Launch Lock Mechanism for Resource Prospector Rover

Gabor J. Tamasy[1], Jonathan D. Smith[2,]
Robert P. Mueller[3] and Ivan I. Townsend III[4]

[1]Lead Design Engineer, Swamp Works Laboratory, NASA Design Engineering Directorate, Kennedy Space Center, Mail Code NE-M2; PH (321) 867-9445; FAX (321) 867-2758; email: gabor.j.tamasy@ksc.nasa.gov
[2]Mechanical Engineer, Swamp Works Laboratory, NASA Technology Development Directorate, Mail Code UBR-10, Kennedy Space Center; PH (321) 867-8726; email: jonathan.d.smith@nasa.gov
[3]Chief Technologist, Swamp Works Laboratory, NASA Surface Systems Laboratory, Kennedy Space Center, Robert.p.mueller@nasa.gov
[4]Lead Technologist, Craig Technologies, Mail Code ESC-853, Kennedy Space Center; PH (321) 867-9442; email: ivan.i.townsend@nasa.gov

ABSTRACT

The Resource Prospector Rover is being designed to carry the RESOLVE (Regolith & Environment Science, and Oxygen & Lunar Volatile Extraction) payload on a mission to the Moon to prospect for water ice. This is a joint project between KSC Swamp Works UB-R1 and JSC. JSC is building the Resource Prospector 2015 (RP15) rover and KSC designed and fabricated a Launch-Lock (LL) hold down mechanism for the rover. The LL mechanism will attach and support the rover on a Lunar Lander during launch and transit to the moon, then release the RP15 rover after touchdown on the lunar surface.

This report presents the design and development of the LL mechanism and its unique features which make it suitable for this lunar exploration mission. An EDU (engineering development unit) prototype of the LL has been built and tested at KSC which is the subject of this paper.

INTRODUCTION

The Resource Prospector (RP) is a scientific suite of instruments which NASA plans to fly to near the Moon's South Pole to explore for the presence of water and other volatiles and possible useful resources. In the permanently shadowed craters previous instruments have indicated the presence of sub-surface water ice. The RP instrument will be mounted on a rover which will navigate the terrain to transport the RP to prospecting sites where the RP will drill down into the regolith and retrieve samples. The figure below shows the prototype rover build and being tested at JSC.

The JSC Resource Prospector Rover (RP15)

The RP Rover will be launched on a rocket attached to the top of a lunar lander. Once in lunar orbit the lunar lander will detach from the rocket and descend to the landing site on the lunar surface. Once on the lunar surface it will deploy a ramp and the LL will release the rover which can descend to the surface and begin its scientific exploration mission.

DESIGN

The design of the LL mechanism started with defining the requirements and performing a trade study to identify the best candidate technologies to meet the requirements.

REQUIREMENTS AND TRADE STUDIES

This is the list of the major functional requirements for the LL Mechanism, some of which are assumed requirements due to lack of detailed mission definitions, these are indicated by TBR (to-be-required) and TBD (to-be-determined) notation:

The LL Mechanism deliverable is an Engineering Development Unit (EDU) for launch lock mechanism to attach the Resource Prospector Rover carrying Resolve to the deck of a Lunar Lander. The EDU LL will be delivered and field tested at JSC.

- LL project supports Resource Prospector Rover Technology Development.
- LL project follows KDP-P-2723 Streamline Design Review Process for hardware.
- LL is a Technology Readiness Level (TRL) 4 project, some components and subsystems may reach TRL 5.
- LL is a flight like EDU proof of concept prototype. Future upgrades and modifications are aimed at developing a flight ready launch lock.

Project Level Requirements

1. Rover + payload net launch mass no greater than 325kg
2. Component mass:
   2.1. Max weight of Rover: 170 kg (374.78lb)
   2.2. Max weight of Payload: up to 105 kg (231.5 lb)
3. Total weight: 275 kg (749.56 lb)
4. The rover shall be designed to withstand a 10 day (TBR) launch period.
5. Survive pre-egress on lander for up TBD (6-24) hours
6. Interface to the Payload and Lander per relevant ICD (Interface Control Document) (TBD)
7. Launch Loads

From Delta IV users guide Section 3.2.4, maximum acceleration loads expected during launch.

   7.1. 6.5g vertical compression
   7.2. 2g tension
   7.3. +/-2g lateral

System level Requirements

Mechanical

1. Be resettable for repeated testing.
2. Attach to rover in 4 locations at corners of chassis.
3. LL Mechanism height range 4in – 7in above lander deck.
4. Attach to lander on flat deck surface.
5. Allow for thermal distortion of lander/rover surfaces.
6. Safe operation: Not to release prior to command, but always release when commanded.
7. Leave (TBD) diameter area centered under the rover open.
8. LL component shall not reduce the ground clearance of the rover.
9. Design stress margins 1.5 yield 2.0 ultimate stress for all mechanical components (TBR)

Electrical

1. The LL shall operate with 28VDC, (TBD) Amp power
2. The LL shall have feedback sensors/switches to indicate latched/unlatched position.
3. The LL shall not produce EMI
4. The LL shall receive power and command from the Lander electrical control system.

Environmental

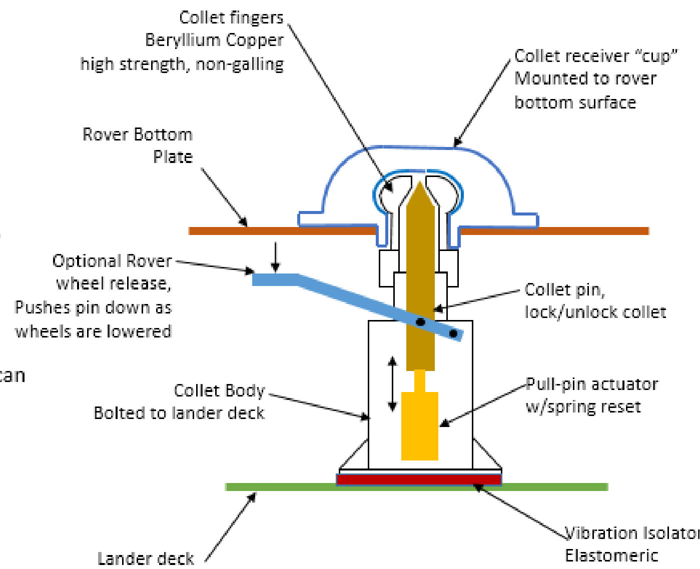
1. Resist dynamic loads during launch and ascent of Delta IV Medium Class launch vehicle. (Included in backup slides)
2. Operating Temperature range: 32-120°F Earth ambient to (TBD) Lunar surface.
3. The LL shall not produce contamination in the form of particles or outgassing.

With these preliminary requirements as a guide a thorough trade study and concept brainstorming review was performed to identify and select the best candidate technologies suitable for the application. The trade study was developed in a presentation format for ease of communicating with the design team and management and included the following information on LLMs (launch lock mechanisms):

LLM Concepts

4.1 Collet Latch

- Main Features
  - Recessed cups in Rover Corners (near suspension mounts)
  - Pedestal configuration with 4-collet posts bolt to lander deck.
  - HOP pin-puller actuators very reliable non-mechanism
  - Actuate to pull pin and release/insert collet
- Pros.
  - Can be preloaded
  - Oversized holes for engaging to rover (ease of alignment)
  - Engagement surface can be spherical to tolerate angular misalignment
  - Failsafe rover wheel actuation can be incorporated
  - 4-identical posts reduce cost, testing, and risk.
- Cons.
  - 4 independent actuators, 4 possible failure points.
  - Sliding under load extraction of collet pin (use bronze fingers with Nitronic pin to avoid galling)

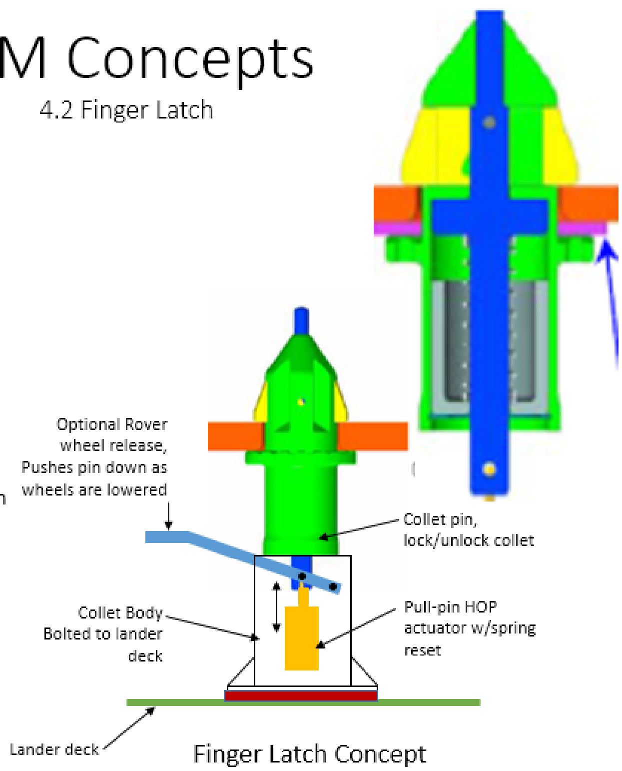


Collet Latch Concept

LLM Concepts

4.2 Finger Latch

- Main Features
  - Similar latch to 2.2 "Payload Latch"
  - Support posts at 4-corners
  - HOP pin-puller actuators very reliable non-mechanism
  - Pull pin to release, spring reset
- Pros.
  - Simple mechanism.
  - Load perpendicular to latch
  - **Only requires hole in rover deck.**
  - Tapered pin for ease of alignment, insertion.
  - Failsafe rover wheel actuation can be incorporated
  - 4-identical posts reduce cost, testing, and risk.
- Cons.
  - Preload is problematic.
  - Release under load is potential issue if lander deck distorts and loads latch.

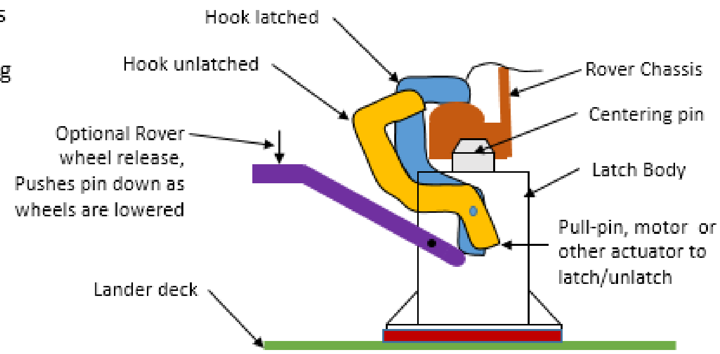


Finger Latch Concept

LLM Concepts

4.3 Hook Latch

- Main Features
  - Support posts at 4-corners
  - Centering pin locates and reacts shear loads
  - Hook rotation can be done using push/pull actuator, or motor rotation
  - Rover wheel secondary release possible
- Pros.
  - Simple one axis pivot mechanism.
  - Load perpendicular to latch
  - Tapered pin for ease of alignment, insertion.
  - Failsafe rover wheel actuation can be incorporated
  - 4-identical posts reduce cost, testing, and risk.
- Cons.
  - More complex rover deck features.
  - Release under load is potential issue if lander deck distorts and loads latch.

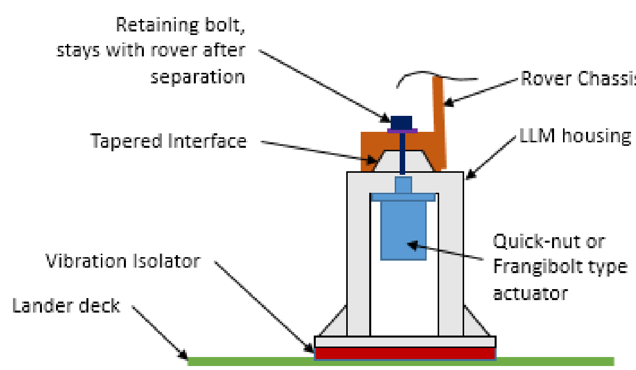


Hook Latch Concept

LLM Concepts

4.4 Bolted Connection released with quick-nut or frangible bolt

- Main Features
  - Support posts at 4-corners
  - COTS SMA quick-nut or frangible bolt actuator
  - Tapered interface aids location and takes shear loads.
  - Bolted connection to rover.
- Pros.
  - Simple COTS mechanism.
  - Axial load/preload with threaded fastener easy to set and verify.
  - Resettable actuator.
  - No special mechanism
  - Simple rover interface
  - Lower cost than custom mechanism.
- Cons.
  - 4-cots actuators needed.
  - Frangible bolt is consumable and hard to reset.



Bolted Connection Concept

LLM Concepts

4.4 Bolted Connection released with quick-nut or frangible bolt

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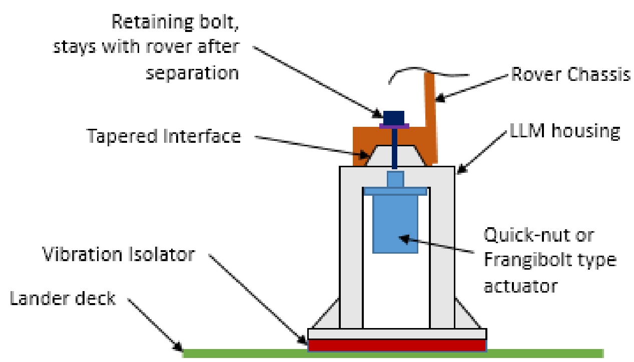
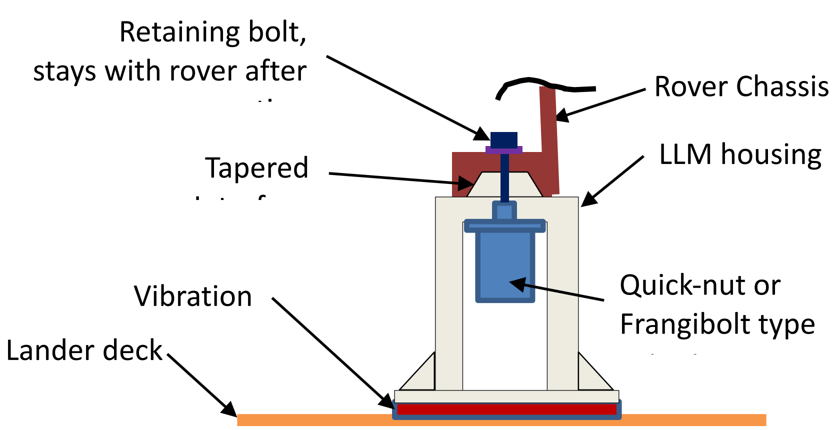


Bolted Connection Concept

After careful engineering review and consideration of these concepts the one presented in (4.4) “Bolted Connection release with quick nut or frangible bolt SMA” was selected (shown in the graphic below). SMA stands for Shape Memory Alloy which is the release mechanism with the most beneficial features for this application.



LL Concept selected from trades study

This concept has many advantages including:

- Meets all the functional requirements.
- Fits with the rover and lander geometry.

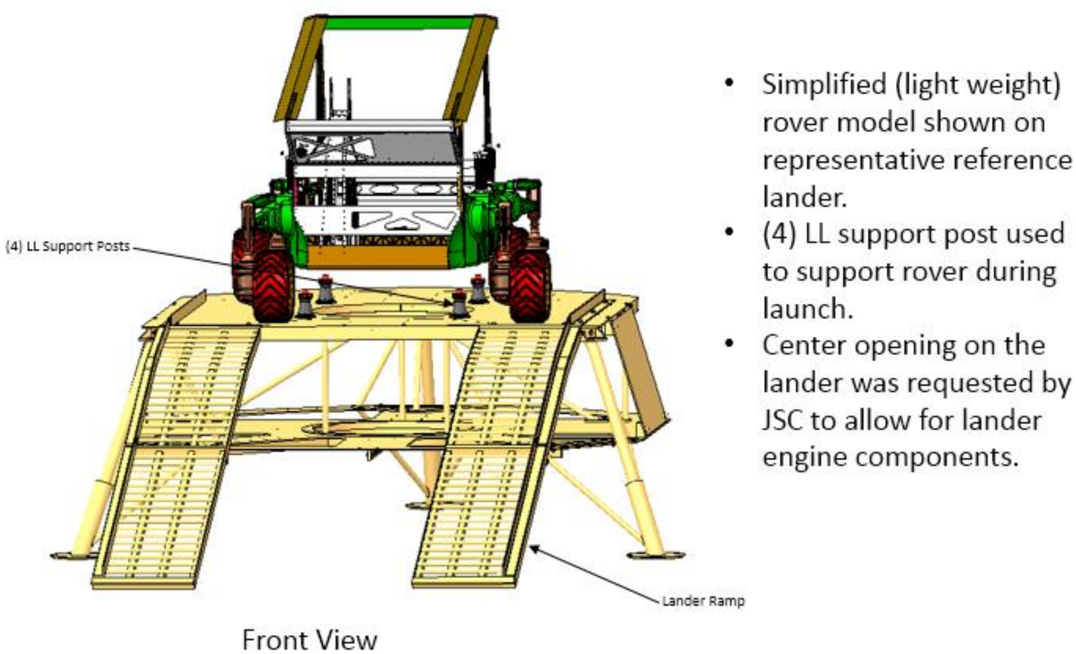
- Robust and high reliability design with low part count, ease of fabrication, installation, and lower cost.
- Hold down preload can be controlled to avoid separation at high G-loads.
- Uses a space qualified COTS (commercial off-the-shelf) SMA actuator which is resettable for repeated use during testing.

DETAILED DESIGN

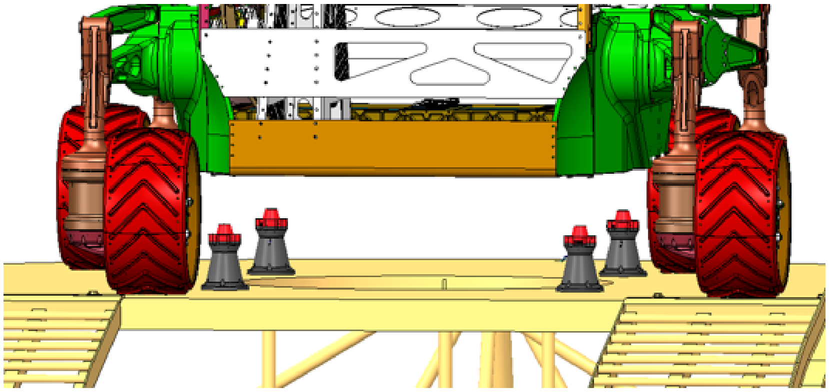
The next step was to develop a CAD model of the LL Mechanism and its interfaces to the Lander and to the rover. The main features of the design are described below in presentation format which illustrates efficiently the highlights of the design.

To reduce the computational burden of working with large models, a simplified 3D model of the rover and the lander was used shown in the screen shots below. This model could be used to realistically model the interface between the rover and lander and was useful for the LL design.

This CAD design work was done on the collaborative JSC engineering server (Windchill) and used the latest rover models which were in the design process by the JSC engineers. So the rover and LL designs proceeded in parallel and coordinated the interface features as the designs evolved.

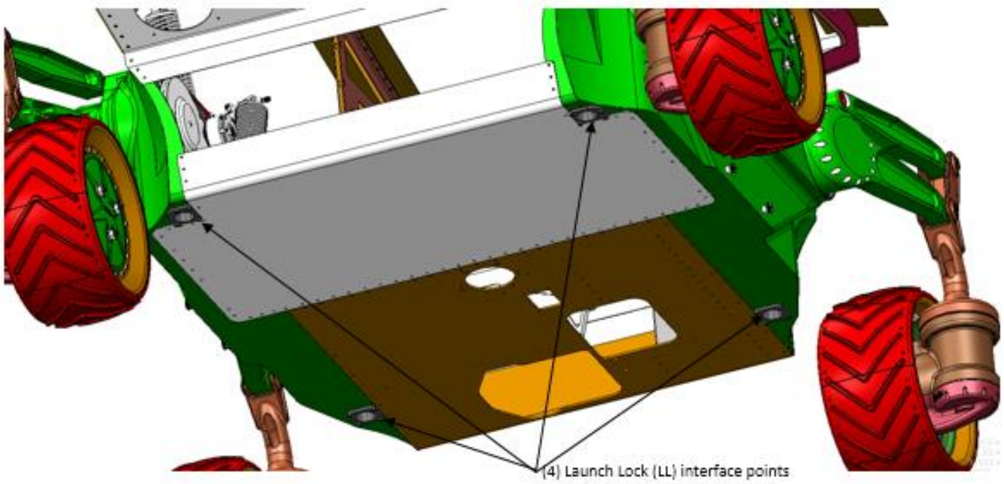


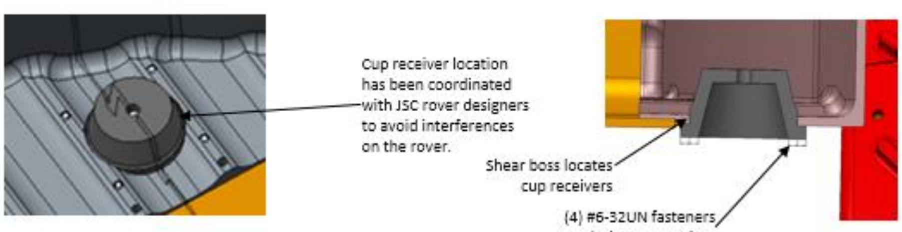
LL Rover/Lander Interfaces



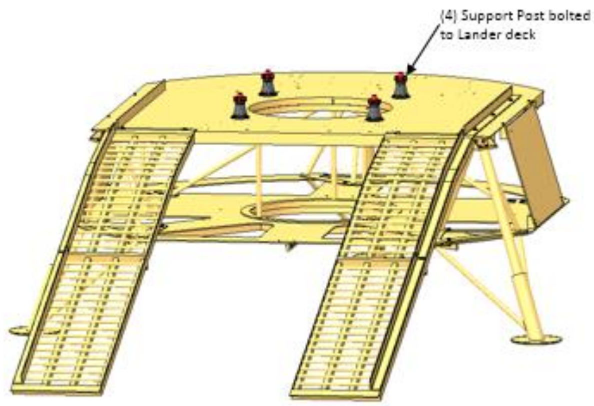
- Front view showing rover raised off LL support posts.
- This would be the configuration after LL release and rover stand up.
- During launch the rover would be down sitting on the LL posts and the wheels raised of lander deck.

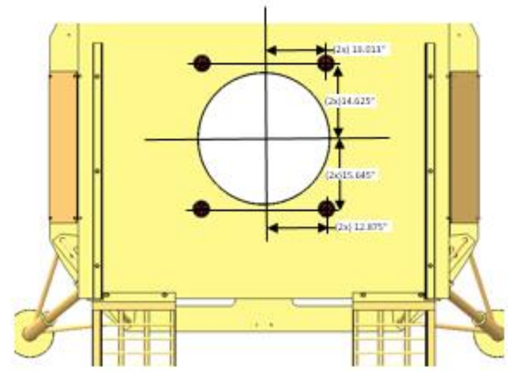
Rover Interfaces





Lander Interfaces

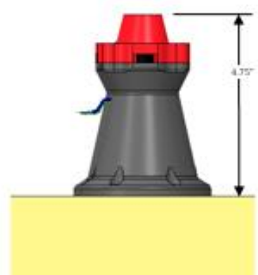


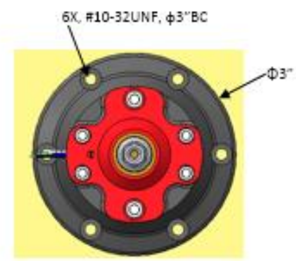


Approximate worst case launch loads at each post:

- 6g compressive 1165 lb
- 2g tensile 358.4 lb
- +/- 2g lateral

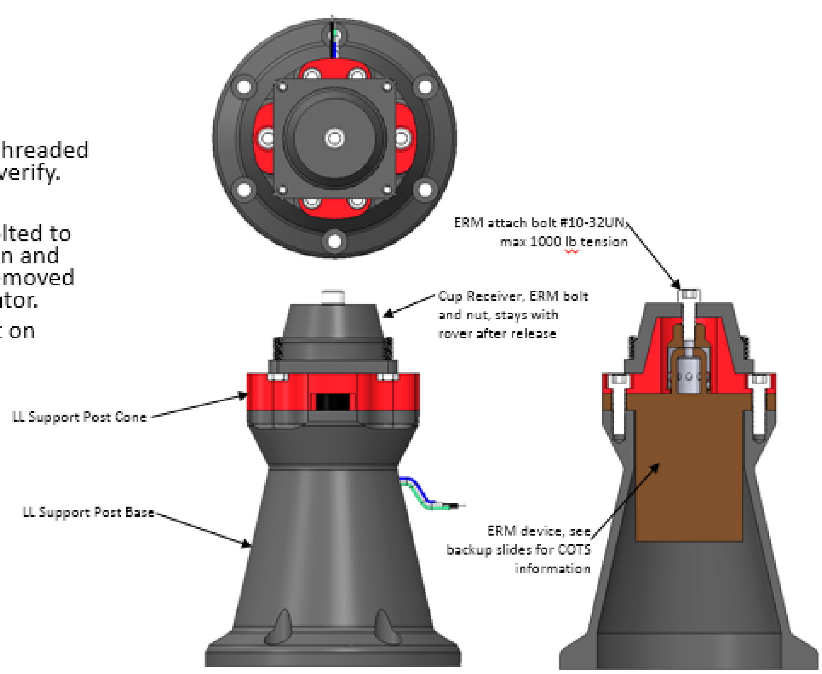
Note: this assumes even distribution of loading among the 4 posts. Further analysis will be required after rover CG location is more accurately known.





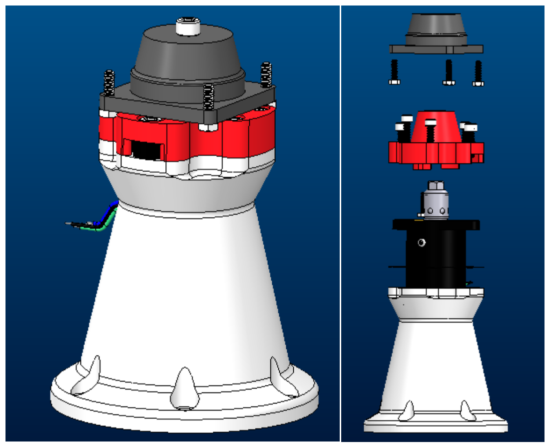
LL Support Post Assembly

- Main Features
  - ERM SMA actuator
  - Resettable actuator.
  - Axial load/preload with threaded fastener easy to set and verify.
  - Simple rover interface
  - Tapered cup interface bolted to rover chassis aids location and takes shear loads. Cup removed from rover to reset actuator.
  - Cup/post assembly - bolt on together after reset.



FABRICATION AND TESTING

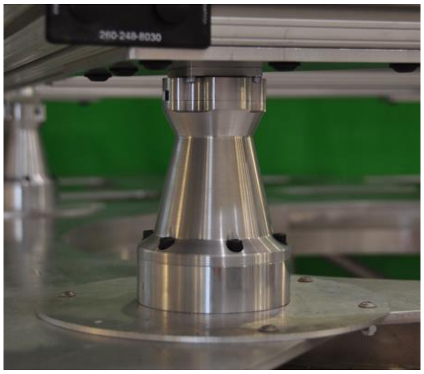
So the final design of the EDU LL mechanism consist of (4) support post assemblies. Each support post has (3) fabricated components and (1) SMA Ejector Release Mechanism (ERM), as shown in the graphic below.



EDU LL Support Post Assembly

These components were designed by KSC Swamp Works UB-R1 and fabricated by KSC Prototype Lab. A flight certified TiNi Aerospace Inc. ERM, part number E1000, was used as the actuator to hold down and release the rover on command.

The picture below shows the fabricated parts which were made out of Aluminum 6061-T6 alloy. The finished parts were hard coat anodized (not shown in the picture which is just the bare aluminum parts).

Installed Launch Lock Support Post   Launch Lock Post Components

Functional checkout and testing was performed at Swamp Works Laboratory using a mock lander and mock rover before sending the mechanisms to JSC for concept of operation testing. The testing proceeded according to an initial Con-ops (shown below) developed to simulate the realistic operation of the LL from installation to release.

Initial Concept of operations (Con-ops)

The following sequence of steps were planned to test and demonstrate the LL.

1. In preparation for LL installation or testing the receiver cup "hold down screw" is installed with a predetermined preload to the top of the post and into the ERM (Eject Release Mechanism) nut, see diagram in the LL concept section.
2. The rover is positioned on top of the lander centered over the (4) LL mechanisms
3. The rover is lowered until the (4) LL conical receivers engage the holes in the rover chassis
4. The (4) screws (#6-32UN) which attach the receiver cup to the rover are installed and torqued.
5. When the release command is given the ERMs release the hold down screw retaining nut, which separated the LL post and cup.
6. The rover is commanded to stand up. The receiver cup and hold down screw go with the rover.
7. Rover can drive off lander ramp to commence its science mission.

Test configuration of mock up lander with mock rover supported by Launch Locks

Testing confirmed that the LL mechanism works very reliably to release the rover over many repeated cycles. It showed the mechanism is easy to reset for multiple testing. And it verified that the design was successful in meeting the functional requirements of the project.

AS the Resource Prospector project moves forward the LL will continue with the evolution and testing of the EDU with follow on designs and testing of the LL mechanism. Follow on testing such as vibrio acoustic, and environmental will further validate and eventually certify the design for flight.