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Session VIII. Airborne LIDAR

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NASA Langley / Lockheed Research Status
Russel Targ, Lockheed

RD&D

Lockheed
LMSC-F415048

CLASS

COHERENT LIDAR AIRBORNE SHEAR SENSOR

WINDSHEAR AVOIDANCE

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Prepared by

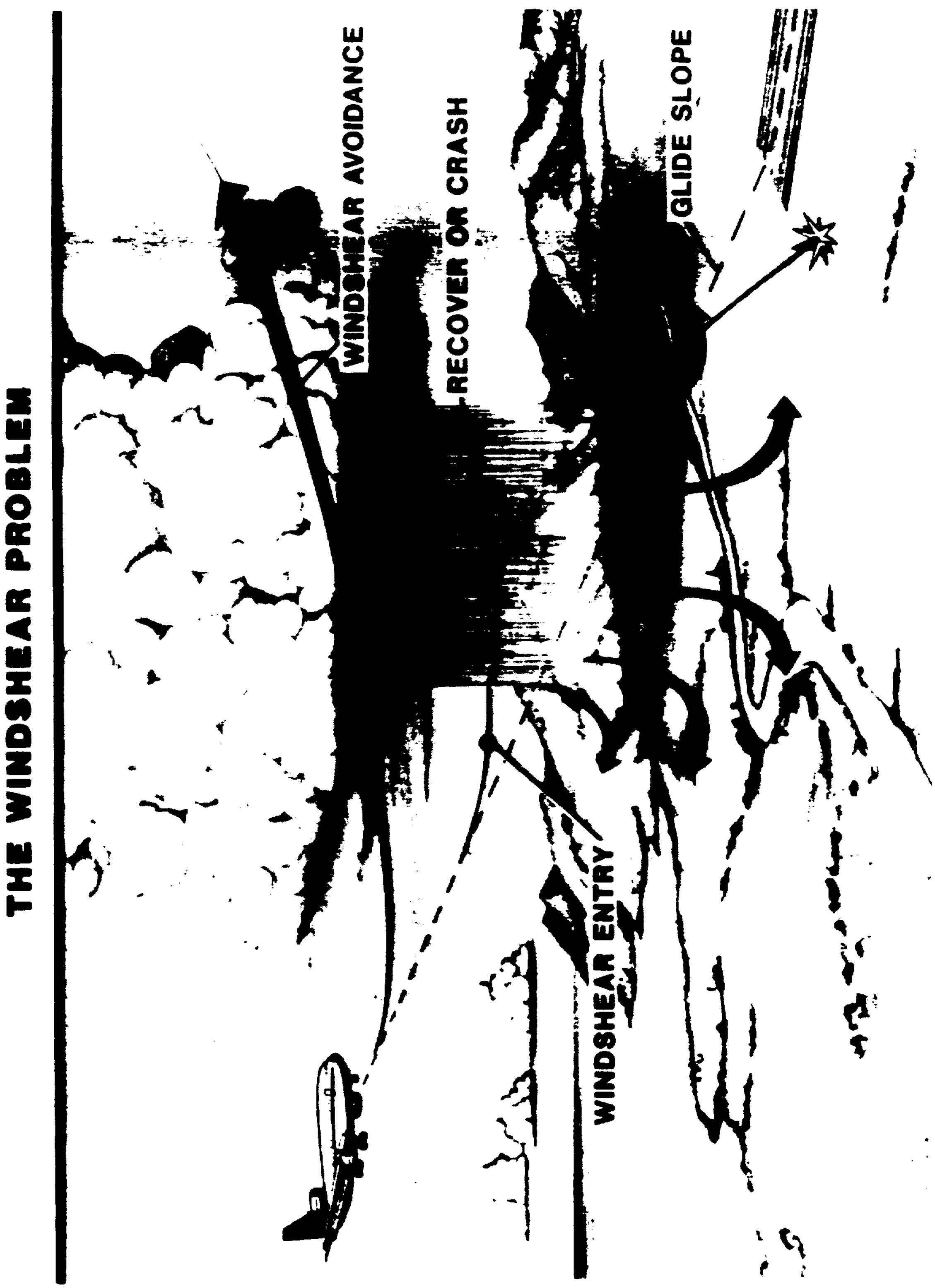
RUSSELL TARG

Electro-Optical Sciences Directorate
Research & Development Division
LOCKHEED MISSILES & SPACE COMPANY, INC.
3251 Hanover Street
Palo Alto, California 94304

THE CLASS PROGRAM

The coherent lidar airborne shear sensor (CLASS) is an airborne CO_2 lidar system being designed and developed by Lockheed Missiles & Space Company, Inc. (LMSC) under contract to NASA Langley Research Center. The goal of this program is to develop a system with a 2- to 4-kilometer range that will provide a warning time of 20 to 40 seconds, so that the pilot can avoid the hazards of low-altitude windshear under all weather conditions. It is a predictive system, which will warn the pilot at time T about a hazard that the aircraft will experience at some later time, $T + \tau$. The ability of the system to provide predictive warnings of clear-air turbulence will also be evaluated.

In order to validate the performance of CLASS, LMSC, together with NASA Langley Research Center, will conduct a 1-year flight-evaluation program. In this program, we will measure the line-of-sight wind velocity from a wide variety of windfields. Measurements made by airborne lidar will be compared with measurements of the same windfields obtained by an airborne radar, an accelerometer-based reactive wind-sensing system, and a ground-based Doppler radar. The success of the airborne lidar system will be determined by its correlation with the windfield as indicated by the onboard reactive system, which indicates the winds actually experienced by the NASA Boeing 737 aircraft.


THE WINDSHEAR PROBLEM
WINDSHEAR AVOIDANCE
RECOVER OR CRASH
GLIDE SLOPE
WINDSHEAR ENTRY

RDD

AIRBORNE WINDSHEAR DETECTION: GENERAL REQUIREMENTS

Lockheed

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

TECHNICAL REQUIREMENTS

The pilot should have as much time as possible to make an informed decision as to whether he will land or go around. If we consider an approach velocity of 100 meters per second (approximately 200 miles per hour), then a 3-kilometer look-ahead range will give the pilot a 30-second warning of a windshear hazard ahead. From our conversations with airline and military pilots, it appears that 30 seconds is an optimum warning time. A longer time is not appropriate since windshear formation is dynamic and changes on a time scale of about 30 seconds. Lockheed has designed the Coherent Lidar Airborne Shear Sensor (CLASS) to meet these requirements.

The CLASS system can give the pilot information about the windshear threat from his present position, extending 3 kilometers ahead. This can be conveniently accomplished by measuring and displaying ten 300-meter segments of the flight path.

To make a land/no-land decision, it is sufficient to measure wind velocity to an accuracy of 1 meter per second (approximately 2 miles per hour). The CLASS flight computers will continuously update the windshear display and alert the pilot by auditory signals if there is a windshear hazard. CLASS does not require the pilot to monitor the sensing equipment or display.

Sensing Range	**2 to 4 km or more**
Range Resolution	**0.3 km**
Velocity Resolution	**approximately 1 m/s**
Advance Warning Time	**20 to 40 s**

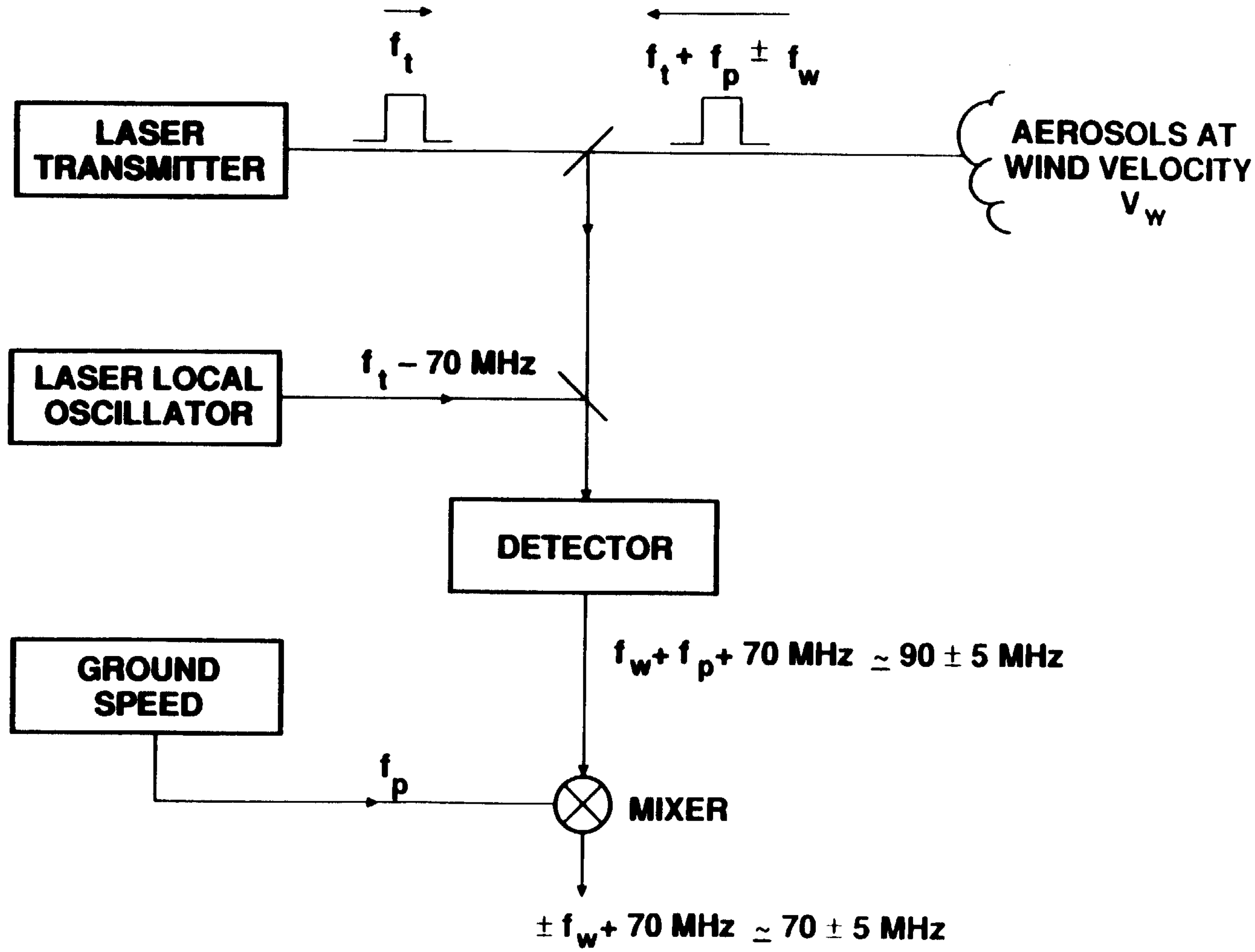
R&DD

SYSTEMS SPECIFICATIONS RATIONALE

Lockheed

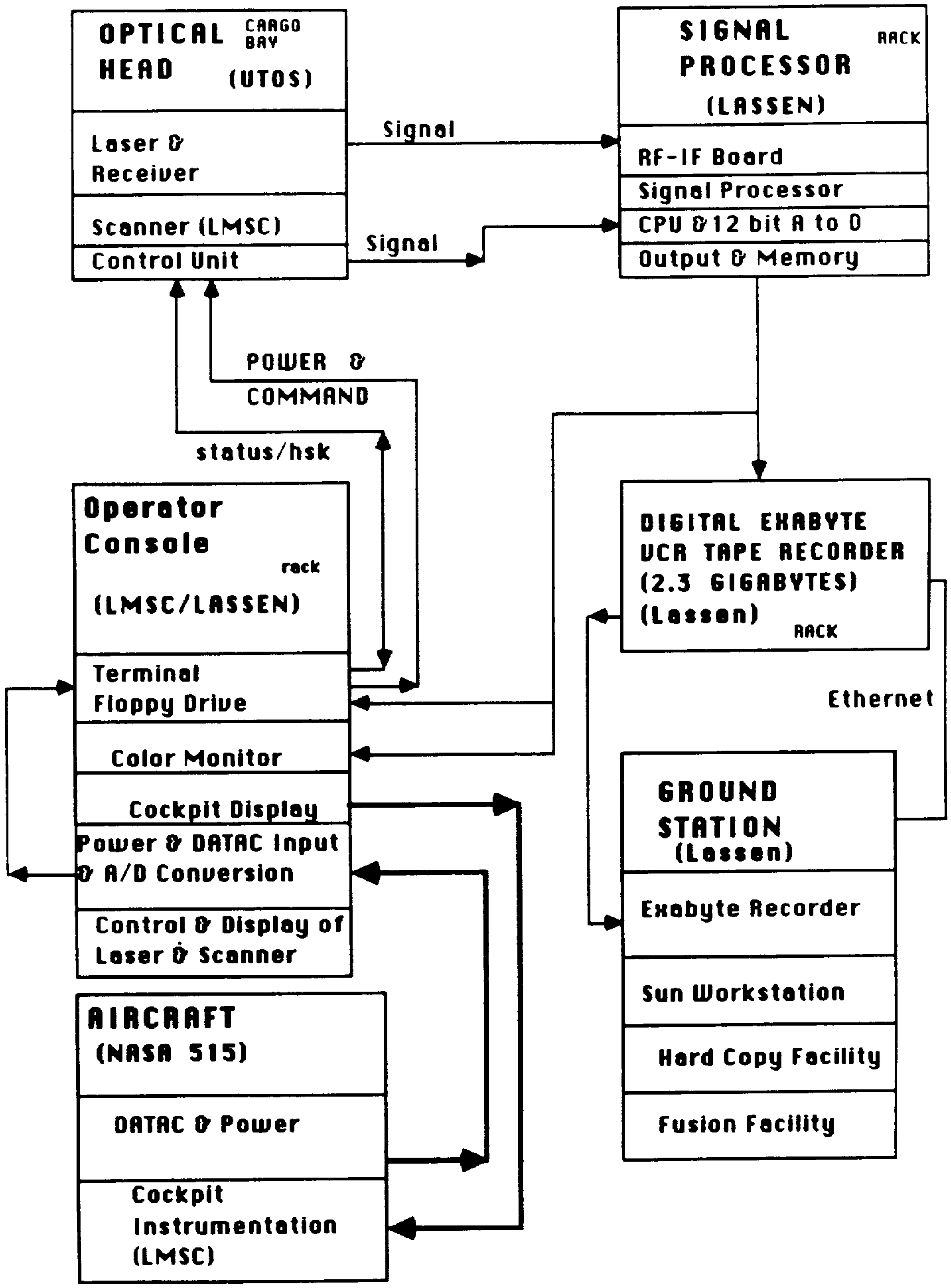
DESIGN ELEMENT	SELECTION	REASON
WAVELENGTH	10.6 μm	EYE SAFETY/MATURITY
LASER TYPE	RF-WAVEGUIDE	RELIABILITY
PULSE ENERGY	10 mJ	4 km RANGE
PULSE DURATION	2 μs	300 m RES./<1 m/s VELOCITY ERROR
PULSE REPETITION RATE	100 Hz	COVERAGE/PULSE AVERAGING
DETECTOR	PV HgCdTe	QUANTUM NOISE LIMITED PERFORMANCE
COOLING	LIN. MECH. REFRIG.	NO EXPENDABLES
TELESCOPE DIAMETER	15 cm	APPROPRIATE FOR 4-km RANGE
TELESCOPE TYPE	OFF-AXIS PARABOLOID	COST
SCANNING CAPABILITY	50° NOMINAL	MICROBURST GEOMETRY
SIGNAL PROCESSOR	POLY-PULSE PAIR	EXPERIMENTAL FLEXIBILITY
LASER LIFETIME	>2000 h	DEMONSTRATE OPERATIONAL PERFORMANCE

DOPPLER WIND VELOCITY MEASUREMENT

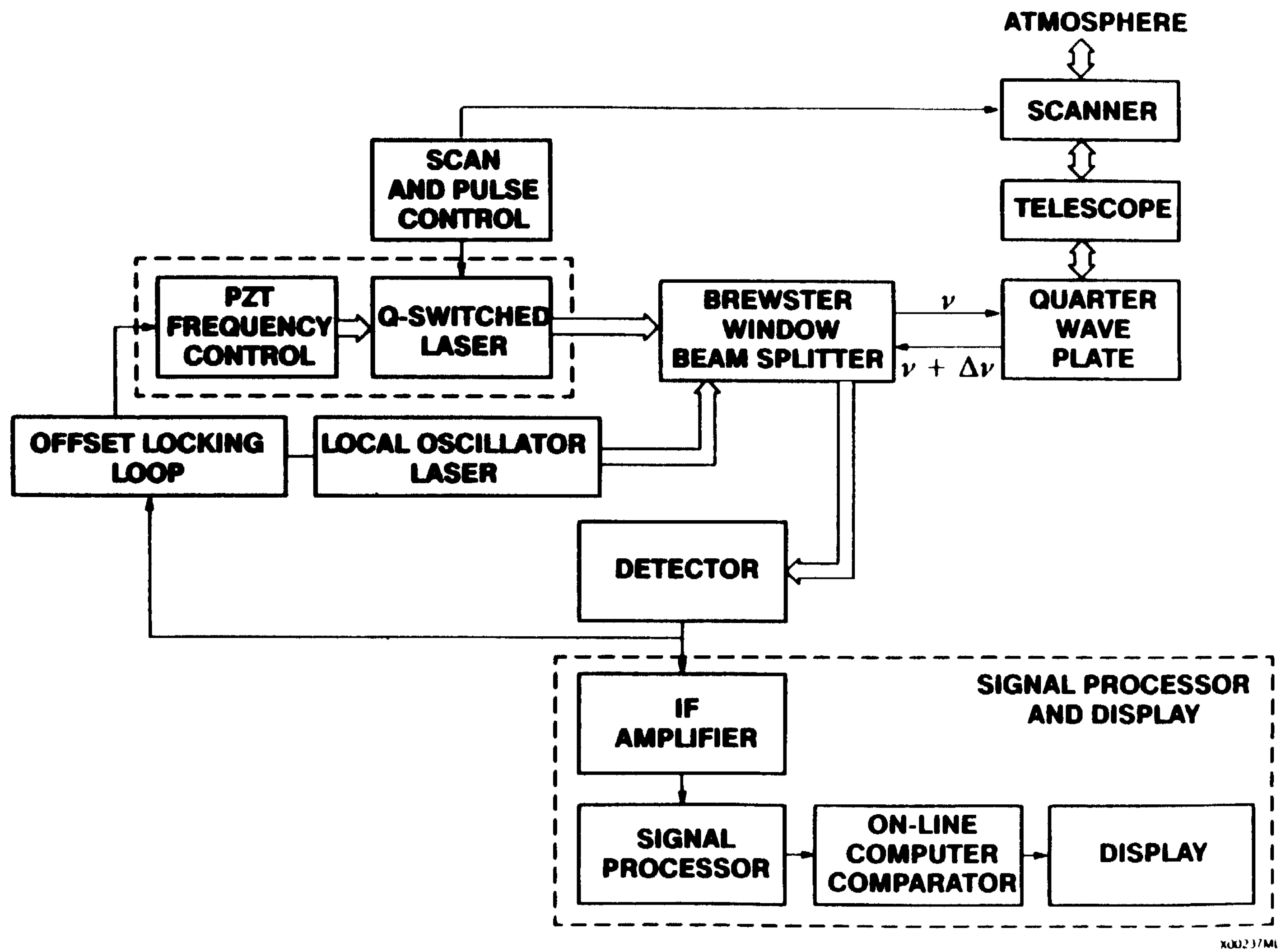


X00047/001PGM

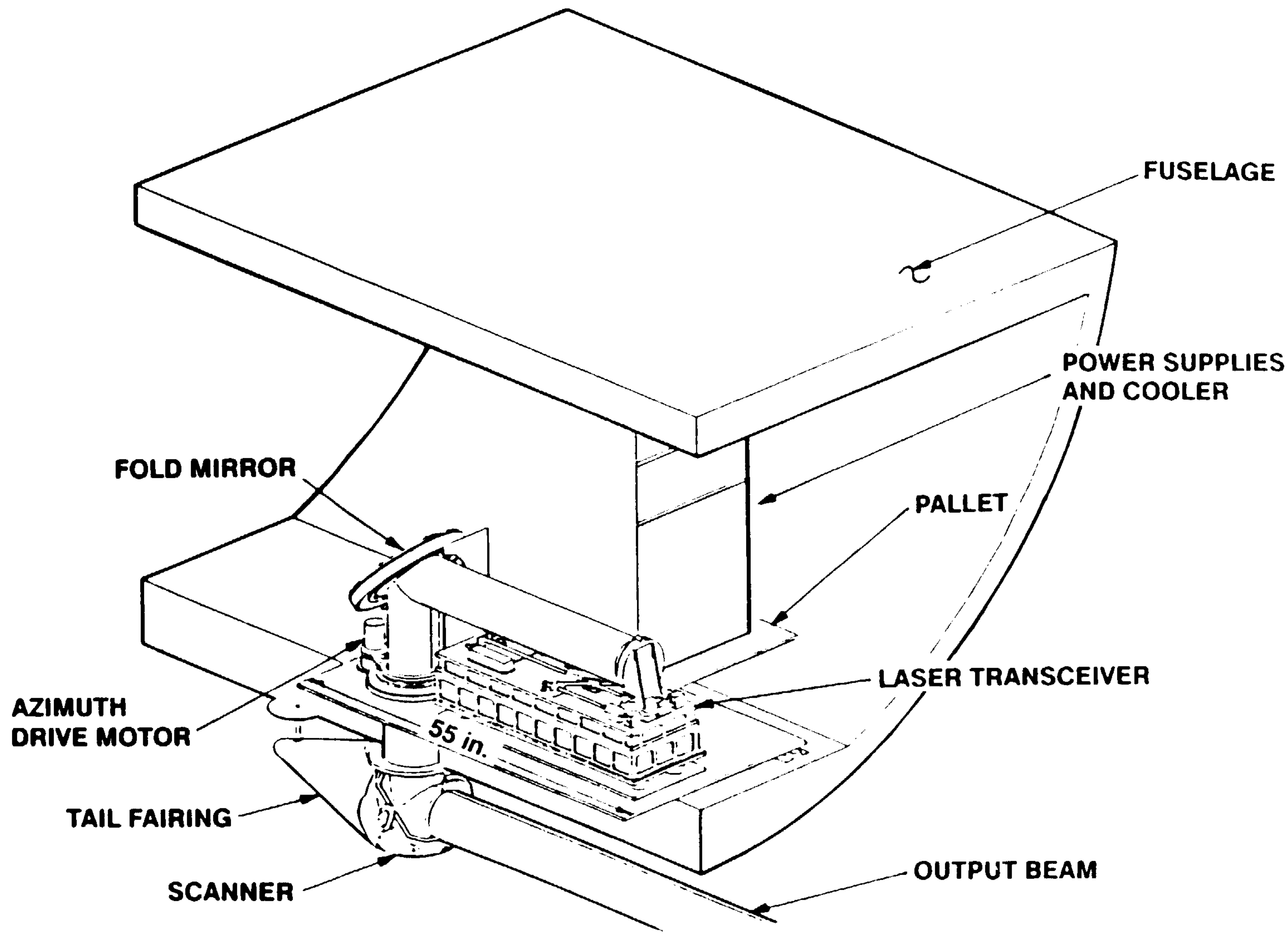
CLASS LASER WINDSHEAR DETECTOR BLOCK DIAGRAM



BLOCK DIAGRAM USING PULSED LASER

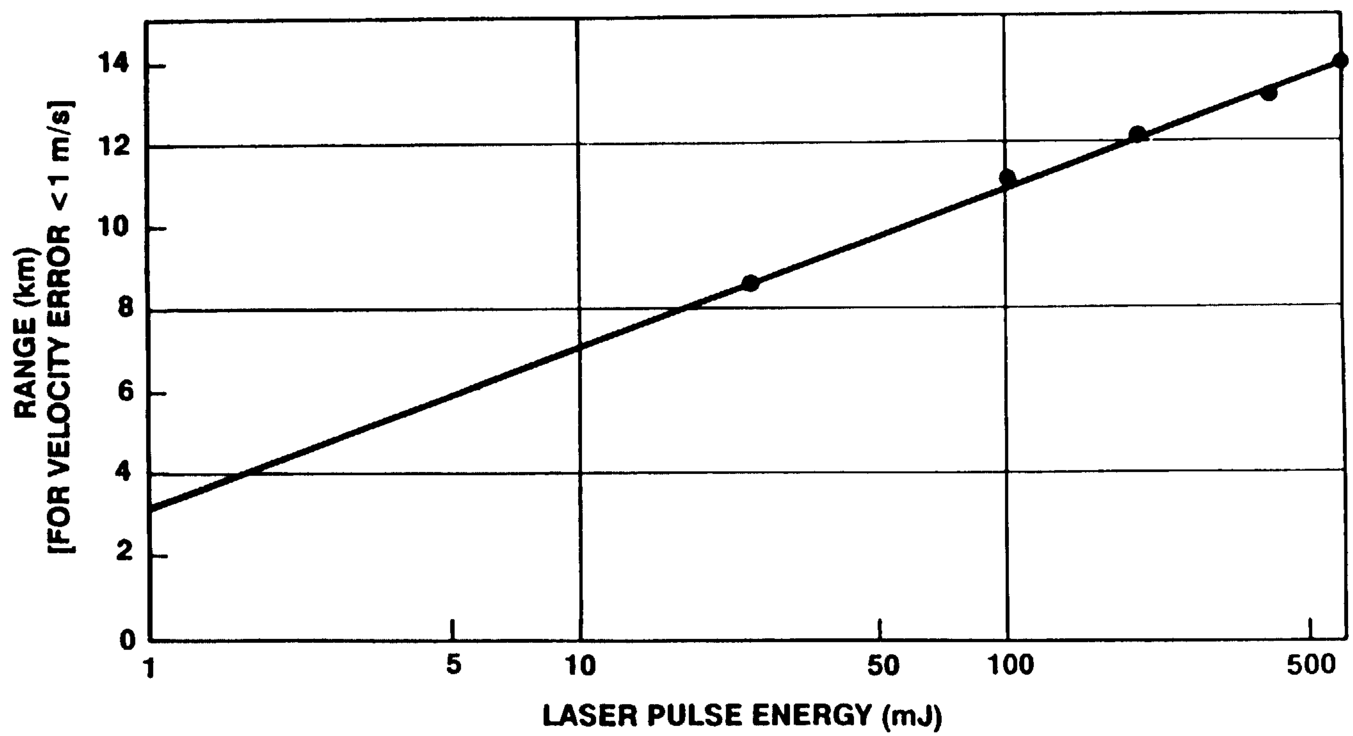


CLASS MECHANICAL DESIGN SYSTEM SOLID MODEL

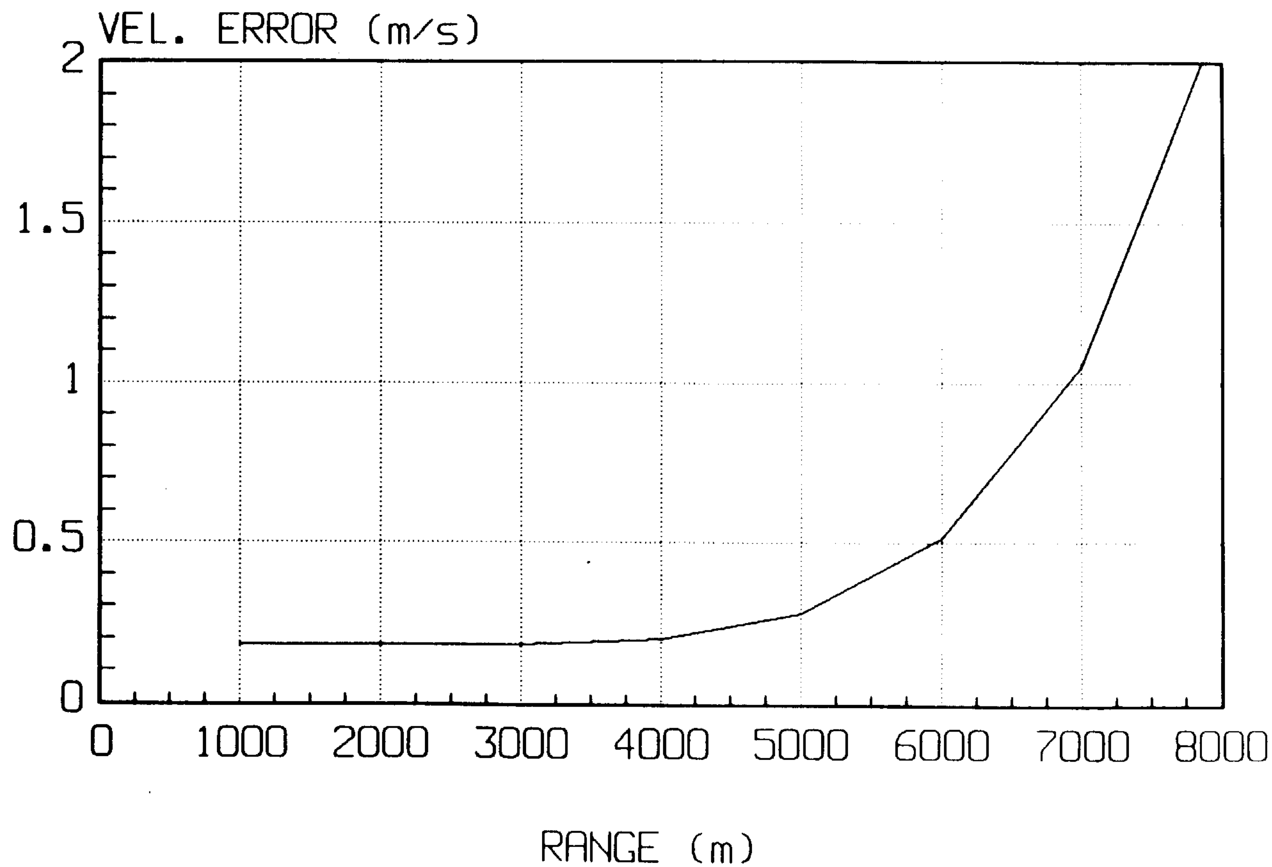


MAXIMUM RANGE VERSUS PULSE ENERGY NOAA LIDAR MEASURED MAY 24, 1990

3-PULSE AVERAGE, 10.6-μm LIDAR 0.9-deg ELEVATION ANGLE



VELOCITY ERROR VS. RANGE
10 MICRON, CLASS LIDAR, 10 mJ
15 cm MIRROR, 1 dB/km EXTINCTION



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RANGE-AZIMUTH DISPLAY FOR A 30-KNOT "DRY" DENVER/STAPLETON MICROBURST, ILLUMINATED BY A 5-mJ CO_2 LIDAR 4 km FROM THE MICROBURST CORE

Lockheed

a. RADIAL WIND VELOCITY CONTOURS

RADIAL VELOCITY (m/s)

< -13
-13 < -11
-11 < -9
-9 < -7
-7 < -5
-5 < -3
-3 < -1
-1 < 1
1 < 3
3 < 5
5 < 7
7 < 9
9 < 11
11 < 13
> 13

b. HAZARD INDEX

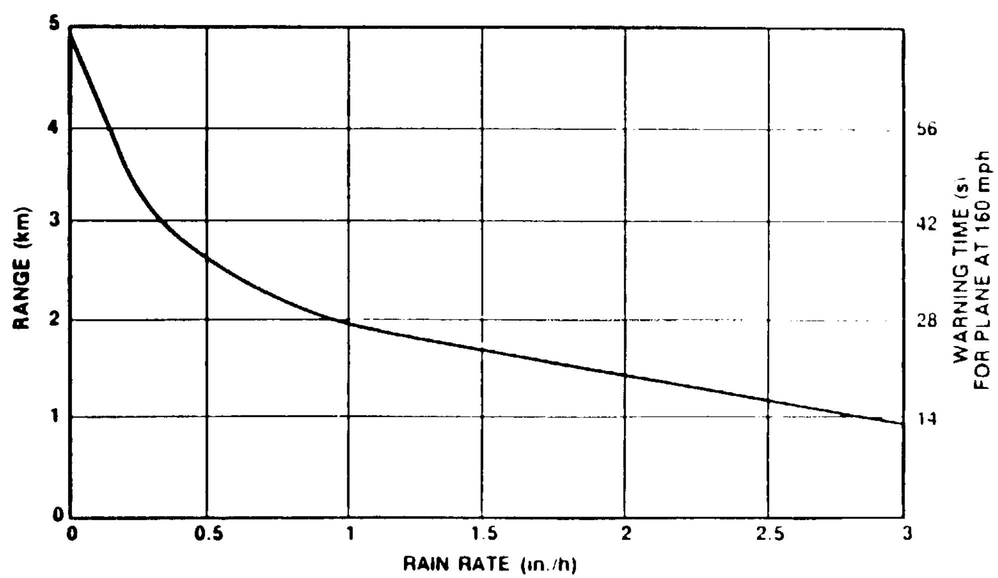
(RED = HAZARD INDEX (F-FACTOR) > 0.1)

HAZARD INDEX F (measured)

F > 0.13
0.11 < F <= 0.13
0.09 < F <= 0.11
0.07 < F <= 0.09
0.05 < F <= 0.07
0.03 < F <= 0.05
0.01 < F <= 0.03
-0.01 < F <= 0.01
-0.03 < F <= -0.01
-0.05 < F <= -0.03
-0.07 < F <= -0.05
-0.09 < F <= -0.07
-0.11 < F <= -0.09
-0.13 < F <= -0.11
-0.13 <= F

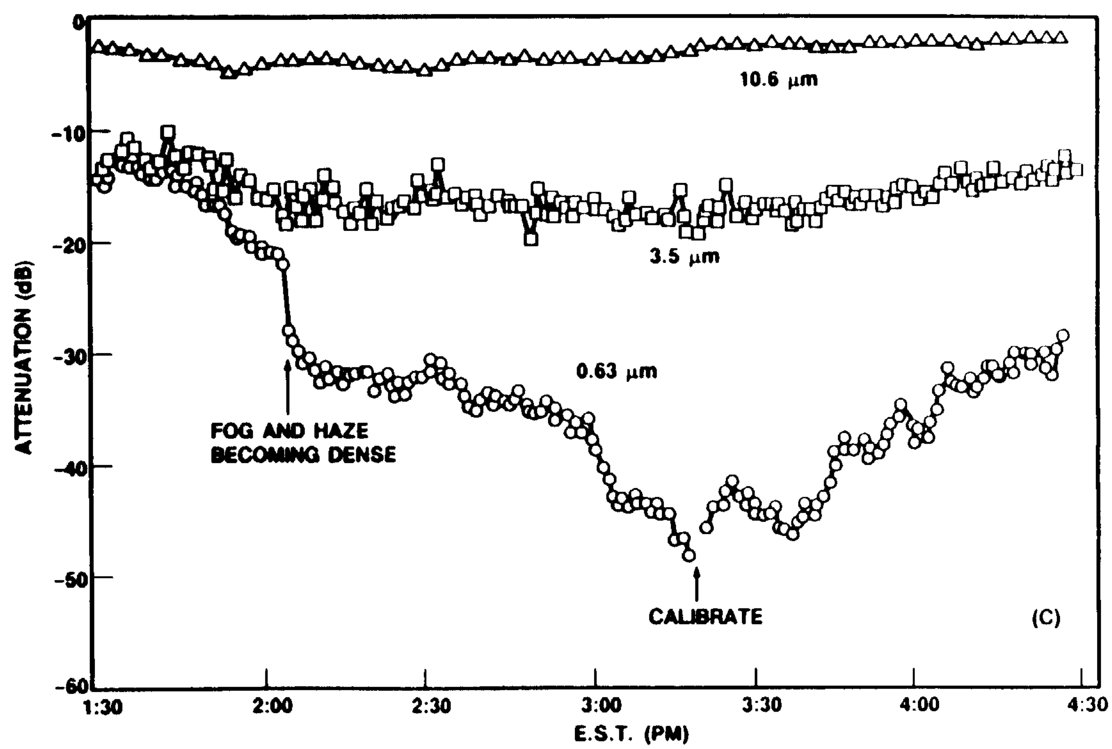
RANGE IN RAIN OF A 10.6-μm SYSTEM WITH A 10-mJ CO_2 LIDAR

It is well known that the 10.6-micron radiation from CO_2 lasers is attenuated by rain, and that will limit the usefulness of such systems in conditions of heavy rain. A systems analysis of an integrated windshear detection and avoidance system will take this into account. The figure shows the effects of rain on range, and indicates that a 10-millijoule CO_2 lidar is able to penetrate rain of moderate levels for a sufficient distance to give a warning of 10 to 20 seconds to a pilot flying into a potentially dangerous situation.



ATTENUATION DUE TO FOG

The data shown here illustrate the measured attenuation experienced by lasers of three different wavelengths. The critical fact to notice is that as the fog increases in density to the point where the red laser, with a 0.63-μm wavelength, is attenuated by more than 40 decibels, the CO_2 laser, at 10.6-μm wavelength, has less than 3-decibel loss.



NASA Langley / Lockheed Research Status - Questions and Answers

Q: JAMES MEGAS (Northwest Air Lines) - What do you feel the cost of an operational coherent pulsed LIDAR would be? What are the trade offs that you feel could be made to reduce the cost?

A: RUSSEL TARG (Lockheed) - The price will be negotiated between our assessment of what it takes to make it and what the airlines find a conceivably acceptable price. I think that's probably the way the price of everything is determined. From our initial inquiries, what it appears is that there's a minimum price under which we think it can't be made and a maximum price above which the airlines wouldn't conceivably pay. We will price this thing some place within there assuming that that's possible. To be serious, for the thing to be ready to be installed into an airplane, it has to be manufactured and installed for about $100,000 or less. That's going to be a high price for the airlines and a challenging price for the manufacturer. At that price it seems to cause equal pain for everybody so it's probably the right price. The big systems that go into the airborne LIDAR are the laser, the photo detector, the scanner and the signal processor. We're going to have to take appropriately big bites out of each of those systems in accordance with what they presently cost to produce. Consequently, in order to even think about putting a LIDAR system into an airplane, the price of the laser has to be greatly reduced from the one of a kind system that we're presently using. We're so late in the day I think this is probably not a good time to go into the kinds of trades that we would do. I can say that choosing between a CO_2 system and a 2 micron system is not a big effect in the ultimate price of the system. There are several different components which I enumerated before in addition to the electronics to hold them all together. So I think that a 100k target is what we'll be looking at and that will be a challenge for any manufacturer in my opinion.

Q: BRUCE MATTHEWS (Westinghouse) - What are the impacts on range and performance of things other than rain? (Rain was already addressed). What are the impacts from fog, dust, smog and other aerosols?

A: RUSSEL TARG (Lockheed) - For the ten micron system the impact of fog is minimal. There have been experiments at Bell Labs measuring the performance of a lighthouse system in fog such as would attenuate a visible beam by 10^5 attenuation and the attenuation for the fog was essentially nil. So I would say that although you could create a fog situation presumably, and I have not seen more detailed data than Bell Labs had, but fog is not a significant problem for the 10 micron LIDAR system. Somebody else is going to have to comment about the 2 micron because I'm ignorant of that. Dirt and dust in the air enhances a performance of all the LIDAR systems so all things being equal this system will work better in Los Angeles than it would in Boulder. Dirty air is a friend of the CO_2 system.

Q: JOE YOUSSEFI (Honeywell) - Will the landing gear be in the way? Will it be a problem for the LIDAR as installed on the NASA aircraft? Are you going to compensate for aircraft attitude, pitch and roll?

A: RUSSEL TARG (Lockheed) - Yes, the landing gear will be a problem, it's right in our field of view. Luckily during the experimental phase of the program we're always going to conduct our experiment wheels up. So during the course of the experiment the landing gear will not be a problem. Presumably on a commercial aircraft we will be located up front, forward of the landing gear, so our scan will not be interfered with by landing gear. And the answer to the second question is affirmative. We will compensate for pitch and roll in real time as the information is given to us by the DATAC. Our two axis ball scanner is all programmed and has the capability to compensate for pitch and roll.

Q: ED LOCKE (Thermo Electron Technologies) - What's the frequency stability of the CO_2 laser?

A: RUSSEL TARG (Lockheed) - It is 200 kilohertz, which is just what you would require in order to maintain the measurement capability that we're looking for which is a meter per second.

Q: TERRY ZWEIFEL (Honeywell Sperry) - Do you anticipate any problems with the optical alignment with the wild temperature swings the airplane might see in G loadings during landing and stuff? Is that going to be a problem?

A: RUSSEL TARG (Lockheed) - The laser that we're building is actively frequency stabilized and is bolted down to a very rugged frame which I showed in the illustration. It's also actively water cooled to provide additional frequency stabilization. I don't anticipate any temperature fluctuations to cause a problem for the system. It's built so that it has a very high frequency loop, that is, we're feeding back at greater than a kilohertz rate so we think that any motion of the airplane will be very small indeed compared to the speed of the feed back loop controlling the laser frequency stability.

ROLAND BOWLES (NASA Langley) - That airplane is carrying so much equipment that we are really having some air conditioner burdens on it. That system will be basically cabin ambient down there and we may very well bit the bullet on that airplane and really upgrade the air conditioning system on it. You must remember, we're not building product runs for consumption in a civil system. The NASA role in this program is to prove the feasibility of the technology. We leave it to you airlines and manufacturers to work out the market place dynamics.