Exhibit on Satellite Laser Demonstration

Executive Summary of Exhibit:

The optical downlink is at 1550nm, operating at 0.5 Watts of output power with an exit waist diameter of 2.6cm and beam divergence of 90.79 microradians. The downlink site is through a BridgeSat, Inc. operated optical terminal at Tabletop Mountain, California. During a TT&C pass, a command is uploaded to the satellite to task it to use the laser downlink the next time it is within sight of the optical ground terminal. The satellite is programmed with the location of the optical ground terminal so when it comes within sight and has been tasked, it turns on, searches and locks onto an optical beacon on the ground terminal. Once lock is achieved, then the downlink occurs. These downlink tests will occur throughout the duration of the mission. The passes will be 5 to 7 minutes each. Scheduling of pass attempts is heavily dependent upon local weather, as the optical link won't close if clouds are present.

Preloaded data files are loaded onto the spacecraft before flight. These are publicly available image data acquired through Amazon Web Services, digital copies of select historical documents, and personal files of members of the team, will be down linked for the tests.

Contents of Exhibit:

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Concept of Operations:

Commands would be sent by the UHF TT&C link telling Radix to attempt laser downlink on its next pass over the optical ground terminal at Tabletop Mountain, California, operated by BridgeSat. Once the TT&C link has tasked Radix, the optical link can be established without Radix being in continuous contact with the TT&C link.

Upon receiving the tasking and coming within sight of the optical ground terminal, as predicted based on the stored GPS location of the terminal, Radix attempts to locate and lock onto an optical beacon on the terminal. Upon lock, Radix commences data downlink.

The downlink tests will commence after checkout of other satellite systems has occurred. The tests will occur throughout the course of the mission.

Each pass will last for approximately 5 to 7 minutes. Availability of passes depends on clear skies as otherwise minor obstructions like clouds can prevent the optical link from closing.

Catalog of Pre-loaded Data:

Type of Data	Specific	File Type(s)
Digital Copies of Historical Documents	• Declaration of Independence • Constitution of the United States • Bill of Rights • Magna Carta • Mayflower Compact • MLK “I have a dream” speech • JFK “We choose to go to the moon…” speech	PDF, JPEG, MP4, MP3
Open Source Imagery Data	• Landsat Data (link: https://aws.amazon.com/public-datasets/landsat/)	TIF
Personal Files of Team Members	• Family Genealogies of team members • Family photos • Team photos	PDF, JPEG

Example of data on Radix (Photo of Analytical Space team):

Eye Safety Summary:
The satellite, known as Radix, has a laser payload on board that operates at 1550 nm (Infrared) with a maximum operational output power of 0.5 W. The maximum technical output power of the payload is 0.75 W, although Radix shall not be programmed to operate above 0.5 W. Analysis in this review was carried out at the maximum technical output power, which provides a 50% margin over the maximum operational limit of the laser.

While the satellite is onboard the station and in pre-deployment, it is inhibited by redundant separation switches, physically constrained inside the NanoRacks deployer with the laser port being blocked by the solar panels, and the entire satellite is electrically inhibited, i.e. the laser is not turned on.

The Nominal Ocular Hazard Distance (NOHD) as specified in FAA AC 70-1, which is a simplified version of the NOHD as outlined in ANSI Z136, yields an unaided range, excluding atmospheric effects, of 340 meters for the 0.75 W output. The NOHD is the point at which the power spatial intensity of the laser drops below the maximum permissible exposure (MPE) level. Given the deployment and software controls defined herein, the spacecraft will be greater than 1400 meters away from the ISS post deployment before any electronics turn on. First light of the laser will not happen for several weeks, given the need for early orbit checkout and attitude control system tuning and calibration.

These calculations were prepared for and shared with NASA to demonstrate that the laser would not pose risk to astronauts.

Radix Laser Payload Parameters		
	Max Operational Power	Max Technical Output
Light Wavelength	1550 nm (Infrared)	1550 nm (Infrared)
Transmit Waist Diameter	2.6 cm	2.6 cm
Beam Divergence ($1/e^2$ standard)	90.79 microradians	90.79 microradians
Operational Output Power for Radix Mission	0.5 Watts	0.75 Watts
Power Spatial Density at Exit Port	0.094 watts per centimeter squared	0.14 watts per centimeter squared

Safety Standards	
NOHD reference	
Relevant Document	FAA AC 70-1
Maximum Allowable Power Spatial Density	0.1 watts per centimeter squared

Safety Risk Mitigation Strategies:

- **While onboard the station,**
- The satellite is physically constrained from deployment by the NanoRacks deployer
- The satellite is electrically inhibited by the NanoRacks deployer
- The laser port is physically blocked by the NanoRacks deployer
- The laser port is physically blocked by the undeployed solar panels
- The solar panels are constrained by burn wires and as contingency, by the NanoRacks deployer
- The satellite is off and the laser cannot by commanded to turn on
- **Once off the station,**
- 30 minute deployment timer will ensure that the satellite is far enough away from the station to be well beyond the NOHD limit
- Slowest relative velocity possible between Radix and ISS (provided by NanoRacks) is **0.8 m/s**
- Radix will be greater than **1400 m** away when deployment executes
- The satellite must detumble before software state transitions can ever achieve laser operations
- Simulation and analysis show detumble will take multiple orbits to finish
- The satellite must be commanded from the ground to schedule laser operations
- Early orbit checkout and calibration are expected to take several weeks before first light

Software Controls Summary:

- 30 minute post-deployment timer before satellite enters 'deployment mode' where solar panels are deployed and electronics are powered on.
- Satellite must detumble, stabilize attitude, and make ground station link before commanding to higher-order operational states.
- Laser firings can only occur over ground passes as per pre-determined, timed operational sequences commanded by the ground. This database of commands will be blank upon launch and deployment.
- Laser cannot operate in full-power or maximum-power mode *until it is beacon illuminated from the ground station* for a stable, predetermined period of time.
- Commands for arbitrary laser firings will never be sent, as the autonomous sequence that does system checks for power and temperature limits for safe operation would have to be bypassed.
- ***Most importantly*** - Laser subsystem is on a software-controlled PDU channel that can only turned on by the spacecraft OBC. Sending power-on sequences without human-in-the-loop scripting would constitute a failure of the spacecraft main computer hardware.

Figure 1: Satellite Pre-Deployment

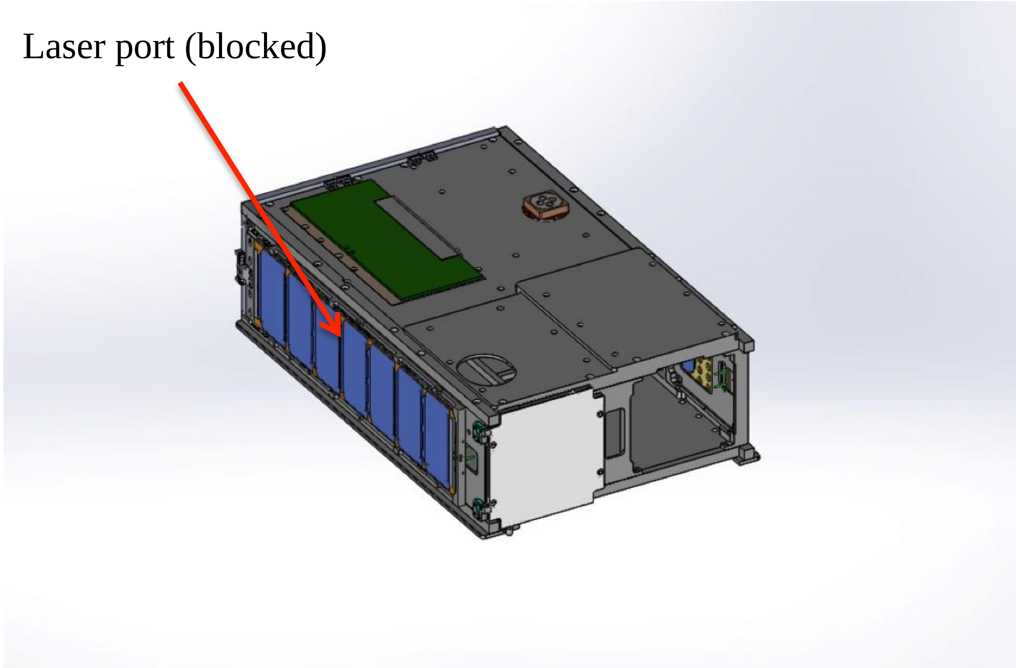

Figure 2: Post deployment