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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

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TENTATIVE TECHNICAL REQUIREMENTS

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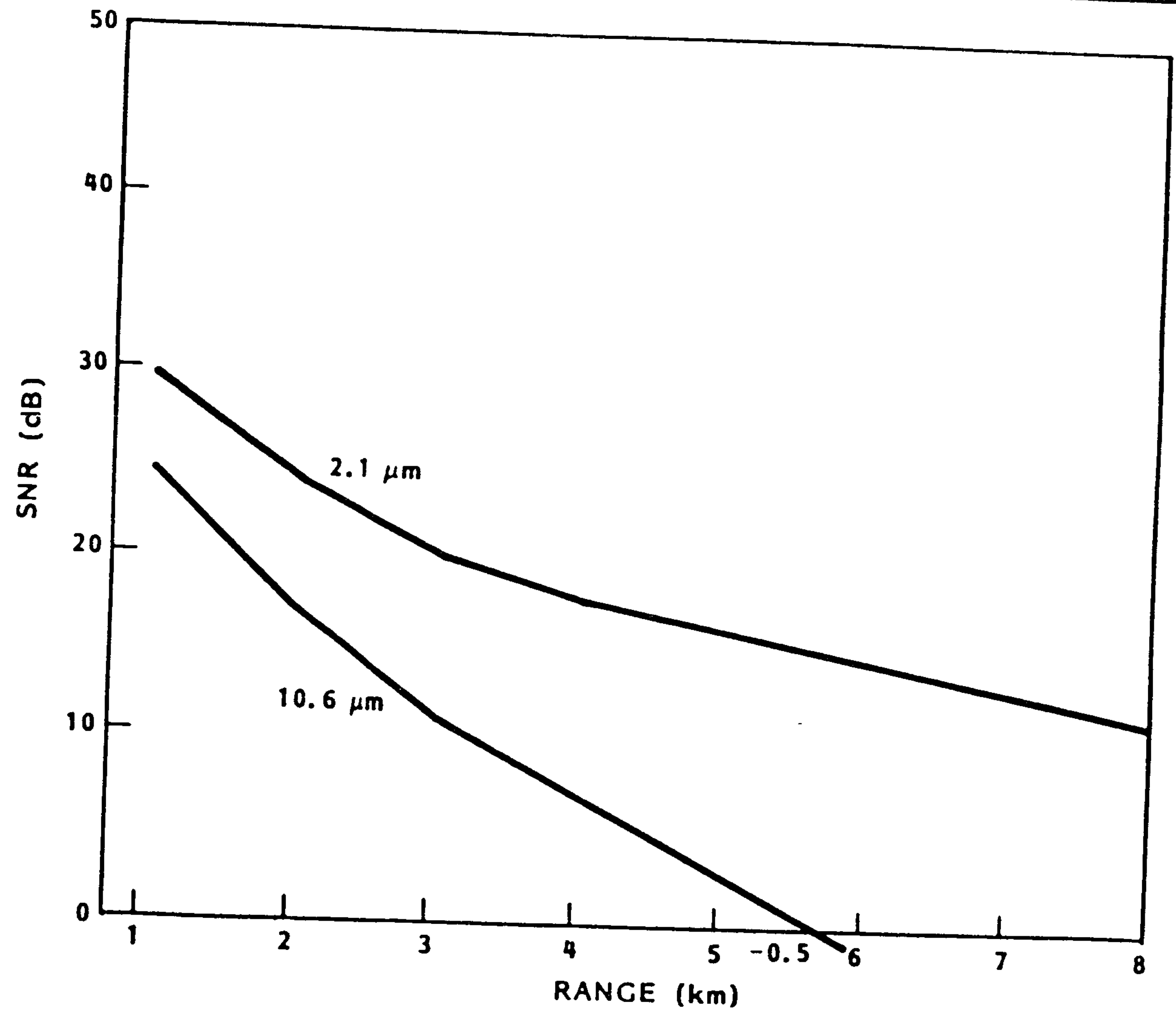
• SENSING RANGE	1 TO 3 km
• RANGE RESOLUTION	0.3 km
• VELOCITY RESOLUTION	APPROXIMATELY 1 m/s
• ADVANCE WARNING TIME	15 TO 30 s

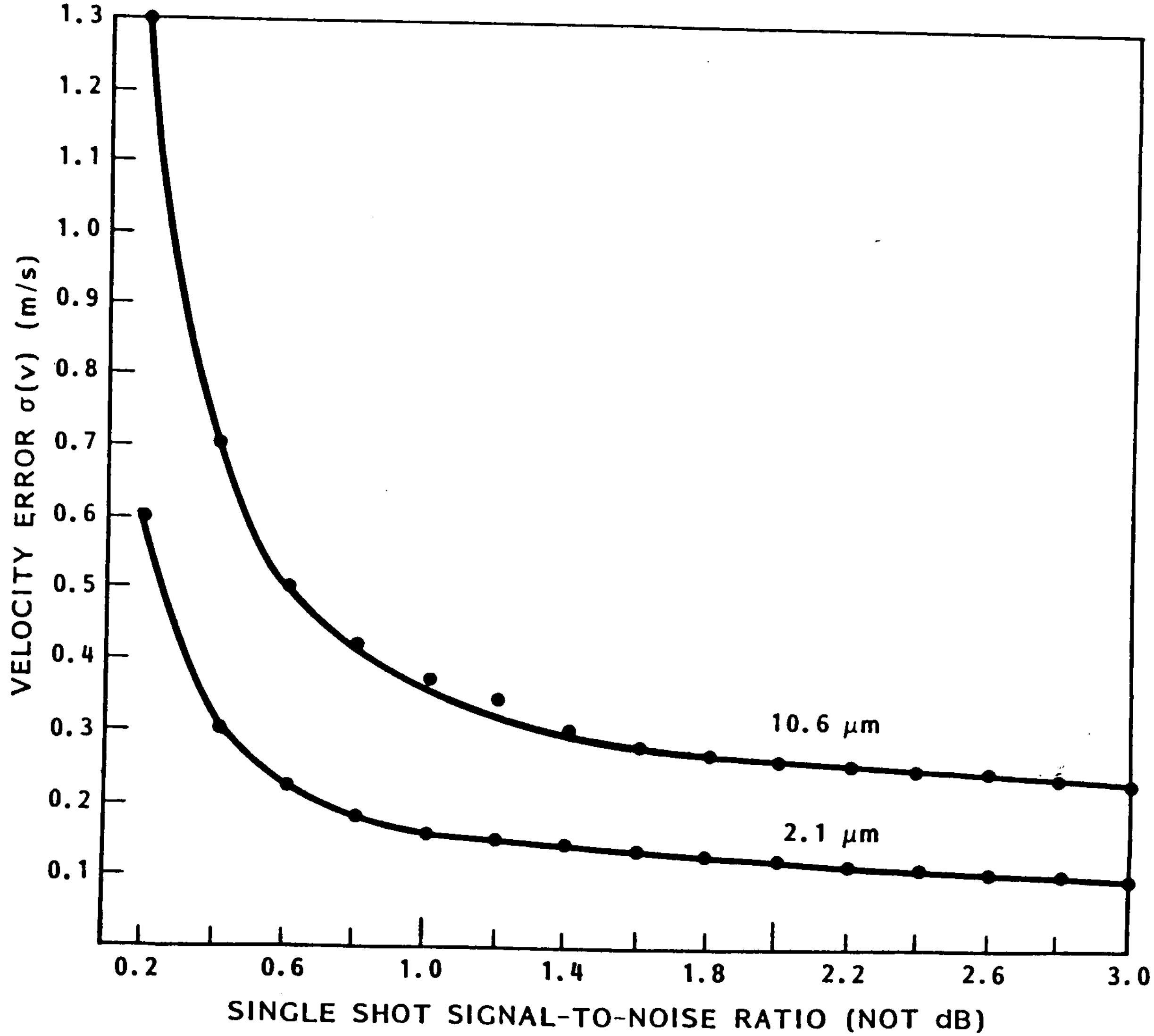
STARTING PARAMETERS FOR LIDAR COMPARISON

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



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



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

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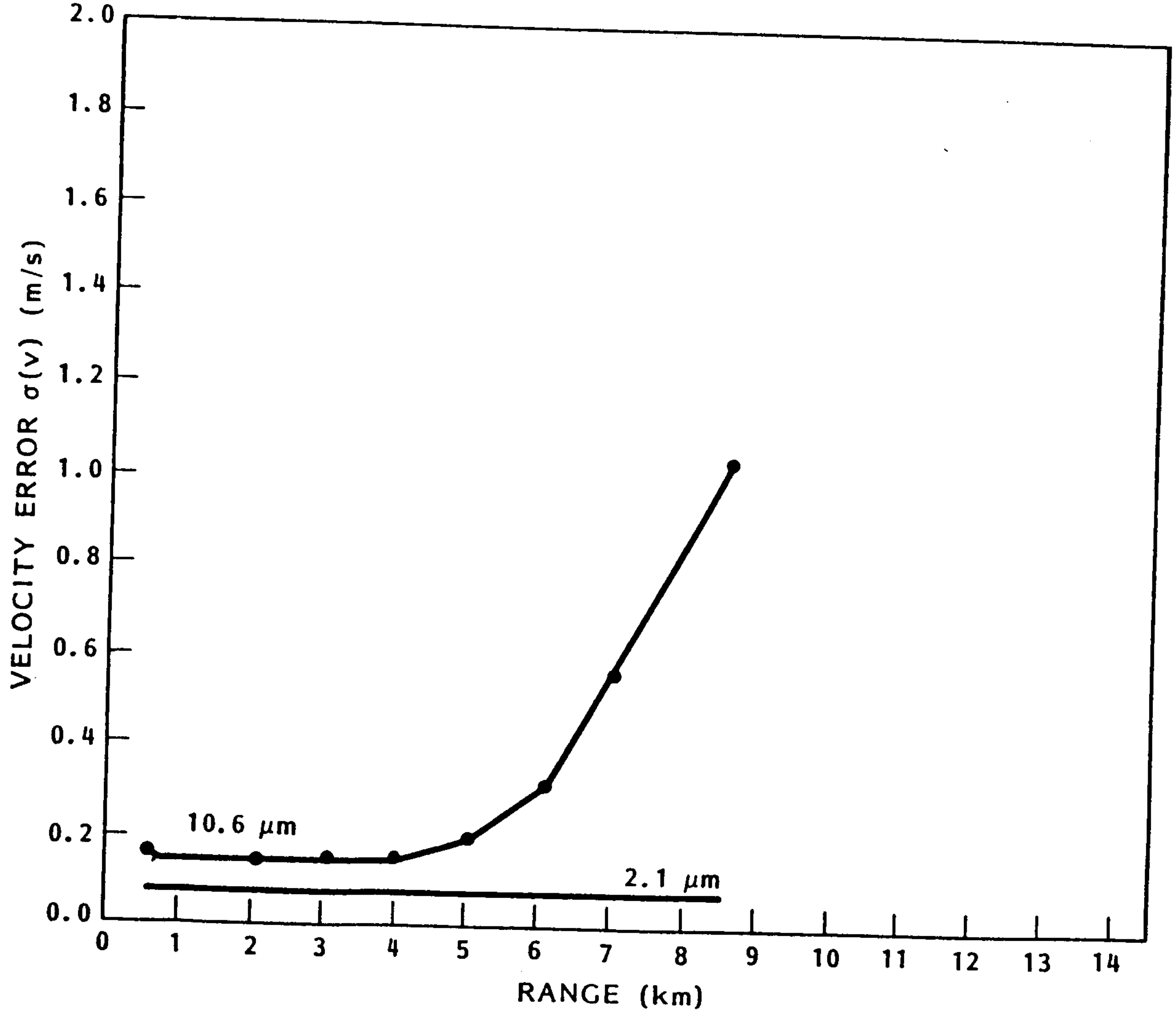
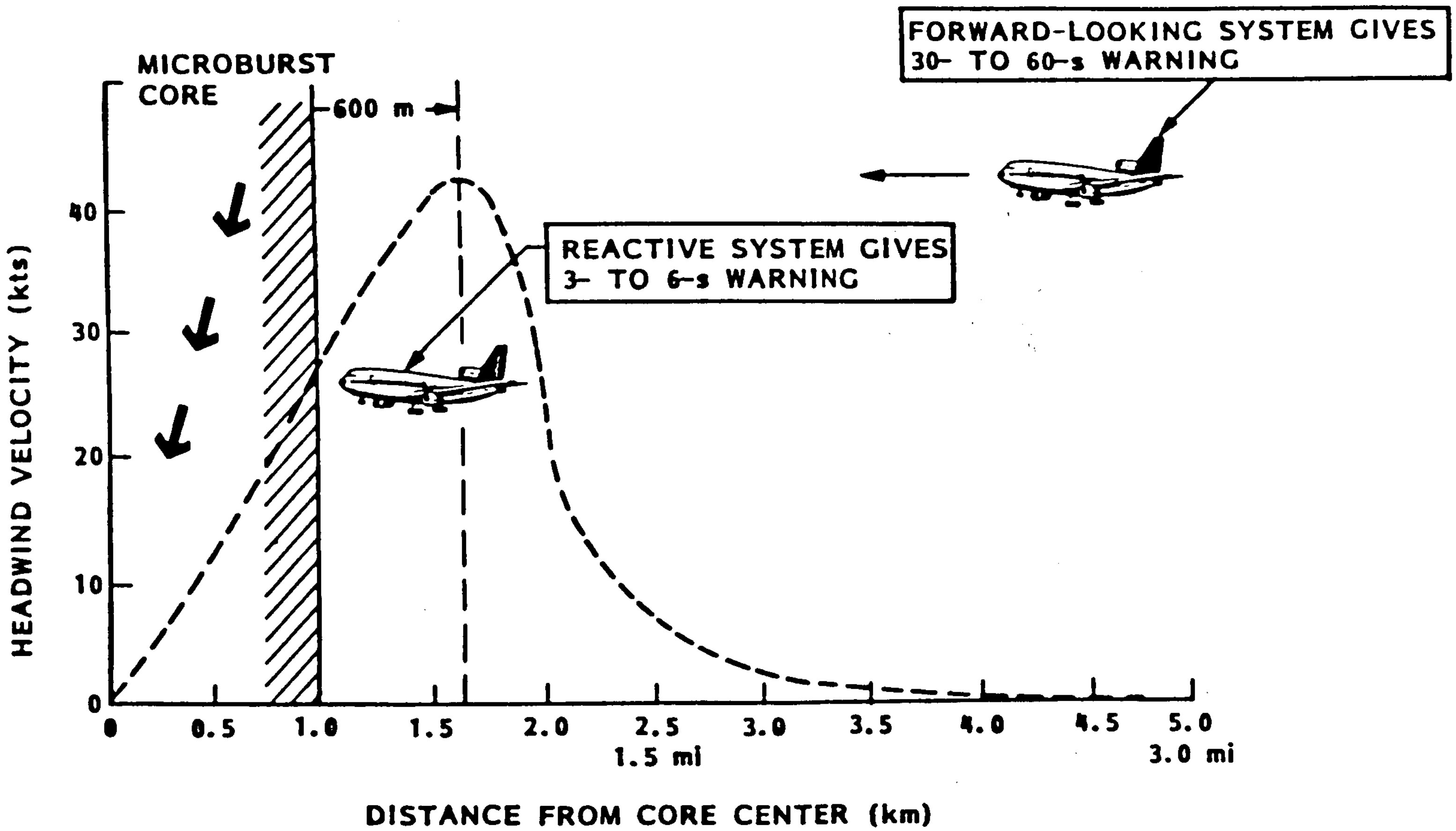
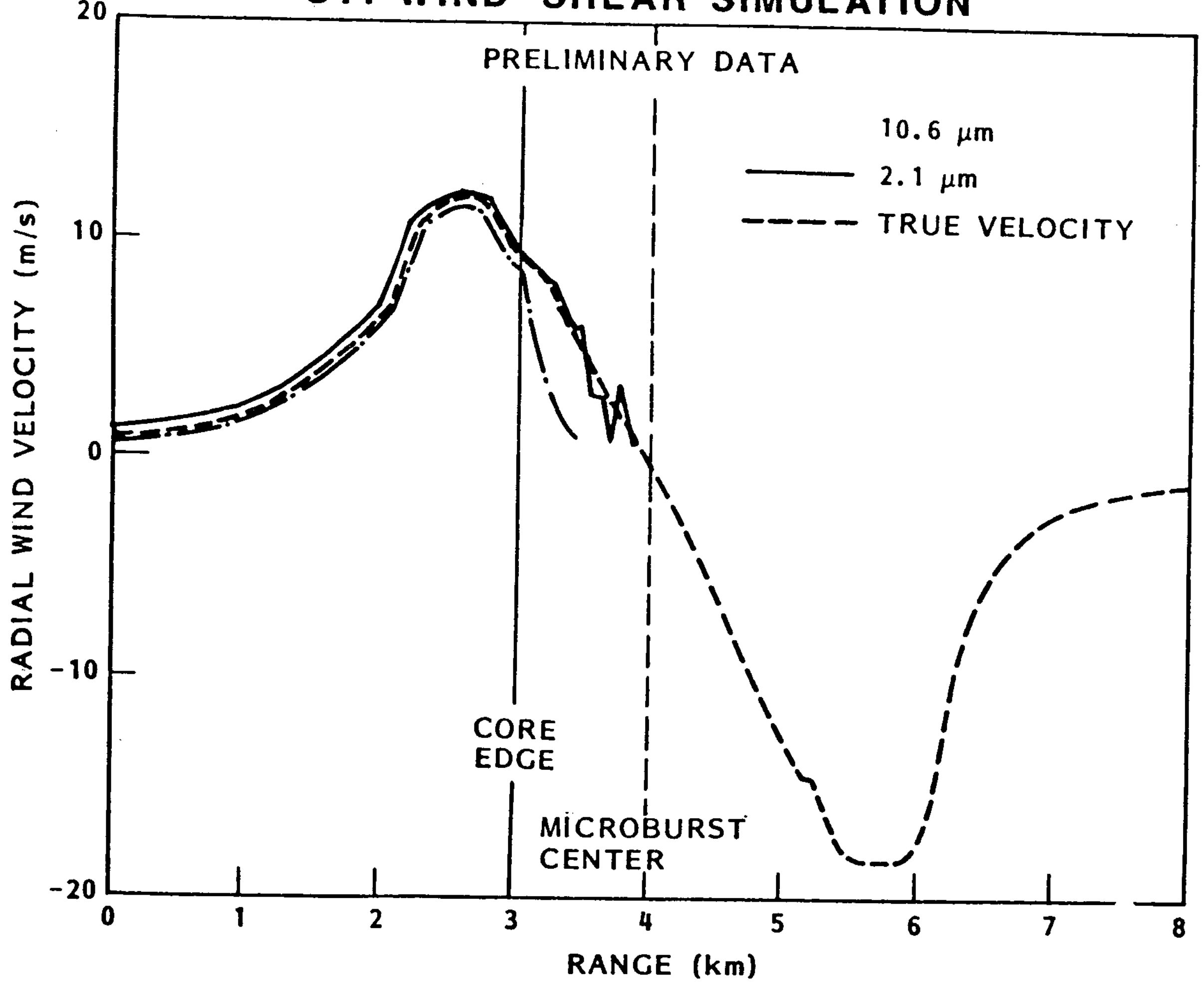


RELATIVE PERFORMANCE OF FORWARD-LOOKING AND REACTIVE SYSTEMS FOR THE DALLAS/FORT WORTH MICROBURST



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.

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

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.

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

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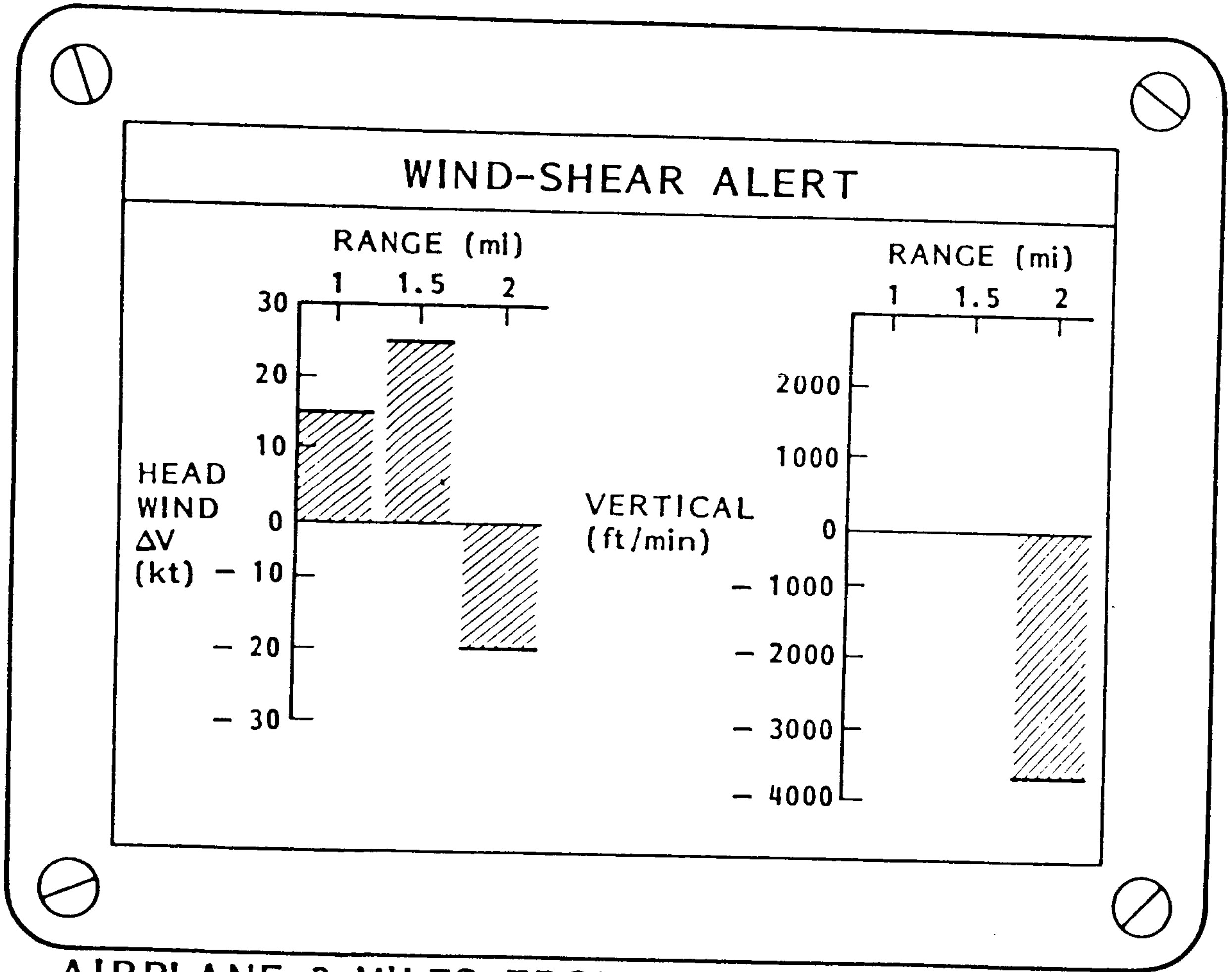

AIRPLANE 2 MILES FROM CORE EDGE
SHOWING HAZARDOUS MICROBURST

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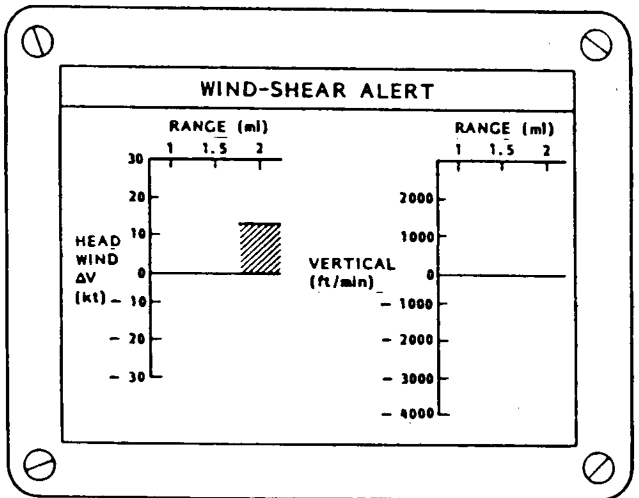
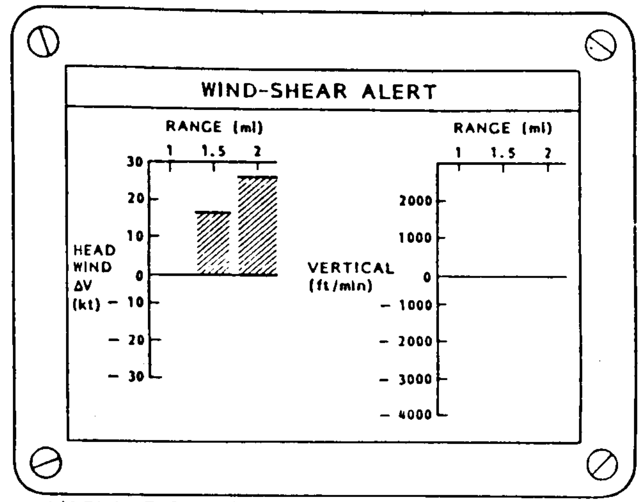
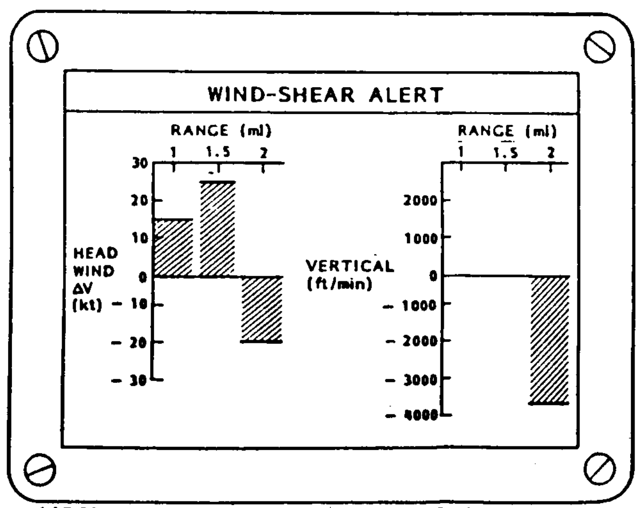
ALTOS DISPLAY FOR APPROACH TO DALLAS/FORT WORTH MICROBURST



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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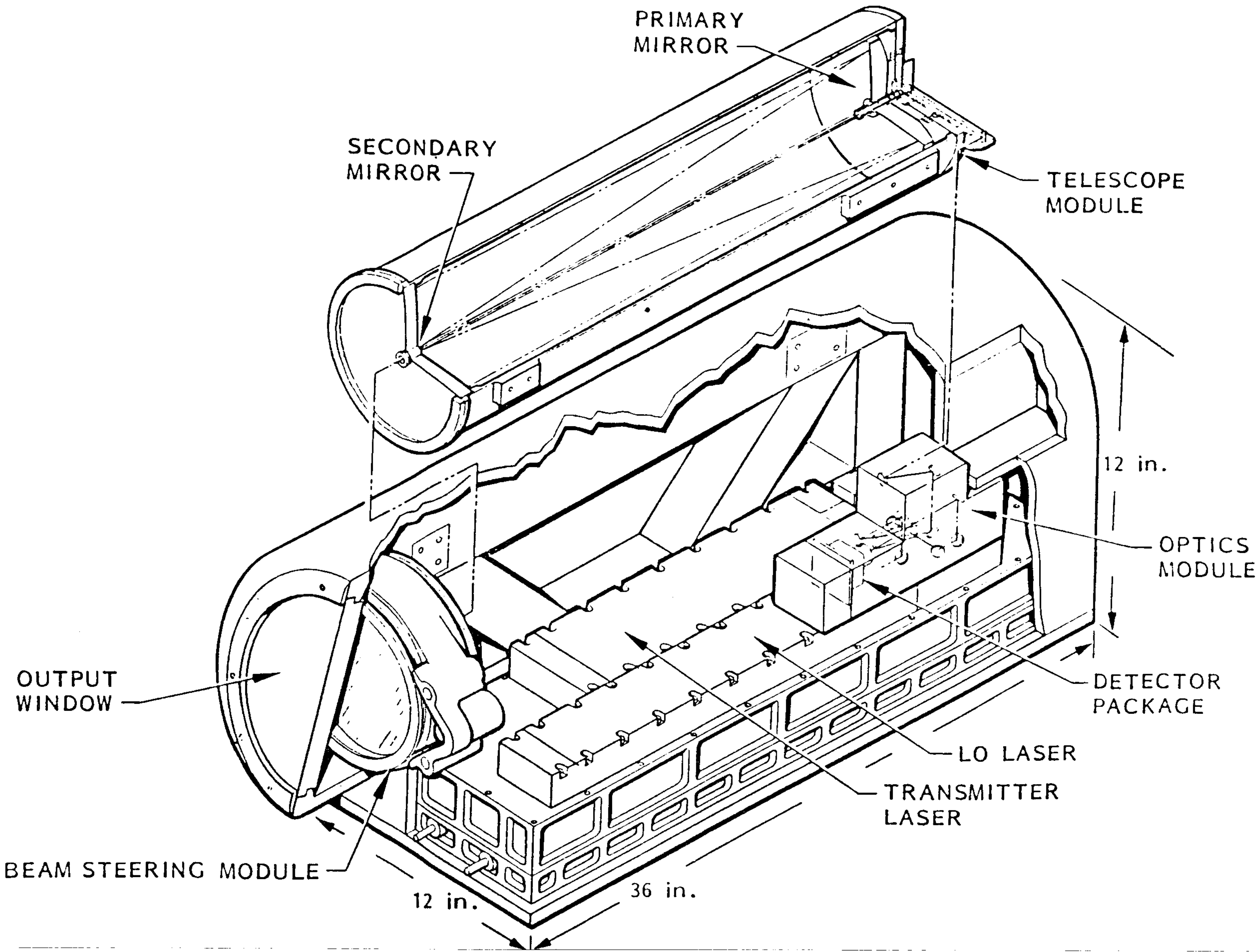
OPTO-MECHANICAL DESIGN



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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.

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OCTOBER 7–8, 1987
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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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