## Advanced Manufacturing Technology

### FY15 Portfolio and Technology Maturation Story

<table>
<thead>
<tr>
<th>Project Element Name</th>
<th>Project Element Lead</th>
<th>FY Start</th>
<th>FY End</th>
<th>TRL Start</th>
<th>TRL End</th>
<th>Appendix No.</th>
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<tr>
<td>Manufacturing Initiative (Activity)</td>
<td>John Vickers</td>
<td>FY14</td>
<td>FY16</td>
<td>4</td>
<td>6</td>
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<tr>
<td>Advanced Near Net Shape Technology</td>
<td>John A. Wagner, Marcia Domack</td>
<td>FY14</td>
<td>FY15</td>
<td>3</td>
<td>4</td>
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<td>Materials Genome Initiative</td>
<td>Terryl Wallace</td>
<td>FY14</td>
<td>FY16</td>
<td>3</td>
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<td>Low Cost Upper Stage-Class Propulsion</td>
<td>Tony Kim</td>
<td>FY14</td>
<td>FY17</td>
<td>3</td>
<td>6</td>
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<td>Additive Construction for Mobile Emplacement</td>
<td>Niki Werkheiser, Rob Mueller</td>
<td>FY15</td>
<td>FY17</td>
<td>3</td>
<td>5</td>
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<td>Bulk Metallic Glass</td>
<td>Peter Dillon</td>
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<td>3-4</td>
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<th>Project Task Name</th>
<th>Project Task Lead and Participants</th>
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<th>TRL End</th>
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<td>Virtual Materials and Manufacturing for Composites (Task)</td>
<td>John Vickers</td>
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<td>Advanced Integrated Composite Structures (Task)</td>
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<td>LOX/GOX Compatibility Testing for Composite LOX Tank Material (Task)</td>
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2015 GCD Annual Program Review
Advanced manufacturing is critical to all NASA mission areas. The AMT project elements and tasks develop and mature innovative, advanced manufacturing technologies that will enable more capable and lower-cost spacecraft and launch vehicles. The AMT Project is making use of cutting edge materials and emerging capabilities including: metallic processes, additive manufacturing, composites, and digital manufacturing. The AMT project supports the National Manufacturing Initiative involving collaboration with other government agencies.

### Integration with other projects/programs and partnerships
- CIF, SBIR/STTR, STRG, TDM, Centennial Challenges
- HEOMD, ARMD
- Industry, OGA, Academia

### Technology Infusion Plan:
- Potential customer infusion (TDM, HEOMD, SMD, OGA, Industry)
- Produce game changing and next generation manufacturing technology and work with various NASA mission directorates and programs (e.g. SLS) to infuse the technology to dramatically improve affordability and capability.
- Collaborate with other Agencies, Industry and Academia.
- Industry Days, NASA roadmap

### Key Personnel:
- **Program Manager:** Steve Gaddis
- **Program Element Manager:** Kevin Kempton
- **Project Manager:** John Vickers
- **Lead Center:** MSFC
- **Supporting Centers:** ARC, GSFC, GRC, KSC, LaRC
- **NASA NPR:** 7120.8
- **Guided or Competed:** Guided
- **Type of Technology:** Push and Pull

### Key Facts:
- **GCD Theme:** Lightweight Materials and Advanced Manufacturing
- **Execution Status:** Thematic Plan
- **Technology Start Date:** N/A
- **Technology End Date:** N/A
- **Technology TRL Start:** 3
- **Technology TRL End:** 6
- **Technology Current TRL:** N/A
- **Technology Lifecycle Phase:** AMT/Project level does not have lifecycle phase, but each technology element does.
## Technology Performance and Comments

<table>
<thead>
<tr>
<th>Technology</th>
<th>Performance</th>
<th>Comments</th>
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<tr>
<td>Manufacturing Initiative</td>
<td></td>
<td>Significant engagement with other agencies and the activities of the National Advanced Manufacturing Initiative (e.g. NNMI’s).</td>
</tr>
<tr>
<td>Advanced Near Net Shape Tech.</td>
<td></td>
<td>Successful sounding rocket flight on October 7th. Resources needed in FY16 to support post-flight analysis due to flight delay. All other milestones on schedule for completion. ANNST is currently unfunded for FY16.</td>
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<tr>
<td>Materials Genome Initiative</td>
<td></td>
<td>Completed all of the FY15 Milestones. Continuation Review scheduled for Oct. 29, 2015 at LaRC.</td>
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<tr>
<td>Low Cost Upper Stage Class Propulsion</td>
<td></td>
<td>Technical – Technical Challenges and complications of EBF3 application of In625 on SLM GRCop-84 for the structural jacket have required additional efforts and schedule than previously anticipated. Schedule – Missed the Original Hot Fire complete date (August 28, 2015, CR submitted). Detailed schedule has been generated that includes a 10 day margin with hot fire testing in the Spring of 2016.</td>
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<tr>
<td>Additive Construction with Mobile Emplacement (ACME)</td>
<td></td>
<td>Completed all FY15 milestones on schedule. Currently one project risk, and it is green.</td>
</tr>
<tr>
<td>National Center for Advanced Manufacturing (NCAM)</td>
<td></td>
<td>Schedule – Procurement delays have caused the tasks to be behind schedule.</td>
</tr>
</tbody>
</table>

**AMT SPI index is 0.77**
AMT Technical Accomplishments

• Completed design, fabrication, testing, integration and flight of a sounding rocket payload adapter fabricated using the integrally stiffened cylinder (ISC) process. (ANNST)

• New models were developed of the melt pool and thermal effects within a build and build plate. These models will be validated and used to assist SLS in developing processing parameters on a new SLM system. (MGI)

• Designed and additively manufactured two full scale chambers out of GRCop powder. Developed process during 1st chamber build and made improvements for 2nd chamber build based on lessons learned. (LCUSP)

• Constructed martian simulant concrete wall, fabricated sintered basalt pavers, and size-sorted and delivered feedstock. (ACME)
### PY 2015 Financial Status

#### Resources: Total Obligations and Cost

<table>
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<tr>
<th>Cost</th>
<th>Obs</th>
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<th>2014</th>
<th>OCT</th>
<th>NOV</th>
<th>DEC</th>
<th>JAN</th>
<th>FEB</th>
<th>MAR</th>
<th>APR</th>
<th>MAY</th>
<th>JUN</th>
<th>JUL</th>
<th>AUG</th>
<th>SEP</th>
<th>Carry Out</th>
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<td>4,659.9</td>
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<td>5,030.5</td>
<td>5,030.5</td>
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### YTD Status

<table>
<thead>
<tr>
<th>YTD Status</th>
<th>Explanation required for YTD Variance in excess of 5% from PM Forecast (shaded red)</th>
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<tr>
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<td>$4,945</td>
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<tr>
<td>Forecast*</td>
<td>$4,971</td>
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<td>Actuals</td>
<td>$4,898</td>
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<tr>
<td>Variance</td>
<td>$(73)</td>
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</table>

*Forecast value is a snapshot of the Forecast from the previous reporting period.*

#### Notes:

- *The obligations are slightly behind plan due to labor under run.*
- *The costs are behind plan for the year due to the delays in the LLCSP Hot Fire Test and the obligations not occurring as soon as initially anticipated. Also behind plan due to labor under run.*
PY 2015 Non-Labor Financial Status

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<tr>
<th>Cum (K$)</th>
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<th>DEC</th>
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<th>FEB</th>
<th>MAR</th>
<th>APR</th>
<th>MAY</th>
<th>JUN</th>
<th>JUL</th>
<th>AUG</th>
<th>SEP</th>
<th>Carry Out</th>
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<tbody>
<tr>
<td>Actuals</td>
<td>163.1</td>
<td>262.9</td>
<td>913.9</td>
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<td>721.6</td>
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<td>1,567.5</td>
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<td>Phasing Plan (RLS)</td>
<td>163.1</td>
<td>262.9</td>
<td>913.9</td>
<td>483.1</td>
<td>721.6</td>
<td>1,326.1</td>
<td>1,503.8</td>
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<td>1,698.4</td>
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</table>

YTD Status | Explanation required for YTD Variance in excess of 5% from PM Forecast (shaded red)

Phasing $1,873 | The obligations are ahead of plan due to NCA/AM funds obligating prior to the end of the fiscal year and ahead of plan.
Actuals $2,121
Variance $238

Phasing $1,959 | The costs are behind plan for the year due to the delays in the LCUSP Hot Fire Test and the obligations not occurring as soon as initially anticipated.
Forecast $1,099
Actuals $923
Variance $176

* Forecast value is a snapshot of the Forecast from the previous reporting period
## PY 2015 Workforce Status

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**YTD Status**

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The FTEs are slightly behind plan due to ACME starting off the year slow due to delays with interagency agreement.

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<tr>
<td>Variance</td>
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</tr>
</tbody>
</table>

The WYE's are behind plan for the year due to the delays in the LCUSP Hot Fire test.

**Explanation required for YTD Variance in excess of 5% from PM Forecast (shaded red)**

* Forecast value is a snapshot of the Forecast from the previous reporting period
Advanced Manufacturing Technology

Manufacturing Initiative
The AMT Project supports multiple activities within the Administration’s National Manufacturing Initiative. A key component of the Initiative is the Advanced Manufacturing National Program Office (AMNPO), which includes participation from all federal agencies involved in U.S. manufacturing. In support of the AMNPO the AMT Project supports building and Growing the National Network for Manufacturing Innovation through a public-private partnership designed to help the industrial community accelerate manufacturing innovation.

Integration with other projects/programs and partnerships

- STMD, HEOMD, other Centers
- Industry, Academia
- OGA’s (e.g., DOD, DOE, DOC, USDA, NASA, NSF)
- Office of Science and Technology Policy, NIST
  Advanced Manufacturing Program Office
- Generate insight within NASA and cross-agency for technology development priorities and investments.

Technology Infusion Plan:

- PC
- Potential customer infusion (TDM, HEOMD, SMD, OGA, Industry)
- Leverage
- Collaborate with other Agencies, Industry and Academia.
- NASA roadmap

Key Personnel:

Project Manager: John Vickers
Project Element Manager: John Vickers
Lead Center: MSFC
Supporting Centers: ARC, GSFC, GRC, KSC, JPL, LaRC
NASA NPR: 7120.8
Guided or Competed: Guided
Type of Technology: Push and Pull

Key Facts:

GCD Theme: Lightweight Materials and Advanced Manufacturing
Execution Status: Thematic Plan
Technology Start Date: N/A
Technology End Date: N/A
Technology TRL Start: 3
Technology TRL End: 6
Technology Current TRL: N/A
- Technology Lifecycle Phase: N/A
NASA is an engaged partner with the other agencies in the activities of the National Advanced Manufacturing Program Office and in the manufacturing innovation institutes. We envision increased specific engagement.

- Led by Space Technology Mission Directorate – Multiple Center Participation
- Member of the interagency Advanced Manufacturing National Program Office (AMNPO)
- Member of the NSTC Subcommittee on Advanced Manufacturing
  - Currently participating on the writing teams for the NNMI Program Strategic Plan (SP)
  - Participated in the US-UK workshop on manufacturing innovation and policy
- NASA NNMI Collaboration
  - Executive committee and technical advisory board members
  - Additive Manufacturing Roadmap Advisory Groups
  - NASA researchers can participate in technical projects in areas that align with NASA interests
  - STMD is providing FTE support for ALL solicitations and institutes in the form of technical reviewers during the solicitation process
- Current Institutes - America Makes, Digital Manufacturing and Design Innovation Institute, Lightweight Innovations For Tomorrow, Power America, Institute of Advanced Composites Manufacturing Innovation, Integrated Photonics, Flexible Hybrid Electronics
- Upcoming Institutes - Clean Energy Institute on Smart Manufacturing, Revolutionary Fibers and Textiles
- Consortium for Advanced Manufacturing Foresights - University of Michigan
- Other related initiatives – Materials Genome Initiative, National Nanotechnology Initiative, Biology Engineering (SynBio)
NASA Engagement with Established Institutes

**National Additive Manufacturing Innovation Institute - Youngstown, OH**

- First of the NNMI institutes; established in August 2012
- Technology: Additive Manufacturing (aka: 3D Printing)
- Prime Awardee: National Center for Defense Manufacturing and Machining (NCDMM)
- Primary Federal Funding Agency: DOD - Air Force
- Initial $30M federal investment matched by $39M industry, state/local; now at $50M federal, with over 100 participants

**NASA Financial Support**
- May 2015, 3D Printed Habitat Challenge, $2.25 million competition to design and build a 3D printed habitat for deep space exploration, Centennial Challenges program

**NASA Collaboration**
- Executive committee and technical advisory board members (MSFC, LARC, GRC)
- Additive Manufacturing Roadmap Advisory Group
- NASA researchers can participate in technical projects in areas that align with NASA interests
Advanced Near Net Shape Technology
**Overall objective:** Develop and mature cryogenic tank manufacturing technology to enable fabrication of single-piece integrally-stiffened launch vehicle structures to replace expensive, heavy, and risky multi-piece welded assemblies. **Status:** Demonstrated feasibility through fabrication of aluminum subscale single-piece cylinders with integrally formed cryogenic tank barrel scale stiffeners using the Integrally Stiffened Cylinder (ISC) process. Successful scale-up of ISC process through fabrication of a single-piece, integrally-stiffened, aluminum sounding rocket (SR) payload adapter. Successful flight demonstration on October 7, 2015.

**Integration with other projects/programs and partnerships**
- Strong alliance among NASA, ESA, DLR and US and German private industry.
- Firm resource commitment from ESA for FY16 to support scale up to 3-meter (~10 feet) in diameter
- Firm resource commitments from DLR and MT Aerospace for FY16 to increase stiffener height at sounding rocket scale diameter
- Collaboration with ESA via a NASA/ESA MOU on Space Transportation
- Working with International Technologies to establish ISC process capability in U.S.

**Technology Infusion Plan**
- Technology developed – Integrally Stiffened Cylinder (ISC) process for manufacture of single-piece stiffened structures in a single processing step.
- Potential customers
  - NASA launch vehicle programs (Sounding Rockets, SLS)
  - Commercial launch service providers
  - DoD launch vehicles
- Comments/Anticipated use
  - Fabrication of single-piece stiffened structures using the ISC process represents a paradigm shift from conventional multi-piece welded construction. Potential applications are cryogenic tank barrels, rocket segments, intertank structures.

**Key Personnel:**
**Project Manager:** John Vickers
**Project Element Manager:** Marcia Domack/John Wagner
**Lead Center:** LaRC
**Supporting Centers:** WFF – Sounding Rocket Payload Team
**NASA NPR:** 7120.8
**Guided or Competed:** Guided
**Type of Technology:** Push

**Key Facts:**
**GCD Theme:** Lightweight Materials and Advanced Manufacturing
**Execution Status:** Year 3 of 3 funded (of 6 planned)
**Technology Start Date:**
**Technology End Date:**
**Technology TRL Start:** 3
**Technology TRL End:** 6
**Technology Current TRL:** 3
**Technology Lifecycle Phase:** Second Formulation Year due to budget cuts
Component and System TRL Quarterly Assessment – ANNST

**Integrally Stiffened Cylinder (ISC) Process**

- FY15:
  - SR MIC: Develop SR fabrication plan
  - SR Mic: Flight test with SR ISC component – Q4 FY15
- FY16:
  - Continue SR component fabrication
  - Cost/Benefit analysis of ISC process
- FY17:
  - Develop manufacturing plan for large scale components
  - Test large scale ISC component in relevant environment (TRL 6)

**KPP #1 (inches)**
- Goal: 75%
- Actual: 75%
- Predicted: 75%

**KPP #2 (lbs)**
- Goal: 30%
- Actual: 30%
- Predicted: 30%

**KPP #3 ($)**
- Goal: 40%
- Actual: 40%
- Predicted: 40%

**Goal**
- Actual Value
- Predicted Value

**SR = Sounding Rocket**
**MIC = Mission Initiation Conference**

**2015 GCD Annual Program Review**
AMT
ANNST Performance

• **Technology Advancements**
  - Demonstrated scale-up of the Integrally Stiffened Cylinder (ISC) process through fabrication of a single-piece integrally-stiffened aluminum sounding rocket payload adapter.
  - Represents a 20 fold increase in scale based on cylinder volume.
  - Demonstrates feasibility of eliminating all longitudinal welds in cryogenic tank barrels.

• **Technology advances mean**
  - ISC process enables 50% cost and 7% weight reductions for cryogenic tank barrel manufacture by eliminating longitudinal welds and minimizing machining.

• **Technology Push**
  - NASA Launch vehicle programs (SLS, Sounding Rockets), Commercial launch providers, Athena, Falcon 9, DoD launch vehicles.
  - Cryogenic tank, dry bay structure, payload fairings and payload adapter applications.

<table>
<thead>
<tr>
<th>Performance Parameter</th>
<th>State of the Art</th>
<th>Threshold Value</th>
<th>Project Goal</th>
</tr>
</thead>
<tbody>
<tr>
<td>KPP1 – Cryogenic Tank Barrel Longitudinal Welds</td>
<td>ET LH2 tank – 7200 in.</td>
<td>1800 inches</td>
<td>0 inches</td>
</tr>
<tr>
<td>KPP2 – Cryogenic Tank Weight</td>
<td>ET – 54K lbs</td>
<td>15% less</td>
<td>30% less</td>
</tr>
<tr>
<td>KPP3 – Cryogenic Tank Cost</td>
<td>ET - $60M</td>
<td>20% less</td>
<td>40% less</td>
</tr>
</tbody>
</table>
ANNST Technical Accomplishments and Technical Challenges

• **FY15 Technical Accomplishment**
  • Completed design, fabrication, testing and integration of a sounding rocket payload adapter fabricated using the integrally stiffened cylinder (ISC) process.

• **Technology firsts**

• **Technical challenges**
  • A cylinder of this size and complexity had never been formed before using the ISC process.
    • Designed tooling to maximize probability of success during forming.
  • As-formed cylinders were slightly out-of-round.
    • Modified machining plan to maximize wall thickness of sounding rocket flight cylinder and match machined mating hardware.
    • Payload adapter successfully fabricated, flight qualified, integrated into sounding rocket payload assembly.
Proposed plans for FY16

- Technical Objectives
  - Scale-up to 3 meter (10 feet) diameter utilizing existing industrial infrastructure.
  - Fabricate SR scale cylinder with cryogenic tank scale stiffeners.
  - Complete analysis of data from sounding rocket flight and preliminary ground testing.

- ANNST is currently unfunded for FY16
  - Resources needed in FY16 to support post-flight and ground test data analysis.
  - See backup for over guide request.
Payload Adapter Made Using the Integrally Stiffened Cylinder (ISC) Process

Sounding Rocket Payload Assembly with NNS Cylinder

Analysis and Testing Qualify Cylinder for Flight

Sounding Rocket Flight
October 7, 2015
Materials Genome Initiative
**Overall objective:** Develop computational tools to assist in the manufacture, design and certification of new materials and processes. These tools will reduce the time and costs to infuse new materials while also improving reliability. This program is currently focusing on additive manufacturing as this technology has high payoff for NASA and requires computational design tools.

**Integration with other projects/programs and partnerships**
- NASA Launch vehicle programs (SLS).
- Commercial launch providers.
- DoD launch vehicles.
- ARMD advanced manufacturing efforts.
- Commercial airframe manufacturers

**Technology Infusion Plan:**
- Tech infusion:
  - PC – SLS.
  - PC - DoD, Establishing collaborations with DoD via the National MGI effort. Work in NASA MGI element is complimentary with efforts in DoD
  - PC – Alcoa, Establishing a SAA to evaluate design tools for use in manufacture of light alloy components.
- Comments/Anticipated use - Process and materials design tools will be developed and supplied to the SLS program to assist in the manufacture and qualification of components via additive manufacturing.

**Key Personnel:**
- **Program Element Manager:** Steve Smith/ Terryl Wallace
- **Project Manager:** John Vickers
- **Lead Center:** LaRC
- **Supporting Centers:** ARC, GRC, MSFC
- **NASA NPR:** 7120.8
- **Guided or Competed:** Guided
- **Type of Technology:** Push

**Key Facts:**
- **GCD Theme:** Lightweight Materials and Advanced Manufacturing
- **Execution Status:** Year 2 of 3
- **Technology State Date:** Oct. 2013
- **Technology End Date:** Sept. 2016
- **Technology TRL Start:** 3
- **Technology TRL End:** 6
- **Technology Current TRL:** 3
- **Technology Lifecycle Phase:** Implementation
Component and System TRL Quarterly Assessment – MGI

- **Goal**: 25% reduction in development time.
- **Threshold**: 20% reduction in development time.
- **Goal**: 20% reduction in certification time.
- **Threshold**: 10% reduction in certification time.

**Task suspended due to cuts in project**

**In-situ monitoring tool (9/2014)**

**Component design tool with res. stress (6/2015) → (8/2015)**

**3D deformation prediction (3/2016)**

**Integrate uncertainty for process and material model (9/2016)**

**Integrated process control model (6/2016)**

**Integrated Additive Manufacturing Modeling**

**Process Optimization for Additive Manufacturing**

**Materials Optimization for Additive Manufacturing**

**Materials Optimization for Woven TPS**

**controlled milestone**

**project level milestone**

**element milestone**

**Mission Infusion KDP**

2015 GCD Annual Program Review
• **Technology Advancements**
  - Demonstrated a thermal model for selective laser manufacturing to model melt pool and thermal history that is also capable of quantifying part distortion and residual stress for manufacturing of components for SLS program.
  - Provided a detailed data schema highlighting the critical data parameters for collection for SLM processing and a proposed method to utilize this data for process improvements.

• **Technology advances mean**
  - Design models will result in reduced development cycle time and certification costs.
    - Currently applying work to affect development time for new SLM system at MSFC.

• **Technology Push**
  - NASA Launch vehicle programs, Commercial launch providers, DoD launch vehicles.
  - ARMD advanced manufacturing efforts, Commercial airframe manufacturers.

<table>
<thead>
<tr>
<th>Key Performance Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Performance Parameter</strong></td>
</tr>
<tr>
<td>KPP1 – Reduce development time for additively manufactured component</td>
</tr>
<tr>
<td>KPP2 – Reduce time and cost for component certification</td>
</tr>
</tbody>
</table>
FY15 Technical Accomplishment

• New models were developed of the melt pool and thermal effects within a build and build plate.
  ▪ These models will be validated and used to continue assisting SLS in developing improved processing parameters on a new SLM system.
  ▪ A TIM was conducted at MSFC. Greater collaboration between the MGI team and the SLS manufacturing team was created. The SLS manufacturing team has allowed the MGI team direct access to one of the SLM systems and the in-situ monitoring cameras on this system.

Technical challenges

• Close coordination between work at centers and needs of SLS Project is required and has presented a challenge.
• Lack of existing material properties and process parameters from SLS Project.
Milestone: Deliver component design tool. *Completed August 2015*

Deliverable: Demonstrate a residual stress prediction model for an identified component to be manufactured by the SLS program.

Problem: The performance of additive manufactured parts relies on the thermal history throughout an entire component. This requires understanding of the thermal history of entire components for material from the molten state to room temperature.

Objective: Develop thermal models to predict material solidification and cooling as a part is manufactured. These models will be used to predict part distortion and residual stress and to guide the manufacturing process to reduce the time and cost to integrate additively manufactured components in service.

Approach: 3D FEM models incorporating transient heat diffusion with phase change (thermal model) and Eigen strains (distortion and residual stress models) were developed and compared to experimental observations.

Impact: Thermal models applied to evaluate melt pools for use on old and new (“production”) systems. The parameters necessary on new system to develop similar processes is very different. These modified parameters have been supplied to MSFC.
• Continuation Review scheduled for Oct. 29 at LaRC.

• The element will work closely with the SLS program to define needs from the SLS program where these computational tools can assist in the greatest means possible. Have established partnership with SLS program. (POC: Kristin Morgan)

• Stacey Bagg awarded follow-on proposal to do volumetric residual stress measurements at Oak Ridge National Laboratories (ORNL). Scheduled for Nov. 18-22.
Advanced Manufacturing Technology

Low Cost Upper Stage-Class Propulsion
The LCUSP will demonstrate the ability to produce a low cost upper stage-class propulsion system using additive manufacturing technologies. LCUSP will do this by (1) developing a copper alloy additive manufacturing design process, (2) building a 25K-class regenerative chamber and nozzle, (3) testing components individually, and (3) demonstrating as a 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 wants to utilize the LCUSP Combustion Chamber or utilize the capability established under this project to fabricate a chamber.
- Industry partners are investigating possible partnerships with LCUSP for possible opportunities for fabrication of SLM combustion chambers.

### Technology Infusion Plan:

Infusion Status as of September 2015: Fabricated GRCop-84 Combustion Chamber Liners & applied Inconel625 on SLM GRCop-84 samples. Testing and Inspections are on-going with good results thus far.

### Key Personnel:
- **Project Manager:** John Vickers
- **Project Element Manager:** Tony Kim
- **Lead Center:** MSFC
- **Supporting Centers:** LaRC & GRC
- **NASA NPR:** 7120.8
- **Guided or Competed:** Guided
- **Type of Technology:** Push

### Key Facts:
- **GCD Theme:** LMAM, Lightweight Materials and Advanced Manufacturing
- **Execution Status:** Year 2 of 3
- **Technology State Date:** April 2014
- **Technology End Date:** June 2017
- **Technology TRL Start:** 3
- **Technology TRL End:** 6
- **Technology Current TRL:** 4
- **Technology Lifecycle Phase:** Implementation (Phase C/D)
LCUSP Component and System TRL Quarterly Assessment

SLM
- EBF3 on 18150 Cu Alloy material Characterization
- Cu Alloy manufacturing process development
- Ni Alloy deposition to Cu Alloys
- Additive Manufacturing of upper stage components

EBF3
- Process Development with 18150 Cu Alloy
- Process Development with GRCop
- Additive Manufacture of Chamber

Goal
- Chamber & Nozzle Hot Fire Test
- Lox/Methane Chamber Hot Fire Test
- Initial GRCop Machining, Metallography, & Mechanical Testing
- Controlled Milestones
- Key Milestone

Actual Value
- Complete EBF3 Jacket & Manifold on GRCop Liner
- EBF3 Bonded Samples Testing
- EBF3 on Lox/Methane Chamber Hot Fire Test

Predicted Value
- Chamber & Nozzle Hot Fire Test
- Fy15
- Fy16
- Fy17

Use in applicable environment
Fabrication process development
Material testing & analysis

2015 GCD Annual Program Review
LCUSP Performance

- **Technology Advancements**
  - Selective Laser Melting (SLM) fabrication with GRCop-84 powder for rocket components. (combustion chamber liner)
  - 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.

- **Technology Push**

### Key Performance Parameters

<table>
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<tr>
<th>Performance Parameter</th>
<th>State of the Art</th>
<th>Threshold Value</th>
<th>Project Goal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process control of using Copper via SLM</td>
<td>SLM demonstrated with Inconel 718, Inconel 625, and Al 357, and CoCr by MSFC, but not with copper</td>
<td>Demonstrate parameter set that allows fabrication of monolithic structures to be used for mechanical properties and surface finish testing</td>
<td>Develop an optimized parameter set to maximize build speed, control surface finish, and maximize mechanical properties of SLM copper</td>
</tr>
<tr>
<td>Copper alloy material characterization using SLM</td>
<td>Not established for copper</td>
<td>SLM'd GRCop-84 thermal conductivity at 90% of baseline extruded GRCop and remaining material properties at or greater than those of OFHC Copper</td>
<td>90% of baseline extruded GRCop material properties</td>
</tr>
<tr>
<td>Deposition of nickel alloy to SLM Copper</td>
<td>Demonstrated for pure nickel to pure copper, but not for nickel alloys to copper alloys</td>
<td>Deposition of nickel alloy to copper alloy that remains intact at the bond through a thermal cycle and with minimum defects</td>
<td>Deposition of nickel alloy onto copper alloy with a ductile transition zone and mechanical properties equivalent to cast annealed condition</td>
</tr>
<tr>
<td>Manufacture of AM upper stage engine components</td>
<td>SLM upper stage engine components demonstrated with Inconel 718, Inconel 625 by MSFC, but not with Copper (GRCop) chambers</td>
<td>Demonstrate build of subscale components or subassemblies with properties and geometry sufficient to be utilized in initial subscale testing</td>
<td>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</td>
</tr>
</tbody>
</table>
LCUSP Technical Accomplishments and Technical Challenges

- Fabrication of 2 sets of SLM GRCop-84 Combustion Chamber Liners with coolant channels.
- A new re-coater system with an array of blades was invented, developed and implemented to mitigate residual stress deformation (>30 micron divots) avoiding propagation of perturbations on SLM. A patent may be pursued for this solution.
- Build Plate bonding challenge would cause failed part, but was overcome by using a steel build plate with a “primed” by printing 1mm Inconel 718 layer.
- Obtaining GRCop-84 Power from vendor that delayed the project schedule significantly but mitigated with SLM practice with more common copper powder surrogates.
- High reflectivity of copper powder for SLM limiting the amount of energy reaching the powder affecting melt pool and thereby affecting densification and angled laser application to avoid possible damage to optics and laser.
- Oxidation of GRCop-84 during Hot Iso-static Press (HIP).
- EBF3 Machine “electron beam current run away” error condition was addressed by professional maintenance service to the EBF3 control system.
• Plans for FY16
  ▪ SLM GRCop-84 Regen Methane Chamber Hot Fire. (Nov. 2015)
  ▪ Application of EBF3 Inconel 625 Jacket on SLM GRCop-84 Liners.
    • On 1\textsuperscript{st} set of liners (pathfinder)
    • On 2\textsuperscript{nd} set of liners for the Hot Fire Test Article
  ▪ Fabricate SLM Nickel Regen Nozzle.
  ▪ Hot Fire test of LCUSP Combustion Chamber (March 2016) & integrated Combustion Chamber/Nozzle. (April/May 2016)
  ▪ Material Property Characterization. (Testing & Analysis)
**MSFC**
- Second set of full forward and aft segments are complete.
- Allows the original set to be used in riskier process trials (HIP and EBF3) which provides the relevant geometry to maximize learning opportunities from the trials.
- 2nd Set uses lessons learned and has improved surface finish.
- Witness samples and materials properties specimens run with part to characterize the build quality further and progress on our materials property tasks.
- **Inconel 718 Nozzle** Conceptual Design is complete and detailed design is progressing.
- Weld prep and final machining drawings for the chamber are released.

**GRC**
- Presented preliminary results of SLM GRCop-84 characterization at JANNAF meeting in Nashville.
- Performed initial tensile testing in Inco 625. Mixed results indicate the need to HIP assembly following jacket build.
- Auger spectroscopy on white precipitate phase observed in GRCop-84 post HIP indicates that it is elemental Chromium. This finding is not a cause for concern.
- Initial microscopy on Inco 625 / GRCop-84 interface completed, and we have been working with LaRC to refine processing parameters.
- Worked through oxidation issues associated with our HIP vendor and have HIP'd two sets of GRCop-84 liners.

**LaRC**
- Electron Beam Freeform Fabrication (EBF3)
  - EBF3 parameters for application of In625 jacket have been developed and repeatable on 3.5” diameter Cu pipes, weld ring trial, and GRCop-84 SLM channel section.
  - Trials building 1.5” diameter In625 manifold revealed challenges such as compressive residual stresses that affect the application. Continued application varying deposition parameters are showing promise.

**Test @ MSFC**
- A LOx/Methane regenerative combustion chamber made with GRCop-84 is planned for fabrication in Sept and the Hot Fire Test is scheduled for Sept/Oct 2015.
- Chamber Hot Fire Test Start Expected to start Jan 2016. Approximately 2 month test of SLM copper chamber with nickel based structural jacket followed immediately with integrated nozzle.
- Once LCUSP hot fire is accomplished, further integrated testing of the chamber and nozzle assembly maybe possible on the Liquid Propulsion System (LPS) Test Bed perhaps late FY16 w/ Lox & H2 Turbopump.
Advanced Manufacturing Technology

Additive Construction with Mobile Emplacement
## ACME Overview

- Additive Construction with Mobile Emplacement (ACME) is 2D and 3D printing on a large (structure) scale using in-situ resources for construction materials.
- 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

- Partnership between MSFC, KSC, the USACE, Contour Crafting Corporation (CCC), and the Pacific International Space Center for Exploration Systems (PISCES).
- A portion of the work completed through a 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)
- In-Situ Resource Utilization (ISRU) project integration & uses

### Technology Infusion Plan:

- Potential Customer: Plan for technology use by USACE in domestic and international venues. HEOMD, Industry also potential customers.
- Phased approach for maturation of hardware: ACME units will serve as prototypes for the USACE devices which will be used in forward bases for B-Huts.
- 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 Vickers
- **Project Element Managers:** Niki Werkheiser and Rob Mueller
- **Lead Center:** Co-led by MSFC and KSC
- **Supporting Centers:** None

### Key Facts:

- **GCD Theme:** LMAM
- **Execution Status:** Year 1 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)
ACME
Component and System TRL/KPP Assessment

Goal
Actual Value
Predicted Value

NASA System (ACME)
USACE System (ACES)

Awaiting feedback on dates for FY15 and FY17 IAA milestones.
• **Technology Advancement**
  - Construction Material – an extrudable martian simulant concrete mixture.
  - Basalt Pavers – successful design for crack-free sintered basalt pavers.
  - Feedstock Size-sorting/Delivery – successful delivery of size-sorted material.

• **Technology advance means**
  - Proof-of-concept for contour crafting technologies / additive construction applications in in-situ resource utilization.
  - Accommodating the cooling properties of basalt by paver design; advancing design based on construction material properties.
  - Proof-of-concept for size-sorting and delivery of in-situ materials for printing.

• **Technology push and pull**

<table>
<thead>
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<th>Threshold Value</th>
<th>Project Goal</th>
</tr>
</thead>
<tbody>
<tr>
<td>KPP-1 Construction Material</td>
<td>Contour crafting with water-based concrete</td>
<td>Use in-situ regolith materials for manufacturing feedstock using imported binders</td>
<td>Use in-situ regolith materials for manufacturing feedstock using no imported feedstock materials</td>
</tr>
<tr>
<td>KPP-2 Emplacement</td>
<td>Gantry mechanisms that are fixed in locations</td>
<td>Non-gantry robots in fixed locations</td>
<td>Mobile-ready print system</td>
</tr>
<tr>
<td>KPP-3 Construction Scale</td>
<td>Small concrete dome: ~1m high</td>
<td>In-situ regolith structure pad and curved wall; 1m diameter dome</td>
<td>In-situ regolith structure pad and curved wall; 4m diameter dome</td>
</tr>
<tr>
<td>KPP-4 Print Head Construction Speed (1cm thick layers material)</td>
<td>30cm/minute</td>
<td>60cm/minute</td>
<td>100cm/minute</td>
</tr>
</tbody>
</table>
ACME Technical Accomplishments:

- Contour crafted martian simulant concrete wall segment constructed.
- Hypervelocity impact testing of martian simulant concrete.
- Demonstration of an delivery/size sorting prototype system.
- Demonstration of remote site preparation in a planetary analog location.

Technical Challenges:

- Not all concrete mixtures can be extruded, and using basaltic aggregate is non-standard. Mixtures were experimentally modified to find an extrudable (3D printable) simulant-bearing concrete.
- Designing paver molds to accommodate the thermal properties of simulant (which tends to shrink when cooled), as well as identifying the proper sintering temperature profile.
- Tele-operated robotic emplacement of inter-locking pavers; various concepts have been traded to select the best design for constructing the Vertical Takeoff/Vertical Landing pad.
ACME Plans for FY2016

Plans for FY16

- Sub-scale curved wall additive construction at lab location using regolith simulant materials (11/23/15)
- Construction of Vertical Takeoff-Vertical Landing (VTVL) pad at PISCES location (12/31/15)
- Feedstock processing/transport hardware demonstration (3/31/16)
- Binder storage and mixing hardware demonstration (4/30/16)
- Pallet design & fabrication (4/30/16)
- Zero launch mass construction material print head demonstration (6/30/16)
- Testing of VTVL pad (7/31/16)

Threats

- None currently identified.
ACME Year End Review
Martian Concrete Straight Wall Segment

- Construction of a straight wall segment using martian simulant concrete. (completed 9/25/15)
National Center for Advanced Manufacturing (NCAM)
NCAM seeks to create partnerships to solve technology-based problems – ranging from activities with one or more companies to solutions to national grand challenge problems. Specifically, to create a public/private partnership in which the resources of NCAM and MAF (and beyond) are integrated with the broader capabilities of industry and research organizations to solve problems that are important to align with NASA missions and the U.S. manufacturing base. Public/private partnership – Cooperative Agreement between NASA, the State of Louisiana, Louisiana State University. Located at the Michoud Assembly Facility, New Orleans, LA. Led by Louisiana Center for Manufacturing Sciences.

<table>
<thead>
<tr>
<th>Integration with other projects/programs and partnerships</th>
<th>Technology Infusion Plan:</th>
</tr>
</thead>
<tbody>
<tr>
<td>• STMD, HEOMD, other Centers</td>
<td>• PC</td>
</tr>
<tr>
<td>• Industry, Academia</td>
<td>• Potential customer infusion (TDM, HEOMD, SMD, OGA, Industry)</td>
</tr>
<tr>
<td>• OGA's (e.g., DOD, DOE, DOC, USDA, NASA, NSF)</td>
<td>• Leverage</td>
</tr>
<tr>
<td>• Public/private partnership – Cooperative Agreement between NASA, the State of Louisiana, Louisiana State University. Located at the Michoud Assembly Facility, New Orleans, LA. Led by Louisiana Center for Manufacturing Sciences.</td>
<td>• Research and Innovation Ecosystem - Foster an integrated framework of technology partners – Government, Industry, Academia</td>
</tr>
<tr>
<td></td>
<td>• Focus areas: composites, metals joining, digital manufacturing, robotics and automation</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Key Personnel:</th>
<th>Key Facts:</th>
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</thead>
<tbody>
<tr>
<td>Program Element Manager:</td>
<td>GCD Theme: Lightweight Materials and Advanced Manufacturing</td>
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<tr>
<td>Project Manager: John Vickers</td>
<td>Execution Status: Thematic Plan</td>
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<td>Lead Center: MSFC</td>
<td>Technology Start Date: N/A</td>
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<tr>
<td>Supporting Centers: N/A</td>
<td>Technology End Date: N/A</td>
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<tr>
<td>NASA NPR: 7120.8</td>
<td>Technology TRL Start: 3</td>
</tr>
<tr>
<td>Guided or Competed: Guided</td>
<td>Technology TRL End: 6</td>
</tr>
<tr>
<td>Type of Technology: Push and Pull</td>
<td>Technology Current TRL: N/A</td>
</tr>
<tr>
<td></td>
<td>• Technology Lifecycle Phase: N/A</td>
</tr>
</tbody>
</table>
White House Fact Sheet October 27, 2014: President Obama Announces New Actions to Further Strengthen U.S. Manufacturing

“NASA is expanding its efforts to engage industry and academia on advanced manufacturing topics central to the nation’s space mission through its National Center of Advanced Manufacturing…”

The NASA National Center for Advanced Manufacturing (NCAM)

- Public/private partnership – NASA, the State of Louisiana, Louisiana State University. Located at the Michoud Assembly Facility, New Orleans, LA. Led by Louisiana Center for Manufacturing Sciences.
- April 1, STMD EPMC: National Center for Advanced Manufacturing (NCAM)
- May 6-7 - Technical Interchange Meeting in composites materials and manufacturing technologies for space applications in New Orleans.
- May 8 - LCMS was selected by NIST for Advanced Manufacturing Technology (AMTech) award valued at $500,000.
- June 16 - NASA, Louisiana Economic Development (LED) and university leaders celebrated the renewal of their partnership in the National Center for Advanced Manufacturing during a signing ceremony in New Orleans.
- August 3 – LSU/NCAM awarded $20 Million NSF grant to form Louisiana Advanced Manufacturing Consortium
- NCAM FSW class - See the video at youtube https://www.youtube.com/watch?v=0YkvdE1Ae8o
## Project Summary Performance

<table>
<thead>
<tr>
<th>Project</th>
<th>Summary Performance</th>
<th>Rationale</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Technical</td>
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<td>Quarter 4</td>
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</tbody>
</table>

### Significant Technical Challenges

- **LCUSP**
  - Technical challenges of material process development for EBF3 In625 on GRCop.

- **MGI**
  - Close coordination between work at centers and needs of SLS Project is required and has presented a challenge.
  - Lack of existing material properties and process parameters from SLS Project.
Back Up Charts

<These charts feed Quarterly Reporting. All charts are required.>
### PY 2015 Non-Labor Financial Status

<table>
<thead>
<tr>
<th></th>
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<th>NOV</th>
<th>DEC</th>
<th>JAN</th>
<th>FEB</th>
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### YTD Status

<table>
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<th>YTD Status</th>
<th>Explanation required for YTD Variance in excess of 5% from PM Forecast (shaded red)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phasing</td>
<td>The obligations are ahead of plan due to NCAM funds obligating prior to the end of the fiscal year and ahead of plan.</td>
</tr>
<tr>
<td>Forecast*</td>
<td>The costs are behind plan for the year due to the delays in the LCSSP Hot Fire Test and the obligations not occurring as soon as initially anticipated.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>% of Cost</th>
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</table>

* Forecast value is a snapshot of the Forecast from the previous reporting period

**AMT is 47% Costed and 91% Obligated for FY2015**
**PY 2015 Workforce Status**

### Resources: Total Project Workforce

**FTEs/WYEs**

**Incremental 2013**

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</table>

**YTD Status**

- **Phasing**
  - **2013 FTE:** 20.2
  - **2014 FTE:** 20.2
  - **Variance:** (0.5)

- **Phasing**
  - **3.6**

- **Forecast**
  - **3.0**

**Explanation required for YTD Variance in excess of 5% from PM Forecast (shaded red)**

- The FTEs are slightly behind plan due to ACME starting off the year slow due to delays with interagency agreement.

- The WYE are behind plan for the year due to the delays in the LCISPY Hot Fire test.

* Forecast value is a snapshot of the Forecast from the previous reporting period
• Over-Guideline Requests

• Leverage FTE support from STMD and SLS
  • FTE requests below reflect additional FTE needed for each task

• Post-sounding rocket flight and ground test data analysis
  • 0.2 FTE and $30K procurement
  • Required due to sounding rocket flight being delayed to October 7.
  • Decision needed by October 30, 2015

• Support for maximizing stiffener height
  • 0.2 FTE and $20K procurement
  • Partnership with forming vendor to modify existing sounding rocket mandrel and produce scaled-up cylinders with taller stiffeners.
  • Decision needed by December 31, 2015

• Support for scale-up of ISC process to 3 meters and develop technology infusion plan
  • 0.5 FTE and $650K procurement
  • Have a confirmed opportunity to advance the ISC process to launch vehicle scale and have firm commitments from ESA and DLR for continued partnership. Matching NASA funding required for continued partnership.
  • Decision needed by December 31, 2015
• Over-Guideline Requests
  • Partner with JPL and Caterpillar for a mobility system for the nozzle.
    • Like a robot arm with awesome stability/accuracy software.
    • Mounted on a CAT system.
  • Team developing proposal and expect to submit around December 2015.
ADVANCED MANUFACTURING TECHNOLOGY
Risk Summary

<table>
<thead>
<tr>
<th>ID</th>
<th>Trend</th>
<th>Approach/Affinity</th>
<th>Risk Title</th>
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<tbody>
<tr>
<td>LC1</td>
<td>↓</td>
<td>M/T</td>
<td>EBF3 weld technology</td>
</tr>
<tr>
<td>NN1</td>
<td>→</td>
<td>M/T</td>
<td>First flight of near net shape (NNS) sounding rocket (SR) part</td>
</tr>
<tr>
<td>MG1</td>
<td>→</td>
<td>M/T</td>
<td>In-situ monitoring system setup and verification</td>
</tr>
<tr>
<td>MG2</td>
<td>→</td>
<td>M/T</td>
<td>Heat input model from physics-based model</td>
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<tr>
<td>MG4</td>
<td>→</td>
<td>M/T</td>
<td>Material properties</td>
</tr>
</tbody>
</table>

Criticality

- **High**
- **Med**
- **Low**

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**

*Updated 10/7/15*
Advanced Near Net Shape Technology
Risk Summary

Updated 9/15/15

Current Risk Status

Risks
1. First flight of near net shape (NNS) sounding rocket (SR) part
2. Low fabrication schedule margin
3. NNS SR Part Specifications

<table>
<thead>
<tr>
<th>Risk ID</th>
<th>Trend</th>
<th>Affinity</th>
<th>Approach</th>
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<td>T</td>
<td>M</td>
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<tr>
<td>2</td>
<td>⬇️</td>
<td>Sc</td>
<td>M</td>
</tr>
<tr>
<td>3</td>
<td>⬇️</td>
<td>T</td>
<td>M</td>
</tr>
</tbody>
</table>

Consequence

*Consequence to sounding rocket flight
**Consequence to ISC process development

Criticality

- **High**
- **Med**
- **Low**

L x C Trend

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

Approach

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

Affinity: T-Tech, C-Cost, Sc-Schedule, Sa-Safety
### Risk Statement:

Given that the near net shape (NNS) part being fabricated for the sounding rocket (SR) using the Integrally Stiffened Cylinder (ISC) manufacturing process has not flown under the SR program, there is increased risk of the skin structurally failing in flight.

### Context

#### Status

Completed structural analysis using flight loads specific to the location of the ISC part on the sounding rocket and results indicate a very high margin of safety.

**Bend test of an identical part manufactured using the ISC process confirmed strain levels below 10% of material yield at maximum anticipated flight loads, confirming a large margin of safety.**

**Bend testing of the complete payload stack, with flight cylinder integrated, confirmed deflections within anticipated tolerances at maximum anticipated flight loads.**

Risk is at minimum achievable through mitigation approaches.

### Mitigation Steps

<table>
<thead>
<tr>
<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>
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</thead>
<tbody>
<tr>
<td>A structural analysis of the sounding rocket part will be conducted based on estimated flight loads and anticipated material properties.</td>
<td></td>
<td>4/17/15</td>
<td></td>
<td>4/30/15</td>
<td>1x5</td>
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<tr>
<td>An identical part manufactured using the ISC process will be subjected to bend testing prior to payload integration to characterize strength.</td>
<td></td>
<td></td>
<td></td>
<td>9/9/15</td>
<td>1x5</td>
</tr>
<tr>
<td>The flight part will be subjected to integration and testing, including bend testing, in the payload flight configuration.</td>
<td></td>
<td></td>
<td></td>
<td>9/15/15</td>
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<tr>
<td>A conventionally manufactured part will be available for payload integration if the test results on the NNS part are not satisfactory.</td>
<td></td>
<td></td>
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<td>8/17/15</td>
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</table>
**Risk Statement:** Given that fabrication of this sounding rocket part involves developing new processing parameters for longer cylinder lengths, the ISC process development may prove more difficult than expected, thereby causing schedule impact on delivery of the sounding rocket part. On-time delivery is also subject to material availability and international shipping regulations.

**Context**

**Status**

Aluminum 6061 material delivered to vendor on 4/27/2015. Fabricated parts delivered to Wallops Flight Facility on June 12. Risk can be closed.

**Mitigation Steps**

<table>
<thead>
<tr>
<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>
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<tr>
<td>Perform an expanded search for suitable aluminum alloy 6061 product forms, both domestic and international.</td>
<td></td>
<td>3/1/15</td>
<td>3/30/15</td>
<td>2x4</td>
<td></td>
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<tr>
<td>Research international shipping regulations to expedite material delivery to forming vendor and final part to Wallops Flight Facility.</td>
<td></td>
<td>3/1/15</td>
<td></td>
<td>2x4</td>
<td></td>
</tr>
<tr>
<td>Investigate reducing the forming temperature and preheat time to reduce the total time for part fabrication.</td>
<td></td>
<td>5/7/15</td>
<td>5/22/15</td>
<td>1x4</td>
<td></td>
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A conventionally manufactured part will be available for payload integration if the NNS is not delivered on schedule.

CLOSED
Risk Statement:  Approach:  Mitigate

Given that the NNS SR part is the first of this size and geometry to be fabricated using the ISC process there is increased risk that the part cannot be successfully fabricated. Risk is primarily associated with forming a part of larger diameter and length than any prior parts. There is also recognized risk that the part may distort during post-fabrication heat treatment beyond what can be corrected during final machining and that the part will not have mechanical properties at least equivalent to the conventionally manufactured part.

Context

Status

Fabricated cylinders distorted slightly during heat treatment but this can be accommodated during machining of the sounding rocket part.

Mechanical property tests of subscale 6061 cylinders indicated values comparable to handbook properties for other 6061 wrought products.

Mechanical property tests on a sounding rocket scale cylinder indicate excellent property uniformity with location and orientation and that values are comparable to handbook properties for 6061 wrought products.

Risk can be closed.

<table>
<thead>
<tr>
<th>Risk ID #</th>
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<td>Criticality</td>
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<tr>
<td>Open Date</td>
<td>05/05/2015</td>
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Mitigation Steps

Design SR part to capitalize on prior experience with aluminum 6061 and geometry (wall thickness; stiffener spacing and size) to increase probability of success.

Fabricate the ISC part with sufficient wall thickness to correct for post-fabrication distortion.

Perform preliminary mechanical property tests on subscale 6061 stiffened cylinders fabricated using the ISC process.

A conventionally manufactured part will be available for payload integration if the NNS is not delivered on schedule.

Perform mechanical property tests on a sounding rocket scale 6061 stiffened cylinder fabricated using the ISC process.

CLOSED, pending Project Office concurrence.
Low Cost Upper Stage-Class Propulsion Risk Summary

Current Risk Status

Consequence

Likelihood

Initial Risk Positions

Risk Positions after Planned Mitigations

1 - EBF3 weld technology of Inconel 625 on GRCop-84
2 - Chamber parts joint and potential leakage (CLOSED)
3 - GRCop process development difficulty (CLOSED)
4 - GRCop blockage of coolant passages (CLOSED)
5 - Coolant passages not adequately cooling chamber
6 - GRCop powder single vendor (CLOSED)
7 - EBF3 System maintenance issues could arise

Updated 9/10/15
**Risk Statement:** Given that this project involves developing new processing parameters in an effort to deposit a Ni-alloy onto the GRCop liner, there are risks associated with deposition of this jacket and with the modeling of the transition region thereby with the possibility that the combined jacket/liner part does not meet the structural or geometric requirements. The result can impact schedule and technical and additional steps will be need to be taken to allow this application.

**Context:** EBF3 application of Inconel on other material process has been used before, but the EBF3 application of Inconel on GRCop-84 has never been done previously.

**Status:** In July & August 2015, extensive application trials were accomplished on 3.5” Cu Tubes and on a 3” tall SLM GRCop-84 chamber section with coolant channels. Currently, the trial samples are at GRC for sectioning, inspection, and analysis. Experiments on available materials have advanced the EBF3 application of the Inconel 625 and the EBF3 operators are focused on the task.

**Mitigation Steps**

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
<th>Dollars to Implement</th>
<th>Trigger/Start Date</th>
<th>Schedule UID</th>
<th>Completion Date</th>
<th>Resulting L/C</th>
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</thead>
<tbody>
<tr>
<td>1.</td>
<td>EBF3 deposition parameters are being developed that do not exhibit hot cracking by modifying the total thermal input (limiting the temperature of the Cu will lower the expansion due to CTE) when depositing In625 on to a pure Cu flat plate.</td>
<td></td>
<td>12/2014</td>
<td>3/4</td>
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<tr>
<td>2.</td>
<td>Experiments are planned on a C18150 Chamber Simulator to assess the effect of higher strength and hoop stresses in a cylindrical geometry</td>
<td></td>
<td>7/2015</td>
<td>skipped</td>
<td>2/4</td>
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<tr>
<td>3.</td>
<td>Prior to EBF3 deposition of the In625 structural jacket on the actual test article, experiments are planned on GRCop subcomponent sections built with internal passages to measure the impact of EBF3 deposition</td>
<td></td>
<td>7/2015</td>
<td>9/2015</td>
<td>2/3</td>
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<tr>
<td>4.</td>
<td>Metallurgical analyses are planned to examine the microstructures and precipitate morphologies at the interface between the GRCop and In625</td>
<td></td>
<td>On going as samples are made</td>
<td>12/2015</td>
<td>2/2</td>
<td></td>
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ACME Risk Assessment

**Risk ID** | **Risk Definition** | **Approach** | **Est. Closure Date**
--- | --- | --- | ---
1 | Procurement risk associated with ACME nozzles | Mitigate | 7/31/15 9/30/15
2 | Insufficient procurement dollars for raw materials / hardware procurements | Closed | 9/30/15 7/20/15
3 | Unnamed personnel needs | Closed | 9/30/15 7/20/15
4 | Insufficient time allowed for major procurements | Closed | 9/30/15 7/20/15
5 | Presence of GCD Procurement Dollars Results in Reduced USACE Funding in FY16 and FY17 | Closed | 9/30/15 2/8/15
6 | Concrete composition research and development for straight wall | Accept | 9/30/15

**CONSEQUENCES**

<table>
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<th>Risk ID</th>
<th>Total</th>
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<th>30 - 60 Days</th>
<th>60 - 90 Days</th>
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<td>Closed</td>
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</table>

5 X 5 is per System Engineering Handbook NASA/SP-2007-6105
**Risk Statement**: Given that Contour Crafting Incorporated is a relatively new company run by a single person (who owns the patents on the technology), there is a possibility they do not have the personnel or ownership of the licenses to deliver the nozzle on schedule resulting in delays in the assembly and testing of ACME 2.

**Approach**: Mitigate

**Context**: In order to make equipment available to the USACE and continue to mature additive construction technology on schedule, a nozzle must be procured early in FY15.

**Status**: 09/22/15 Agreement signed. Contract expected the week of 9/28/15. Trend is now down, changed likelihood from 3 to 1.

09/14/15, Dr. Khoshnevis informed us the licensing agreement will be signed at 10AM on 9/22/15.

07/20/15 added “or ownership of the licenses” and “nozzle” to risk statement.

**Additional statuses available in notes section of this slide.**

<table>
<thead>
<tr>
<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>1 Line up procurement through an existing NASA contract</td>
<td>Potentially 12% of quote</td>
<td>1/8/15</td>
<td>N/A</td>
<td>7/31/15-9/30/15</td>
<td>1/1</td>
</tr>
<tr>
<td>2 Procurement can be delayed, but the time allocated to learn from the first NASA/ACME nozzle prior to procurement of the first ACES nozzle will be affected.</td>
<td>none</td>
<td>10/8/15</td>
<td>N/A</td>
<td>1/1/16</td>
<td>1/1</td>
</tr>
</tbody>
</table>
### Key and Controlled Milestones

<table>
<thead>
<tr>
<th>FY15 Key and Controlled Milestones</th>
<th>Baseline Completion Date</th>
<th>Actual Completion Date</th>
<th>Estimated Completion Date</th>
<th>Variance Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FY15 Q1 (Oct 1 through Dec 31)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MGI Prediction of Deposit Shape (layer height and width) 3D thermal history, residual stress, and Distortion</td>
<td>12/30/14</td>
<td>12/30/14</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LCUS Begin Mechanical Testing</td>
<td>12/31/14</td>
<td>12/31/14</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>FY15 Q2 (Jan 1 through March 31)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ANNST Mandrel Design TIM</td>
<td>1/15/15</td>
<td>1/28/15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LCUS Nozzle Design Complete</td>
<td>2/27/15</td>
<td>2/27/15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LCUS Begin GRCop Powder Procurement #2</td>
<td>1/30/15</td>
<td>4/30/15</td>
<td>Scheduled for 6 weeks, however Procurement was actually 6 months</td>
<td></td>
</tr>
<tr>
<td><strong>FY15 Q3 (Apr 1 through June 30)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ANNST Develop plan for fabrication of sounding rocket component</td>
<td>6/30/15</td>
<td>3/30/15</td>
<td>Develop fabrication, testing, and analysis plans for sounding Rocket applications for an ISC barrel - Completed early in order to reduce schedule risk</td>
<td></td>
</tr>
<tr>
<td>MGI Deliver Component Design Tool to Demonstrate Improved Component Reliability for Reduced Mass</td>
<td>6/30/15</td>
<td>8/31/15</td>
<td>Requested 2 month delay due to difficulty with measurement equipment</td>
<td></td>
</tr>
<tr>
<td>LCUS Application of AM Structural Jacket &amp; Manifolds Complete</td>
<td>5/29/15</td>
<td>10/15/15</td>
<td>The test completion date slipped due to delays in manufacturing complete chamber</td>
<td></td>
</tr>
<tr>
<td>LCUS Begin Hot Fire Test - Chamber</td>
<td>6/30/15</td>
<td>1/8/16</td>
<td>The test completion date slipped due to delays in manufacturing complete chamber</td>
<td></td>
</tr>
<tr>
<td>LCUS Manufacture of Selective Laser Melting (SLM) Copper Chamber Complete</td>
<td>4/30/15</td>
<td>4/30/15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ACME Sub-scale Straight Wall Additive Construction Demo at Lab Location</td>
<td>4/30/15</td>
<td>9/25/15</td>
<td>Milestone slipped due to difficulties extruding Martian simulant-based concretes</td>
<td></td>
</tr>
</tbody>
</table>

**NOTE: Bold font represents Control Milestone**
## Key and Controlled Milestones

<table>
<thead>
<tr>
<th>FY15 Key and Controlled Milestones</th>
<th>Baseline Completion Date</th>
<th>Actual Completion Date</th>
<th>Estimated Completion Date</th>
<th>Variance Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FY15 Q4 (Jul 1 through Sep 30)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ANNST</td>
<td>Design and Fabricate Sounding Rocket Scale Mandrel</td>
<td>9/30/15</td>
<td>5/31/15</td>
<td></td>
</tr>
<tr>
<td>ANNST</td>
<td>Structural Analysis of Sounding Rocket Component</td>
<td>9/18/15</td>
<td>8/24/15</td>
<td>Structural analysis shows safety factors above 5 for sounding rocket component at anticipated flight loads; indicates a very high margin of safety.</td>
</tr>
<tr>
<td>ANNST</td>
<td>Sounding rocket flight of near net shape component fabricated using the ISC Process.</td>
<td>9/30/15</td>
<td>10/30/15</td>
<td>Sounding rocket flight re-scheduled due to payload integration delays unrelated to the ANNST NNS component.</td>
</tr>
<tr>
<td>MGI</td>
<td>Develop Data Schema for Process Parameters of SLM Development Part.</td>
<td>9/30/15</td>
<td>9/30/15</td>
<td></td>
</tr>
<tr>
<td>LCUS</td>
<td>Mechanical Testing Complete - IN625/GRCop Bonded Samples</td>
<td>7/31/15</td>
<td>8/12/15</td>
<td>Mico-Structural Analysis Complete, Mechanical Test Coupons planned to be built and tested in 2nd Quarter of 2016 for IN625/GRCop Bonded Samples. Slippage resulted from lack of GRCop availability and EBF3 equipment problems.</td>
</tr>
<tr>
<td>LCUS</td>
<td>Complete Chamber Hot Fire Test</td>
<td>8/28/15</td>
<td>3/4/16</td>
<td>The test completion date slipped due to delays in manufacturing complete chamber.</td>
</tr>
<tr>
<td>LCUS</td>
<td>Chamber Delivery to Test</td>
<td>8/31/15</td>
<td>2/3/16</td>
<td>The test completion date slipped due to delays in manufacturing complete chamber.</td>
</tr>
<tr>
<td>ACME</td>
<td>Regolith/Blender combination layered structure subjected to Hyper-Velocity Micro-meteorite/Ballistic Impact Testing – demonstration</td>
<td>8/31/15</td>
<td>8/31/15</td>
<td></td>
</tr>
<tr>
<td>ACME</td>
<td>Field Demonstration of Rover-mounted Implement in Situ Field Demonstration (PISCES)</td>
<td>9/30/15</td>
<td>9/30/15</td>
<td></td>
</tr>
<tr>
<td>ACME</td>
<td>Demonstration of Sub-scale Excavation/Size-sorting Regolith Stimulant Delivery System</td>
<td>8/31/15</td>
<td>9/28/15</td>
<td>Delay in arrival of the MIPR caused a slip in the milestone.</td>
</tr>
<tr>
<td>ANNST</td>
<td>Cost benefit Analysis</td>
<td>9/30/15</td>
<td>8/7/15</td>
<td>CBA shows 50% cost reduction and 7% mass reduction enabled by the ISC process</td>
</tr>
</tbody>
</table>

**NOTE:** Bold font represents Control Milestone
Milestone Completion and Burndown

Incomplete Milestones
- Sounding rocket flight of near net shape component fabricated using the ISC Process – ECD 10/30/15
- Application of AM Structural Jacket & Manifolds – ECD 10/15/15
- Begin Hot Fire Test – Chamber - ECD 1/6/16
- Complete Chamber Hot Fire Test – ECD 3/4/16
- Manufacture of Selective Laser Melting (SLM) Copper Chamber Complete – ECD 2/3/16

<table>
<thead>
<tr>
<th>Month</th>
<th>Number of Milestones</th>
</tr>
</thead>
<tbody>
<tr>
<td>October</td>
<td>22</td>
</tr>
<tr>
<td>November</td>
<td>22</td>
</tr>
<tr>
<td>December</td>
<td>20</td>
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<tr>
<td>January</td>
<td>18</td>
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<td>February</td>
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<td>March</td>
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<td>April</td>
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<tr>
<td>May</td>
<td>14</td>
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<td>June</td>
<td>11</td>
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<tr>
<td>July</td>
<td>10</td>
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<tr>
<td>August</td>
<td>6</td>
</tr>
<tr>
<td>September</td>
<td>0</td>
</tr>
</tbody>
</table>
Technology Transfer or Infusion

- Technology
- New Technology Request
- Invention Disclosure
- Patents Pending
- Patents
- Licensing Agreements
- Space Act Agreements
- Comments

**Use Excel file sent with the template and located on NX**

<table>
<thead>
<tr>
<th>Technology</th>
<th>New Technology Request</th>
<th>Invention Disclosure</th>
<th>Patents Pending</th>
<th>Patents</th>
<th>Licensing Agreements</th>
<th>Space Act Agreements</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANNST</td>
<td></td>
<td></td>
<td>LAR-18600-1, December 18, 2014; Patent pending</td>
<td></td>
<td></td>
<td></td>
<td>New Technology Report, &quot;In-situ Selective Reinforcement of Near Net Shape Formed Structures&quot;.</td>
</tr>
</tbody>
</table>
EPO: Activities, Conferences, and Students

• Conferences, Technical Publications, Students, and EPO Activities

Use Excel file sent with the template and located on NX
<table>
<thead>
<tr>
<th>Date</th>
<th>EPO Activity (Quarter 4)</th>
<th>Representative</th>
</tr>
</thead>
<tbody>
<tr>
<td>9/3/2015</td>
<td>Optical micrograph from analysis of Integrally Stiffened Cylinder selected for publication in the 2016 Buehler calendar. (image below)</td>
<td>ANNST</td>
</tr>
<tr>
<td>8/24-28/2015</td>
<td>Keck Institute Workshop on 3D Additive Construction for Space using In-Situ Resources</td>
<td>Rob Mueller, Corky Clinton, Jennifer Edmunson, Mike Fiske, Van Townsend</td>
</tr>
<tr>
<td>9/18/2015</td>
<td>Media tour for the release of “The Martian” at MSFC</td>
<td>Jennifer Edmunson</td>
</tr>
<tr>
<td>ongoing</td>
<td>3D Printed Habitat Centennial Challenges Rules Committee</td>
<td>Jennifer Edmunson, Rob Mueller</td>
</tr>
</tbody>
</table>
## EPO: Conferences

<table>
<thead>
<tr>
<th>Project Name</th>
<th>Type</th>
<th>Conference, Journal, Symposium, NASA Technology Report</th>
<th>Publication Title</th>
<th>Author(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMT: LCUSP, ANNST, ACME</td>
<td>Exhibits</td>
<td>AIAA SciTech Conference</td>
<td>Exhibited materials as part of the STMD booth</td>
<td></td>
</tr>
<tr>
<td>AMT: ANNST</td>
<td>Conference attendance, presentation</td>
<td>Mission Initiation Conference</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AMT: MGI</td>
<td>Technical Publication</td>
<td>CIMJSEA (Center for Integrative Materials Joining Science for Energy Applications) annual meeting in Columbus, OH</td>
<td>&quot;Computational Process Modeling for Additive Manufacturing&quot;</td>
<td>Stacey Bagg/MSFC in collaboration with Dr. Wei Zhang/The Ohio State University</td>
</tr>
<tr>
<td>AMT: MGI</td>
<td>paper</td>
<td>Neutron Characterization of Additively Manufactured Components Workshop at Oak Ridge National Lab.</td>
<td></td>
<td>Craig Brice</td>
</tr>
<tr>
<td>AMT: ACME</td>
<td>Conference attendance</td>
<td>Stacking Layers II Symposium (Tallahassee, FL)</td>
<td></td>
<td>Rob Mueller</td>
</tr>
<tr>
<td>AMT: MGI</td>
<td>Conference attendance</td>
<td>Minerals, Metals and Materials Society (Orlando, FL)</td>
<td></td>
<td>Chantal Sudbrack (GRC) and Jake Hochhalter (LaRC)</td>
</tr>
<tr>
<td>AMT</td>
<td>Conference attendance</td>
<td>Composites Materials and Manufacturing Technologies for Space Applications TIM in New Orleans</td>
<td></td>
<td>John Vickers, John Fikes</td>
</tr>
<tr>
<td>AMT: MGI</td>
<td>Technical Publication</td>
<td>3rd World Congress on Integrated Computational Materials Engineering (ICME 2015), Colorado Springs, CO.</td>
<td>Multiscale Modeling of Thermal Protection Materials I: Atomistic Modeling of Constituent Properties</td>
<td>John Lawson (ARC); Joshua Monk (ARC); Charles Bauschlicher (ARC); Steven Arnold (GRC); Pappu Murthy (GRC); Brett Bednarcyk (GRC)</td>
</tr>
<tr>
<td>AMT: MGI</td>
<td>Technical Publication</td>
<td>3rd World Congress on Integrated Computational Materials Engineering (ICME 2015), Colorado Springs, CO.</td>
<td>Multiscale Modeling of Thermal Protection Materials II: Micromechanical Modeling of Composite Performance</td>
<td>Steven Arnold (GRC); Pappu Murthy (GRC); Brett Bednarcyk (ARC); John Lawson (ARC); Charles Bauschlicher (ARC); Joshua Monk (ARC)</td>
</tr>
<tr>
<td>AMT: MGI</td>
<td>Invited talk</td>
<td>Advanced Qualification of AM Materials Workshop, sponsored by LLNL</td>
<td></td>
<td>C.Sudbrack/GRC</td>
</tr>
<tr>
<td>AMT: ACME</td>
<td>Technical Publication</td>
<td>AIAA SPACE 2015</td>
<td>On The Development of Additive Construction Technologies for Application to Development of Lunar/Martian Surface Structures Using In-Situ Materials</td>
<td>Mike Fiske</td>
</tr>
<tr>
<td>AMT: ACME</td>
<td>Technical Publication</td>
<td>Composites and Advanced Materials Expo, Dallas TX</td>
<td>Development of Additive Construction Technologies for Application to Development of Lunar/Martian Surface Structures Using In-Situ Materials</td>
<td>Erick Ordonez</td>
</tr>
<tr>
<td>AMT: MGI</td>
<td>Conference attendance</td>
<td>Materials Science &amp; Technology (MS&amp;T) 2015, Columbus, OH</td>
<td>Poster</td>
<td>Chantal Sudbrack/GRC</td>
</tr>
</tbody>
</table>
## EPO: Students

<table>
<thead>
<tr>
<th>Student Name</th>
<th>Institution</th>
<th>Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cecilia Stoner</td>
<td>Princeton University</td>
<td>Junior</td>
</tr>
<tr>
<td>Wyatt Witzen</td>
<td>North Carolina State University at Raleigh</td>
<td>Senior</td>
</tr>
<tr>
<td>Peyton Young</td>
<td>University of Virginia</td>
<td>Senior</td>
</tr>
<tr>
<td>Austin Hehir</td>
<td>Virginia Polytechnic Institute and State University</td>
<td>Freshman</td>
</tr>
<tr>
<td>Brian Katona</td>
<td>Kent State University</td>
<td>Masters</td>
</tr>
<tr>
<td>Samantha Frederick</td>
<td>Mississippi State</td>
<td>Graduate</td>
</tr>
</tbody>
</table>
Economic Development

- Vendor Name
- Contract Number
- What is being completed
- Where is the work being completed
- Type of Business
- Program Year Cost

Use Excel file sent with the template and located on NX
Publically Releasable Technology Charts

<These charts multiple GCD data requests and all charts are required. Please review questions on the next chart to ensure proper data control>

<Only update these charts if there have been changes since the STI review was completed>
Please answer the questions below:

<table>
<thead>
<tr>
<th>Question</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Was the data been reviewed by the NASA Center and approved for release?</td>
<td></td>
</tr>
<tr>
<td>- Science and Technical Information Review</td>
<td></td>
</tr>
<tr>
<td>Are the pictures of the people included NASA Civil Servants? If not, has permission been granted for use?</td>
<td></td>
</tr>
<tr>
<td>Are images included in the briefing? If so are these NASA images? If not, please provide reference for inclusion and to ensure that licensing agreements are in place. (See Chart 23)</td>
<td>ANNST – all pictures are NASA owned</td>
</tr>
<tr>
<td>Is a Space Act Agreement mentioned or included? If so, please ensure that this is approved for release.</td>
<td></td>
</tr>
</tbody>
</table>

If pictures are not confirmed, all will be removed from the following charts to ensure release.
PROBLEM / NEED BEING ADDRESSED

Innovative, low-cost manufacturing processes and products including: metallic processes, additive manufacturing, composites, and digital manufacturing

PROJECT DESCRIPTION/APPROACH

Develop advanced manufacturing technologies that enable the development of more capable and lower-cost space missions and launch vehicles.

- Identify strategic/critical technologies and manufacturing capabilities
- Mature "Game Changing" high impact technologies to address and close technology gaps
- Utilize and integrate computational and model-based technologies
- Implement projects across NASA centers with partnerships with other government agencies, industry and academia

STATUS QUO

- Widespread recognition of the problem
- Long and costly RDT&E and production
- Lack of integrated design and manufacturing
- Expensive and incremental manufacturing technology advancements

NEW INSIGHTS

- New innovative materials continually being developed and improved.
- Computer-based modeling improvements due to computational advancements.
- Improvements in the areas of sensing, automation, software, networking, physical sciences, etc.

QUANTITATIVE IMPACT

- Demonstrate 5X-10X reduction in cost and schedule.
- Address National needs manufacturing is the most important cause of economic growth – 70% of private sector R&D, over 90% of patents issued, and 60% of U.S. engineering and science jobs.

PROJECT GOAL

- Produce game changing or next generation manufacturing innovation and technology
- Create technologies that dramatically improve affordability, capability or reduce schedule
- Address the technology gaps in manufacturing capabilities in areas such as: composites, metals, additive manufacturing, inspection, model-based tools, environmental solutions
- Utilization of computational and model-based technologies that integrate the disciplines (i.e. materials, design, and manufacturing)
**Problem / Need Being Addressed**

Machined/welded construction for launch vehicles structures is expensive, heavy and risky.

**Project Description/Approach**

- Develop the Integrally Stiffened Cylinder (ISC) process for fabrication of launch vehicle structures
- Adapt proven technology from automotive steel to aerospace Al and Al-Li alloys
- Scale-up and optimize process for launch vehicle stiffened cryotank structure
- Conduct trade studies to optimize integrally-stiffened tank structure
- Demonstrate process by fabrication and testing of intermediate scale (0.5-2 meter diameter) barrel
- Validate process by fabrication and testing of large scale (2-5 meter diameter) barrel

**Status Quo**

- SOA is multi-piece welded construction of components machined from thick Al plate
- 90% material to waste
- High cost; labor intensive
- Welds are sites for defects, catastrophic failure

**New Insights**

- Sought manufacturing process to eliminate welds and efficiently use material
- Identified commercial automotive manufacturing process for transition to aerospace structures and materials

**Quintitative Impact**

- Eliminate longitudinal welds in cryogenic tank barrel; Shuttle External Tank has half a mile of welds
- Reduce weight by >30%
- Reduce cost by >40% by reduced touch labor, material scrap rate & NDE

**Project Goal**

- Efficient manufacturing methods for robust full-scale one-piece integrally-stiffened launch vehicle structures

**Revolutionizing Metals Forming - Low Risk, Big Payoff**
Development of new materials for aerospace applications is too costly and time intensive. Computational design of materials will enable accelerated insertion.

**PROJECT DESCRIPTION:**

Develop integrated computational / experimental / processing methodologies for accelerating discovery and insertion of materials to satisfy NASA’s unique mission demands.

- The challenges:
  - Validated design tools that incorporate materials properties, processing and design requirements
  - Materials process control to rapidly mature emerging manufacturing methods to industry ready
- Approach:
  - Physics-based modeling to guide material design e.g. matrix composition, crosslinking between CNTs, grain size and texture
  - Multiscale modeling influence of materials design on mechanical properties and durability
  - Process modeling to determine processing parameters required to produce as-designed material nano-/micro-structures and enable advanced manufacturing methods utilization
  - Utilize material data management to support robust material design methodology

**PROGRAM GOAL:**

- Cross-center effort including computational, experimental and processing expertise to develop emerging material systems including multifunctional materials.
- Define path for compressed materials maturation and insertion through multiscale modeling to reduce materials testing and shorten iterative cycle for materials optimization.
- Capability for materials “designers” to assess the trade-off between various material properties of interest and enable rapid prototyping.

**QUANTITATIVE IMPACT**

- Reduce time between discovery and technology insertion by >50%.
- Shorter maturation and insertion translates to lower costs, greater affordability and lower risk of failure.
- Computational materials design will reduce time and cost to certify new flight hardware (50% reduction in time and cost, long-term national goal; 25% reduction in time to certify, current NASA MGI goal).

**PROBLEM / NEED BEING ADDRESSED**

Current materials development based on empirical design approaches results in incremental material improvements and long maturation and insertion time. For example, carbon fibers were invented in 1958 yet significant use of carbon fiber composites in aerospace applications has required 50 years of development.

Existing material certification approach inhibits the utilization of new processing methodology.

**STATUS QUO**

- Physics-based models for the characterization of materials processing and structure-property relationships are maturing.
- Synergistic efforts in multiscale modeling, information management, experimental characterization and materials processing will accelerate design, development and sustainment of ultra-durable material systems.

**NEW INSIGHTS**

Computational material design is enabling to NASA’s aerospace needs.
**Low Cost Upper Stage-Class Propulsion (LCUSP) Penta**

**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

**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

2015 GCD 2nd Quarter Review
Additive Construction with 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)

- 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*

**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

**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

2015 GCD 2nd Quarter Review
Materials Genome Initiative
Technical Accomplishment:
Thermal Modeling of Additive Manufacturing

Milestone: Develop data schema for process parameters of SLM development part. Completed September 2015

Deliverable: Provide a detailed data schema highlighting the critical data parameters for collection for SLM processing and a proposed method to utilize this data for process improvements.

Problem: Selective laser manufacturing is a complex process, with many variables associated with the machine, processing parameters, initial material, and build geometry. To develop a certifiable process, accurate information must be stored and evaluated critically.

Objective: Develop a data schema for a complex data management system that can be used to track the process configuration and identify uncertainties and potential issues in the process.

Approach: NASA worked closely with the Materials Data Management Consortium to develop the data schema for an existing materials data management system specific for additive manufacturing.

Results: The proposed schema will be shared with the manufacturing team and MSFC and the MI Granta software will also be supplied.
If 3rd Party Images were utilized, please provide the details of which image and the details of the location of the image.

Found on the Penta chart for ACME
All images (with the exception of the two NASA images highlighted above) are courtesy of Dr. Behrokh Khoshnevis the University of Southern California.
• Hypervelocity impact testing (HVIT) of martian simulant concrete, White Sands NM 8/19/15, in collaboration with JSC HVIT team.

Martian simulant concrete was hypervelocity impact tested at White Sands on 8/19/15. An aluminum sphere of 1.99mm diameter struck the 25.4mm-thick concrete block at 6.83km/s. The crater was roughly 30mm in diameter, the maximum crater depth was measured at 10.3mm, and there was no damage or evidence of microcracking on the back side of the block.
• Regolith Size Sorting & Feed System for 3D Printing Feedstock (KSC Swamp Works, completed 9/28/15)

Emplacement of fines with a robot arm  
Size Sorting and Auger Feed
• Design and Fabrication of an in-situ sintered basalt inter-locking paver system for Vertical Takeoff, Vertical Landing (VTVL) pad to protect against rocket plume impingement and intrusion (KSC Swamp Works & PISCES, completed 9/30/15)
• Design and Fabrication of an Paver Deployment Mechanism (PDM) for tele-robotically laying inter-locking pavers to remotely construct a Vertical Takeoff, Vertical Landing (VTVL) pad. (KSC Swamp Works, completed 9/30/15)
CAD Model of a Planetary Surface

Basalt Fines shaped to form the Planetary Surface in the CAD model

20 meter diameter simulated planetary terrain area shown in a basalt quarry in Hilo, Hawaii
• Field demonstration of rover-mounted implement for site preparation. (PISCES, completed 9/30/15)
If 3rd Party Images were utilized, please provide the details of which image and the details of the location of the image.

These four images are courtesy of PISCES.
Tele-robotic Paver Deployment Mechanism

- Design and Fabrication of an Paver Deployment Mechanism (PDM) for tele-robotically laying inter-locking pavers to remotely construct a Vertical Takeoff, Vertical Landing (VTVL) pad. (KSC Swamp Works, completed 9/30/15)

Tele-Operation of PDM

Paver Deployment Mechanism (PDM) robotic arm assembly, with pavers stack, on a Rover Mockup