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LASER CALIBRATION EXPERIMENT FOR SMALL OBJECTS IN SPACE

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ABSTRACT

The Air Force Research Laboratory/Directed Energy Directorate (AFRL/DE) and NASA/Marshall Space Flight Center (MSFC) are looking at a series of joint laser space calibration experiments using the 12J 15Hz CO_2 HIgh Performance CO_2 Ladar Surveillance Sensor (HI-CLASS) system on the 3.67 meter aperture Advanced Electro-Optics System (AEOS). The objectives of these experiments are to provide accurate range and signature measurements of calibration spheres, demonstrate high resolution tracking capability of small objects, and support NASA in technology development and tracking projects. Ancillary benefits include calibrating radar and optical sites, completing satellite conjunction analyses, supporting orbital perturbations analyses, and comparing radar and optical signatures. In the first experiment, a Global Positioning System (GPS)/laser beacon instrumented micro-satellite about 25 cm in diameter will be deployed from a Space Shuttle Hitchhiker canister or other suitable launch means. Orbiting in low earth orbit, the micro-satellite will pass over AEOS on the average of two times per 24-hour period. An onboard orbit propagator will activate the GPS unit and a visible laser beacon at the appropriate times. The HI-CLASS/AEOS system will detect the micro-satellite as it rises above the horizon, using GPS-generated acquisition vectors. The visible laser beacon will be used to fine-tune the tracking parameters for continuous ladar data measurements throughout the pass. This operational approach should maximize visibility to the ground-based laser while allowing battery life to be conserved, thus extending the lifetime of the satellite. GPS data will be transmitted to the ground providing independent location information for the micro-satellite down to sub-meter accuracies.

Keywords: ladar, HI-CLASS, Space Shuttle, calibration, micro-satellites, Advanced Electro-Optical System, GPS

1. INTRODUCTION

The Air Force Research Laboratory/Directed Energy Directorate (AFRL/DE) and NASA/Marshall Space Flight Center (MSFC) are looking at a series of joint laser space calibration experiments using the 12J 15Hz CO_2 HIgh Performance CO_2 Ladar Surveillance Sensor (HI-CLASS) system on the 3.67 meter aperture Advanced Electro-Optics System (AEOS). This system is part of the Maui Space Surveillance System (MSSS), on the summit of Haleakala, Maui, HI. The objectives of these experiments are to provide accurate range and signature measurements of calibration spheres, demonstrate high resolution tracking capability of small objects, and support NASA in technology development and tracking projects. Ancillary benefits include calibrating radar and optical sensors, completing satellite conjunction analyses, supporting orbital perturbations analyses, and comparing radar and optical signatures (cross sections).

This paper describes the Global Positioning System (GPS) technology development, the experiment operating concept, the current status of the experiment, and an overview of the HI-CLASS/AEOS capabilities.

2. HI-CLASS/AEOS SYSTEM

The AEOS facility, a description of its capabilities to support multiple users, and the location of the HI-CLASS system within AEOS are shown in Fig. 1. HI-CLASS/AEOS system is situated in Suite 4 and has available a large optical table suitable for other visiting experiments. This table has access to the AEOS and HI-CLASS beam trains via a remotely controlled mirror assembly.

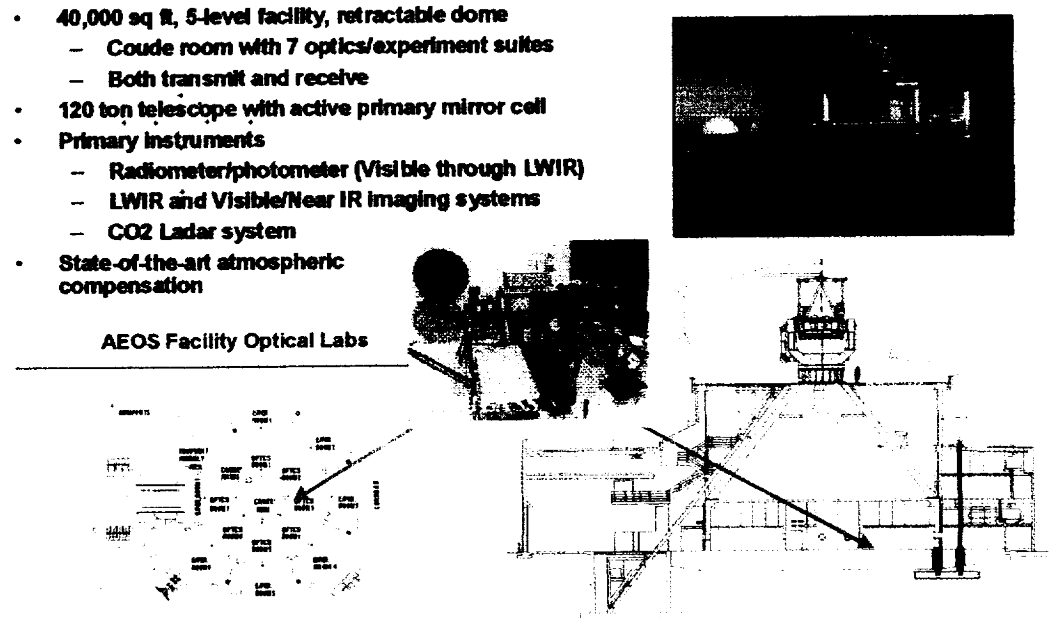

Fig. 1. AEOS Facility with HI-CLASS System

The parameters of the HI-CLASS/AEOS system are shown in Fig. 2. The moderate power HI-CLASS/AEOS system generates multiple, coherent waveforms for precision satellite tracking and characterization of space objects smaller than 30 cm at ranges to 1,000 km. The carrier-to-noise-ratio (CNR) at fixed range and transmitter energy scales as diameter^4 Significant increases in CNR, range, and gain over other ladar systems at MSSS are anticipated.

- Power-oscillator, single channel receiver/processor, controller (no amplifier)
- 12 Joule 15 Hz wideband system
- Pulse Tone & Pulse Burst waveforms
- 11.13 μm wavelength
- Single 4μs pulse width
- Single resonator
- Heterodyne receiver imaging capability (~.5 GHz bandwidth)
- "Holey" mirror Transmit/Receive (TR) Switch

Precision 1m^2 satellite tracking	to 10,000 km
Measurement accuracy	Range (m) ± 4 Rrate (m/s) ± 1
Range-Doppler imaging spatial resolution	sub-meter
Range-Doppler imaging range	to 5,000 km
Small object tracking to 1,000 km	1 cm^2

Fig. 2. HI-CLASS/AEOS System Parameters

HI-CLASS/AEOS has a power oscillator producing approximately 180 watts as the transmitter. The transmitter can switch from pulse-tone to pulse-burst waveforms at its system repetition rate of 15 Hz. In addition, the transmitter is equipped with an Output Pulse Monitor (OPM) that uses coherent detection to capture the output waveform phase and amplitude to assist in signal processing. Transmitter coupling to the beam director incorporates a transmit/receive (T/R) switch to effect isolation between the high output power and the extremely sensitive, heterodyne receiver. The HI-CLASS/AEOS employs a mirror with a small central aperture as the T/R switch by taking advantage of the "point-ahead" angular offset between the transmitted and return beams

The heterodyne receiver employs a wideband, quad-element, Hg:Cd:Te detector illuminated with a local oscillator to functionally achieve a photon counting capability as well as to extract the Doppler shift of the target. The microwave receiver amplifies, band limits and "Doppler tracks" the return signal, i.e., it utilizes a variable frequency microwave oscillator to shift the return signal to baseband. The nominal bandwidth for the pulse-tone waveform is 40 MHz and 750 MHz for the pulse-burst waveform. The microwave receiver generates in-phase and quadrature outputs to facilitate processing.

The digital processor digitizes and records the narrow and wideband waveforms at the full system repetition rates. In addition, it captures the OPM signals along with all system operating and status parameters (more than 100) at the respective system repetition rates. HI-CLASS/AEOS will generate real-time range and range-rate estimates at 15 Hz.

The HI-CLASS/AEOS system will provide precision metrics and range-amplitude measurements of low earth orbit (LEO) objects. HI-CLASS/AEOS operates purely as a tracking and imaging Ladar at a fixed wavelength of 11.13μm. Since orbiting objects are not generally amenable to inverse synthetic aperture-type imaging, the waveforms were simplified to provide a tracking and range-amplitude imaging capability only. These capabilities are derived from a 5μs injection-seeded (acquisition) pulse-tone waveform and a mode-locked pulse-burst imaging waveform with the same 5μs envelope duration. The transmitter will provide average powers of ~ 180w (12J at 15Hz) in an oscillator configuration.

3. LASER CALIBRATION EXPERIMENT CONCEPT

This investigation should answer important questions about tracking small, hypervelocity objects in LEO through a turbulent, non-linear atmosphere. In the first experiment, a Global Positioning System (GPS)/laser beacon instrumented micro-satellite about 25 cm in diameter will be deployed from a Space Shuttle Hitchhiker canister or other suitable launch means (Fig 3).

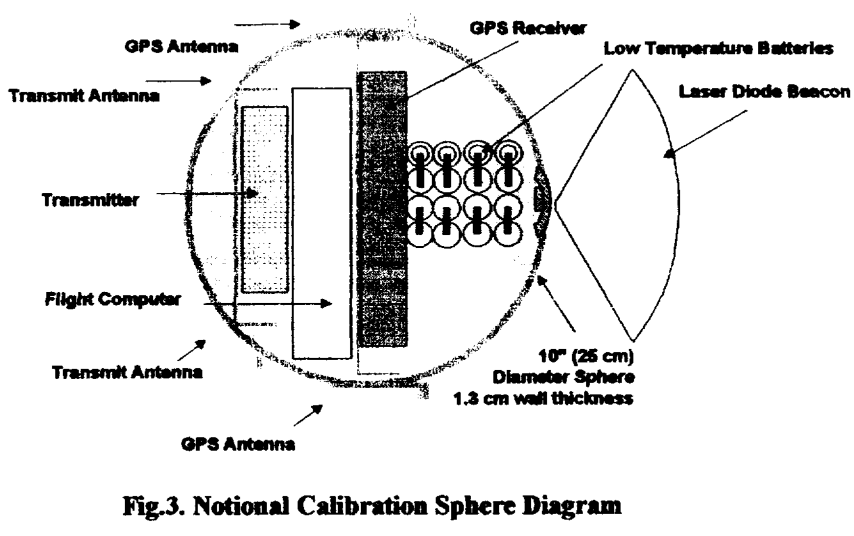

Fig.3. Notional Calibration Sphere Diagram

Orbiting in LEO, the micro-satellite will pass over AEOS several times per 24-hour period. An onboard orbit propagator will activate the GPS unit and a visible laser beacon at the appropriate times. The HI-CLASS/AEOS system will detect the micro-satellite as it rises above the horizon, using acquisition vectors generated from GPS downlinked data from prior orbit passes. The visible laser beacon will be used to fine-tune the tracking parameters. Continuous track and ladar data measurements will occur throughout the pass. This operational approach should maximize visibility to the ground-based laser while allowing battery life to be conserved thus extending the lifetime of the satellite. GPS data shall be transmitted to the ground providing independent location information for the micro-satellite down to sub-meter accuracies.

4. ORBIT ANALYSIS

A key determination made from orbital analysis was that the micro-satellite would only be visible to MSSS 1-6 times per day depending on altitude and only for a few minutes each time (Fig. 4). This analysis was based on a typical Shuttle orbit with a 51.6-degree inclination. Currently there is a constraint that HI-CLASS can only track during morning or evening terminator period but there are on-going activities to determine if the use of an infrared acquisition sensor could extend the observing period. Therefore, a primary objective of the micro-satellite design is to extend its orbital lifetime as much as possible to ensure ample periods of observation.

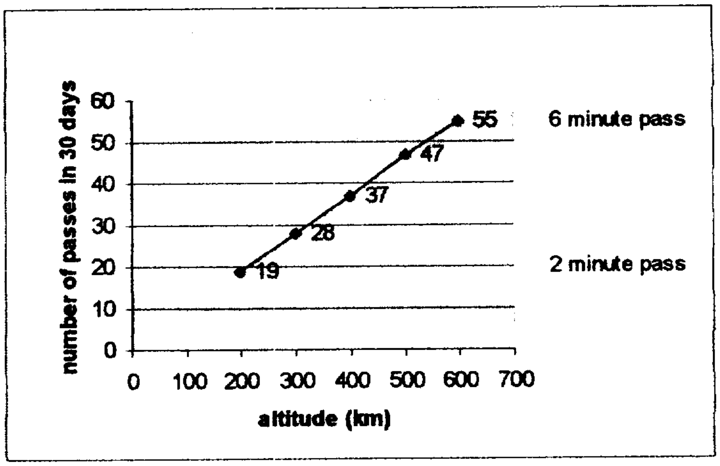

Fig.4. Number (Duration) Micro-Satellite Passes vs Orbit Altitude

5. GPS CONSIDERATIONS

A space-capable GPS Receiver will be placed aboard the micro-satellite to provide data for both real-time and post-processed position and velocity information. A GPS receiver design will be selected that will fit into the 25-cm diameter sphere. As the micro-satellite orbits the Earth, it is cycled on and off at a predetermined rate by the Flight Computer (to save power), and GPS position and raw data is stored in memory. When the GPS Receiver and Flight Computer determine that the micro-satellite is over a ground station, the Flight Computer commands the Radio Frequency Transmitter to turn on, and the contents of the memory are transmitted to the ground. Earth-based GPS Post-Processing software will then be used to provide the required navigation output data. This technique has been successfully addressed by the manufacturers and tested in MSFC laboratories.

Once on the ground, the GPS data will be sent to a central data collection facility, where it will undergo two stages of processing to determine the micro-satellite position and velocity profile. First, the data will be sent through a Rapid-Processing Algorithm to quickly provide position prediction information for the next few orbital passes, to aid the AEOS/HI-CLASS in determining the next acquisition time and tracking parameters for the micro-satellite's next orbital pass. Second, the data will be sent through a Precision Orbit Determination Algorithm and combined with GPS Data collected from around the globe by the International Geological Survey's GPS data collection network to provide after-the-fact sub-meter level ephemeris information for the micro-satellite. This precision orbit determination information will be later used to help calibrate the HI-CLASS/AEOS system, and for comparison and evaluation purposes.

Because sub-meter post-processed accuracy levels are required of the micro-satellite's GPS, a dual-frequency GPS Receiver will be used aboard the micro-satellite. This will enable the on-board GPS receiver to measure, rather than mathematically calculate, the ionospheric delay that the GPS signals encounter during their travel from the GPS Satellites to the micro-satellite. This is an important consideration because, since Selective Availability has been deactivated, ionospheric delay is now the largest source of GPS measurement uncertainty, and thus becomes the largest cause of measurement error for non-military GPS receivers today. Without correcting for this ionospheric delay, post-processed accuracies at the sub-meter level would be extremely difficult, if not impossible.

6. LASER BEACON CONSIDERATIONS

The purpose of a laser beacon is to improve the acquisition process of the micro-satellite by the AEOS system. Being considered is a 100mW Laser Diode with power regulation circuitry. Its timer circuitry will turn on as the micro-satellite passes over the MSSS site. A 50% duty cycle is anticipated during turn on. Off-the-shelf alkaline batteries will work if a heat source is provided and the electronics are insulated from sphere skin. Detailed heat budget needs to be worked out when the micro-satellite design is completed.

7. POWER CONSIDERATIONS

Battery life management becomes a principle consideration in the design of the micro-satellite. Clearly, a way to turn on and turn off satellite principle functions at the appropriate time was the best means for conserving battery life. GPS (as discussed in the earlier section) was one convenient approach for determining the appropriate time to turn on and turn off the principle functions. The micro-satellite is to be illuminated by the HI-CLASS ladar and therefore there are requirements for the surface reflectivity of the satellite. This combined with the desire to minimize cost and complexity has led to no plans for photovoltaics to provide power. Therefore, batteries internal to the satellite will provide power and the active capabilities of the satellite will be dependant on battery life.

The primary power consumers are the GPS receiver and the RF transmitter that will telemeter data to the ground. Both of these are cycled by the on-board Flight Computer to conserve power and only operate when needed. The GPS receiver is assumed to have a 33% duty cycle and a 3.5 W power draw while the transmitter is assumed to operate once per orbit for five minutes at 20 W. The average "continuous" power is approximately 2.5 W. The size of identified electronics inside the satellite will define the volume remaining for incorporation of batteries. The larger the satellite diameter the more batteries can be carried and the longer the life. However, there is a desire to keep the satellite size small to maintain sub-meter positional accuracy. Assuming a battery energy density of 850 Whr/liter and a packing factor of 0.6, the projected lifetime of the satellite versus size is indicated in Fig. 4. Currently, the design for the satellite is 25 cm that means that the battery will last approximately 1.5 months.

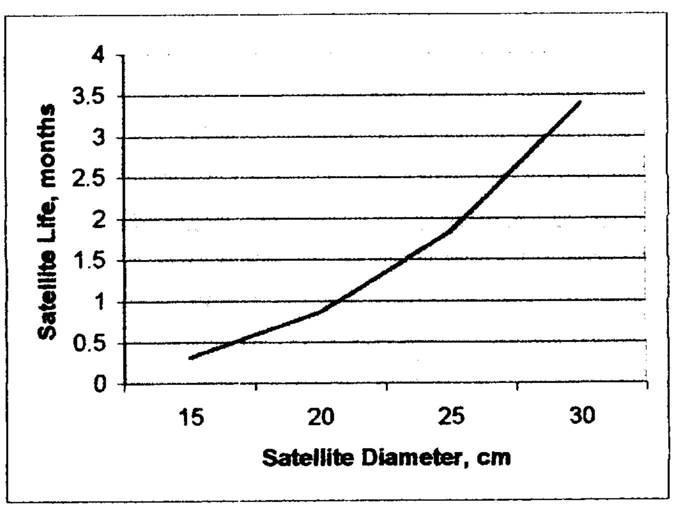

Fig. 4. Satellite Battery Life versus Satellite Size

8. THERMAL CONSIDERATIONS

For the preliminary assessment of thermal conditions for the spherical satellite, a diameter of approximately 25-cm was chosen with a wall thickness of 1.3 cm. Conditions of no power expenditure and of a power input in the satellite of 10 W for a third of each orbit were examined. A LEO satellite at 28-degree inclination was assumed with spin and an arbitrary spin axis. Various candidate satellite surface coatings were considered that provided a range of emittance and solar absorptance conditions. The silvered Teflon (Ag/FEP) provided such low absorptance and high emittance that the temperatures ran very cold indicating heaters would be required. Anodized and alodined aluminum surfaces provided better ranges but in some cases ranged on the hot side. The Chromic anodized aluminum surface provided a temperature range during the orbit of between 57^0 F and $9\ ^0$ F or 13.8^0 C and 35.6^0 C, making this the most feasible option based on thermal considerations. Below it will be shown that this surface coating also appears to meet surface reflectance requirements for visibility and laser reflectance.

9. PRELIMINARY SPHERE REFLECTANCE RESULTS

There are several factors that drive the sphere reflectance requirements. As mentioned above in the thermal considerations, there is a desire to have emittance and solar absorptivity values that will allow the satellite's temperature to be controlled passively. This saves heater power and the complexity of having to add heaters. If this can be accomplished without the use of multi-layer insulation (MLI) then this also saves volume and complexity. There is a desire to visually acquire the satellite from reflected sunlight if the geometrical conditions allow it. Therefore, good reflectance in the visible wavelength region is important. Also, the reflectance of the satellite at 11.13 microns, the HI-CLASS ladar wavelength, must be sufficient to provide the necessary intensity in the reflected signal for it to be easily measured on the ground. Several candidate thermal control coatings were examined including Z-93 white paint, silvered Teflon (Ag/FEP), and different anodized aluminum processes. A Chromic anodized aluminum has been preliminarily selected as the outer surface. The thermal aspects of this coating are discussed above. Figs. 5 and 6 give the coatings' reflectance as a function of wavelength. This illustrates that the reflectance is both high in the visible and infrared wavelengths of interest.

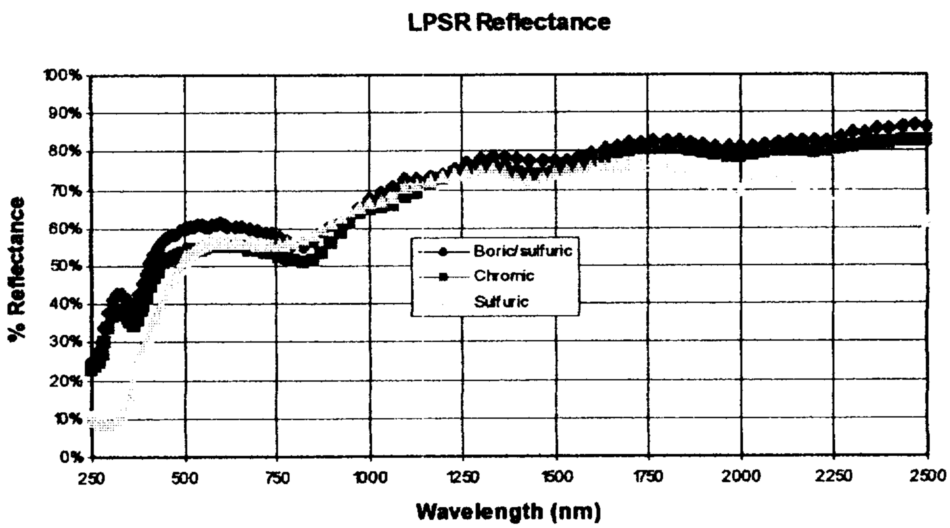

Fig. 5. Reflectance of Candidate Satellite Surfaces in the Visible

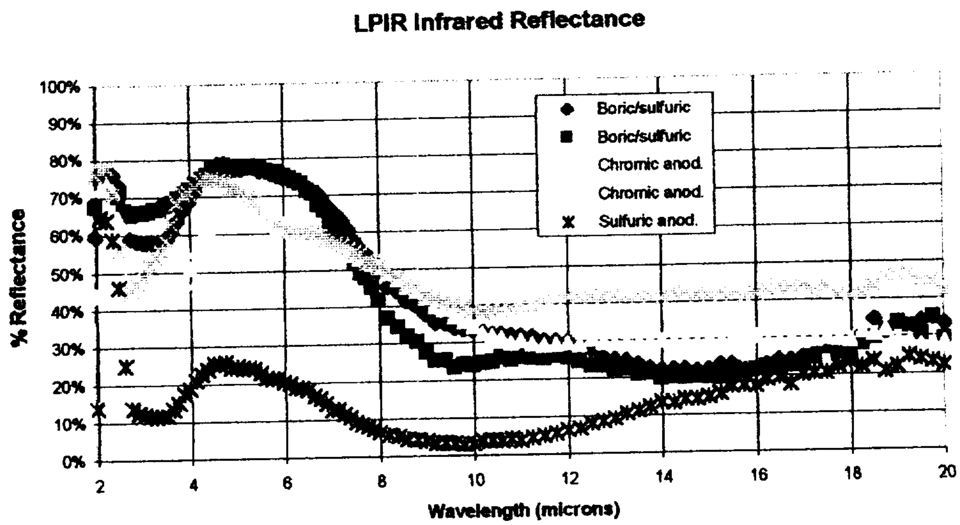

Fig. 6. Reflectance of Candidate Satellite Surfaces in the Infrared

10. SUMMARY

This paper has summarized the joint AFRL/DE-NASA/MSFC laser space calibration experiments using the HI-CLASS CO2 ladar system on AEOS at MSSS. The design of the micro-satellite (25-cm diameter), to include GPS, laser beacon, power, and reflectance, were addressed. These experiments are to provide accurate range and signature measurements of calibration spheres, demonstrate high resolution tracking capability of small objects by the HI-CLASS/AEOS system, and support NASA in technology development and tracking projects. Other benefits of the experiment data include calibrating radar and optical sites, completing satellite conjunction analyses, supporting orbital perturbations analyses, and comparing radar and optical signatures.

11. ACKNOWLEDGEMENTS

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