
Leon Alkalai, Anthony Spear (retired)
Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, CA, USA

Contact Author: +1 (818) 354-5988,
Leon.Alkalai@jpl.nasa.gov
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Outline

• Motivation for Topic of Briefing

• Micro Spacecraft Technologies & Spacecraft Systems

• CubeSats growing in popularity

• Two Case Studies at JPL:
  – Lunar Gravity Mapping micro-sat science instrument
  – Remote Vehicle Inspection for lunar exploration missions

• Vision of micro-spacecraft and lunar exploration
  – To be presented at the 56th International Astronautical Congress, 2005, Fukuoka, Japan.
Micro Spacecraft Components and Sub-System Development funded by NASA, DOD, etc.

- MEMS Gyros & Accelerometers (IMU)
- MEMS and APS based Sun sensors & Star Trackers
- MEMS Micro Thrusters & MEMS Micro Valves
- MEMS Piezo-Electric Actuators
- Integrated micro-electronics & digital/analog
- Multi-Functional Structures
- Advanced Thermal Management Techniques
- On-board Spacecraft Autonomy
- Advanced LiI Batteries for low temperatures
- Advanced Solar Array Architectures and Cells
- Re-configurable Avionics Hardware
- Science and Spacecraft Sensors and Instruments
Advanced Microsystems Enable Future New Mission Capabilities

Advanced micro-systems will enable new capabilities for future space exploration missions.

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ILC, 2005, Toronto, Canada
CubeSat Overview

- Practical platform for experimentation
  - Standardization and ridesharing
  - Students participate in entire mission life cycle
- CubeSat standard defines 10 cm / 1 kg cube
- P-POD deployer carries 3 single CubeSats
  - Protects primary payload, spring reliable ejection
  - Compatible with multiple LV
CubeSats

- Initiated in 1999 by Stanford and Cal Poly
- 60+ universities, private companies & government labs building picosatellites
- Multiple manifest & repetition reduces costs to $40K/cube
  - Includes CubeSat/P-POD launch fee, launch interface & campaign, licensing and export fees
- First launch in 06/03: Eurokot / 6 CubeSats
- Upcoming launches (dates to be confirmed)
  - 10/05: Dnepr / 14 CubeSats
  - 03/06: Dnep / 7 CubeSats
- Future US launch capability
  - ESPA, Falcon-1, FALCON, Delta-2, Pegasus, Shuttle
MEMS Picosat Inspector (MEPSI) Stack

- All boards conformal coated (Uralane 5750)

DC DC converter
IMU bottom board
IMU upper board
Radio Board (RF)
Radio board (digital)
Flight Computer
Memory

IMU daughterboard (1 of 2)

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1. Lunar Gravity Subsatellite Concept
2. Inspector Micro-Satellite Project
Lunar Gravity Subsatellite
Mission Concept and Assumptions

- Consider a low-altitude lunar polar orbiter
- Orbiter deploys a small ‘cube-sat’ corner-cube reflector
  - Launcher mounted in +velocity direction on spacecraft
  - Subsatellite has small delta-V imparted by launcher (~ 1 cm/sec)
- Laser tracking system pointed in -velocity direction on spacecraft
- Subsatellite Initially enters FOV of fixed-direction coarse-acquisition 3-degree laser near end of first relative orbit
  - Dwells in FOV for approx. 20 minutes before departing
- Phasing of orbit brings it approximately 300 m further behind after each rev
- 1 month of laser tracking data will yield high precision gravity field of entire moon
- For 28 days of measurements, approx 63 days of operations, assuming:
  - Subsat 1: 7 day deployment walk-out, plus 14 day measurement phase
  - Subsat 2: 21 day “wait” before deploy, 7 day walk-out, plus 14 day measurement phase
- Gravity measurement subsystem: < 10 kg total mass, < 10 Watts power
Subsatellite Initial Deploy Orbital Geometry

Subsatellite Local Vertical vs Local Horizontal Relative Position

Distance (km)

(2) First entry into 3-deg laser FOV

(1) Spring-launch at ~ 1 m/sec

S/C motion

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Subsatellite Deploy Orbit

Subsatellite Local Vertical vs Local Horizontal Relative Position

Distance (km)

Subsatellite walk-out

-32.0 -27.0 -22.0 -17.0 -12.0 -7.0 -2.0

Deploy Trajectory
0.75 deg Half Angle
0.75 deg Half Angle
3 deg Half Angle
3 deg Half Angle
Subsatellite Visibility during Measurement Phase

LVLH X (negative behind main s/c), km

-120 -100 -80 -60 -40 -20 -10 0 1 2 3

t = 10 days  
x = -56.9 km  
z = 566 m

t = 5 days  
x = -43.8 km  
z = 622 m

Subsat Meas Phase Traject.
15 arcmin Half Ang
30 arcmin Half Ang
45 arcmin Half Ang
Gravity Subsatellite Components

Transmitter:
- Passively Q-switched microchip laser pump diode:
  - ~3W input, ~1.5 W output, 1500 Hz firing rate
- frequency doubling crystal, and thermoelectric cooler
- variable-beam-divergence transmitter (3 deg to 45 arcmin half-angle)

Receiver:
- Telescope with time-of-flight electronics
- Range rate precision (1-sec averaging) of approx. 140 microns/sec over range of 30 to 70 km

Corner Cube Micro-Satellite:
- Passive Subsatellite is octahedral, with 8 cube-corner faces
- Dimensions of each subsatellite = 3-4 inches in diameter
- Subsatellite mass = < 0.8 kg

Launcher:
- Spring-based ejection system mass < 5 kg
A gravity subsatellite is currently under study for high-precision lunar gravity mapping.

- Total system is estimated at < 10 kg and < 10 watts
- A gravity subsatellite is passive
- Precision tracking is performed using existing laser ranging technology
- A cube-sat launcher is used to deploy 1 or more subsatellites.
- A more capable system may use an active subsatellite with a beacon, imaging, etc.
Project Management:
Juergen Mueller (PI), Leon Alkalai (PM), Hannah Goldberg (PSE)

Team Members:
NASA Johnson Space Center, Boeing Phantom Works, Vacco Industries Inc., Ashwin-Ushas Inc.

Project Overview:
Demonstrate, in a ground-based space related environment at TRL 6, an ultra-low mass micro-inspector spacecraft demonstration model for vehicle inspection to enhance safety and reduce risk of future human and robotic space exploration missions.

Features:
- Ultra-Low Mass and Size: 3-5 kg
- Celestial Attitude Determination: Operations beyond Earth orbit
- Continued Operation in Sun at 1 AU: Solar powered with Li-Ion battery backup
- Ultra-low power consumption: Xilinx Virtex II processor, piezo propellant valves
- Safety: Collision avoidance system, Low-pressure, low leakage liquid butane propulsion system, Low delta-v (15 m/s)

Imaging:
- Wide and narrow angle cameras, hazard detection, Real-time video, UHF - Local com to host

Communications:
5. End of Mission Disposal
Final maneuvers place πλs. safely away from the host. This helps mitigate additional risk to the host with the presence of a non-operational hazard.

4. Inspection and Communication
πλs. performs through commanded sequences for external inspection of the host vehicle. Downlink of inspection pictures and health data telemetry, uplink of commands.

3. Orientation and Calibration
πλs. locates and tracks the position of both the host and sun and performs on orbit calibrations as necessary.

2. Deployment
After verifying πλs. health, the host severs electrical/mechanical connection and πλs. is ejected away from the host.

1. Launch and Transport
πλs. launches attached to host and powered off until needed.
Performance and Capabilities

- Free-Flying remote vehicle inspector: Autonomous ops – uplinked sequences – host in the loop
- Visual Inspection resolution: 1 cm (at 10 m range)
- Monitoring: Real-time video
- Lifetime: 6 hours min operation
- 2 hours lifetime from battery power
- Unlimited operating power in full sun

- Attitude Determination, Celestial Navigation: Micro Sun Sensor, Gyro, Star Tracker
- Pointing control accuracy: 1 degree
- Position control accuracy: 1 m; 10 mN thrusters
- Power: Solar Arrays, Lil Batteries
- Communications: 1 Mbit/sec downlink, 5 kbits/sec uplink
- Propulsion: Cold gas prop, plenum
- Thermal Management: Passive, Active: Electro-chromics
- Hazard Avoidance: Laser ranging, HW/SW checks, low delta-V, impact analysis, etc.
- Human Rated performance: Designed for use in human missions

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Flight System Block Diagram

- Optional Power When Docked
- Solar Array → Peak Power Tracker → Power Switch → Voltage Converters (x5) → Step-Up Converter (x2)
- Regulated 5V Bus
- +1.5 V, +2.5 V, +3.3 V, +12 V, -12 V
- +150 V

- Liquid Reservoir → Butane Plenum → Microthrusters

- Avionics Hardware: 2 Processor Xilinx Virtex-II Pro FPGA w/EDAC, SDRAM, Flash, config. Mem.
- Valve Drivers → Electrochromics Controller
- Heaters → MUX/ADC
- Antenna → Transceiver → GSE Connector
- RS422
- UART
- 3-axis Gyro
- -Z axis Camera (x2)
- -Y axis Camera (x2)
- +X axis Camera
- LED Flash
- Coll. Av. Camera
- Laser Spot Generation

- Controlled Emissivity Surface

- Votages (x7), Currents (x2), Pressure (x2), Temperatures (x8), Sun Presence Sensors (x5)
System Description

- Sandwich structure (8.4" x 8.4" x 2.6")
  - Multifunctional Tank (MFT)
  - Multilayer Circuit Board (MCB)
  - Solar Panel Assembly (SPA)
- Solar panel is thermally isolated from tank
  - Thin fiberglass standoffs provide structural support
  - Long, small gauge wires connect antenna, solar cells, and temperature sensor from SPA to circuit board
- Electrochromic surface mounted to bottom side of tank
- Payload components mounted on standoffs over circuit board underneath solar panel and mounted through tank
  - Battery assemblies (x2)
  - Gyro
  - Cameras (x6)
  - Micro Sun Sensor
  - Laser
System Integration

- Wide Angle Camera
- Sun Sensor
- Gyroscope
- Narrow Angle Camera
- Laser Radiator
- 14 X Solar Cell
- 4 X Battery
- Laser Radiator
- Laser
- -Z Camera
- Collision Avoidance Camera
- Laser Grating
- Flash
- + X Camera
- Multifunctional Tank
- 8 X Thruster
- 4 X Stand Off
- Latching Liquid Valve Manifold

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The Micro-Inspector Multifunctional tank has two chambers. (1) The liquid butane tank and (2) the Plenum. The liquid butane is converted to vapor using the heat of the electronics and transferred into the plenum using the latching/liquid valves. The thrusters use the vapor in the plenum to propel the spacecraft.
Key Technical Resource Margins

- Inspector Satellite Mass:
  - < 10 kg
  - CBE < 4 kg (> 100% margin)
- Power
  - 13.3 W power available from solar array: 30% margin
  - Assumes cooler operating temperature than what is probable
- Propellant mass
  - 100 g propellant, equivalent to 15 m/s delta-V
  - Propellant usage dependant upon operations
  - Tank sized for 300 g propellant (45 m/s delta-V): 200 % margin
- HW and SW Computer
  - Xilinx Virtex II Pro, dual-CPU for SEU detection
  - Extensive features for radiation tolerance, fault tolerance
  - 300 MHz CPU > 75% margin
- Communications
  - 1 Mbit/sec downlink: 45% margin
Summary of Micro Inspector Satellite

- Micro-Inspector satellite designed for remote vehicle inspection in space beyond Earth orbit: Moon, Mars, etc.
  - CBE < 4 kg
- System directly applicable to ESAS
  - Vehicle remote inspection
  - Monitoring of vehicle docking and rendezvous
  - E/PO
- Schedule:
  - Project just completed its System Requirements Review
  - PDR is scheduled for January 2006
  - Project Schedule: 3.5 years to full TRL 6 including qual test and demonstration in ground testbed
- Cost:
  - Phase 1: 2.7 M$
  - Phase 2: 15.3 M$
Highly miniaturized (nano/pico) satellites can be used effectively to perform useful science and exploration objectives at the moon.

CubeSats or other forms of pico-sats are affordable to a broad group of international (small) space agencies, universities, small businesses, etc.

Consider a ‘World Lunar Project’:
- A single integrating organization (company) provides the s/c bus,
- Other institutions may support operations, navigation, management
- Vehicle carries multiple (10-12) individual ‘CubeSats’
  - Each CubeSat is from a different institution
  - Functions vary from imagers, beacons, penetrators, orbiters, etc.
- Mission engages the world, including universities, high-schools, public
- Project is funded by a combination of government funds and private investors