Lunar Exploration Communications Relay Microsatellite

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ABSTRACT

In 2005 Andrews Space, Inc. completed some preliminary microsatellite design work for a NASA Cislunar flight experiment known as Micro-X. This paper describes a low-risk satellite design option that leverages the work completed under the Micro-X contract and addresses NASA's near-term Robotic Lunar Exploration Program (RLEP) Objectives. Specifically, this paper describes enhancements to the Micro-X design that includes additional communication and data relay technologies with the Lunar Robotic Orbiter as a pathfinder for a mission to the Lunar South Pole. This Andrews conceptual design is known as the Lunar Advanced Relay Satellite (LARS).

SUMMARY

In April 2005 Andrews Space, Inc. (Andrews) was awarded a $20M Exploration Research and Technology contract to design, develop, integrate, launch, and operate a Cislunar flight experiment microsatellite (Micro-X). This spacecraft was originally designed to be launched as a secondary payload on an EELV in October 2008 to a GTO orbit, where it would use on-board electric propulsion to spiral out to Lunar Lagrange Point 1 (LL1) and transition to a final Lunar Lagrange Point 2 (LL2) halo orbit. In November 2005, the Andrews Micro-X team completed a Systems Requirements Review and was working towards a system Preliminary Design Review with some systems nearing the Critical Design Review phase when NASA terminated the effort due to Constellation program reprioritization.

This paper describes a low-risk microsatellite design option that leverages the work completed under the Micro-X contract and addresses NASA's Robotic Lunar Exploration program. Specifically, the Andrews concept will give NASA a lunar communications option by enhancing our existing Micro-X design to include additional communication capabilities and demonstrate data relay technologies with the Lunar

Reconnaissance Orbiter (LRO) as a pathfinder for a mission to the Lunar South Pole.

Lunar Communications and Navigation.

The baseline LARS concept modifies our Cislunar flight experiment spacecraft to serve solely as an LL2 communications /navigation relay. The major modification required is to implement a higher bandwidth system. The LARS Spacecraft would act as a proximity relay for LRO and future ground assets and "backside" navigation. It could use an UHF proximity transceiver (Deep Space Network (DSN) capable S-band transceiver). This LARS concept could be used as part of any future follow-on Communications and Navigation on the Shuttle (CANDOS) demonstrations. This concept is shown in Figure 1.

Features:
• **High data rates**
• **Continuous far side coverage if at LL2**
• **Demo next step follow-up to CANDOS**

Relay

LRO

LRO Secondary Spacecraft serves as LL2 Comm / Nav node

Figure 1: Lunar Comm/Nav Relay Node

By focusing solely on RLEP communications and navigation needs, several potential mission objectives could be realized. These include:

1. Demonstrate orbit maintenance of a proximity relay satellite in a halo orbit about the Lunar Lagrange Point 2 for lunar far side and polar region coverage.

2. Demonstrate communications relay capabilities with LRO or other Lunar assets.

3. Demonstrate networking capability.

4. Demonstrate ranging support for future lunar assets as a precursor to the Lunar Relay Satellite system.

A derivative of the Cislunar Flight Experiment spacecraft could support any of these missions. This spacecraft was designed to be fully compatible with DSN-S band ground systems and was originally designed to loiter in LL1 and LL2 halo orbits. To enhance data rates, the medium gain antenna would be replaced by a larger 1 m dish antenna.

In addition to the primary communication and navigation goals described above, characterization of the lunar environment will be accommodated by carrying the Compact Environmental Anomaly Sensor (CEASE) II instrument payload. The CEASE instrument was developed and flight proven by AmpTek specifically for the Van Allen Belt environment. CEASE measures ionizing radiation dose and dose rates, Single Event effects, surface and deep dielectric charging, and stores the data onboard the spacecraft.

The objectives for the proposed mission are summarized in Table 1. These objectives support lunar network and interoperability goals of the current NASA Space Communications Architecture Working Group, while improving knowledge of the space environment.

Table 1: LARS Mission Objectives.

Category	Mission Objective	Implementation
Communications Relay	Demonstrate efficient maintenance of highly elliptical lunar relay orbit	Optimized navigation & control plan developed by JPL
	Demonstrate data relay from LRO to earth during first year	
	Provide full relay coverage of lunar lander after 1st year	
Space Networking	Repeat CANDOS networking experiment at lunar distances	
Space Environments	Expand database at lunar distances of ionizing radiation, single event effects, and dielectric charging	CEASE II payload

SPACECRAFT DESIGN

The Cislunar Flight Experiment was to demonstrate low-thrust orbit transfer using advanced trajectory design methods developed by NASA's Jet Propulsion Laboratory. The original spacecraft was 3-axis stabilized. Its primary propulsion was a single Hall thruster, it had 900 W End-of-Life (EOL) power from two deployable solar arrays, and it met lunar GN&C requirements. It could also withstand lunar environments (e.g., high energy particles that lead to single event upsets/latch-ups).

Most of this design can be used to support the LARS mission. The advantages of modifying the Micro-X spacecraft are simplicity and efficiency. The primary modification is to the communications subsystem. The original Micro-X Telemetry Tracking & Control (TT&C) subsystem was sized to provide adequate ground data rates using the Deep Space Network (DSN) and a secondary lower power system. To serve as a lunar communications relay, higher data rates would be desired, and the Micro-X medium gain antenna would be replaced by a 1 m antenna. Preliminary link margin analyses indicate that S-band data rates from the LRO 5 W transmitter of >10 Mbps could be achieved at 1000 km for a secondary spacecraft in lunar orbit, and that data rates >20 kbps are possible between LRO and a secondary spacecraft at LL2 (~65,000 km away).

The revised configuration incorporates an Aerojet N2H4 propulsion system instead of the original Hall thruster, which allows the total power level to drop to <400W. A summary of the capabilities of the LARS is given in Table 2.

Table 2: LARS Capability Summary

Function		LARS Capability
Attitude	Star tracker	22 x 22 degrees field of view
		1.0 arcsec pitch and yaw, 5.0 arcsec roll
		0.5 deg/sec slew rate
		30 deg sun 1/2 angle exclusion, 25 deg moon and earth 1/2 angle exclusion
	Sun sensor	2 Π steradian field of view
		+/- 1 deg accuracy
	Orientation	Control to 1.0 deg in each axis, knowledge to 0.1 deg
Maneuvering	Delta Velocity	2.4 km/s using N2H4
	Primary propulsion	Single Aerojet N2H4 MR-104 440 N
	Auxiliary propulsion	Eight Aerojet N2H4 MR-111 4 N
	Maneuver command	All maneuvers except de-tumble and safe modes performed under ground control
Communications	Earth downlink/uplink data rates	100 kbps
	Telemetry format	CCSDS
Navigation	Trajectory determination	DSN
Autonomy	De-tumble	Activated at LV separation
	Safe modes	Spacecraft to enter safe modes, hold power positive, establish ground contact
Power	EOL Power	<400W
	Arrays	2 deployable 2 panel arrays
	Batteries	Li batteries sized for 6 hours eclipse
	Launch power	None required
Mass		< 450 kg at launch (150 kg dry mass)
Structure	Decks and panels	Aluminum honeycomb
	Support structure	Aluminum honeycomb
Mechanisms	Solar arrays deployment	Two deployable arrays, 2 panels each
	Solar array articulation	Single axis solar array drive actuator (SADA)
	LV separation	To be developed with LRO launch provider
Thermal control	Heaters	Thermostatically controlled heaters
	Radiators	Passive radiators
	Multi-layer insulation	

The following sections summarize the design maturity of the LARS spacecraft as derived from the Cislunar (Micro-X) program.

Spacecraft Configuration

The LARS is a rectangular six sided bus with two solar array wings projecting out two of the faces, as shown in Figure 2 and Figure 3. This simple structural approach is inherently stiff, and supports rapid design and development. The solar arrays rotate about a single axis. Each solar array wing is comprised of two panels, a yoke and solar array drive assembly, and are mounted on the +Y/-Y faces. These faces also include the passive radiators. The components and avionics are attached to the two side radiator panels and a 71.1 cm

diameter N2H4 tank is situated in the center volume of the spacecraft.

The thermal control approach includes passive radiators, multi-layer insulation blankets, temperature sensors, thermostats, and heaters. The power dissipating components are attached directly to the structural panels/radiators, which in turn radiate the excess heat to space. The MLI blankets cover all spacecraft surfaces aside from the radiators. When power loads are low, heaters are used to keep components within their operating temperature limits through the use of temperature sensors and thermostats.

An initial mass properties statement for the LARS is given in Table 3, projecting a launch mass of 411 kg.

Figure 2: Lunar Advanced Relay Spacecraft Design

Figure 3: Spacecraft Structural Layout-Arrays Deployed

Table 3: LARS Mass Properties Summary.

Part / Assembly Name	Mass - kg		
	Mass Est.	% Grwth	Expected Mass
Mechanical / Structure	43.22	12%	48.34
Thermal control	3.56	18%	4.21
Command & Data Handling (C&DH)	5.00	5%	5.25
Electrical Power System (EPS)	26.00	20%	31.16
Telemetry, Tracking, and Communication (TT&C)	5.59	7%	5.97
Guidance Navigation & Control (GN&C)	14.53	5%	15.31
Propulsion	22.48	7%	23.96
Payload	1.43	5%	1.50
Propellant Residuals. Reserves	17.5	0%	17.50
Launch Adapter	2.00	5%	2.11
Auxiliary Propellant – Nominal	256.00	0%	256.00
Total	**397.32**	**4%**	**411.30**

Command and Data Handling (C&DH) Subsystem

The heart of the command and data handling subsystem is the integrated avionics unit. Our concept uses an integrated avionics unit from Broadreach Engineering.

This unit has flown on XSS-11, meets a 30 kRad environment, and includes most of the interfaces and power processing capability required for LARS. It weighs only 5.1 kg and uses 35 W average power.

Guidance, Navigation, and Control (GN&C) Subsystem

The primary GN&C subsystem components are shown in Table 4. Each of these components is flight proven and meets the requirements for a lunar flight.

Table 4: GN&C Component Summary

Component	Qty
NGC LN 200 IRU:	1
Terma HE 5AS Sun Sensor	1
Ithaco TW-4A12 Reaction Wheel	3
Adcole 45840 2-axis Startracker	2

Tracking, Telemetry and Command (TT&C) Subsystem

The primary S-band TT&C subsystem components include an S-band Transponder (DSN Capable), an Omni antenna, a high gain antenna, and a low power transceiver.

Preliminary link budget analyses are summarized in Table 5 for earth communications. Data rates of 100 kbps are achievable with uplink and downlink margins of 16 and 12 dB, respectively.

Table 5: Preliminary Link Budgets Using 26 m DSN Antenna

		Uplink	Downlink
Freq	Ghz	2.1150	2.2950
Wavelength	M	1.418E-01	1.307E-01
Trans P	W	100	5
Trans P	dBW	20.00	6.99
Trans Line Loss	dB	0.00	-2.30
Trans Beamwidth	Deg	0.40	20.00
Pk Trans Ant Gain	dBi	51.40	18.28
Ant Dia	M	24.82	0.46
Trans Ant pointing error	Deg	0.05	10.00
Trans Pointing loss	dB	-0.19	-3.00
Net Trans Ant Gain	dBi	51.21	15.28
EIRP	dBW	71.21	19.97
Path Length	km	3.84E+05	3.84E+05
Space Loss	dB	-210.64	-211.35
Prop/Pol loss	dB	-0.30	-0.70
Rcv Ant Dia	M	0.46	26.00
Pk Rcv Ant Gain	dBi	12.26	52.20
Rcv Ant Beamwidth	Deb	20.0	0.4
Rcv Ant pointing error	Deg	5.0	0.2
Rcv pointing loss	dB	-0.75	-2.50
Line Loss	dB	-2.30	0.00
Net Rcv Ant Gain	dBi	9.21	49.70
System Noise Temp	K	627	122
Data Rate	Bps	1.00E+05	1.00E+05
Calc Eb/No	Db	19.36	12.85
C/No	dB-Hz	69.36	62.85
BER	-	1.E-05	1.E-05
Required Eb/No	dB	1.00	1.00
Atm Loss	dB	-2.00	-0.30
Margin	dB	16.36	11.55

Electrical Power Subsystem (EPS)

The EPS has been sized to provide an EOL power of 400 W after two years and can support eclipse period of up to 6 hours. The Broadreach Integrated Avionics includes the power control function, and provides the interfaces with the solar array, the batteries, and the vehicle subsystems.

Propulsion Subsystem

Primary propulsion components are shown in Table 6. This subsystem is sized to provide a minimum of 2500 m/s deltaV. A single 440 N thruster mounted on a 2-axis gimbal is used for all primary trajectory maneuvers. Eight 4 N thrusters are used for momentum management.

Table 6: Propulsion Component Summary

Component	Qty	
Aerojet MR-104 440N N2H4 thruster	1	
Aerojet MR-111 4 N N2H4 thruster	8	
Aeroflex 2-Axis Gimbal	1	

Component	Qty	
ATK-PSI 80297-1 Diaphragm Tank	1	

Spacecraft and Mission Software

The partition of the spacecraft and mission software is shown in Figure 4. The use of the Broadreach integrated avionics also brings with it a large portion of the flight control software, as indicated in green. This greatly reduces the software development risk for an October 2008 launch.

Flight Software Architecture

Experiment Management	Navigation Managment	Control Management	Electrical Power Management	Communications Management	
Mobile IP Demonstration	IRU	Solar Array Positioning / RCS Valves / Reaction Wheels / Primary Thruster Control / ACS Control Laws	Solar Array Monitoring	Vehicle Health	Mission Manager
CEASE II	Sun Sensor		Heater Control	Uplink	Software Update
Low Power Transceiver (option)	Star Tracker		Electrical Power Distribution	Telemetry	

VxWorks

RS 422 Driver | Analog to Digital Converter Driver | Digital to Analog Converter Driver

COTS | To Be Developed

Figure 4: LARS Software Partition and Availability

SUMMARY.

This paper describes how the Andrews Cislunar Flight Experiment (Micro-X) can be modified to serve as a communication and navigation demonstrator to reduce programmatic and technical risk for potential RLEP follow-on missions. Furthermore, this demonstrator provides the ability to maintain an outpost at Lunar L2 which serves as a national asset and building block for other near-term NASA applications. Finally, small constellations of similar affordable microsatellites can support the communication and navigations requirements for other near term RLEP missions to the Moon or Mars.

A summary of the Cislunar Flight Experiment spacecraft design capabilities and some of the possible modifications identified to support LRO secondary mission options are shown in Table 7.

Table 7: Cislunar Flight Experiment Design Evolution Options

Function		Cislunar Flight Experiment Existing Design Capability	Preliminary Modifications to Support LRO Secondary Mission Options
Attitude	Star tracker	22 x 22 degrees field of view	
		1.0 arcsec pitch and yaw, 5.0 arcsec roll	
		0.5 deg/sec slew rate	
		30 deg sun 1/2 angle exclusion, 25 deg moon and earth 1/2 angle exclusion	
	Sun sensor	2 Π steradian field of view	
		+/- 1 deg accuracy	
	Orientation	Control to 1 deg in each axis	
Maneuvering capability	Tanks	Single tank with 45 kg Xe storage capability	Cylindrical PMD N2H4 tank, 300 kg storage capability (~85 cm dia.)
	Delta Velocity	Minimum of 3.1 km/s	Up to 2.4 km/s using N2H4
	Primary propulsion	600W nominal power Hall thruster	COTS N2H4
	Auxiliary propulsion	8 Xe cold gas thrusters for momentum management	COTS N2H4
	Maneuvers	All maneuvers except de-tumble and safe modes performed under ground control	
Communications	Downlink / uplink data rates	Omni antenna: 400 bps with separate ground system, 10,000 bps with DSN	>10 Mbps at 1000 km with 1 m dish from 5 W LRO transmitter
		Medium gain antenna: 1000 bps with separate ground system, >10,000 bps with DSN	
	Telemetry format	CCSDS	
Navigation		DSN 26 m primary	
Autonomy	De-tumble	Activated at LV separation	
	Safe modes	Spacecraft to enter safe modes, hold power positive, establish ground contact	
Power	EOL Power	922 W	< 500 W
	Launch power	None required	
Mass		< 180 kg at launch	< 450 kg at launch (150 kg dry mass)
Structure	Decks and panels	Aluminum honeycomb	
	Support structure	Aluminum honeycomb	
Mechanisms	Solar arrays deployment	Two deployable arrays, 4 panels each	2 panels each
	Solar array articulation	Single axis solar array drive actuator (SADA) with full 360 degree range of motion	
	Gimbal	Hall thruster 2-axis gimbal with +/- 5 degree range	Fix N2H4 primary engine
	LV separation	Passive side of 38 cm Lightband motorized separation ring	To be developed
Thermal control	Heaters	Thermostatically controlled heaters	
	Radiators	Passive radiators	
	Multi-layer insulation		