THE DESIGN OF A NEW AIRBORNE OF A HIGH SPECTRAL RESOLUTION LIDAR.

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ABSTRACT

This paper describes a high spectral resolution lidar designed for operation in the new Gulfstream V research aircraft operated by the National Center for Atmospheric Research(NCAR).

1. A NEW RESEARCH AIRCRAFT

The National Science Foundation has acquired a Gulfstream V aircraft for atmospheric research. This high performance aircraft is operated by the National Center for Atmospheric Research (NCAR) in Boulder, Colorado. It provides the nation with a powerful new tool for environmental studies [1], and [2]. This aircraft is capable of flight to altitudes of greater that 50 k ft and ranges of over 7000 miles while carrying payloads of 2500 kg. It will allow investigators to probe the upper edges of hurricanes and thunderstorms and provide access to the upper troposphere for atmospheric chemistry studies.

This aircraft operates most efficiently at high altitude flying above most of the weather and the utility of the aircraft will be greatly extended equipping it with remote sensing instruments to probe the air column beneath the aircraft.

2. DESIGN FEATURES OF THE AIRBORNE HSRL

The airborne HSRL design is based on the system we constructed for long term operation in the Arctic [3]. Both systems are designed to operate as Internet appliances, and are capable of autonomous operation and self calibration. Both systems are eye safe for direct viewing of the output beam.

Figure 1 – NSF / NCAR Gulfstream V

The HSRL uses an iodine absorption filter to separate molecular and particulate scattering[2]. The laser output wavelength is locked to the center of iodine absorption line #1109[3]. In order to allow locking to a line edge (where it is easy to determine the sign of the correction needed to maintain lock) an offset frequency source is created using Brillouin backscattering from a silica fiber. The Brillouin scattering, which is offset by -31.6 Ghz, lies of edge of line 1105 of the iodine spectrum. Figure 2 shows the iodine absorption spectrum and the position of the Brillouin offset frequency.

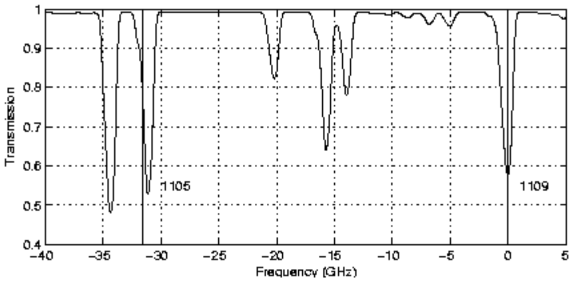

Figure 2--The iodine absorption spectrum. The lidar operates tuned to the center of line 1109. The transmission of Brillouin scattered light through the edge of line 1105 is used to lock the laser wavelength.

An optical schematic of the frequency locking system is shown in figure 3.

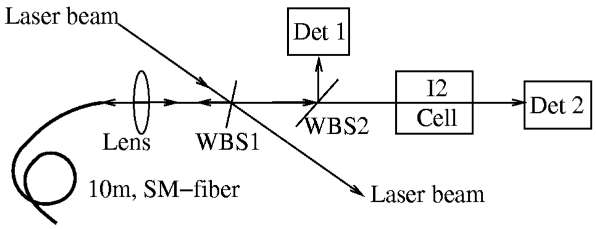

Figure 3--The frequency locking system. A small part of the transmitted laser pulse is reflected from the wedged beam splitter WBS1 and focused on the end of a 10 m silica fiber. Backscattered Brillouin frequency shifted light is directed though a 2 cm absorption cell and the transmission of the cell is monitored by two detectors.

Calibration of the HSRL requires that the frequency bandpass of the receiver must known. This is accomplished by measuring the system transmission as the laser frequency is scanned across the receiver bandpass. An interferometer has been constructed in order to measure the frequency during the scan (figure 3).

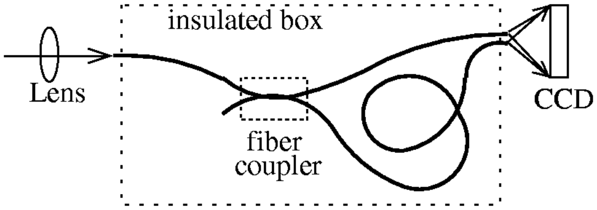

Figure 3--Fiber pinhole interferometer.

Laser light is focused on a fiber. This light is divided into unequal length fibers by a fiber coupler. The output ends of the fibers are epoxied very close together and the light from the fibers projects an interference pattern on the CCD camera. An image capture board provides pictures of the interference pattern to the computer where a Fourier transform is used to track phase shifts in the interference pattern. These are converted to frequency offsets. This system easily provides relative frequency measurements at the MHz level. The interferometer is mounted inside an aluminum block housed in a carefully insulated shell to minimize thermal drifts during the calibration scan.

Table 1--HSRL specifications:

Aperture:	40 cm
Angular field-of-view	45 micro radian
Average power	400 mW
Pulse repetition rate	6 kHz
Wavelength	532 nm
Laser bandwidth	<100 MHz
Detectors	Perkin-Elmer SPCM's Geiger Mode APD's QE ~50%
Sky noise bandwidth	~ 8 GHz
Iodine filter bandwidth	1.8 GHz
Range resolution	7.5 m

Eye safety operation is of the HSRL enabled by use of a micropulse design where low energy laser pulses are transmitted at a high repetition rate and where the transmitted beam is expanded over a large aperture. In order to maintain high signal to noise ratios while using low energy laser pulses in the presence of background sky light the lidar operated with a very small angular field-of-view (45 micro radian) and a small spectral bandpass(8 Ghz). This allows the lidar to operate with very high signal to noise ratios even in the presence of brightly lit clouds. Sky noise suppression is so complete that it is difficult to tell the difference between daytime and night time data. The need to both expand the Gaussian laser beam to a large aperture and to maintain system alignment at a 45 micro radian field-of-view dictates the need for a transceiver design where the laser beam is transmitted through the receiving telescope. Both the Arctic HSRL and the new airborne system use an afocal beam expander for the transceiver.

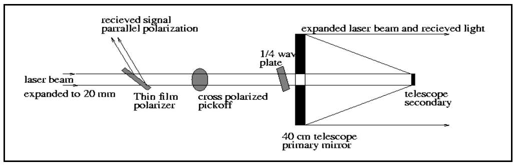

Figure 6—An afocal beam expander expands the transmitted beam from 2 cm to 40 cm. It is used both for the transmitter and receiver. A ¼-wave plate converts the linearly polarized laser beam to circular polarization. On return it converts the polarized part of the received beam to the orthogonal linear polarization so that the thin-film polarizer can direct the beam to the receiver. The cross-beam polarized pickoff is used to measure depolarization.

NCAR plans to install windows in both the floor and ceiling of the Gulfstream aircraft. The HSRL must be configured to operate in either zenith or nadir pointing directions. To accomplish this, the telescope is equipped with a 45-degree turning mirror in front of the primary mirror. This directs the 2 cm collimated beam along the axis of a bearing which allows the telescope to be manually rotated from down-looking to up-looking. This can be accomplished in flight as the aircraft changes altitude. The telescope is aimed 4° off vertical to reduce specular reflection from oriented ice crystals. Airborne operation of the telescope imposes stringent requirements on thermal stability and structural strength.

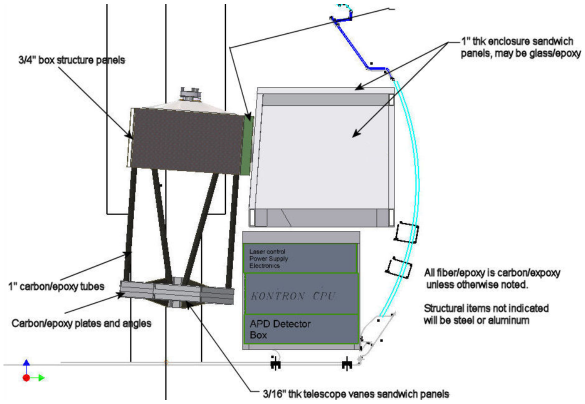

Figure 7—Lidar position in aircraft

The telescope must maintain near diffraction limited performance in the presence of large temperature changes. In addition, the structure must have the strength to withstand FAA mandated standards for crash loadings. The optical design of the lidar was accomplished using an end-to-end model of the optics. This included a detailed simulation of the projected laser beam pattern as a function of distance from the lidar and the influence of primary mirror imperfections on the beam distribution. Figure 8 shows the configuration used to determine the effect of telescope aberrations on system performance (figure 9).

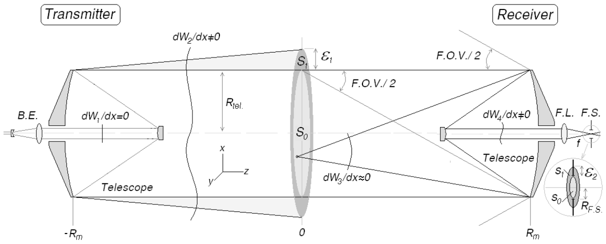

Figure 8--For the purpose of modeling the transceiver was separated into a transmitting and a receiving telescope. Wavefront aberrations dW/dx were then introduced to model the energy distribution at the focal plane caused by defects in the telescope.

The Zemax model was used to determine mechanical and optical tolerances for all components of the system. Based on this we selected a Dall-Kirkham telescope design with a center hub-mounted f/2 primary mirror constructed of Zerodur with a surface accuracy of 1/8 lambda specified at 632 nm. The back of the primary was thinned towards the edges in a single-arch design to reduce weight. Our optical model showed that the primary to secondary separation distance was critical and must be maintained to within 10 microns.

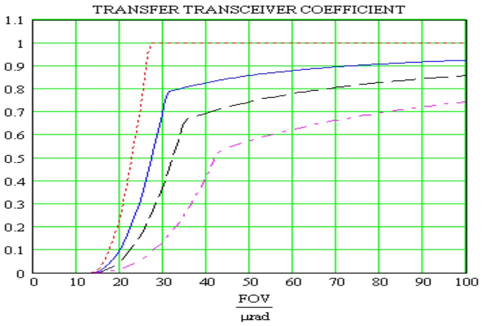

Figure 9--Transceiver efficiency as a function of field-of-view and primary mirror surface accuracy

determined from the aberration model(top curve ideal mirror, 1/8, 1/4, ½ lambda).

The telescope mechanical structure was designed using finite element analysis (figure 10). The design uses graphite-epoxy construction to provide thermal stability, light weight and high strength. The truss is composed of graphite-epoxy tubes. Structural panels are built up with graphite-epoxy skins over fire resistant foam cores while the fillets and the central hubs are machined from G10 fiberglass. Finite element analysis was used to tune the vibrational response of the structure to eliminate resonances at frequencies which might be excited by aircraft noise.

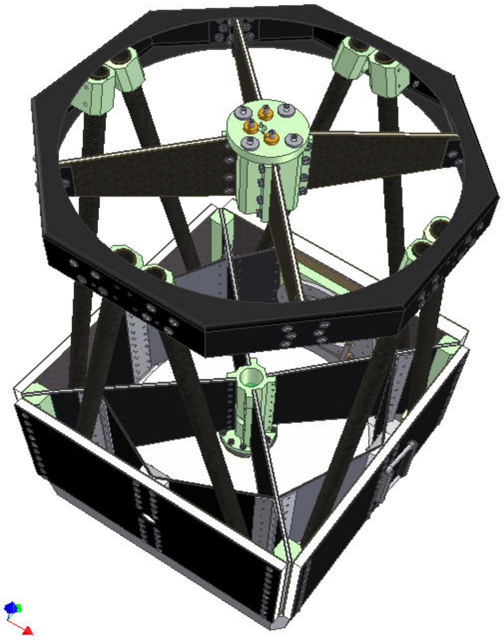

Figure 10—The HSRL telescope.

Figure 11 shows a picture of the completed telescope along with images of a single-mode fiber source a distance of 60 m. These point spread function images were obtained using a 100X microscope objective and show how the image changes with defocus. This artificial star test was one of the tests used to verify that the telescope meets the HSRL optical requirements.

Figure 12 shows the transmitter section of the HSRL optical bench on the left and the receiver section on the right.

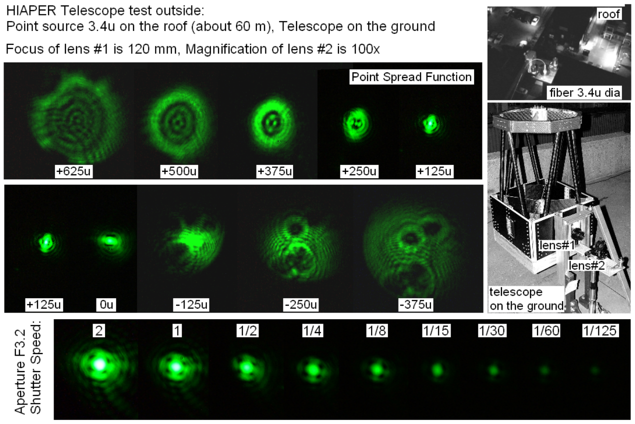

Figure 11—Artificial star test of telescope using a single mode fiber source a distance of 60 m.

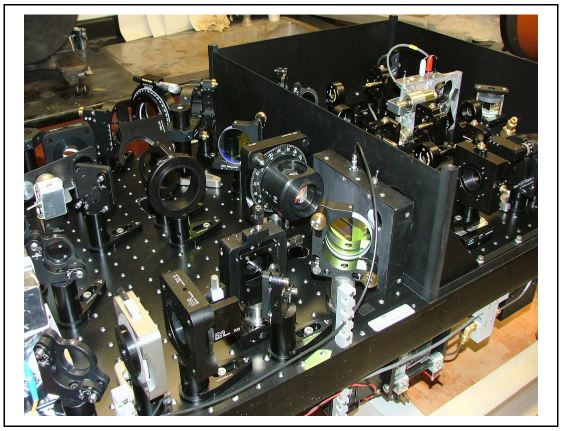

Figure 12—HSRL optical bench

2. ACKNOWLEDGMENTS

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