



Game Changing Development (GCD) Mid-Year Review Presentations

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MON25/MMH 100lb. Thruster

All charts in this package are NASA Internal only.

Presented By: William P. Ondocsin, P.E.

Please only include ITAR or SBU data if it is essential for conveying project status. It must be appropriately marked and include a coversheet.

April 24, 2017

TECHNOLOGY DRIVES EXPLORATION



MON25/MMH Thruster Overview



Advancing deep space thruster technology of MON25/MMH bi-propellant. MON25/MMH has never been flown in space, however this technology allows us to build lighter, physically smaller, and cheaper engines that can operate at much colder environments than previously flown. Propellant that can operate at colder temperatures requires less power for propellant conditioning in deep space, thus lowering battery mass requirements. This technology provides more payload volume, power, and mass for deep space missions than currently available. The MON25/MMH thrusters are baselined to fly demonstration missions on the commercial CATALYST partner, Astrobotic, lunar lander as well as the NASA Resource Prospector Mission Lander. The objective is to fly the Astrobotic lander by December 2019.

Integration with other projects/programs and partnerships

- This is a collaborative effort between SMD, HEOMD, STMD, and industry IR&D funding.
- In work: Follow on of MON25/MMH technology on an MDA Phase III commercialization SBIR

Technology Infusion Plan:

- MI: Baselined for Resource Prospector as well as CATALYST partner Astrobotic
- Technology Developed: Deep Space Engine
- Infusing/potential customer (HEOMD, SMD, STMD, Industry)
 - CATALYST commercial Partner, Astrobotic Lunar Lander
 - NASA Resource Prospector Lander

Key Personnel:

Program Element Manager: Wade May

Project Manager: Bill Ondocsin

Lead Center: MSFC

Supporting Centers:

NASA NPR: 7120.8

Guided or Competed: Guided

- **Type of Technology:** Pull: Baselined for Resource Prospector, CATALYST partner Astrobotic and advocated by SMD for deep space mission utilization

Key Facts:

Thrust Areas: Propulsion

Execution Status: Year 1 of 1

Technology Start Date: October 2016

Technology End Date: September 2017

Technology TRL Start: 3

Technology TRL End: 6

Technology Current TRL: 3

Technology Lifecycle Phase: Guided (Post PDR, Phase C)



Level 1 Project Goals



Level 1 Project Goals

Bipropellant MON25/MMH -100 lb. thruster

Goal #1

Confirm performance margins against required functional environments and lifetime.

Goal #2

Demonstrate vibration acoustic shock and thermal cycle loads meet mission relevant design margins.

Goal #3

Validate thrust performance using ultra low temperature propellant source.

Notes:



Key Performance Parameters (KPP)



Key Performance Parameters

Bipropellant MON25/MMH -100 lb. thruster

Performance Parameter	State of the Art (MON3 Engine)	Threshold Value	Project Goal	Estimated Current Value
Engine Thrust(lb _f)	110	90	110	137
Minimum Impulse(lb _f -sec)	3.5	1	<0.9	1.09
Total Impulse (lifetime) (lb _f -sec)	4.5x10 ⁶	3.0x10 ⁴	>2.4x10 ⁵	2.8x10 ⁴
ISP (sec)	300	298	>300	294
Propellant Temperature (°F)	45*	-22	-30	-6.3

Notes:

- **State of the art engine can only operate at higher temperatures using MON3 propellants.**
- **Estimated Current Values were obtained during June 2016 hot fire testing of the ISE-100 engines where significant combustion noise led to a shorten test series and redesign efforts. Numbers represented were off nominal inlet conditions and do not represent the targeted inlet pressure performance.**



Key Technical Risks



Key Technical Risks

Bipropellant MON25/MMH -100 lb. thruster

RISK ID	Title	Description	L/C	Trend
ISE 100 – T1	Two Phase Flow	Vapor pressure of MON25 at high temperatures may cause two phase flow leading to chug (G3)	3/3	→
ISE 100 – T2	Internal Flow Separation	Flow separation that leads to non-uniform flow into the manifold and acoustic modes source of excitation (G1)	3/4	↓
ISE 100 – T3	Internal Acoustic Resonance	Resonance of internal flow acoustic modes leading to low frequency oscillations (G1)	5/4	↓
ISE 100 – T4	Combustion Instability	Improper design of the propellant manifold leading to maldistribution and heat affected zones (G1)	5/5	↓

Notes:

1. Red risks were realized during ISE100 development testing in FY16
2. Red risks are trending down based on proposed path forward that includes risk mitigation workhorse hardware and tests to resolve current ISE100 thruster design issues.
3. Yellow risk is expected to be resolved during proposed risk mitigation testing activities.

Criticality	L x C Trend
High	↓ Decreasing (Improving)
Med	↑ Increasing (Worsening)
Low	→ Unchanged
	■ New Since Last Period



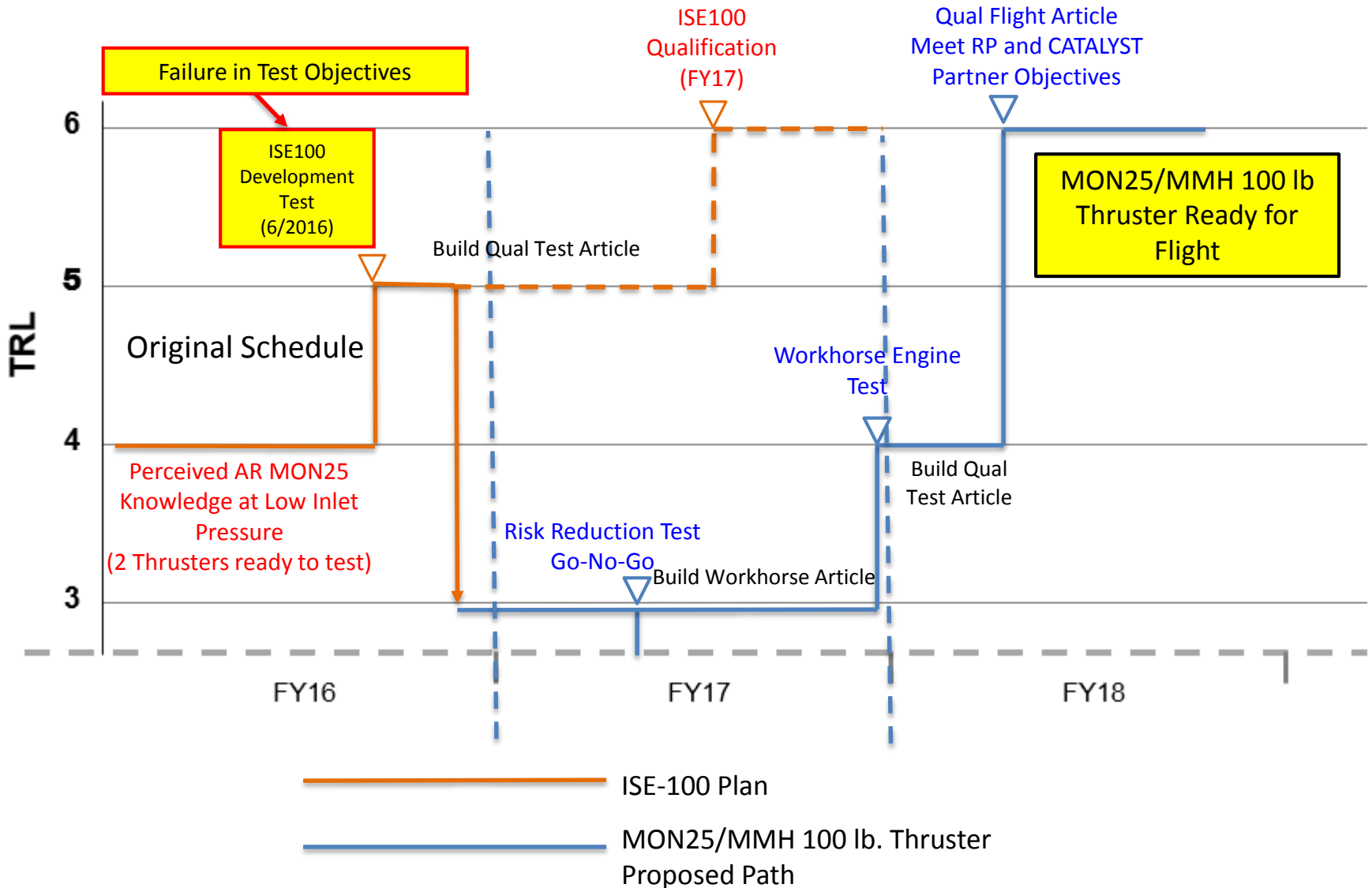
Project Manager 2nd Quarter Assessment



Technology	Performance				Comments
	C	S	T	P	
MON25/MMH propulsion					<p>Technical – Acoustic Anomalies and possible combustion instability detected during June 2016 hot fire testing of the ISE 100 thruster.</p> <p>Cost – Vendor costs increasing based on failed ISE100 demonstration article which resulted in unforeseen redesign costs, anomaly resolution, and fault tree closure.</p> <p>Schedule – Qual testing was delayed.</p> <p>Programmatic – Anomaly resolution and fault tree closure of demonstration engine continue to impact schedule demands, which resulted in significant costs increase.</p>



Technology Readiness Level (TRL) Assessment





Milestones and Forward Plans



FY17 Key and Controlled Milestones	Baseline Completion Date	Actual Completion Date	Estimated Completion Date	Variance Explanation
<i>FY17 Q1 (Oct 1 through Dec 31)</i>				
<i>FY17 Q2 (Jan 1 through March 31)</i>				
Long lead items (six months)	June 2017	x	x	Fault tree still open/ could not order long lead
<i>FY17 Q3 (Apr 1 through June 30)</i>				
<i>FY17 Q4 (Jul 1 through Sep 30)</i>				
Complete flight qual articles	July 2017	x	x	Fault tree still open could not build flight qual articles
Qual Test complete	August 2017	x	x	Fault tree still open could not build flight qual articles

Proposed Forward Path

- Risk Reduction test activities begin in May 2017
- If successful, MON25/MMH workhorse testing will begin in September 2017
- Qualification testing completed by April 2018



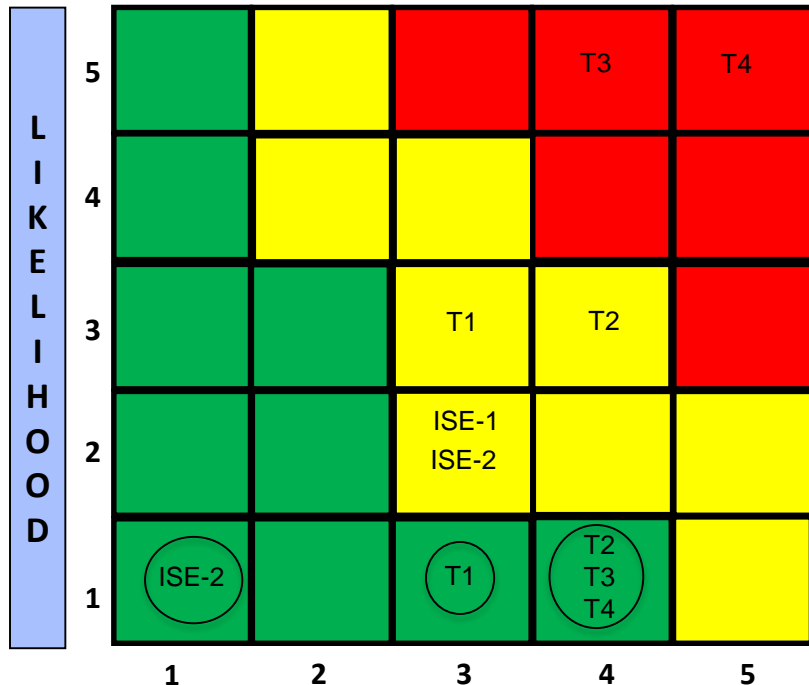
MON25/MMH Thruster Technical Accomplishments and Technical Challenges



- **Proposal to Qual test ISE 100 thrusters sent to GCD submitted prior to initial Hot Fire**
- **Anomalies detected during initial Hot Fire**
 - High frequency acoustic resonance and combustion noise
- **Identified Major cost and schedule problems to Jason Crusan - HEOMD, Wade May- GCD, Ron Litchford-STMD August 2016**
- **Discussions underway to reformulate Project Forward Plan**
- **These discussions include possible cost sharing opportunities with STMD, HEOMD**



Risk Summary



CONSEQUENCES

Risk ID Trend	Approach/Affinity	Risk Title
ISE-1	A/TSc	Key Performance Parameters
ISE-2	W/CSc	Funding not Adequate to complete ISE100 Qual
T1	M/T	Two Phase Flow
T2	M/T	Internal Flow Separation
T3	M/T	Internal Acoustic Resonance
T4	M/T	Combustion Instability

- The technical risks were demonstrated during the ISE-100 engine development testing.
- The proposed path forward will significantly mitigate the risks with appropriate off-ramps

Criticality	L x C Trend	Approach
High	↓ Decreasing (Improving)	M - Mitigate
Med	↑ Increasing (Worsening)	W - Watch
Low	→ Unchanged	A - Accept
	□ New Since Last Period	R - Research

Affinity: T-Technical C-Cost Sc-Schedule
 - Sa-Safety ○ Post Mitigation



EPO Summary Chart

- **ISE 100 test results published and presented at JANNAF conference April 2017, Huntsville, AL**
- **No Academic involvement at this time**



FY17 Forward Plans



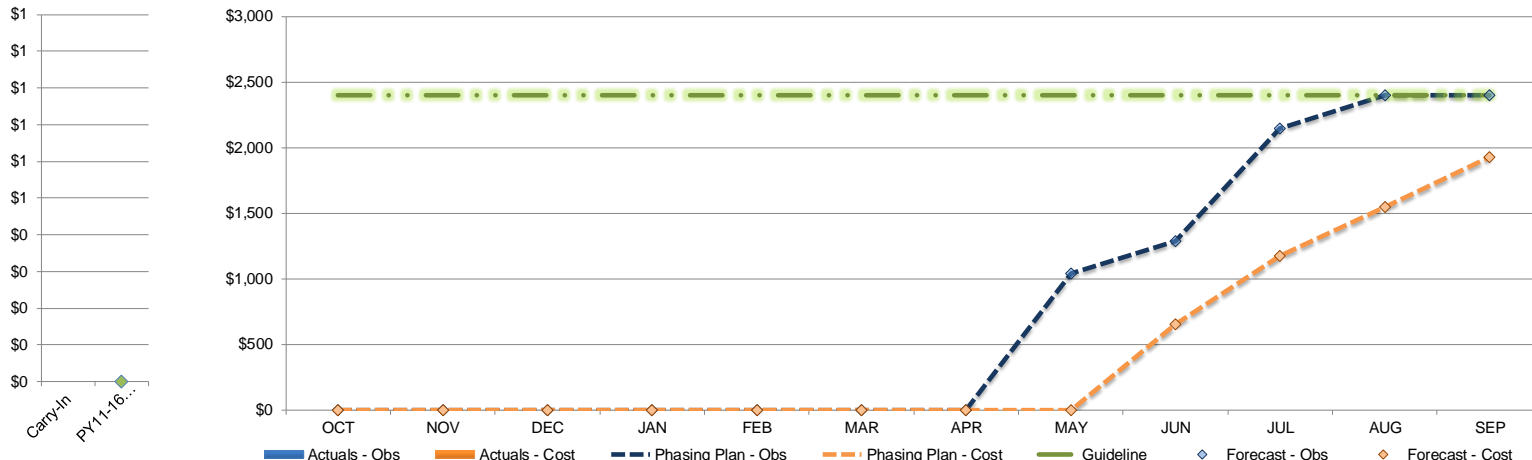
- **AES HEOMD/STMD discussion on cost sharing and recovery plan in work**
- **Risk Reduction testing September 2017 (with additional funding)**
- **Test continuation into “workhorse” testing if approved October 2017**
- **There is continued Pull from AES to complete MON25/MMH Thruster testing since this technology is baselined on NASA CATALYST commercial partner, Astrobotic’s, Lunar Lander as well as the NASA Resource Prospector Lander.**



Resources: Non-Labor Obligations and Cost



FY 2017 Non-Labor Financial Status



	Cum (\$K)	Carry-In	PY11-16 Funds	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	Carry Out	
Obs	Guideline		0.0	2,400.0	2,400.0	2,400.0	2,400.0	2,400.0	2,400.0	2,400.0	2,400.0	2,400.0	2,400.0	2,400.0	2,400.0	2,400.0	
	Phasing Plan (RLP)					0.0	0.0	0.0	0.0	0.0	1,036.0	1,287.0	2,146.0	2,400.0	2,400.0	0.0	
	Actuals	0.0	0.0			0.0	0.0	0.0	0.0								
Cost	Forecast										1,036.0	1,287.0	2,146.0	2,400.0	2,400.0		
	Phasing Plan (RLP)					0.0	0.0	0.0	0.0	0.0	0.0	650.0	1,175.0	1,550.0	1,925.0	475.0	
	Actuals	0.0	0.0			0.0	0.0	0.0	0.0								
	Forecast											650.0	1,175.0	1,550.0	1,925.0	475.0	

Note: Carry-In is the unobligated/uncosted portion of PY11-16 funding end of FY16

Explanation required for YTD Variance in excess of 5% from Phasing Plan (shaded red)

	YTD Status	Explanation required for YTD Variance in excess of 5% from Phasing Plan (shaded red)
'17 Obs	Phasing \$	-
	Actuals \$	-
	Variance \$	-
'17 Cost	Phasing \$	-
	Actuals \$	-
	Variance \$	-

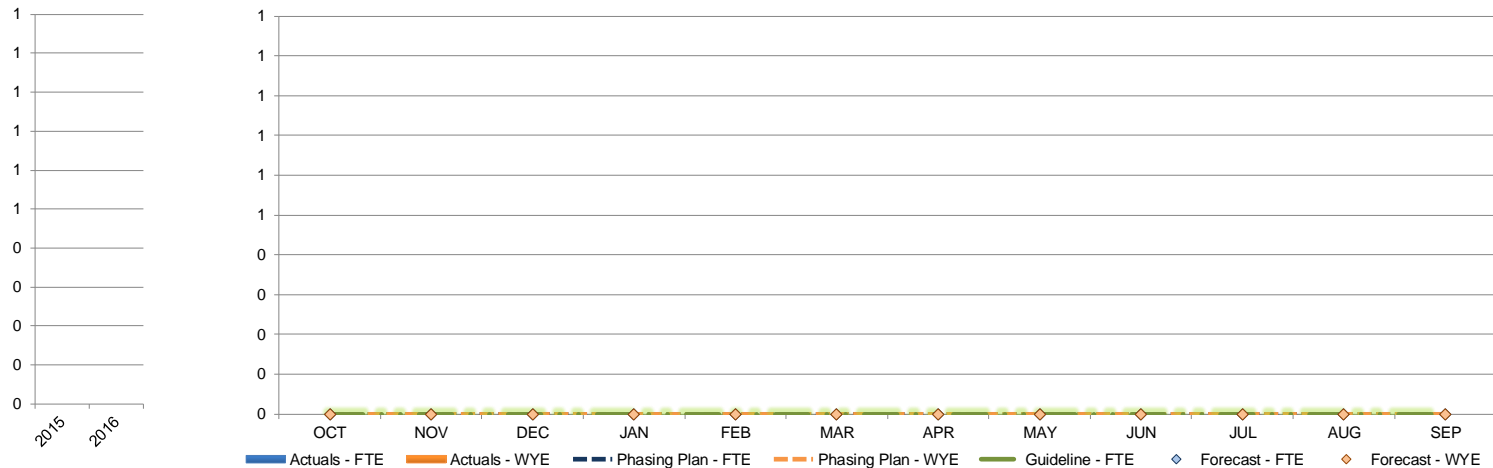
Note: Due to technical challenges no funds have been expended



Resources: Total Project Workforce FTEs/WYEs



FY 2017 Workforce Status



	Incremental	2015	2016	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	2017 Avg
FTE	Guideline				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Phasing Plan (RLP)															
	Actuals	0	0													
WYE	Forecast															
	Phasing Plan (RLP)															0.0
	Actuals	0.0	0.0													
	Forecast															

	YTD Status	Explanation required for YTD Variance in excess of 5% from Phasing Plan (shaded red)
'17 FTE	Phasing	N/A
	Actuals	N/A
	Variance	N/A
'17 WYE	Phasing	N/A
	Actuals	N/A
	Variance	N/A



Project Quarterly Summary Performance



Quarterly Summary Performance

Project	Summary Performance			
	Cost	Schedule	Technical	Programmatic
Quarter 1	Red	Red	Yellow	Yellow
Quarter 2	Red	Red	Red	Yellow
Quarter 3	Grey	Grey	Grey	Grey
Quarter 4	Grey	Grey	Grey	Grey



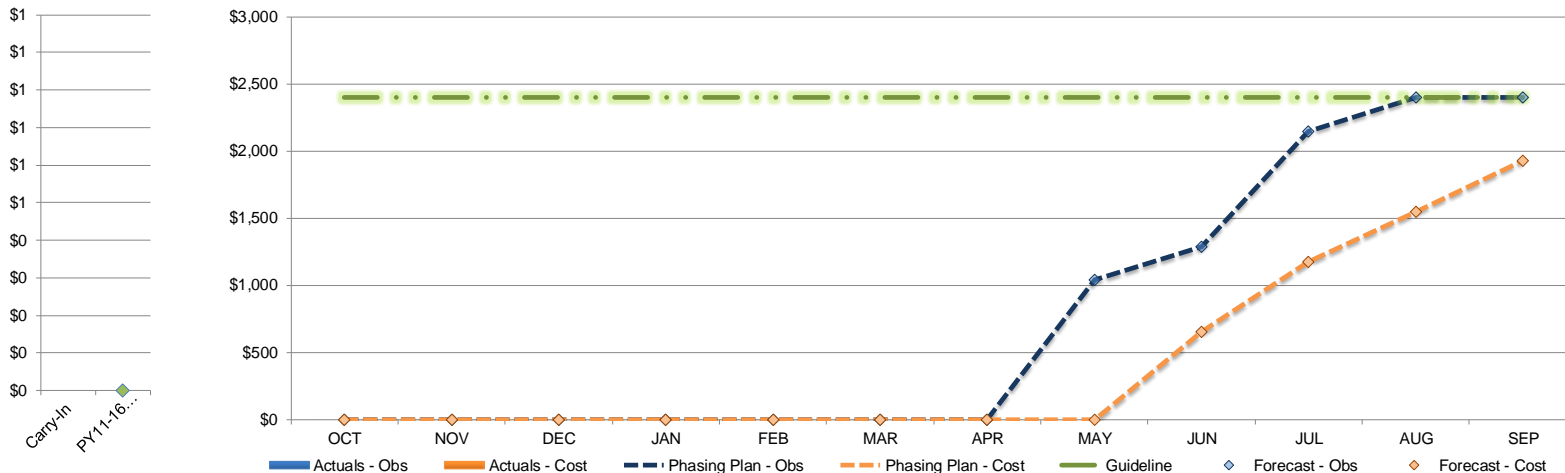
Back Up Charts



Resources: Total Obligations and Cost



FY 2017 Non-Labor Financial Status



	Cum (\$K)	Carry-In	PY11-16 Funds	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	Carry Out	
Obs	Guideline		0.0	2,400.0	2,400.0	2,400.0	2,400.0	2,400.0	2,400.0	2,400.0	2,400.0	2,400.0	2,400.0	2,400.0	2,400.0	2,400.0	
	Phasing Plan (RLP)				0.0	0.0	0.0	0.0	0.0	0.0	1,036.0	1,287.0	2,146.0	2,400.0	2,400.0	0.0	
	Actuals		0.0	0.0		0.0	0.0	0.0	0.0								
Cost	Forecast										1,036.0	1,287.0	2,146.0	2,400.0	2,400.0		
	Phasing Plan (RLP)				0.0	0.0	0.0	0.0	0.0	0.0	0.0	650.0	1,175.0	1,550.0	1,925.0	475.0	
	Actuals		0.0	0.0		0.0	0.0	0.0	0.0								
	Forecast											650.0	1,175.0	1,550.0	1,925.0	475.0	

Note: Carry-In is the unobligated/uncosted portion of PY11-16 funding end of FY16

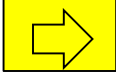
		YTD Status	Explanation required for YTD Variance in excess of 5% from Phasing Plan (shaded red)
'17 Obs	Phasing	\$ -	
	Actuals	\$ -	
	Variance	\$ -	
'17 Cost	Phasing	\$ -	
	Actuals	\$ -	
	Variance	\$ -	



MON25/MMH 100 lb Thruster

Key Performance Parameters – Bill Ondocsin



<p>Risk ID: ISE 1</p> <p>Trend/Criticality </p> <p>Current L/C 2x3</p> <p>Affinity Group Cost, Schedule</p> <p>Planned Closure April 2018</p> <p>Open Date May 2017</p>	<p>Risk Statement: Key Performance Parameters Approach: Mitigate</p> <p>Given that the ISE 100 had not been hot fired prior to the submittal to go into qual there is a possibility that the Key performance Parameters will not be met in the hot fire resulting in a redesign of the thruster.</p> <p>Context Given that the ISE 100 was post PDR phase C, the assumption was that the ISE 100 would perform well during hot fire and we would be able to go straight into Qual testing.</p> <p>Status April 2017 update. We have not used any GCD funds, and plan to evaluate the path forward using an MDA Phase III SBIR</p> <table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr style="background-color: #d9e1f2;"> <th>Mitigation Steps</th> <th>Dollars to implement</th> <th>Trigger/Start date</th> <th>Schedule UID</th> <th>Completion Date</th> <th>Resulting L/C</th> </tr> </thead> <tbody> <tr> <td>Coordinate financial partnering between HEOMD and STMD in order to award a contract using an MDA Phase III SBIR</td> <td>\$2.9M</td> <td>May 2017</td> <td></td> <td>April 2018</td> <td>1x1</td> </tr> <tr> <td> </td> <td> </td> <td> </td> <td> </td> <td> </td> <td> </td> </tr> </tbody> </table>	Mitigation Steps	Dollars to implement	Trigger/Start date	Schedule UID	Completion Date	Resulting L/C	Coordinate financial partnering between HEOMD and STMD in order to award a contract using an MDA Phase III SBIR	\$2.9M	May 2017		April 2018	1x1						
Mitigation Steps	Dollars to implement	Trigger/Start date	Schedule UID	Completion Date	Resulting L/C														
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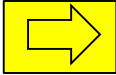
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MON25/MMH 100 lb Thruster

Funding Not Adequate – Bill Ondocsin



<p>Risk ID: ISE 2</p> <p>Trend/Criticality</p> <p style="text-align: center;"></p> <p>Current L/C 2x3</p> <p>Affinity Group Technical, Cost, Schedule, Performance</p> <p>Planned Closure April 2018</p> <p>Open Date May 2017</p>	<p>Risk Statement : Funding not adequate to complete ISE 100 qual Approach: Mitigate</p> <p>AR has been unable to close the fault tree from the anomalies discovered during hot fire. AR's solution was to redesign the thruster and go back into "workhorse" testing. There was never any dollars in the project to go through a redesign. The subsequent estimate to go back into "workhorse" testing and then into qual to estimates to complete were well above the amount that GCD provided.</p> <p>Context</p> <p>Once we received an updated estimate from AR we informed GCD of the problems and attempted to negotiate with AR. Subsequent conversations with AR to reduce their estimate have been unsuccessful.</p> <p>Status</p> <p>April 2017 update. We have not used any GCD funds, and plan to evaluate the path forward using an MDA Phase III SBIR</p> <table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr style="background-color: #d9e1f2;"> <th>Mitigation Steps</th> <th>Dollars to implement</th> <th>Trigger/ Start date</th> <th>Schedule UID</th> <th>Completion Date</th> <th>Resulting L/C</th> </tr> </thead> <tbody> <tr> <td>Coordinate financial partnering between HEOMD and STMD in order to award a contract using an MDA Phase III SBIR</td> <td style="text-align: center;">\$2.9M</td> <td style="text-align: center;">05/2017</td> <td></td> <td style="text-align: center;">05/2018</td> <td style="text-align: center;">2x3</td> </tr> <tr> <td> </td> <td> </td> <td> </td> <td> </td> <td> </td> <td> </td> </tr> </tbody> </table>	Mitigation Steps	Dollars to implement	Trigger/ Start date	Schedule UID	Completion Date	Resulting L/C	Coordinate financial partnering between HEOMD and STMD in order to award a contract using an MDA Phase III SBIR	\$2.9M	05/2017		05/2018	2x3						
Mitigation Steps	Dollars to implement	Trigger/ Start date	Schedule UID	Completion Date	Resulting L/C														
Coordinate financial partnering between HEOMD and STMD in order to award a contract using an MDA Phase III SBIR	\$2.9M	05/2017		05/2018	2x3														

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MON25/MMH 100 lb Thruster

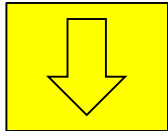
Two Phase Flow – Bill Ondocsin



Risk ID #

T1

Trend/Criticality



Current L/C

3x3

Affinity Group

(could be more than one) Technical, Cost, Schedule, Performance

Planned Closure

05/01/2017

Open Date

02/01/2017

Risk Statement :

Approach: Mitigate

Given that operating MON25 at high temperatures and low pressures, there is a possibility that the MON25 oxidizer can vaporize within the injector resulting in combustion instability, with detrimental structural vibrations.

Context

Develop the margin between MON25 vapor pressure and injector operating pressure utilizing analysis that is based on empirical data, so the engine can operate with confidence in all propellant temperature regimes at low inlet pressure conditions.

Status

04/2017 – Coordinating with AES HEOMD and STMD to revise forward plan that would include risk reduction testing that would demonstrate two phase flow is not an issue and mitigate the risk entirely. Cost impacts are also part of the discussion with cost sharing between Mission Directorate as an option.

Mitigation Steps	Dollars to implement	Trigger/ Start date	Schedule UID	Completion Date	Resulting L/C
Perform Risk Reduction Testing	\$500K	05/2017		06/2017	1x3

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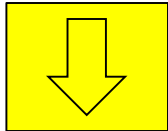
MON25/MMH 100 lb Thruster Internal Flow Separation– Bill Ondocsin



Risk ID #

T2

Trend/Criticality



Current L/C

3x4 (demonstrated)

Affinity Group

Technical

Planned Closure

05/01/2017

Open Date

02/01/2017

Risk Statement :

Approach: Mitigate

Given that the ISE-100 engine tests demonstrated internal flow separation in the feed system, there is a possibility that the internal acoustics could be excited resulting in high frequency structural/combustion dynamics and hardware life degradation.

Context

Redesign/new design of a MON25 engine can mitigate this effect by performing the proper fluids analysis and implementing proper flow passage design techniques that would prevent flow separation and acoustic excitation.

Status

04/2017 – Coordinating with AES HEOMD and STMD to revise forward plan that would include risk reduction testing that would demonstrate two phase flow is not an issue and mitigate the risk entirely. Cost impacts are also part of the discussion with cost sharing between Mission Directorate as an option.

Mitigation Steps	Dollars to implement	Trigger/ Start date	Schedule UID	Completion Date	Resulting L/C
Workhorse Testing leads to mitigation	\$600K	09/2017		11/2017	1x4

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MON25/MMH 100 lb Thruster

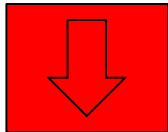
Internal Acoustic Resonance – Bill Ondocsin



Risk ID #

T3

Trend/Criticality



Current L/C

5x4 (demonstrated)

Affinity Group

Technical

Planned Closure

05/01/2017

Open Date

02/01/2017

Risk Statement :

Approach: Mitigate

Given that the ISE-100 engine tests demonstrated internal acoustic resonance in the feed system, there is a possibility that the internal acoustics would result in high frequency structural/combustion dynamics and hardware life degradation.

Context

Redesign/new design of a MON25 engine can mitigate this effect by performing the proper acoustic analysis and implementing proper flow passage design techniques and implementing proper injector fluid resistance that would result no resonant acoustics communicating from the combustion chamber through the feed system.

Status

04/2017 – Coordinating with AES HEOMD and STMD to revise forward plan that would include risk reduction testing that would demonstrate two phase flow is not an issue and mitigate the risk entirely. Cost impacts are also part of the discussion with cost sharing between Mission Directorate as an option.

Mitigation Steps	Dollars to implement	Trigger/ Start date	Schedule UID	Completion Date	Resulting L/C
Workhorse Testing leads to mitigation	\$600K	09/2017		11/2017	1x4

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MON25/MMH 100 lb Thruster

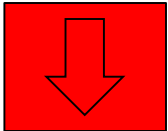
Combustion Instability – Bill Ondocsin



Risk ID #

T4

Trend/Criticality



Current L/C

5x5 (demonstrated)

Affinity Group

Technical

Planned Closure

05/01/2017

Open Date

02/01/2017

Risk Statement :

Approach: Mitigate

Given that the ISE-100 engine tests demonstrated combustion instability, there is a possibility that the internal excitation would result in high frequency structural/combustion dynamics and led to hardware life degradation.

Context

Redesign/new design of a MON25 engine can mitigate this effect by designing the injector face with proper flow resistance, restricting acoustic communication between the combustion chamber and system feedline flow.

Status

04/2017 – Coordinating with AES HEOMD and STMD to revise forward plan that would include risk reduction testing that would demonstrate two phase flow is not an issue and mitigate the risk entirely. Cost impacts are also part of the discussion with cost sharing between Mission Directorate as an option.

Mitigation Steps	Dollars to implement	Trigger/ Start date	Schedule UID	Completion Date	Resulting L/C
Workhorse Testing leads to mitigation	\$600K	09/2017		11/2017	1x4

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Excel File: STMD and GCD Data Request



Project	Program Year	Vendor Name (Who is building the Technology)	Contract Number	What is Being completed? (H/W, S/W, Analysis)	Where is the Work being Completed? (Where work is being performed)		Type of Business (Academia, SBIR, Large, etc)	Program Year Cost (\$M)
					City	State		
ISE 100 Qual	PY 17	Aerojet Rocketdyne	NNM13AA33C	Qual testing thruster	Canoga Park	California	Large Rocket Engine Manufacturer	2.4000



MON25/MMH 100 lb Thrusters



STATUS QUO

- Current state of the art MON3/MMH bi prop systems operate at approximately 45° F.
- When spacecraft operate out past Jupiter solar radiation becomes a limiting factor to power propellant heating systems. Battery size and weight must increase and payload goes down.



NEW INSIGHTS

Advancements in MON25/MMH hypergolic bipropellant thrusters represent a promising avenue for addressing these deficiencies, heavy, high costs, and requiring room temperature propellant operation, with tremendous mission enhancing impacts.



PROBLEM / NEED BEING ADDRESSED

NASA S/C primarily rely on 1960's heritage hydrazine-based in-space thrusters that are relatively heavy, have high production & prop-handling costs, require room temperature propellant operation, and are performance plateaued.

PROJECT DESCRIPTION/APPROACH

• **ISE-100 MON-25/MMH Thruster**

- Integral valve/ injector and high-temperature lightweight composite thrust chamber/ nozzle
- Advanced and efficient manufacturing with low cost materials for enhanced affordability
- Two complete 100-lbf thrusters available for hot-fire testing
 - Qual test Existing ISE 100 thrusters to a mission profile to match the NASA Resource Prospector Lander Mission requirements
 - Qual increased TRL-4 to TRL-6

QUANTITATIVE IMPACT

- Enhanced Isp/p-Isp & Reduced System Weight & Volume
- Lower Freezing Point & Increased Vapor Pressure
- Unconstrained Duty Cycle Limitations
- Integrated Design, Lightweight, Advanced Manufacture (cost \$200k vs \$700K)

300% Lighter
50% Smaller
1/3 Cost

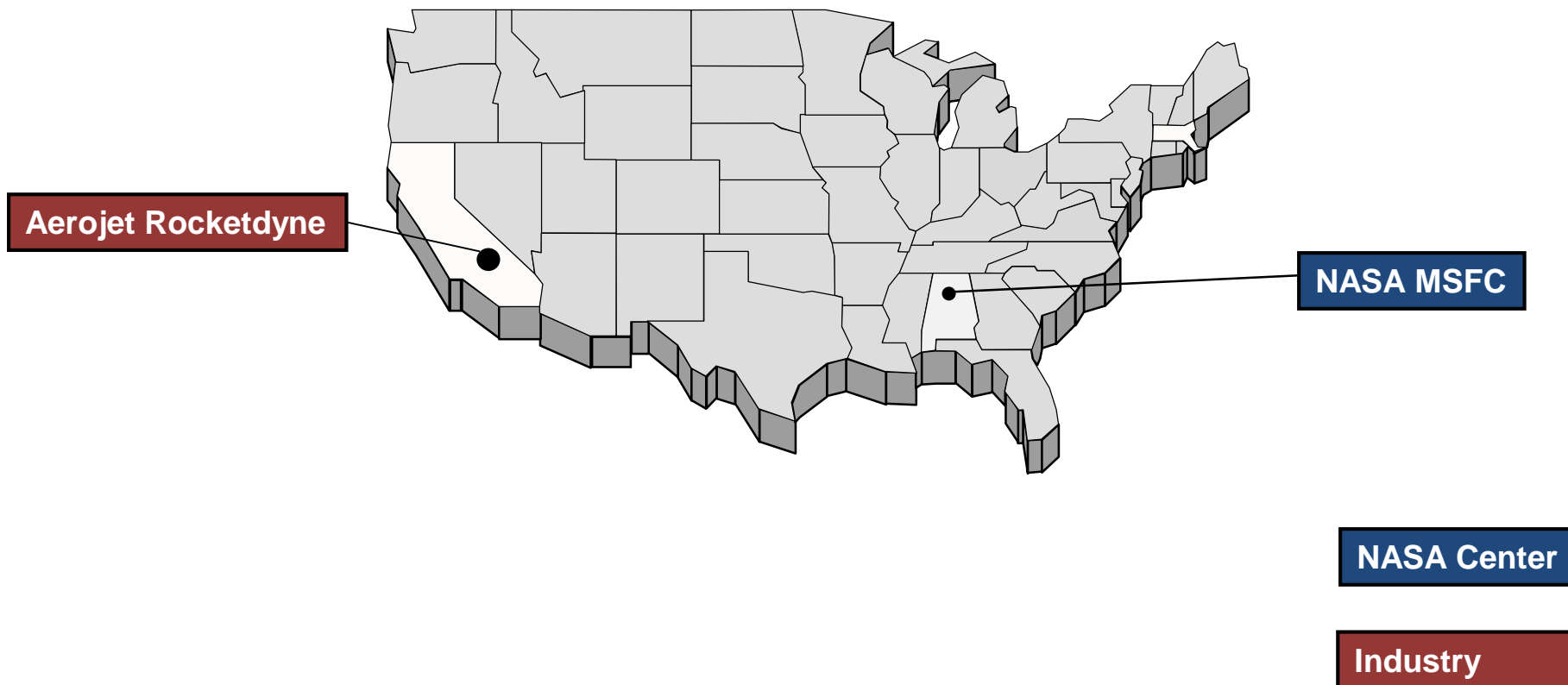


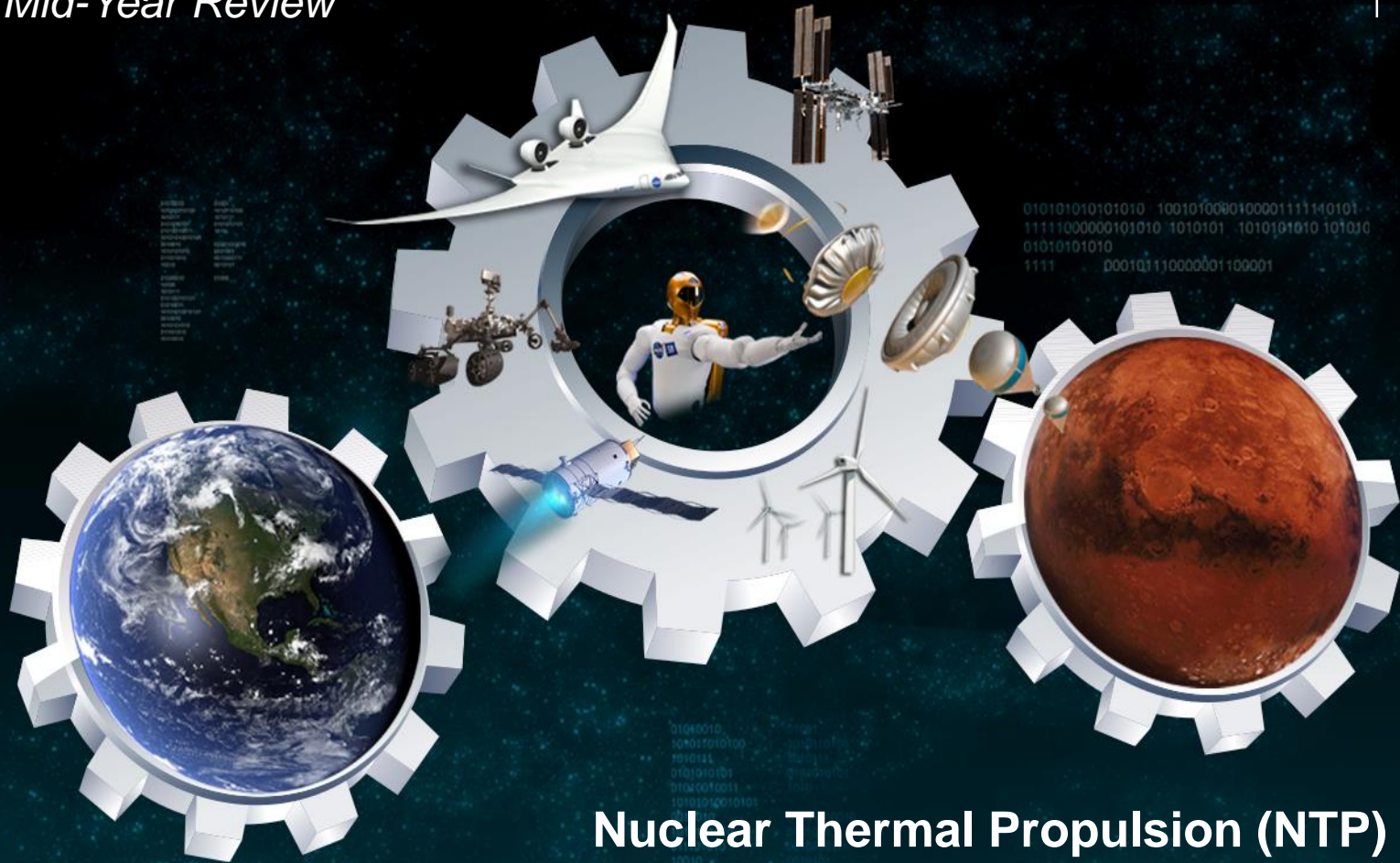
PROJECT GOAL

- HAVE MON25/MMH Mission Infusion Opportunities ready for:
- SMD / Planetary Science Division
 - New Frontiers AO
 - Mars Sample Return
- HEOMD
 - CATALYST
 - Resource Prospector



MON25/MMH 100 lb Thrusters Members





Nuclear Thermal Propulsion (NTP)

Presented By: Sonny Mitchell, PM

4/26/17

TECHNOLOGY DRIVES EXPLORATION

Project Manager 2nd Quarter Assessment



Technology/ Task	Performance				Comments
	T	C	S	P	
Demonstration of Purified Tungsten (W)	Yellow	Green	Yellow	Green	<p>Technical: Dynetics is investigating an issue with the earlier sample analysis and is evolving the sample analysis process to improve confidence in baseline/unprocessed material assay and the overall purification metrics. The earlier sample analysis was used to predict the purity increase with each cycle and set the milestone due date.</p> <p>Schedule: GCD milestone: Completion of 1mg W-184 @ 50% slipped from 4/14/17 (working due date) and may slip beyond 5/15/17 (due date with margin). Will update the milestone completion date once the issue with the sample analysis is understood.</p>
Low Enriched Uranium (LEU) Engine & Cost Analysis	Green	Green	Green	Green	<p>FY17 Aerojet Rocketdyne (AR) is making good progress and will have significant engine analysis results to report by the 6/1/17 milestone date. Cost analysis work is progressing on schedule.</p>
Fuel Reactor Design & Fabrication	Green	Green	Green	Green	<p>Technical: BWXT is working an alternate reactor design that reduces amount and percentage of purified W required for fuel element (FE) fabrication. With the additional funding provided by GCD, BWXT will be able to perform multiple iterations of the baseline design and alternate concepts with enhanced fidelity, and examine FE fabrication techniques in greater detail. This work may reduce cost, schedule and FE fabrication risk. MSFC in-house work to produce the surrogate cermet fuel segment for testing in the Compact Fuel Element Environmental Test (CFEET) system is making good progress. The segment fabrication milestone is on schedule.</p>
NTP Project Summary	Yellow	Green	Yellow	Green	<p>Technical: Continued challenges with purified tungsten (W) work have resulted in elevating the risk of this task. However the Project developed and is investigating mitigation options that could be implemented including alternative LEU Cermet FE formulation that reduces and eliminates reliance on purified W.</p> <p>Schedule: Purified W milestone due 4/14/17 has slipped and completion date is TBD.</p>



NTP Overview



What would you say to a Senator in an elevator?

NTP is the most promising advanced in-space propulsion option for crewed Mars missions. NTP is a safe, affordable 'game changing' technology for space propulsion that enables faster trip times and safeguards astronaut health.

Integration with other projects/programs and partnerships

- **MSFC Center Innovation Fund:** "Developing Multi-scale Modeling Tool to Simulate CERMET Fuel Performance"
- **SBIR**
 - **2015 Phase 2:**
 - Superconducting Electric Boost Pump for NTP; Florida Turbine Technologies, Inc.
 - Hydrogen Wave Heater for NTP Component Testing; ACENT Laboratories LLC
 - Fabrication and Testing of NTP Ground Test Hardware; Ultramet
 - Cellular Load Responsive MLI: Structural In-Air and In-Space LH2 Insulation; Quest Thermal Group
 - **2016 Phase 2:**
 - Passive Technology to Improve Criticality Control of NTP Reactors; Ultra Safe Nuclear Corporation

Technology Infusion Plan:

PC, In-space Propulsion, HEOMD, Mars 2030

Key Personnel:

Program Element Manager: Wade May

Project Manager: Sonny Mitchell

Lead Center: MSFC

Supporting Centers: GRC, SSC

NASA NPR: 7120.8

Guided or Competed: Competed

Type of Technology: Push

Key Facts:

GCD Theme: FPES

Execution Status: Year 2 of 3

Technology Start Date: 1/7/16

Technology End Date: 9/30/18

Technology TRL Start: 2 (Overall LEU engine)

Technology TRL End: 3 (Overall LEU engine)

Technology Current TRL: 2 (Overall LEU engine)

Technology Lifecycle Phase: Implementation



Level 1 Project Goals



Level 1 Project Goals	
Nuclear Thermal Propulsion (NTP)	
Goal #1	Demonstrate the ability to purify tungsten at the levels and quantities needed for fuel core manufacturing.
Goal #2	Establish robust manufacturing methods for a LEU reactor core.
Goal #3	Establish a concept design for an NTP LEU engine in the thrust range of interest for a human Mars mission.
<u>Notes:</u>	



Key Performance Parameters (KPP)



Key Performance Parameters				
Nuclear Thermal Propulsion (NTP)				
Performance Parameter	State of the Art	Threshold Value	Project Goal	Estimated Current Value
Manufacture of Purified Tungsten	N/A	1 kg @ 90%	1 kg @ >90%	N/A
Specific Impulse (analysis)	$I_{sp} = 450$ sec.	$I_{sp} = 850$ sec.	$I_{sp} > 900$ sec.	N/A
Cermet FE Operating Temperature (tested)	2500K	2700K	2850K	N/A
<u>Notes:</u>				



Key Technical Risks

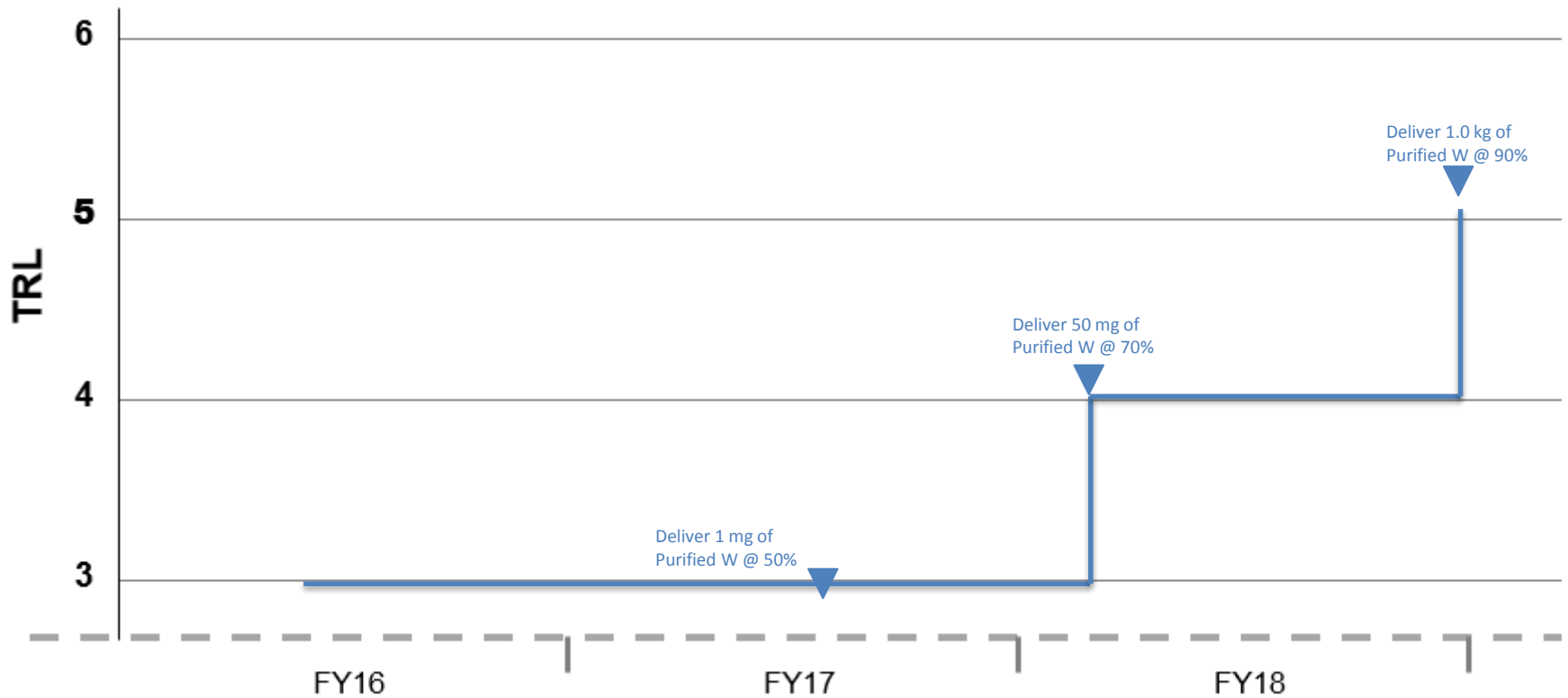


Key Technical Risks				
Nuclear Thermal Propulsion (NTP)				
RISK ID	Title	Description	L/C	Trend
NTP- T1	Tungsten Purification	It may not be affordable to produce purified tungsten in quantities required to make the baseline LEU Cermet Fuel Element a viable option.	3/3	➔
Notes:				

Criticality	L x C Trend	
High	↓	Decreasing (Improving)
Med	↑	Increasing (Worsening)
Low	➔	Unchanged
	■	New Since Last Period



Technology Readiness Level (TRL) Assessment





Milestones and Forward Plans



FY17 Key and Controlled Milestones	Baseline Completion Date	Actual Completion Date	Estimated Completion Date	Variance Explanation
<i>FY17 Q1 (Oct 1 through Dec 31)</i>				
<i>FY17 Q2 (Jan 1 through March 31)</i>				
<i>FY17 Q3 (Apr 1 through June 30)</i>				
1.0 mg of W purified to 50 percent	4/14/17 (with margin: 5/15/17)		TBD	Dynerics reports issues with the earlier sample analysis and is evolving the sample analysis process to improve confidence in baseline/unprocessed material assay and the overall purification metrics. The earlier sample analysis was used to predict the purity increase with each cycle and set the milestone due date. Additional process runs are necessary to determine revised schedule to meet the milestone.
<i>FY17 Q4 (Jul 1 through Sep 30)</i>				
Testing of surrogate Cermets FE in the Compact Fuel Element Environmental Test (CFEET) System	9/1/17			
50.0 mg of Tungsten purified to 70% (or greater)	9/1/17		12/31/17	TBD – see above.



NTP Technical Accomplishments



- **Accomplishments**

- Completed LEU System Quarterly Cost Review, 1/25/17
 - Set the baseline work breakdown structure and schedule
 - Began development of the of cost basis of estimates (BOEs)
- Received positive results on initial LEU engine performance and feasibility analysis from Aerojet Rocketdyne
 - Updated report due 6/1/17 (Project Milestone): On schedule
- Finalized Technology Maturation Plan: Defines engine development to TRL 6
- Fabricated initial Cermet tungsten surrogate FE segment at MSFC for testing in the Compact Fuel Element Environmental Test (CFEET) System
 - Final fabrication due 6/1/17 (Project Milestone): On schedule
- Completed support of HQ In-space Transportation Study - Human Mars Mission
- Participated in the Nuclear and Emerging Technologies for Space (NETS) Conference, Orlando, FL, 2/27/17 – 3/2/17
 - Held a Technical Interchange Meeting with KSC on 3/3/17 to discuss KSC facility requirements and issues for NTP Con-ops



NTP Technical Challenges

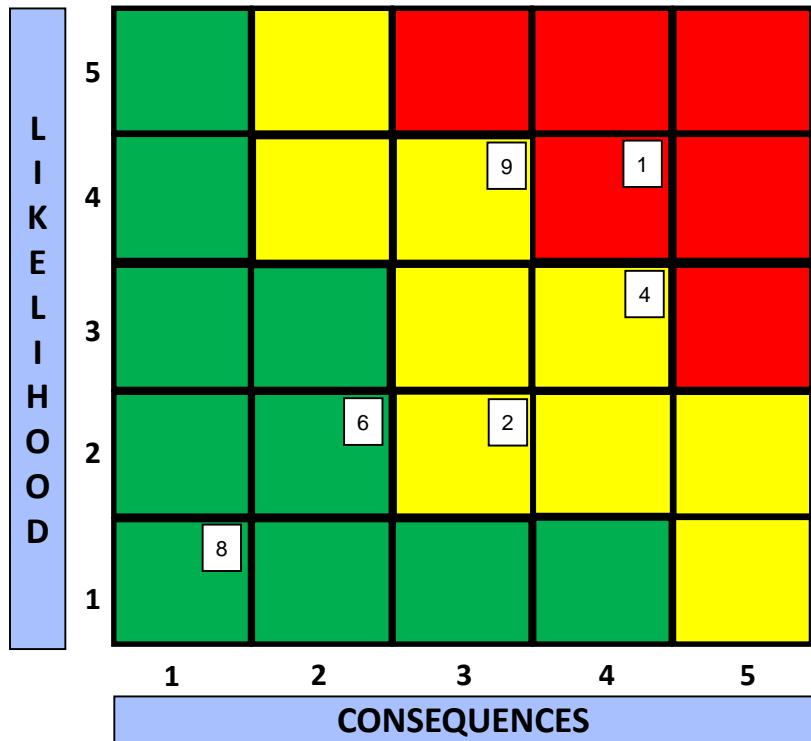


- **Significant Technical Challenges**

- Processing time to affordably produce purified W at required levels for a LEU engine continues to be challenging
 - Installed a higher resolution Inductively Coupled Plasma Mass Spectrometer (ICP-MS) enabling greater fidelity to sample analysis for purified W
 - Identified issues with baseline data that resulted in overly optimistic predictions for achieving milestone results
 - Working to better understand sample analysis and update the milestone schedule
- Design and Manufacturability of Cermet FE(s)
 - Investigating alternate BWXT LEU Cermet reactor/FE design which requires less tungsten and less purified tungsten
 - Received \$2.2M funding increase to further design and reduce/eliminate project risk



Risk Summary



Risk ID Trend	Approach/Affinity	Risk Title
#1 ↑	M/T	Tungsten (W) Purification
#4 →	R/T	LEU Cermet Engine Feasibility
#9 □	R/T	FY18 Budget
#2 ↓	M/T	Cermet FE Fabrication
#6 ↓	M/Sc	Nuclear Indemnification
#8 →	A/Sa	S&MA Support

Criticality

- High (Red)
- Med (Yellow)
- Low (Green)

L x C Trend

- ↓ Decreasing (Improving)
- ↑ Increasing (Worsening)
- Unchanged
- New Since Last Period

Approach

- M - Mitigate
- W - Watch
- A - Accept
- R - Research

Affinity: T-Technical C-Cost Sc-Schedule Sa-Safety



EPO Summary Chart



- **Education and Public Outreach Events: None**
- **Conferences & Journal Articles**
 - **AAS Guidance, Navigation and Control Conference, Breckenridge, CO**
 - Low Enriched Uranium Nuclear Thermal Propulsion Systems, Michael Houts, Sonny Mitchell, Ken Aschenbrenner (MSFC)
 - **Nuclear Emerging Technologies for Space (NETS) 2017, Orlando, FL**
 - Development and Utilization of Space Fission Power and Propulsion Systems, Michael G. Houts, Sonny Mitchell, Ken Aschenbrenner, Anthony Kelley (MSFC)
 - Multiscale NTP Fuel Element Material Simulation, Robert Hickman, Marvin Barnes (MSFC) Dr. Michael Tonks (Penn State University), Kelsa Benensky (University of Tennessee)
 - NTP CERMET Fuel Fabrication Study, Marvin W. Barnes, Dr. Dennis Tucker (MSFC), Lance Hone, Steven Cook (Center for Space Nuclear Research (CSNR))
 - Hot Hydrogen Testing of Silicon Carbide for Nuclear Thermal Propulsion Applications, Kelsa Benensky (University of Tennessee), Marvin Barnes, Douglas Trent, Robert Hickman (MSFC), Kurt Terrani (Oak Ridge National Laboratory (ORNL)), Michael Houts (MSFC), and Steven Zinkle (ORNL)
 - **Journal: Journal of Nuclear Materials**
 - High Density, Uniformly Distributed W/UO₂ for Use in Nuclear Thermal Propulsion, Dr. Dennis Tucker, Marvin W. Barnes (MSFC), Lance Hone, Steven Cook, (CSNR)



FY17 Forward Plans



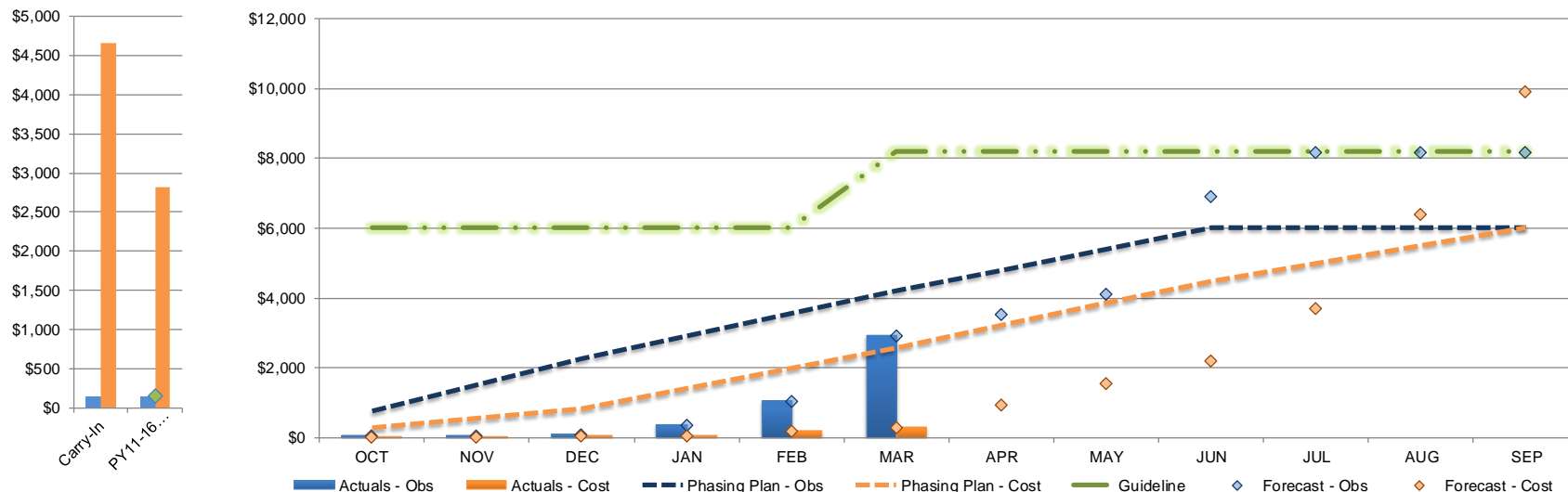
- **Remaining Events for FY17**
 - Complete Project Milestones:
 - Deliver 1mg Purified W-184 @ 50%, (TBD)
 - Complete Surrogate Cermet FE for Testing in CFEET, (6/1/17)
 - Engine Performance and Feasibility Analysis, (6/1/17)
 - Testing of Surrogate Cermet FE in CFEET, (9/1/17)
 - Updated LEU NTP System Cost Analysis (includes the purified tungsten cost estimate), (9/1/17)
 - Hold Periodic Technical Review 2 (PTR-2), August (TBD)
- **Technical Development**
 - Issues with W Purification have delayed task milestones
 - Mitigation options being worked
 - All other tasks have no technical issues and are on schedule
- **Plans for Continuation Review**
 - W purification results will determine go forward plan for FE development
 - Determine if sufficient progress is being made towards achieving Project KPP's
 - Includes satisfactory cost and schedule performance
 - Continuation Review @ MSFC, 9/28/17 (Placeholder)



Resources: Non-Labor Obligations and Cost



FY 2017 Non-Labor Financial Status



	Cum (\$K)	Carry-In	PY11-16 Funds	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	Carry Out
Obs	Guideline		141.0	6,000.0	6,000.0	6,000.0	6,000.0	6,000.0	8,200.0	8,200.0	8,200.0	8,200.0	8,200.0	8,200.0	8,200.0	8,200.0
	Phasing Plan (RLP)			758.0	1,516.0	2,274.0	2,916.7	3,559.3	4,202.0	4,801.3	5,400.7	6,000.0	6,000.0	6,000.0	6,000.0	2,200.7
	Actuals	141.0	140.3	50.0	61.6	96.1	360.3	1,043.7	2,927.3							
Cost	Forecast			50.0	61.6	96.1	360.3	1,043.7	2,927.3	3,526.7	4,126.0	6,925.3	8,200.7	8,200.7	8,200.7	(0.0)
	Phasing Plan (RLP)			270.7	541.3	812.0	1,402.0	1,992.0	2,582.0	3,220.0	3,858.0	4,496.0	4,997.3	5,498.7	6,000.0	1,993.8
	Actuals	4,666.3	2,812.1	12.7	19.5	50.1	64.6	198.7	293.8							
	Forecast			12.7	19.5	50.1	64.6	198.7	293.8	931.8	1,569.8	2,207.8	3,709.1	6,410.5	9,911.8	282.7

Note: Carry-In is the unobligated/uncosted portion of PY11-16 funding end of FY16

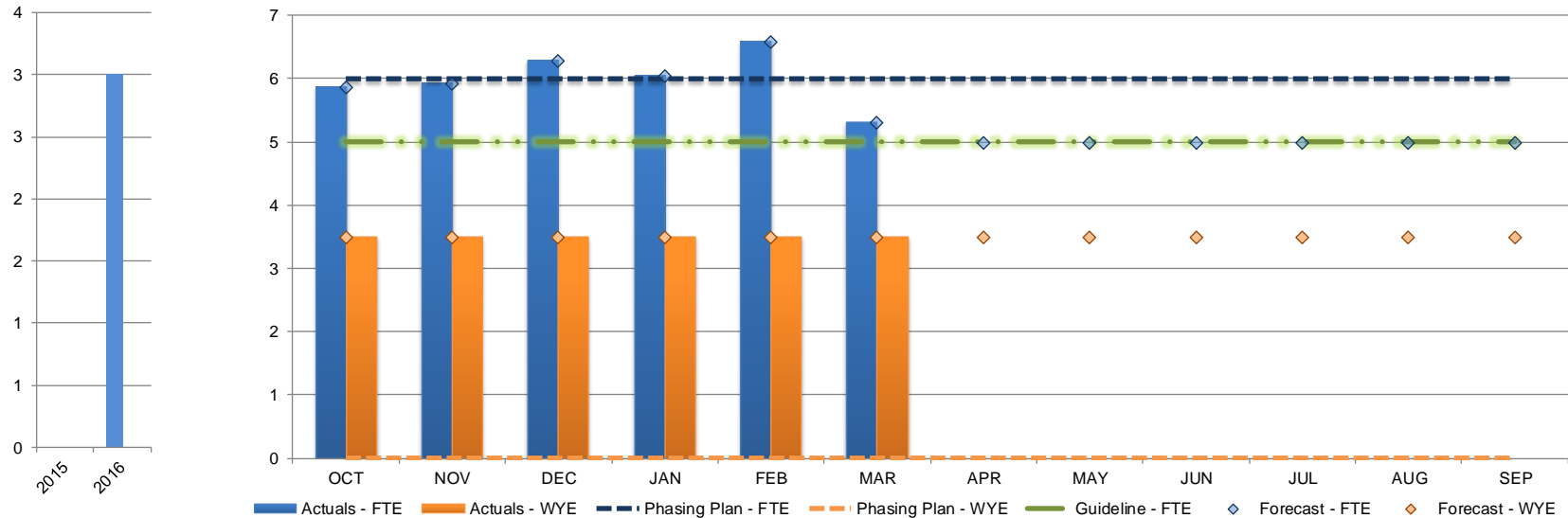
	YTD Status	Explanation required for YTD Variance in excess of 5% from Phasing Plan (shaded red)
'17 Obs	Phasing \$ 4,202	The current plan is to obligate an additional \$1.5M on Dynetics in May and \$2.2M on BWXT once contract is awarded in June 2017.
	Actuals \$ 2,927	
	Variance \$ (1,275)	
'17 Cost	Phasing \$ 2,582	Although \$1.5M has been awarded and expended on Dynetics NTP task; contract set up on straight-line accounting method or "First In/First Out" for cost. Project activities on-going and no impact to project at this time.
	Actuals \$ 294	
	Variance \$ (2,288)	



Resources: Total Project Workforce FTEs/WYEs



FY 2017 Workforce Status



	Incremental	2015	2016	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	2017 Avg
FTE	Guideline			5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
	Phasing Plan (RLP)			6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
	Actuals	0	3.0	5.9	5.9	6.3	6.1	6.6	5.3							6.0
	Forecast			5.9	5.9	6.3	6.1	6.6	5.3	5.0	5.0	5.0	5.0	5.0	5.0	5.5
WYE	Phasing Plan (RLP)															0.0
	Actuals	0.0	0.0	3.5	3.5	3.5	3.5	3.5	3.5							3.5
	Forecast			3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5

	YTD Status	Explanation required for YTD Variance in excess of 5% from Phasing Plan (shaded red)
'17 FTE	Phasing	Project plan baseline is 6 FTEs; guideline shows 5 FTEs due to SSC headcount limitations. MSFC labor charges coordinated with engineering to reduce charges in the next few months in those areas not effecting project milestones.
	Actuals	
	Variance	
'17 WYE	Phasing	MSFC WYEs running approximately 2.5.
	Actuals	
	Variance	



Project Quarterly Summary Performance



Project Summary Performance

Project	Summary Performance			
	Cost	Schedule	Technical	Programmatic
Quarter 1	Yellow	Green	Green	Green
Quarter 2	Green	Yellow	Yellow	Green
Quarter 3	Grey	Grey	Grey	Grey
Quarter 4	Grey	Grey	Grey	Grey



Back Up Charts

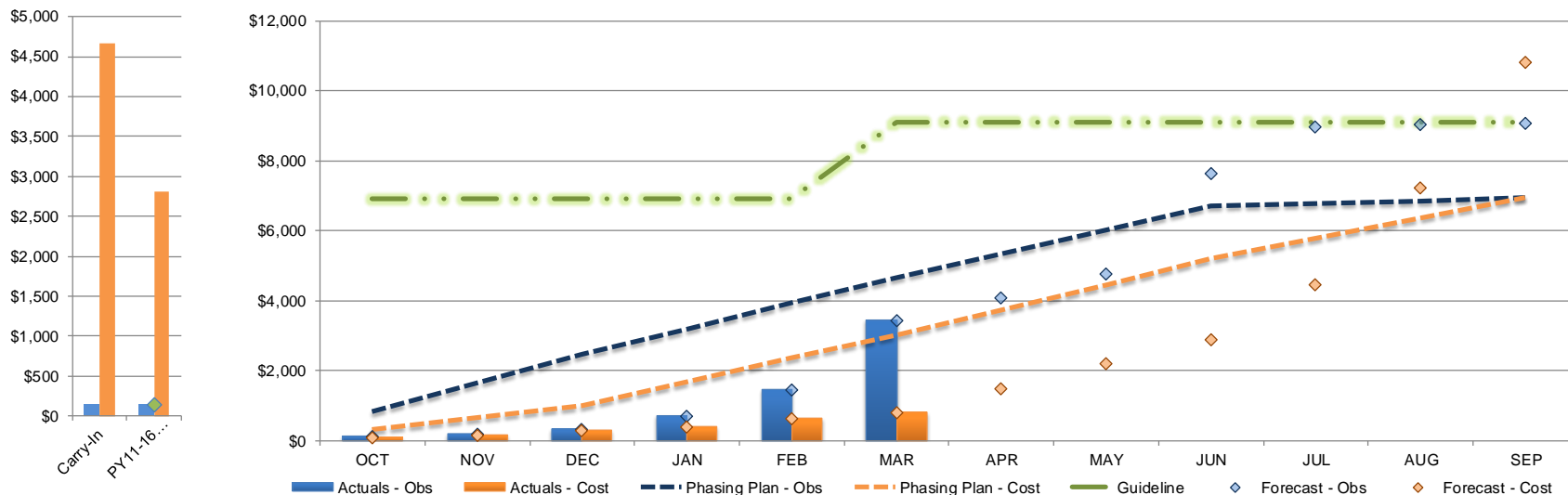
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Resources: Total Obligations and Cost



FY 2017 Financial Status



	Cum (\$K)	Carry-In	PY11-16 Funds	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	Carry Out
Obs	Guideline		141.0	6,900.0	6,900.0	6,900.0	6,900.0	6,900.0	9,100.0	9,100.0	9,100.0	9,100.0	9,100.0	9,100.0	9,100.0	
	Phasing Plan (RLP)			827.1	1,654.2	2,481.3	3,205.7	3,930.0	4,654.4	5,335.4	6,016.4	6,697.4	6,779.1	6,860.8	6,942.5	2,158.3
	Actuals	141.0	140.3	136.1	222.1	347.7	705.3	1,480.3	3,443.7							
Cost	Forecast			136.1	222.1	347.7	705.3	1,480.3	3,443.7	4,108.1	4,772.4	7,636.7	8,977.1	9,040.1	9,100.7	(0.0)
	Phasing Plan (RLP)			339.8	679.6	1,019.3	1,691.0	2,362.7	3,034.4	3,754.1	4,473.7	5,193.4	5,776.4	6,359.4	6,942.5	1,993.8
	Actuals	4,666.3	2,812.1	98.8	179.9	301.8	409.5	635.4	810.2							
	Forecast			98.8	179.9	301.8	409.5	635.4	810.2	1,513.2	2,216.2	2,919.2	4,485.5	7,249.9	10,811.8	282.7

Note: Carry-In is the unobligated/uncosted portion of PY11-16 funding end of FY16

	YTD Status	Explanation required for YTD Variance in excess of 5% from Phasing Plan (shaded red)
'17 Obs	Phasing \$ 4,654	The current plan is to obligate an additional \$1.5M on Dynetics in May and \$2.2M on BWXT once contract is awarded in June 2017.
	Actuals \$ 3,444	
	Variance \$ (1,211)	
'17 Cost	Phasing \$ 3,034	Although \$1.5M has been awarded and expended on Dynetics NTP task; contract set up on straight-line accounting method or "First In/First Out" for cost. Project activities on-going and no impact to project at this time.
	Actuals \$ 810	
	Variance \$ (2,224)	



NTP: Tungsten Purification – Melissa Van Dyke, NTP CE



Risk ID #1

Trend



Worsening

Criticality

High

Current L/C

4x4

Affinity Group

Technical

Planned Closure

10/03/2017

Open Date

03/01/2016

Risk Statement :

Given that the process is still under development, there is a possibility that purified tungsten (W) will not be produced in a timely affordable manner, resulting in the Cermet Fuel Element (FE) not being a viable option.

Approach: Mitigate

Context:

The ability to affordably produce isotopically pure tungsten would be required for the development of a Cermet fueled NTP system using LEU. This potentially “game changing” technology is key to the development of a Cermet-based LEU NTP engine that could have extensibility beyond the current Mars campaign, and may provide the ability to develop these systems at an affordable level of budgetary commitment. The process to purify W is complex and challenging. Process details are classified.

Status

04/11/17: Milestone is slipping from 4/14/17 date, and likely will slip from 5/15/17 (with margin)

03/14/17: Current status from Dynetics indicates progress, however, any additional unforeseen incidents may delay achievement of milestone.

10/16/16: Completion of 1mg W-184 @ 50% will probably slip from 4/14/17 (working due date) and possibly beyond 5/15/17 (due date with margin)

09/22/16: Completion of small test quantities of purified W are in work with the goal of 1.0mg at 50 percent. Finish date slipped from 10/3/2016 to 11/15/16 due to an inadvertent chemical release during processing. Anticipate no issues hitting the purification target for this milestone.

Mitigation Steps	Dollars to implement	Trigger/ Start date	Schedule UID	Completion Date	Resulting L/C
1. Develop decision logic for potential off-ramps from baseline LEU Cermet development strategy.	N/A	06/01/2016	Pending	06/01/2017	1x3
2. Before off-ramps are implemented submit and obtain approval on a CR.	N/A	06/01/2016	Pending	06/01/2017	1x3
3. BWXT is exploring an alternative LEU system concept that does not require purified tungsten.	CR/\$2.2M planned for BWXT feasibility study	06/02/2017	Pending	9/30/2019	4x4



NTP: LEU Cermet Engine Feasibility – Melissa Van Dyke, NTP CE



Risk ID #4

Trend



Unchanged

Criticality

Med

Current L/C

3x4

Affinity Group

Performance

Planned Closure

06/01/2017

Open Date

03/01/2016

Risk Statement :

Given that limited studies have been done on the LEU Cermet engine feasibility, there is a possibility that further studies will uncover significant technical or programmatic issues, resulting in the LEU Cermet engine not being a viable option

Approach: Mitigate

Context:

To date, all nuclear propulsion system designs have been derived from reactors fueled by highly enriched uranium (HEU). Recent advances in materials technology may provide a more affordable pathway to development of a nuclear rocket engine. A shift to LEU – defined as a concentration of lower than 20 percent 235U – offers several potential advantages for any propulsion system development program including security, handling regulations, and fully contained engine testing. However, limited analysis has been done on LEU Cermet based engine systems. Task 3 of the NTP Project focuses on LEU feasibility, engine cost and analysis.

Status

09/22/16: No change.

04/26/16: Made risk specific to Cermet to better align with NTP decision logic.

03/2016: Working to execute contract vehicle for industry partners to begin initial reactor and cost analysis. Initial in-house work on fully contained engine testing will also begin. Both engine and architecture recommendation/rationale and an initial LEU NTP system cost analysis report are due in early September, 2016.

Mitigation Steps	Dollars to implement	Trigger/ Start date	Schedule UID	Completion Date	Resulting L/C
1. Conduct a detailed feasibility assessment of the LEU engine concept for a given thrust level.	\$0	06/01/2016	Pending	06/01/2017	1x3
2. If the LEU engine proves not to be feasible begin initial assessments of non-category I HEU engines as potentially the next most affordable option..	\$0	05/01/2016	Pending	06/01/2017	1x3



NTP: FY18 Budget – Sonny Mitchell, NTP PM



Risk ID #9

Trend



New

Criticality

Med

Current L/C

4x3

Affinity Group

Technical

Planned Closure

9/30/2017

Open Date

04/11/2017

Risk Statement :

Given that the baseline budget is \$6.9M for FY18, there is a possibility that the budget may not be sufficient to execute the scope defined in the NTP Project Plan, resulting in a reduction in scope.

Approach: Research

Context:

1. Planned budget in FY18 reduced from \$7.5M to \$6.9M and made full cost (includes labor).
2. BWXT estimates for performance of their part of the baseline scope in FY18 significantly exceeds budget levels.
3. AR estimate for FY18 exceeds budget levels.
4. AMA cost estimation effort was not included in the baseline.

Status

04/11/17: \$2.2M budget increase for FY17 approved, risk remains for FY18.

09/22/16: Added as a risk.

Research Steps	Dollars to implement	Trigger/ Start date	Schedule UID	Completion Date	Resulting L/C
1. Investigate options to keep cost close to baseline \$6.9M.	0				



NTP: Cermet Fuel Element Fabrication – Melissa Van Dyke, NTP CE



Risk ID #2

Trend



Decreasing

Criticality

Med

Current L/C

2x3

Affinity Group

Technical

Planned Closure

06/01/2017

Open Date

03/01/2016

Risk Statement :

Given previous challenges in developing a Cermet FE, there is a possibility of not being able to fabricate a FE that meets requirements, resulting in the Cermet FE not being a viable option for a LEU engine.

Approach: Mitigate

Context:

Cermet FE(s) enable the development of LEU reactors. Recent development of Cermet fuel element segments with depleted uranium presented challenges regarding structural integrity. In-house research is being utilized to refine fabrication techniques. Contracts are in work with industry partners who have extensive background in the design and manufacturing of Cermet FE(s). They are tasked with the development and manufacture of FE segments meeting requirements for LEU reactors. FE segments will be tested in representative thermal environments in the NTREES and/or the Compact Fuel Element Environmental Test (CFEET) system

Status

- 03/14/17: Recent work with BWXT on fabrication approaches and Agency architecture analysis on assembly orbits have reduced engine performance sensitivity.
- 01/11/17: Scope of fuel element (FE) work for BWXT was not executable at baselined budget levels
- 09/22/16: Executed contract with BWXT; information provided reduces likelihood.
- 04/26/16: Added FE manufacturer to mitigation
- 03/2016: In-house Cermet research and development using MSFC CIF continues. Contracts are in review to begin Cermet work by industry partners. Projected start is 05/01/2016.

Mitigation Steps	Dollars to implement	Trigger/ Start date	Schedule UID	Completion Date	Resulting L/C
1. Continue MSFC in-house Cermet FE R&D activities (CVD coating, HIP process experimentation, etc..)	\$0	06/01/2016	Pending	06/01/2017	1x4
2. Contract with experienced FE manufactures in industry to design, develop, and manufacture initial FE segments suitable for NTREES testing.	\$500k	05/01/2016	Pending	06/01/2017	1x4
3. Additional funding approved by GCD for fuel element development work.	\$2.2M	06/02/2017	Pending	09/30/2018	1x4



NTP: Nuclear Indemnification – Sonny Mitchell, NTP PM



Risk ID #6

Trend



Decreasing

Criticality

Low

Current L/C

2x2

Affinity Group

Schedule

Planned Closure

06/02/17

Open Date

09/22/2016

Risk Statement :

Given that BWXT requires nuclear indemnification to conduct work beyond the FY16 scope, there is a possibility that the indemnification process may take longer than the time available before the start of FY17, resulting in delays in getting the fuels manufacturing work started.

Approach: Mitigate

Context: N/A

Status

- 03/14/17: MSFC management has made the BWXT contract/indemnification a priority for procurement and legal. The target date for having the contract/indemnification is 2JUN17. This should not impact the NTP schedule.
- 09/22/16: Added as a new risk.

Mitigation Steps	Dollars to implement	Trigger/ Start date	Schedule UID	Completion Date	Resulting L/C
1. BWXT contract/indemnification in process	N/A	03/14/2017	Pending	06/02/2017	1x1
2. Raise the issue with STMD Management and attempt to work indemnification at the Agency to BWXT level.	N/A	09/22/2016	Pending	12/31/2016	1x3
3. Explore other options (DOE, DOD, alternative contractors, etc.)	N/A	09/22/2016	Pending	12/31/2016	1x3

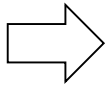


NTP: S&MA Support – Sonny Mitchell, NTP PM



Risk ID #8

Trend



Criticality

Low

Current L/C

1x1

Affinity Group

Safety

Planned Closure

9/30/2018

Open Date

11/16/2016

Risk Statement :

Given that project currently has no day-to-day S&MA support, there is a possibility that important S&MA issues may not be addressed, resulting in inadequate formulation of the full scale development NTP project.

Approach: Accept

Context

Currently there is an agreement between the MSFC S&MA Office and the NTP project that, due to the early stage of formulation, the activities will be covered by the Science and Technology Office Chief Safety Officer. The agreement also stipulates that as activities ramp up, the project will add S&MA support as required.

Status

03/14/17: Currently there is an agreement between the MSFC S&MA Office and the NTP project that, due to the early stage of formulation, the activities will be covered by the Science and Technology Office Chief Safety Officer. The agreement also stipulates that as activities ramp up, the project will add S&MA support as required.

Mitigation Steps	Dollars to implement	Trigger/ Start date	Schedule UID	Completion Date	Resulting L/C
1					



Excel File: STMD and GCD Data Request



- **EPO: Activities, Conferences, and Students**
- **Economic Development**
- **Post Excel File to the following link on NX: :**
<https://nx.larc.nasa.gov/dsweb/View/Collection-97354>

Use Excel file sent with the template and located on NX



Nuclear Thermal Propulsion (NTP)

PROBLEM / NEED BEING ADDRESSED

NTP could enable rapid earth-Mars transits and provide many other benefits. NTP benefits only realized if NTP is affordable and viable to develop and utilize.

PROJECT DESCRIPTION/APPROACH

- Focus on demonstrating the affordability and viability of NTP
- Develop technology needed for low-enriched uranium (LEU) based NTP. Significant cost, schedule, programmatic, and policy benefits
- Identify technology needed for fully contained NTP ground testing and estimate costs
- Mature fuels technology for first generation NTP and estimate reactor/fuels cost and schedule

QUANTITATIVE IMPACT

- Improved astronaut safety (reduced trip time / transit time)
- Reduced architecture cost from affordable NTP (fewer launches)
- Affordable NTP helps enable both fission surface power and advanced fission propulsion

PROJECT GOAL

- Affordably produce material needed to enable LEU NTP
- Complete design study of a fully contained NTP ground test facility and a potential demonstration system
- Fabricate fuel segments and complete non-nuclear fuel segment testing

STATUS QUO

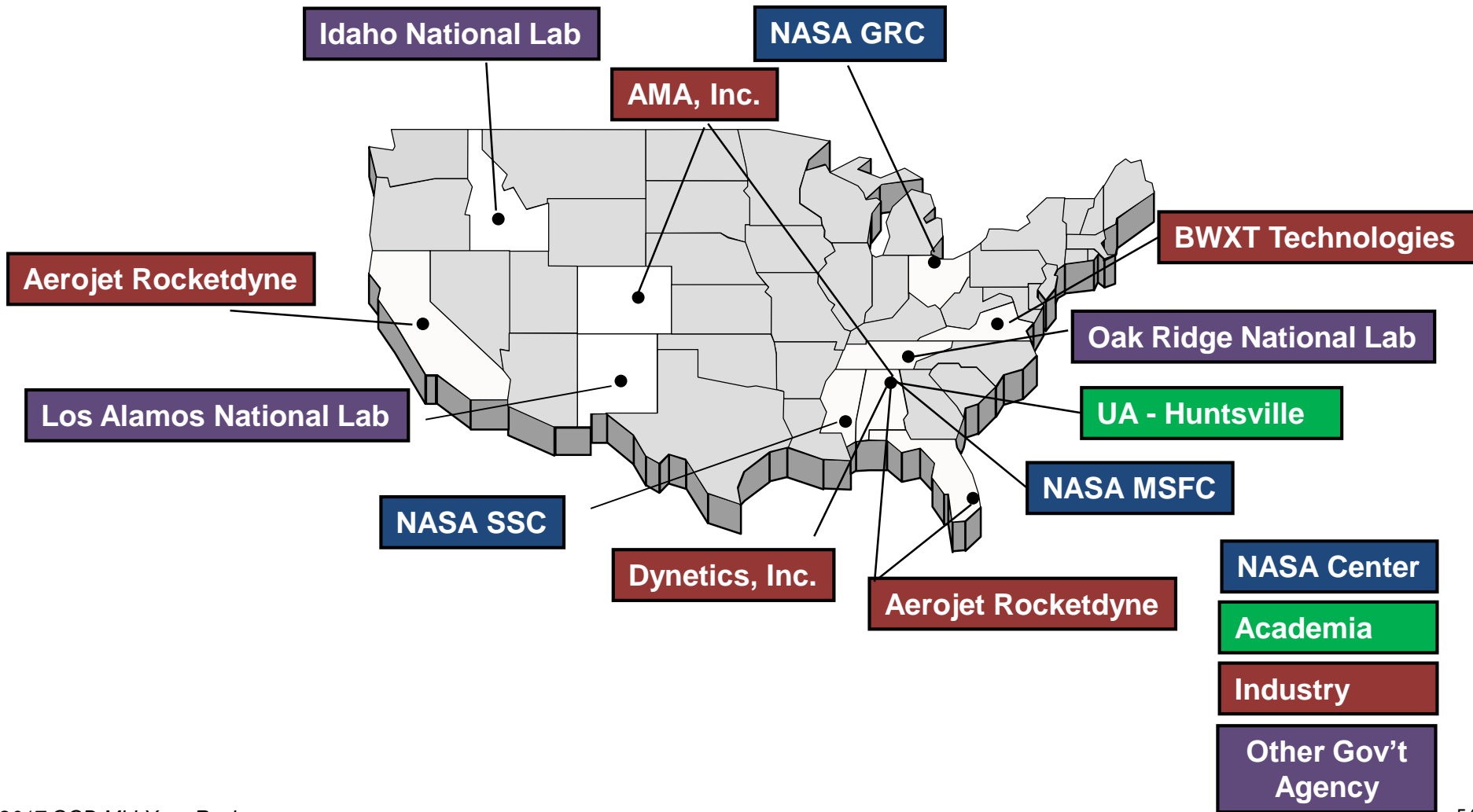
- Chemical Propulsion, Maximum Isp ~450 s
- NTP (first generation Isp ~ 900 s) often considered in architectures, but then deemed “unaffordable” or “non-viable”

NEW INSIGHTS

- An emerging technology could make using low-enriched uranium (LEU) instead of highly enriched uranium (HEU) feasible in the thrust range of interest. This could greatly improve affordability and viability
- Potential for fully contained ground test facility



NTP Organization and Key Members





Advanced Manufacturing Technology

Presented By: John Fikes

April 26, 2017

TECHNOLOGY DRIVES EXPLORATION



AMT Project Manager 2nd Quarter Assessment



Technology	Performance				
	T	C	S	P	
Low Cost Upper Stage Class Propulsion	Yellow	Green	Yellow	Green	<p>Technical is yellow due to the final machine and manifold weld operations on Units 2.2 and 3.0 remain. Although critical operations including SLM and EBF³ of Units 2.1, 2.2 & 3.0 are complete, final machine and manifold weld operations have development risks associated and are critical to LCUSP success.</p> <p>Schedule is yellow due to minimum schedule reserves to meet project goals and deliverables.</p>
Additive Construction with Mobile Emplacement (ACME)	Yellow	Green	Yellow	Green	<p>Technical is yellow due to not verifying ACES-2 hardware nozzle operational requirements and due to the untested design of the ACES-3 nozzle.</p> <p>Schedule is yellow due to the tight schedule with minimum margins to deliver U.S. Army Corp of Engineers ACES-3 hardware.</p>



AMT Milestones and Forward Plans



	FY17 AMT Milestones	Approved Completion Date	Actual Completion Date	Estimated Completion Date	Variance Explanation
<i>FY17 Q1 (Oct 1 through Dec 31)</i>					
ACME	ACME (Zero Launch Mass In-Situ (ZLM) Construction) Materials Development (KSC & MSFC)	12/30/16	12/30/2016(A)		
ACME	Completion of Environmental Modeling Analyses	12/31/16	12/31/2016(A)		
<i>FY17 Q2 (Jan 1 through March 31)</i>					
MGI	Reduce Uncertainty in Knowledge of Constitutive Parameters by 25%	3/23/17	3/23/2017(A)		
MGI	Include Uncertainty in Identified Critical Inputs for Thermal and Structural Analysis	3/23/17	3/23/2017(A)		
LCUSP	Mechanical Testing Complete - SLM Deposited GRCop-84 (2nd buy)	3/31/17	2/24/2017(A)		
LCUSP	Standardized NDE Techniques for Flight HW Documented	3/31/17	3/30/2017(A)		
LCUSP	Standardized SLM Process for Flt HW Documented	3/31/17	3/30/2017(A)		



AMT Milestones and Forward Plans



	FY17 AMT Milestones	Approved Completion Date	Actual Completion Date	Estimated Completion Date	Variance Explanation
<i>FY17 Q3 (Apr 1 through June 30)</i>					
ACME	ACME (Zero Launch Mass In-Situ (ZLM) Construction) Material Print Head Demonstration	4/30/17			
ACME	Feedstock Processing/Transport Hardware Demonstration	5/19/17			Change due to weather constraints and onsite resource availability.
ACME	Integrated Excavation and Handling System Test	5/19/17			Change due to weather constraints and onsite resource availability.
ACME	ACES 3 Gantry Design & Fabrication Complete	5/25/17			A slip in release of design drawings due to increased part complexity and quantity resulted in a delay of fabrication completion.
ACME	Print Head Integration with Mobility System (KDP 3)	3/31/17		5/25/17	Change Request (CR) being processed.
ACME	Optimized Planetary Structure Demos with Integrated Systems at a Lab or Planetary Analog (local) Site	6/21/17			
LCUSP	Mechanical Testing Complete - SLM Deposited GRCop-84 for Orientation & Size Study	6/22/17			
<i>FY17 Q4 (Jul 1 through Sep 30)</i>					
LCUSP	Begin Hot Fire Test - Chamber	7/26/17			Unit 2.2 for Hot Fire Test
LCUSP	Complete Chamber Hot Fire Test	8/15/17			Unit 2.2 for Hot Fire Test
LCUSP	Hot Fire Test (Integrated Assembly)	8/16/17		9/5/17	Unit 3 for Integrated Hot Fire Test
LCUSP	Complete Integrated Hot Fire Test	9/12/17		9/29/17	Unit 3 for Integrated Hot Fire Test
ACME	Complete Full Scale Demonstrations	9/30/17			



AMT Resources: Non-Labor Obligations and Cost



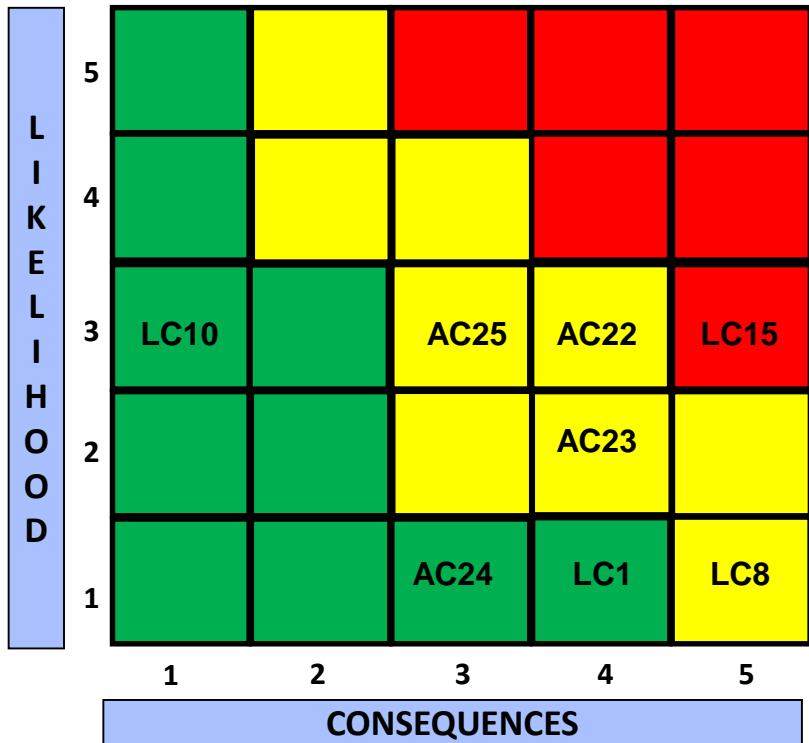


AMT Resources: Total Project Workforce FTEs/WYEs





AMT Risk Summary

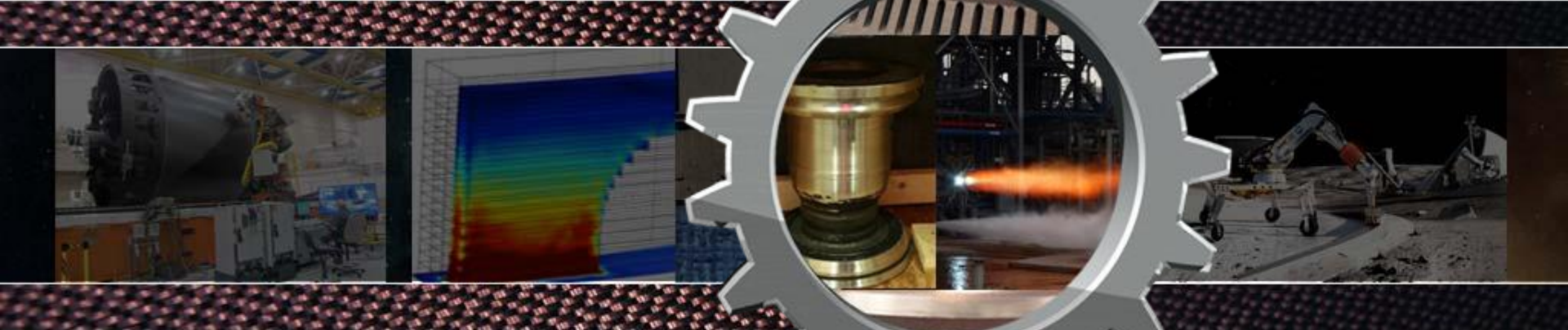


ID	Trend	Approach/Affinity	Risk Title
AC15		W/Sc	Facility Operating Space CLOSED
AC22	→	Sc/C	Logistics for Fabrication, Assembly, Integration
AC23	↓	T	Nozzle Development and Test
AC24	↓	T	Accumulator Development and Test
AC25	→	Sc/C	Dry Goods and Liquid Goods Delivery System
LC1	↓	M/T,C,Sc	EBF3 weld technology
LC8	→	M/T	GRCop-84 and Inconel625 Interface flaws
LC10	↓	M	Residual Stresses impacting material capability
LC15	↓	M	SLM & EBF ³ Process development impacting schedule

Criticality	L x C Trend	Approach
High	↓ Decreasing (Improving)	M - Mitigate
Med	↑ Increasing (Worsening)	W - Watch
Low	→ Unchanged	A - Accept
	□ New Since Last Period	R - Research
	Affinity: T-Technical C-Cost Sc-Schedule Sa-Safety	



Low Cost Upper Stage- Class Propulsion





Advanced Manufacturing Technology LCUSP Overview



The LCUSP will demonstrate the ability to produce a low cost upper stage-class propulsion component system using additive manufacturing technologies. LCUSP will do this by (1) developing a copper alloy additive manufacturing design process, (2) developing a new Nickel Jacket additive manufacture/application process (3) additive manufacture of a 35K-class regenerative chamber/nozzle, (4) testing chamber and then chamber/nozzle system in a hot fire resistance test.

Integration with other projects/programs and partnerships

Liquid Propulsion System (LPS) Test Bed (being developed at MSFC with additive manufactured components such as injectors, LOx and H₂ Turbopumps plans to utilize the LCUSP Combustion Chamber or utilize the capability established under this project to fabricate a chamber. Test and Fabrication Data infused into Lander Technology Office methane thruster work. Follow-on regen Methane Engine Thrust Assembly for 4K lbf (META4) chamber design utilized SLM GRCop-84 process developed by LCUSP and incorporates LCUSP chamber mid-line weld design to enable required length. LCUSP printed faceplate provided strength, conductivity, and oxidation resistance needed for staged combustion testing in a much shorter time than it would have taken to procure stock and machine a traditionally fabricated GRCop faceplate, allowing MSFC to provide the first US data to USAF SMC. Industry partners are investigating possible partnerships with LCUSP for possible opportunities for fabrication of SLM combustion chambers to reduce cost of engine development.

Technology Infusion Plan:

PC, Propulsion, HEOMD, Potential use in manufacturing process of flight engines 2017. Military & Industry, SpaceX, Aerojet-Rocketdyne, Orbital-ATK, ULA, Blue Origin, ASRC Federal, numerous copper machine shops, suppliers, and electronics manufactories.

Key Personnel:

Project Manager: John Fikes

Project Element Manager: Jeramie Broadway

Lead Center: MSFC

Supporting Centers: LaRC & GRC

NASA NPR: 7120.8

Guided or Competed: Guided

Type of Technology: Push

Key Facts:

Thrust Areas: LMAM, Lightweight Materials and Advanced Manufacturing

Execution Status: Year 3 of 3

Technology Start Date: April 2014

Technology End Date: September 2017

Technology TRL Start: 3

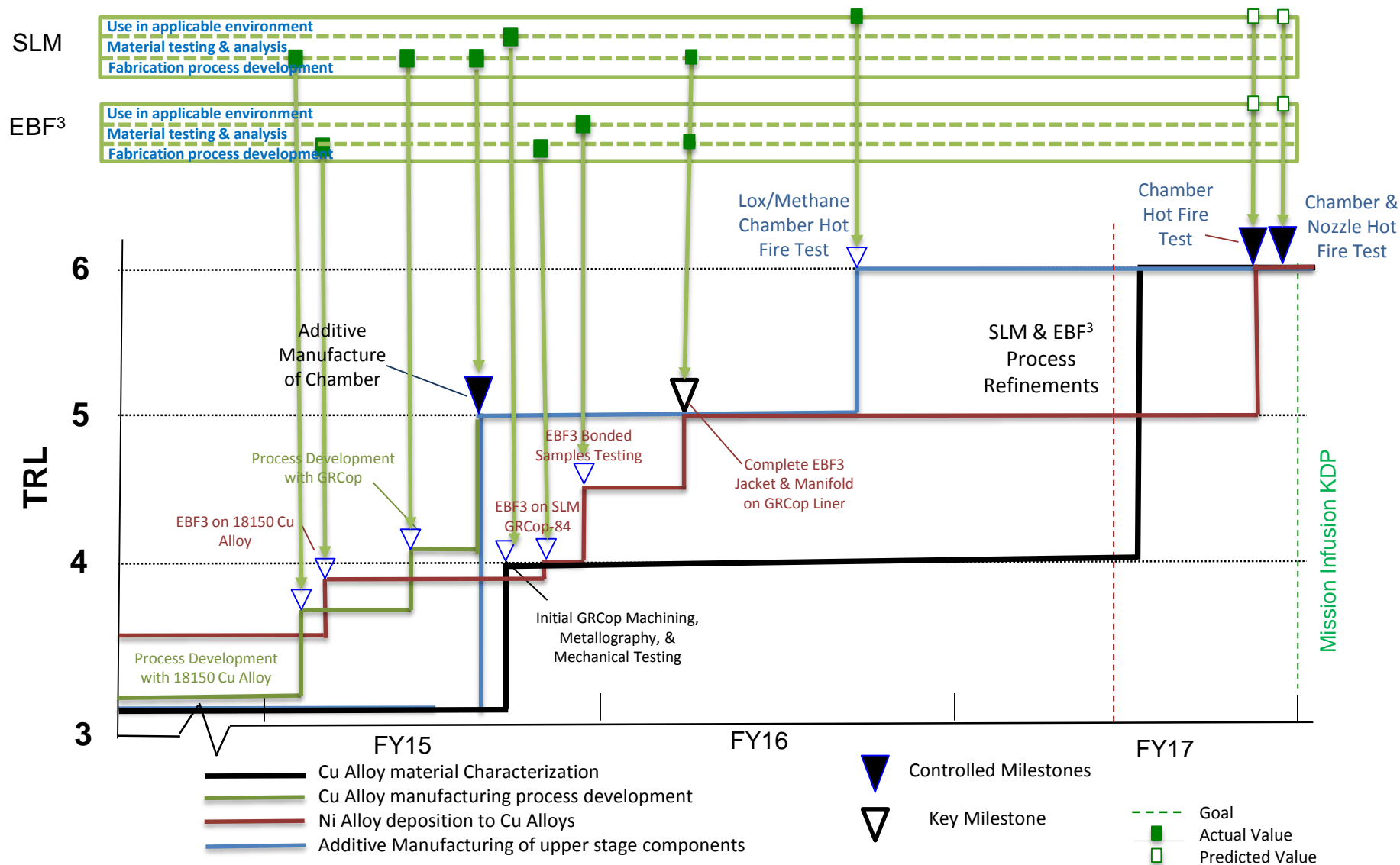
Technology TRL End: 6

Technology Current TRL: 4/5

Technology Lifecycle Phase: Implementation (Phase C/D)



LCUSP Component and System TRL Quarterly Assessment





Advanced Manufacturing Technology LCUSP Performance



- **Technology Advancements**
 - Selective Laser Melting (SLM) fabrication with GRCop-84 powder for rocket components (combustion chamber).
 - Electron Beam Free Form Fabrication (EBF3) application of In625 on SLM GRCop-84 (structural jacket for combustion chamber).
- **Technology advances mean**
 - Additive Manufacturing techniques to reduce cost and shorten schedule as well as produce intricate rocket propulsion components that may have been expensive or impossible to build with conventional techniques.
- **This is push technology**
 - Missions that require new propulsion systems can take advantage of this technology.

Key Performance Parameters

Performance Parameter	State of the Art	Threshold Value	Project Goal	Estimated Current Value
Process control of using Copper via SLM	SLM demonstrated with Inconel 718, Inconel 625, and Al 357, and CoCr by MSFC, but not with copper	Demonstrate parameter set that allows fabrication of monolithic structures to be used for mechanical properties and surface finish testing	Develop an optimized parameter set to maximize build speed, control surface finish, and maximize mechanical properties of SLM copper	GRCop SLM process yielding >99% dense parts with properties comparable to traditionally manufactured GRCop84 samples. External vendor has extended process to commercial application.
Copper alloy material characterization using SLM	Not established for copper	SLM'd GRCop-84 thermal conductivity at 90% of baseline extruded GRCop and remaining material properties at or greater than those of OFHC Copper	90% of baseline extruded GRCop-84 material properties	GRCop SLM process yielding >99% dense parts with properties comparable to traditionally manufactured GRCop84 samples.
Deposition of nickel alloy to SLM Copper	Demonstrated for pure nickel to pure copper, but not for nickel alloys to copper alloys	Deposition of nickel alloy to copper alloy that remains intact at the bond through a thermal cycle and with minimum defects	Deposition of nickel alloy onto copper alloy with a ductile transition zone and mechanical properties equivalent to cast annealed condition	Deposition process developed. Joint samples microscopy inspection and pull tests with no initial cracking show sufficient bond strength for design application. Further process improvements to remove cracking utilized for units 2.2 & 3.0 builds.
Manufacture of AM upper stage engine components	SLM upper stage engine components demonstrated with Inconel 718, Inconel 625 by MSFC, but not with Copper (GRCop) chambers	Demonstrate build of subscale components or subassemblies with properties and geometry sufficient to be utilized in initial subscale testing	Demonstrate build of full-scale monolithic GRCop component parts with materials properties and geometric tolerance meeting key design features that allow successful tests with flight like conditions	Successful methane tests of SLM printed chamber occurred 08/10/2016. Recovery path implemented with units 2.1, 2.2 and 2.3 builds. Work continues to prep units 2.2 and 3.0 for hot fire tests.



Technical Accomplishments

- Completed the GRCoP chamber liner Select Laser Melting (SLM) build for Units 2.1, 2.2 and 3.0 (MSFC)
- Completed the Electron Beam Freeform Fabrication (EBF³) Inconel 625 structural jacket for Units 2.1, 2.2 and 3.0 (LaRC)
- **Milestone complete-** Mechanical testing of SLM fabricated GRCoP-84 (GRC)
- **Milestone complete-** Report documenting the standardized NDE techniques for flight hardware (MSFC)
- **Milestone complete-** Report documenting the standardized SLM process for flight hardware (MSFC)



Advanced Manufacturing Technology LCUSP



Unit 2.1

Unit .2

Unit 3.0



Recovery Plan Includes

- Unit 2.1 for EBF³ process validation
- Unit 2.2 for E-beam weld process trial and backup hot-fire unit
- Unit 3.0 for primary hot-fire test article

Unit 2.1



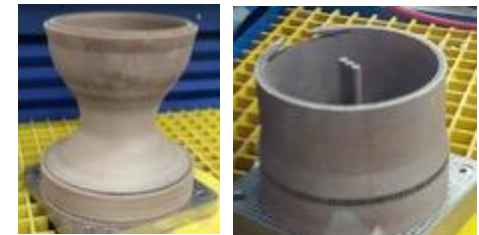
SLM & EBF³ complete

Unit 2.2



SLM & EBF³ complete

Unit 3.0

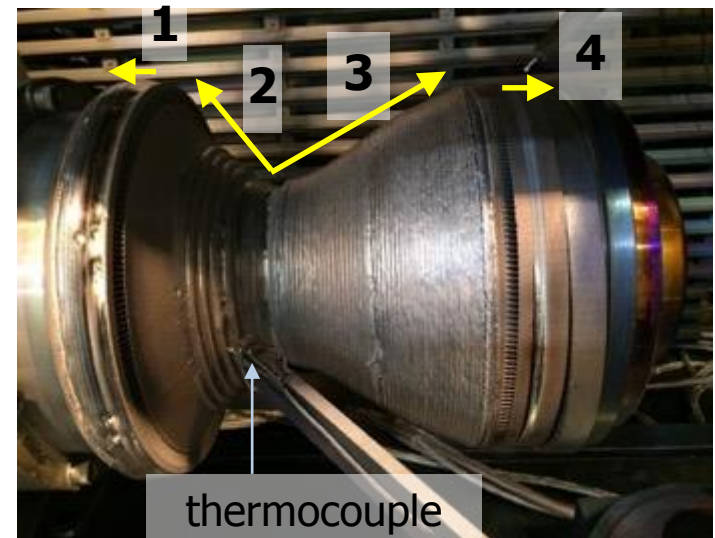


SLM & EBF³ complete

LCUSP Accomplishments and Technical Challenges



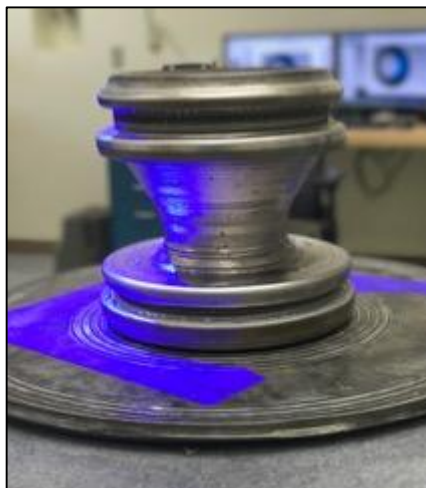
- Understanding EBF³ processes and the impacts to the hardware
 - EBF³ laser overheating. Developed deposition paths to fit within a 30 min window and not overheat the system.
 - EBF³ deposition sequencing was required in order to minimize excessive heat input, reduce thermal cycles on the part, and minimize part shrinkage.
 - Radial and axial shrinkage were measured from EBF³ processing.
 - Lessons learned from Unit 2.1 radial shrinkage led to internal mandrel tooling changes to aid in throat section support during deposition and to optimize the post EBF³ tooling removal.
- Unit 3.0 EBF³ excessive heat input caused the split ring to shrink exposing the cooling channels between the forward and aft sections of GRCoP liner. A IN625 TIG weld repair was performed to complete the channel closeout and allow the completion of the IN625 jacket.



Unit 2.2 Deposition Sequence



Unit 2.2



Before Tooling Removal



After Tooling Removal



Unit 3.0



GRCop SLM



Cooling Channels



Tooling Removal



**Before: Center Scaffold
Opening ~1/8"**



**After: Hand TIG Weld Repair
Completely Bridged All Gaps
Around Center Scaffold**



After Tooling Removal



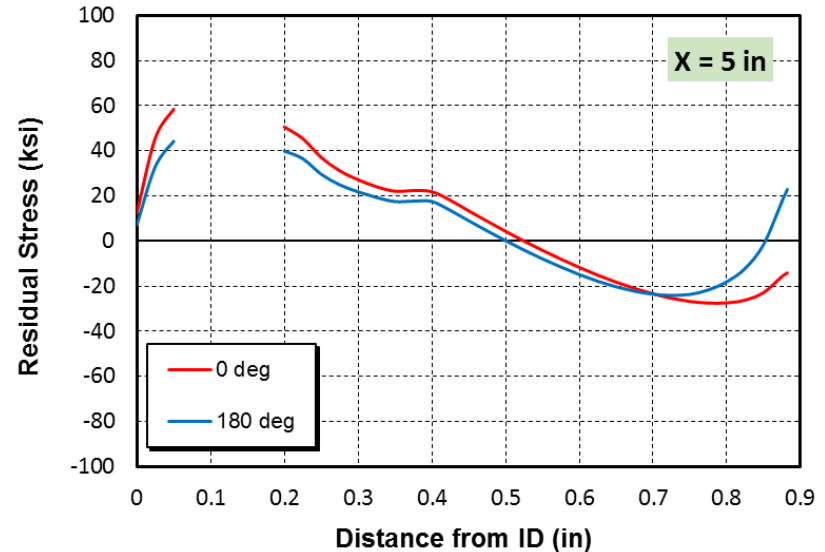
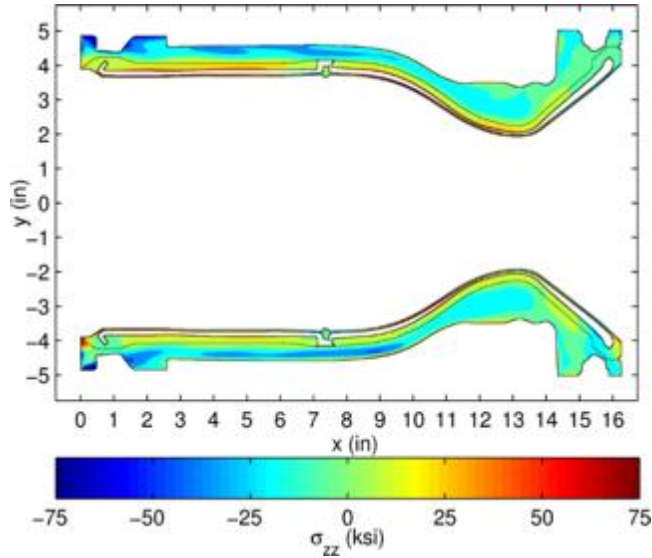
MATERIALS CHARACTERIZATION at GRC

- **SLM GRCop-84 mechanical testing**
 - Testing completed and final report being written
 - Tensile Testing
 - Low Cycle Fatigue Testing
 - Crack Growth Testing (first data ever)
 - Creep Testing
 - *SLM GRCop-84 is at least equal to and normally exceeds baseline as-extruded GRCop-84, which means that there is no need for a knockdown factor for SLM parts*
- **EBF3 IN-625 mechanical testing**
 - Mechanical testing is ongoing
 - Tensile Testing (100% complete)
 - Low Cycle Fatigue and High Cycle Fatigue Testing (33% complete)
 - Creep Testing (10% complete)
 - Some differences have been noted such as higher annealing temperature



MATERIALS CHARACTERIZATION at GRC

Residual Hoop Stresses Measured In Chamber



- Unit 2 after HIPing was cut in half using EDM and the movement of the material was measured
- Using elastic modulus and Poisson's ratio, the residual stresses were calculated
- Residual stresses were up to about ± 70 ksi (483 MPa)
 - IN-325 jacket in compression
 - GRCop-84 liner in tension



LCUSP FY17 Forward Plans



GRCop-84/Inconel 625 Chambers

- **Complete Unit 2.1 test chamber**
 - CT Scan inspection
 - Destructive testing
- **Complete Unit 2.2 chamber**
 - Machining and prep for manifold welding
 - Weld manifolds to Unit 2.2
 - Leak/pressure check
- **Complete Unit 3.0 chamber**
 - Visual and CT scan inspection
 - Machining and prep for manifold welding
 - Weld manifolds to Unit 3.0
 - Leak/pressure check

- Project is on task to complete the technical objectives in FY17
- FY17 is the final year of LCUSP
- FY18 New Start Proposal submitted to STMD/GCD (RAMPT Proposal) will include technologies developed under LCUSP (AM Copper Chamber)
- Commercial vendors setting up to produce GRCoP AM components based on technology developed for LCUSP

Hot Fire Testing (Unit 2.2 or Unit 3)

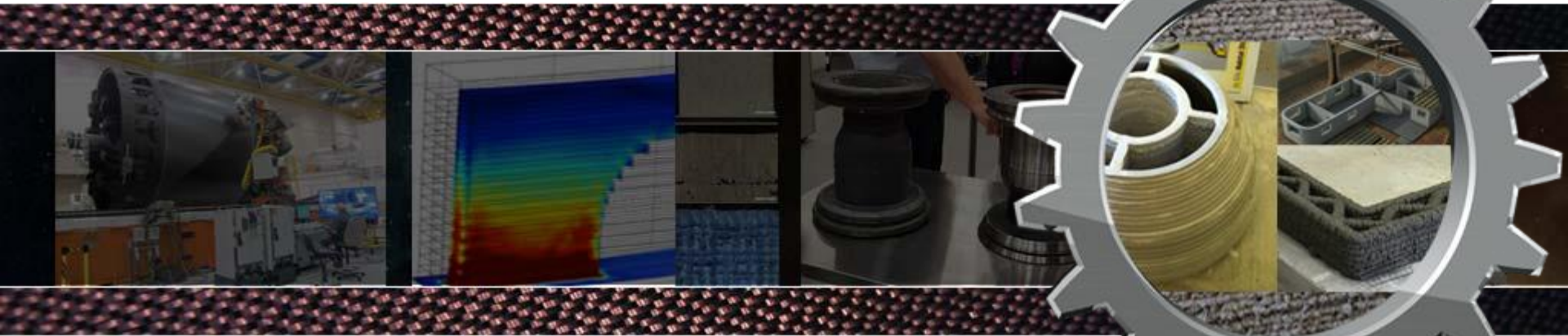
- Complete Chamber test in August
- Complete integrated nozzle test in September

Materials Work

- Mechanical Testing
 - SLM Deposited GRCop-84 for Orientation & Size Study.
Estimated completion in June 2017



Additive Construction with Mobile Emplacement





Advanced Manufacturing Technology ACME Project Overview



- Additive Construction with Mobile Emplacement (ACME) is 2D and 3D printing on a large (structure) scale using in-situ resources as construction materials to help enable on-location surface exploration.
- ACME is a joint effort between NASA/GCD and the U.S. Army Corps of Engineers (USACE).
- Applications are in the construction of infrastructure on terrestrial and planetary surfaces.

Integration with other projects/programs and partnerships

- Current partnership between MSFC, KSC, the USACE, Contour Crafting Corporation (CCC), and the Pacific International Space Center for Exploration Systems (PISCES).
- Collaboration with the JSC Hypervelocity Impact group.
- ACME personnel involved in the 3D Printed Habitat Centennial Challenge rules committee and serving as judges and subject matter experts (SME) for the various activities.
- 3D printing materials research involves members of industry (BASF, Premier Magnesia) and academia (Auburn University, Mississippi State, University of Mississippi).
- In-Situ Resource Utilization (ISRU) project integration & uses.

Technology Infusion Plan:

- Potential Customer: HEOMD, USACE and Industry (Caterpillar Inc.).
- Phased approach for maturation of hardware: ACME units intended to serve as prototypes for the USACE devices which will be used in domestic and international venues.
- ACME project advances in-situ resource utilization (ISRU), contour crafting, and zero launch mass construction materials development.
- Designed for use on planetary surfaces, can be deployed prior to human landing. Technology developed has terrestrial applications, and has large implications for the art of the possible in construction

Key Personnel:

Project Manager: John Fikes

Project Element Managers: John Fikes and Rob Mueller

Lead Center: Co-led by MSFC and KSC

Supporting Centers: None

NASA NPR: 7120.8

Guided or Competed: Guided

Type of Technology: Push for planetary ISRU, pull for terrestrial applications

Key Facts:

Thrust Areas: LMAM

Execution Status: Year 3 of 3

Technology Start Date: 1/31/15

Technology End Date: 9/30/17

Technology TRL Start: 3

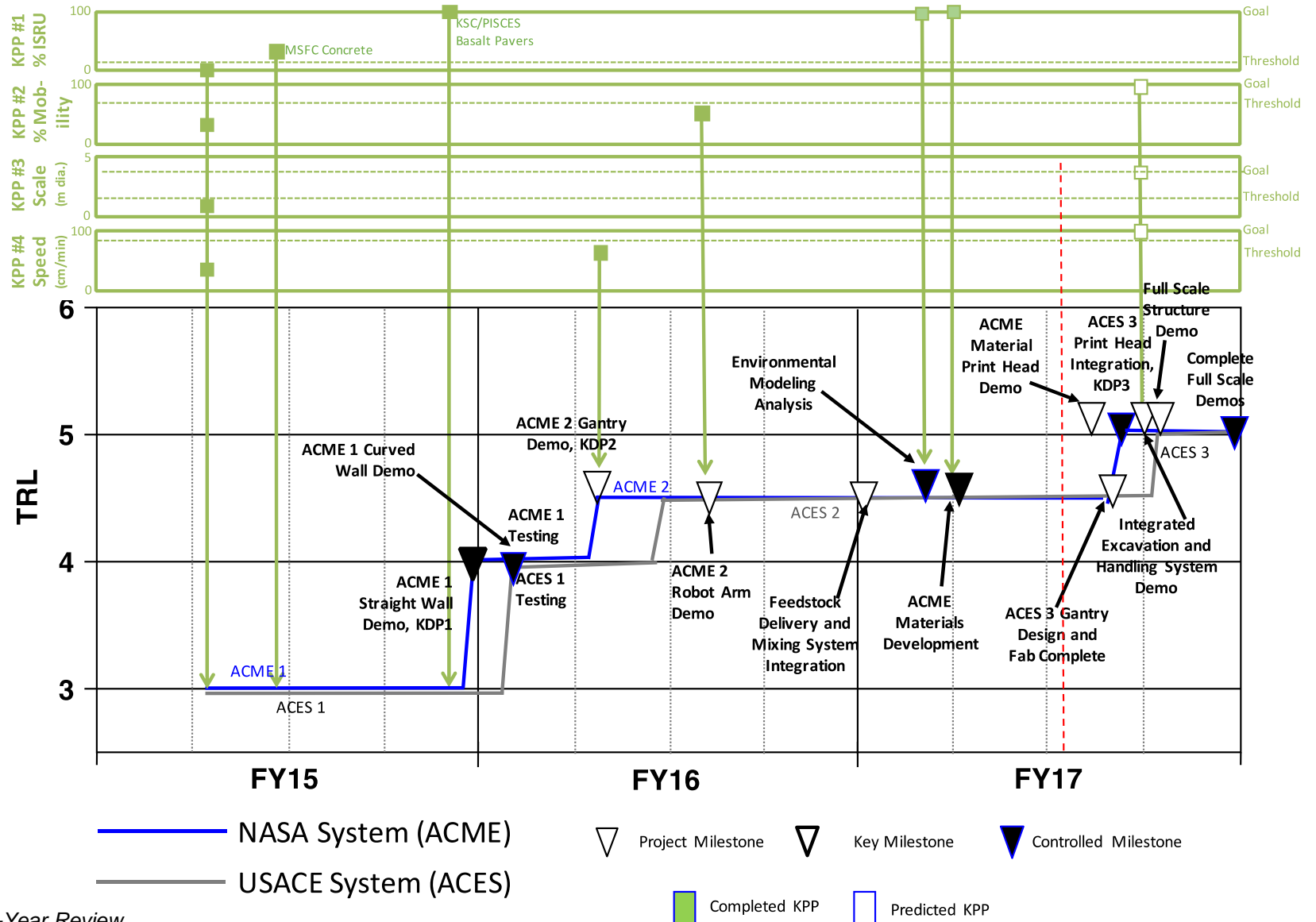
Technology TRL End: 5

Technology Current TRL: 4

Technology Lifecycle Phase: Formulation (Phase A)



Advanced Manufacturing Technology ACME TRL/KPP





Advanced Manufacturing Technology ACME Performance



- **Technology Advancement**
 - Developed a continuous feed system for construction materials.
 - Integrated ACME 2 training nozzle into system.
- **Technology advance means**
 - Moving from batch processing to continuous feed; need further understanding of how feedstock viscosity, pump speed, and nozzle speed affect printing.
 - Ability to print structures continuously; no start/stop due to refilling with feedstock
- **Technology push and pull**
 - Impacts future planetary missions, in-situ resource utilization, and terrestrial applications (includes US Army and potentially industry)

Key Performance Parameters

Performance Parameter	State of the Art	Threshold Value	Project Goal	Estimated Current Value
KPP-1 Construction Material	Contour crafting with water-based concrete	Use in-situ regolith materials for manufacturing feedstock using imported binders	Use in-situ regolith materials for manufacturing feedstock using no imported feedstock materials	Demonstrated fabrication of construction material using regolith simulant and multiple binders (polymers, cements), as well as sintered regolith simulant. Performed compression tests and hypervelocity impact tests.
KPP-2 Emplacement	Subscale gantry mechanisms that are fixed in locations	Full scale gantry mechanisms in fixed locations	Mobile-ready print system	Demonstrated larger size gantry system. (ACES 2) Developed continuous feed capability. (ACME 2 and ACES 2) Design near complete for large scale mobile gantry system. Manufacture and assembly underway. (ACES 3)
KPP-3 Construction Scale	Small concrete dome: ~1m high	In-situ regolith structure pad and curved wall; subscale optimized planetary structure	In-situ regolith structure pad and curved wall; full scale optimized planetary structure	Contour crafted martian simulant concrete straight and curved wall segments constructed. USACE additive printed guard shack (6'x8') on 7/6/16.
KPP-4 Print Head Construction Speed (1cm thick layers material)	30cm/minute	60cm/minute	100cm/minute	ACME 2 – 206 cm/minute ACES 2 – 508 cm/minute ACES 3 goal- 1270 cm/minute

ACME Technical Accomplishments and Technical Challenges



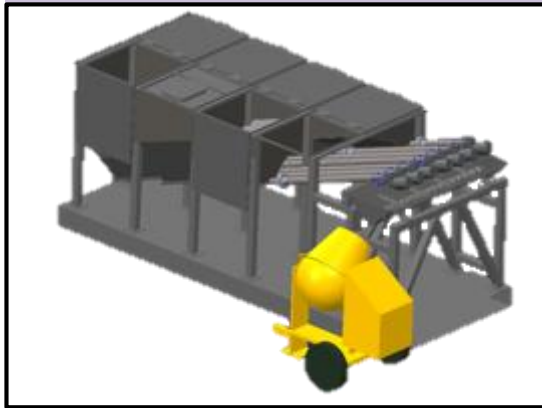
- Testing using the modified ACES-2 accumulator with the USACE material recipe with 3/8” aggregate was successful.
 - Modifications were made to the ACES-2 accumulator and the accumulator was integrated into the current ACME-2 system.
 - A batch of the USACE mixture with 3/8” aggregate successfully flowed through the modified ACME-2 system.
 - The modified ACES-2 accumulator operated as expected and provides confidence for the ACES-3 accumulator design.
- ACES-3 gantry and accumulator
 - Procurement of raw materials, fasteners ,and other COTS items is nearly complete.
 - Nearly 80% of the expected 220+ drawings have been issued.
 - Fabrication of piece parts has begun. Building of lower-level assemblies is in process. Development of electrical systems and wiring is progressing.



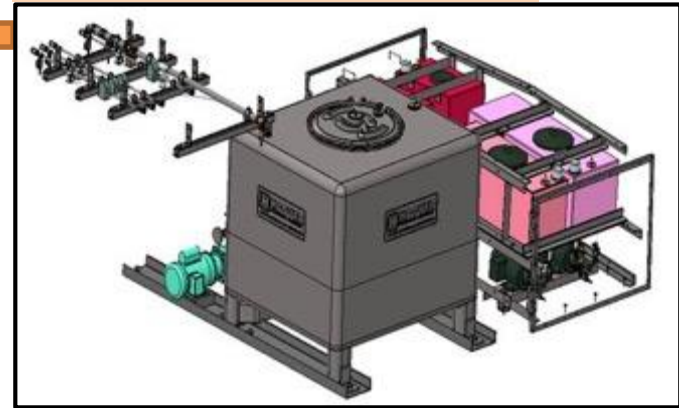
Advanced Manufacturing Technology ACES 3 System



Dry Good Storage Subsystem

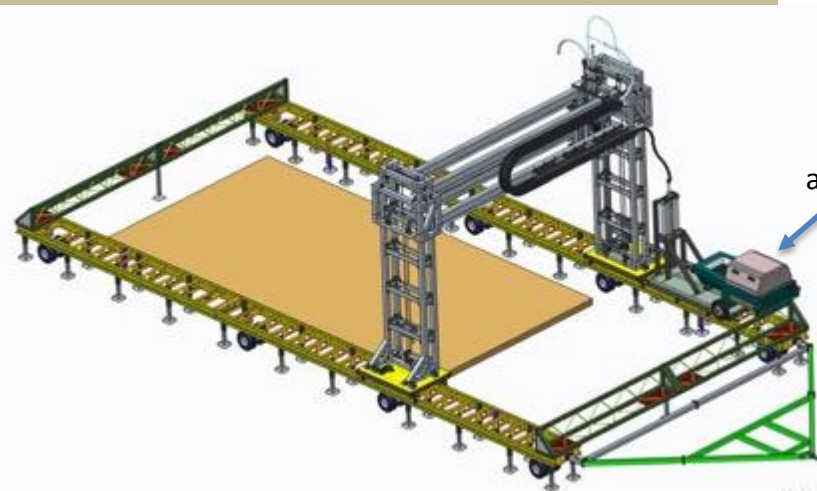


Liquid Storage Subsystem



Continuous Feedstock Mixing Delivery Subsystem (CFDMS)

- Accumulator
- Pump Trolley
- Gantry
- Hose Management
- Nozzle
- Electrical & Software

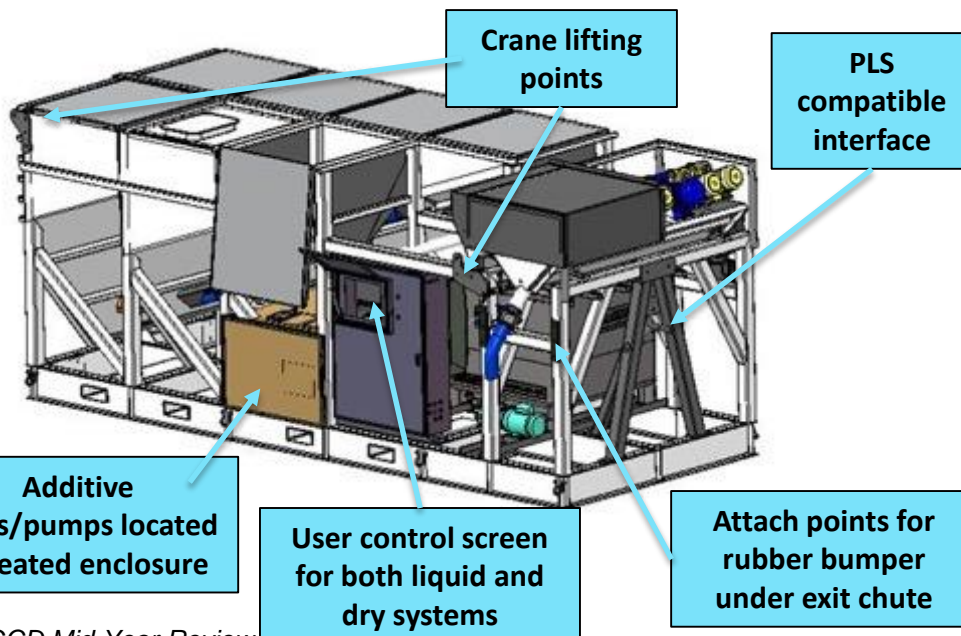


Dry Goods & Liquid Goods parked on side and mix in trolley



ACES-3 Dry Goods Delivery System

- The ACES-2 DGFS was delivered to the United States Army Construction Engineering Research Laboratory (CERL) the first week of November 2016.
 - A more powerful weigh bin motor was successfully installed on the DGDS in March 2017.
- Several enhancements for the DGDS, requested by the customer, are currently in fabrication & will be installed in June to upgrade to the ACES-3 design.
 - Crane lifting points, a Palletized Loading System (PLS) compatible interface on the structure, a protective bumper underneath the weigh bin exit chute, & sun shade for better touch screen visibility.
- The Liquid Goods Delivery System (LGDS) will be co-located on the DGDS structure.

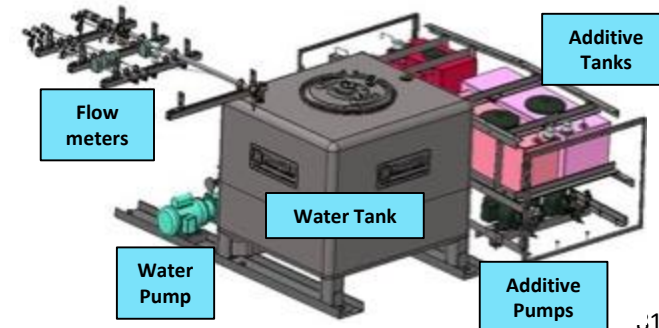


DGDS at CERL in March 2017



ACES-3 Liquid Goods Delivery System

- PDR held 11/29/16, CDR held 1/26/17 at KSC
- Electrical & mechanical drawings complete
- Procurement of components complete
- Pressure Vessel System (PVS) exclusion document in final approval
- Hardware assembly on mock-up wood frame in work through 4/28
 - Mockup is for testing prior to transportation to CERL, then will be disassembled & reassembled onto DGDS structure
- Electrical wiring in work through 4/21
- Control system programming in work through 5/12
- Component & subsystem level testing will take place 4/17-5/19
- LGDS and Acceptance Data Package (ADP) will be shipped to CERL the week of 5/29
- KSC support on-site at CERL 6/5-6/16 for installation of LGDS components onto DGDS structure & testing of combined subsystems



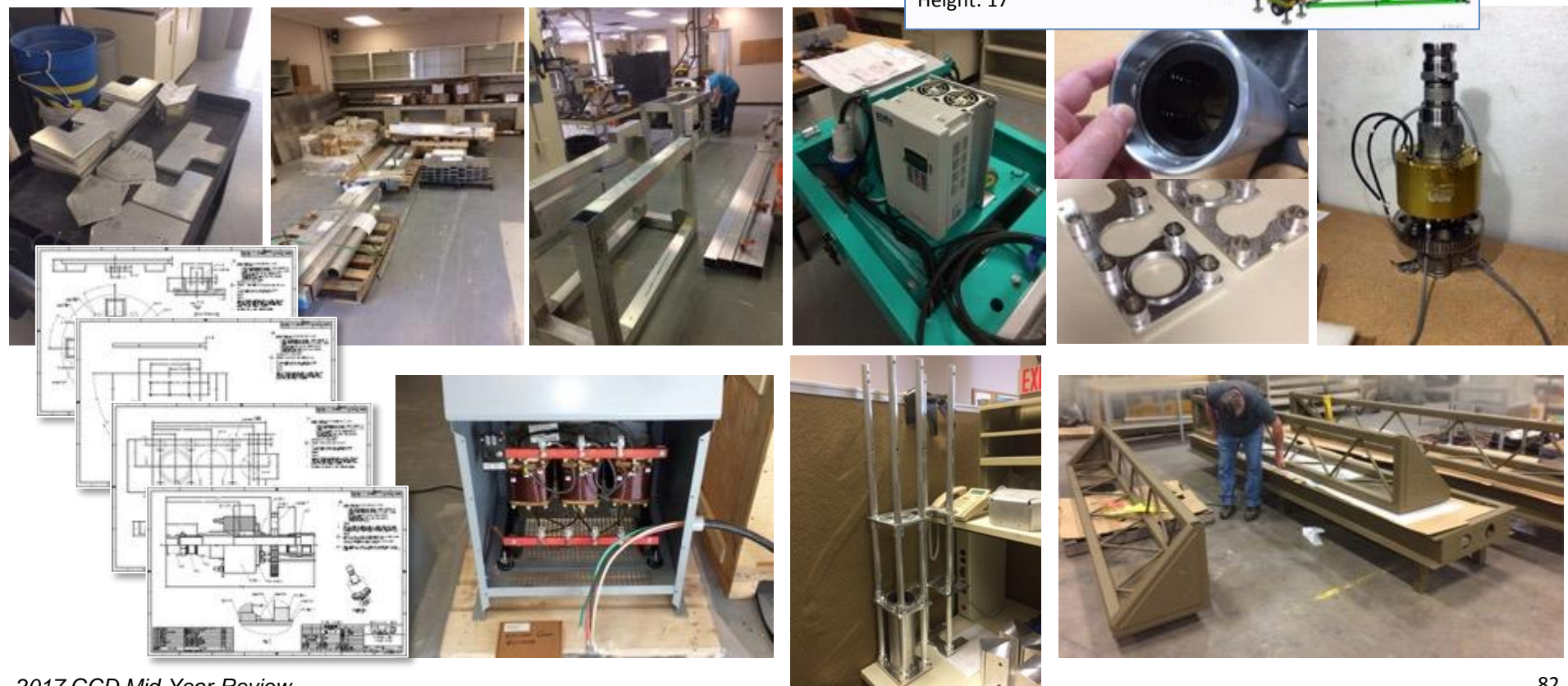
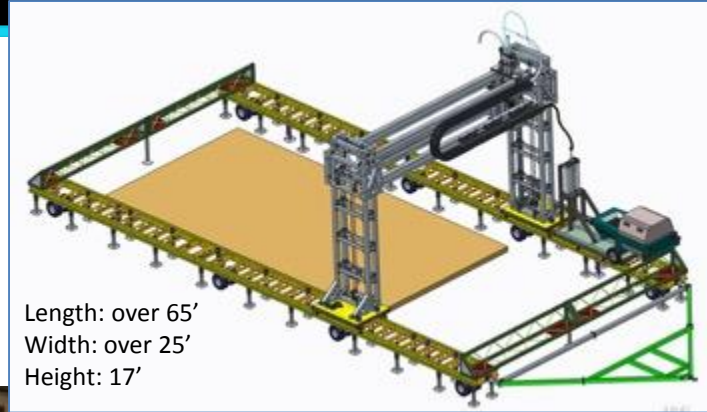


Advanced Manufacturing Technology ACME Technical Accomplishments and Technical Challenges



ACES-3 Entire System

- Nearly 80% of the expected drawings have been issued. Fabrication of piece parts has begun. Building of lower-level assemblies is in process.
- Coordinating with facilities (forklift, crane, transfer of hardware, etc)





Advanced Manufacturing Technology ACME Technical Accomplishments and Technical Challenges



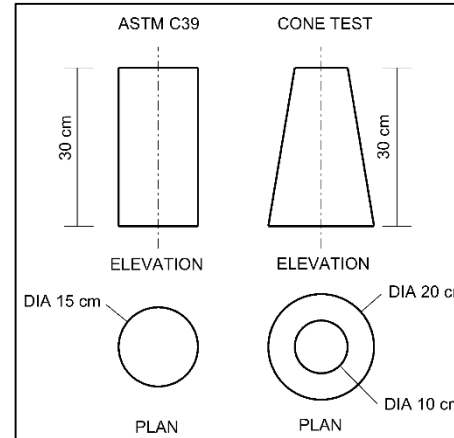
ACES-3 Entire Gantry System





Zero Launch Mass Print Head

- The ZLM Print Head will extrude a mixture of BP-1 regolith simulant (85%) and High Density PolyEthylene (HDPE) (15%) through a heated nozzle.
- The ZLM Print Head will print a 30cm tall cylinder & cone for initial demo. These specimens will be strength tested.



Print Demo Shapes



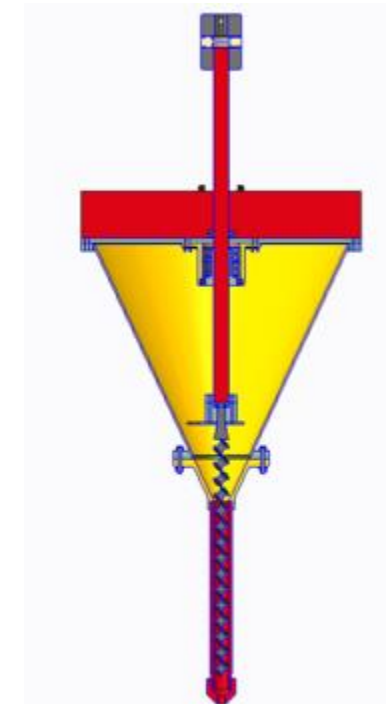
BP-1/HDPE Extrusion Trial

Status:

- Design, modeling and analysis complete. (3/31)
- Held tabletop review of model and analysis with KSC Chief Engineer. (4/10)
- Programming of FANUC robot arm to perform printing in work through April 21st.
- Procurement/Fabrication of print head components in work through April 21st.
- Thermal controller and motor/drive operational & tested. (4/14)
- Assembly of print head and print demonstration to be complete by April 30th.



ZLM Print Head Demo Illustration



ZLM Print Head Model



ACME Plans for FY2017



FY17 Plans

- ACES 3 Pre-ship Review: May 23rd
- ACES-3 Gantry and Accumulator Ship: May 25th
- ACES-3 Liquid Goods Delivery Subsystem (LGDS) Pre-Ship Review: May 24th
- ACES-3 LGDS Ship: May 26th
- ACES-3 Verification and Testing: May 31st – June 28th
- ACES-3 Formal Delivery to USACE: June 29th
- Zero Launch Mass In-Situ Construction Materials Development – Printing Demonstration (April 30th)
- Planetary construction material development continues through FY17
 - Summer Faculty fellows support
 - 3D Printed Habitat Challenge competitors
 - Material Testing

FY17 Threats

Deliver third generation ACES hardware by May 25th.

The visibility of this project within the Armed Forces has resulted in the Marine Corp asking NASA for a quote for a duplicate system, to be built starting in October 2017.

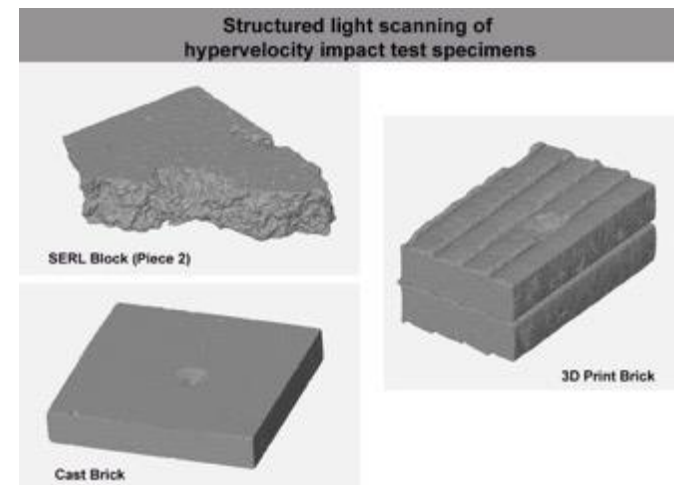


Advanced Manufacturing Technology ACME EPO Summary Chart



ACME

- **Technical Subject Matter Experts were provided to the Centennial Challenges program for the “ 3D Printed Habitat” challenge and several public webinars were supported (>100 participants)**
- **Conference: 2017 Hypervelocity Impact Symposium (at the University of Kent, Canterbury, UK, April 24-28, 2017) .**
 - ACME presentation to be presented by one of our collaborators at JSC.
 - Titled: “Hypervelocity impact testing of materials for additive construction: Applications on Earth, the Moon and Mars”





AMT Quarterly Summary Performance



Quarterly Summary Performance

Project	Summary Performance			
	Cost	Schedule	Technical	Programmatic
Quarter 1	Yellow	Yellow	Yellow	Green
Quarter 2	Green	Green	Green	Green
Quarter 3	Grey	Grey	Grey	Grey
Quarter 4	Grey	Grey	Grey	Grey



Back Up Charts

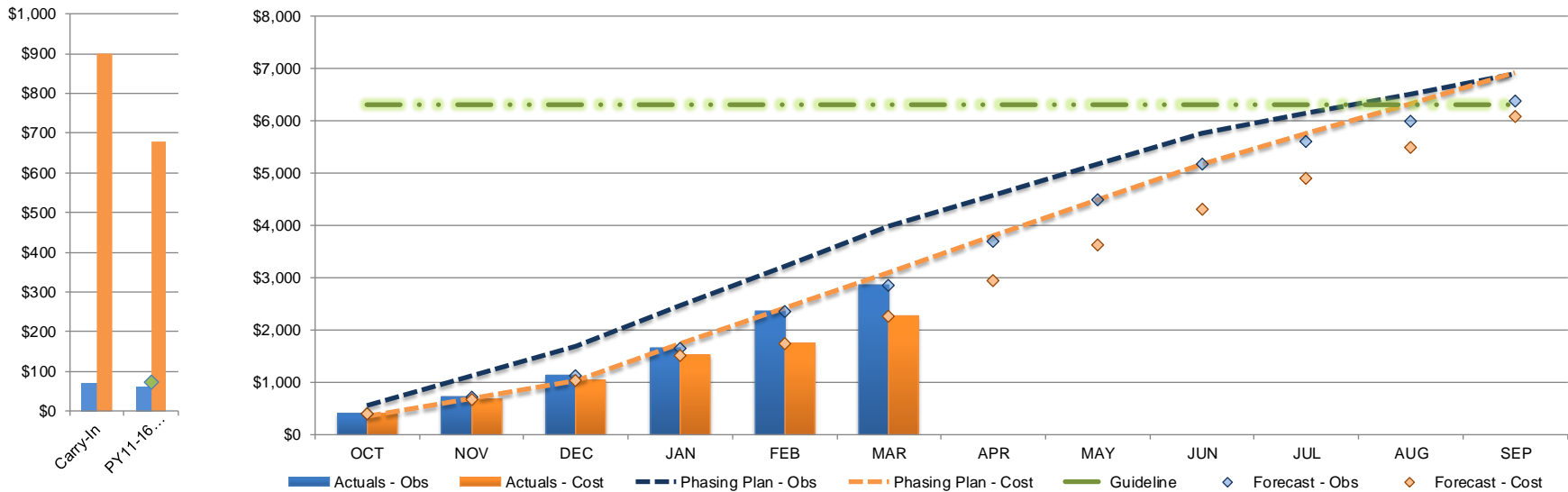
<These charts feed Quarterly Reporting. All charts are required. >



Resources: Total Obligations and Cost



FY 2017 Financial Status



	Cum (\$K)	Carry-In	PY11-16 Funds	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	Carry Out
Obs	Guideline		71.8	6,314.0	6,314.0	6,314.0	6,314.0	6,314.0	6,314.0	6,314.0	6,314.0	6,314.0	6,314.0	6,314.0	6,314.0	
	Phasing Plan (RLP)			560.7	1,121.3	1,682.0	2,453.7	3,225.4	3,997.1	4,585.3	5,173.6	5,761.9	6,139.8	6,517.8	6,895.8	(573.0)
	Actuals	71.8	63.0	406.1	731.0	1,120.7	1,646.3	2,368.0	2,864.4							
Cost	Forecast			406.1	731.0	1,120.7	1,646.3	2,368.0	2,864.4	3,697.7	4,506.0	5,194.3	5,625.6	6,003.6	6,381.5	(58.8)
	Phasing Plan (RLP)			345.2	690.3	1,035.5	1,727.0	2,418.5	3,110.0	3,795.1	4,480.2	5,165.3	5,754.2	6,343.1	6,932.1	241.8
	Actuals	901.3	677.6	394.3	685.9	1,037.9	1,508.9	1,749.8	2,267.1							
	Forecast			394.3	685.9	1,037.9	1,508.9	1,749.8	2,267.1	2,952.2	3,637.3	4,322.4	4,911.3	5,500.3	6,089.2	570.5

Note: Carry-In is the unobligated/uncosted portion of PY11-16 funding end of FY16

	YTD Status	Explanation required for YTD Variance in excess of 5% from Phasing Plan (shaded red)
'17 Obs	Phasing \$ 3,997	
	Actuals \$ 2,864	
	Variance \$ (1,133)	
'17 Cost	Phasing \$ 3,110	
	Actuals \$ 2,267	
	Variance \$ (843)	



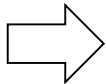
Technology Name

Risk Title (*short risk title*) – Risk Owners name



Risk ID #

No. unique to this risk- stays with risk even when closed/retired.



Trend

High

Criticality

Current L/C

5x5

Affinity Group

(could be more than one) Technical, Cost, Schedule, Performance

Planned Closure

mm/dd/yyyy

Open Date

mm/dd/yyyy

Risk Statement :

Approach: (choose one) Mitigate, Watch, Accept, Research, Transfer, Exploit, Share, Enhance

Risk Statement in the format “Given that (state the fact)...there is a possibility (state the concern)...resulting in (state the consequence..)”

Context

Info and background NOT in the Risk Statement. Captures the what, when, where, why, and how of the risk, specifically: What do we need to know to fully understand the risk? What are the relevant and related circumstances, contributing factors, and related issues?

Status

mm/yyyy of update. Information regarding current status. Revisited monthly. Current month on top. OK to eliminate status updates more than three months old to keep this page from getting too large.

(Note: The Schedule UID is the unique id no of the mitigation step in your schedule if appropriate.

Dollars to implement are not extra approved \$ from the Program Office but \$ set aside as part of project budget to mitigate.)

Mitigation Steps	Dollars to implement	Trigger/ Start date	Schedule UID	Completion Date	Resulting L/C
1					

Continue on second page if required



Excel File: STMD and GCD Data Request



- **EPO: Activities, Conferences, and Students**
- **Economic Development**
- **Post Excel File to the following link on NX: :**
<https://nx.larc.nasa.gov/dsweb/View/Collection-97354>

Use Excel file sent with the template and located on NX



Low Cost Upper Stage-Class Propulsion (LCUSP) Penta



STATUS QUO

- Rocket Engine Propulsion Elements are typically high cost and have long manufacturing times
- No data exist for Additive Manufacturing of Cu alloys
- US government is sole user of engines from sole provider



NEW INSIGHTS

- AM can significantly reduce development time and cost of complex rocket propulsion hardware
- GRCop material shows high promise for engine component use



PROBLEM / NEED BEING ADDRESSED

Current rocket propulsion manufacturing techniques are costly and have lengthy development times

PROJECT DESCRIPTION/APPROACH

- Develop materials properties and characterization for SLM manufactured GRCop
- Develop and optimize SLM manufacturing process for a full component GRCop chamber and nozzle
- Develop and optimize the Electron Beam Freeform Fabrication (EBF3) manufacturing process to direct deposit a nickel alloy structural jacket and manifolds onto an SLM manufactured GRCop chamber and nozzle
- Demonstrate the process for integrating the engine system by performing a hot fire, resistance test.

QUANTITATIVE IMPACT

- Order of magnitude savings of cost and schedule
- New competitive markets for Cu Alloys
- New material property database and processes to implement AM into manufacturing processes



PROJECT GOAL

- Develop material properties and characterization of GRCop
- Optimize SLM for GRCop
- Optimize EBF3 to deposit Ni onto GRCop
- Demonstrate the integrated process via hot fire test



Additive Construction for Mobile Emplacement (ACME) Penta

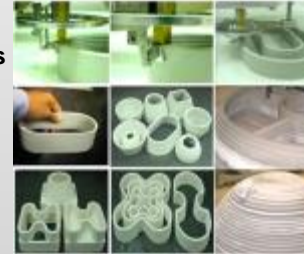


PROBLEM / NEED BEING ADDRESSED

NASA lacks in-space construction capabilities and cannot fabricate Deep Space mission infrastructure. This technology directly addresses the NASA Advanced Manufacturing **subject matter areas of additive manufacturing, robotics and non-metallic materials processes.** (TA 12, TA04, TA07, TA09)

PROJECT DESCRIPTION/APPROACH

- Several **construction tasks** will be necessary to achieve safe and productive conditions for extended robotic & human presence at extraterrestrial sites
 - Roads, landing pads, berms
 - Unpressurized shelters for protection of rovers, etc.
 - Pressurized shelters for long-term crew protection



- The proposed work will establish the body of knowledge required for co-robotic Additive Construction **of in-space radiation shielding (flight & surface) and infra-structure for human settlement**, with research in 3 major categories:
 - **Robotic control & coordination**
 - **Materials, processes, and system modeling**
 - **Construction tooling and robot testbeds**

QUANTITATIVE IMPACT

- **Reduce mass of materials** that must be transported to the space destination by a factor of 2,000:1
- **Mitigate space radiation effects on humans** full (SPE/GCR) protection while in a regolith shielded shelter in-space & surface
- **Reduce cost** of large scale Earth construction by 10:1

PROJECT GOAL

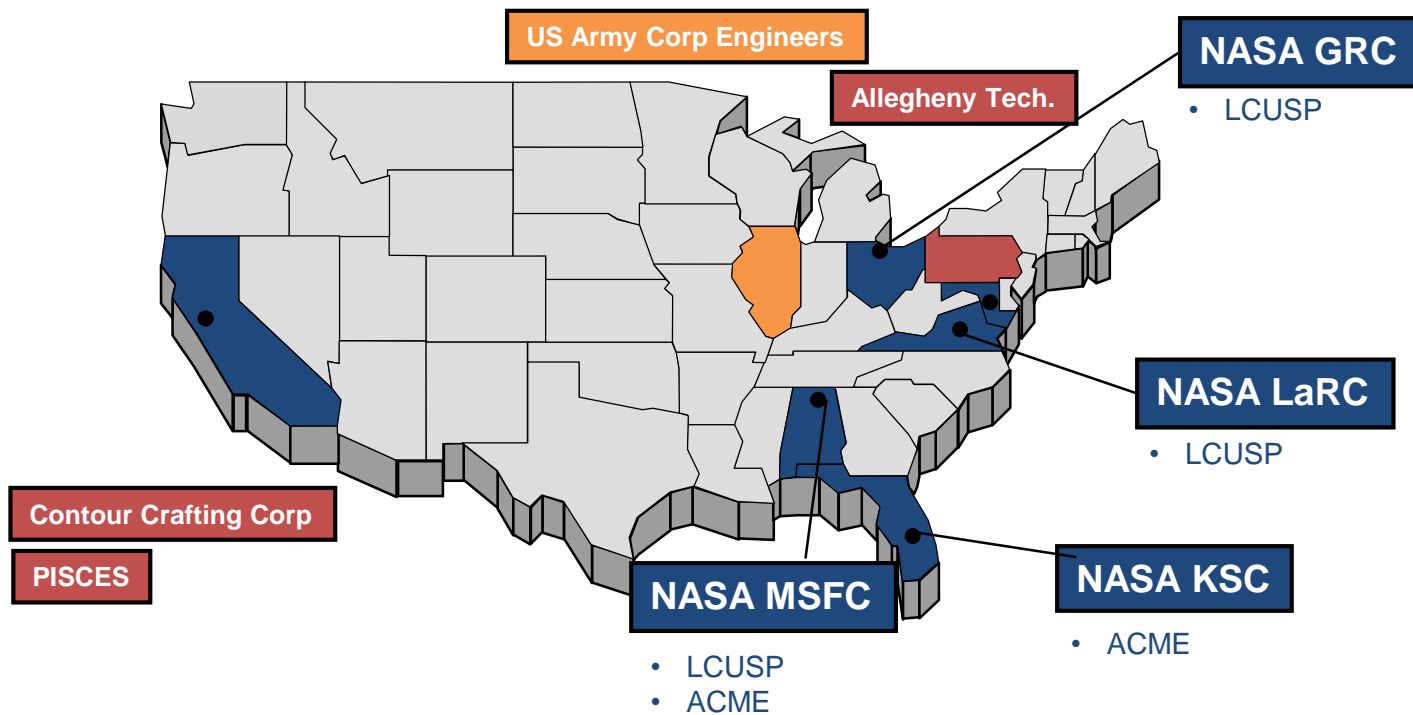
- **Construct a 4 meter diameter demonstration domed structure (habitat, radiation shelter, heat shield) on terrestrial and planetary analog sites**
- Develop regolith based structural materials & print process combinations functional in space environment analog & vacuum testing (TRL 6)
- Prototype a regolith print head for emplacement
- Use existing NASA GCD robots to position and follow tool paths with the regolith print head end effector

- ### STATUS QUO
- **Large structures for habitats and infrastructure on Earth require substantial form work and/or manual labor**
 - **Terrestrial applications of this technology are being investigated by the Army Corps of Engineers**
 - **Space Habitats and infrastructure must be transported from Earth at high cost and low packaging volume**
 - **3D additive construction has been completed in the lab using terrestrial materials (TRL 4)**
 - **Regolith based materials Additive Construction is at TRL 3**

- ### NEW INSIGHTS
- **New regolith based structural materials** can be created in-situ using sintering, sulfur binding, polymer binders, thermite self sintering, synthetic biology binders and more methods, to be developed.
 - **New robotic technologies** and digital manufacturing allow additive construction on a large scale



AMT Organization and Key Members



Industry Partners

- NASA Center
- Academia
- Industry
- Other Gov Ag

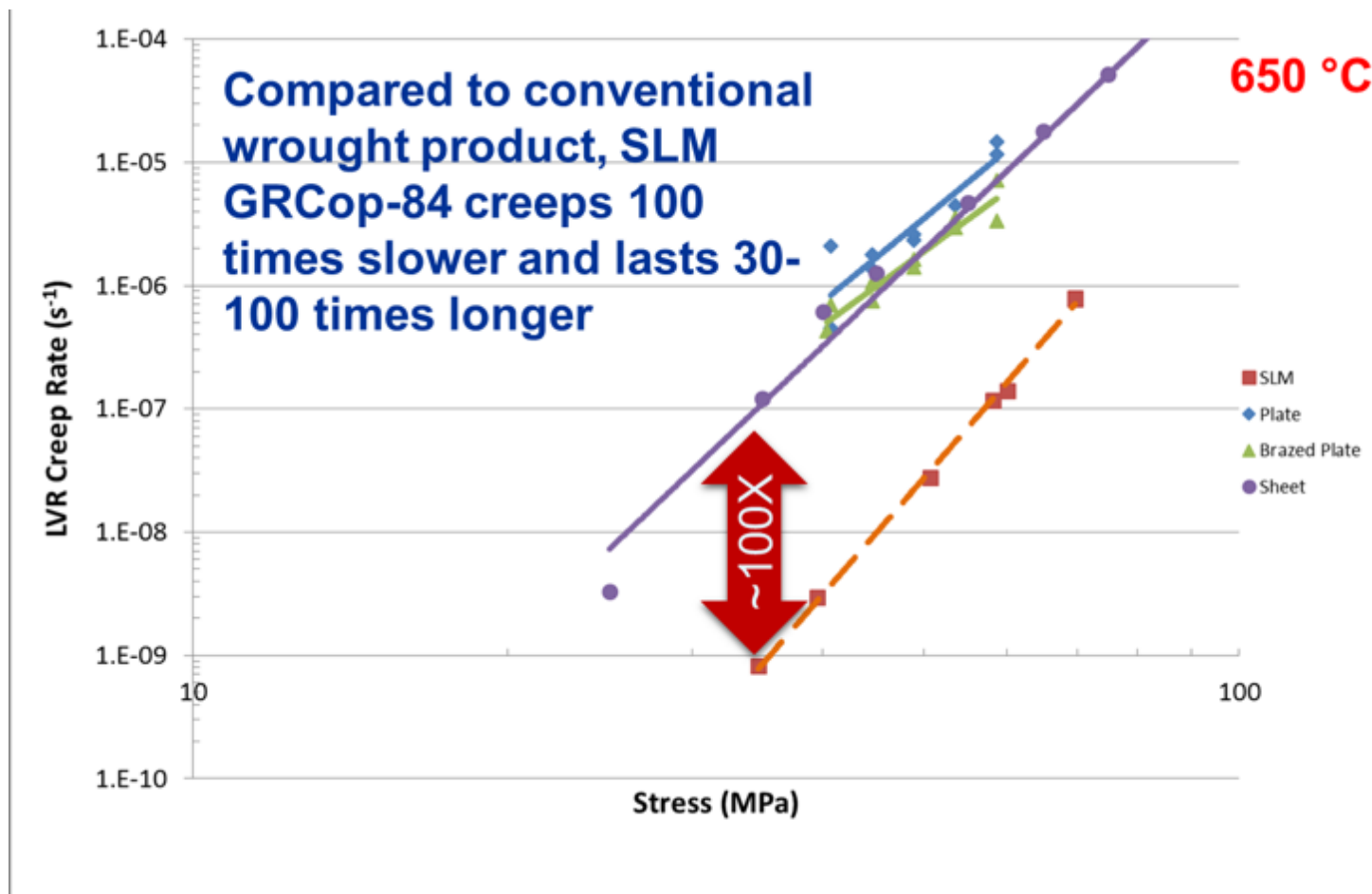
MI	MGI	LCUSP	ACME
		<ul style="list-style-type: none"> • Allegheny Technologies Inc., Pennsylvania (GRCop Powder) 	<ul style="list-style-type: none"> • PISCES - Hilo, HI • USACE – Champaign, IL • CCC – Marina del Rey, CA



MOVE TO BACKUP?

MATERIALS CHARACTERIZATION at GRC

Creep Properties of GRCo-84 Improved By SLM



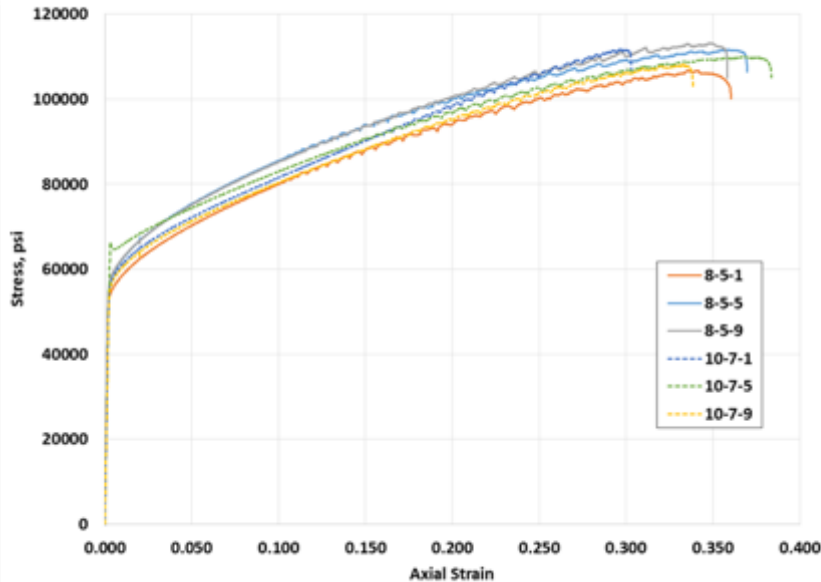


MOVE TO BACKUP?

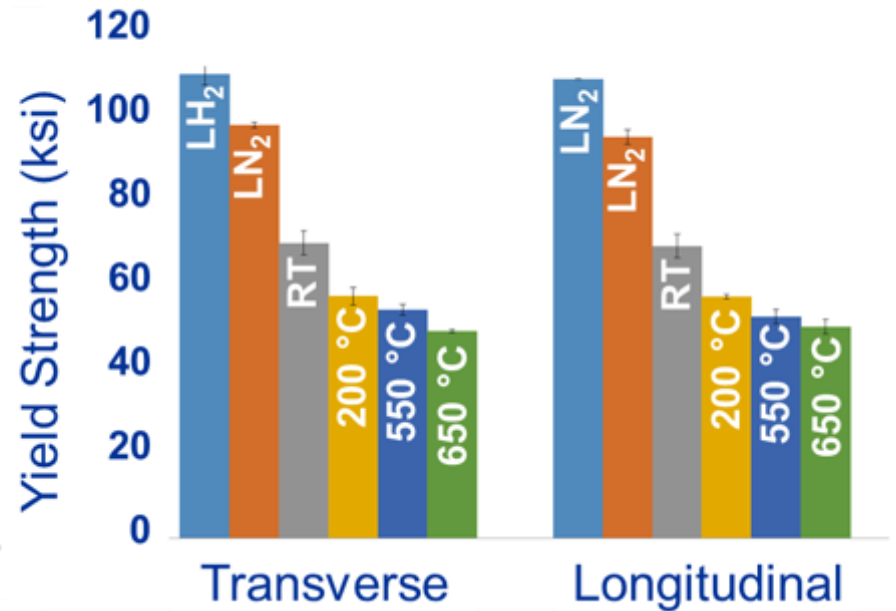
MATERIALS CHARACTERIZATION at GRC

Tensile Properties Of IN-625

200 °C Stress-Strain Curves



0.2% Yield Strength

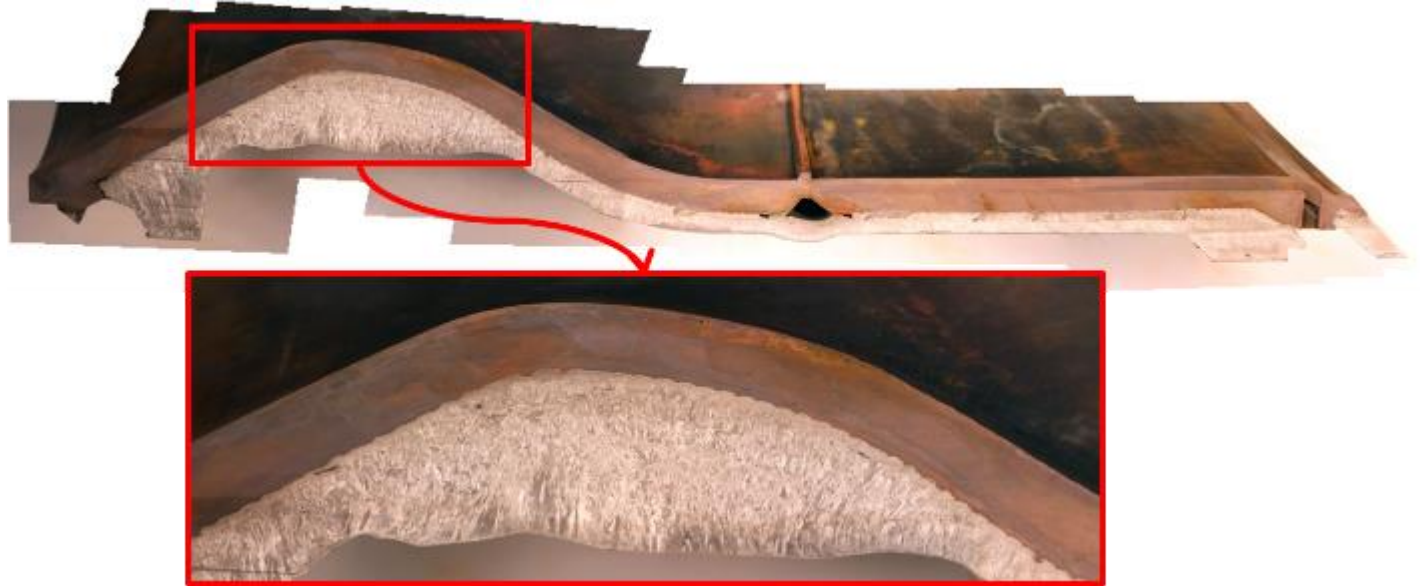


- Tensile testing shows that EBF3 IN-625 meets minimum tensile properties for wrought IN-625
- Minimal to no anisotropy observed



MATERIALS CHARACTERIZATION at GRC

Macrostructure Of Unit 1



- Unit 1 was cut into quarters for analysis
- Macroetching revealed that there were large columnar grains extending from the GRCop-84 liner outwards radially
- Die penetrant reveals some minor defects and a few larger ones but no debonding along interface



Materials Development

Accomplishments:

- The hypervelocity impact samples have been structured light scanned. This is used to calculate the volume of material ejected during impact. (This will be included in the HVIS paper)
 - The compression strength data will be used to update the Environmental Modeling Analysis report and provide more data points for an Artificial Neural Network that will assist in obtaining the optimum multifunctional properties for planetary construction materials. (An ANN is a computer program that is like a human brain – it takes data points that seem to be random (e.g., mortar mixtures) and ties them together (connects the dots) to predict the behavior of mixes that have yet to be made.)
- Data continues to be obtained for different planetary construction materials in an effort to down-select the optimum construction material to be used on a Mars or Moon mission.
- Data is being obtained from multiple sources (MSFC, KSC, USACE, and competitors in the 3D Printed Habitat Challenge) to help NASA down-select the planetary construction materials to be used in future planetary surface missions.

Technical challenges:

Printing with martian simulant mixtures.

- The martian simulant / ordinary Portland cement is more difficult to print with because the mixture is harder to pump through the system – Experiments continue with the rheology of the mix (adjusting admixtures to find the right balance) as time allows.



Advanced Manufacturing Technology ACME EPO



NASA 3D Printed Habitat Challenge Involvement

- **Rules focused toward building a habitat on Mars. Bradley University is the allied organization and affiliated sponsors include: Caterpillar, inc, Bechtel Construction Co., and Brick & Mortar Ventures.**

ACME team members have provided valuable subject matter expertise since the beginning of this challenge from proposal involvement to corresponding/ answering questions from individual competitors.

Rob Mueller provided engineering advice, Jennifer Edmunson provided geological knowledge and Tracie Prater consulted on polymer-type materials and additive manufacturing. They are also members of the judging team and involved in writing the rules. Every week they answer FAQs (are on call for that)

This project is proving to be a good complimentary effort between NASA expertise and learning from companies on material choices, robotic vs gantry type mechanisms and more. Benchmarking of materials properties data is valuable for ACME.

Some of the more well known contenders in this challenge are Made In Space, inc. and Foster & Partners Architects partnered with Branch Technologies, inc.

80 initial entries narrowed down to 20 teams that submitted the \$1,000 entry fee. Level 1 has been completed, Level 2 /3 in work. Head to head competition will take place at the Caterpillar proving grounds, Peoria, Illinois in August 2017

<https://youtu.be/KKPtMiUEnX8>

habitats where astronauts can live and work?

NASA's 3-D Printed Habitat Challenge

NASA 360

Subscribe 7.7K

4,171 views

Add to Share More

Published on Jan 10, 2017

NASA Centennial Challenges wants YOUR help building a 3-D printed habitat on Mars.

Albania	1
Canada	4
Colombia	2
China	1
Czech Republic	1
India	10
Ireland	1
Italy	1
Japan	1
Malaysia	1
Morocco	1
Pakistan	1
Peru	1
Russia	1
Spain	1
Singapore	1
South Korea	1
Ukraine	1
United Kingdom	1
USA	44
United Arab Emirate	1



Composite Technology for Exploration

Presented By: John Fikes

April 27, 2017

TECHNOLOGY DRIVES EXPLORATION



CTE

Level 1 Project Goals



Level 1 Project Goals

Composite Technologies for Exploration (CTE)

Goal #1

Develop and validate high-fidelity analysis tools and standards for predicting failure and residual strength of composite bonded joints.

Goal #2

Develop and demonstrate an analytical tailoring approach that enables the reduction of the baseline 2.0 safety factor for composite discontinuities.

Notes:



CTE Project Manager 2nd Quarter Assessment



Technology	Performance				Comments
	C	S	T	P	
Composite Technology for Exploration					<ul style="list-style-type: none"> • CTE Project Plan containing task definition, baseline schedule and milestones has been approved by the Program. • Material re-certification panels have been fabricated and coupons machined ready for testing. • 24 of the 36 equivalency panels have been fabricated. These panels will be sent to the National Institute for Aviation Research (NIAR) for testing in May. • The design and analysis team held a Face-to-Face Meeting at LaRC on March 13th-14th to discuss analysis tools/methodologies for composite bonded joints and potential validation efforts using planned CTE joint tests.



Composite Technology for Exploration Overview



The CTE Project will develop and demonstrate critical composites technologies with a focus on joints that utilize NASA expertise and capabilities. The project will advance composite technologies providing lightweight structures to support future NASA exploration missions. The CTE project will demonstrate weight-saving, performance-enhancing bonded joint technology for Space Launch System (SLS)-scale composite hardware.

Integration with other projects/programs and partnerships

- HEOMD – SLS SPIE Payload Attach Fitting (PAF) composite design risk reduction

Technology Infusion Plan:

- Composite Bonded Joint Design and Analysis
- HEOMD – SLS
- Block upgrades

Key Personnel:

Program Element Manager: Michael Meador

Project Manager: John Fikes

Lead Center: MSFC

Supporting Centers: GRC, GSFC, LaRC

NASA NPR: 7120.8

Guided or Competed: Guided

Type of Technology: Push

Key Facts:

Thrust Areas: Lightweight Materials and Advanced Manufacturing

Execution Status: Year 1 of 3

Technology Start Date: FY2017

Technology End Date: FY2019

Technology TRL Start: 3

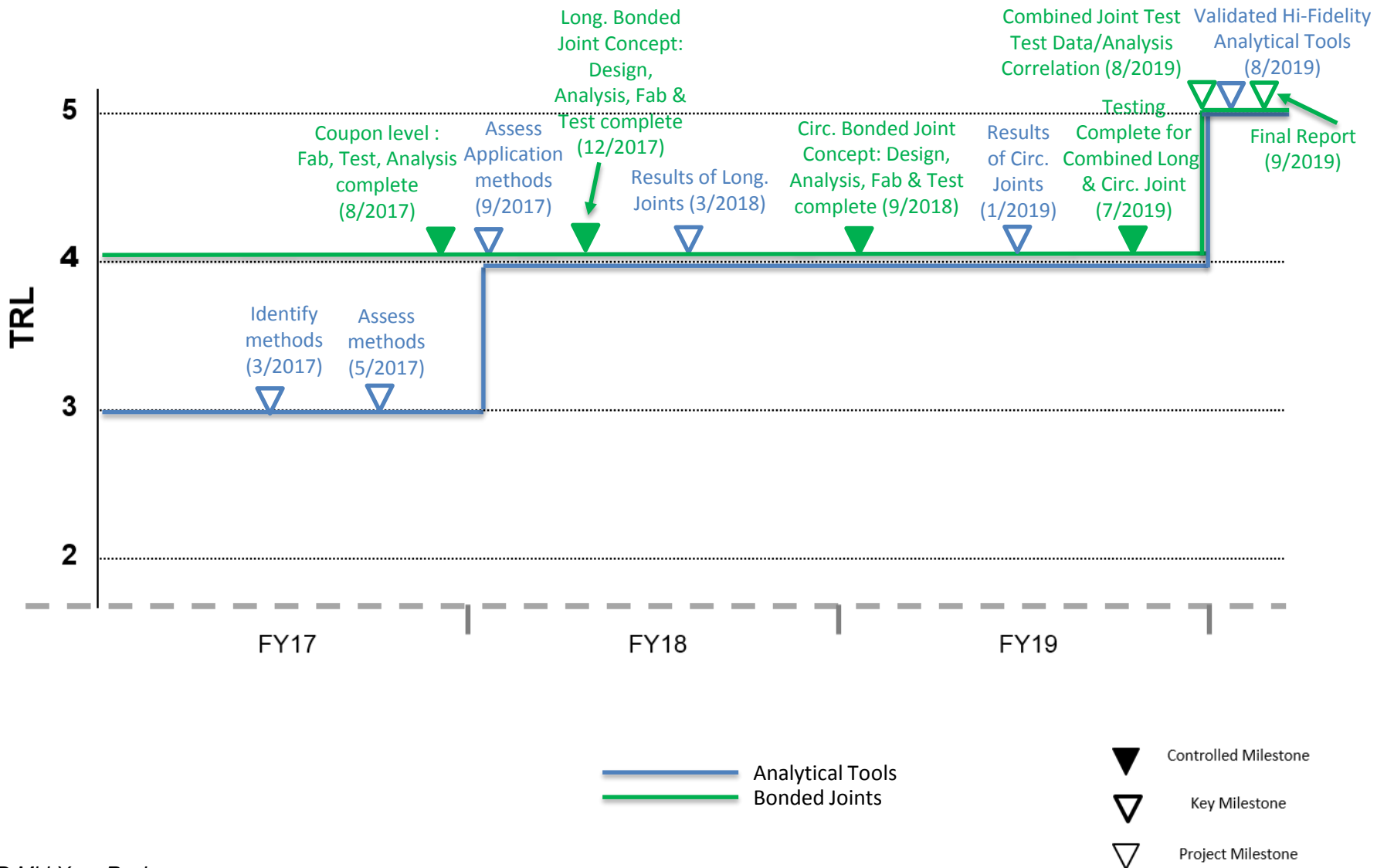
Technology TRL End: 5

Technology Current TRL: 3

Technology Lifecycle Phase: Phase A



CTE TRL/KPP Assessment





CTE Performance



Key Performance Parameters				
Composite Technologies for Exploration (CTE)				
Performance Parameter	State of the Art (SOA)	Threshold Value	Project Goal	Estimated Current Value
Failure Prediction	±25% of mean	±15% percent of mean	±5 percent of mean.	SOA
Risk Reduction Factor ¹	2.0	1.8	1.4	SOA
Part Count ²	100%	75%	50%	SOA
Weight ²	100%	85%	75%	SOA
<p>Notes:</p> <p>1. Safety for joints in primary load path for an SLS-like composite structure Discontinuity Factor of Safety = $J * 2.0$, where J is a risk reduction factor based on new analytical techniques and test data.</p> <p>2. State of art metal bolted joint in primary load path for 8.4 M diameter scale structure. Weight associated with metal/bolted joints (<i>e.g., 3 lb/ft metal bolted joint to lower weight per linear foot bondline</i>)</p>				



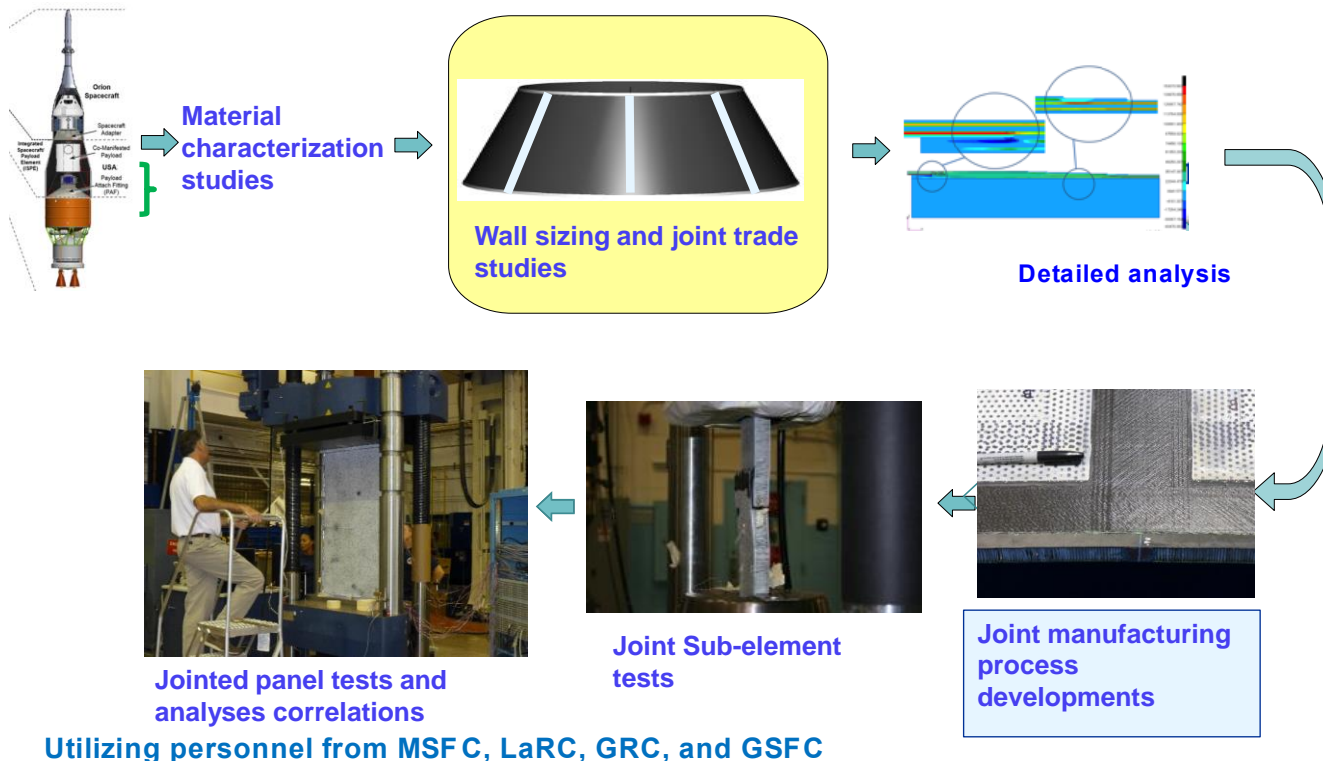
CTE Milestones and Forward Plans



FY17 CTE Milestones	Planned Completion Date	Actual Completion Date	Estimated Completion Date	Variance Explanation
<i>FY17 Q1 (Oct 1 through Dec 31)</i>				
<i>FY17 Q2 (Jan 1 through March 31)</i>				
Report- Evaluation of Prior Program & Project Composite Joint Activities for Lessons Learned	02/08/17	2/15/17(A)		
<i>FY17 Q3 (Apr 1 through June 30)</i>				
OoA Material down select & Procurement	05/26/17			
Down select of Longitudinal Joint Design Concept for SLS Specific application (i.e. EUS, PAF)	05/08/17			
<i>FY17 Q4 (Jul 1 through Sep 30)</i>				
Report- Material Equivalency Testing & Analysis of IM7/8552-1	07/31/17			
Complete Fabrication, Testing & Data Analysis for Coupon Level Material Development	08/04/17			
Report- Correlation of Digimat Computational Models with Material Property Test Data	09/26/17			
Report- Assess, Apply & Compare Bonded Joint Strength Prediction Methodologies	09/29/17			
Report- Application & Implementation of New Manufacturing Process Control and NDE Technologies	09/29/17			
Report- Shell Buckling Knockdown Factor (SBKF) Sensitivity Analysis	09/29/17			



CTE Joint Technology Advancement



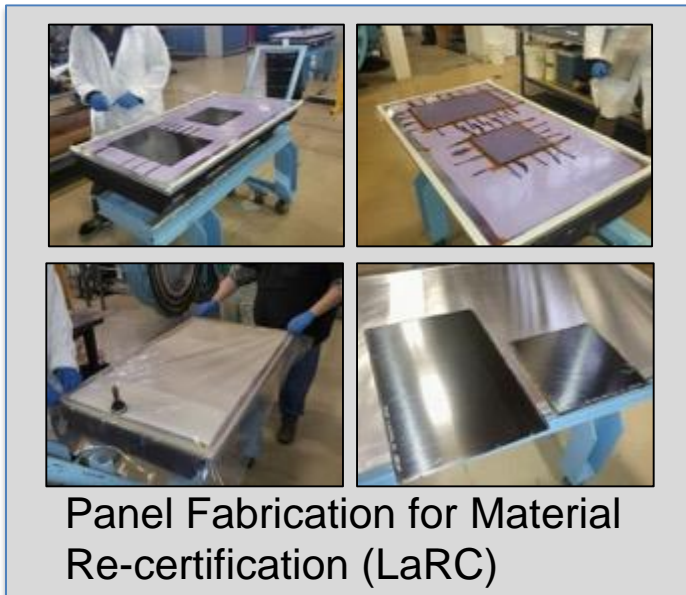
Joints – determine recommended joint concept	Inputs: <ul style="list-style-type: none"> • Wall construction • Loads & environments • Materials (e.g. OoA composites) • Construction type (bolted, bonded) 	Outputs:	
		Figures of Merit <ul style="list-style-type: none"> • Joint weight • Cost (recurring/non-recurring) • Inspectability • Damage tolerance • Manufacturability 	Recommended joint concepts <ul style="list-style-type: none"> • Build, analyze and test joints • Correlate analyses tools



CTE Technical Accomplishments and Technical Challenges



- **Re-certification work has begun on material that was left over from the CEUS project (~ 2,000 lb at MSFC and 200 lb at LaRC).**
 - LaRC and MSFC panel fabrication complete.
 - Coupons machined at MSFC and ready to test.
 - MSFC will perform compression stiffness and short beam shear testing. NIAR (National Institute for Aviation Research) will perform the compression strength tests.



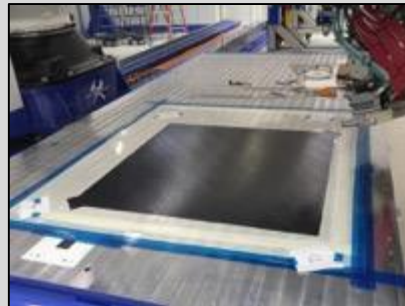
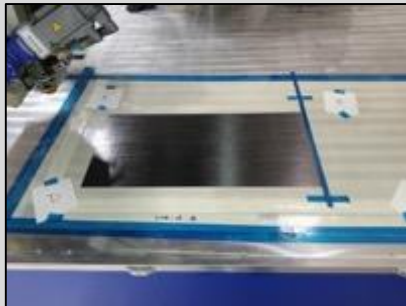


CTE Technical Accomplishments and Technical Challenges



- **Equivalency Panels**

- LaRC completed fabrication of 12 equivalency panels on ISAAC system. Panels are currently in the freezer awaiting autoclave availability for cure.
- MSFC has completed 12 of 24 panels for fabrication. MSFC panel count based on 2 batches of prepreg and LaRC panel count based on one batch.
- Expect the Purchase order for NIAR testing of Equivalency panels to be ready in May.



Panel Fabrication for Material Equivalency (LaRC)



Panel Fabrication for Material Equivalency (MSFC)



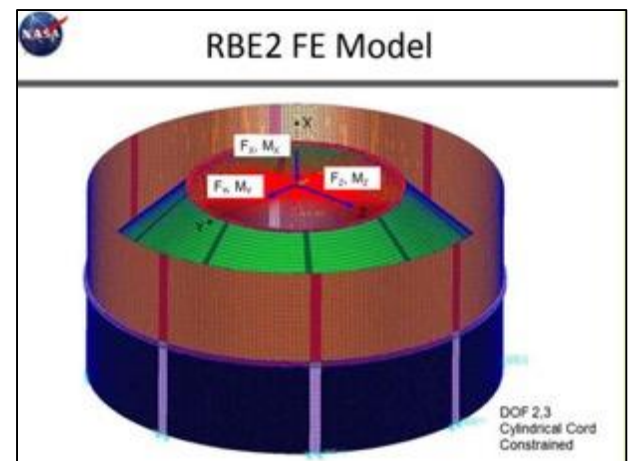
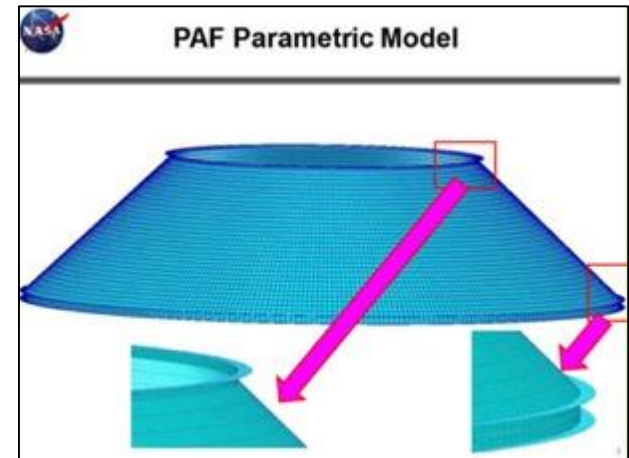
CTE Technical Accomplishments and Technical Challenges



- Design studies are being performed to determine range of loads in the longitudinal joints for developing longitudinal joint designs
- Models developed for design studies for various PAF geometries (cone angle and height)

CTE Longitudinal Joint Sensitivity Study Cases

CASE	Angle	Height (inches)	Lower Diameter (inches)	Upper Diameter (inches)
1	45.0	60.0	331.0	211.0
2	35.0	60.0	331.0	159.6
3	45.0	120.0	331.0	91.0
4	35.0	120.0	331.0	62.0





CTE Technical Accomplishments and Technical Challenges

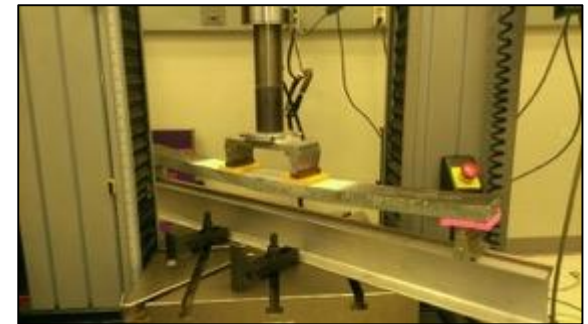


Bonded Joint Analyses Tool Methodology Assessment

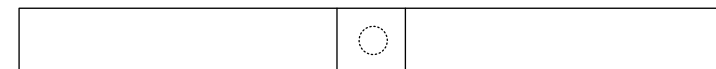
- Composite joints for launch vehicles advanced under Composites for Exploration (CoEx). CTE starts its joint analyses assessment leveraging CoEx developed out-of-autoclave all composite bonded longitudinal joints tested in pristine and flawed conditions.
- **Task**
 - Model jointed 4-point bend test coupons, with and without flaws using Virtual Crack Closure Technique (VCCT) and Cohesive Zone Modeling (CZM) methods
 - Report analysis limitations, and recommendations to improve predictive capabilities
- **Status**
 - Design data, material property data, and engineering models compiled for analyses team.



CoEx developed bonded joint



Jointed 4 point bend coupons tested joint without and with flaws



Centered flaw



Edge flaw



CTE Technical Accomplishments and Technical Challenges

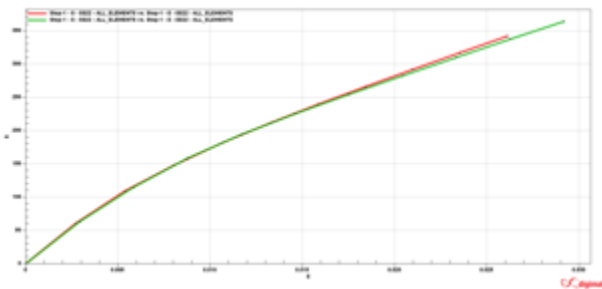
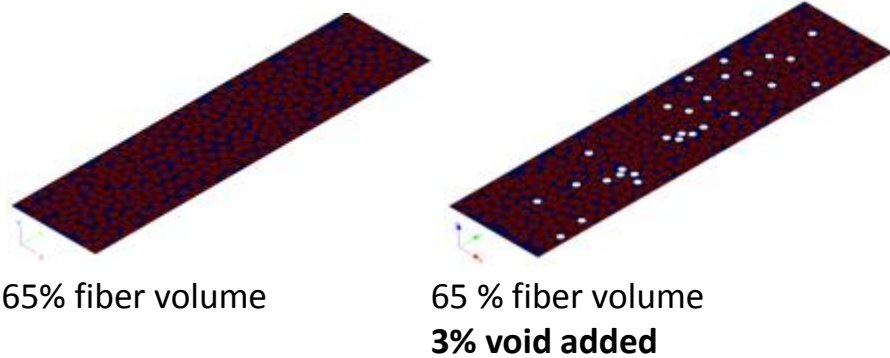


Computational Materials Modeling

DIGIMAT software procured

- Investigating voids effect on mechanical performance the tool capabilities:

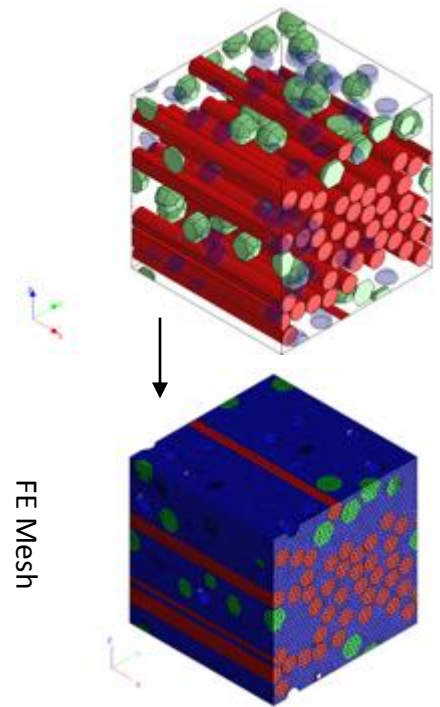
Modeling voids at lamina level



3% voids stiffness affect is negligible based on virtual testing (analyses done to specific load, not to failure load)

Modeling multiple phases at Finite Element level

50% fiber volume
2% void
4% third phase
(nano-particulate)



Created finite element models with fibers, matrix, and voids and additional phase for detailed analyses



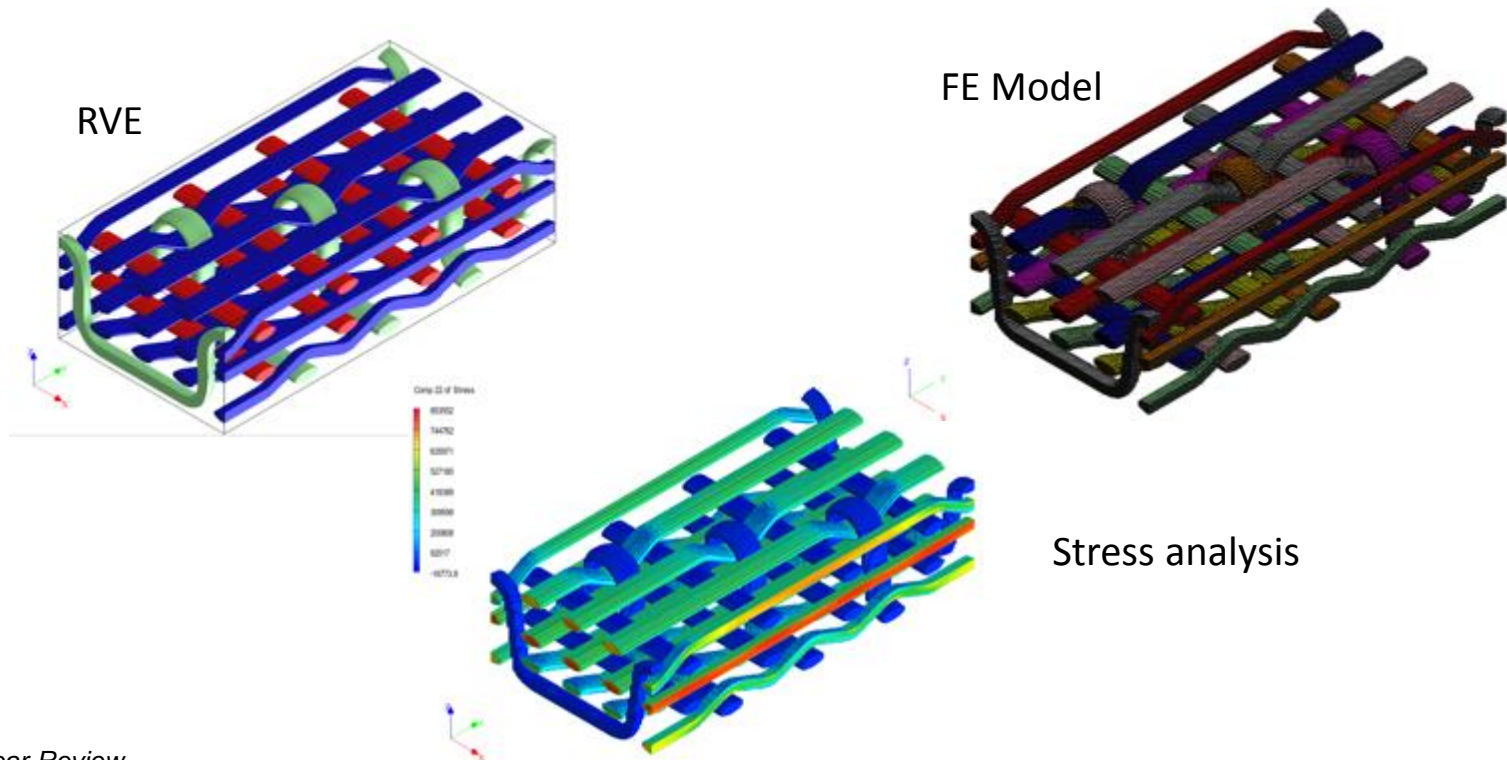
CTE Technical Accomplishments and Technical Challenges



Computational Materials Modeling

- **Investigating 3D woven joint material property and structural modeling (Longitudinal and Circumferential joint options)**

Working with tools to develop Representative Volume Elements (RVEs) to convert them into Finite Element (FE) models for detailed failure predictions of fiber and matrix.





CTE Technical Accomplishments and Technical Challenges



Computational Materials Modeling

Investigating how well constituent material properties can predict lamina and laminate engineering properties. To be compared to CEUS/CTE equivalency data.

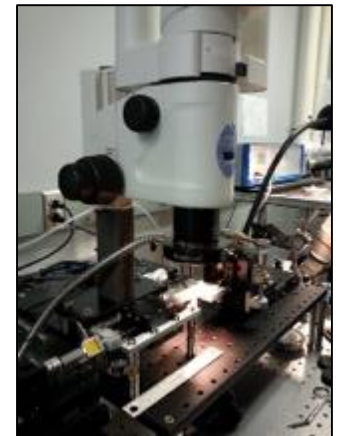
IM7 Fiber Testing:

- Completed path-finder single filament (5 microns dia) tensile tests
 - Failure load is ranging from 12 to 14.5 g
 - Good agreement with Hexcel published data- expected 14g failure load

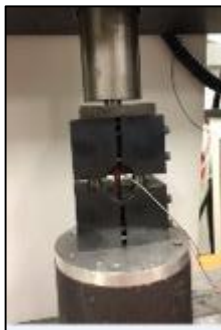
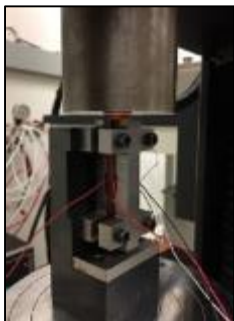
8552-1 Neat Resin Testing:

- Completed path-finder tension, compression and shear coupon tests
 - Changed compression test from ASTM 695 to ASTM 6641 to achieve resin failure.
 - Tension tests with a few tests showing high variability, need more data to understand if this is one bad panel or systematic problem

Fiber Micro Testing



Compression Testing



Tension Testing



Shear Testing





CTE Technical Accomplishments and Technical Challenges



- **Material Procurements**
 - Joint Coupon materials: Purchase Order (PO) for out of autoclave prepreg was issued on March 24th. Lead time is ~16 weeks; expect delivery at MSFC by July 15th. Film adhesive procurement initiated with the NSSC.
 - Aluminum honeycomb core was delivered to MSFC in April.
- **Trip to Bally Ribbon Mills plant in March to discuss 3D-Woven composite joints**
 - Identified potential approach to reduce metallic circumferential end ring mass by 50%.
- **Analysis Team Face-to-Face Meeting at Langley on March 13th-14th**
 - Discussed analysis tools and validation effort with planned CTE joint tests.
 - Completed presentations on analysis tools/methodologies for composite bonded joints.
- **Initiated bonded joint analyses tool methodology assessment**



Key Technical Risks



Key Technical Risks

Composite Technologies for Exploration (CTE)

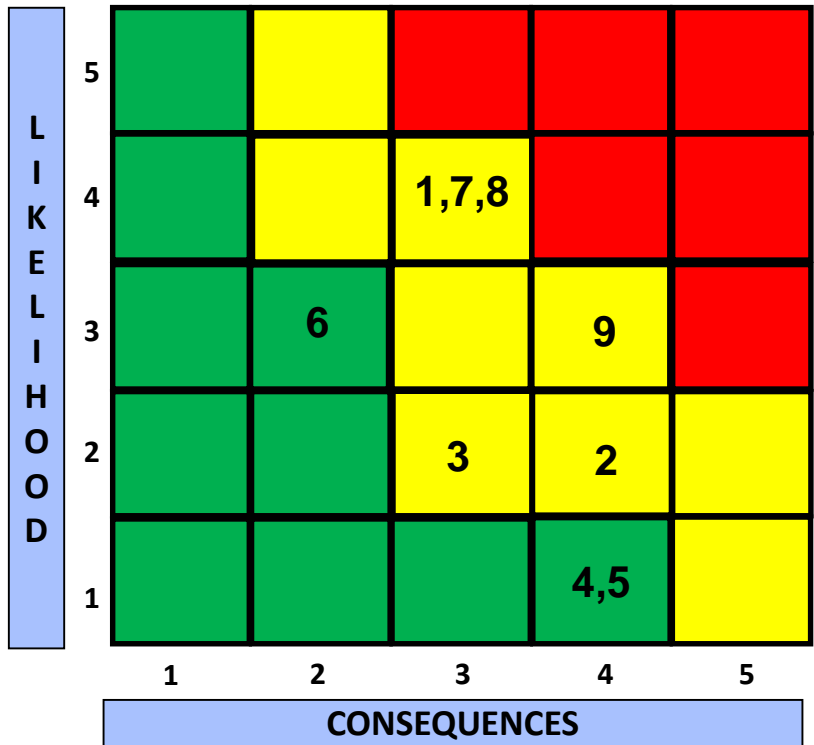
RISK ID	Title	Description	L/C	Trend
CTE – T1	Relevant Environment	Difficulty of testing large scale structures in relevant environment may limit advancement past TRL 5	4/3	➔

Notes:

Criticality	L x C Trend	
High	↓	Decreasing (Improving)
Med	↑	Increasing (Worsening)
Low	➔	Unchanged
	■	New Since Last Period



CTE Risk Summary



ID	Trend	Approach/Affinity	Risk Title
1	⇒	M/T,Sc,C	Lowered TRL Achievement
2	⇒	M/T	Limited Verification of Structural Capability
3	⇒	M/T	Inadequate Point Design CLOSED
4	⇒	W/Sc,C	Material Recertification Failure
5	⇒	W/Sc,C	Material Equivalency Failure
6	⇒	W/Sc	Facility Availability
7	⇒	M/Sc	3D Woven Joint Lead-Time
8	⇒	M/T	NDE Inspection Capabilities
9	⇒	W	Scale-Up

Criticality	L x C Trend	Approach
High	↓ Decreasing (Improving)	M - Mitigate
Med	↑ Increasing (Worsening)	W - Watch
Low	⇒ Unchanged	A - Accept
	□ New Since Last Period	R - Research

Affinity: T-Technical C-Cost Sc-Schedule
- Sa-Safety



CTE FY17 Forward Plans



- Down select of Longitudinal Joint Design Concept (May)
- Material Equivalency Testing & Analysis of IM7/8552-1 Report (July)
- Bonded Joints – Coupon level fabrication, test, and analysis complete (August)
- Assess, Apply & Compare Bonded Joint Strength Prediction Methodologies Report (September)
- Correlation of Digimat Computational Models with Material Property Test Data Report (September)

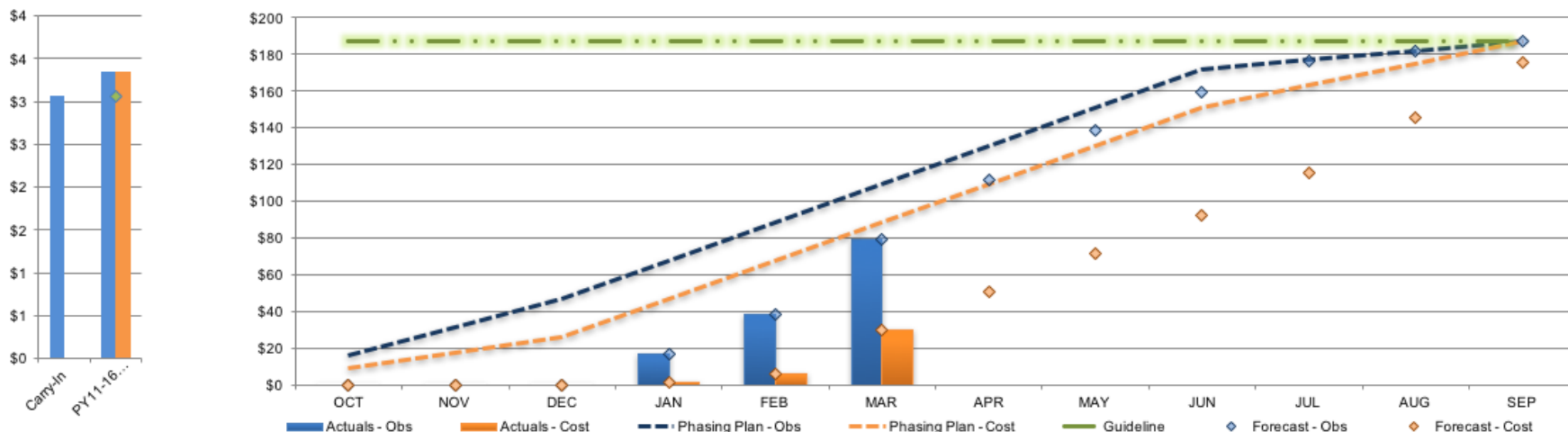
The CTE project is on schedule to complete the FY17 milestones and report at continuation review in September/October.



Resources: Non-Labor Obligations and Cost



FY 2017 Non-Labor Financial Status



	Cum (\$K)	Carry-In	PY11-16 Funds	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	Carry Out	
Obs	Guideline		3.1	187.5	187.5	187.5	187.5	187.5	187.5	187.5	187.5	187.5	187.5	187.5	187.5	187.5	
	Phasing Plan (RLP)			15.6	31.1	46.7	67.5	88.3	109.1	129.9	150.7	171.5	176.9	182.2	187.5	(0.3)	
	Actuals	3.1	3.3	0.0	0.0	0.0	16.9	38.4	78.9								
	Forecast			-	-	-	16.9	38.4	78.9	111.9	138.9	159.7	176.7	182.0	187.4	(0.1)	
Cost	Phasing Plan (RLP)			8.6	17.2	25.8	46.6	67.5	88.3	109.1	129.9	150.7	163.0	175.2	187.5	0.3	
	Actuals	0.0	3.3	0.0	0.0	0.0	1.1	6.0	30.1								
	Forecast			-	-	-	1.1	6.0	30.1	50.9	71.8	92.6	115.6	145.6	175.6	12.1	

Note: Carry-In is the unobligated/uncosted portion of PY11-16 funding end of FY16

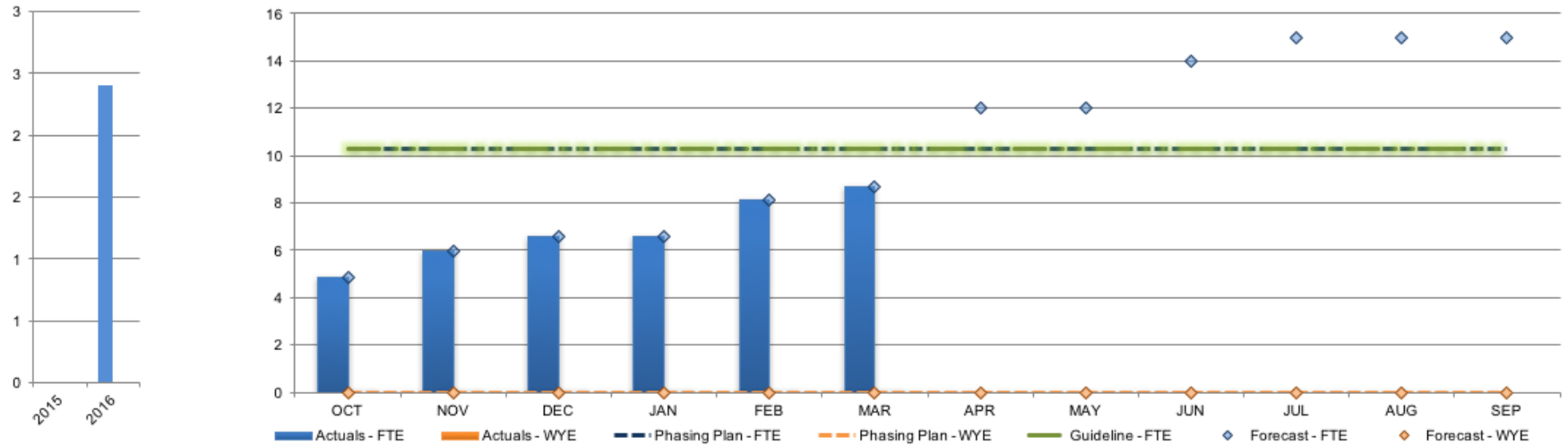
	YTD Status	Explanation required for YTD Variance in excess of 5% from Phasing Plan (shaded red)
'17 Obs	Phasing \$ 109	Slightly behind planned obligations for backpack funds.
	Actuals \$ 79	
	Variance \$ (30)	
'17 Cost	Phasing \$ 88	Slightly behind planned costs for backpack funds.
	Actuals \$ 30	
	Variance \$ (58)	



Resources: Total Project Workforce FTEs/WYEs



FY 2017 Workforce Status



	Incremental	2015	2016	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	2017 Avg
FTE	Guideline			10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3
	Phasing Plan (RLP)			10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3
	Actuals	0	2.4	4.9	6.0	6.6	6.6	8.1	8.7							6.8
WYE	Forecast			4.9	6.0	6.6	6.6	8.1	8.7	12.0	12.0	14.0	15.0	15.0	15.0	10.3
	Phasing Plan (RLP)															0.0
	Actuals	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							0.0
	Forecast			-	-	-	-	-	-	-	-	-	-	-	-	-

	YTD Status	Explanation required for YTD Variance in excess of 5% from Phasing Plan (shaded red)
'17 FTE	Phasing	10.3
	Actuals	6.8
	Variance	(3.5)
'17 WYE	Phasing	N/A
	Actuals	-
	Variance	N/A

Behind planned FTE utilization due to project formulation. FTEs are currently ramping up.



CTE Quarterly Summary Performance



Quarterly Summary Performance

Project	Summary Performance			
	Cost	Schedule	Technical	Programmatic
Quarter 1				
Quarter 2				
Quarter 3				
Quarter 4				



Back Up Charts

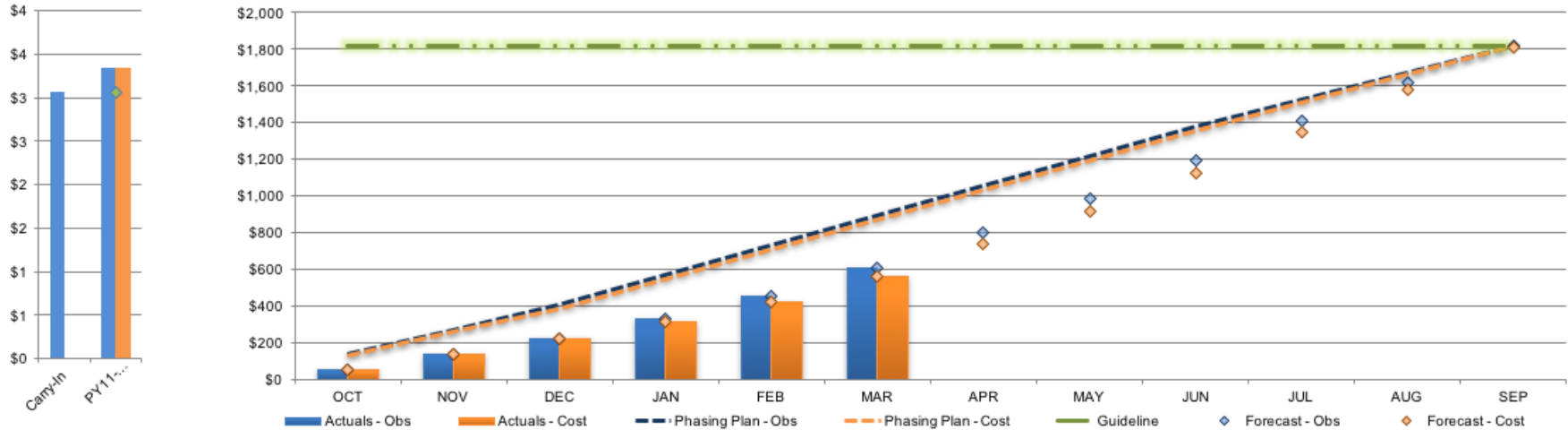
<These charts feed Quarterly Reporting. All charts are required. >



Resources: Total Obligations and Cost



FY 2017 Financial Status



	Cum (\$K)	Carry-In	PY11-16 Funds	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	Carry Out
Obs	Guideline		3.1	1,815.7	1,815.7	1,815.7	1,815.7	1,815.7	1,815.7	1,815.7	1,815.7	1,815.7	1,815.7	1,815.7	1,815.7	
	Phasing Plan (RLP)			135.0	269.9	404.9	566.8	728.7	890.6	1,052.5	1,214.5	1,376.4	1,522.8	1,669.2	1,815.7	(0.3)
	Actuals	3.1	3.3	51.9	137.4	218.6	331.5	449.9	606.1							
Cost	Forecast			51.9	137.4	218.6	331.5	449.9	606.1	799.1	986.1	1,193.9	1,410.9	1,616.2	1,821.5	(6.1)
	Phasing Plan (RLP)			128.0	256.0	384.0	546.0	707.9	869.8	1,031.7	1,193.6	1,355.5	1,508.9	1,662.3	1,815.7	0.3
	Actuals	0.0	3.3	51.9	137.4	218.6	315.7	417.5	557.3							
	Forecast			51.9	137.4	218.6	315.7	417.5	557.3	738.1	918.9	1,126.7	1,349.7	1,579.7	1,809.7	12.1

Note: Carry-In is the unobligated/uncosted portion of PY11-16 funding end of FY16

	YTD Status	Explanation required for YTD Variance in excess of 5% from Phasing Plan (shaded red)
'17 Obs	Phasing \$ 891	Obligations are behind plan due to FTEs under running. FTEs are ramping up to meet guidelines at the end of the fiscal year.
	Actuals \$ 606	
	Variance \$ (285)	
'17 Cost	Phasing \$ 870	Costs are behind plan due to FTEs under running. FTEs are ramping up to meet phasing plan at the end of the fiscal year.
	Actuals \$ 557	
	Variance \$ (312)	



CTE Technology Name

Risk Details



Detailed Risk charts found on GCD Sharepoint.



Excel File: STMD and GCD Data Request



- **EPO: Activities, Conferences, and Students**
- **Economic Development**
- **Post Excel File to the following link on NX: :**
<https://nx.larc.nasa.gov/dsweb/View/Collection-97354>

Use Excel file sent with the template and located on NX



Composite Technologies for Exploration



STATUS QUO

- Joints are heavy and not optimized. Majority of joints are mechanically fastened, creating the opportunity for self-induced damage from the joining process.
- Analytical tools and techniques do not accurately predict composite failure modes.
- Inspection techniques and tools are time consuming and need improvement in certain configurations (bondline, core).
- Limited model-based virtual materials, design and manufacturing capabilities lead to extensive development cycles.



NEW INSIGHTS

- Recent USA RFI responses from industry indicated bonded joints as being a key enabling technology for the development of efficient sandwich composite launch vehicle structures.
- To maximize performance potential for composite structures there needs to be improved analytical techniques and tools.
- Advances in several technology areas will enable significant improvements in performance and cost of SLS composite structures.
- Development and assessment of light-weight, stiffness-neutral joint concepts.
- Development and implementation of improved process control and NDE processes.
- Development and validation of high-fidelity analysis tools for predicting failure and residual strength of said bonded joints.

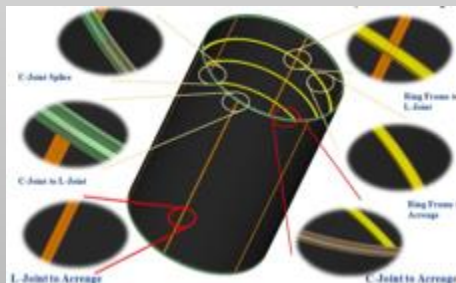


PROBLEM / NEED BEING ADDRESSED

NASA lacks experience with large-scale (8.4m diameter) composite joints; joining of composites has been called the *Achilles heel* of composite structures.

PROJECT DESCRIPTION/APPROACH

- Revisit past composite studies and activities dealing with composite joints, analysis tools and inspection. Also investigate industry standards in these areas.
- Design, fabricate, and test a suite of light-weight stiffness-neutral bonded joint concepts for SLS-specific applications.
 - Test coupons (small panels) and large-scale cylindrical panels to assess the performance of selected jointing concepts subjected to relevant loading conditions, with and without impact damage, manufacturing flaws and repairs.
- Develop design values and guidelines for selected joints for SLS-specific applications.
- Additional panels with design features will be analyzed, fabricated, and tested.
 - Design features include a large opening representing a door and a small opening representing a vent, both of which are non-load bearing.
 - One large segment panel test and one smaller curved panel test will be conducted using representative compression loads.
- Develop and validate high-fidelity analysis tools and standards for the prediction of failure and residual strength of selected joints.
 - Design and execute tests to verify predicted strain and deformation response in bonded joints.
 - Validated analysis tools may be used as virtual tests to reduce reliance on testing necessary for design justification and certification → reduce design cycle time and cost.



QUANTITATIVE IMPACT

- Provides potential cost savings, weight savings and improved performance with increased reliability compared to metallic structures/joints.
- Demonstrates composite materials, manufacturing, and validated design technologies.
- Reduces risk, lowers lifecycle cost, and enables architectures for future exploration missions.
- Supports SLS composites risk reduction for the Universal Stage Adapter (USA) and the Payload Attach Fitting (PAF).
- Builds on previous work, sustains critical composites competencies, and uses innovative new capabilities at NASA Centers.



PROJECT GOAL

- Advance composite technologies that provide lightweight structures to support future exploration missions. Focus on the areas of joints and analysis techniques/tools specifically applicable to lightweight composite structures.
- Develop and demonstrate critical composites technologies with a focus on joints and analysis; incorporate materials, design, manufacturing, and tests that utilize NASA expertise and capabilities.
- Mature technologies in cross-cutting areas including materials (alternative fibers), design (tailored laminates, optimized fiber orientation), and manufacturing (in-situ NDE, automation, repeatability)
- Advance analytical approaches that utilize model-based virtual materials, design, and manufacturing.



CTE Organization and Key Members

