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NASA/LMSC Coherent LIDAR Airborne Shear Sensor: System Capabilities and Flight Test Plans

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Overall Objectives of the Flight Tests

The primary objective of the NASA/LMSC[1] Coherent Lidar Airborne Shear Sensor (CLASS) system flight tests is to evaluate the capability of an airborne coherent lidar system to detect, measure, and predict hazardous wind shear ahead of the aircraft with a view to warning flight crew of any impending dangers. On NASA's Boeing 737 Transport Systems Research Vehicle, the CLASS system will be used to measure wind velocity fields and, by incorporating such measurements with real-time aircraft state parameters, identify regions of wind shear that may be detrimental to the aircraft's performance. Assessment is to be made through actual wind shear encounters in flight.

Wind shear measurements made by the CLASS system will be compared to those made by the aircraft's in situ wind shear detection system as well as by ground-based Terminal Doppler Weather Radar (TDWR) and airborne Doppler radar. By examining the aircraft performance loss (or gain) due to wind shear that the lidar predicts with that actually experienced by the aircraft, the performance of the CLASS system as a predictive wind shear detector will be assessed.

The CLASS System

Definition

The CLASS system is required to measure wind shear ahead of an aircraft and relate that measurement to the effect on the aircraft's performance. In addition the system must be

[1]National Aeronautics and Space Administration/Lockheed Missiles and Space Co.

able to combine these measurements with current aircraft state parameters to predict the effect on aircraft performance.

The CLASS system comprises a CO_2 laser radiating with a pulse energy of 10 mJ at a wavelength of 10.6 μm and pulse length of 2 μs, and employing optical heterodyne detection. The range resolution is 300 m, and the velocity error is required to be less than 1 m/s. The range can extend to 10 km (depending on aerosol size and density conditions), and the scan can be centered ±90° about the aircraft nose with an azimuth sweep of up to ±50°. Velocity estimation uses a poly-pulse pair algorithm (Reference 1). The system is described in detail in Reference 2.

The capability to read data tapes recorded in flight and reproduce all events seen in flight is available on a ground-based workstation. Reprocessing of the data in order to assess alternate calculation algorithms is also possible.

Measurement Capabilities and Wind Shear Products

This section describes how the CLASS system uses wind velocities measured by the coherent lidar, and produces a higher level wind shear detection product quantifying the effect of the wind field on the aircraft's performance.

The high level measurements of interest made by the system are Doppler return intensities and line-of-sight wind velocities. The relation between the wind shear and the aircraft's performance is given by the F-factor, F, (Reference 3)

$$F = \frac{\underline{\dot{W}}_I \cdot \underline{\hat{e}}_a}{g} + \frac{W_z^I}{V_a}$$

The first term is the time rate of change of the inertial wind vector along and in the direction of the airspeed vector, and the second term is the ratio of the inertial vertical wind speed to the airspeed. Forward looking wind shear detectors can measure the wind field at some region ahead of an aircraft and calculate an F-factor as follows.

Doppler return frequencies are processed to provide velocities at 300 m intervals (Δr). The processing of the return signals to yield velocities is described in Reference 1. The first term in the F-factor (the 'horizontal' term, F_h) may be approximated by differencing wind velocities, v, along a lidar measurement radial. The value at the *i*th range bin is given by

$$F_{h_i} = \frac{v_{i+2} - v_i}{2\Delta r}\frac{V_G}{g}$$

The differencing scheme arises from using an unweighted least-squares fit over three range bins (Reference 4). If required the velocities may be weighted in order to reduce the effect of spurious velocity returns. The computed F_{h_i} is that which the aircraft would experience if it flew along the measurement radial through the hazard at the aircraft's ground speed (V_G) at the time of measurement.

The second term in the F-factor is introduced by implementing a simple linear vertical wind estimator (Reference 5), giving the total F-factor at the *i*th range bin as

$$F_i = F_{h_i}\left(1 + \frac{3gh_i}{2V_aV_g}\right) + \left|F_{h_i}\right|\left(\frac{gh_i}{2V_aV_g}\right)$$

As described in Reference 6, the actual threat to an aircraft is based on the average F over approximately 1 kilometer. Therefore the above F-factor is averaged over three range bins (900 meters) giving $\overline{F_i}$ as

$$\overline{F_i} = \frac{F_{i-1} + F_i + F_{i+1}}{3}$$

It has been determined (Reference 6) that a value of $\overline{F_i} \geq 0.105$ represents a threat to the aircraft. The minimum criterion for a hazard region is at least one range bin radially with $\overline{F} \geq 0.105$, as well as another range bin on an adjacent radial contiguous with it, also with $\overline{F} \geq 0.105$(see Figure 1). NASA's flight tests require a representational display of the hazard region on the aircraft's research cockpit navigational display. This system is described in Reference 7 for data produced by the airborne radar system. A similar technique will be used in 1992 for the CLASS system. For this purpose a box is generated with its center at the centroid as the hazard region, and with dimensions proportional to the spatial extent of the measured hazard region.

Interpretation of the Wind Shear Products

The measurements and wind shear products described above will be assessed by several means. By actually penetrating microburst wind shears the predicted location and intensity of the shears may be compared directly with those measured by the aircraft's in situ system, the latter being taken to be the measurement standard. This will allow an appraisal of the CLASS measurement accuracy. The CLASS wind shear measurement can also be corroborated by the independent ground-based wind shear measurement of the Terminal Doppler Weather Radar (TDWR). The aircraft will also be operating an enhanced airborne weather radar (Reference 7). A comparison between the CLASS measurement and this radar's measurement will provide a comparison of the relative merits of radar- and lidar-based forward-looking wind shear detection systems.

Results to Date and Future Goals

To date, flight tests have been carried out to evaluate the overall system performance prior to making actual wind field measurements. The laser has been found to be stable and reliable. The ability of the scanner to point and compensate for aircraft motion has been tested and is currently being assessed. In addition, the performance of the signal processor, computer, and data recording system is under evaluation.

Tests to be carried out include a velocity calibration. This will determine the system's capability to account for the aircraft's motion in making wind velocity measurements.

CLASS performance in obscuring and non-obscuring atmospheric phenomena will also be studied. Examples of obscuring phenomena are rain, fog, and cloud. Typical non-obscuring phenomena are planetary boundary layer shear, gust fronts, and sea-breeze fronts.

The capability of the system to detect and measure actual microburst wind shears will be evaluated this summer (1992) when the TSRV aircraft will penetrate microburst wind shears in Orlando, FL, and Denver, CO.

<u>References</u>

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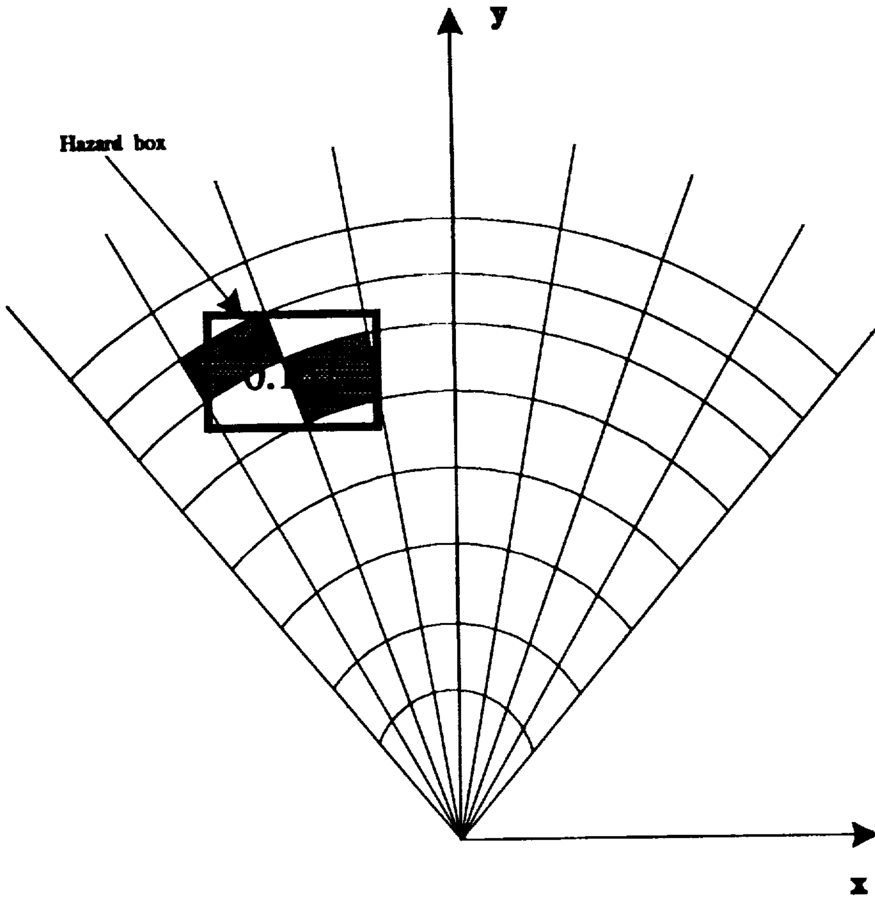

Figure 1: Hazard Region Definition on $\overline{F}$ map.

NASA/LMSC Coherent Lidar Airborne Shear Sensor (CLASS): Flight Test Evaluations

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Fourth Combined Manufacturers' and Technologists' Airborne
Wind Shear Review Meeting
Williamsburg, Va. April 14-16 1992

Objectives of Flight Tests

To evaluate the ability of airborne lidar technology to detect and predict hazardous wind shear ahead of an aircraft with a view to warning flight crew of impending dangers.

System Definition

Requirement

To measure wind shear ahead of the aircraft and relate that measurement to an effect on the aircraft's performance.

- Measure wind shear hazard accurately at least 10 seconds ahead of an aircraft.
- Combine those measurements with aircraft state parameters to assess the effect of any wind shear on the aircraft.

In Flight Measurements

Return Intensities

Line of sight wind velocity

In Flight Products

F-factor

1 Km averaged F-factor ($\bar{F}$)

Hazard regions

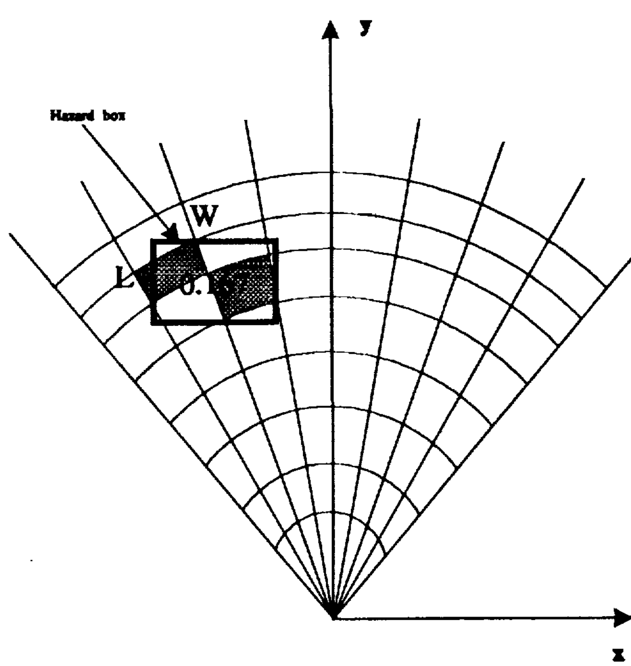
Discrete alerts

Interpretation of Products

Location and intensity of regions of hazardous wind shear.

Comparison with airborne and ground-based radar systems.

Comparison with aircraft's in situ detection system.



Wind Shear Hazard Region Definition

$$\boxed{F = \frac{\underline{W}_l \cdot \hat{\underline{e}}_a}{g} + \frac{Wf}{V_a}}$$

Horizontal: $$F_{II} = \frac{v_{i+2} - v_i}{2\Delta r}\frac{V_g}{g}$$

Total: $$F = F_{II}\left(1 + \frac{3gh}{2V_aV_g}\right) + |F_{II}|\left(\frac{gh}{2V_aV_g}\right)$$

Averaged: $$\overline{F_i} = \frac{F_{i-1} + F_i + F_{i+1}}{3}$$

Current Status

Laser operation and stability.

Scanner stability and positioning accuracy.

Data system operation.

Future Goals

1. Velocity calibration.

2. Investigation of lidar performance in obscuring and non-obscuring weather phenomena.

3. Investigation and assessment of lidar performance in hazardous wind shears.

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System Capabilities and Flight Test Plans
Questions and Answers

Q: Pete Sinclair (Colorado State University) - In calculating the F-factor what errors magnitude do you expect from the technique used to estimate the vertical velocity term?

A: Paul Robinson (Lockheed) - The errors that were studied by Dan Vicroy and presented earlier today where from 0 to 600 meters above ground. The estimation is plus or minus 2.5 meters per second.

Dan Vicroy (NASA Langley) - The results that I presented earlier from the In Situ data showed about 2.5 to 3 meters per second RMS error in computing the vertical winds. We think we can probably do much better than that once we get into some signal processing with the radar data. We will be able to give you a more definitive number after we do the simulation with the asymmetric microburst models. We will have that answer in about two or three months. From our preliminary work, it looks like we can probably do at least 2.5 meters per second.