AeroCube-OCSD Mission:

- Funded by NASA’s Small Satellite Technology Program
- Demonstrate optical communications from a CubeSat to a 30-cm diameter ground station from low Earth orbit (LEO) at rates between 5 and 50 Mbps.
- Demonstrate tracking of a nearby cooperative spacecraft using a commercial, off-the-shelf (COTS) laser rangefinder.
- Demonstrate attitude determination using a sub-cubic-inch star tracker.
- Demonstrate orbit control using variable drag.
- Demonstrate propulsive orbit control using a steam thruster.
- Launch will be in the summer of 2015.

A demonstration of downlink laser communications from a CubeSat is the primary goal.
Why Laser Communications?

- Modern optical sensors can generate raw data at rates exceeding 10 gigabits per second.
  - With 50 X compression, it will take 11 hours to fill a terabyte of memory

- Modern flash memory enables terabytes of data storage within a 1U CubeSat.
  - 256 Gbyte SD cards are readily available

- Downloading a terabyte from low Earth orbit will take ~2 years using a single ground station at a 5 Mbit/s rate.

- Need to increase the downlink rate by more than an order of magnitude.
  - <400 Mbit/s using X-band; 800 Mbit/s using advanced modulation
  - <1200 Mbit/s using Ka band
  - 5.6 Gbit/s laser communications demonstrated by TeSat-Spacecom and The Aerospace Corporation

The OCSD flight is a pathfinder for small laser communications transmitters and small ground stations.
The downlink laser is hard-mounted to the satellite. Laser pointing is controlled by the spacecraft attitude control system.
The AeroCube OCSD Spacecraft
Satellite Attitude Control for Laser Downlink

- **Crude attitude control (1° pointing accuracy)**
  - Six 2-axis sun sensors (in-house legacy design)
  - One infrared Earth Nadir sensor array (in-house legacy design)
  - Four Earth horizon sensors (Melexis 90620 infrared thermometer arrays)
  - Two 3-axis magnetometers (Honeywell 5883 and in VectorNav VN-100)

- **Inertial navigation sensors**
  - Sensonor STIM-210 3-axis MEMS rate gyros (in helium-proof case)
  - VectorNav VN-100 (in helium-proof case)

- **Closed loop control**
  - 10 W, 1550-nm uplink beam from optical ground station
  - Lensed quad photodiode provides 0.1° pointing accuracy

- **Open loop control**
  - Two star trackers with better than 0.1° accuracy (new in-house design)

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*We have two independent spacecraft, and each spacecraft can tolerate multiple sensor failures while still providing laser communications.*
Our Optical Ground Station

MOCAM: Mt. Wilson Optical Communications and Atmospheric Measurements System

The optical ground station already exists and is used on other projects.
Our Optical Ground Station

- **AeroCube OCSD**
- **1060-nm Downlink**
- **5 or 50 Mbps**
- **1550-nm Uplink**
- **10-kbps**
- **2-Axis Rotation Drivers**
- **Tracking Computer**
- **WFOV Tracking Camera**
- **MOCAM**
- **GPS Time Base**
- **FPGA Transceiver**
  - **1 GHz DAC**
  - **1 GHz ADC**
- **Modulated Uplink Data**
- **1 GHz ADC**
- **Rx Electronics**
  - **Waveform Capture**
  - **BER Test Meter**
- **Existing**
- **New**
- **1060-nm Uplink**
- **5 or 50 Mbps**
- **1060-nm Filter APD**
- **NFOV Track**
- **Tracking Computer**
- **Modulated Uplink Data**
- **Downlink Comm. Computer**
Data rates of 5 through 80 megabits per second can be accommodated using a 0.35° FWHM downlink beam with OOK modulation. One beam does it all.

Data Rates vs. Pointing Error at 900-km range

- 0.35° FWHM beam
- 10-W average output power
- On-Off Keying (OOK) modulation
- 8:1 signal to noise ratio
- 32% scintillation loss
  - 99% availability
  - 30° elevation
- Detector NEP: 5 x 10^{-14} W/Hz^{1/2}
**Downlink Laser**

- **PM Yb-doped fiber (9 m)**
  - (10/125 micron dia.)
- **Master Oscillator & Data Board**
- **Pump diode**
- **Pump/signal combiner**
- **10 nm Filter**
- **Isolator**
- **PM Yb-doped fiber (6 m)**
  - (20/130 micron diameter)
- **Output coupler**

- **Amplitude-modulated, single-frequency, ~1064 nm diode laser**
- **Single-diode-emitter laser**, Set pt.: ~ 1-2 W @ 915 nm, EO efficiency ~ 48%
- **3-diode-emitter laser**, Set pt.: 17.5 W output @ 915 nm, EO efficiency ~ 47%

- **Gain-switched diode + 2-stage fiber amplifier**
- **Operation at 1.06 mm**
- **All-fiber design**
  - *Fusion-spliced components without alignment-sensitive free-space optics*

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*Pump wavelengths, fibers, and other components were changed to accommodate temperature rise during laser operation.*
AeroCube-OCSD will use a 2.4:1 to 4:1 variation in ballistic coefficient to provide propellantless orbit rephasing and altitude changes.
AeroCube-OCSD Variable Drag: Orbit Modification

Time (days) to move chase to target altitude using 4:1 differential drag on our 2-kg CubeSats
Proximity Operations

1. Start from distance > 10 km
2. Use differential drag to approach "staging point"
3. Arrive at staging point 2 km from target
4. Perform propulsion/maneuvering tests at staging point
5. Depart staging point for RPO start point
6. Begin RPO from start point
7. Perform RPO: Chaser "corkscrews" around target.
8. End RPO
Multi-point GPS fixes, followed by high-accuracy orbital ephemeris fitting, yields range errors or about 10-meters.
Laser Rangefinder

- Jenoptic DLEM SR
  - 1550-nm eyesafe class 1
  - Max range of 2500 meters for 10-Hz unit (5000 meters for 1-Hz unit)
  - 1-meter range accuracy
  - 0.1-meter resolution
  - 40 grams mass
  - Beamwidth: 1.6 x 1.8 milliradians
  - Power: 3.0V, < 2W max
  - RS-232 interface
  - Operating temperature range: -40 °C to +85 °C
  - Shock resistance: 1500 g, 1-ms

The 1-Hz unit has been tested to 2.24-km range. Good return from a ~¼” diameter corner cube.
We measured 4 mN of thrust at 1 psi (6.9 kPa) propellant tank pressure. This is the vapor pressure of water at 40 °C.
Steam Thruster Flight Module

• Properties:
  - Additively-manufactured in plastic
  - Nozzle is machined in aluminum
  - 5 mN maximum thrust
  - 0.5 mN-s minimum impulse bit
  - 75 s specific impulse
  - Mass: less than 200 grams
  - Operating temperature: 5 to 50 °C
  - Standby temperature: -20 to 60 °C
  - Propellant management system holds both water and ice

• Why water?
  - Less than 1 bar storage pressure; no “pressure vessels” required
  - Non-toxic, non-flammable, non explosive, non-corrosive

• Why not add alcohol or another freezing point depressor?
  - Most additives are either flammable, corrosive, or have high molecular weight.

The steam thruster was chosen to easily get through launch safety reviews.
Low delta-V per orbit simplifies on-orbit operations.
Hero will be happy.
AeroCube-6: Flight Test of Computer/GPS/Radio Board

- **Launched by Dnepr on June 19, 2014**
  - Deployed by Unisat-6 on June 20
  - 1U assembly separated into two 0.5U CubeSats 10 minutes later
  - Space radiation monitoring mission; both spacecraft operational
  - AC-6 separation into AC-6A and AC-6B increased the number of satellites on this record-setting launch from 37 to 38

- **New AeroCube OCSD components and systems on CubeRad:**
  - Flight Computer/ GPS receiver / Advanced radio board
  - Earth horizon sensor (Melexis 90620)
  - Magnetic torque rods

*The AC-6 flight tested some new bus technologies for AC-OCSD.*
Our Ground Station Infrastructure

Automated Ground Network (AGN)
• Built by The Aerospace Corporation and hosted at two universities
• Geographically spaced for maximum coverage
• Control antenna from any computer (unmanned stations)
• Automated operations
• Optical ground station near El Segundo, CA

RF Station
Optical Station
Summary

• A CubeSat optical communications flight experiment sponsored by NASA’s Small Satellite Technology Program
  - Initiated September 1, 2012
  - Flight demonstration in summer of 2015

• The optical downlink will demonstrate 5-Mbps and higher rates
  - Ground receiver is a 30-cm diameter telescope
  - 50-Mbps is possible

• A commercial off-the-shelf laser rangefinder will be flown
  - 1-meter inter-satellite range accuracy

• We will demonstrate variable drag orbit rephasing, altitude modification, and proximity operations
  - Safe steam thruster for out-of-plane maneuvers and more rapid response

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