







Fourth Barcelona TechnoWeek

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LightSail 1 & 2

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LightSail 1 & 2 TWO SPACECRAFT - ONE MISSION

Justin Foley California Polytechnic State University Barcelona Techno Week – June 17th, 2019

- Founded in 1980 by world leaders in interplanetary exploration:
 - Bruce Murray
 - Carl Sagan
 - Louis Friedman



 Mission: To empower the world's citizens to advance space science and exploration



Introduction – The Planetary Society





LightSail Mission Conception





LightSail Mission Conception





Sagan & Carson





Solar Sailing Concept







- 1. Avionics
- 2. Momentum Wheel
- 3. Gyros
- 4. Torque Rods
- 5. Battery Module
- 6. Stowed Solar Sail
- 7. Solar Panel
- 8. Camera
- 9. Sail Deployer
 10. Antenna



LightSail Design



2015 – NASA CSLI offers Atlas V launch

- TPS announces decision to launch spare unit as LightSail 1
- Demonstrate sail deployment and prove other system functions, but altitude too low for solar sailing





Launch Opportunity – LightSail 1

• 2018 2019 – SpaceX Falcon Heavy, STP-2 Mission

 LightSail 2 to be proximity operations target deployable payload of Prox-1 (Georgia Tech)



AGAA AGAA AGA













Georgia Tech



Mission Partners

LIGHTSAIL 1





- Baselined as a technology demonstration
 - Attitude control
 - Communications
 - Cameras
 - Solar panel deployment
 - Sail deployment



- Operational Readiness Tests (ORTs)
 - Demonstrate system functionality
 - Practice for operations (run-through)
 - Identify hardware and software anomalies
 - Generally performed on "BenchSat"



Testing – Operational Readiness Tests





Testing – Operational Readiness Tests

- Day in the Life (DITL) Test
 - Performed on flight unit
 - Run-through major mission milestones



Power-up





Antenna deployment







Beacon transmission





Solar panel deployment





Sail deployment with imaging





Data downlink





DITL Test Lessons Learned

- 1st test attempt unsuccessful, radio output power unusually low, fixed
- Battery current monitor inaccurate, fixed
- Refined motor count for full sail deployment



Vibration testing

Verifies satellite can survive dynamic launch environment













- Round 1 Protoqual Levels
 - Standard testing flow for unqualified flight hardware
 - Maximum Predicted Environment (MPE)
 plus 3 dB



Round 1 – Protoqual Results





Round 2 – Acceptance Levels

 Agreed to by launch provider
 MPE, unmodified



Round 2 – Acceptance Results





• Round 3 – Acceptance / Workmanship

- Agreed to by launch provider

 Combination of MPE in one axis, standard workmanship profile in others



Round 3 – Acceptance / Workmanship Results



It survived!



- Thermal Vacuum Bake-Out
 - Verifies satellite can survive launch temperature range
 - Outgasses volatile compounds





Testing – Thermal Vacuum

- Ready for launch!
 - LightSail 1 was integrated into its P-POD
 - The P-POD was integrated with 7 other P-PODs
 - The 8 P-POD system was delivered to the launch site
 - Launch occurred May 20, 2015



LightSail 1 Launch











Atlas V Deployment (example)

Typical Tracking Station





Tracking Station

- Utilizing simple Software Defined Radios (SDR)
 - Used heavily during LightSail 1 operations
 - Aided in Doppler analysis







HackRF One ~\$300 FunCube Pro+ ~\$175 RTL2832 TV Stick ~\$20



Tracking Station





Justin Foley Quatercloky

Downlinking first #LightSail camera checkout image during last pass over @calpoly ground station







• SDR data





Tracking Station

- LightSail 1 Operations
 - Initial beacons picked up on first passes
 - Amateur radio tracking stations picked up signals



- Pre-launch bug
 - During a pre-launch ORT, a software bug was discovered that limited ADCS function
 - Upon launch, initial beacon data showed ADCS routines suspended as expected

Limited ability to test ADCS functions



- Tip-off rates higher than expected
 - Estimated to be 1-2 °/s rotation
 - Initial gyro data indicted 7 °/s about X-axis



- Gyro sensor power state
 - Telemetry indicated gyros defaulted to On

Coding error missed during testing



- File system issue
 - It was discovered the on-board beacon log file was growing unusually quickly
 - File system crashed 55 hours after launch
 - LightSail 1 went silent for several days then spontaneously rebooted
 - The issue was avoided by commanded reboots once a day



- Camera checkout
 - Images were taken with panels stowed, showing inside of satellite







- Rotation rate concerns
 - Initial rotation rates higher than expected, and increasing
 - Pushed for solar panel deployment to reduce rotation rate
 - Panels were deployed successfully, as indicated by gyro data



- Battery protection issue
 - After panel deployment batteries read full, however battery protection disconnected all eight cells
 - It is believed the solar panel deployment event caused an upset in battery system
 - During the next pass and for three days LightSail 1 was silent
 - When contact resumed, telemetry showed battery protection was activated in sun, and in eclipse



- Sail deployment
 - It was decided if battery protection behaved, the sail would be commanded to deploy
 - The command was sent on June 7th, and telemetry indicated deployment motor activity





Rotation rates





- Image downlink
 - Telemetry indicated sail deployment was successful, work began to downlink deployment images
 - It was discovered all the image data taken during deployment was corrupt
 - The cameras were commanded to take another set of images, which was successful















- Post-deployment
 - Limited orbit lifetime with sail deployed
 - Some work retrieving additional images, but most were corrupted
 - JSpOC TLEs became stale quickly
 - Amateur optical satellite trackers provided valuable data







- Re-entry
 - LightSail 1 re-entered the atmosphere June 14, 2015

- 7 days after sail deployment
- 25 days after launch



LIGHTSAIL 2





- Solar sailing demonstration
 - Will be launched aboard Falcon Heavy
 - Carried inside Prox-1, built by Georgia Tech
 - LightSail 2 originally intended to be prox-ops target - descoped
 - Goal is to raise orbit using solar pressure



- Changes from LightSail 1
 - Upgraded avionics, correcting some timing and memory issues
 - Coding errors discovered during LS 1 operations corrected
 - Battery protection parameters adjusted
 - System watchdogs implemented in hardware and software to reboot spacecraft
 - Updated solar panel burn wire design
 - Revised attitude control software

LightSail 2: Changes from LightSail 1

- Improved antenna tuning
- Optimization of beacon data layout
- File management software updated
- Camera and image data transfer code re-written
- Retro-reflector array added for laser ranging
- Morse code beacon <u>"LS2"</u> FCC call sign





LightSail 2: Changes from LightSail 1

- Operational Readiness Tests (ORTs)
 - Similar procedures run to validate changes from LightSail 1



Testing – Operational Readiness Tests

- Deployment testing
 - Boom-only test
 - Sail deployment #1
 - Additional boom-only testing
 - DITL test with sail deployment #2



Deployment Testing





Deployment Testing

- Vibration testing
 - LightSail 2 incorporated all lessons learned from LightSail 1 vibration testing

Environmental Testing

- No issues
- Thermal vacuum testing
 - Identical test to LightSail 1
 - No issues



LightSail 2 is in Florida ready for launch!











Thank you!



