Additive Manufacturing Challenges With Parts That Fly In Space: Demo!

Zach Etier
Blaine Baker
9/18/2018

GLOBAL PRODUCT DATA INTEROPERABILITY
SUMMIT
2018

ELYSIUM Parker Aerospace NORTHROP GRUMMAN BOEING

Background Information

Zach Etier – Mechanical Engineer

Education

- B.S. Aerospace Engineering
- B.S. Mechanical Engineering
- Minor in Computer Science

Experience

- Lead AM for NGC:IS, Chandler
  - FDM
- 4 Years in Aerospace Industry

Blaine Baker – Mechanical Engineer

Education

- B.S. Mechanical Engineering

Experience

- Design for Additive Manufacturing
  - R&D, Tooling
- 6 Years in Aerospace Industry

Northrop Grumman Innovation Systems (NGIS) Summary

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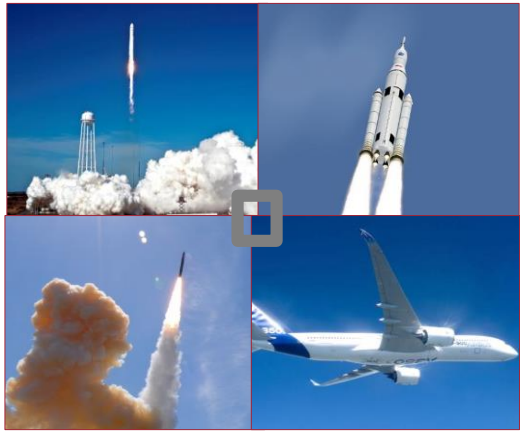


$5B in Revenue
13,000 Employees
3 Operating Groups in 20 States

Flight Systems Group

2017 Revenue ~$1.7 Billion

Workforce ~5,500 People

3 Divisions
- Launch Vehicles
- Propulsion Systems
- Aerospace Structures

Defense Systems Group

2017 Revenue ~$1.9 Billion

Workforce ~4,800 People

4 Divisions
- Missile Products
- Armament Systems
- Defense Electronics
- Small Caliber Systems

Space Systems Group

2017 Revenue ~$1.3 Billion

Workforce ~3,000 People

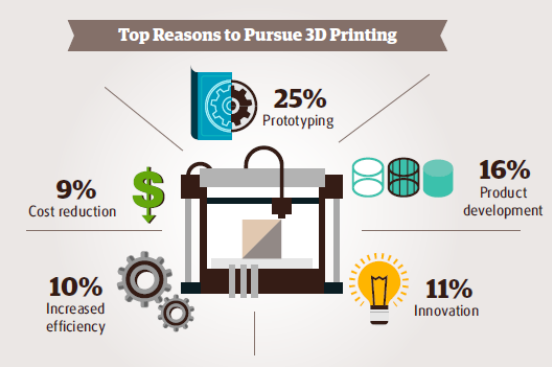
4 Divisions
- Satellite Systems
- Advanced Programs
- Space Components
- Technical Services

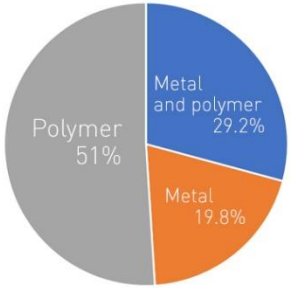
Current State of Additive Manufacturing

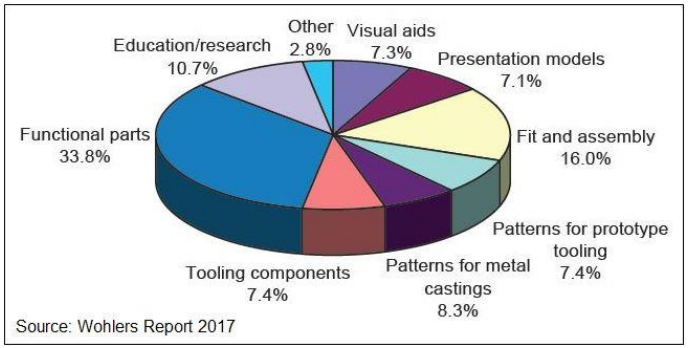
- Only ~34% of US based manufacturing executives have implemented AM

  (Boston Consulting Group)

- UPS reported that AM parts only represent 0.04% of the global market

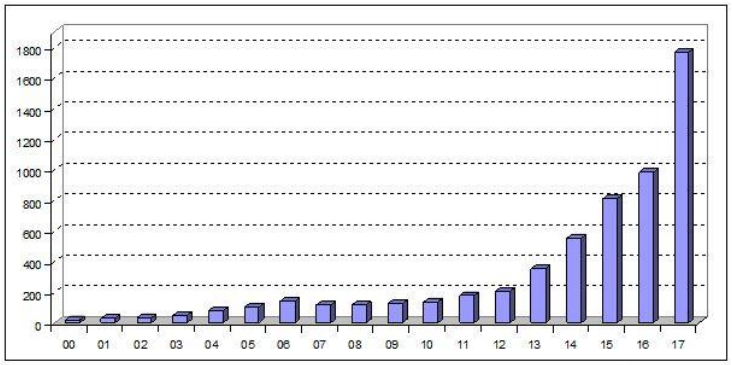






Current State of Additive Manufacturing

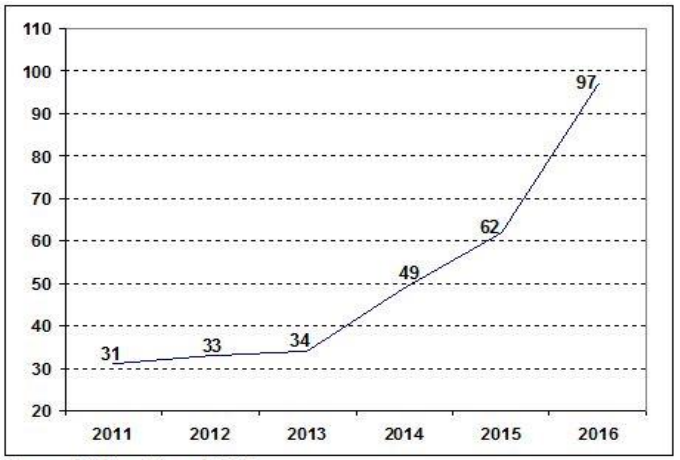
AM Systems Sold



Dramatic rise in metal AM system sales

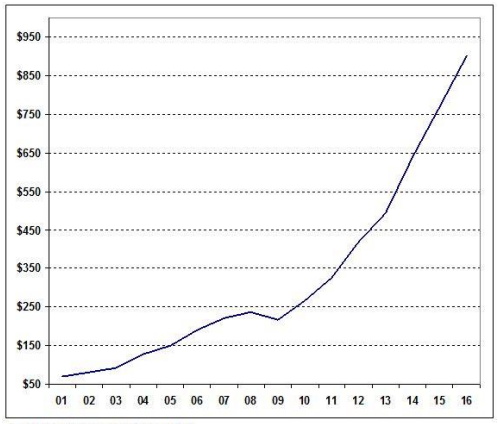
Source: Wohlers Report 2018

Total number of AM Manufactures



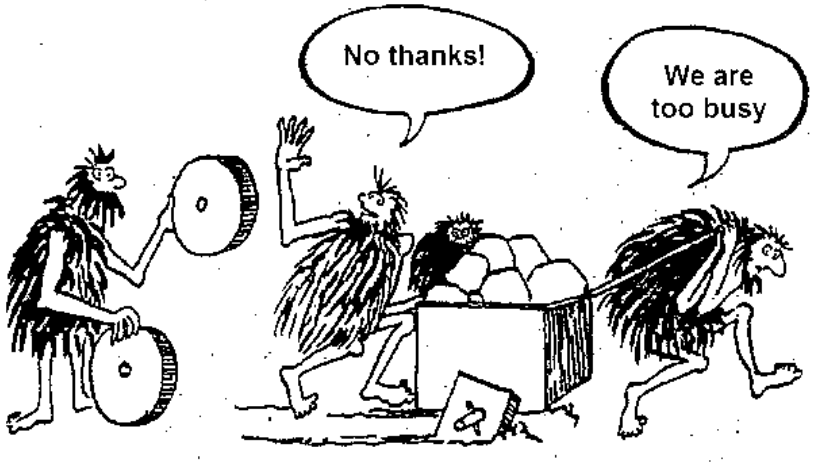
Source: Wohlers Report 2017

AM Material Sales



Source: Wohlers Report 2017

AM Challenges



AM Challenges

- **According to Forbes Technology Council top reasons for slow adoption**
  - **Financial**
    - **Initial Capital investment**
  - **Certification and Regulation**
    - **Consistent quality and reliability**
    - **Customization and individualization**
  - **Repeatability**
    - **Machine settings**
    - **Variability between similar machines**
  - **Skills Gap**
    - **Obtaining qualified workforce**
  - **Designing for AM**
    - **Engineers understanding of the AM capability is lagging**
      - Restrictive design – designing to the limitations of the machine (min feature size, overhang, supports, machine or process specific limitations)
      - Opportunistic design – designing to take advantage of AM (free design complexity, eliminate unneeded material, combination of parts, topology optimization)
    - **Lack of integrated software packages**
  - **Production Volume / Part Size limitation**

Overcoming the Challenges

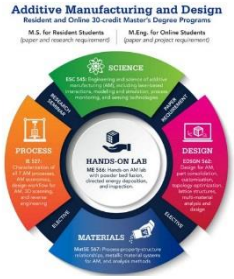
- **Financial**
  - **Pilot programs to measure ROI**
  - **Participate in beta testing**
  - **Use service bureaus to develop a business case**

- **Certification and Regulation**
  - **New standards from ISO and ASTM to be released soon**
  - **Develop in house certification programs**

- **Repeatability**
  - **Configuration management of AM machine files (stl, cmb, STEP, etc)**
  - **Routine material testing and inspection comparison to a qualified part**
  - **ATP each part**

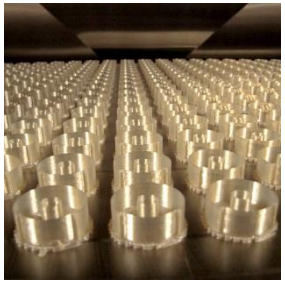
Overcoming the Challenges

- **Skills Gap**
  - **Master's degree programs being offered**
  - **Many engineering schools are beginning to offer AM course work**



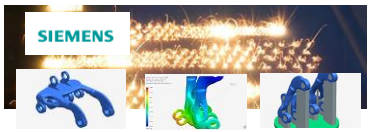
- **Designing for AM**
  - **Engineers understanding of the AM capability is lagging**
  - **Lack of integrated software packages**
  - **Integrated software packages are maturing**

- **Production Volume / Part Size limitation**
  - **AM manufactures are addressing production volume**



NGIS– Additive Manufacturing

- **Northrop Grumman Innovation Systems– Launch Vehicle Division AM involvement**
  - **Polymer AM flight parts flown on Antares vehicles since 2013 and have since flown on several other vehicles**
  - **Participated on alpha, beta, and early bird programs with Stratasys in developing new materials**
  - **Involved in internal and external user groups**
    - **Monthly internal AM meetings with the CTO**
    - **Siemens NX 11.2 AM Module team members**
  - **University research and senior capstone projects**
    - **Two AM Capstone project funded in 2017**
    - **Currently funding university research to improve FDM Isotropy values**
  - **Presented at 2017 AM seminars such as AMUG, SAMPE, Science in the Age of Experience, and CAMX**



NGIS– Additive Manufacturing

- **Participated in hands on workshops at Penn State**
  - **Employee enrolled in the new AM Masters Program**

PennState Applied Research Laboratory

- **Very active with STEM events, both local and national**
  - **Chandler Science Spectacular, Chandler AZ**
  - **NASA Day in the Park, Huntsville AL**

- **Current member of the AZ Tech Council and local manufacturing groups**
  - **Member of the Research Collaboration and AM Workforce Subcommittees**

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a place to connect and grow

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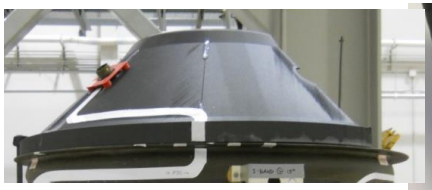
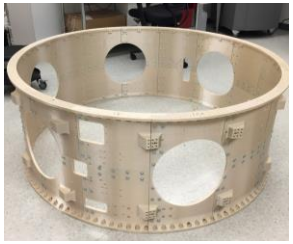
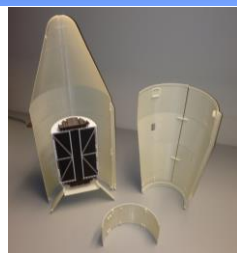
AMP Arizona Manufacturing Partnership

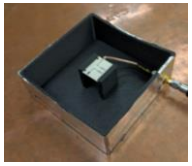
AM Embraced throughout the Division

- **From tooling to flight hardware, LVD produces thousand of parts each year**



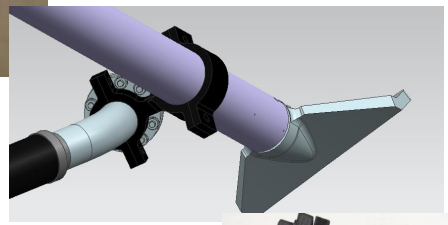




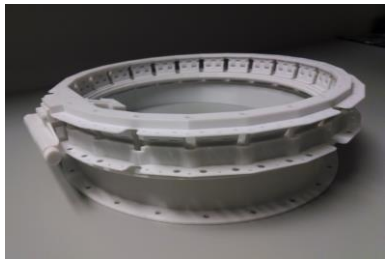
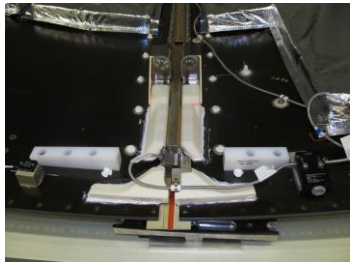







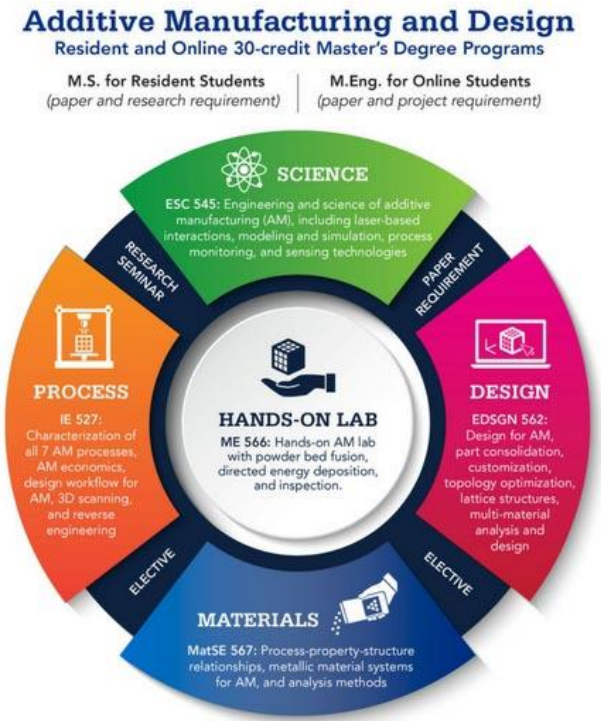




AM Education (Cont)

- **AM Masters Program at Penn State University**
  - **Five core areas of emphasis: Design, Science, Materials, Process, Hands-on Lab**
  - **Engineers can participate in future design manual updates and department training**



PennState Applied Research Laboratory

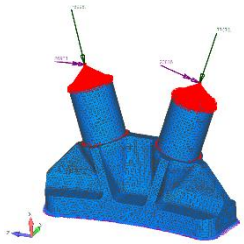
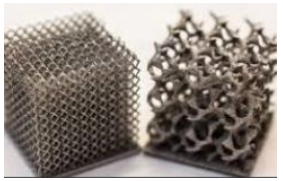
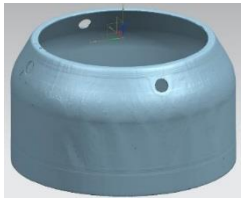
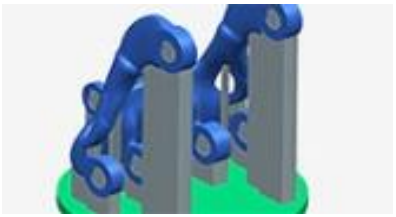
Core Courses (19 credits)			
Title	**Abbreviation**	**Description**	**Credits**
Design for Additive Manufacturing	EDSGN 562	Explore design methods and tools for additive manufacturing, including opportunistic and restrictive aspects of different additive manufacturing processes and their related industry applications	4 credits
Scientific and Engineering Foundations of Additive Manufacturing	E SC 545	Explores processes with a focus on the fundamentals of sintering and fusion of metals, ceramics, and polymers	4 credits
Additive Manufacturing Processes	IE 527	Comprehensive study of the fundamentals, process characteristics, economics, and practical applications of various additive manufacturing processes	4 credits
Additive Manufacturing of Metallic Materials	MatSE 567	Expose students to the state of the art in understanding processing, structure, and property relationships in materials fabricated using additive manufacturing	4 credits
Metal Additive Manufacturing Lab	ME 566	Gain hands-on experience to all aspects of metal additive manufacturing including design, prototyping, build preparation, fabrication, post-processing, machining, inspection, and characterization.	3 credits

Culminating Project and Research (3 credits)	
Description	**Credits**
A paper must be completed to meet the specific requirement of the culminating experience. Completion of (3) credit hours in one of the following offerings: EDSGN 596, E SC 596, IE 596, MATSE 596, and ME 596, leading to a final paper, which demonstrates student's depth of knowledge in the field of additive manufacturing and design.	3 credits

AM Software Evaluation

- **NGIS Launch Vehicle Division is currently testing the new AM tools in Siemens NX 11**
  - **These new tools include topology optimization, multiple lattice geometries, convergent modeling, and 3D printer interfaces**
    - **Topology optimization allows us to input our loads and volume constraints and the software places material only where needed.**
    - **Lattice structures geometries are now available in several geometric types and are customizable**
    - **Convergent modeling allows us to use facet, surface and solid geometry in one environment. Ex: importing scanned data or stl files directly into our model**
    - **3D Printer interfaces such as support structure generation, overhang angle checks, and other validation checks prior to committing to a build**



Manufacturing Applications for Nylon12CF

- **Nylon12CF was introduced in late 2015 as a beta program with Stratasys**
  - **Entered into production parts by mid 2016**

- **What we like about Nylon12CF**
  - **High tensile Strength is 8-15 ksi depending on X-Y orientation**
  - **High stiffness**
  - **ESD safe properties**

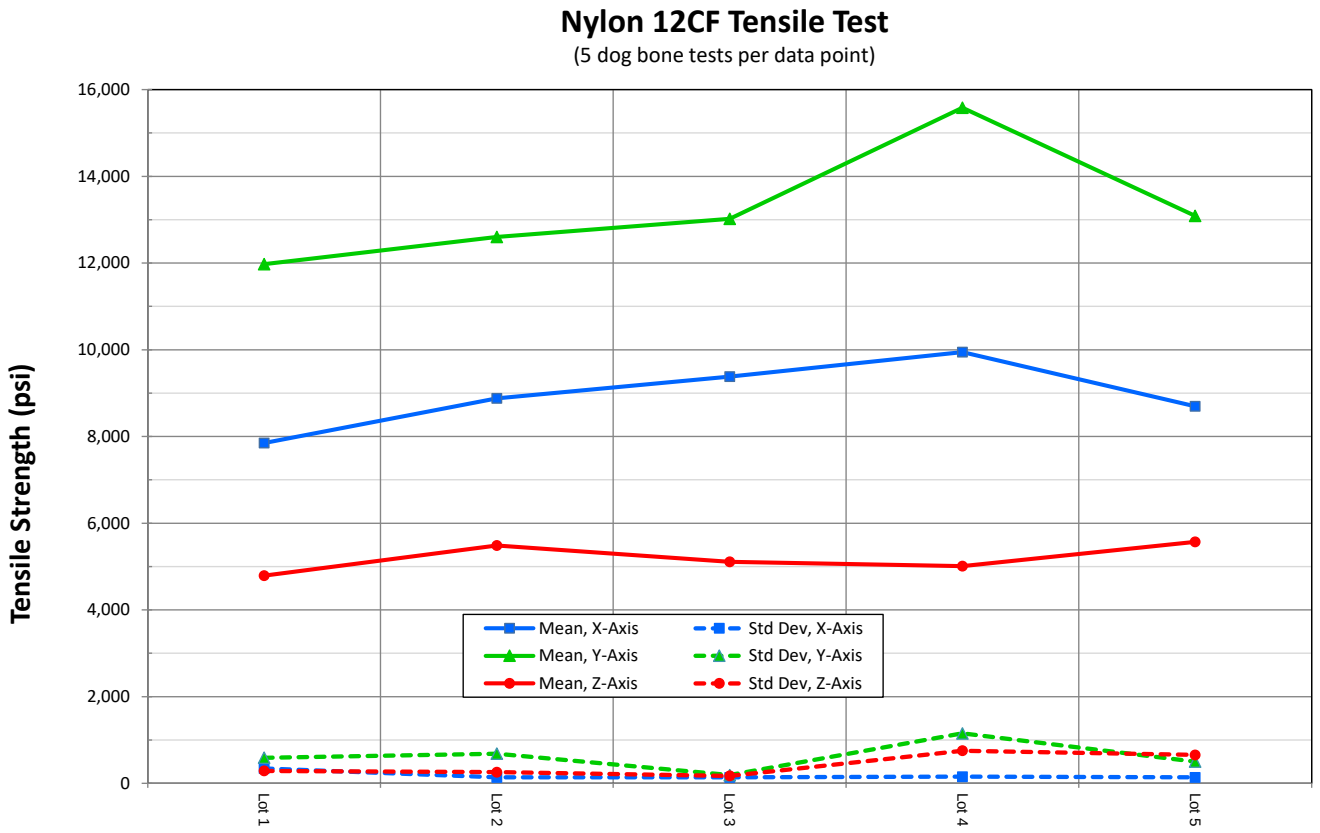
- **What we don't like about Nylon12CF**
  - **Typical z-axis knockdown for FDM part, ~5 ksi in Z-axis**
  - **Surface finish using the T20 tip requires additional touch time**
    - **Tumbler would be a good solution**
    - **Better internal training on the Insight software for seam control**

Fortus 450 Beta Testing

- **Printed 12,000 in^3 of Nylon12CF**
  - **2,200 parts built to date**
- **Tensile Strength is 8-15 ksi depending on X-Y orientation**
  - **~5 ksi in Z-axis**
- **Conductivity testing completed per ANSI/ESD STM11.11-2006 standards**
  - **The static dissipative range must be between $1x10^5$ to $1x10^{12}$ ohms/square for ESD safe classification**
  - **Results were 2.63 x 10^5 ohms/square**

Fortus 450 Beta Testing

- **Tensile Strength is 8-15 ksi depending on X-Y orientation**
  - **~5 ksi in Z-axis, typical FDM z-axis knockdown**

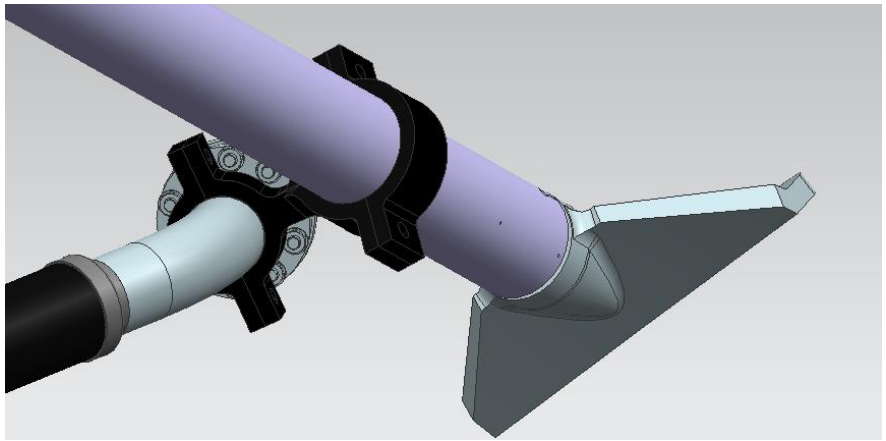


Hose Clamps

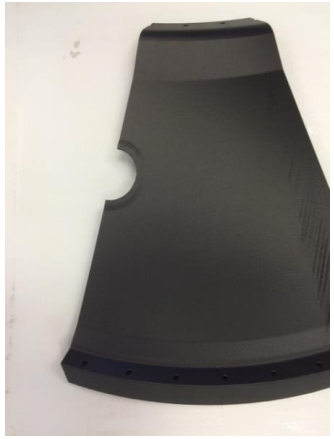
- **Part is used to clamp rubber tube dispensing nitroglycerin**
- **These clamps replace the old ball valve design**
  - **Ball valves are easily contaminated and have to be replaced often**
- **After two design iterations, the tool was functioning as required**

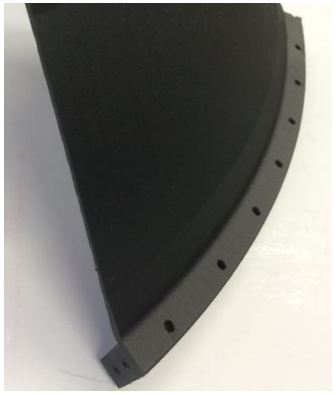
Support Clamps

- **Used during shipping for support the LOX Feed lines to the thrust frame**
- **Simple low cost solution**



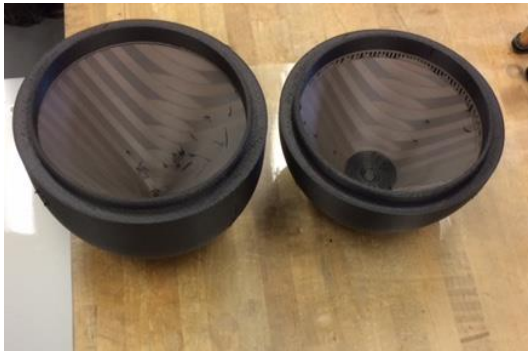
Payload Cone Panels





Pressure Vessel

- **Mock up tank needed to assist in designing a protective blanket**
  - **Actual tank was not available in a timely manner**
  - **3D printed part allowed Engineering to continue with integration activities**

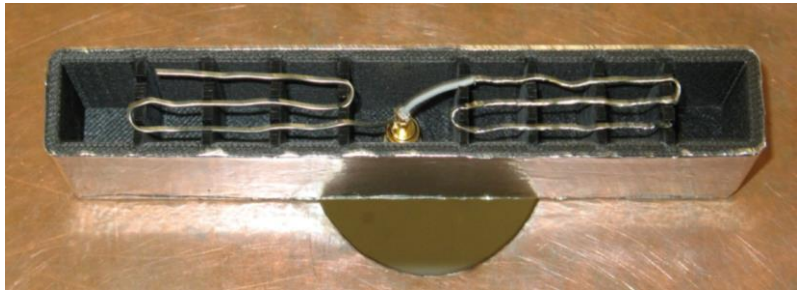


S-Band RF XTMR & FTS RCVR Antenna HATS

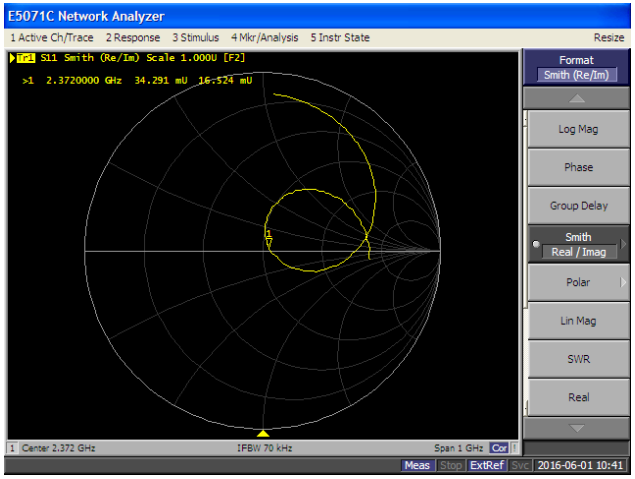
These antenna hat were all fabricated in-house using Nylon12CF material

- The carbon fibers absorb RF energy
- The aluminum tape is used on the exterior to shield RF energy
- Eliminates having to coat the interior surface with nickel based material called Wave-X

S-Band XMTR Hat 2361.5 / 2383.5 MHz



FTS RCVR Hat (421 – 428) MHz



Smith Chart showing a perfect match at S-Band

Captures both Magnitude and Phase of HAT RF impedance (50 Ohms goal)

GPS RF Antenna HATS

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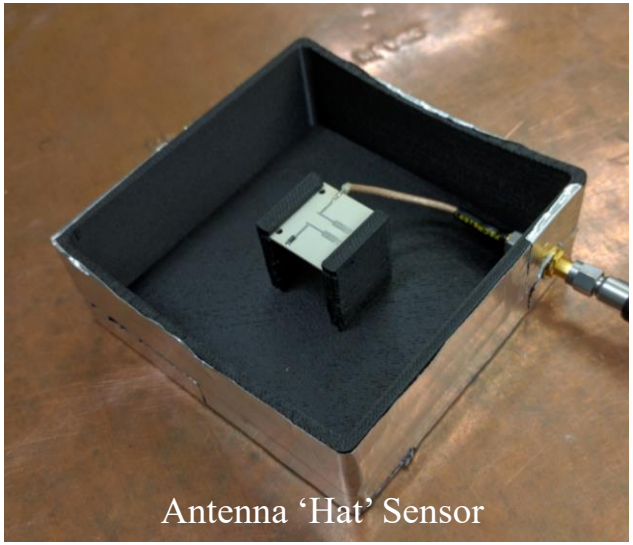
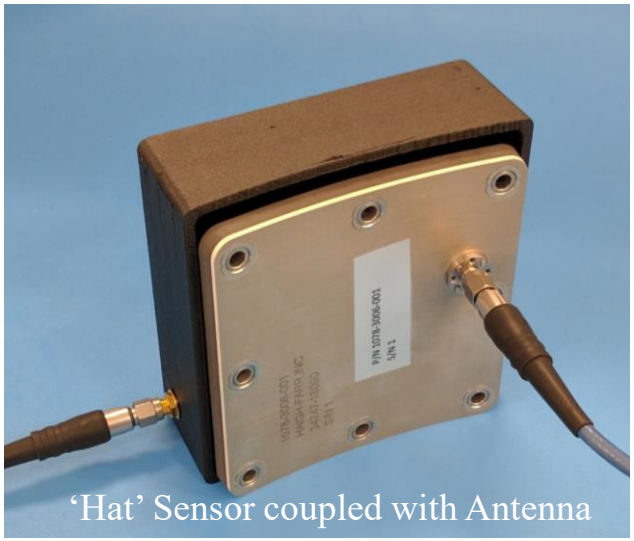
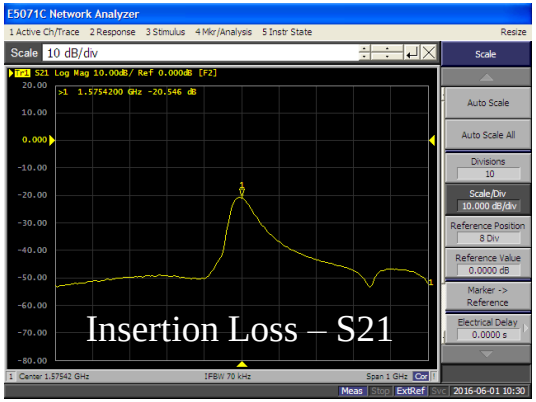
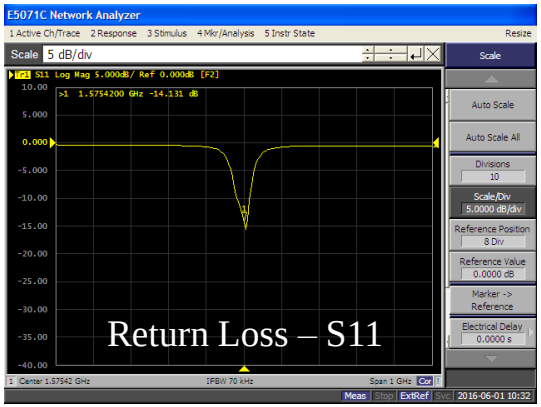






$P_0/P_1 = S21$
Transmission



$P_{reflect}/P_{incident} = S11$
Reflection

GPS RF Antenna HATS

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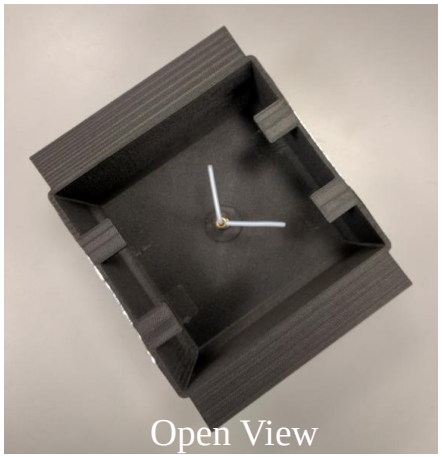
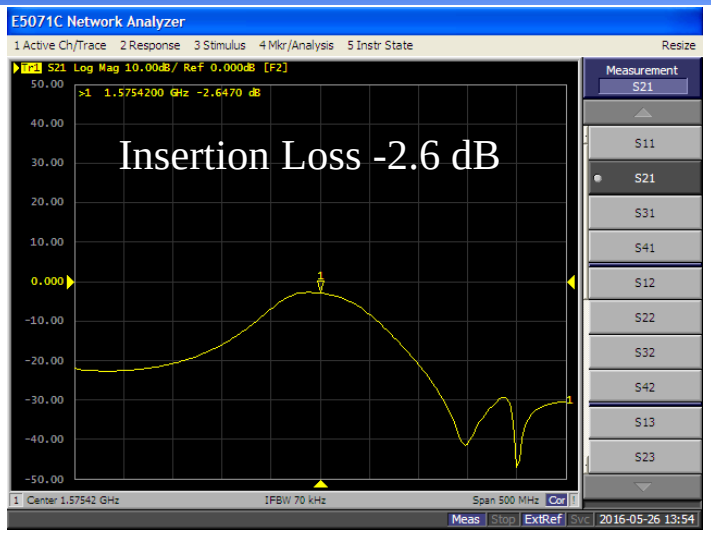
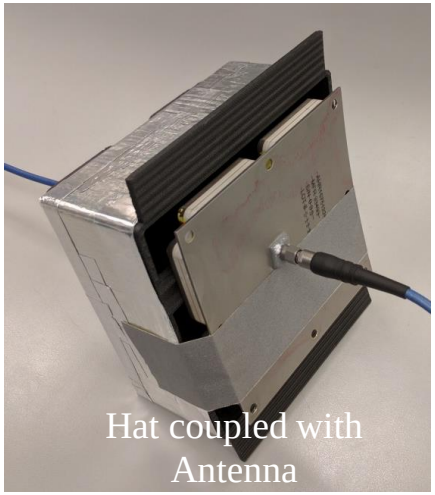
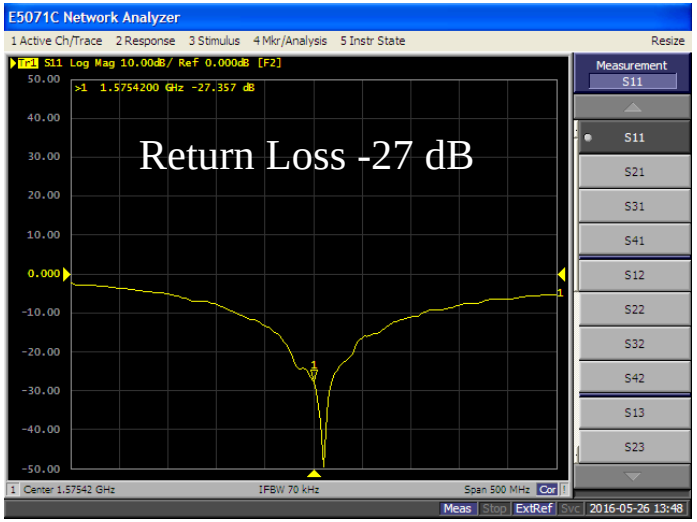


Open View



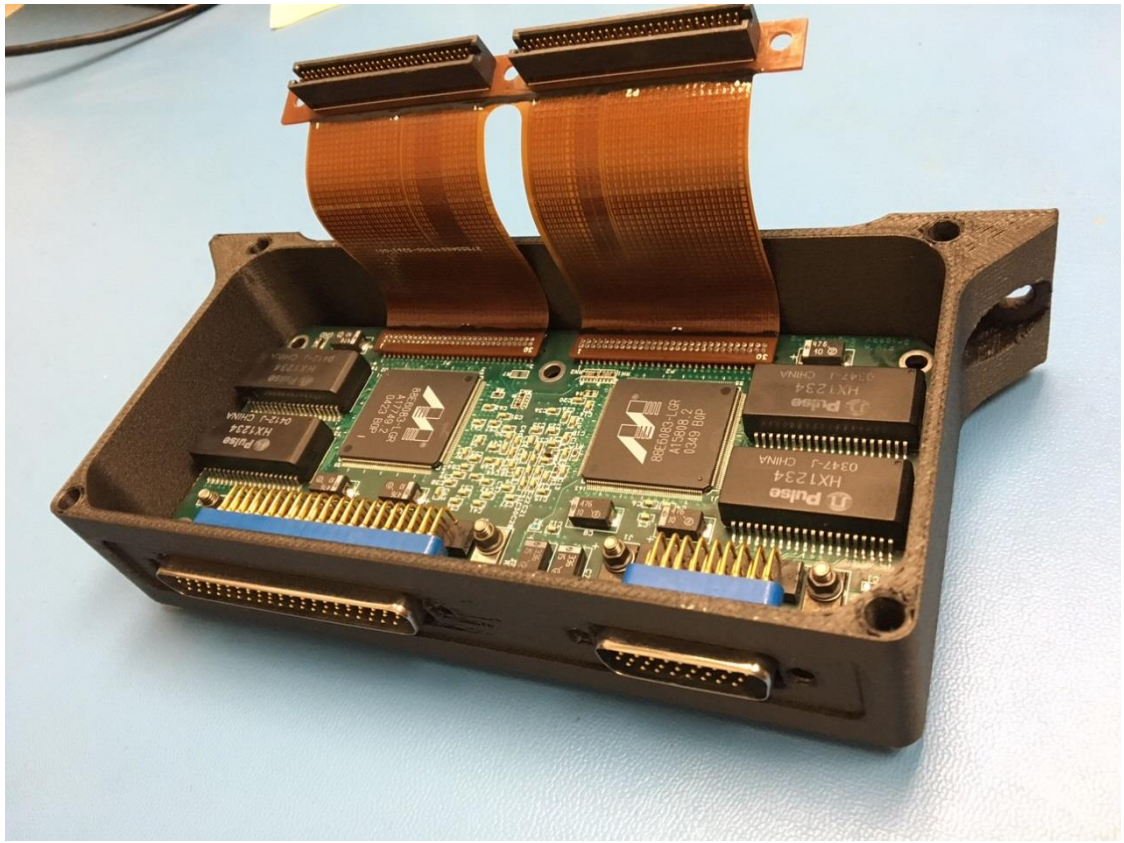


Hat coupled with Antenna



Avionics Module

- **Mockup housing created in Nylon12CF material used for its ESD safe properties**
- **Prototype board fit perfectly**



Brackets

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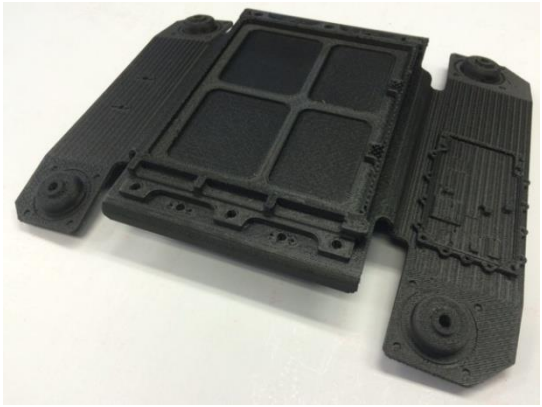
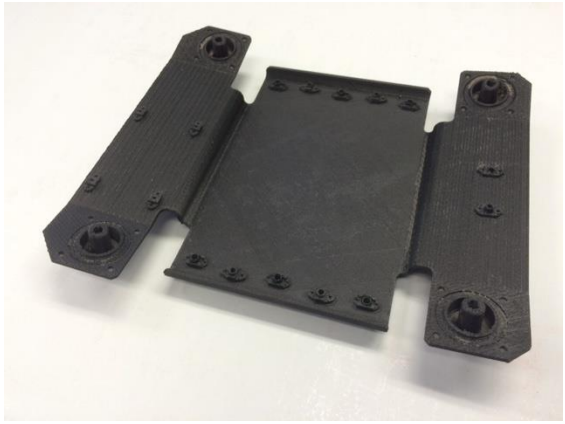
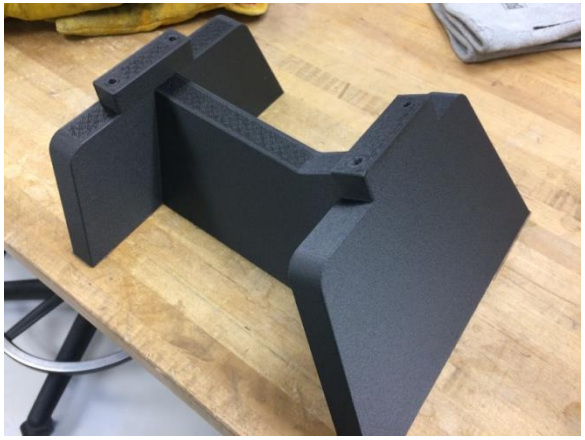
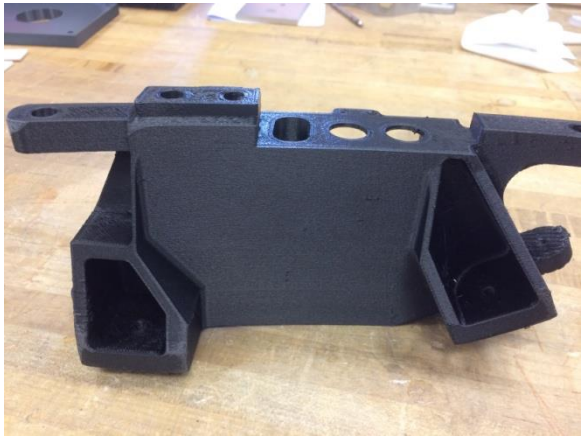








Manufacturing Tools

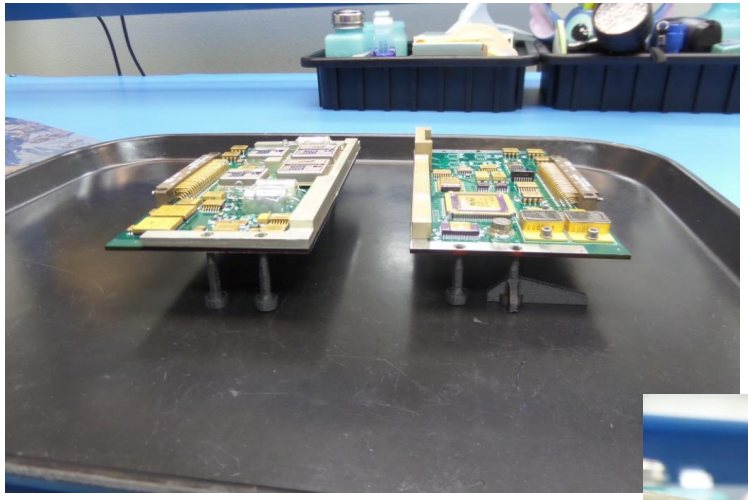
- **Tool in use was difficult to use**
- **Assemblers modified the tool with Moxi tape**
- **New 3D printed tool ergonomically designed to fit the hand**
- **Well received by the assemblers**

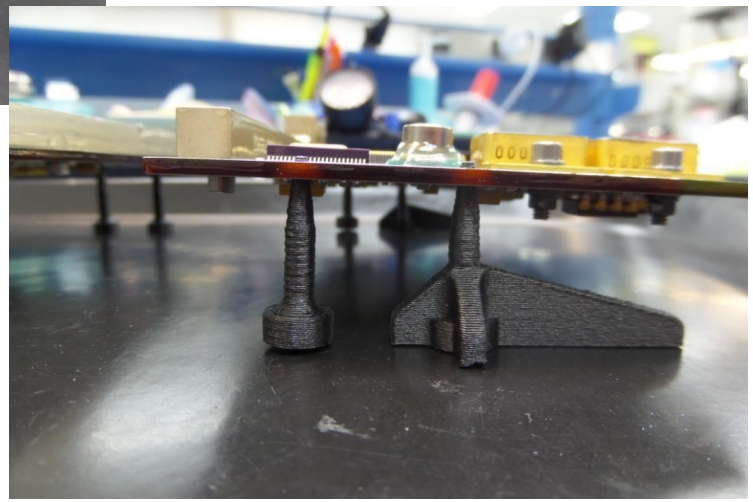
Manufacturing Tools

- **When the lacing cord is tied by hand the cord cuts into your fingers. Many assemblers have calluses and even cuts to their fingers from the cord**
- **Many of them wrap fiberglass tape around their pinky fingers to prevent being cut. Imagine tying a 100 ft ground support cable every 10”**
- **This process is very hard on your hands. Also, we have had failed inspections because the lacing is too loose**
- **The new tool allows you to wrap the cord around the tool instead of your fingers. You can get tighter lacing using the tool and there is a lot less stress on your hands**

Manufacturing Tools

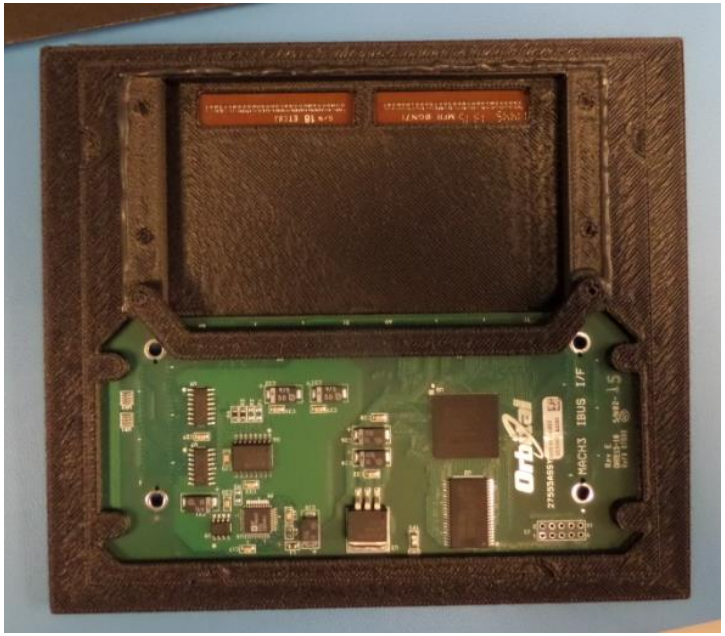
- **Nylon12CF standoffs used to hold the PWA off the tray while the Conformal Coat dries so it will not be disturbed**





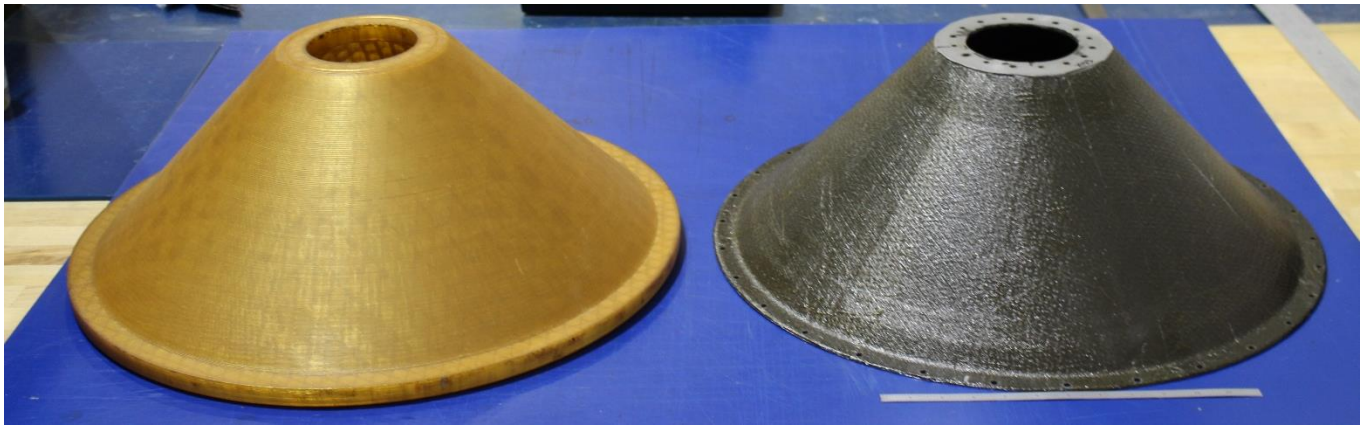
Conformal Coating Tools

- **Creating 3D printing tools to streamline the conformal coating process**



Composite Structure Layup Tools

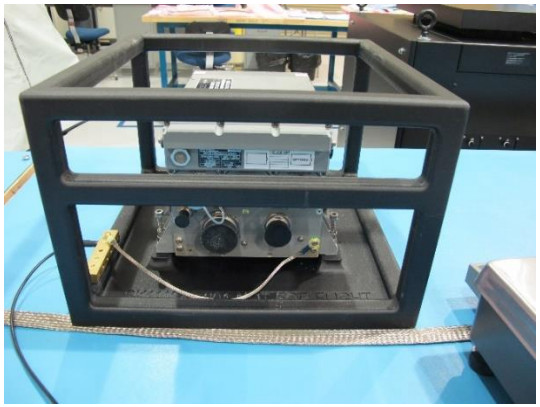
- **3D printed layup tools have been used on several projects**
  - **The layup tool is printed from material that can withstand cure temperatures of 350° F**
  - **Pre-preg carbon fiber is placed on the layup tool and then cured, resulting in the molded part**
  - **The cone below was made for a NASA research project and went from design to completed part within two weeks' time**
  - **Four larger cones have been built on printed tooling, 2 have flown to date**
  - **Largest composite structure built using a printed tool was an anisogrid cylinder 5 ft. tall and 5 ft. in diameter. That structure flew on a mission a year ago October**

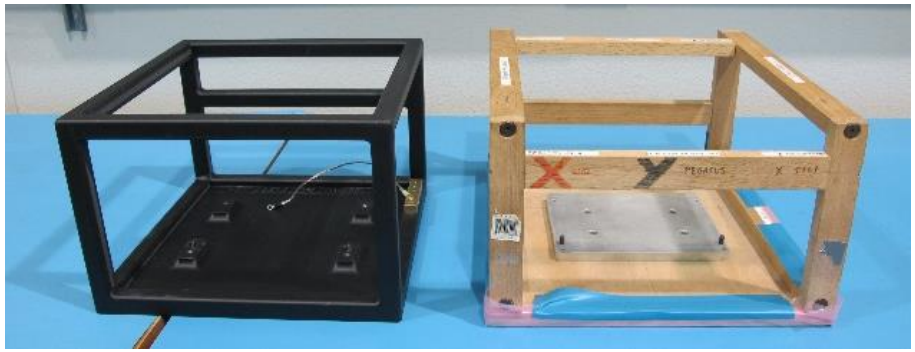


Layup Tool Finished Part

Inertial Navigation Phasing Fixture

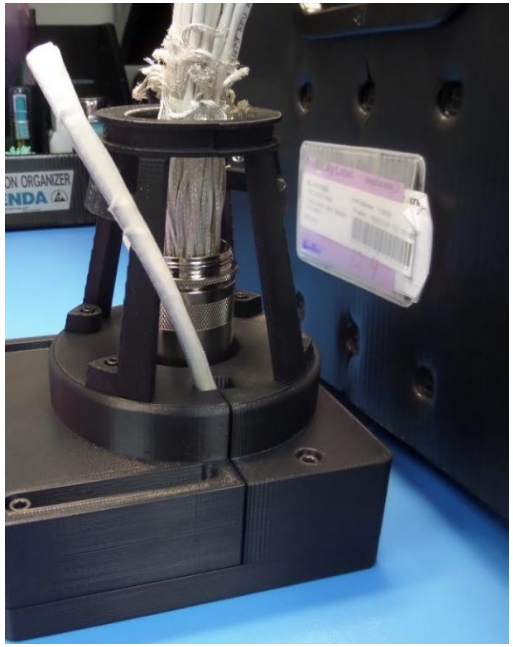
- **3D printed phasing fixture**
  - **Desired ESD safe material**
  - **Lighter than the old fixture, easier to maneuver**
  - **Old fixture was wearing out, made from wood**





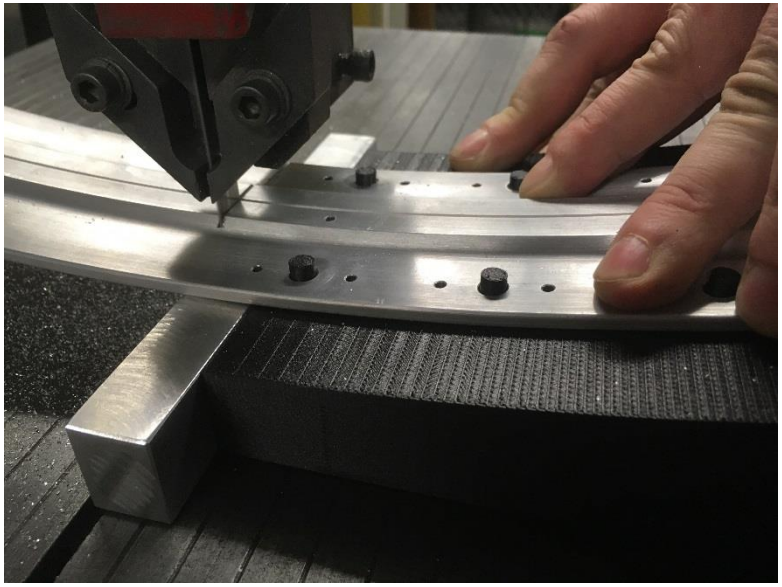
Cable Potting Fixture

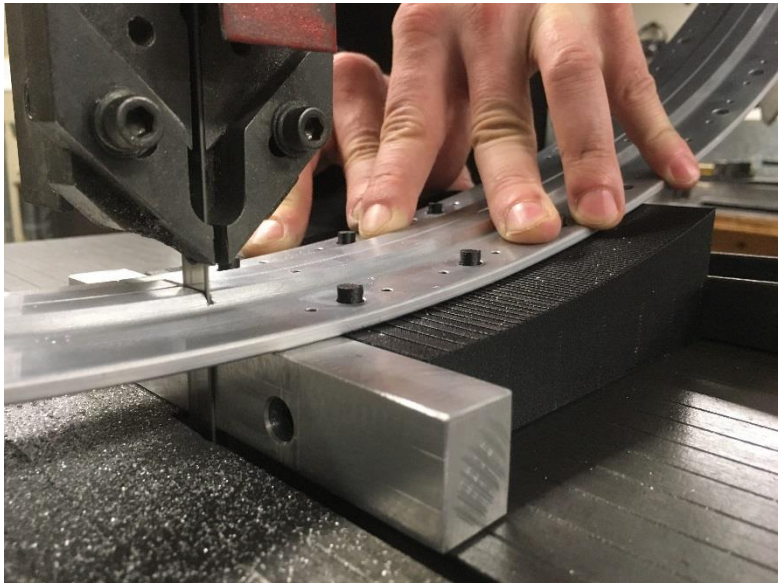
- **3D printed potting fixture made from Nylon12CF**
  - **The operators in the conformal coat room have no tool to properly arrange the connector for potting operations**
  - **The current operation of dangling the cable over the edge of a box or shelf to align the cables is prone to disturbances during the curing process**
  - **The new tool ensures proper curing in the desired orientation while protecting the connector**



Cut Tool

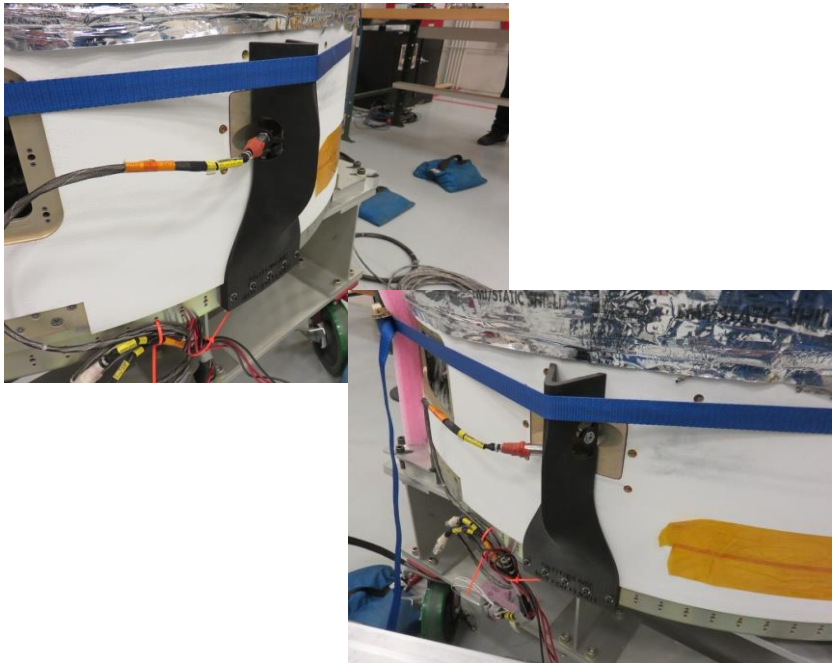
- **3D printed fixture locates the rolled forging for precise cut and proper section length**
  - **Tool provided a secure base for cutting operation**

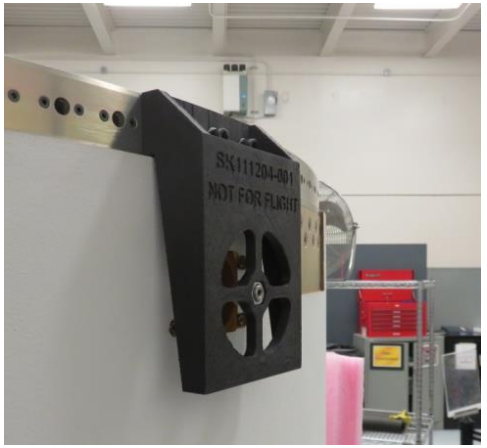




Sub Orbital Vehicles

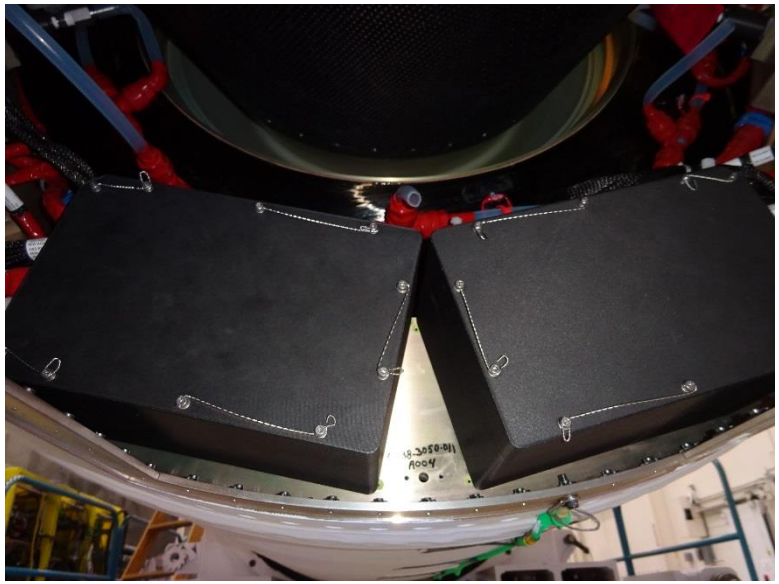
- **The pitot tube brackets were designed for the module assembly of the vehicle to be used during cold gas thruster functional testing**
  - **3D printed brackets were attached over the pitch/yaw thruster nozzle and the roll thruster nozzles**
  - **These brackets allowed a pitot tube to be placed in-line with the flow of the thrusters to measure pressure data with a quicker response time than other methods.**

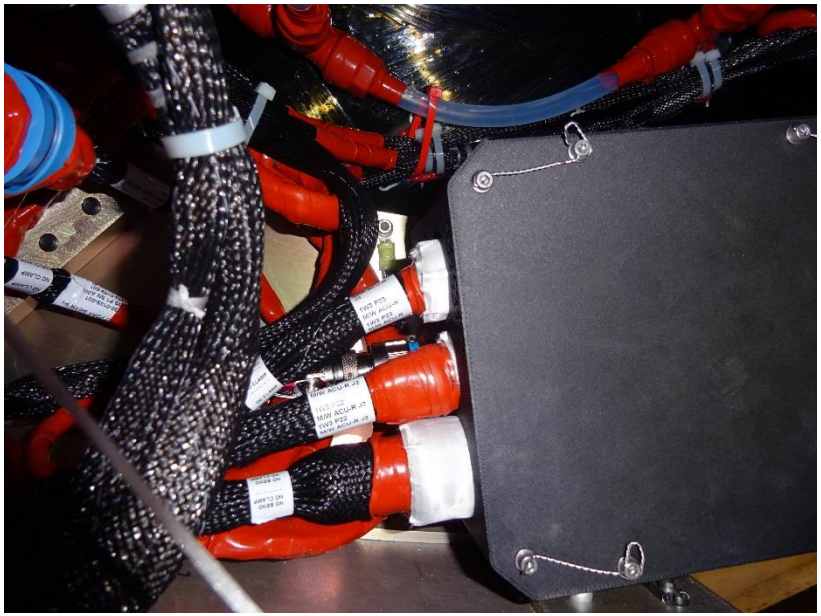




Orbital Vehicles

- **Actuator Control Unit (ACU) Enclosure**
  - **Nylon12CF boxes enclose the ACUs for thermal conditioning**
  - **Heater strips are placed on the ACU. The Nylon12CF box is a decent insulator of the heat**





Conclusion

- **Although 3D printed parts pose a challenge for most organizations that deal with government agencies, the cost and schedule savings far outweigh the negatives**
- **High probability that you will soon be using the technology in ways you never imagined**
- **Get involved in Users Groups to help mature the technology**
- **Create Maker Groups within the organization**

Demo and Q/A