



NASA Propulsion Concept Studies and Risk Reduction Activities for Resource Prospector Lander

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Resource Prospector Mission “Big Picture”

- Mission elements include a lunar lander, a rover, a sampling & analysis payload, and a launch vehicle.
- Payload consists of a drill, a small oven to heat the sample, and a suite of three different spectrometers to guide surface navigation and characterize the volatiles located in the lunar regolith.

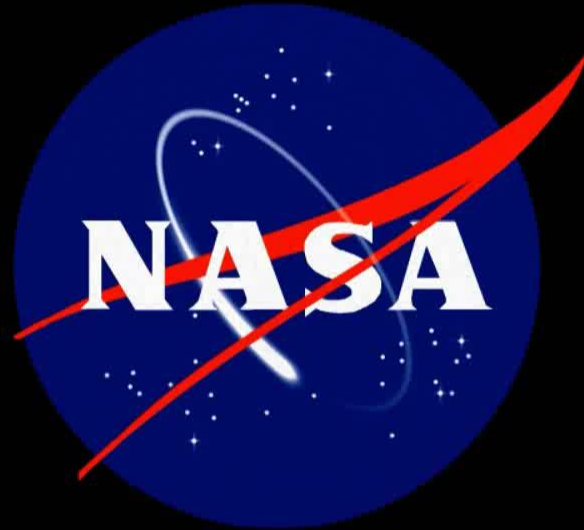
The Resource Prospector Mission (RPM) is a NASA mission to prospect for volatiles (water ice) in the polar regions of the Moon.

Utilizing lunar resources to produce oxygen and propellants could enable new mission architectures for human exploration.

RPM is targeted for launch in 2019.

- NASA Robotic Lander Concept
 - NASA class D, requirements driven, low cost, rover delivery lunar lander (~325 kg rover+payload)
 - This lander is low cost and will fit on a Falcon 9 V1.1
 - This lander that can be built with little technology development

Resource Prospector Mission Lander Animation



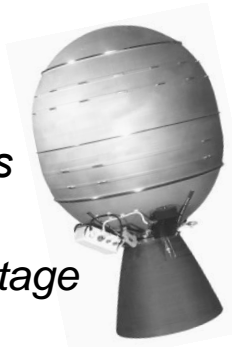
Resource Prospector Mission Lander

Propulsion Trade studies (1 of 2)



Braking Stage

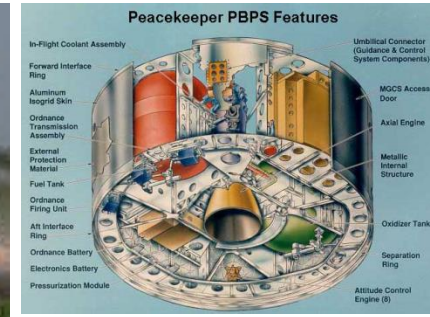
- **REFERENCE** : SRM STAR-48 V
- LOX/LCH4 propulsion – derived from JSC’s Morpheus vertical test bed
- Storable bi-prop – 4th Peacekeeper (PK) stage components and Space Shuttle OMS.



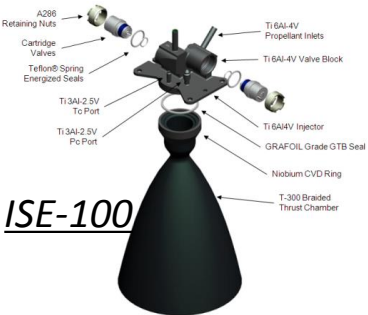
SRM
STAR-48V



Morpheus
Ground Test



4th Peacekeeper
Stage



ISE-100



DACS



PK PS-34

Lander Stage

- **REFERENCE**: Combined PK & COTS components
- Existing DACS and enhanced ISE-100
- PK thrusters and major components
- Bi-prop COTS
- Mono. prop hydrazine COTS

ACS



LERO-2B



MR-80B

11 configurations are derived from the combinations

Propulsion Trade studies (2 of 2)

Pros & Cons on Configuration Options

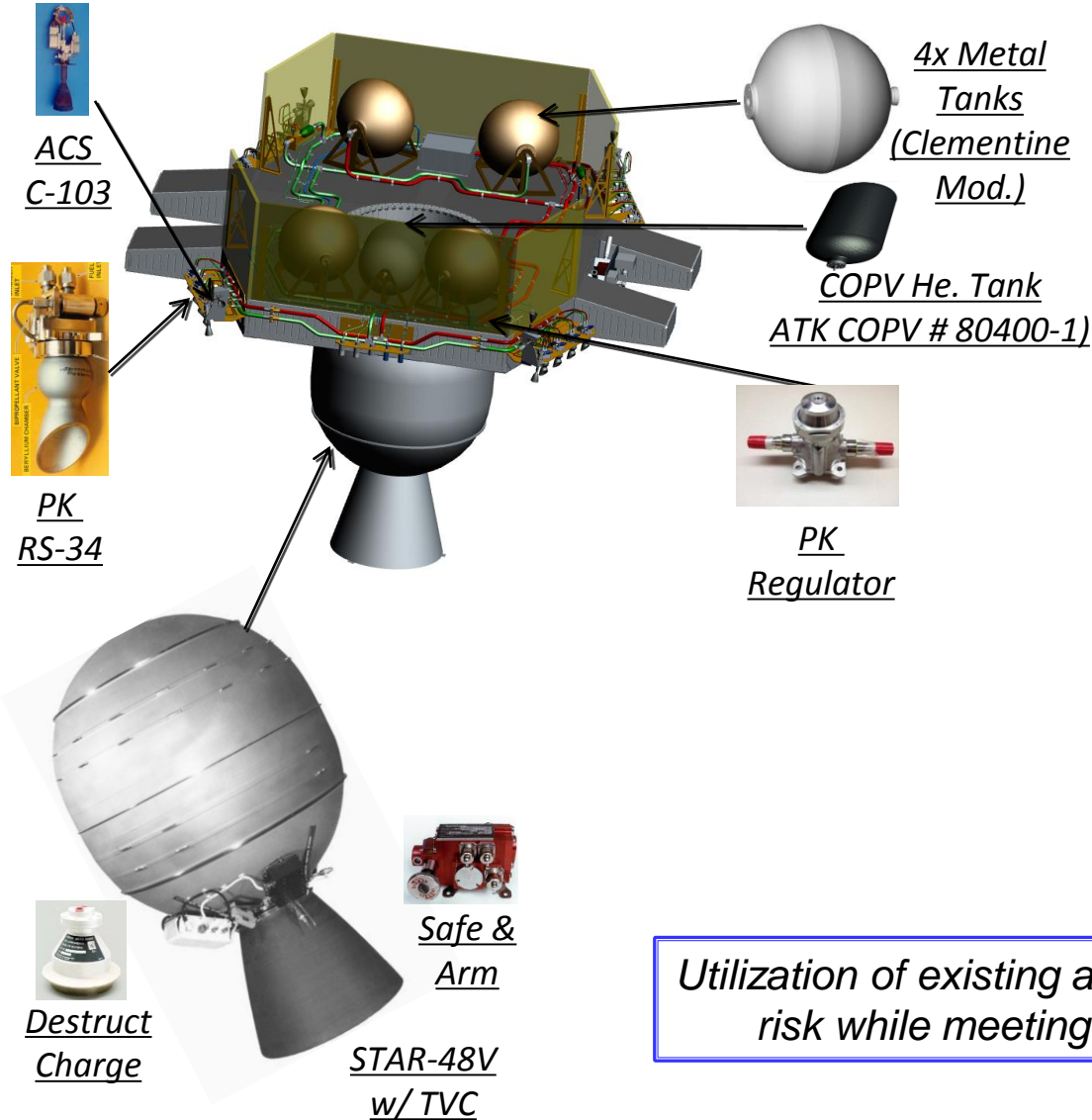


Option	Config.	Cost	Mass	Pros	Cons	Risk
Original Reference	ISE/ SRM	Hi.	Low	<ul style="list-style-type: none"> • Lightest weight • New technology demo. • Reduced heater requirements 	<ul style="list-style-type: none"> • Highest cost • High risks (technical and schedule) 	<ul style="list-style-type: none"> • Still in development phase. • 1st use of MON-25/MMH in space and at wide temperature range
Option 1	PK/ SRM	Low	Med.	<ul style="list-style-type: none"> • Lowest cost, hardware available without cost. 	<ul style="list-style-type: none"> • Moderate weight increase • Lowest performance • No technology demo. 	<ul style="list-style-type: none"> • Aging hardware (soft-good) • Nozzle made of Beryllium (toxic) • Min. impulse bit repeatability
Option 2	Existing DACS/ SRM	Med.	Med.	<ul style="list-style-type: none"> • New technology demo. • Reduced heater requirements. 	<ul style="list-style-type: none"> • Moderate cost • Moderate weight increase 	<ul style="list-style-type: none"> • Hardware mod. (new Teflon seal) • 1st use of MON-25/MMH in space. • Relatively hi. pressure system
Option 3	Mono Prop hydrazine / SRM	Med.	Hi.	<ul style="list-style-type: none"> • Low/moderate cost • Simple, reliable system w/ extensive flight data 	<ul style="list-style-type: none"> • Heaviest • No technology demo. 	<ul style="list-style-type: none"> • Interference w/ optical landing devices due to continuous thruster operation (throttling instead of pulsing) • Plume effects to SRM • Not in production. • Hi. pressure operation & large size of feed lines & large tanks

Selection of reference configuration



System w/ Low Cost & Flight Proven Components



- Extensive use of government owned PeaceKeeper (PK) propulsion components and already flight-qualified hardware
 - Minimal cost in hardware improvement & re-qualification
 - Hardware can be assessed right away to shorten the schedule.
- Existing flight tank design and development
- Flight operational SRM for braking stage.

Utilization of existing available hardware for low cost and low risk while meeting the mass allocation and schedule

Risk reduction: Propulsion system cold flow test

Objectives & Test Series



- Obtain parametric test data to characterize the propulsion system during the transient (waterhammer, fluid system slump), steady state pressure distribution on the feed line system.
- Obtain test data for anchoring analytical models of the propulsion fluid system in support of flight design and flight prediction.
- Verify operational performance and hardware integrity of flight propulsion components used in the test setup.
- Serve as a propulsion system mockup to evaluate the physical and dynamic interfaces with other sub-systems, specially the structure and thermal.

Test Series	Test Description
<i>System Priming</i>	<ul style="list-style-type: none"> • Burst disk will be used instead of the pyro valve. • Highest surge pressure due the initial activation of the propulsion system,
<i>Waterhammer / Slump</i>	<ul style="list-style-type: none"> • Single and multiple-thruster waterhammer tests. • Address the system dynamic response to the operation.
<i>Regulator Slam Start and Ullage Sensitivity</i>	<ul style="list-style-type: none"> • Evaluate the regulator performance with initial ullage tank volumes . • Burst disk up stream of the regulator to simulate the helium pyro valve.
<i>Representative Conceptual Usage Profile</i>	<ul style="list-style-type: none"> • Perform conceptual usage profile tests. • Provide integrated information for GNC in development of the mission profiles.

Cold flow test video



Results of the cold flow tests



- Priming test series suggested a design change of adding a small bypass line across the isolation pyro-valve for reducing pressure surge.
 - The surge pressure (>2500 psi) was exceeded the hardware pressure limited on the original feed line design.
 - Adding a small bypass across the isolation valve brought down the surge under 1000 psia.
- Waterhammer did not exceed component pressure ratings
 - Tested with all valve opening/closing scenarios and frequency ranges (25-50 Hz) as if shown on conceptual flight profiles.
- Regulator slam start tests indicated that the ullage volume can be further minimized than the value stated the regulator spec.
 - PK regulator requires a min. ullage
 - Optimizing the ullage volume if for reducing the propellant tank mass.

Propulsion system cold flow test series have provided not only considerable data to anchor the fluid flow analytical model for the future flight design, but also familiarization of propellant loading, hardware propulsion/structure integration.

Objectives

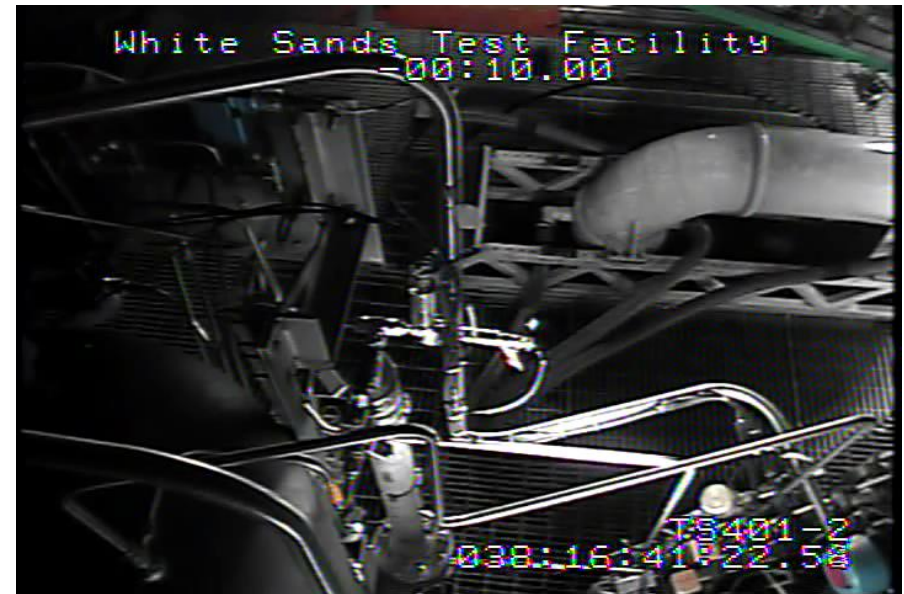
- Demonstrate the robustness of the RS-34 hardware
 - Hardware usage exceeded the service life (10 years)
 - Demonstrate leak checks and valve functional test for flight w/ minimal efforts.
- Collect additional RS34 operation data for Resource Prospector mission and other future NASA mission.
 - Operate the thruster outside of the operation qualification regime, specially the engine inlet pressure.
 - Plan to run at various duty cycles (pulse width and frequency) and long burn durations.



Test setup & conditions

- Highly instrumented with temperature sensors and pressure measurements
- Thrust and flow rate measurements for performance assessment.
- Test with various pulse width and valve operation frequencies in vacuum conditions

50 short pulses (.03 seconds ON, .05 seconds OFF)



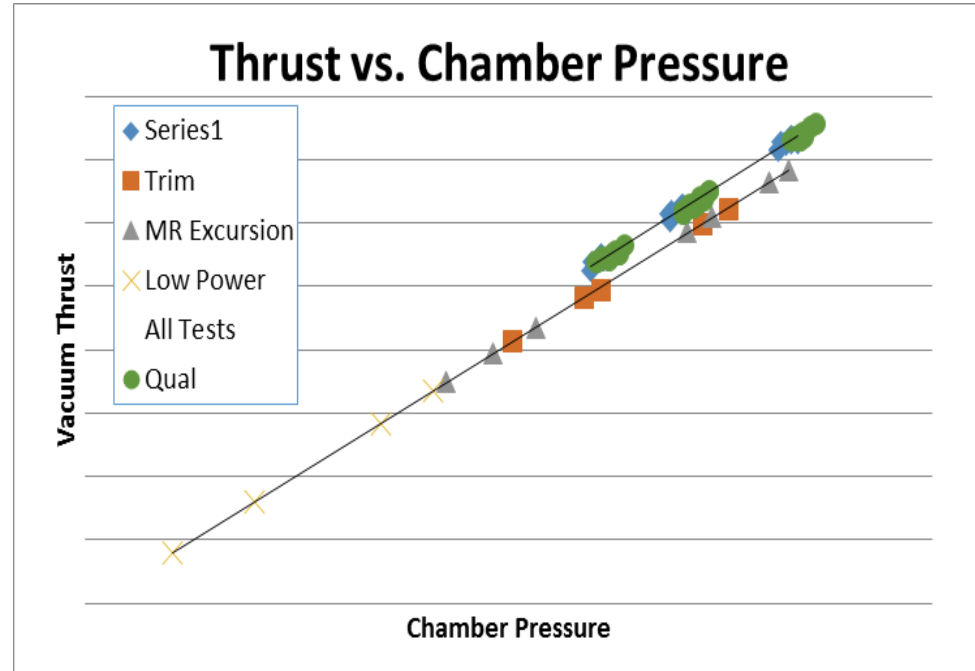
Total of 88 hot-fire tests at various duty cycles and flow rate/inlet pressure conditions.

- 6 tests on the 1st thruster and 82 tests on the 2nd unit.
- Series of pulsing and steady-stated burns derived from flight mission scenarios.

Results of the RS-34 thruster hot-fire test



- The tests results showed the engines operated as they were qualified.
 - Thruster valve was operated normally without indication of leak.
 - No issues and concerns on hardware aging at this time.
- RS-34 performed exceedingly well as expected even outside of the previous qualification regimes (MR, flow rate, and inlet pressure)
 - Isp values of 255 to 260 sec were maintained.



Thrust vs. Chamber Pressure



Summary & Conclusions

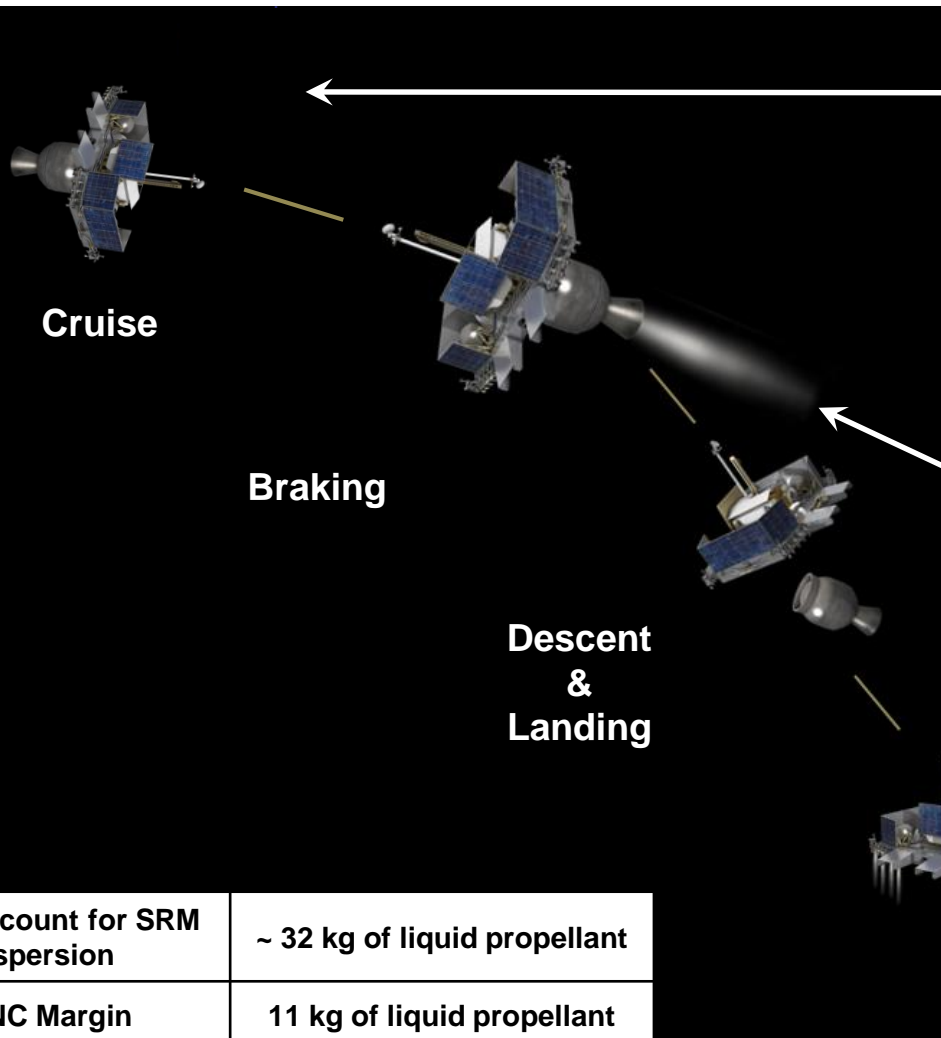
- The trade study has led to the selection of propulsion concept with the lowest cost and net lowest risk
 - Government-owned, flight qualified components
 - Meet mission requirements although the configuration is not optimized.
- Risk reduction activities have provided an opportunity
 - Implement design improvements while development with the early-test approach.
 - Gain knowledge on the operation and identify operation limit
 - Data to anchor analytical models for future flight designs
- The propulsion system cold flow tests series have provided valuable data for future design.
 - The pressure surge from the system priming and waterhammer within component operation limits.
 - Enable to optimize the ullage volume to reduce the propellant tank mass.
- RS-34 hot fire tests have successfully demonstrated of using the engines for the RP mission
 - No degradation of performance due to extended storage life of the hardware.
 - Enable to operate the engine for RP flight mission scenarios, outside of the qualification regime.
 - Provide extended data for the thermal and GNC designs.

Significant progress has been made on NASA propulsion concept design and risk reductions for Resource Prospector lander



Backup Charts

Delta-V Requirement Breakdown



Flight Phase	Engine Thrust (N)/ ISP (Sec)	Delta V (m/sec)
Trajectory Correction Maneuver	280N/255 Sec	70
AC, Spin up/down, TCM control, nutation damping	22N/294 Sec	10

Flight Phase	Engine Thrust (kN)/ ISP (Sec)	Delta V (m/sec)
<i>Braking</i>	67kN/ 292 Sec	2444

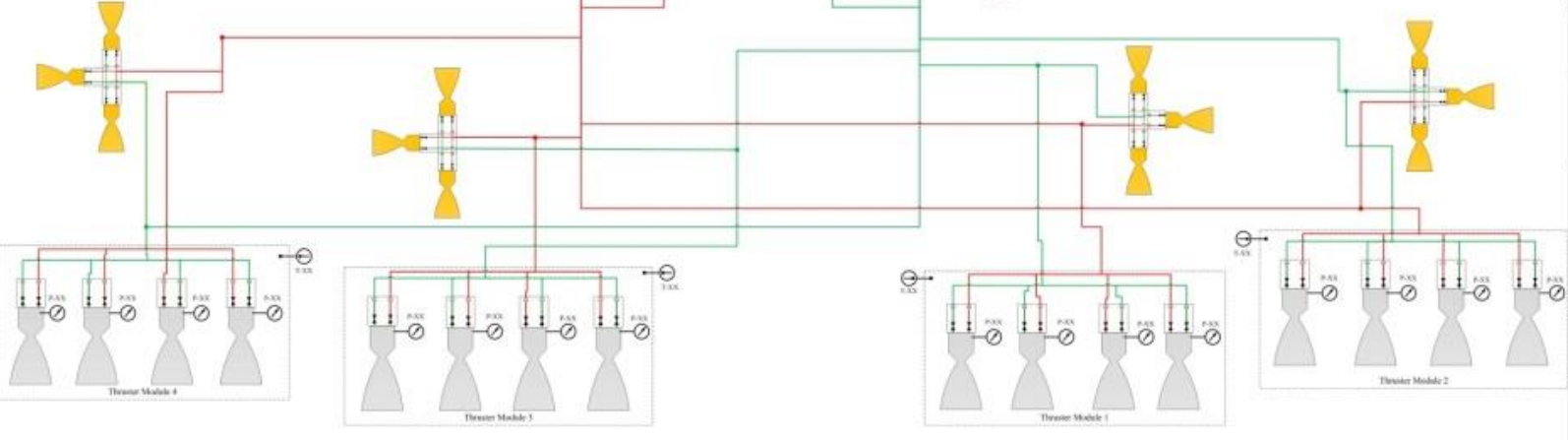
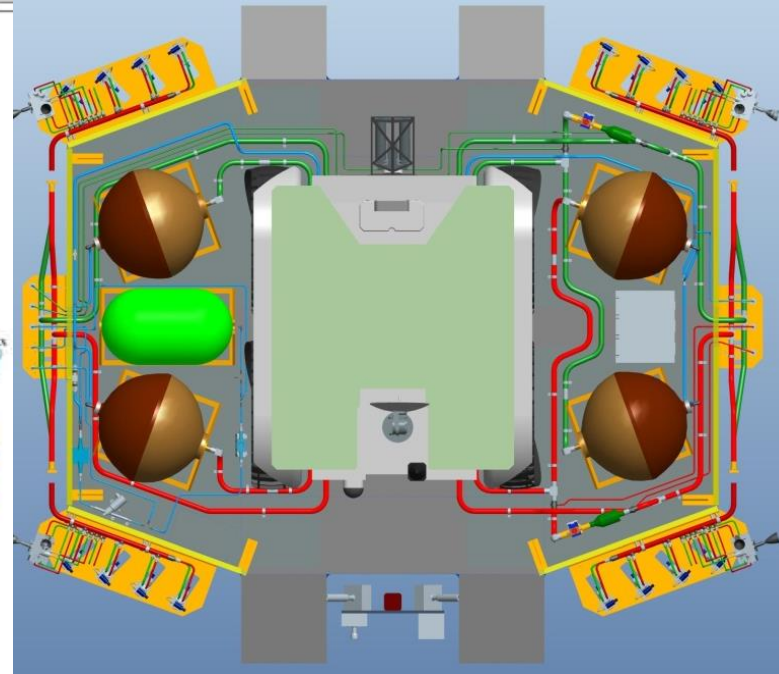
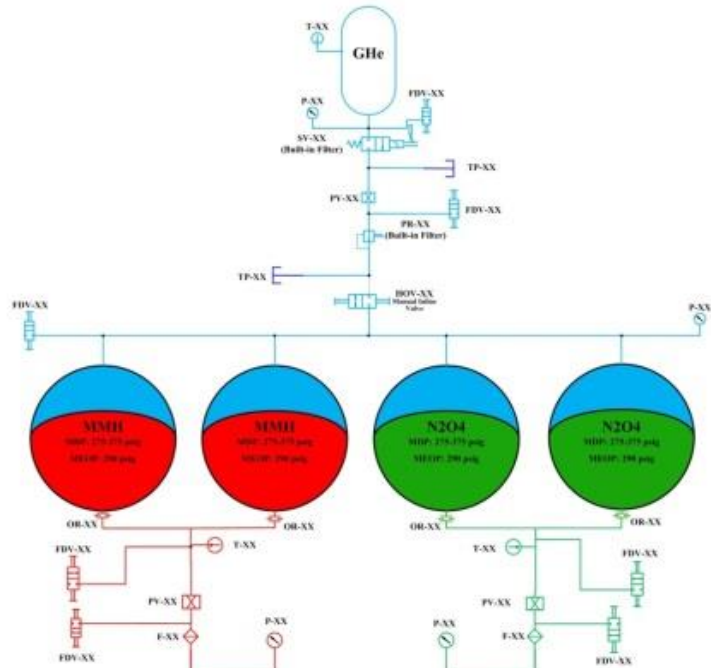
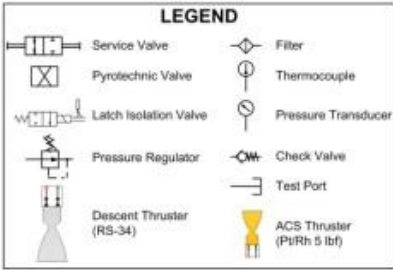
Flight Phase	Engine Thrust (N)/ ISP (Sec)	Delta V (m/sec)
Landing Site Navigation	280N/255 Sec	227.4

Account for SRM Dispersion	~ 32 kg of liquid propellant
GNC Margin	11 kg of liquid propellant

Assuming the lander mass of 3495 kg at the launch vehicle separation



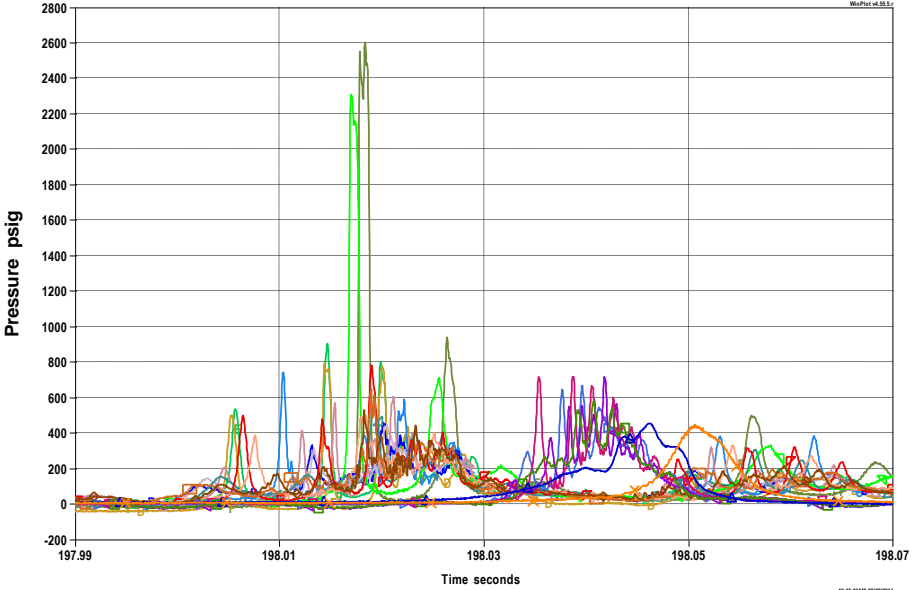
Flow Schematic of Liquid Propulsion



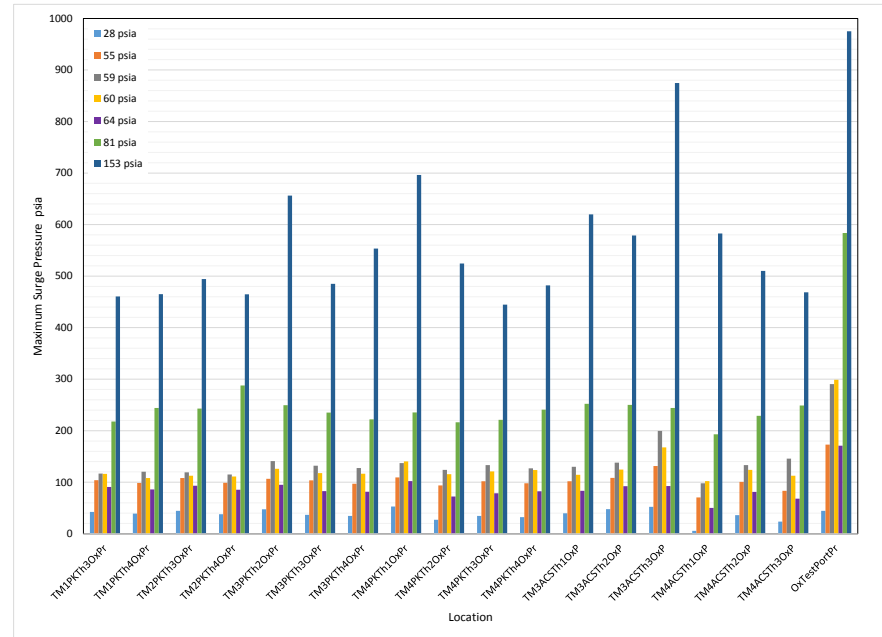
Priming test results



- Ox/DrPr-Ds psig PT03X
- OxTestPortPr psig PT05X
- TM1PKTh3OxPr psig PT13X
- TM1PKTh4OxPr psig PT14X
- TM2PKTh3OxPr psig PT23X
- TM2PKTh4OxPr psig PT24X
- TM3PKTh2OxPr psig PT32X
- TM3PKTh3OxPr psig PT33X
- TM3PKTh4OxPr psig PT34X
- [TM3ACStH1OxP]-1
- TM3ACStH2OxP psig PT36X
- TM3ACStH3OxP psig PT37X
- TM4PKTh1OxPr psig PT41X
- TM4PKTh2OxPr psig PT42X
- TM4PKTh3OxPr psig PT43X
- TM4PKTh4OxPr psig PT44X
- [TM4ACStH1OxP]-1
- TM4ACStH2OxP psig PT46X
- TM4ACStH3OxP psig PT47X

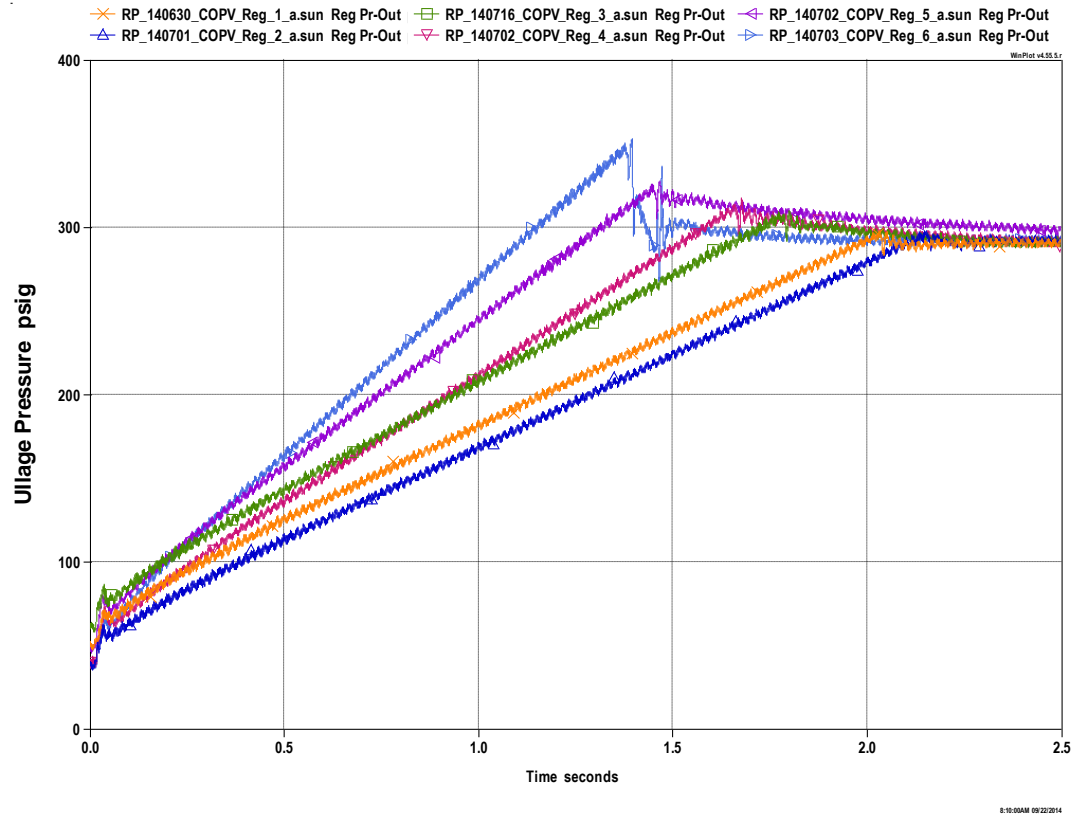


Priming surge with remotely-operated ball valve



Priming surges with bypass line

Regulator Slam Start & Ullage Sensitivities



Ullage Overshoot Pressure with Varying Initial Ullage Volumes