that. Our power plant group have an idea, but they don't specifically know how many of the manufacturers and on what model types. The individual manufacturers have independently looked at this region outside the envelope. And we never see that on the certification program. Manufacturers don't like to show us anything they don't need to. And that's okay, that is a defense mechanism on their part and that's acceptable. They show us the operation of the airplane in the envelope they seek to have approved. We have no data, and many times we have no knowledge of how far the airplane is taken out of the envelope and explored by the manufacturer. We know that goes on and it's okay, but we don't have data or knowledge of just what that is. I think what we hope is that this kind of a "hey caution fellows, let's take a look at this," is going to stimulate the equipment manufacturers' interest in contacting the manufacturer and perhaps on getting some data from the manufacturer on this. This may also stimulate new model types that are being certified into, perhaps, taking a look at this region now that it is identified, that we will be operating in this region more often because of the wind shear guidance algorithms.

DAN LABRIOLA (Tech AirServices) - I would suggest to you that if the FAA doesn't solicit this kind of information it might be a little tough for any of the rest of us to find that out.

RAY STOER (FAA) - I can agree with that Dan, and that is a good thought. We didn't want to hold this [advisory circular] up, and we tried to work a way out that we could put something in here that perhaps was defendable (and we think it is defendable outside this document). But we really didn't have the time to do that. And what I would like to take an action item to you, if I may, is discussing this with the manager of our power plant section to see, in more detail, if there could be some interest generated within the FAA to look into this region outside the envelope and how we can control that. If we say we have an approved envelope, do we have the right to ask the manufacturer to show us data? I don't know that, but I think we need to explore that a little bit. It is a good point.

OMIT TO
END

Myron Clark - FAA/HQ/Air Transport Div

Good morning. I didn't know I was going to deserve a blue ribbon getting down here. A funny thing happened to me on the way to Dallas, I was going out the door Monday, or about to go out the door, and my boss grabbed me and said "hey you remember you're going to cover Langley for me" and I said "yeah, but I don't get back from Dallas til Thursday", he said "that's all right go on down there Friday and see what's going on" and before I got out the door, he said "oh yeah, by the way you might check and see what the status of the rule-making is, I think they want to know." And so, here I am, I didn't even bring a view graph or anything for you all to look at, but I did find the man that has really been the driver on this rule-making and I can give you a little bit of status on that. My facetious remarks aside, I did, late Monday afternoon, take some time to find the docket and try to do a hurried scan of the docket material. One thing I would say, I guess we've been beating on this wind shear problem for quite some time. (For those of you who don't recognize me as being with flight standards, you might remember that I was in the wind shear program office back about 1976.) But the comments that came in on this rule making were generally very favorable. I was surprised to find that docket was not as thick as I thought it would be. There were good comments and a wide range of opinion. It is always a good forum for people to speak their mind.

The rule was officially published the first of June and the docket is now closed. The comments revealed a wide ranging public awareness, on the phenomenon. In general, I think everybody for the most part, zeroed in on the problem. There was a limited amount of wandering around discussing other issues in the comments that were received. I would say, for the most part, the people who wrote in or commented supported what we are trying to do. Some did take strong umbrauge and disagreed strongly with the idea of retrofit (Ray Stoer sort of touched on that) and we recognize the problem. Several of the companies substantiated the problem--strongly--that would be involved if we enforced a total retrofit, so that issue is going to be closely looked at. They also took strong issue, at times, with our economic analysis of what the costs were going to be. There were some commenters that urged that we provide for the installation of look ahead detection equipment in the final rule. And one group said: "let's don't put helicopters in this same box with us, will you not." (And I think that came from the helicopter people, truthfully.) They didn't want the helicopters to be included in the ground training portion of the final rule that applies to the escape procedures, since their airplane performance is not quite like a fixed wing and the standard procedures may not apply.

I might point out, as you all know, there are already several wind shear warning and flight guidance systems on the market and installed and flying and this is not (as Ray has fought the battle for quite a few years) something that is brand new to us all. We still see incidents occasionally, and we haven't counted out wind shear--it hasn't gone away. We still need to keep working on it, we're still faced with the fact that we are having accidents that are attributed to wind shear. What about the rule making plans? I think this is what you really want to hear. For the final rule, and I'm going to read this from a summary that was written by the man who has the prime action on this. The "Rule Making Plan" is the title of the summary. The FAA proposed revisions to the NPRM for the final rule. Installation of low altitude wind shear warning with flight guidance equipment for certain turbojet airplanes operated under part 121 should be expanded to include detection, and provide for a compliance date with a minimum of four years after the effective date of the proposed rule. "Initially it was two years. We got some very very strong strong input that two years would just not be enough time to respond. They needed additional time; so that it looks like the final rule is going to propose a four year compliance period"--and provide that flight guidance be required on airplanes built after a specified date that has not been determined yet. In other words, we still have to decide what that certain date is. If you manufacture an airplane after a certain date, you've got to build into it the flight guidance requirement. And the other point under rule making was revise the proposed requirement to provide that only Part 135 certificate holders operating airplanes should be required to develop procedures for escaping from inadvertent low altitude wind shear encounters. You know, I read this on the airplane coming back from Dallas, and I'm not really sure what the writer meant. "Revise the proposed requirement to provide that only Part 135 certificate holders operating airplanes..." ahh, that is differentiating between helicopters. That suddenly dawns on me that is what that's about. It was the complaint from the helicopter people. The bottom line on this whole thing is we have to rewrite the schedule on the rulemaking and that hasn't been published yet - so stand by for the next issue. And I really don't know what the rule makers will do as far as that revised schedule. But, I am certain it will be another 60 days before the schedule is even published on what the final rule making will be. So it is going to be at least a couple months before you see that in print.

I also noticed that Herb gave me a little opportunity to talk about flight standards issues and views of new technology. I will deliberately avoid the second half of that. How can I gracefully say our view of new technology is that some times it can be overwhelming and we don't want to commit to anything right now in writing. Okay? Good government bureaucrat that I am, I am not about to be pinned down on that issue too tightly. However, I thought Al Lee had been reading my though when he got up to talk. I don't know where he's been, I think he's been in some of

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the same meetings with my boss, and some of the rest of the guys from our shop on this new issues business. Data link, among other things is an issue that from a flight standards point of view is going to be pressing. We have a new boss that is quite interested in that area, and so I think we are going to be very interested because if we aren't interested in it, he's going to ensure that we get interested in it. I'm on a working group that is addressing the issue of how to accelerate our current programs when it comes to data link. And not just what Al was showing you with Mode S data link, but I think it is going to look at other alternatives for data link that are available, that includes: satellite, UHF, VHF, HF, the current ACARS System that many of the carriers are using. How can we expand ACARS operation and how can we support them? So, that is an issue with us, and there is going to be more and more work put into that area in the very near future.

Another thing that is always of concern--training issues. We've got to make some decisions--some hard decisions on training. For you all in the manufacturing group, I don't know that this is near as critical an issue as it is with the operators of the major carriers. Does wind shear training entail a requirement to add to the total training hours or are we going to knock something out and let them maintain the number of hours that are now required for training for recurrency and for initial training? Those decisions haven't been made yet and I think it is going to be a little while before you can really come to the conclusions--draw the right decisions in that area. There is a lot involved in wind shear training. I personally happen to be very involved in weather programs for the branch and for flight standards. I guess my official title really is weather programs manager for flight standards. Beyond wind shear, there is a concern that maybe our pilots are not really getting a good understanding of weather. Maybe there is a field to be plowed out there --- a fertile field to take a look at what we are doing and what we are offering our pilots and what we are requiring of them as far as just underlying basic knowledge in weather. So that ties into the training issues and these things are very prime issues for flight standards right now.

Cockpit resource management, that is, I don't want to call it a buzz word, I don't want to tread on anybody's feelings about that, but it has become kind of a key set of words that you see crop up all over the place. Cockpit resource management. What the devil does that mean? Well you get the airplane in the air and you try to do it safely and try to get back on the ground without hurting it or anybody. And you use everybody in the cockpit to do the job. What else is new, right? Well, there is a lot of work going on in that area, and I think that you are going to see more and more consideration given to how we handle our procedures in the cockpit. We have kind of, ah, I better not, I'm not sure what the schedule is. I maybe ought to ask Al to comment on that again. Al might have a better feel for some of the things that are coming down the road, but I can assure you that there is going to be a hard look taken at the way we manage our cockpits and there are plans for some seminars and for additional meetings, training and workshops in that area, and I think you are going to hear more and more about that in the very near future from the flight standards. I think I already touched on the last item, I really had a note here on the weather for air crews. We are concerned, not only just from wind shear standpoint--that too, certainly that--because that seems to be the most dangerous of the weather situations we get into. But the issue that we are getting ready to address and we will look at very closely, is what are we providing to air crews? Are they getting what they really need and if not, what can we do to promote that? And I will entertain questions from the floor, if I can't answer them I'll certainly take an IOU on them, and try to get you a response.

Anyone? Weather is great in Dallas. Cowboy fans are crying. Fort Worth Times headlines says: White and Dorsett Take Charge, Cowboys Lose. Got any Texans here in the crowd that are going to throw rocks at me?

Anybody? Okay, thank you very much.

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STATUS REPORT
AIRBORNE LOW-ALTITUDE WINDSHEAR EQUIPMENT AND TRAINING REQUIREMENTS

BACKGROUND:

- FAA published Notice of Proposed Rule Making (NPRM) No. 79-11A on June 1, 1987 (52 FR 20560), which solicited comments and recommendations to solve the windshear problem.

- Comments received reveal public awareness of the phenomena and a commitment to help solve the problem through new technology. Commenters generally agreed that airborne equipment is needed; however, they disagreed that flight guidance retrofit is needed and they took issue with the FAA's economic analysis. Other commenters urged that the FAA provide for the installation of look-ahead detection equipment in the final rule and that helicopters not be included in the ground training portion of the final rule as it applies to escape procedures since not enough is known about how aircraft other than airplanes are affected by low-altitude windshear.

- Several airborne windshear warning and flight guidance systems are certified and installed in certain turbojet airplanes.

- Incidents of encounters with hazardous low-altitude windshear by air carrier airplanes continue to be reported.

- Some accident investigations have listed low-altitude windshear as a possible contributing factor to a number of general aviation accidents.

RULEMAKING PLANS:

- The FAA proposed revisions to NPRM for the Final rule -

  - installation of low-altitude windshear warning with flight guidance equipment for certain turbojet airplanes operated under Part 121 should be expanded to include detection, provide for a compliance date of a minimum of 4 years after the effective date of the proposed rule, and provide that flight guidance be required on airplanes built after a specified date to be determined later; and

  - revise the proposed requirement to provide that only Part 135 certificate holders operating airplanes should be required to develop procedures for escaping from inadvertant low-altitude windshear encounters.

RULEMAKING SCHEDULE:

- The FAA is developing a milestone schedule for the final rule.

COMPUTER RESOURCE MANAGEMENT, INCORPORATED

Rosemarie L. McDowall

I. CRMI HAS BEEN ASKED BY THE FAA TO CREATE A DATABASE OF INFORMATION ABOUT LIGHTNING.

A. HAVE BEEN WORKING ON THIS TASK FOR A YEAR NOW.

B. TASKS

1. PLAN THE PROJECT.

2. IDENTIFY SOURCES OF INFORMATION ABOUT LIGHTNING.

3. SET UP THE DATABASE.

4. CONVERT IDENTIFIED SOURCES.

5. STATISTICAL ANALYSIS OF THE DATA TO PRODUCE A WAVEFORM CHARACTERISTIC OF LIGHTNING.

II. PROBLEMS WE HAVE ENCOUNTERED.

A. IDENTIFICATION OF SOURCES - NOT A MAJOR PROBLEM.

B. GETTING INFORMATION ABOUT THE DATA FROM SOURCE OWNERS.

1. DATA IS OLD.

A. POORLY DOCUMENTED & NO ONE REMEMBERS WHAT'S THERE.

B. POORLY STORED; MAY NOT BE READABLE.

(1) ATMOSPHERIC CONDITIONS.

(2) DATA STORED VIA OBSOLETE EQUIPMENT.

C. ORIGINAL RESEARCHER IS NO LONGER AVAILABLE.

D. ORIGINAL RESEARCHER IS NO LONGER INTERESTED.

C. DATA IS NOT CONSISTENT FROM ONE SOURCE TO ANOTHER.

1. IN ROUGHLY 20 SOURCES, THE ONLY FIELD CONTAINED BY ALL 20 WAS THE TIME.

2. DIFFERENT RESEARCHERS FOCUS ON DIFFERENT PARTS OF THE LIGHTNING EVENT.

A. MEASURE DIFFERENT PARAMETERS.

B. TRIGGER MEASUREMENTS DIFFERENTLY.

D. CREDIBILITY.

1. RESEARCHERS DON'T BELIEVE IT CAN BE DONE.

    A. DON'T WANT TO BE BOTHERED.

2. BELIEVE THAT IF IT DOES GET DONE, THE RESULTS WON'T BE BELIEVABLE.

III. SUMMARY.

QUESTIONS AND ANSWERS

EMEDIO BRACALENTE (NASA Langley Research Center) - Do you definitely have plans to try to put a wind shear data base system together like you did with lightning? Is that in the works?

ERNIE ADMIRAL (Douglas Aircraft) - I was wondering if you could give us just a little brief historical perspective as to how long this activity has been going on and basically what type of data you are looking for.

ROSE MARIE MCDOWELL - We've been working for about a year on this. We are somewhat behind schedule because what we found was, talking with the researchers, it is hard to get data from them about what data they have. It is like catching smoke for a bonfire in a bed sheet. It is a lot harder than we thought it would be. We are behind schedule because we haven't identified a machine to put the data on. That is in part because although some of the airborne stuff have, they have very few strikes but they have loads and loads of data. Wave form data takes up an awful lot of space. If we go for periphial information such as temperature, altitude, air speed, turbulence condition, precipitation intensity, precipitation type--on the C580 [Convair 580) three years of data have 41 strikes. So there are very small numbers of records and very small pieces of information and you can put that on a PC. But if you look at the wave form that you want to sample every 5 nanoseconds for an event that lasts--not a second, a second would be too long, but you are still talking a great number of sampling points on a wave form and to do that, we've come up with a rough estimate for existing data of something on the order of 25 gigabites. Now we can't quite do that on a PC. The question is where do we want to go in between? In the lightning community the waveform is very important. We want to be able to say to a manufacturer not just this is the peak current but this is the rate of rise, this is the rate of fall, this is the continuing current because those are all so important. Does that answer the question?

ERNIE ADMIRAL (Douglas Aircraft Co.) - Pretty much, yes. Thank you.

JOE YOUSSEFI (Honeywell) - Can you tell us who we would contact to get information on the lightning data base? What source we should contact?

ROSE MARIE MCDOWELL - People who want to talk to me about the work that I have done, can contact me at Computer Resource Management. My phone number is 609-484-6911. The official FAA contact for lightning would be Mike Glynn and his number is 609-484-4138. Thank you.

SAM SAINT - COMMENTS

The very considerable attention being given to onboard "predictive" systems for wind shear warning, grows out of the fact that we would all like to give the pilot an earlier warning as to when he should abandoned an approach or takeoff and go all out to escape the microburst that has suddenly appeared in front of him. We would like to give him earlier warning. I want to point out that there is an option for earlier warning in the "reactive" systems that has not been given enough consideration. I refer to the option of asking the on board reactive system to warn on energy gain as well as on energy loss. The reactive systems are coming. I heard someone say yesterday, I think, that 4% of aircraft are already equipped. FAA I think, will be making a rule to mandate the use of the currently available on board wind shear warning systems. So, the question is should we ask the on board computer to tell us when the outside environment is seeing an energy gain that is outside the limits of normal turbulence? This information is in the computer. As a pilot, I want the computer to warn me that something is going on that is outside the limits of normal turbulence--whether this is a measure of energy gain or a measure of energy loss. And when I get that word I want to be on the way out of there. So the question is, should we warn on energy gain? And I'm not talking about a caution alert. Some manufactuerers of windshear systems are given a "caution" alert on energy gain. I'm confused about a caution alert. I'm talking about a "warning" on energy gain. I agree with Ray Stoer that we should not give a caution alert, whether on energy gain or energy loss, that is triggered at a lower threat level than the warning level. I'm talking about a warning that calls for pilot action. To find out how valuable, how important it is to warn on energy gain, I have gone back to look at the accident record from Eastern 66 in 1975 to Delta 191 in 1985. So let me read just a simple statement of what I found in each of these 8 accidents in the NTSB records. And I might add, in looking at these accidents I assumed that we would warn on energy gain, I assumed also that we would warn during the takeoff roll.

In the case of Eastern-66, June 24th, 1975 at JFK, the warning would have come 22 seconds before impact with the airplane at 420 feet, ballooning above the glideslope, with a head wind of 17 knots and an updraft of 300 feet per minute. Two seconds later he was looking at the loss of that head wind plus a 1200 foot per minute down draft. What actually happened was disasterously different. Those pilots didn't take action to get out of there until 2 seconds before impact in the approach lights. If they had pushed the throttles and gone to a go round mode at 420 feet while balooning above the glideslope, instead of pulling the power off as they did, there is not much question. That accident would not have happened. The go-around would have been a relaxed operation.

Continental 426 at Denver. This takeoff at Denver, got up to 50 feet and crash landed back on the airport. The warning in this case, on energy gain, would have come during the take-off roll, on the basis of the 7 knot per second increase in the headwind outflow with a ground speed of 70 knots with 10,000 feet of runway still in front of him left to stop.

Look at Allegheny 121 at Philadelphia. This pilot decided to go around at 60 feet on approach. In 17 seconds this aircraft went from 60 feet to 260 feet and back down to a 10-G crash landing in the middle of the airport. That is what actually happened. But what do you think would have happened if the warning had gone off on energy gain while these pilots were 270 feet above the ground, looking at 160 knots in rapidly increasing headwinds. The problem this pilot was struggling with was how to get rid of that extra speed--extra speed that he had all the way down almost to the point where he started his go round at 60 feet. If he had started out of there at 270 feet I just don't think that pilot would have been on the deck a few seconds later with a broken back.

Continental 63 at Tuscon is the fourth windshear accident in the MTSB record. In this case a takeoff roll was started with a 40 knot headwind. We are looking here at a warning on the basis of energy loss. That warning would have come 26 seconds into the takeoff roll, at 90 knots with 4500 feet of runway left in which to get stopped. The NTSB figured all he needed was 2200 feet to get stopped.

Then came Pan American at New Orleans. This warning would have come right at liftoff. And the thing that would have kept him 130 feet above the tree line, that he eventually hit would have been the warning at liftoff, telling him to put the power all the way up, and keep it there, plus recovery guidance on the pitch command basis to optimize the escape trajectory. And again, what actually happened was disasterously different. The actual knowledge of the problem they were in did not come for these pilots until after they had peaked out at 150 feet and were actually on the way down. The Captain said to the Co-pilot, "you're sinking." They should of had the warning right at lift off, put the power on, and followed the command bars in the recovery guidance mode. Safe Flight figured they would have passed safely, 130 feet above the tree line.

Now we get to United 633, a takeoff at Denver. For those pilots the warning would have come on energy gain 33 seconds after brake release, with 8300 feet of runway in which to get stopped. The warning would have come on energy loss a short space after that, with still plenty of time to stop. That warning, on energy loss, would have come at just about the time the Captain testified later, that he was considering aborting the takeoff. But he did not abort. When the airspeed started to pick up again, he decided to keep on going. He ended up burning a track in the grass for 1074 feet off the end of the runway with the tail engine of the airplane and knocking out the antenna of the ILS system. If he had been 5 or 6 ft. lower I think he'd of scattered that airplane over a 1/2 mile of territory. That is how close he was to total disaster. But the point is, he would have had a warning on energy gain early enough that he could have coasted to a stop.

Let's look at number seven. This was USAIR 183 at Detroit, a landing approach. This one is a confused mish mash of stuff. Any one of several things, including better training would have kept that pilot from second guessing the situation. He started a go round and then he came out of the storm, the runway was in front of him and he changed his mind and decided to land. The gear wasn't down when he finally impacted. Almost certainly the words "Windshear! Windshear! Windshear!" from the cockpit loudspeaker (and recorded in the cockpit voice recorder) would have kept that pilot from second guessing his original decision to go around. The airspeed record indicates this aircraft was in no real danger.

Finally, there was Delta 191 at DFW. The warning on energy gain, for Delta 191 would have come at 770 feet with 173 knots on the air speed indicator. Which of you in this room is going to tell me that if the warning from the cockpit loud speaker had said, "Wind shear, Wind shear, Wind shear!"--at that altitude, in that strong wind outflow, with a starting airspeed of 173 knots--which of you will argue that the go-around would have constituted any problem at all? Those pilots, knowing that warning was going into the voice recorder, would have been on their way out of there. If they had pushed the throttles at that point, with all that energy going for them and all that altitude--if they had pulled the gear up and gone to go around flaps, they would have been somewhere like 900 or 1000 feet over those water tanks instead of appearing on millions of t.v. tubes.

The warning on energy loss for Delta 191 would have come 27 seconds before initial impact. Still plenty of time for a safe escape, but the warning on energy gain would have come 35 seconds before initial impact.

What actually happened was sadly different. The record shows those pilots didn't know the trouble they were in until 17 seconds before initial impact. At that point--where they pushed the throttles all the way for the first time (those engines were never up to full power until 11 or 12 seconds before initial impact)--at that late point in time those pilots were into a dangerously different ball game.

With this I rest my case. A "reactive" windshear warning system, especially one that is programmed to warn on energy gain, as well as on energy loss, would have changed the accident record dramatically for the better.

RAY STOER - FAA Aircraft Certification

Sam, I have one comment to make on that. We concur in principle to your remark Sam, and let me read from the top of page 8 in the advisor circular. The paragraph is entitled: "Caution Threshold." Although not specifically required, the applicant should provide the system with the capability of detecting a rapidly increasing head wind or updraft and to display this condition with a caution annunciation. These conditions are routinely precursors of severe adverse wind shear conditions. So that is an endorsement by the advisory circular of your position. We do everything but require it. And we are really in a weak position to make a requirement in the absence of a regulation or rule, Sam.

SAM SAINT

I understand your position very well Ray, and I appreciate it. Ray, the only question I have about that is that I think we should be thinking in terms of this being a warning which requires action rather than talking about a caution. One of the biggest problems I see in examining the records of various accidents is the problem that we give the pilot a whole cross section of information as to what other pilots said, what the LLWAS is saying and a whole lot of other things, and then we toss the problem back to the pilot. We are suddenly asking the pilot in three seconds, to sort this all out and come up with the right answer. We have got to do something better than that. I want something simple that tells the pilot, with reasonable accuracy, what is happening outside--when the outside environment has gone outside the limits of normal turbulence.

With this simple warning we would then be telling the pilot: it is the best judgement of a lot of qualified people, including your own mangement, that the smartest and safest thing to do is get out of there.

I think we all recognize that the pilot is still in charge of the aircraft, but I think we should also agree that, if the escape manueuver the computer is calling for is a safe maneuver, the pilot should act on it, because the pilot has no way of knowing what may still be ahead. It is my feeling that the pilot should not countermand the computer's warning unless he knows with certainty that there is a terrain feature that is known to trigger an unnecessary alarm.

QUESTIONS AND ANSWERS SESSION
23 October 1987

BOB HALL (Airline Pilots Assoc.) - We are here today as an industry to develop wind shear warning and guidance devices. In order for a user to evaluate the device we think it is mandatory to establish a baseline from which all guidance systems can be compared. One such baseline could be the trajectory work done by Dr. Angelo Miele of Rice University. There may be others, but in any case a baseline should be established.

ROLAND BOWLES (NASA LaRC) - I think I ought to discuss why NASA got involved in that. What the intentions were etc. Three and a half years ago, several people came to us and said: "Wouldn't it make a good study to investigate, for a given wind shear, what the best we could do with a given airplane capability, keeping it in the air as long as you can and cover as much distance over the ground as you can." Since not a lot of work at that time had been done of a very substantial level, we thought that was a good idea to pursue. And NASA has funded that for three years. We were dealing with Dr. Angelo Miele whose reputation and credentials to do that work are extremely good: he is a well-accepted individual in optimization theory. We even got into some very elegant classes of optimization such as "Mini-Max's." Least Squares, minimum error, quadratic error, went by the wayside. Bill Melvin was introduced to this problem and helped Angelo formulate the basic questions. We let Bill Melvin stay involved in that work soley to advise on the practical aspects of Angelo's work, because Bill is an experienced airline captain and had a lot of background in wind shear.

The work is to be considered basic and fundamental. The industry should learn lessons from it. But nobody has been successful in implementing those techniques in practical flight director guidance concepts per se. That is, no flight director concept that I know of yet--and Kioumars you may want to speak on this--has been developed which will implement optimal guidance as formulated by the work out of Rice University with Miele. What you heard from Dave Hinton was a close approximation to that. Dick Bray has done this kind of work over a time. Kioumars is doing it presently and we all will continue to do it. We are learning lessons from it. It was discussed by the training team. Charlie Higgins who was leading the industry/training consortium at the time, posed this to the team as a possible way to compare recovery techniques: Do the best the airplane can do. Through analysis, manufacturer's could compare their concept to the best you can do. Overall I think that the team came to the conclusion that this is one way, but not the only way. And what was already being done is just as good in the long run. So it got put on the back burner. That is about all I can say about it. It could be done, but it is not the only way to go about working the problem.

DICK BRAY (NASA) - I would say that in effect this has been done and still is being done. Roland, the other day, in a discussion on this matter stated what I firmly believe too--history tells us that by the time you have recognized you are in a shear you are already very slow. So that the difference between most of the optimal trajectories in which you will get by some simpler methods, from that particular flight condition are not as greatly different as might be seen in a purely analytical study (in which everything happens right with the start of the shear from your nominal flight condition). So, to my mind, the memo there on the view graph implies that this hasn't been considered. I would say that this has been considered. Would you agree?

ROLAND BOWLES (NASA LaRC) - In discussion, Sperry indicated they have used some of this basic work to arrive at a practical implementation of the F factor recovery guidance technique. Many people have looked at it. I think the Aerospatiale people have followed the work to some extent and have capitalized on it. I think the point is: the difference in doing batch analytical simulations with certain state information and perfect knowledge of a threat windfield environment is one thing and it is valuable. But, as Dave Hinton showed, when you close the loop with the pilot, things begin to wash out and advantages of one technique, some of the "optimal approximations" sort of wash out relative to what is currently being recommended in the training procedure. So, it comes down to very small differences can make big changes. And given the uncertainty of human performance closure around the machine and other things it would be useful but I don't think it is a compelling thing to do, frankly.

BOB HALL (Airline Pilots Assoc.) - I wasn't necessarily trying to push anybody's theory over another but it just seemed that if you are a manufacturer trying to build something you ought to have some baseline to be going by. And if you are United Airlines, or whoever, trying to buy something then you would like to have something to judge it by. That was the only thought, and I think we have generated enough discussion. I'm satisfied with what you are saying.

PAUL CAMUS (Airbus Ind.) - In principal it might be very interesting to compare different solutions, but from present and past experience we have seen that there are very large variations even between identical runs with the same situations and coming out from different pilots. But, what I would suggest is at least to show that with an automatic system we can do better than with a manual procedure. Otherwise, we will invest very much to gain to have a low gain, compared to established and the well-trained procedures.

DICK BRAY (NASA) - In regard to looking at any algorithm for recovery, whether it be takeoff or landing, that using the batch process or the computer to compare one with the other is very valid, but I think it should also be assumed one with a whole matrix of delay conditions--assumptions of pilot delay and response. Certainly, even the present warning systems are very likely to have you start your recovery 15 knots below your initial speed or well below even normal approach speed. I think as these conditions exists, you'll find that the difference between the optimum path and any of the simpler paths gets smaller and smaller. So I just recommend that anybody doing a study certainly consider a large range of delay times.

KIOUMARS NAJMABADI (Boeing) - I would just like to make a remark about delay. The study was done by Angelo Miele in fact. He found that with a delay of more than 4 seconds, there was absolutely no difference between the optimal trajectory and the other suggested strategies for the takeoff case.

PAUL CAMUS (Airbus Industries) - Does that hold true for the approach case?

KIOUMARS NAJMABADI (Boeing) - He hasn't done any study on that and we are in the middle of doing that study ourselves.

HERB SCHLICKENMAIER (FAA) - [Reading from John Chisholm's question:] A question was raised as to the ability to detect weak microburst echoes in the presence of ground clutter as viewed by a weather radar in a landing airplane.

The obvious next question is - what is the lowest altitude that can be viewed with such a constraint?

"The answer appears to be that by a combination of appropriately programming tilt angle and range gating the data it is possible to insure no main beam ground illumination and yet view 400 feet. altitude outflow, to ranges of a mile, i.e. 30 seconds advance warning over the reactive type systems. Following this line of reasoning, 2 mile range is achievable, with altitude coverage down to 750 feet, and three miles, with altitude coverage down to 1200 feet. In other words ground clutter appears to be manageable.

"The question of the magnitude of ground clutter at low grazing angles, i.e. 3 to 0, is still controversial. For this reason the data NASA is arranging to be obtained is highly important."

If one assumes a clutter reflectivity of -20db, (Evans used -10db for low grazing angles, TDWR uses a mean value of -40db) and a dbz of +10db the signal/clutter ratio becomes -50db, a difficult signal to clutter ratio to handle, especially from a moving platform. However, if only side lobes illuminate the ground the signal to clutter become 0db which is much more manageable.

John, anything you need to add to that?

JOHN CHISHOLM (Sierra Nevada Corp.) - If anybody is curious, I have one view graph that will illustrate this concept of program tilt. This was a question that Jim Evans raised yesterday as regards to the difficulty of picking out weak echoes in heavy ground clutter. And his argument, which is valid, is that if you illuminate the ground with the main beam you are down in the -50 -60 db signal to clutter ratio which is at the limits of what you could get with a good doppler processor or good radar because of the stability of components. The argument, or the discussions that we have had with NASA on this subject in effect state, why illuminate the ground just as you come in for a landing, which is the worst case, you just tilt your antenna beam up and you program the range at which you are looking. And for a mile ahead you get your coverage down to the magic out flow region of 400 feet and as you tilt it up you get coverage out to 3 miles the altitude goes to 1200 feet and you can argue whether that is a good valid outflow region, but you can also argue that you will get very useful data.

EMEDIO BRACALENTE (NASA Langley) - I would like to comment a little bit on this subject. This is a great idea and it is one we plan to evaluate extensively. This is one approach for reducing the large clutter signals. obviously, since the signals are distributed "spectrum-wise", other techniques of signal processing can also be applied, even for the case when the beam is pointed straight down the glide slope, to reduce the clutter signals. So, there are many approaches, to possibly solving the problem, that need to be addressed. That is part of what we are trying to do. I think that it's a significant problem, and we need to understand it and hopefully reach that point where we will be able to indicate ways of managing the problem with clutter.

DAVE HINTON (NASA Langley) - We don't have a view foil on this one, the question was from Bob Ireland. He says, "given that most wind shear accidents have been preceded by excessive lowering of the nose or allowing the nose to drop, and given that your flight path guidance was not clearly successful in the wind shear modeled afeeter real world conditions; Do you recommend any aggressive nose lowering in the absence of guidance, i.e. today?"

Some things I couldn't get into in the discussion, in looking at the scattering of data, part of the reason for that scatter is that the research pilots wanted to vary their gain somewhat from run to run. Fly more aggressively or less aggressively. The success of that guidance was dependent on close adherence to the pitch schedule that was programed. In some cases the pilot decided that if lowering the nose to 10 degrees is good then maybe I'll lower it to 8 degrees and that will be even better. And that put the airplane in the ground. Here's the view foil. In other cases, and there were numerous cases where the pilots, and perhaps even myself sitting in the right seat, thought we had successfully penetrated the shear, thought everything was looking good, the trends were good, but a few seconds later we are on the ground wondering what happened. The point is that the middle of the shear is a very confusing place for a pilot to be, and to go back to the answer I've written down here. The flight path angle guidance looks like the way to go. It's the direction to pursue. I would not take the guidance I have now and advise anybody actually installing that, as is, in an airplane in an operational environment. So it was the best, and showed the most promise of all the options tested, but it is not a technique, and this is my belief, that a pilot could reliably fly in the absence of guidance. The pitch that you would need at any particular instant is going to depend on the necessary flight path angle at that point, the airplane's air speed, what the wind is doing to you. The success of that technique depends on closely following that pitch, and on todays flight decks you do not have flight path angle information available. If you try to get that information from looking at a vertical speed indicator, you are going to have lags, especially if you have someone else reading the vertical speed to you. Same with the radar altimeter. You'll have lags just from someone reading that to you, uneveness in the ground, that sort of thing. Any excessively low nose attitude, pitch attitude, will put the airplane on the ground. Rotating the nose back up, to flare, too late can put the airplane on the ground. So, I can not advocate aggressively, and I'm talking about a take off case now, aggressively putting the nose back down. If you try to do that now, we would have to give the pilot a procedure that would depend on where he is. We would say, okay if you are above 500 feet on approach, for example, do this. If you are below a certain altitude on approach do something slightly different. If you've just lifeeted off, there is a third action to take. If you have lifeeted off and you are climbing through 300 feet there is yet another target pitch to go to. And I don't believe you could train to that. You cannot give the pilot half an hour of training each year and then expect a line crew to go out an reliably follow that. So, does that answer the question? He's not here. Well, I guess it does.

DAN LABRIOLA (Technical AirServices) - Just as an aside, I know this debate is going to continue for some time, guidance versus no guidance. But, I would like to reiterate that at least in all of my experiences and everyone else I know, you can still do better with a good guidance system then you can without. Sometimes that emphasis seems to be getting lost in the debate. So I will mention it again since it makes me feel better to say it. Thank you.

FRED PROCTOR (MESO) - This question is from Joe Youssefi (Sperry Honeywell). "Why are the peak outflow winds derived from model less than the actual data for altitudes above 300 meters?" The slide that Joe is referring to is the vertical profile for the peak differential outflow velocity for the Denver 30 June simulation (see presentation). The simulated profile is given by the heavy solid line, but also shown are the observed profiles for the JAWS averaged and the JAWS 5th of August cases. There are several possible reasons why the simulated profile indicates weaker outflow speeds above 300 m than indicated in the JAWS profiles. First, profiles from different dates are being compared. Another possible reason is that the model simulation assumes an axisymmetric microburst, while many of the JAWS microbursts were, in fact, asymmetric. Lastly, the JAWS profiles are not actual data, but are derived data from Doppler radar measurements -- and therefore may suffer some inaccuracies such as due to ground clutter, beam-width averaging, and data filtering.

The second question Joe Youssefi asks is "What physical elements cause multiple vortex shears such as in the DFW flight recorder data?" Well, I can only speculate there but, if you are familiar with the Delta 191 incident, there were some very strong oscillations in the vertical velocity just before the plane crashed. Some people have attributed these oscillations to multiple vortex rings, although I am not convinced by this explanation since the oscillations were pronounced only in one side of the microburst. However, I have seen strong vertical oscillations in some of my model simulations when a shallow, ground-based stable layer is present. Thus, another possible explanation for the vertical oscillations experienced by the Delta 191 could be due to gravity wave oscillations. As a downdrafeet penetrates through a stable layer, it will set up gravity oscillations, somewhat analogus to dropping a rock into a pond and seeing the waves propagate outward.

Next, I will attempt to answer several questions addressed to the general audience by Bob Otto. "What is the extent of spatial asymmetry in microbursts? And do we have sufficient data to assess the asymmetry?" In the JAWS program a large portion of the microburst were detected as having asymmetric outflows; I can't remember the exact percentage, but on the order of 60-70% did show at least some asymmetry. However, in the FLOWS program, a much smaller percentage of the microburst outflows were notably asymmetric; 85% were reported to have a least near symmetry. So in some areas or cases the axisymmetric assumption may not be a bad assumption. I suppose a good question to ask is under what conditions favor symmetrical or nearly symmetrical microbursts versus those conditions which favor microbursts being skewed from symmetry. The condition which probably has a strong influence on the symmetry of asymmetry of a microburst is the environmental winds in which the microburst occurs. If microburst occur in environments which have weak winds and weak vertical wind shears then they may show a high degree of symmetry. The DFW microburst was probably a good example of this situation. Now, in cases where there is moderate to strong ambient winds and ambient wind shear, the downdrafeets are going to transport momentum downward toward the ground which will skew the outflows from symmetry. In the future we plan to investigate the symmetry question using our three-dimensional model.

In the second question that Bob Otto asks is "If there is significant asymmetry in microburst phenomena, then what effect does this have on aircraft aerodynamics? Qualitiative, conceptual trends are desired." I'll let someone who is an expert on aerodynamics answer that question.

HERB SCHLICKENMAIER - Before we ask Bob Otto, let the record show that all eyes went to Roland Bowles. Bob.

BOB OTTO (Lockheed) - The intent of the question is, really is there any special types of algorithms that need to be developed because of a microburst being asymmetric as opposed to it being symmetric. I am addressing the question from the point of view of a sensor technologist who wants to build a system. And I am looking for things in the phenomenology of microbursts which will help me determine the requirements for a sensor.

ROLAND BOWLES (NASA Langley) - Let me ask the question back. Do you feel this is a more significant problem than the ability to scan to get vertical wind information and what does the remote sensor technology people feel about the scanning opportunities with pulse doppler systems whether they be light or microwave?

BOB OTTO (Lockheed) - I think the question that you gave back to me is a subset of the question that I am asking. I have concern that whatever algorithms or whatever procedures or whatever requirements eventually get developed for a particular sensor, that I wonder if they are going to be general enough to handle all cases or are there going to be some specific things which will be anomilies. You see, what I am really looking at is any sensor guy is going to develop something based upon what the average requirements are. Or perhaps a nominal cases, in some cases he may even go to a pathological case. What I am trying to get at is, are there pathological cases here that we ought to be aware of up front? What percentage of the time do we meet those types of things? Or are things relatively benign?

ROLAND BOWLES - Okay, I'll answer it in a general way. What we want is, the winds in the vertical plane? I don't know of any cases where we have seen cross wind shear that has caused an accident. So you know you are largely looking at what is along my flight-path-extended and above and particularly below that flight path in a vertical plane. I do think that the remote sensor people have to give serious consideration to looking at what you can do with vertical scanning. But, the asymmetrical aspects--I don't see a problem. We discussed this among some of us recently, I don't see a problem of where asymmetries upset the situation if you've got the sensor on the airplane. If the microburst is elongated, orthogonal to your flight path, that is what you are going to see. You are going to see a small wind shear. If it is elongated along the flight path, that is what you are going to see, a pretty significant shear over a characteristic dimension that may be hazardous. So I don't see the assymmetry question as critical when the sensor is on the airplane to the same extent if the sensing device is ground based.

RUSS TARG (Lockheed) - Roland asked an interesting question with regard to assymmetry in the microburst more significant for a system designer than the general question of scanning. I thought Sam Saint's questions this afeeternoon were very apropos to that. It may be that as you examine the interplay of the phenomenology of the microburst and the flight dynamics that you will decide that you can establish a significant threat from the "performance-increasing" portion of the microburst so that conceivably it will not be necessary to do scanning. That is as you come into a microburst such as the one at Dallas Fort Worth and you look out in front of the aircrafeet and see that you are going to pick up 20-40 knots unasked for performance increasing head wind, that may be such a pathological (case) outside the envelope head wind that you really don't want to get any more information and that you will take a missed approach at that point without determining what is inside the funnel or whether or not in addition to the bizzar head winds you are running into there is also a vertical component.

So I think there is a significant flight dynamics question that may allow us to use these precursor winds as a signature of a threat without any further ado. That is a proposal obviously, that is not a considered answer to your question, but based on Sam's comments I think that that is a significant worthwhile area for us to look at.

JIM MOORE (NCAR) - Let me offer a few observations that we've had, that I have specifically had in the tower and I think that a few others might have seen as well. Just to give some input to the technologists who are trying to deal with something other than just the always symmetric case. Assymmetry at least in the bursts in Colorado seem to be pretty common, in fact, I think the figures were quoted quite accurately. A lot of that is driven by the fact that the winds coming off the Rockies are a lot faster than whatever is at the surface so you jet this natural like a titled rain shafeet type of effect and you expect

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winds on one side of that to be quite a bit stronger than they are on the other. So assymmetry at least in the high planes of the United States is probably more common than symmetry. The next thing is the phenomenon that I noticed most recently visually at Stapleton during the event that I showed a slide of this morning where microburst moved across the airport. The microburst went through a pulsing phenomenon where it seemed to dump or it seemed to occur with a down drafeet you would get the curl of dust by the way, it was only one side as well, that doesn't mean it wasn't symmetrical but there was no evidence of dust on one side where there was a lot of dust on the other. So there is a pulsing phenomenon and it died away and then a few minutes later it was back and as the cloud moved essentially down wind, you got a very distinctive feeling of a pulsing phenomenon. Yet another, is something that we have dealt with now 3 or 4 times in fact, in 1984 during the CLAWS (Classify, Locate, and Avoid Wind Shear) program it proved to be one of the most damaging to airport facilities that we had. It was not an isolated symmetric or asymmetric microburst, it is something that we call a Microburst Line, which is a real interesting bird. It is almost like it is a line of verga that produces a down drafeet along a very long axis, a quite long axis so you have divergence on either side of an essentially fairly straight line. That did some remarkable damage, physical damage to the airport itself and we shouldn't ignore some phenomenon like that. I'm not indicating that the instrumentation necessarily has to be changed, but I'm trying to give you a feel for what we see with our eyes, what we see visually when we are sitting in a tower and can observe this. There is one last thing I would like to say with respect to Russell's comment and a comment offered earlier concerning reactive instrumentation as soon as you see increasing headwinds. And that is that if you have a scenario of a simple cold front or in the high plains another very common thing is a gust front one would have to be real careful about a real high false alarm rate by responding only to an increase in energy because, unless there is something behind that, there is something else, the occurrence, the preponderence of a gust front phenomenon in Colorado is quite regular during the summer. And in and of itself it is not particularly hazardous to aviation because of the nature of the impact and no particular following wind behind it to adversely effect aircrafeet performance. I think that is all.

HERB SCHLICKENMAIER - We just rapped up question three as well.

KIOUMARS NAJMABADI (Boeing) - I would just like to make a remark that we at Boeing are also involved in evaluation of the sensors before looking as well as hazard index evaluation to find out what is the proper index for hazards, under the same contract.

HERB SCHLICKENMAIER (FAA)- This is a question posed to me from Dan Labriola from Tech AirService Inc. "What is being done to assist the operators with smaller training departments to implement the training aid?"

I'll be happy for anyone else to chime in at some point but let me give you some preliminaries. You'll remember in the Integrated Wind Shear Program Plan, that we do talk to transfering the information from the 121/135 community into the 91 (the general aviation) community. At this point we are looking at some different approaches for evaluating that. Looking at the general aviation fleet compared to the air carrier is looking at very large number of manufactured airplanes and pilots as compared to a relatively few number of airplanes in the 121 side. So at this point we are looking at some evaluations to transfer the information. Does that get to some of the point Dan? Or does anybody else have something to contribute to this.

DAN LABRIOLA - Well, you know the reason I asked that Herb is because we are trying to help some of the really small carriers and you know the people out in the boon docks in third world. People who are interested in this thing but don't really, some don't, most don't know if its existence even though they have been sent copies of the aid and it is rare that you can find a small carrier who recognizes the significance of what is going on. You know the general feeling out in the community outside of our environment you know, we are used to talking to United, American, and Delta and people who are really on top of this. The overwhelming number of folks out there have no idea what is going on. Have no idea that there are things they can do in the interum to improve their likelihood of surviving one of these encounters. I mean, I am one person I am certainly not going to change that and it seems like once again it takes an effort maybe on the part of this whole group I don't know, to get to that. But, there seems like there is something missing in this.

HERB - Questions, points? As I mentioned earlier, we are not there yet Dan. I think through some conserted effort and through some response back into the program maybe the recommendations could come in for us to look at that.

ROLAND BOWLES (NASA Langley) - Jim Mitchell of Boeing asked a question of me. "In noting that stickshaker speed is increased in heavy rain do you mean that stickshaker should activate or will it activate at higher speed, stall warning system doesn't know that it is raining. It is my understanding, stickshaker is activated on angle of attack. So for fixed configuration, weight, and lift drag polar, that will occur at some speed. If you change the lift drag polar it will occur at a different speed."

BUD LAYNER (NTSB) - Along the same line, has Earl's research shown where the stall margin is reduced at stickshaker activation with the different "CL-ALPHA" curve?

ROLAND BOWLES - No.

BUD LAYNER (NTSB) - Is that no, or don't know?

ROLAND BOWLES - No he's not prepared to reveal that to anybody. There is a second question from Jim Mitchell of Boeing. "What is your source for the statement that 6% of airplanes now have wind shear systems? 6% of which airplanes?"

My source Jim, is Boeing. But, more recently upon further research the answer has changed and it now looks like that 4% of major and national aircraft by the end of 1987, will be wind shear equipped. And that is pretty solid data from your people in Seattle.

JIM MITCHELL (Boeing) - That doesn't necessarily mean that all of the airplanes we've got equipped have activated the system, that is important for people to understand that a lot of airlines are waiting till they have retrofitted their entire fleet before they activate. Especially those that incorporate a guidance system also. It is a crew training problem. That is something to be aware of.

ROLAND BOWLES - That posses an interesting question in terms of what we heard this morning. That means that some may not be equipped for four years. If that is a strategy that is going to be followed then safety may be compromized.

SPEAKER - I'd like to ask the French what is the number for the French airplanes.

PAUL CAMUS (Airbus Industrie) - All our aircraft are equipped with airborne windshear systems. By the way, they are equipped from 1974.

HERB SCHLICKENMAIER (FAA)- Sam, you've become a speaker. This is from Jim Mitchell (Boeing) for Sam Saint: "How will your warning energy gain or energy loss on the runway deal with the dangers of an aborted takeoff? With active winds on the runway, "V-One", may be reached further down the runway than predicted. Therefore, even if airspeed is below V1, there may not be room lefeet to stop."

SAM SAINT (SFIC) - The concern about triggering an abort at the dangerous point of the "go no-go" point where the runway length is critical, has got to be a real concern. And I can understand the worry of a manufacturer at the possibility of being held responsible in a liable suit if the airplane received a warning at the critical point and then wound up in a smoking heap at the end of the runway. That is a very real concern. And I thought a long time about this before giving my inputs to SafeFlight on this, and my position became and has strengthened with everything I've learned since. The greater responsibility is to have a computer on board the airplane that knew that United 633 should abort the takeoff while he had a lot of runway still in front of him, but withheld that information from the pilot. And this was one of the things that caused me to go back through the accident record to find out if indeed any of the experiences we've had to date happened at the critical "go no-go" point with a marginal situation for the pilot. And as I indicated in those eight accidents, the warning would not have come even close to that critical time in any one of the accidents we looked at. Now, I point that out to SafeFlight and advising them and I acted very much as an individual on this. When I even walk in the door at Safe-Flight, I take my Safe-Flight badge off and put it aside and talk from the point of view an airplane pilot who flew airplanes all the way from the DC2 up to the 747; did a fair amount of engineering test flying; and I think I know how pilots act and how they think, and how what we can expect from the pilots at the low end of the spectrum. Because an airline pilot is not a standard item having a perfectly standardized performance response, and I conclude that the pilot in this case is going to have to make a decision anyway. United 633 rolling down the runway, the captain testified that he thought of aborting when the airspeed indication hung up and then changed his mind and kept on going when the airspeed indicator picked up. No matter what happens during that takeoff roll even at the critical "go no-go" point, the pilot is faced with a necessity to make a decision. I think it borders on the immoral (that is probably not the right word) to withhold from that pilot who has to make the decision anyway, to withhold from him information that the computer knows very well as to what the level of the threat actually is.

JIM MITCHELL (Boeing) - I think the issue is so complicated on the runway (if given the current generation of wind shear alerting systems) you are really talking about taking the "go no-go" situation decision away from the pilot almost. If you're going to, there ought to be a window where you either take into account in the alert of, if you reach a certain speed on the runway then you are going to inhibit that alert because if he has made the decision to go right then, it is probably not going to help him until he is up off the ground, then you can alert? Or, are you going to include in your alert algorithm a computation based on a known length of the runway and friction coefficients and all that to make a judgement as to whether you should recommend an abort? I mean, what is the crew action going to be? I think that is a really complicated issue.

SAM SAINT (SFIC) - Anyone who has ever operated in command of an airline airplane knows that there is no way you can give the pilot out of any computer that now, or in the future an arbitrary judgement that takes that judgement out of the hands of the pilot. You just can't do that. What we are talking about here is giving the pilot the benefit of a computers measurement of what is actually happening. The warning is telling the pilot, look the outside environment is at this moment exceeding acceptable limits, in the speed with which the head wind is going to a tail wind or visa versa. But there is no way that that computer can tell the pilot who is in command of that airplane that he now must stop thinking and abort. Okay? The pilot of that airplane gets paid pretty well for using his judgement. And he is not going to pass that judgement off to a computer. But he would like to have the help of that computer in knowing what is actually going on.

DICK BRAY (NASA Ames) - I just wanted to quickly bring up another technical point, that while you are rolling on the runway up to 60-70 or 80 knots your system is measuring a W dot and wind rate of change. While the airplane is going at those lower speeds it is going to see that rate of change as a fairly low value, a lot lower value than if you are steaming by at 140. So, it might be that your normal threshold is going to be way too high to recognize. I wanted to bring up that point. You are going to have to do a little adjustment on the thresholds in that condition.

SAM SAINT (SFIC) - There has to come a point Dick, at which you say the air speed has now reached a level of reliability that we can feed it in the computer. Now, SafeFlight said that speed should be 80 knots and I've heard others say that that should be down to 60. And I've talked this problem with Joe Yoeseffi and some other people, and I fully understand that you have to have stable air speed information to compare to the inertial acceleration in order to get a valid indication of what is happening.

SPEAKER - I had a similar question in that some of the reading I've been doing indicates that (pause) my question sais, it is a comment really. One of the speakers yesterday pointed out that the takeoff microburst can be more hazardous than the landing one due to high gross weights, low potential energy, etc. I have seen some proposals that call for activation of the sensor or warning system late in the takeoff roll or afeeter air borne and in my opinion that is too late and systems must be required to operate for brake release. Now, I know there are some technical problems, but we should be shooting at developing a system that gives us this information as soon as possible on the takeoff roll.

KIOUMARS NAJMABADI (Boeing) - Has there been any modification to Airbus detection systems since 1976. If yes, how many?

PAUL CAMUS (Airbus Industrie) - All our airplanes which have been in service from 1974 have been equipped with two basic systems. The first one, the "Alpha-Floor Protection System", takes care of wind shear. The other system is a "Speed Reference System", which can be used on takeoff and go around phase. It is a guidance system which feeds the flight director bars. In fact, for the time being, we have no detection on takeoff. But what we do really, is to provide an adaptive control which is able to take care, automatically, of any aircraft performance degredation. The only thing which is missing for the time being is a detection system on takeoff. But just to cope with situation where we takeoff with derated thrusts. This is because the pilot has to apply immediately the full maximum takeoff thrust. And as a matter of fact, it appears from our experience on our simulators with many different pilots, that the application of thrust on takeoff is not obvious and there are some pilots who miss applying full thrust to cope with wind shear encounter. From that time, we have not yet implemented additional modification. However, we have improved design in various areas. First, guidance on takeoff, an improved detection of the vertical wind component. As you may know, the last generation Airbus airplane which is the A-320 has a flight control system concept. And on that airplane we also have a specific feature which is to protect the aircraft flight enveloped against excessive angle-of-attack. And therefore, that means in a wind shear encounter the pilot is able to apply, as required, full stick-back and the computers will regulate the maximum angle of attack to obtain the maximum possible lift. This feature is very important because the pilot is sure that he will not endanger the aircraft at high angle of attack. I hope that answers your question.

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16. Abstract

The "First Combined Manufacturers' and Technology Airborne Wind Shear Meeting" was hosted jointly by NASA Langley (LaRC) and the Federal Aviation Administration (FAA) in Hampton, Virginia, on October 22-23, 1987. The meeting was co-chaired by Dr. Roland Bowles of LaRC and Herbert Schlickenmaier of the FAA. The purpose of the meeting was to transfer significant, ongoing results gained during the first year of the joint NASA/FAA Airborne Wind Shear Program to the technical industry and to pose problems of current concern to the combined group. It also provided a forum for manufacturers to review forward-look technology concepts and for technologists to gain an understanding of the problems encountered by the manufacturers during the development of airborne equipment and the FAA certification requirements. The present document has been compiled to record the essence of the technology updates and discussions which followed each.

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