Lunar In-Situ Landing / Launch Environment (LILL-E) Pad

LSIC Dust Mitigation Focus Group

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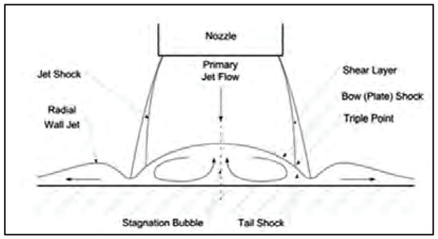
Overview

- Problem Statement
- System Overview
- Potential Stakeholders
- Systems Engineering
- Landing/Launch Pad (LLP)
- Anchors
- POlymer Nozzle Distribution (POND) Area
- Verification Testing
  - Cold Gas
  - Anchor Pull Testing
  - Vacuum Chamber Testing
  - Masten Plume-Surface Interaction
- Results /Conclusions

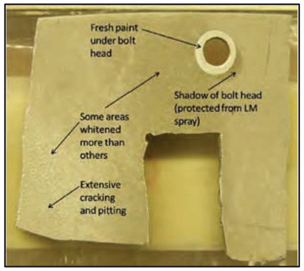
Problem Statement

High-impact launch/landing events on the lunar surface produce significant shear forces and temperatures. These events, compounded by the vacuum and reduced gravity environment, propel exceedingly abrasive regolith ejecta at velocities sufficient to sandblast local infrastructure. Development of a solution must mitigate regolith ejecta and withstand the significant shear forces and temperatures.



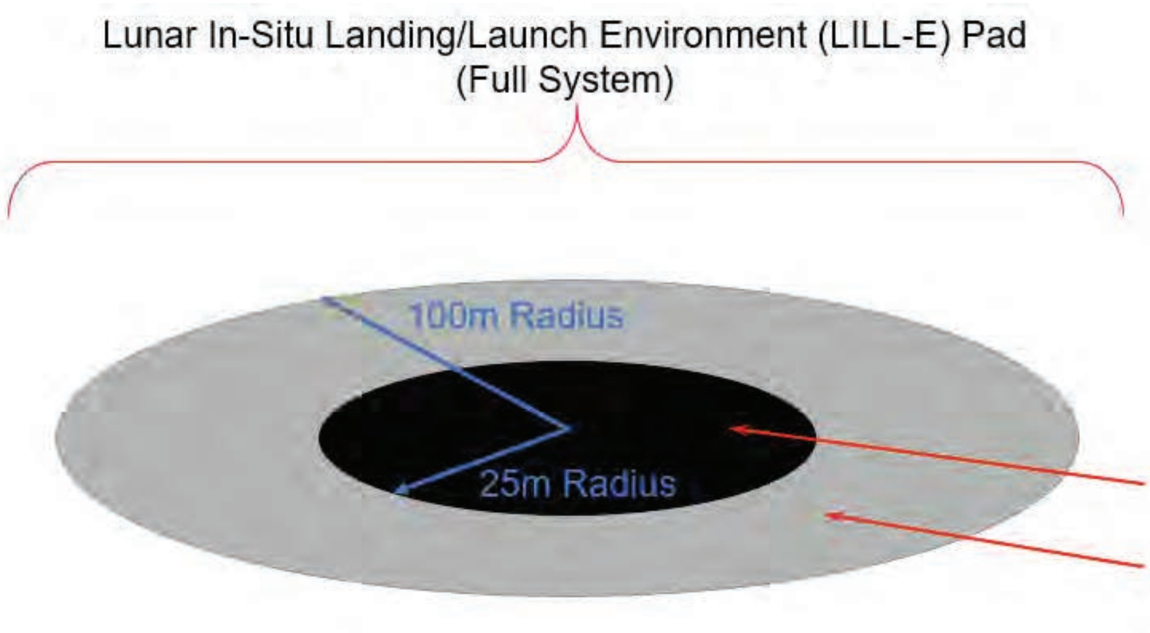
Plume-Surface Interaction Shock Structure (Source: Mehta)


Apollo 15 Surface Erosion During Landing (Source: UCF CLASS)



Surveyor 3 Damage (Source: Immer)

System Overview



Systems Engineering: Requirements

- Level 1 Requirements
  - The LILL-E Pad System shall mitigate 92% of dust ejecta during a nominal landing event
  - The LILL-E Pad System shall mitigate 75% of dust ejecta during an off-nominal landing event
  - The LILL-E Pad System shall function for both a landing event and a launch event

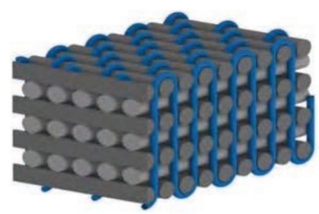
Landing/Launch Pad (LLP)

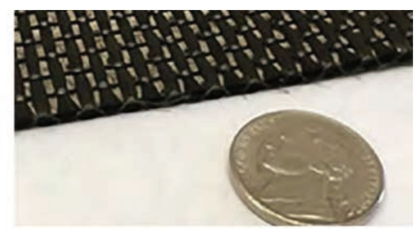
COMPOSITE APPLICATIONS GROUP

TEXTECH INDUSTRIES

- 3 carbon fiber blanket layups
- Mark II & III
  - Incident Face: Oxidized polyacrylonitrile (OPAN) felt
  - Middle Layer: Plain weave pitch carbon or 3D carbon fabric
  - Back Layer: Silica felt and glass scrim as insulation
- Mark IV is 3D carbon fabric only
- *Note:
  - Combustion of OPAN produces hydrogen cyanide (HCN)
  - Levels are considered low in this application (20 ppm)

Material	opsy	Mark II	Mark III	Mark IV
OPAN Felt	5	X	X	
(8) Layers of PW Pitch Carbon Fabric	57	X		
3D Carbon Fabric (Style 3D-10009)	58		X	X
Silica Felt	14	X	X	
Glass Scrim	2.4	X	X	
Silica Felt	14	X	X	
Glass Scrim	2.4	X	X	
Total Mass per Area (opsy)		94.8	95.8	58
Total Mass per Area (kg/m²)		3.21	3.24	1.96

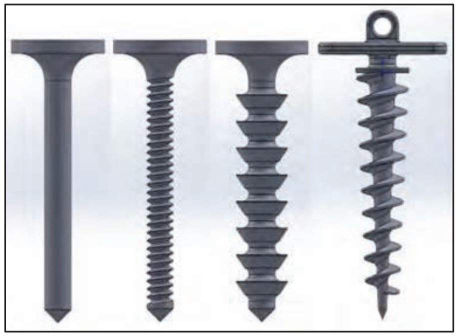




(Source: Tex Tech Industries)

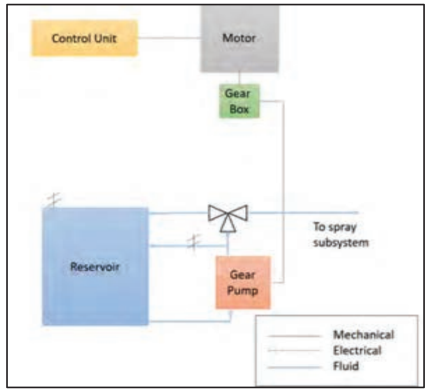
Anchors

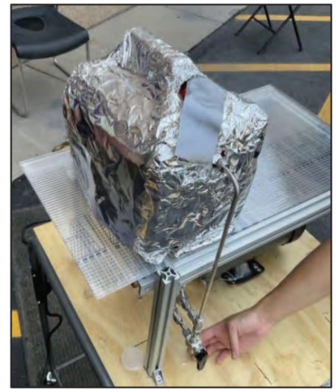
- Custom anchors were designed to hold LLP samples to potential test-beds
- Four iterations of a basic anchor design went through lab-scale testing before a final variant was selected for machining
- In order to ensure survival of the anchor through multiple Masten PSI tests, anchors were fabricated out of 303 stainless steel

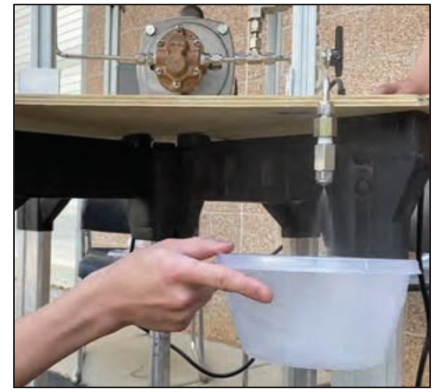


POND

- Initially proposed as 2 part (A-B) resin with pressure feed
- Revised to single part UV cure with pump
- Top row shows P&ID, prototype system, and waterflow testing
- Bottom row shows regolith application test, spray cone calibration, and sunlight UV cure test

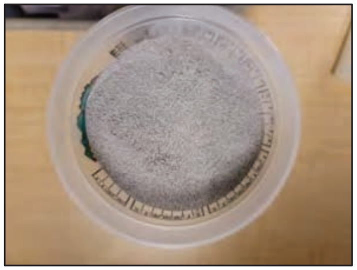






Verification Testing

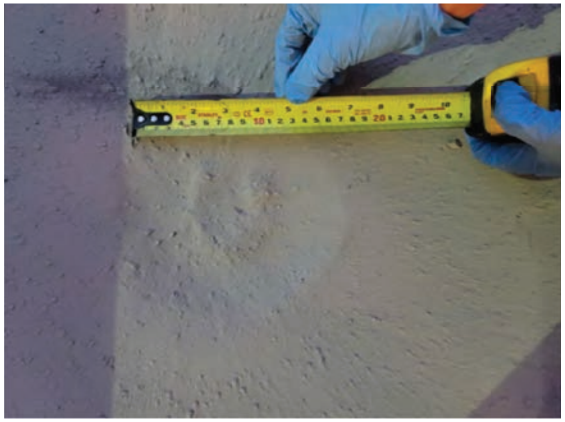
- Developed requirements and verification matrix
- Relevant environmental conditions
  - Simulant
    - CSM-LHT-1
    - BP-1
  - Vacuum
  - Rocket plume
- Primary Tests
  - Cold gas
  - Anchor pull testing
  - Vacuum chamber
  - Masten plume-surface interaction test stand (static & dynamic)



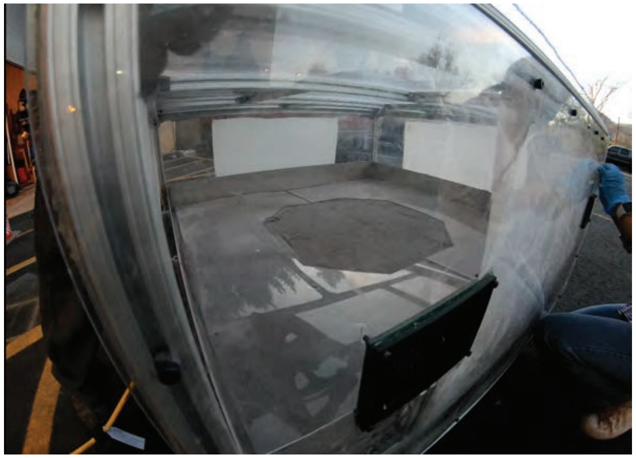
MASTEN

Verification Testing: Cold Gas

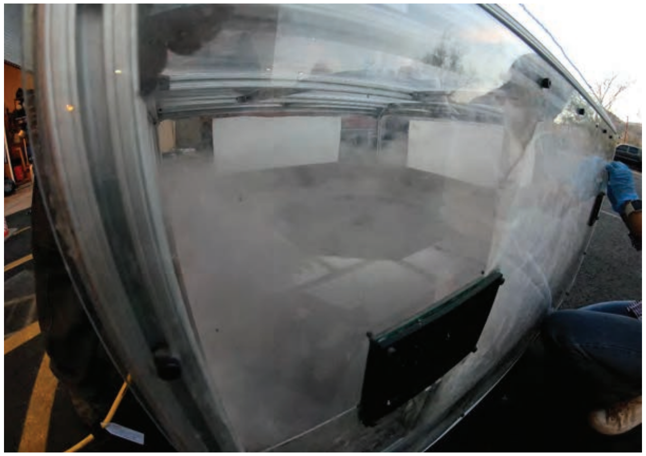
- LLP Mark II, III and IV were placed inside the testing chamber and fired once with 50 psi and 100 psi of cold gas air each.
- No POND was present during this testing
- There was a baseline test to evaluate the amount of regolith kick-up without the presence of a blanket.
- Some blankets had previous damage from Masten plume testing.
- There was minimal to no regolith kick-up with the blankets and no craters left behind.
- Next slides will display photos of baseline and LLP Marks II, III and IV results



Verification Testing: Cold Gas



Before



During

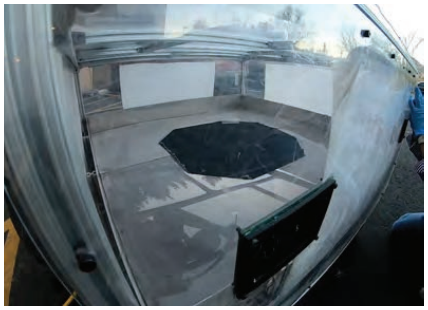
After

Baseline Test Results @ 100 psi

Verification Testing: Cold Gas

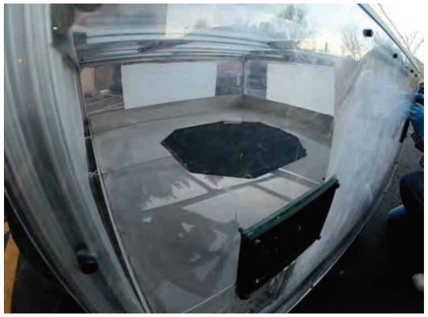
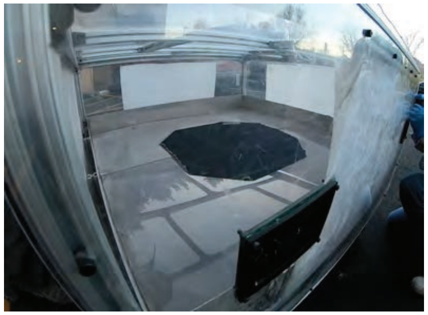
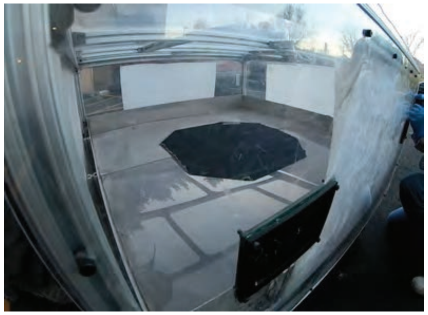
Mark II Test Results @ 50 psi





Before *During* *After*

Mark II Test Results @ 100 psi

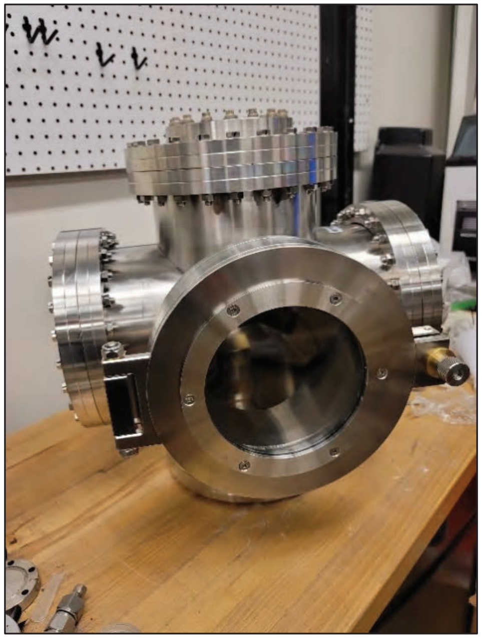
Verification Testing: Anchor Pull Test

- Anchors were subjected to lifting force (orthogonal), and sheer force (lateral), measured with a digital force gauge
- 264 total tests were completed, with the best performing anchor chosen for more robust fabrication (Shank Pile)

Anchor Type:	Buried length (cm):	Shaft Diameter (cm):	Mass (PLA) (g):	Mass (Aluminum) (g):	Maximum orthogonal force value (N):	Maximum lateral force value (N):
Simple Pile (Anchor 1)	19.06	2	98	290	72	132
Helical Pile (Anchor 2)	19.06	2 (Including threads)	94	243	70	124
Shank Pile (Anchor 3)	19.06	2 (Excluding threads) 3.914 (Including threads)	178	362	147	421
Auger Screw (Anchor 4)	19.06	Variable	112	308	144	400

Verification Testing: Vacuum Chamber

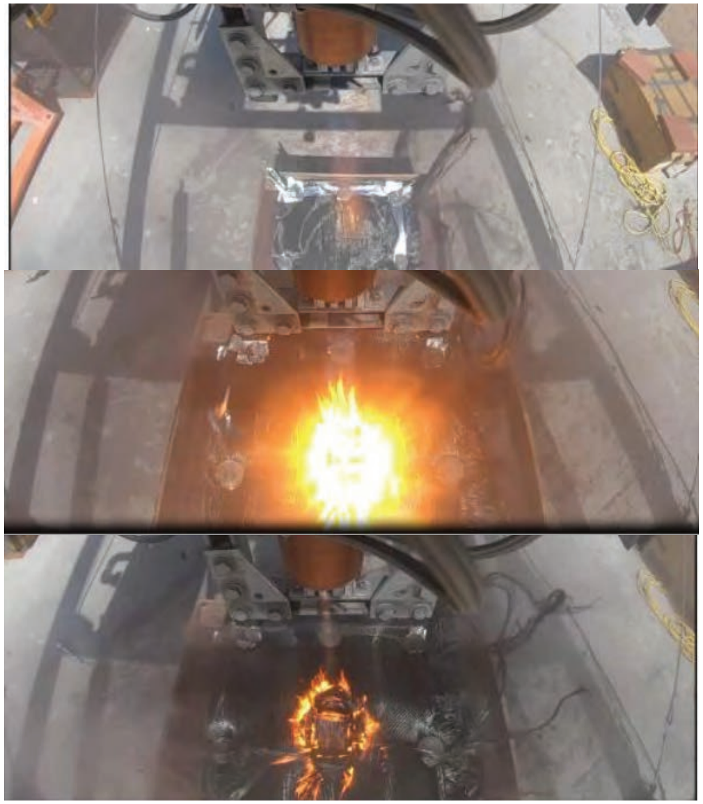
- In order to test the POND system in vacuum conditions without impairing other teams in the CSM CSR Lab, a custom, small form factor vacuum chamber was constructed
- The vacuum chamber will be used for further testing of the following areas:
  - ATI Resin spray pattern and flow rate in vacuum
  - ATI resin cure time and strength, after application in vacuum
- Vacuum chamber has been designed draw pressure down to at least $1*10^{-7}$ Torr for all future tests
  - $1*10^{-7}$ Torr reachable within 10 minutes
  - Internal volume for spray testing is approximately 15,500 cm^3, depending on nozzle spray height



Verification Testing: Masten Plume-Surface Interaction (PSI) Test Stand

Verification Testing: Masten Plume-Surface Interaction (PSI) Test Stand

- Four Static Tests
  - 1-2 seconds
  - 18” or 38” engine height
  - Mark III
  - Mark II with center anchor
- Three Dynamic Tests
  - 3 seconds
  - 104” to 27.5” engine height
  - Mark III
  - Mark II double layer
  - Mark IV four-layer fold [Best Results]



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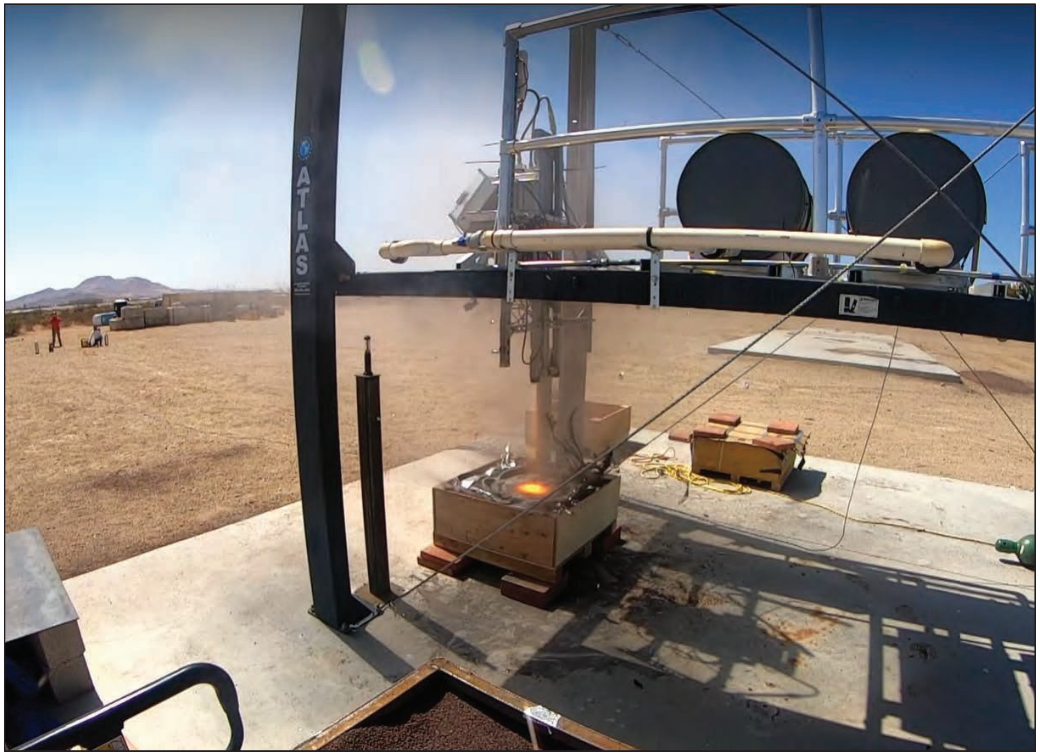

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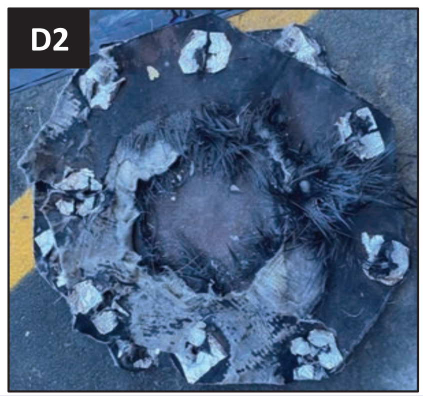


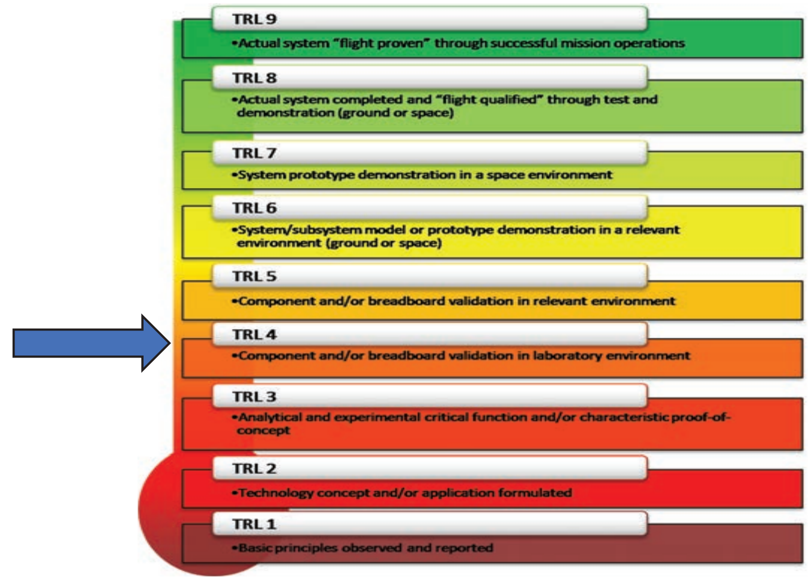
Verification Testing: Masten Plume-Surface Interaction (PSI) Test Stand

- **Third Dynamic Test – D3**
  - Mark IV Blanket Quadruple Layer
  - 104” to 27.5” Engine Height Range
  - 3 Second Fire
  - Larger Blanket with More Coverage

- **Result**
  - Top Two Layers Damaged
  - Bottom Two Layers Little to No Damage
  - Ballooning of Top Two Layers

Results / Conclusions

- LLP
  - Mark III and IV performed best
  - Added layers to improve functionality
  - Survived landing; Launch survivability requires further development
  - Minimal dust generated from gas permeation
- Anchors
  - Secured the during hot fire testing
  - Performance better than expected
- POND
  - Promising early results
  - Further POND + LLP system testing required
- POND Distribution System
  - Proved basic functionality
  - Testing in vacuum with resin required



- Level 1 Requirements – "The LILL-E Pad system shall…"
  - mitigate 92% of dust ejecta during a nominal landing event
  - mitigate 75% of dust ejecta during an off-nominal landing event
  - function for both a landing event and a launch event

Thank You!

Q & A

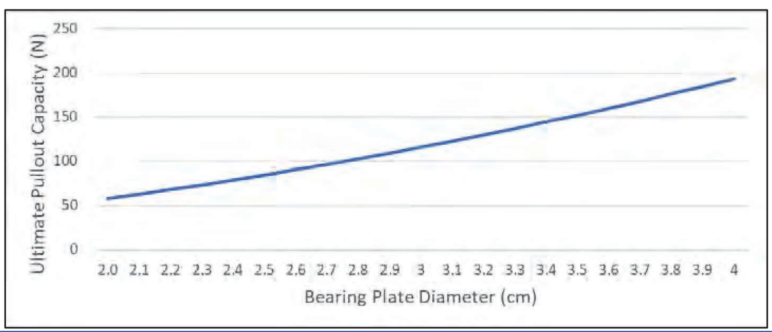
Backup Slides

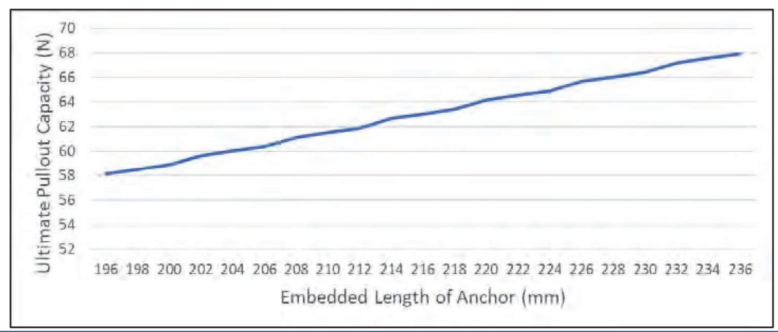
Systems Engineering: Risks

Risk:	Completed/Planned Risk Mitigation Testing Regime:
“The system will not deploy correctly”	Systems Engineering ConOps development
“The LLP will come loose during a nominal or off-nominal landing/launch event”	Anchor Pull Testing
“The lunar vacuum environment will adversely affect the spray characteristics of the resin”	Vacuum Chamber Testing
“The lunar vacuum environment will inhibit proper curing of the resin”	Vacuum Chamber Testing
“The lunar vacuum environment will cause the POND resin to off-gas significantly before it can cure”	Vacuum Chamber Testing
“The LLP and POND will not interface correctly”	Masten Plume-Surface Interaction (PSI) Test Stand
“The LLP/POND material will deteriorate during a landing/launch event”	Masten Plume-Surface Interaction (PSI) Test Stand
“Gas permeation through the LLP will result in lofted regolith or excessive movement of the blanket”	Cold Gas Testing, Masten Plume-Surface Interaction (PSI) Test Stand
“The LLP will come loose during a nominal landing/launch event”	Cold Gas Testing, Masten Plume-Surface Interaction (PSI) Test Stand

Anchors

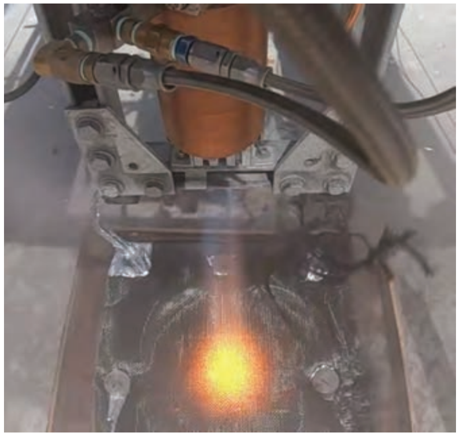
- Three primary factors influencing how well an anchor will hold:
  - Number of bearing plates
  - Diameter of the bearing plates
  - Depth of anchor deployment
- Large diameter bearing plates were favored for this design
  - Reduces the mass of the anchors
  - Testing bin depth did not allow for long length anchors to be used





POND

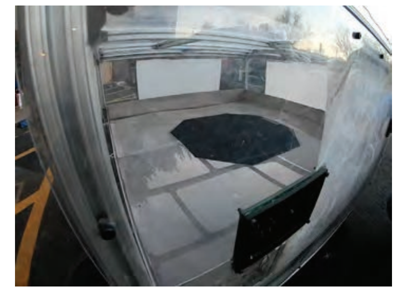
- Logistical requirements of testing required application by hand at test site (upper left)
- Upper right shows full LLP and Pond assembly
- Bottom left shows hot fire test
- Bottom right shows Pond fragment sample after testing (illustrating thickness and mechanical properties)



Verification Testing: Cold Gas

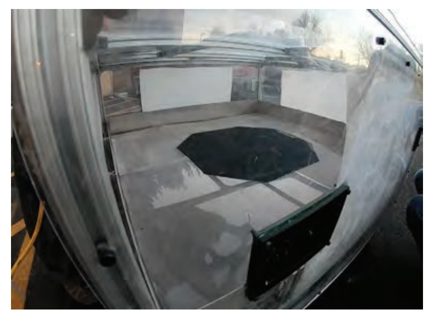
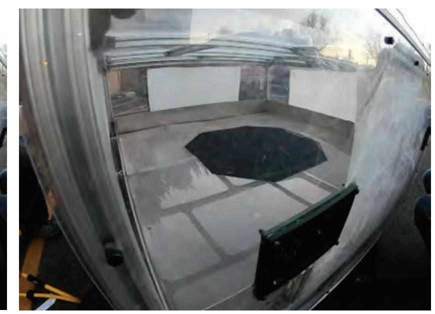
Mark III Test Results @ 50 psi





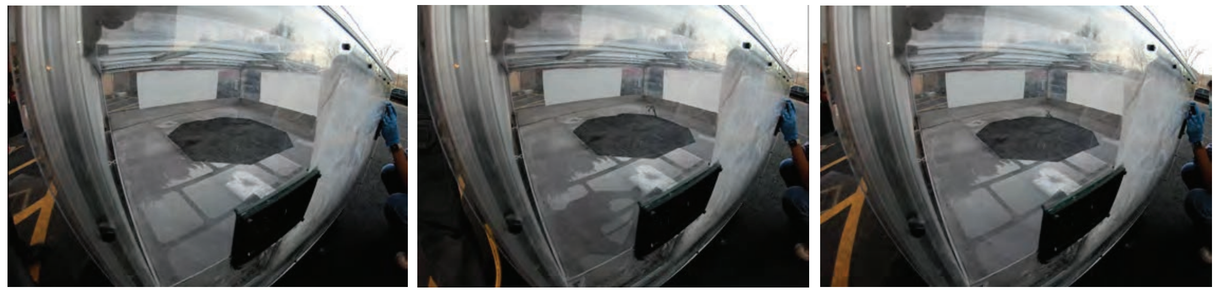
Before *During* *After*

Mark III Test Results @ 100 psi

Verification Testing: Cold Gas

Mark IV Test Results @ 50 psi

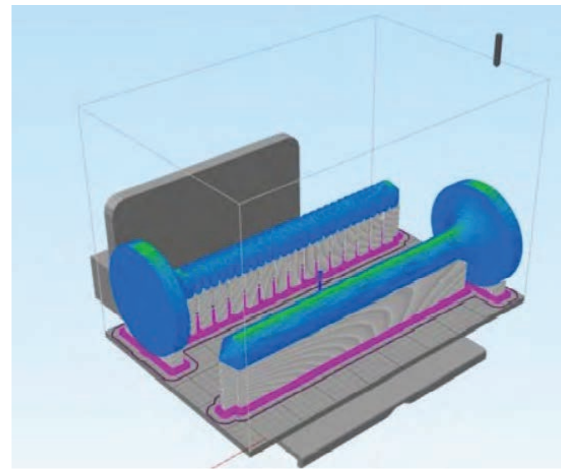


Before *During* *After*

Mark IV Test Results @ 100 psi

Verification Testing: Anchor Pull Test

- All anchor variants used in pull-testing were fabricated with the aid of a 3D-printer
  - Material: Polylactic Acid (PLA)
  - 100% Infill
- Prior to the final selection of a anchor design, each variant was placed in a sample container filled with simulants of different fidelities
  - Playground sand
  - Portland cement
  - JST-1A analog



Verification Testing: Masten Plume-Surface Interaction (PSI) Test Stand

- **First Static Test – S1**
  - Mark III Blanket
  - POND and Instrument Suite
  - 18” Engine Height
  - 2 Second Fire

- **Result**
  - Blanket Destroyed
  - 7” Deep Crater
  - Instruments Provided Path for Exhaust

Verification Testing: Masten Plume-Surface Interaction (PSI) Test Stand

- **Second Static Test – S2**
  - Mark III Blanket
  - Leftover POND, No Instruments
  - 38" Engine Height
  - 1 Second Fire

- **Result**
  - Blanket Survived
  - First Layer Damaged

Verification Testing: Masten Plume-Surface Interaction (PSI) Test Stand

- **Third Static Test – S3**
  - Mark III Blanket (Reused from S2)
  - Leftover POND, No Instruments
  - 38” Engine Height
  - 2 Second Fire

- **Result**
  - Reused Blanket Destroyed
  - Shallow Crater
  - Some Excavation

Verification Testing: Masten Plume-Surface Interaction (PSI) Test Stand

- **Fourth Static Test – S4**
  - Mark II Blanket w/ Center Anchor
  - No POND, No Instruments
  - 38” Engine Height
  - 2 Second Fire

- **Result**
  - Blanket Destroyed
  - Anchor Only Cosmetic Damage
  - Gromets Seemed to Help

Verification Testing: Masten Plume-Surface Interaction (PSI) Test Stand

- **First Dynamic Test – D1**
  - Mark III Blanket
  - 104” to 27.5” Engine Height Range
  - 3 Second Fire

- **Result**
  - Top Layer Damaged
  - Carbon Fiber Balooning
  - Insulation Survived

Verification Testing: Masten Plume-Surface Interaction (PSI) Test Stand

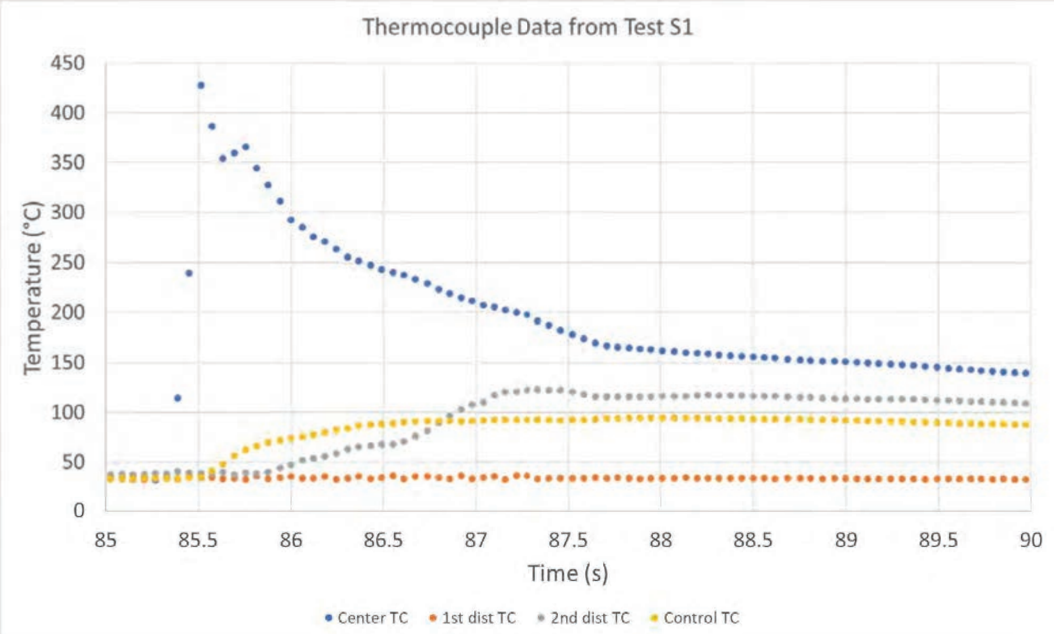
- **Second Dynamic Test – D2**
  - Mark II Blanket Double Layer
  - 104” to 27.5” Engine Height Range
  - 3 Second Fire

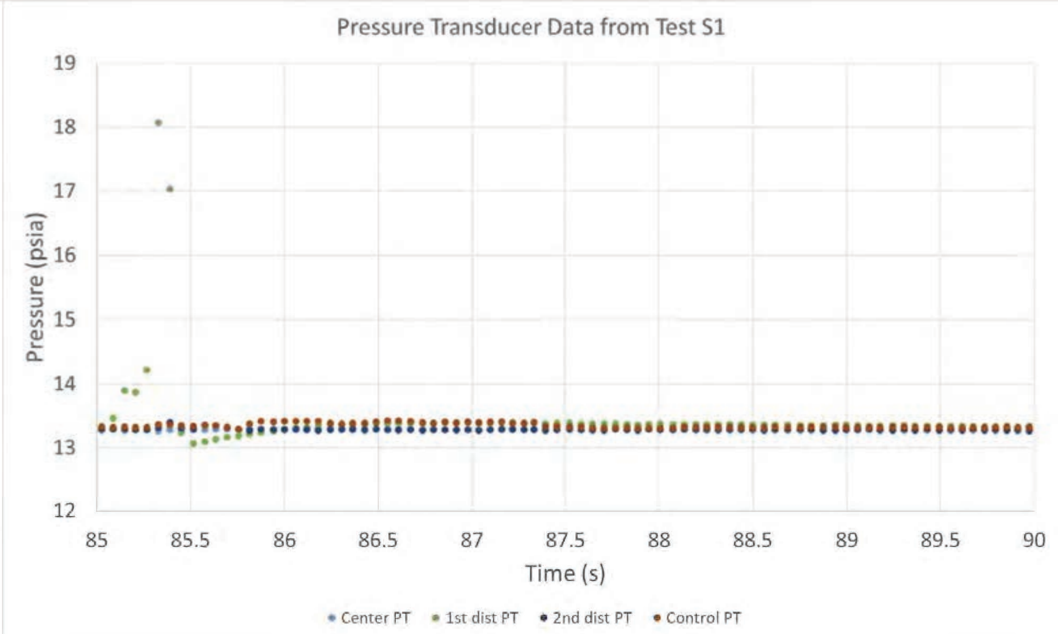
- **Result**
  - Top Blanket Destroyed
  - Second Blanket Damaged
  - Insulation Survived

Masten Plume-Surface Interaction (PSI) Test Stand

Test ID	Test Stand Type	Blanket	Blanket Diameter	Resin	Engine Height	Engine Fire Time
S1	Static	Mark III	2 ft	Yes, Full cover	18 in	2 s
S2	Static	Mark III	2 ft	Reused	38 in	1 s
S3	Static	Mark III (reused from previous test)	2 ft	Reused	38 in	2 s
S4	Static	Mark II (w/ middle anchor)	2ft	No	38 in	2 s
D1	Dynamic	Mark III	2 ft	No	104 in – 27.5 in	3 s
D2	Dynamic	Mark II (2-layer)	2 ft	No	104 in – 27.5 in	3 s
D3	Dynamic	Mark IV (4-layer)	3 ft	No	104 in – 27.5 in	3 s

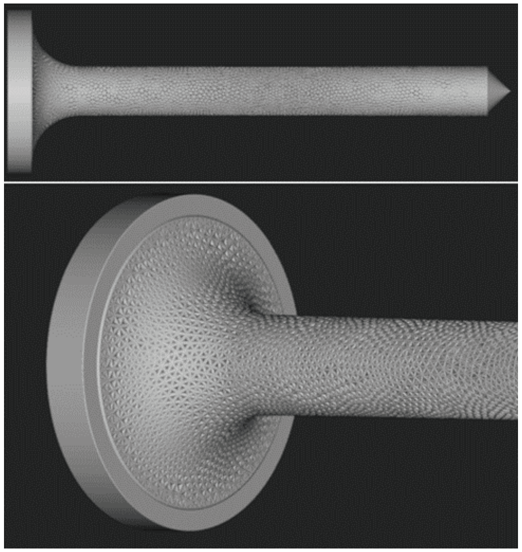
Test ID	Observations
S1	Blanket destroyed; 7 in deep crater in center; Scattered POND fragments survived
S2	Blanket survived, first layer deteriorated
S3	Reused blanket destroyed; Shallow crater in center; Excavation beneath anchor heads
S4	Blanket destroyed; Gas intrusion at the central anchor may have accelerated deterioration
D1	Top layer deteriorated, insulation layer survived
D2	Top blanket destroyed, second survived
D3	2 layers deteriorated, the other 2 layers survived; Top layer ballooned and stiffened





- 0 ms: A small rise in pressure indicates the oxygen purge that precedes engine ignition
- 50 ms: Engine ignition
- 241 ms: Max pressure is reached, 18.1 psia
- 301 ms: Blanket is breached by engine plume
  - This is indicated by a rapid temperature spike, as well as a drop in pressure
  - The pressure drop likely occurs because the breach in the blanket releases the air trapped beneath it
- 972 ms: Pressure returns to ambient readings
- 2,000 ms: Engine stops

Path to Flight



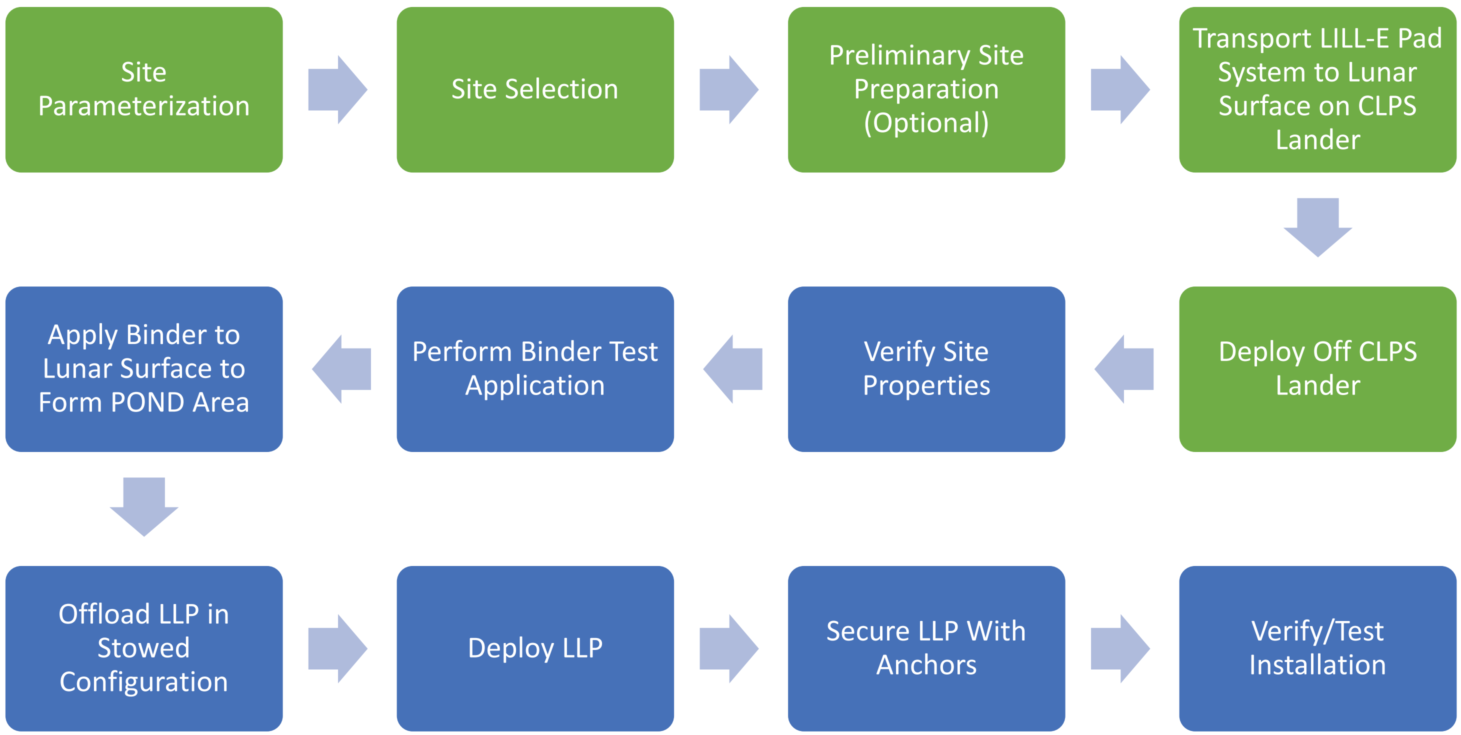
- Positive outlook for path-to-flight by 2026
- Design / testing iterations
- Trades on current & new designs
- Feasibility studies on cost & mass
- POND system shows promise but requires additional testing
- Hot-fires on POND
- System tests in relevant lunar conditions
- Cryovac testing for lunar night cycle survival

Path to Flight

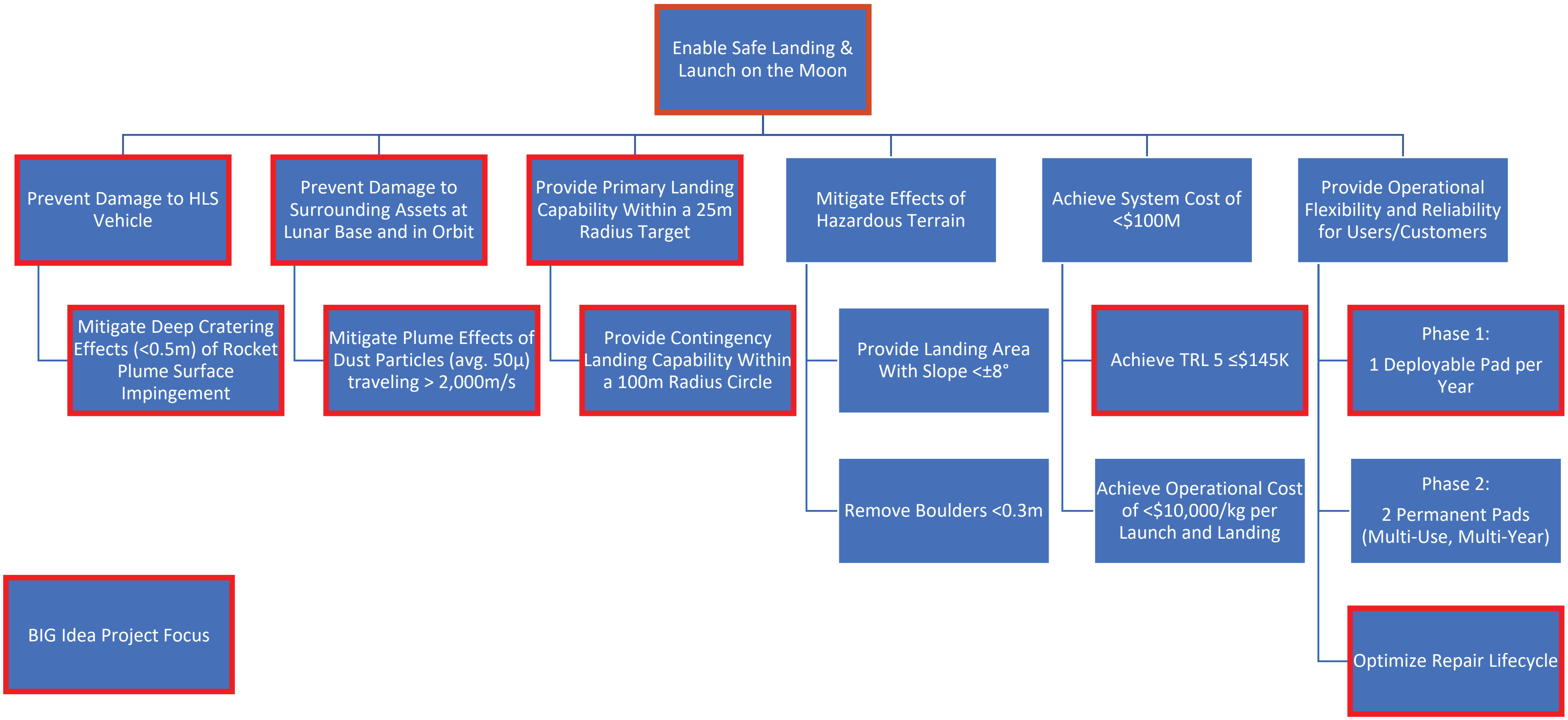
- Hot and/or cold gas testing within vacuum while system is deployed on regolith bed
- Additional design work prior to final flight hardware
- LLP blanket maturation via 3D fabric designs
- Reduction in permeability of LLP for pressure mitigation
- Anchor design optimization
- Deployment method of full system configuration finalized
- NASA SBIR and STTR funding opportunities for funding

LLP Material	Density (g/cm^3)	Unit Cost (per/cm^3)	Tensile Strength (MPa)	Packaging Capability (Qualitative Rating)
Carbon Fiber Fabric (Fibre Glast, 1K Plain Weave)	0.52	$0.80	3,516	High
Carbon-Carbon Plates (CeraMaterials, CFC Sheets)	1.50	$0.15	200	Medium
Carbon Foam Panels (CFOAM, Carbon Foam)	0.48	$0.01	5	Low
Inconel Wire Cloth (Cleveland Wire, Inconel Alloy 600)	3.42	$4.33	758	High
Tungsten Wire Cloth (Cleveland Wire, Tungsten Wire Cloth)	4.81	$100.71	2,275	High
Graphite Foil (CeraMaterials, Graphite Foil Rolls)	1.00	$0.07	5.5	High

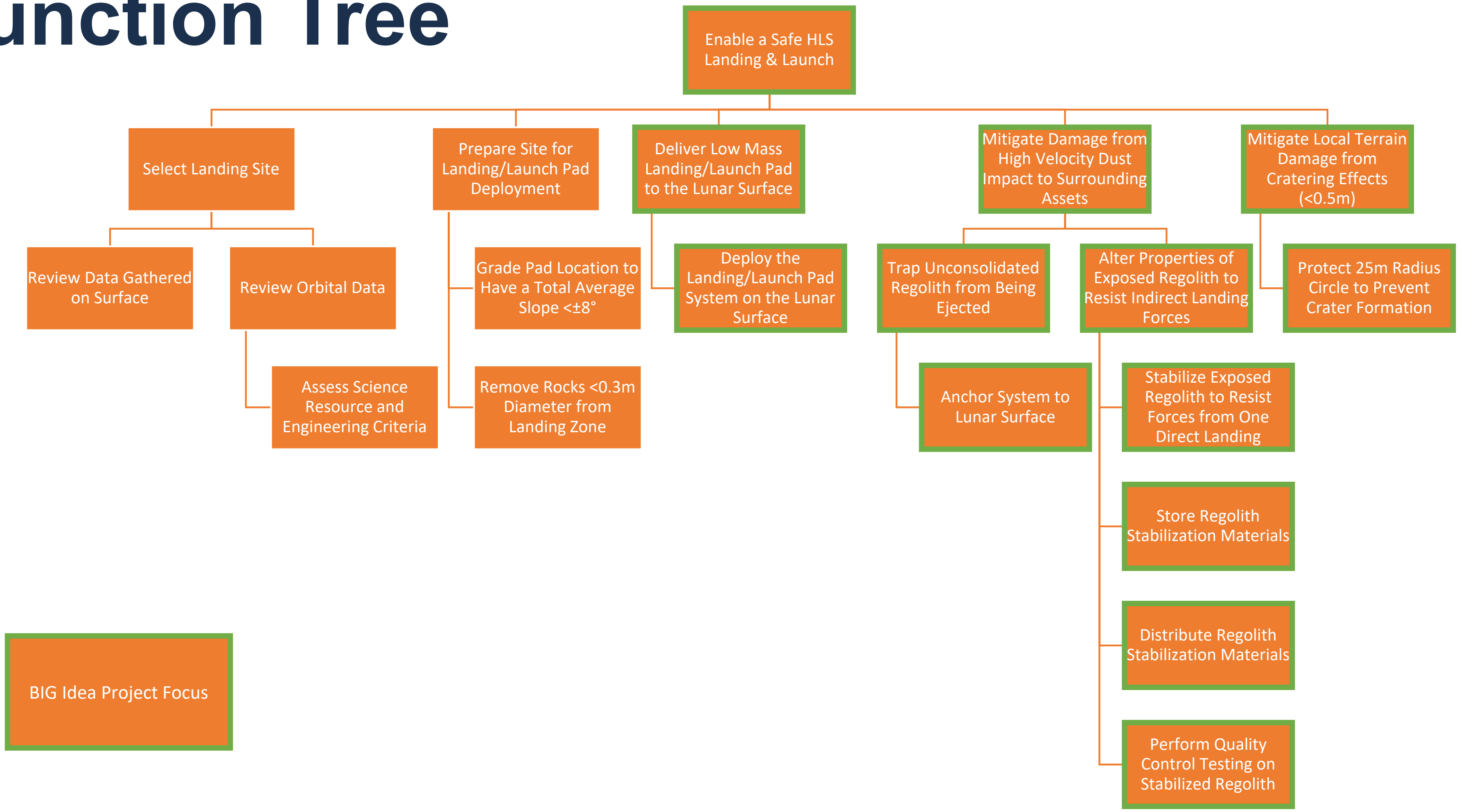
Systems Engineering: ConOps



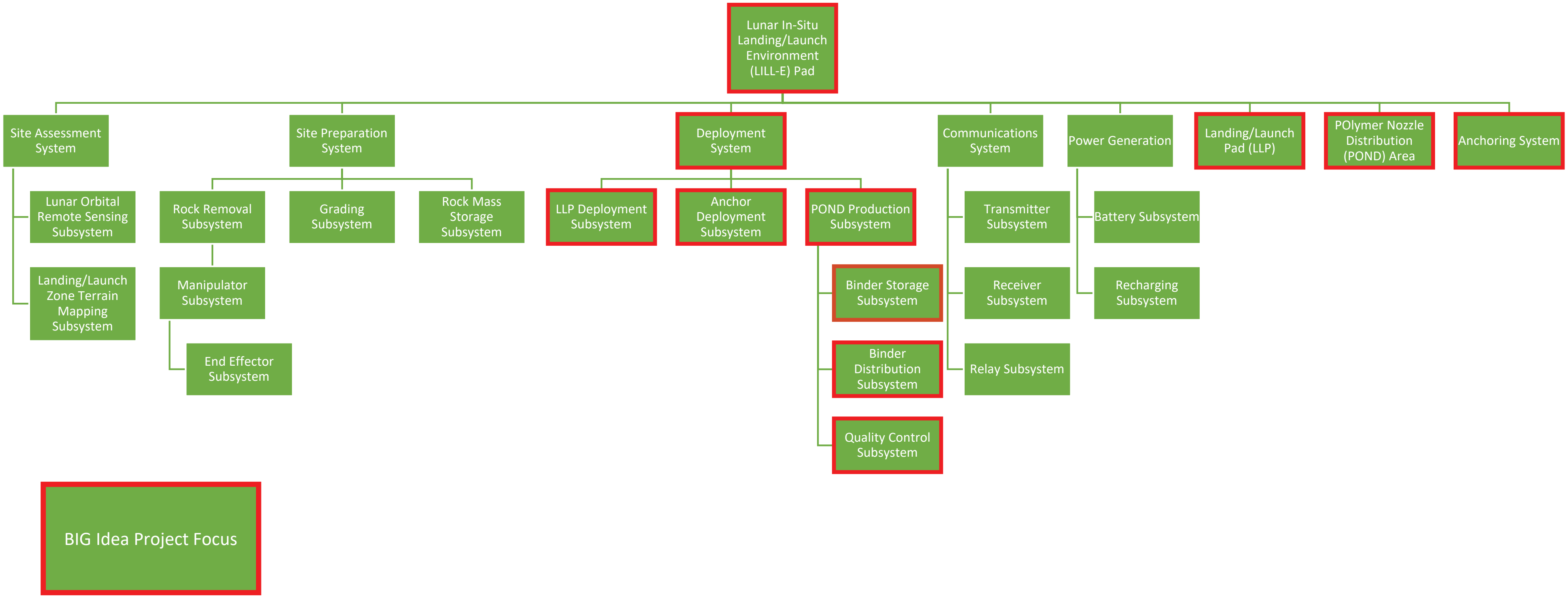
System Objectives



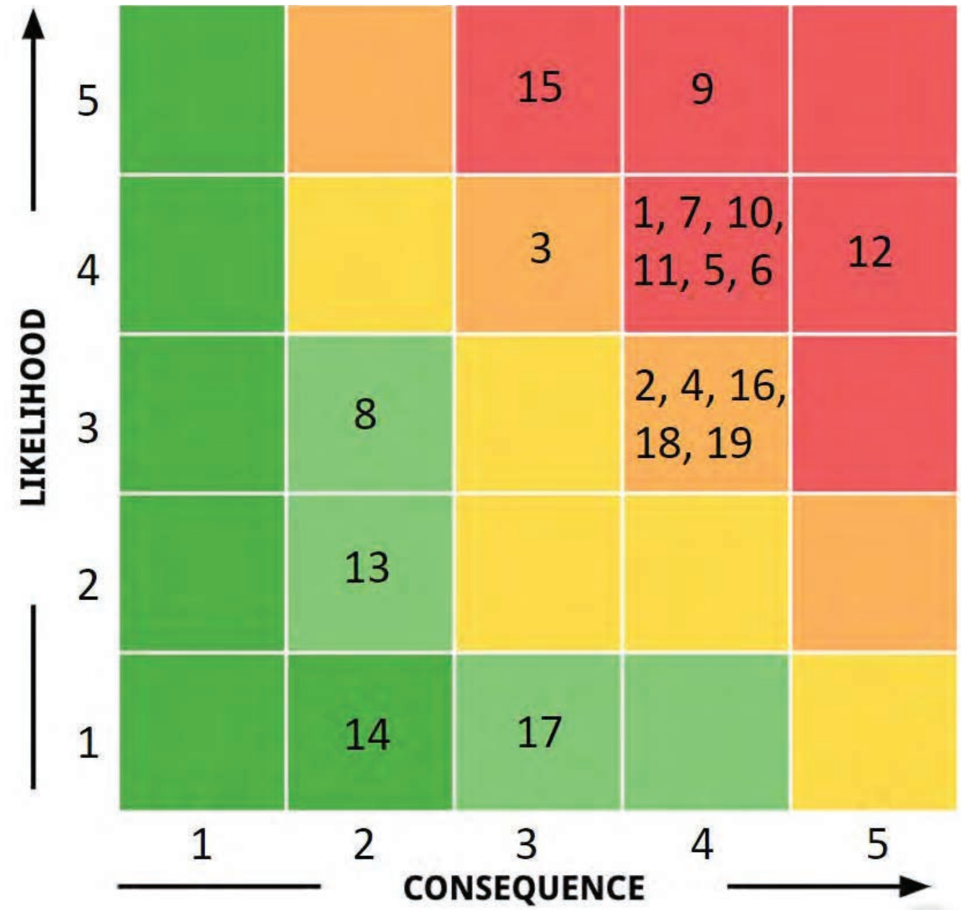
Function Tree



Product Tree



Risk #	Risk Activity	Risk Type	Internal/External	Mitigation	Consequence (1 - 5)	Likelihood (1 - 5)	Total Score	Rank	Last Assessed Date	Movement (↓/↑)
9	The POND will deteriorate during an off-nominal landing/launch event	Technology	Internal	*Develop test plan w/ Masten	4	5	20	1	3/18/2021	
12	The system will not deploy correctly	Technology	Internal	*Develop deployment ConOps *Develop POND application system *Coordinate with Lunar Outpost as industry partner to development robotic deployment platform	5	4	20	1	3/18/2021	New
1	System will not achieve TRL 5 within BIG Idea timelines	Performance	Internal	*Create baseline schedule *Review schedule at weekly meetings	4	4	16	3	3/18/2021	New
5	The LLP will come loose during a nominal landing/launch event	Technology	Internal	*Test various anchor designs and use test results to iterate upon design *Increase the number of anchors that will secure the LLP *Spray a seal of binder at the edge of the LLP	4	4	16	3	5/17/2021	↑
6	The LLP will come loose during an off-nominal landing/launch event	Technology	Internal	*Test various anchor designs and use test results to iterate upon design *Increase the number of anchors that will secure the LLP *Spray a seal of binder at the edge of the LLP	4	4	16	3	5/17/2021	↑
7	The LLP will deteriorate from exposure to the lunar environment	Technology	Internal	*Establish requirements based on the operating environment *Test in relevant environment	4	4	16	3	3/18/2021	New
10	The POND will deteriorate from exposure to the lunar environment	Technology	Internal	*Test POND samples before and after exposure to lunar environment	4	4	16	3	3/18/2021	New
11	The LLP and POND will not interface correctly	Technology	Internal	*Develop interface requirements *Develop V&V plan	4	4	16	3	3/18/2021	New
15	Assembly of test systems will take longer than expected	Performance	Internal	*Hire additional team members who are on-site at the school	3	5	15	9	3/18/2021	New
2	System will not achieve TRL 5 within provided budget	Performance	Internal	*Create budget tracker *Review budget tracker at weekly meetings *Re-design of POND cut procurement requirements in half	4	3	12	10	3/18/2021	New
3	Testing systems for verification/validation will not be available	Performance	External	*Develop schedule and reserve test platforms ahead of time *Leverage industry partnerships	3	4	12	10	3/18/2021	New
4	The LLP material will deteriorate during a landing/launch event	Technology	Internal	*Test LLP material with hot and cold gas testing	4	3	12	10	3/18/2021	New
16	Cannot complete ConOps within one lunar day	Technology	Internal	*Develop ConOps and analyze lunar day/night cycles *Develop binder requirements (spray rate, temp, etc.)	4	3	12	10	3/18/2021	New
18	POND resin will cure within the application system due to premature exposure to sunlight	Technology	Internal	*Test system robustness for sunlight exposure	4	3	12	10	5/19/2021	New
19	POND resin will cure within the application system due to exposure to lunar radiation environment	Technology	Internal	*Test system in radiation environment	4	3	12	10	5/19/2021	New
20	Gas permeation through the LLP will result in lofted regolith or excessive movement of the blanket	Technology	Internal	*Test system for gas permeability	4	3	12	10	10/19/2021	New
8	The POND will deteriorate during a nominal landing/launch event	Technology	Internal	*Test POND samples with hot and cold gas testing	2	3	6	17	3/18/2021	New
13	The system will be difficult to manufacture/fabricate	Technology	Internal	*Coordinate w/ Adherent on system design *Perform systems engineering	2	2	4	18	3/18/2021	New
17	Regolith simulant not available for testing purposes	Performance	External	*Use low fidelity simulants *Source simulant from other sources	3	1	3	19	5/13/2021	↓
14	The student team may shrink due to graduations	Performance	Internal	*Spring 2021 graduates have committed to continuing their participation on the team	2	1	2	20	3/18/2021	New


LIKELIHOOD
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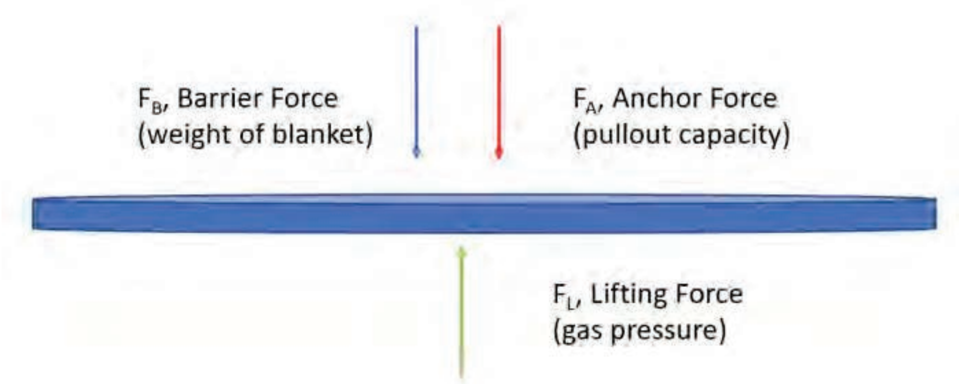
CONSEQUENCE

Requirement	Verificaiton Method (Analysis, Demonstration, Inspection, Test)	Method Description
The LLIL-E Pad system shall mitigate 92% of dust ejecta during a nominal landing event	Test, Analysis	Cold Gas Test; Masten PSI Test Stand
The LILL-E Pad system shall mitigate 75% of dust ejecta during an off-nominal landing event	Test, Analysis	Cold Gas Test; Masten PSI Test Stand
The LILL-E Pad system shall function for both a landing event and a launch event	Test	Masten PSI Test Stand
The system shall withstand a surface plume impingement maximum temperature of 4,000°C	Test, Analysis	Model Rocket Test; Masten PSI Test Stand
The system shall withstand a surface plume impingement maximum heat flux of 200 W/cm^2	Test, Analysis	Model Rocket Test; Masten PSI Test Stand
The anchor system shall resist a lifting force of 10,000 Newtons	Test, Demonstration	Anchor Pull Test; Cold Gas Test; Masten PSI Test Stand
The anchor system shall function in regolith of bulk density 1.6 g/cm^3	Test	Anchor Pull Test; Cold Gas Test; Masten PSI Test Stand
The landing/launch pad (LLP) should not allow any rocket plume gas to permeate through it to the regolith surface	Demonstration, Inspection	Cold Gas Test; Model Rocket Test; Masten PSI Test Stand
The system shall withstand a surface plume impingement maximum gas velocity of 3,000 m/s	Demonstraiton, Test, Analysis	Cold Gas Test; Model Rocket Test; Masten PSI Test Stand
The system shall remain stationary when subjected to a maximum shear stress of 3,000 Pa	Demonstration, Analysis	Cold Gas Test; Model Rocket Test; Masten PSI Test Stand
Anchors shall perform their function after exposure to adfreeze forces	Test	Cryovac Anchor Test
The LILL-E Pad system shall operate during lunar daytime temperatures of 182K ± 42K (-132°F ± 75°F / -91°C ± 42°C)	Test	Cryovac POND Application & Material Test; Cryovac LLP Test
The LILL-E Pad system shall survive lunar nighttime temperatures of 61K ± 20K (-350°F ± 36°F / -212°C ± 20°C)	Test	Cryovac POND Application & Material Test; Cryovac LLP Test
The LILL-E Pad system shall operate in a vacuum ranging from 1x10^4 to 2x10^5 $molecules/cm^3$	Test	Cryovac POND Application & Material Test; Cryovac LLP Test
The POND application system shall produce a TBD mm thick coating of polymer	Test, Demonstration	POND Application System Test
The POND application system shall distribute a polymer coating over a 31,400 m^2 area	Analysis	LILL-E Pad System Analysis
The POND application system shall be self-clearing of unused precursor	Demonstration	POND Application System Test
POND packaging dimensions should not exceed TBD	Analysis, Demonstration	LILL-E Pad System Analysis;POND Application System Test
The LILL-E Pad system shall deploy within one lunar day	Analysis	LILL-E Pad System Analysis

Anchors

- Analysis of data from Masten revealed that the anchors performed exceptionally well, resisting lifting forces much greater then expected (Roughly 10x)
- Potential Factors affecting increased performance:
  - Mass of the anchors
  - Plume force “pinning” the LLP sample to the test-bed
  - Fidelity of regolith simulant (grainsize and shape)

Anchors



$$F_L = A_B \cdot \Delta p = \pi r^2 \cdot \Delta p = \pi \cdot (0.3m)^2 (4.8psi)\left(\frac{6{,}894Pa}{psi} \cdot \frac{N/_{m^2}}{Pa}\right) = 9{,}356N$$

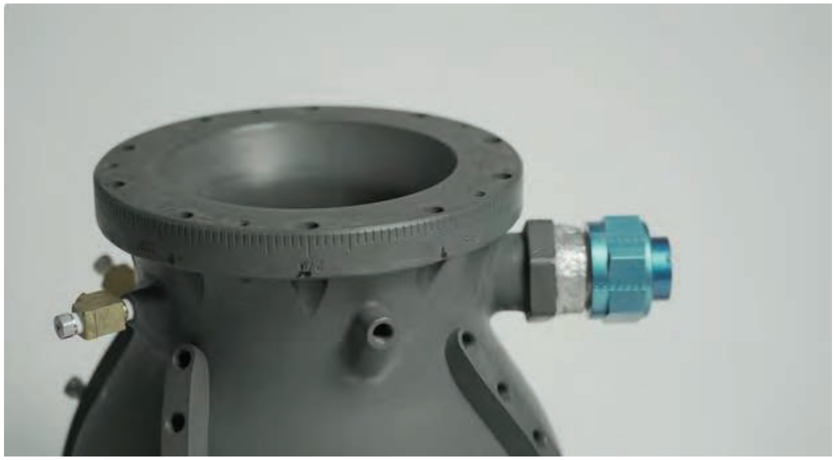
$$F_B = m_B \cdot g = 95.8\frac{oz}{yd^2}\left(\frac{kg}{35.3oz} \cdot \frac{1.2yd^2}{m^2}\right) \cdot \pi \cdot (0.3m)^2 \cdot 9.81\frac{m}{s^2} = 9N$$

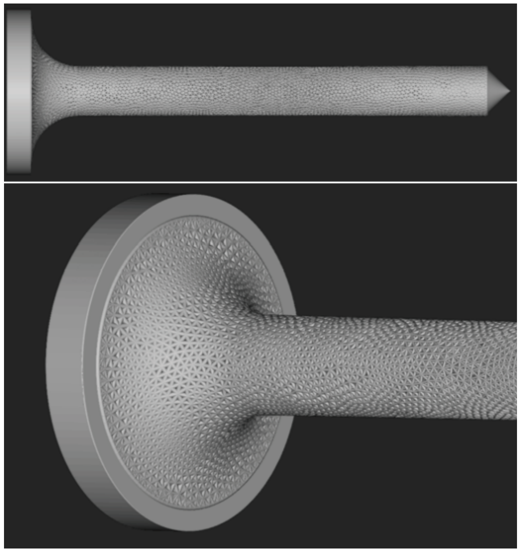
$$F_B + F_A = F_L \rightarrow F_A = F_L - F_B = 9{,}356N - 9N = 9{,}347N$$

- ***Number of Anchors used during Masten PSI Tests: 8***
- ***Lifting force resisted per anchor: 1,168 Newtons***

Anchors

- Further work:
  - Topology and mass optimization of the anchors for large scale system deployment
  - Anchor material selection
    - A1000-RAM10 aluminum alloy
    - Titanium alloy
  - Anchor fabrication
    - Additive manufacturing
  - Anchor deployment method
    - Deployment angle





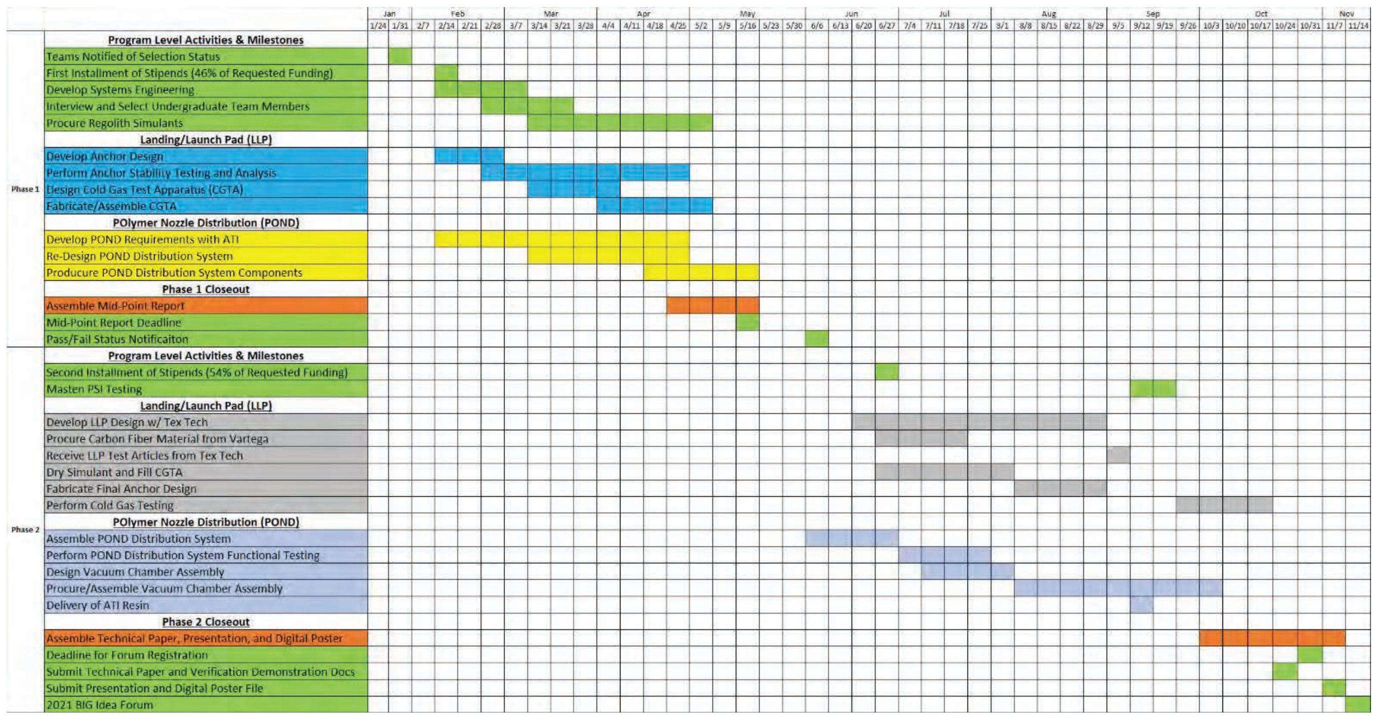
Mass / Power / Volume

- LLP
  - Single-layer, 25m radius Mark III blanket
  - A mass-optimized blanket can be chosen later in the development process
- Anchors
  - Stainless steel (lighter material will be used in the future)
  - The number of anchors is calculated by scaling up from the number of anchors that were used on the smaller test articles in Mojave.
- The POND
  - 100m radius area with a 2mm layer of material

Subsystem	Mass	Power	Volume
LLP	512 kg	n/a	25 m^3
Anchors (83 total)	99 kg	n/a	0.09 m^3
POND Resin	53,407 kg	n/a	63 m^3
POND Distribution Sys.	12 kg	373 W	0.02 m^3
LLP/Anchor Deployment Sys.	TBD	TBD	TBD
Total	**54,030 kg**	**373 W**	**88.11 m^3**

Project Schedule

- Phase 1:
  - Systems engineering and requirements development,
  - Anchor design and testing,
  - CGTA design and assembly
  - Re-design of the POND distribution system
- Phase 2:
  - LLP development with Tex Tech
  - Fabrication of the final anchor design,
  - POND distribution system assembly and function testing
  - Cold gas testing, and Masten PSI testing



Budget

- Summary
  - Total: $145,250
  - Spent: $127,539
  - Remaining: $17,711
- Less than expected spending on student stipends
- Materials/supplies spent more than originally estimated overall
- Simulant procured at no-cost
- Rover not developed within program

	Phase 1				Phase 2				Totals		
	Allocation	Actuals	Variance	Source	Allocation	Actuals	Variance	Source	Allocation	Actuals	Variance
Labor											
Student Stipends	$26,125	$9,544	$16,581		$27,500	$21,500	$7,000		$53,625	$30,044	$23,581
									Total Variance		**$23,581**
Materials/Supplies											
LLP	$5,000	$415	$4,585	ICON	$1,000	$17,121	-$16,121	ICON	$6,000	$17,536	-$11,536
Anchors	$1,500	$0	$1,500	BIG Idea	$500	$1,864	-$1,364	BIG Idea	$2,000	$1,864	$136
Binder	$9,000	$3,075	$5,925	BIG Idea	$1,000	$0	$1,000	BIG Idea	$10,000	$3,075	$6,925
POND	$8,000	$1,828	$6,172	BIG Idea	$1,000	$18,269	-$17,269	BIG Idea	$9,000	$20,097	-$11,097
Simulant	$3,000	$0	$3,000	BIG Idea	$1,000	$0	$1,000	BIG Idea	$4,000	$0	$4,000
Rover	$0	$0	$0	BIG Idea	$5,000	$0	$5,000	BIG Idea	$5,000	$0	$5,000
Misc. Lab	$1,000	$0	$1,000	BIG Idea	$1,000	$0	$1,000	BIG Idea	$2,000	$0	$2,000
Liquid N2	$400	$0	$400	BIG Idea	$200	$200	$0	BIG Idea	$600	$200	$400
Test Facility Fees	$17,426	$17,426	$0	BIG Idea	$17,426	$17,426	$0	BIG Idea	$34,851	$34,851	$0
									Total Variance		**-$4,173**
Domestic Travel											
Travel - Masten (Travel to Mojave, CA)	$0	$0	$0	BIG Idea	$1,000	$13,372	-$12,372	BIG Idea	$1,000	$13,372	-$12,372
Travel - ASCEND Flights (9x Plane Tickets to BIG Idea Forum ($300/each))	$0	$0	$0	BIG Idea	$2,700	$0	$2,700	BIG Idea	$2,700	$0	$2,700
Travel - ASCEND Hotels (9x Hotel, Check-In 16 Nov / Check-Out 20 Nov, 4 days ($100/ea))	$0	$0	$0	BIG Idea	$3,600	$0	$3,600	BIG Idea	$3,600	$0	$3,600
Travel - ASCEND Rental Cars (2x Rental Cars, 5 days ($250/ea))	$0	$0	$0	BIG Idea	$500	$0	$500	BIG Idea	$500	$0	$500
Travel - ASCEND Registration (9x Registration Fee, BIG Idea Forum / ASCEND 2021 ($500/ea))	$0	$0	$0	BIG Idea	$4,500	$0	$4,500	BIG Idea	$4,500	$0	$4,500
									Total Variance		**-$1,072**
Overhead											
Colorado Space Grant Consortium Indirect Costs	$0	$0	$0	BIG Idea	$6,500	$6,500	$0	BIG Idea	$6,500	$6,500	$0
									Total Variance		**$0**

	Phase 1				Phase 2				Total		
	Received Funds	Actuals	Remaining		Received Funds	Actuals	Remaining		Received Funds	Actuals	Remaining
BIG Idea Funding	$55,625	$31,872	$23,753		$65,300	$78,131	-$12,831		$120,925	$110,003	$10,922
ICON Sponsorship	$24,325	$415	$23,910		$0	$17,121	-$17,121		$24,325	$17,536	$6,789
Total	$79,950	$32,287	$47,663		$65,300	$95,252	-$29,952		$145,250	$127,539	$17,711

NIOSH – Hydrogen Cyanide

- 1988 OSHA Permissible Exposure Limits – Hydrogen Cyanide
  - "The ACGIH (1986/Ex. 1-3) has summarized the extensive body of human evidence on the adverse effects resulting from exposure to hydrogen cyanide. The Documentation notes that exposure to levels of 45 to 54 ppm hydrogen cyanide can be tolerated for one hour with no immediate or delayed effects, but that 18 to 36 ppm produces "slight" symptoms after several hours of exposure. The ACGIH also cites Grabois (1954/ Ex. 1-1150), who reported that workers in apricot kernel processing plants experienced no ill effects when exposed to hydrogen cyanide at a concentration of approximately 10 ppm."
- https://www.cdc.gov/niosh/pel88/74-90.html