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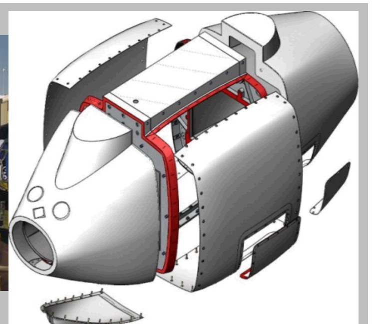


Composite Design, Fabrication, Prototyping, and Production

David A. Calkins

Microsystem Packaging and Polymer Processing Department 1833

Sandia National Laboratories, Albuquerque, NM

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Outline

- Polymer Processing Laboratory
- Composites Capabilities
- Some Recent Project Results (to illustrate our capabilities)
  - Smart Wind Turbine Blade Rotor
  - Radar Cross Section (RCS) Turbine Blade
  - Carbon Fiber Aero Panel
  - Improved Flywheel Materials
  - Aerospace Pod
- Conclusions

The Polymer Processing Laboratory in Department 1833 provides the following expertise:

- **Encapsulation -** of components and systems using filled or unfilled epoxies, silicones, urethanes, gels, foams, and other materials. Encapsulation is often critical to hardware meeting severe environmental requirements (shock, vibration, high voltage standoff, *etc.*)
- **Adhesion Science and Applications -** materials selection, tooling processes, surface preparation, and forensic analysis of weapon and non-weapon related bonding applications. Expertise includes: adhesion science; surface preparation; thermal, anaerobic, aerobic, and UV curing adhesives; wetting and bond formation studies; aging analyses; crack propagation and failure mode analysis.
- **Composites -** prototype to production support of DOE and DoD programs. This includes: design, material selection, tooling production, fabrication (wet layup, pre-preg layup), cure, and final/finish machining. We partner with engineering science analysts in Center 1500 for stress analyses and performance modeling.
- **We partner with Polymer Physicists and Polymeric Material Characterization Experts in Department 1853**
  - Thermal Analysis- T_g, C_p, cure kinetics, CTE, glassy and rubbery modulus, volatile and organic content (DSC, TMA, TGA, DMA)
  - Rheological Testing – for liquids, melts and solids
  - Mechanical Testing – tensile, compression, torsion, shear, peel, flexure, fatigue, and fracture toughness

Composites Capabilities

- **<u>Equipment</u>**
  - Dry Wall (paint booth) - 12’W x 10’T x 7’D, 154 fpm airflow
    - used for processing materials, wet layups, grinding, cutting, spray painting
  - Eastman Static Cutting Table - 6’W x 12’L
    - 2-D computer controlled (+/-0.01” marking, cutting, and routing of thin films, wood, plastics, and fiber-reinforced epoxy composites (pre-preg)
  - Walk-In Oven - 6W’ x 10D’ x 7’T, 300 ± 3°F. 22”Hg vacuum service, programmable cure profiles. Used for out-of-autoclave cures.

Dry Wall Room

Eastman Cutting Table

Walk-In Oven

Composite Capabilities *(continued)*

- **Equipment**
  - Wabash Vacuum Hot Press - 3'W x 3'D x 16"T, 50 Ton capacity, 22 in Hg, 400^{o}F. Programmable. Used for producing flat laminates, composite panels, and match metal mold processes.
  - Baron Autoclave, ø4' x 8'D, 100 ft^{3} volume, programmable with 600^{o}F at 300 psi capability. Used for high temperature cures of parts with complex geometries.
  - Haas CNC Milling Machine, Lathe, Other Tools – Our machine shop facility is tailored to machine composites.

Vacuum Press

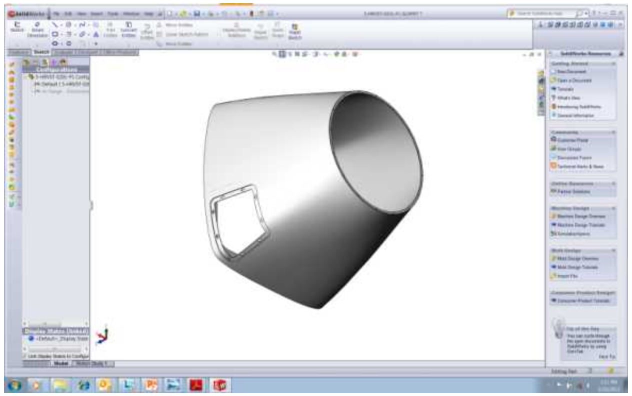
Baron Autoclave

Machine Shop

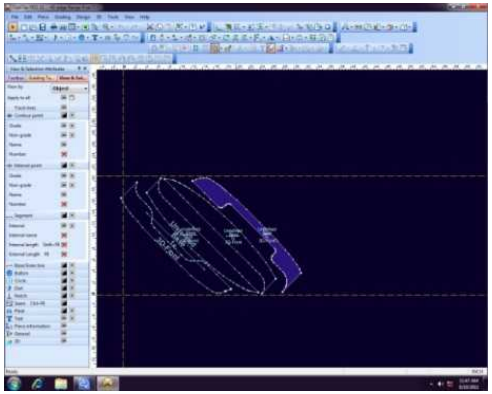
Composite Capabilities *(continued)*

- **Materials**
  - Fiber-reinforced epoxy pre-preg materials
  - Dry fiberglass and carbon fabrics
  - Epoxy resins (and other resin systems)
- **Composites Design and Expertise**
  - David Calkins – composites technical SME (> 15 years experience)
- **Software**
  - ProEngineer, SolidWorks, OptiTex, Mastercam

Composite/Consumable Materials



SolidWorks –Aft Cowl Part



OptiTex 3-D Flattening Software

Smart Rotor Project

- **<u>Program Synopsis</u>:** Sandia's Wind Energy Program is researching active aerodynamic load control (AALC) devices controlled by sensor inputs to reduce loads on wind turbine rotors. This concept should result in a lower overall cost of wind energy by enabling larger rotors and reducing wear-and-tear. Org. 6121 needed field test data to compare with their simulations.
- We supported the project by:
  - modifying three 9 meter rotor blades
  - Producing custom replacement structural elements (riblet and spar)
  - Integrating replacement structural elements into blades

Smart Rotor Assembly

Rotors Installed on Wind Turbine

Smart Rotor Project *(continued)*

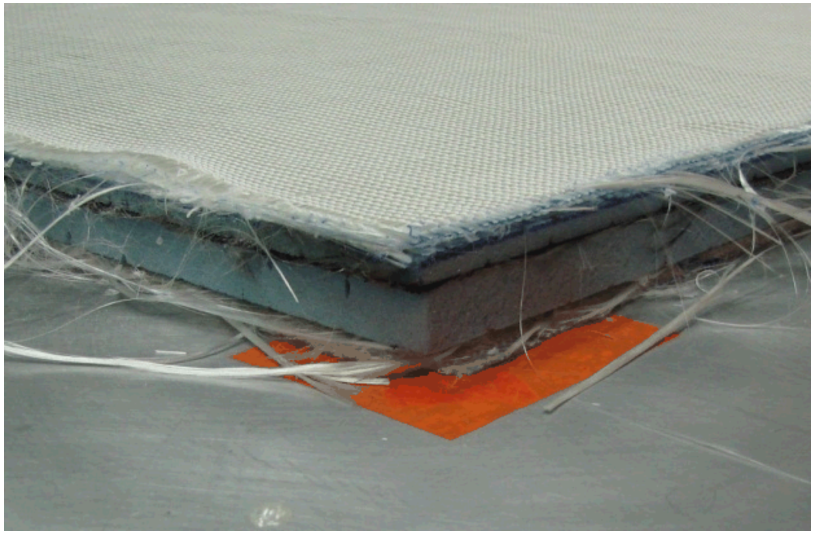
- On-site modification of wind turbine blades
- Spar - wet layup of unitape and 6K tows
  - required precise alignment and hole locations
- Fabrication process used economical Melamine tooling board
- Integration - a coordinated effort
  - Installation required precise axial alignment
  - Used filled adhesive (Epikote BPR 135) to fill large bond lines

Bonding Spar and Riblet in Place

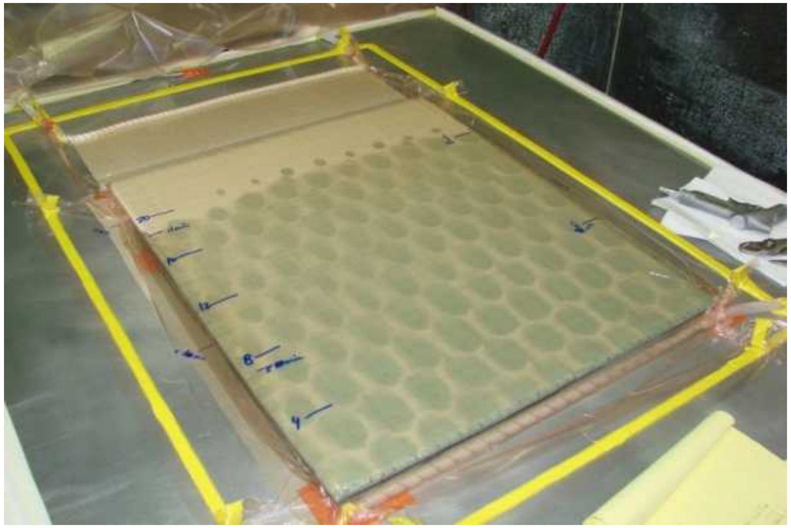
Spar Structural Member

RCS Turbine Blades Project

- **<u>Program Synopsis</u>:** Wind Energy Farms interfere with radar operation of defense, air traffic control, and weather related programs in the United States. This project was focused on reducing the Radar Cross Section (RCS) of turbine blades through the use of radar absorbent material in a manner consistent with Wind Energy Industry turbine manufacturing processes.
- Our customer needed physical parts that could be used to confirm their analyses. We produced simulated rotor blade structural elements using common industry standard materials (E-glass fabric and Hexion MGS 135/1366 resin).



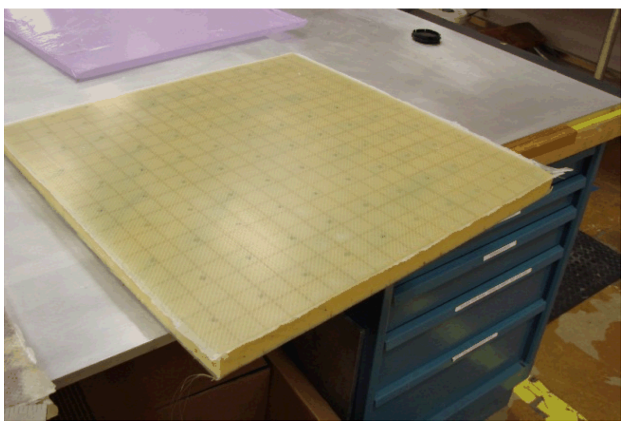
Panel – Glass Facesheets/Foam Core Embedded Resistive Fabric Layer (in black)



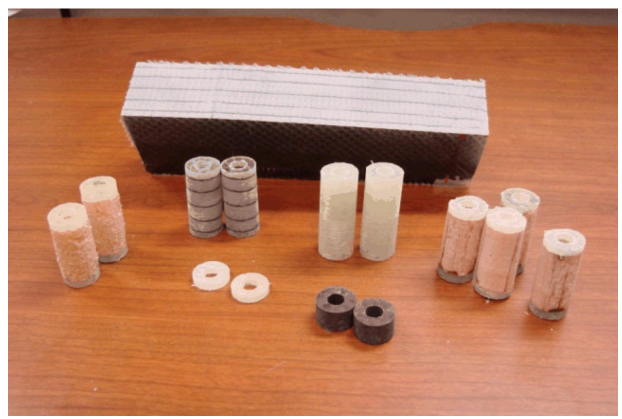
Foam Core Flat Panel Being Infused with Resin

RCS Turbine Blades Project *(continued)*

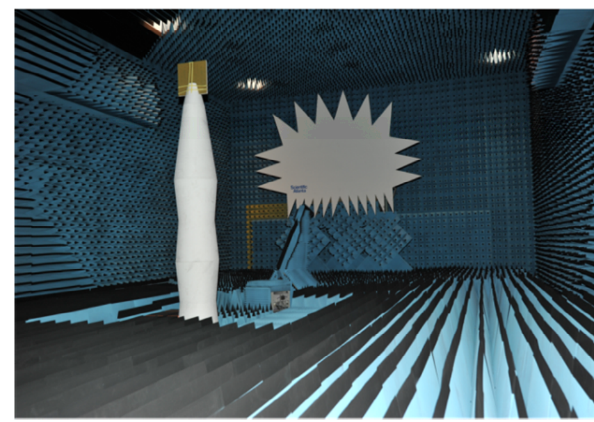
- The simulated 'structural elements' were flat laminates and core panels.
- Machined samples were used for materials characterization.
- We suggested and implemented an economical 'bread-boarding' approach that provided quick turnaround analysis and verification



Panel Infused with Resin



Material Machined for Characterization

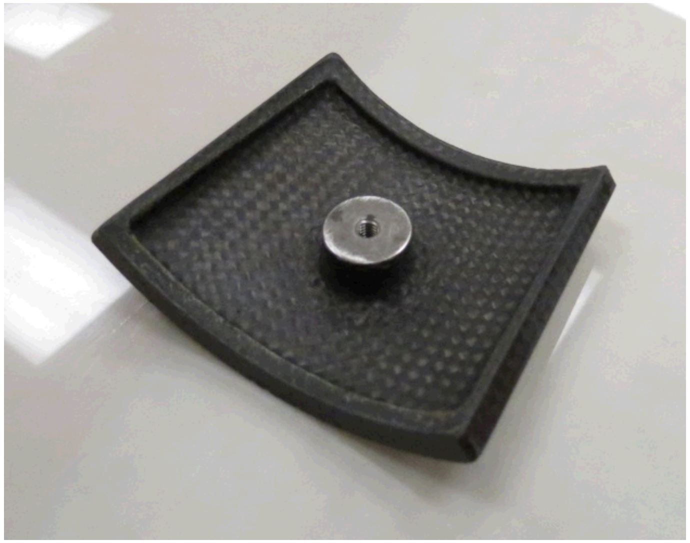


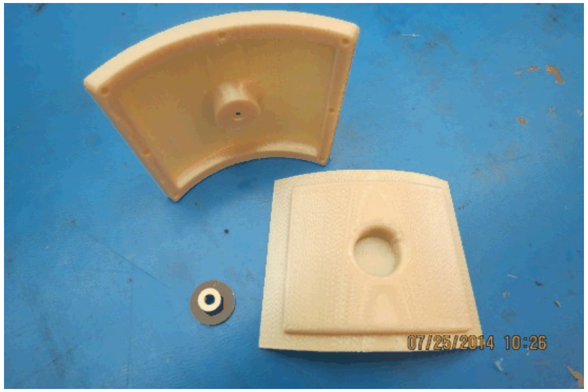
Panel (atop column) at FARM *(SNL Facility for Antenna and RCS Measurement)*

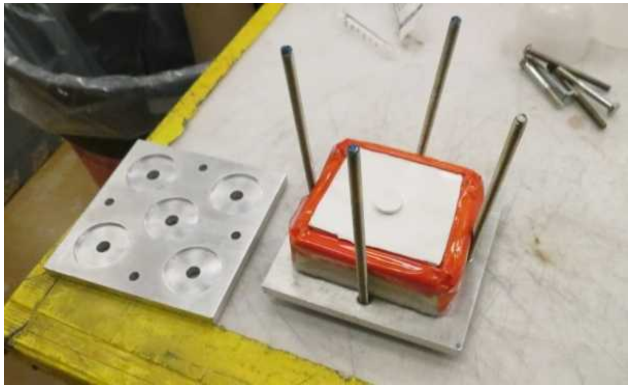
Carbon Fiber Aero Panel Project

Sandia LDRD Project "Reducing the Adverse Effects of Boundary-Layer Transition on High-Speed Flight Vehicles", Katya Casper, SNL Dept. 1515, Principal Investigator.

- Produced a thin composite panel for an air flow experiment
- Part required 'near-net' as-molded geometry for precise fit to cone (0.005" on profile)
- Used Cytec MTM-45 (2 X 2 twill) carbon fiber pre-preg
- Used steel base tool. Printed a 3-D secondary tool (Ultem™) used for making a silicone intensifier to achieve good consolidation
- Part fit perfectly



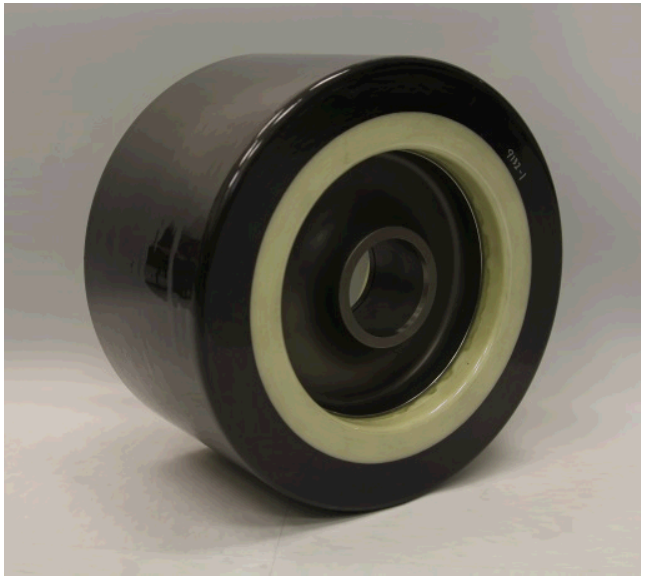


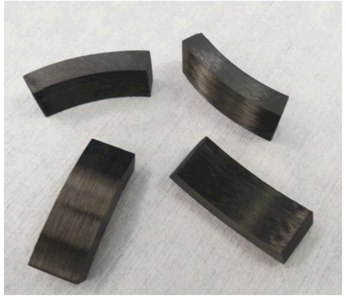


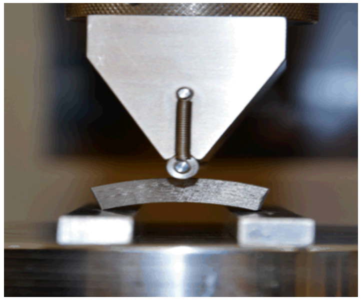
Improved Flywheel Materials Project

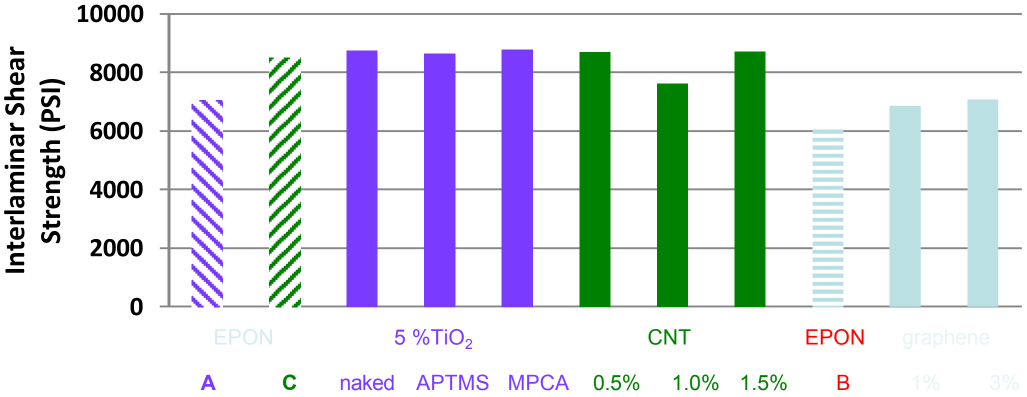
Tim Boyle, SNL Dept. 1815, Principal Investigator

- Multiyear project funded by DOE Office of Energy to improve the strength of flywheel materials. A stronger flywheel can spin faster; thus, it can store more energy.
- Phase 1 - Mechanical testing of various nanofilled materials identified a 20% improvement in interlaminar shear strength of composites for a naked TiO_2 nanowire filler.
- Phase 2 - Sandia is currently teaming with 3 companies to incorporate Sandia fillers into an existing commercial flywheel product. These Sandia flywheels will be performance tested by manufacturer (spin and pit testing).
- Performance flywheel testing of four flywheels will occur in August 2015.







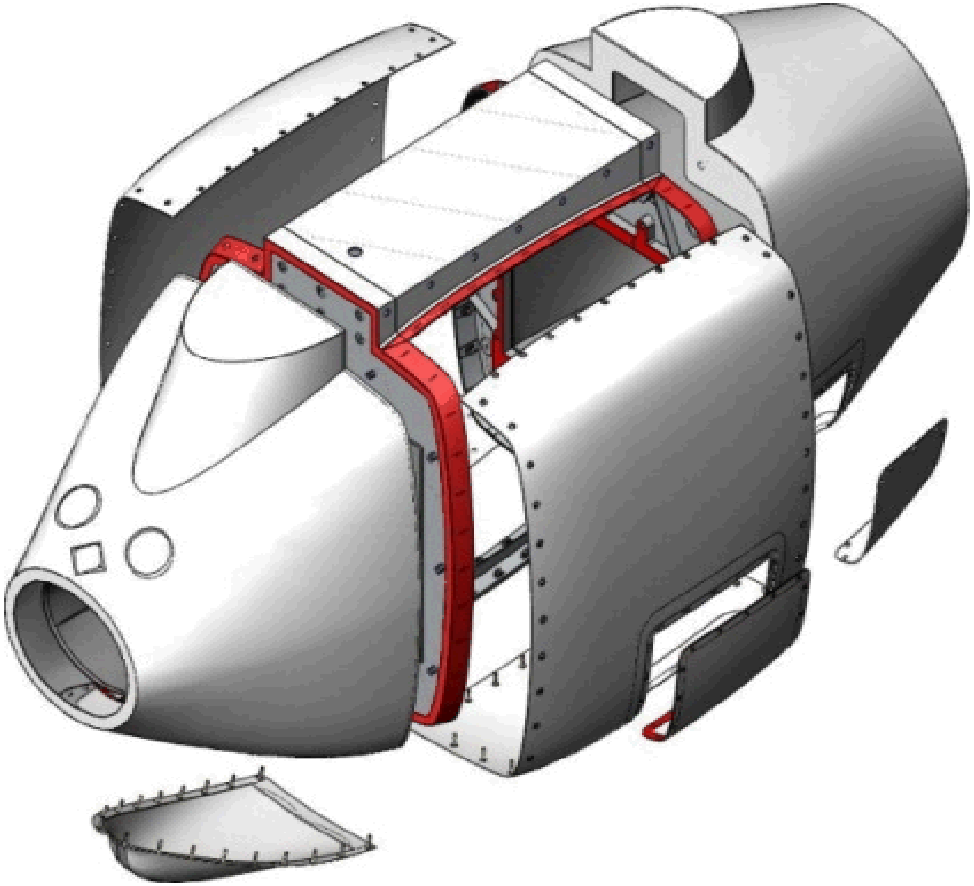


Aerospace Pod Project

Project Synopsis: Production of Air Force Unmanned Aerial Vehicle (UAV) TRL 7 Technology Demonstrator Pod for nuclear non-proliferation treaty applications

Our scope of work:

- We were integrally involved in the mechanical design of the carbon fiber cowling design with an industry partner.
- We developed fabrication processes and produced the first complete set of composite parts.
- These parts were integrated into the final assembly and performed successfully in flight testing.
- We subsequently transferred the fabrication process to an industry vendor for production of numerous additional aerospace pods.



Aerospace Pod – Exploded View Composite Cowlings and Doors

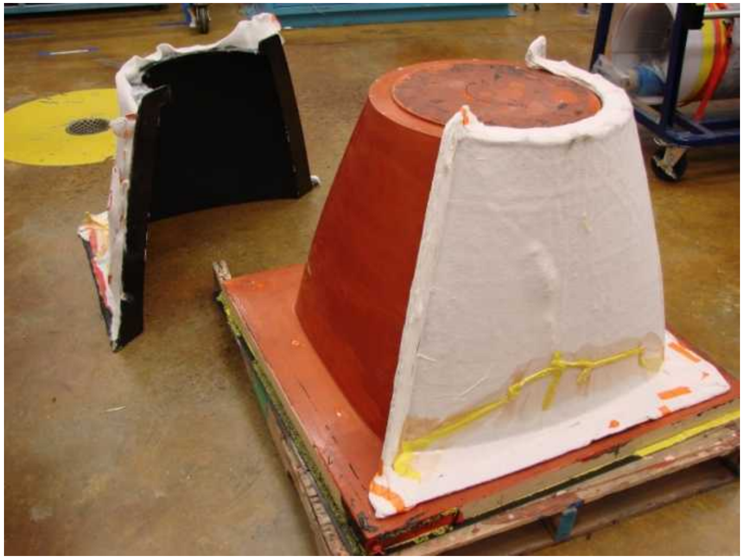
Aerospace Pod - Overview

- Pod consisted of 5 Cowlings (with 2 molded-in doors), and 2 internal ducts
- Pod system size 28”W x 28”T x 78”L)
- Complex overall geometry of large parts
- Project required the use of aerospace qualified pre-preg materials (ACG MTM45-1)
- Fabrication process consisted of:
  - Producing tooling necessary to make cowlings
    - 10 lb/ft^3 urethane male master tools
    - Used male master tools to produce female production tooling (using a Vacuum Infusion Resin Transfer Molding process - VARTM)
  - Designing material cut patterns, part layup, autoclave cure, and finish machining of parts to per print specifications (tight tolerances)

Aerospace Pod – Tooling

- The female production tools are used to produce the final parts. They are the negatives of the male masters.
  - The tools are produced by impregnating dry carbon fabric layup with resin in one VARTM shot
    - 10 layers of 2x2 twill dry carbon fabric
    - Layers: 0/0/45/-45/90/90/-45/45/0/0
    - Impregnation resin -Infusion Coat and Tool Fusion Resin/Hardener
  - VARTM shot of large parts is technically challenging (resin working time, maintaining vacuum bag integrity, *etc.*).

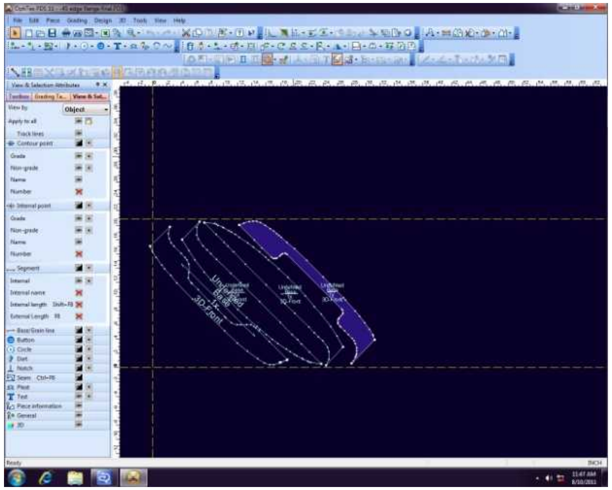
VARTM Shot - Resin Impregnating Laminate Buildup



Aft Cowl Master and Female Production Tool

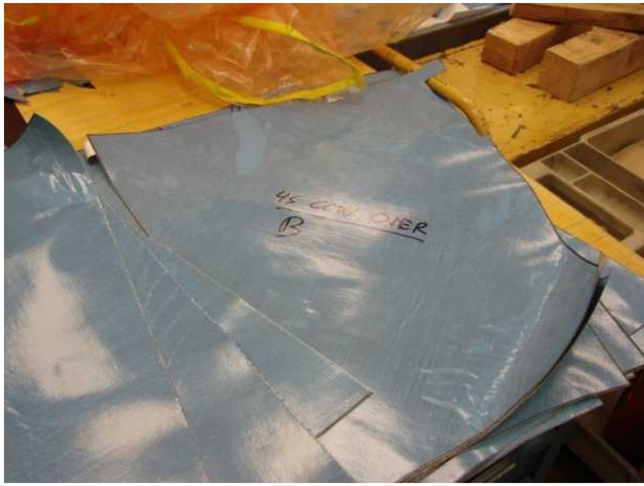
Aerospace Pod – Producing Parts

- Part Layup and Cure
  - Example shown here is for the Aft Cowl
  - SolidWorks models were imported into OptiTex software (textile software). OptiTex software takes complex 3-D geometry (multiple surfaces) and constructs an associated flat pattern.
  - Flat patterns are then exported to Eastman cutting table and used to prepare the pre-preg sheets for the layup operation to follow.



OptiTex Software Flat Pattern Aft Cowl

Eastman Cutting Table

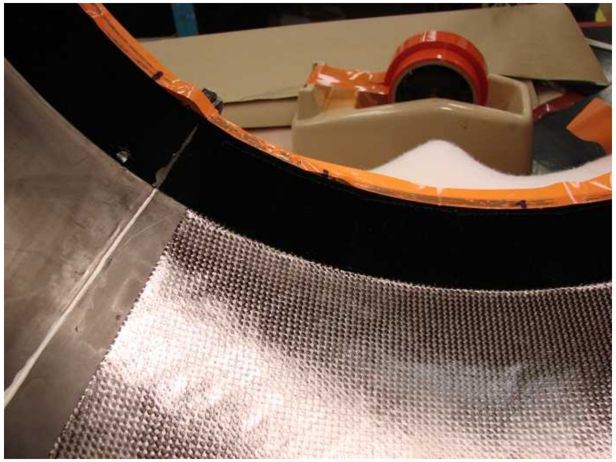


Pre-Cut Pre-Preg Patterns Aft Cowl

Aerospace Pod – Part Layup and Cure

- Female Production Tool assembled
- Pre-preg material applied layer-by-layer using layup schedule
- Laminate vacuum-bagged for cure (32.2 psi, autoclave)

Female Tool Assembled

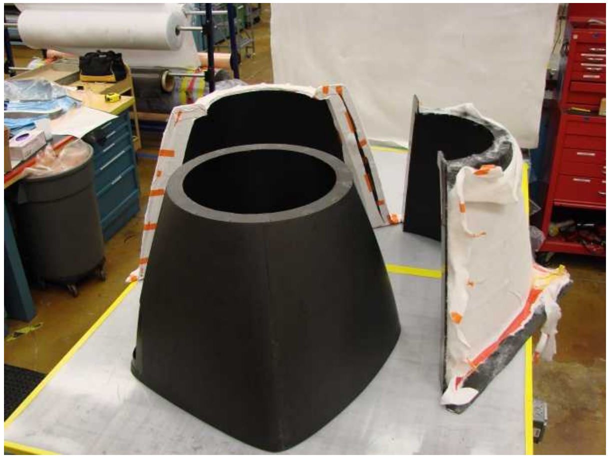


First Layer of Pre-Preg Material Applied

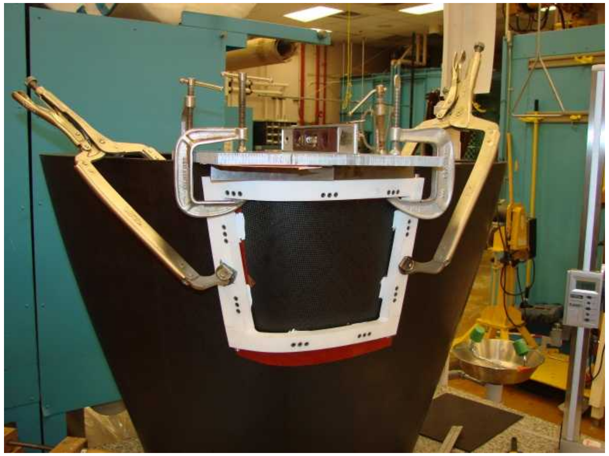
Laminate Vacuum-Bagged for Cure

Aerospace Pod – Part Finishing Details

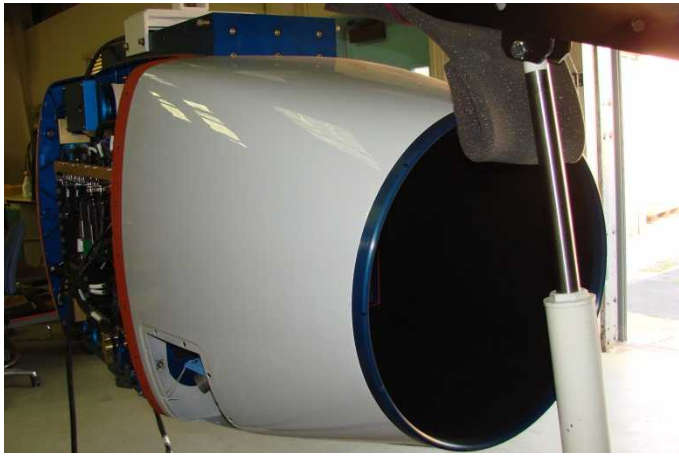
- Cured part is demolded from Female Production Tool
- Custom sintered Nylon fixtures are used to produce final holes
- Cowl surface is prepared, primer is applied, and surface is painted



Aft Cowl Demolded and Removed from Female Tool



Custom Fixtures used to add Final Holes



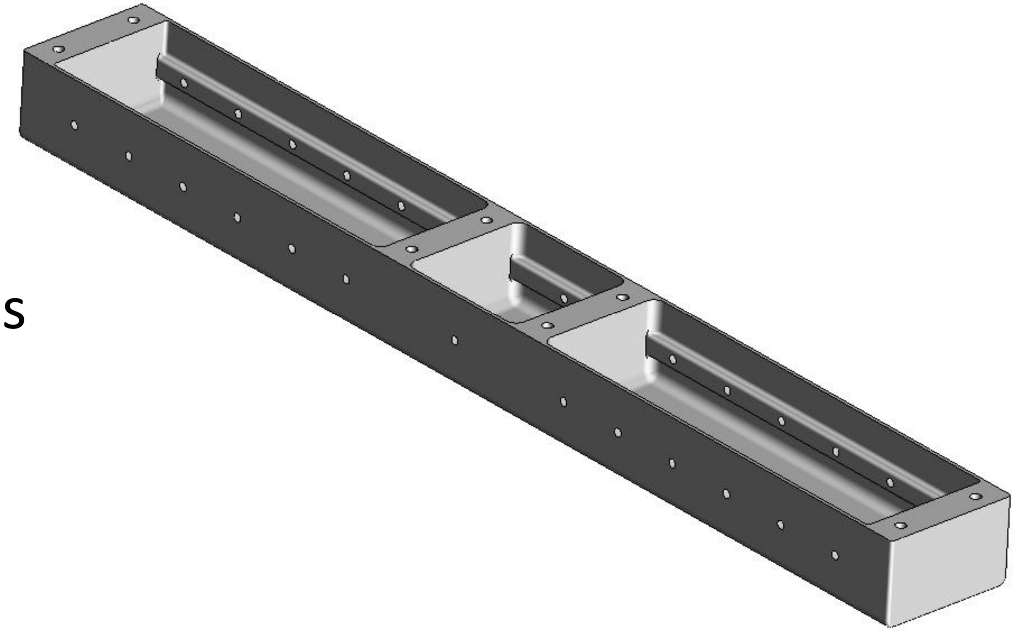
Aft Cowl (Painted) Installed on Pod

Development and Manufacture of AFT-2 OBA Optical Gantry Beam

Sandia National Laboratories

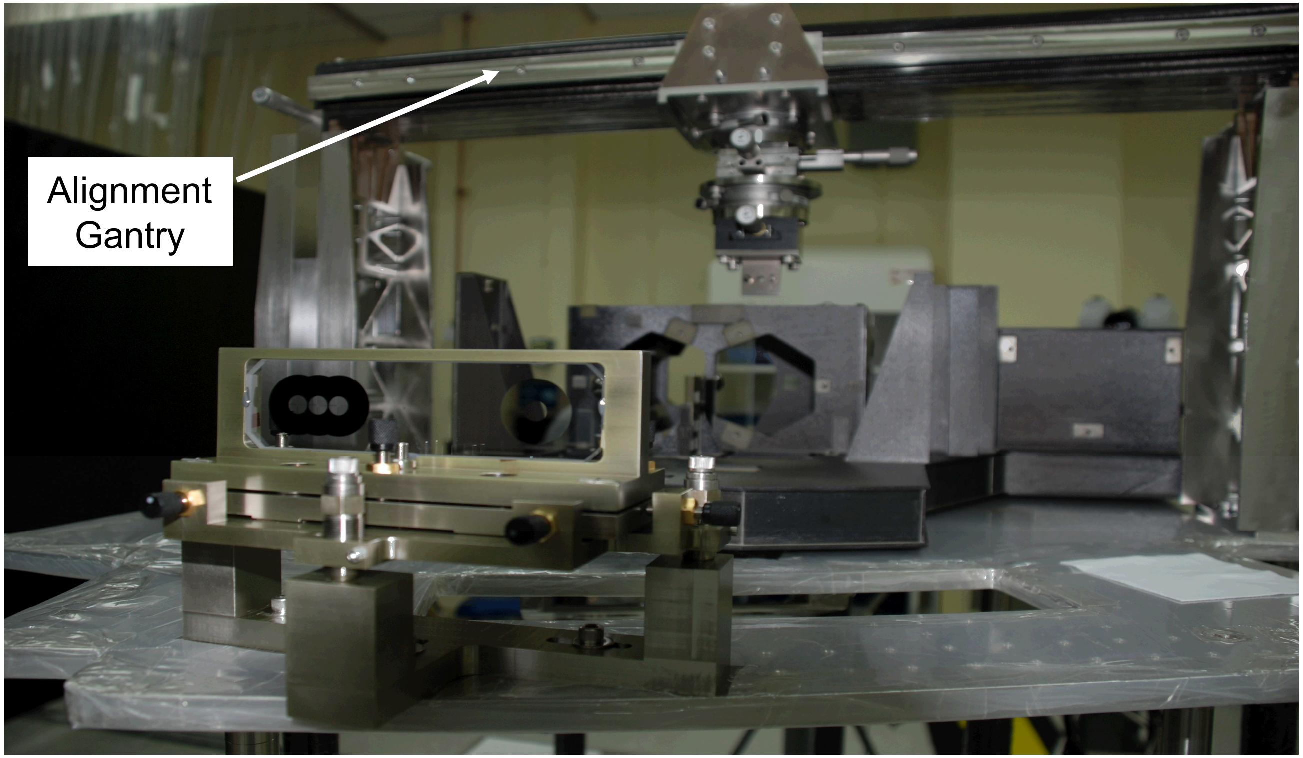
Outline

- Background
  - Optics Bench Assembly
  - Composites
- Purpose
- Layup Process
- Conclusions
- Acknowledgments



Background - Optics Bench Assembly

- Sandia is involved in the design and fabrication of complex optics bench assemblies
  - Built to demanding specifications
  - Includes variety of components
    - Lenses, mirrors, beam splitters, filter wheels

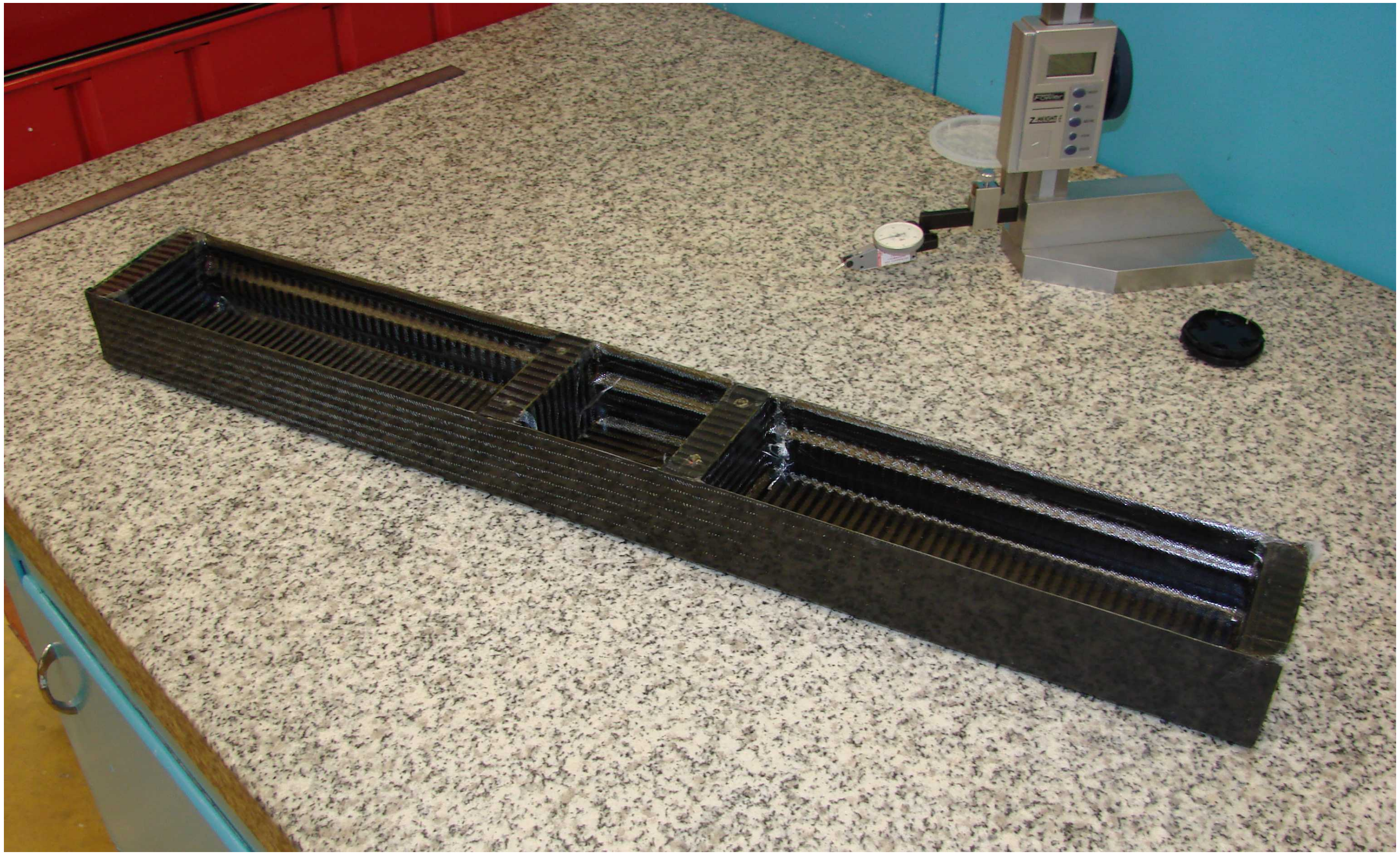


SNL Org. 2453 Composites Capabilities

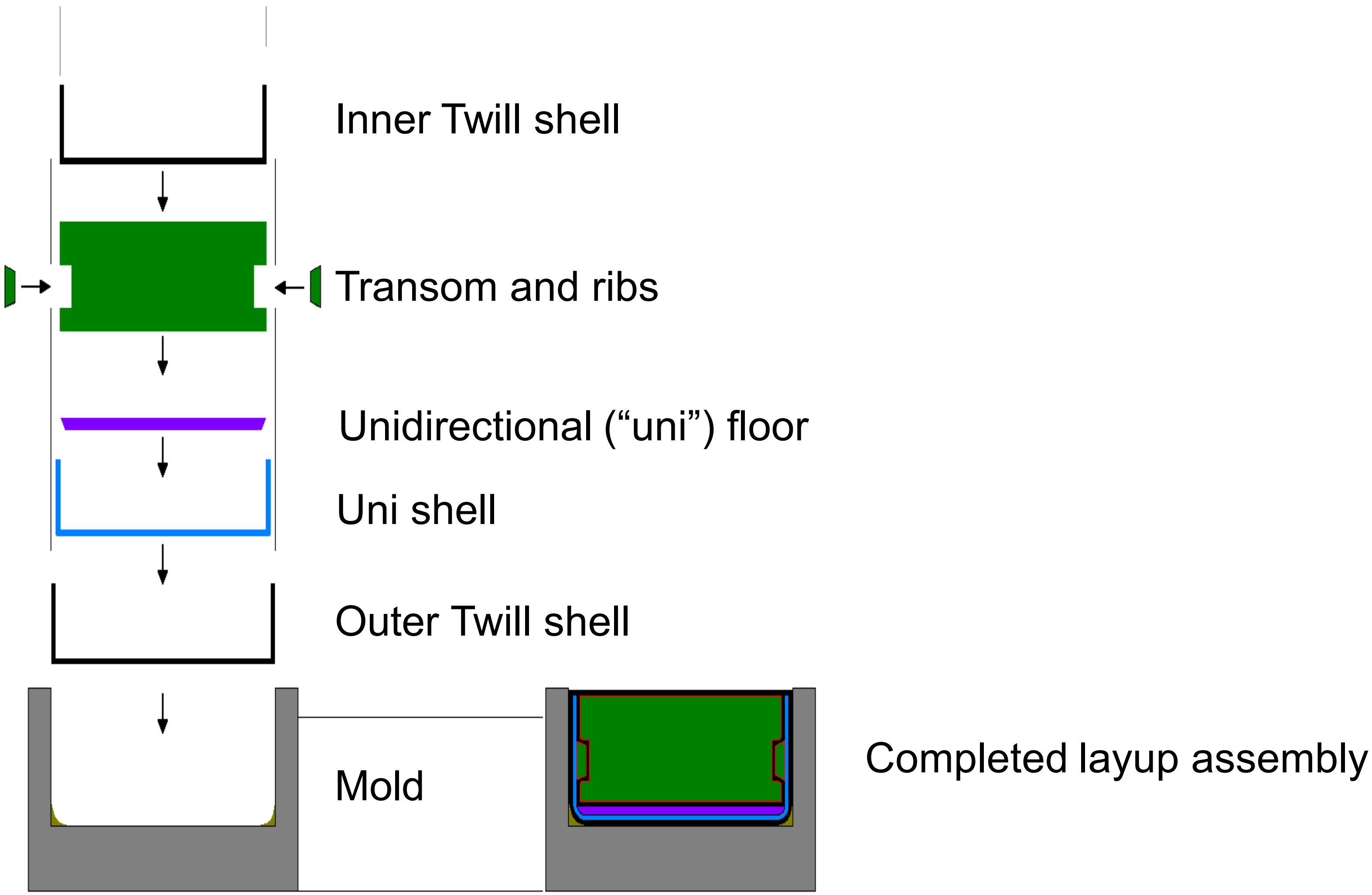
- **Mold design and fabrication**
- **Pre preg materials and processes**
- **Wet layup materials and processes**
- **Vacuum assisted resin transfer molding (VARTM)**
- **Vacuum bag processes and cures**
- **Autoclave for pressure-assisted cure at temperature**
- **Vacuum Press**

Purpose - Gantry Beam

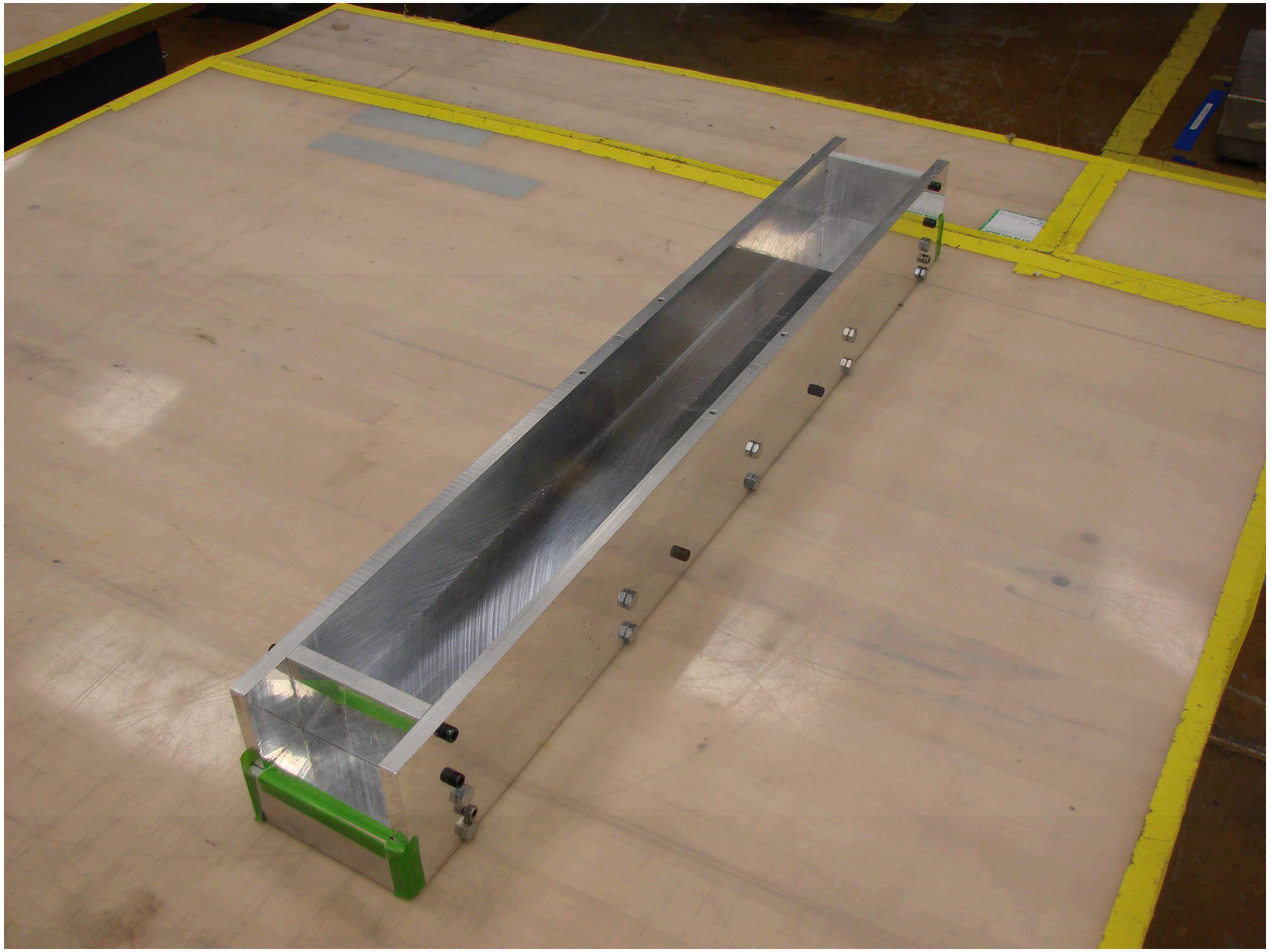
- We describe the development and manufacturing of a gantry beam crucial to the alignment of the OBA



Layup Process



Mold



Can be fully disassembled

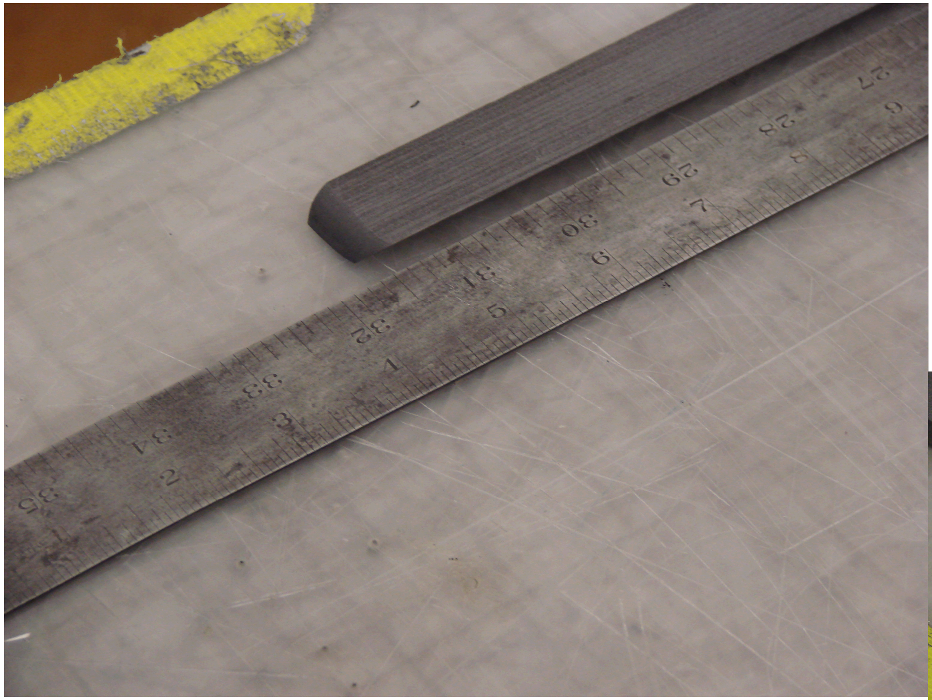
Female mold

Blanchard-ground cast Al plate

No corner radius - reduces mold complexity

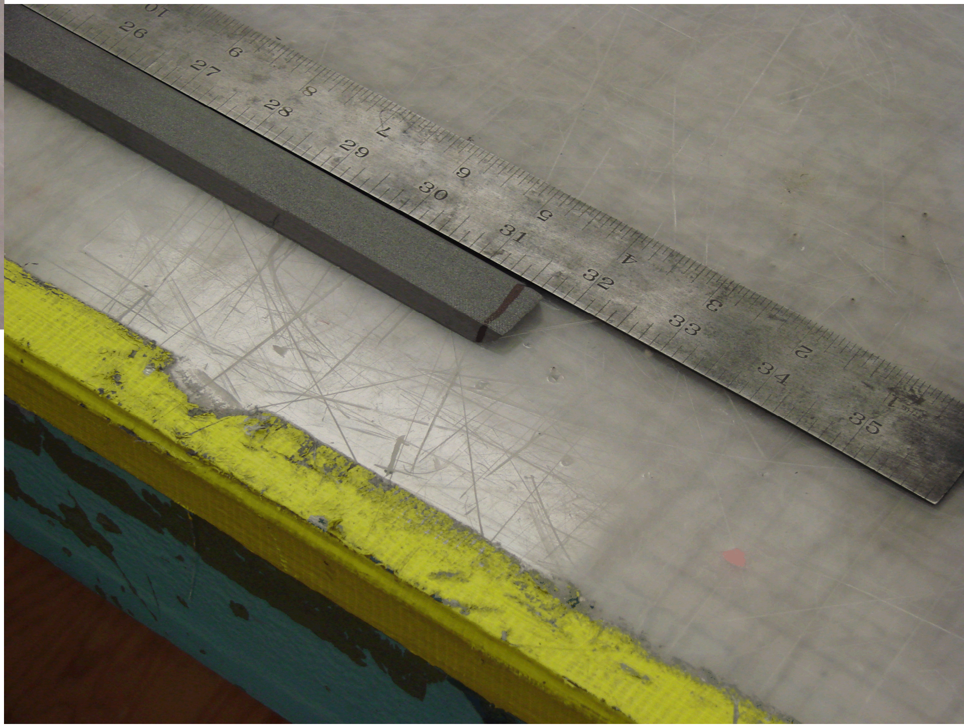
We form the radius using sacrificial Sylgard 184

Ribs

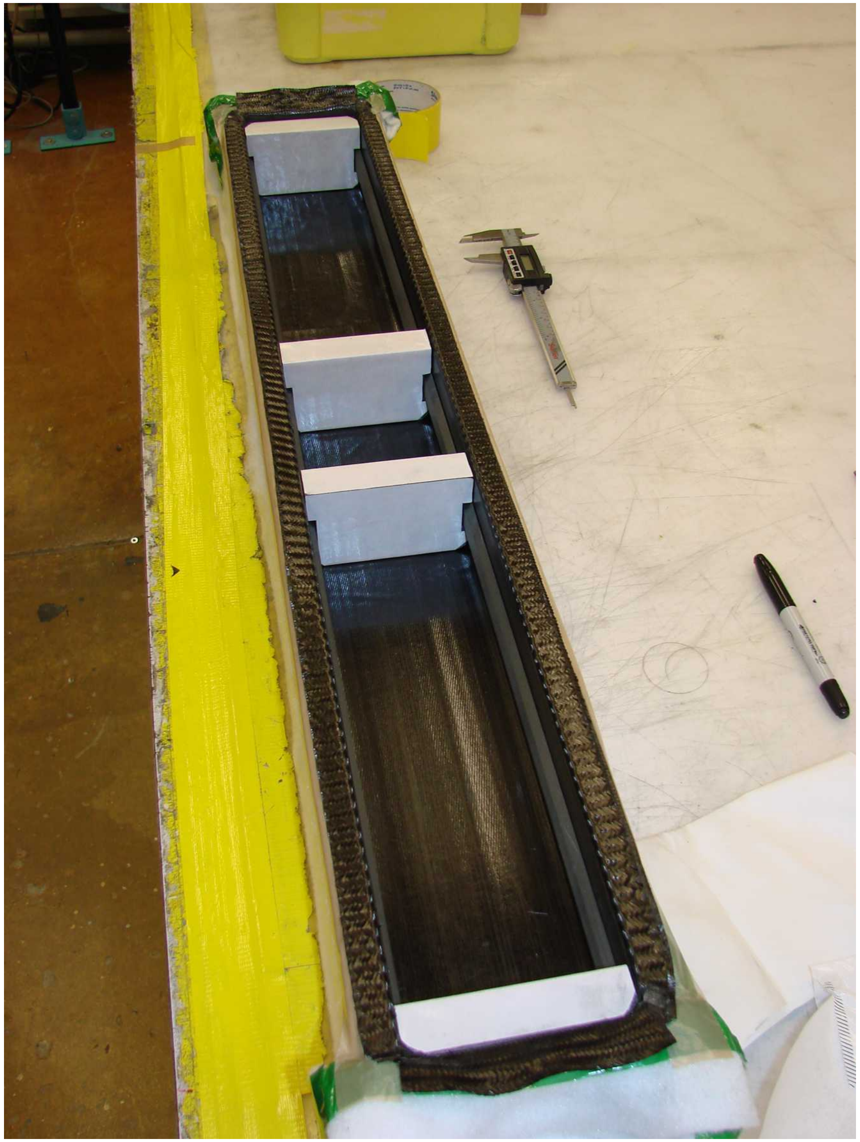


Completely made from uni pre preg

Layed up in advance as flat panel, precured, and then cut to size



Transoms

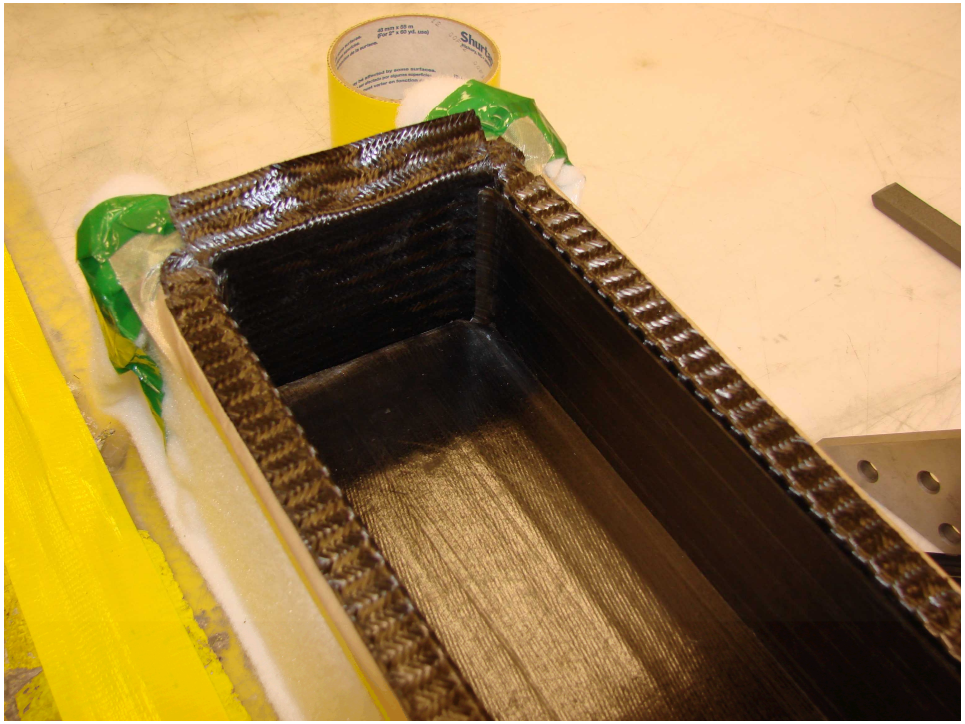


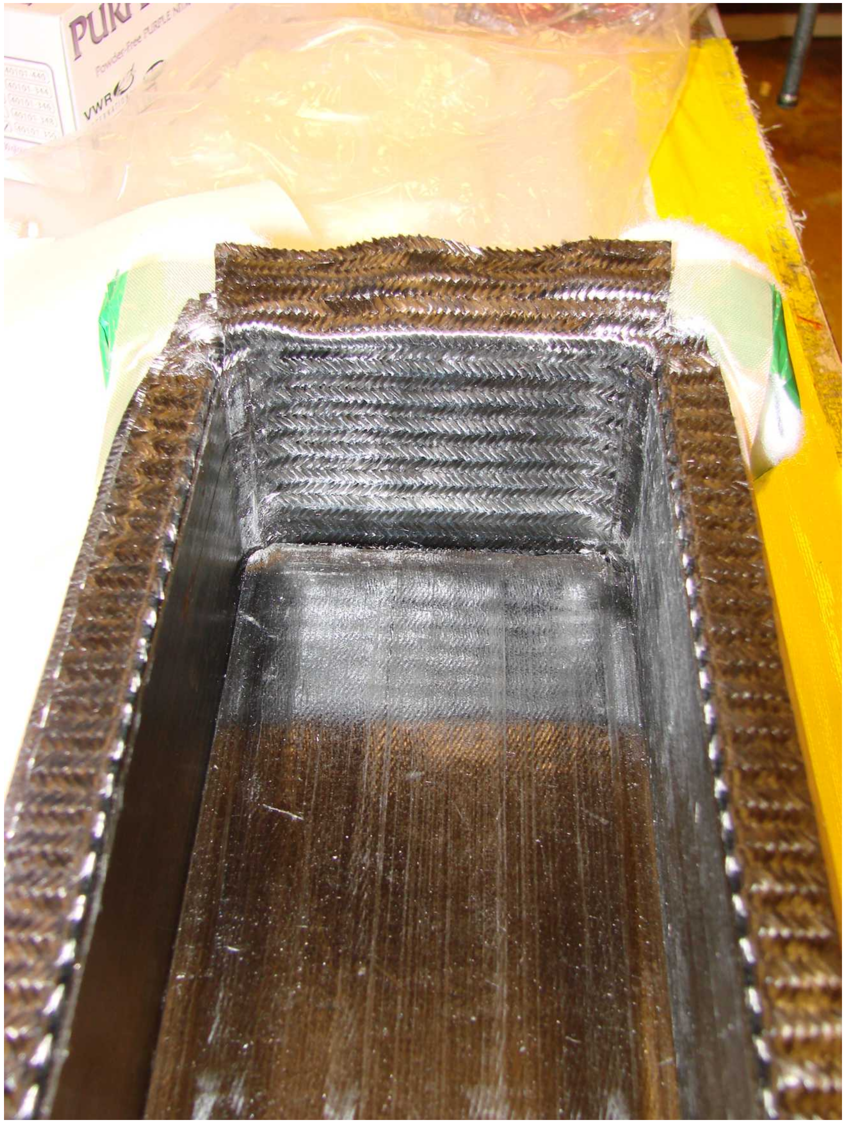
Precured solid quasi-isotropic laminates

Machined to shape

Wrapped with adhesive film prior to layup

Twill Shell and Uni Shell

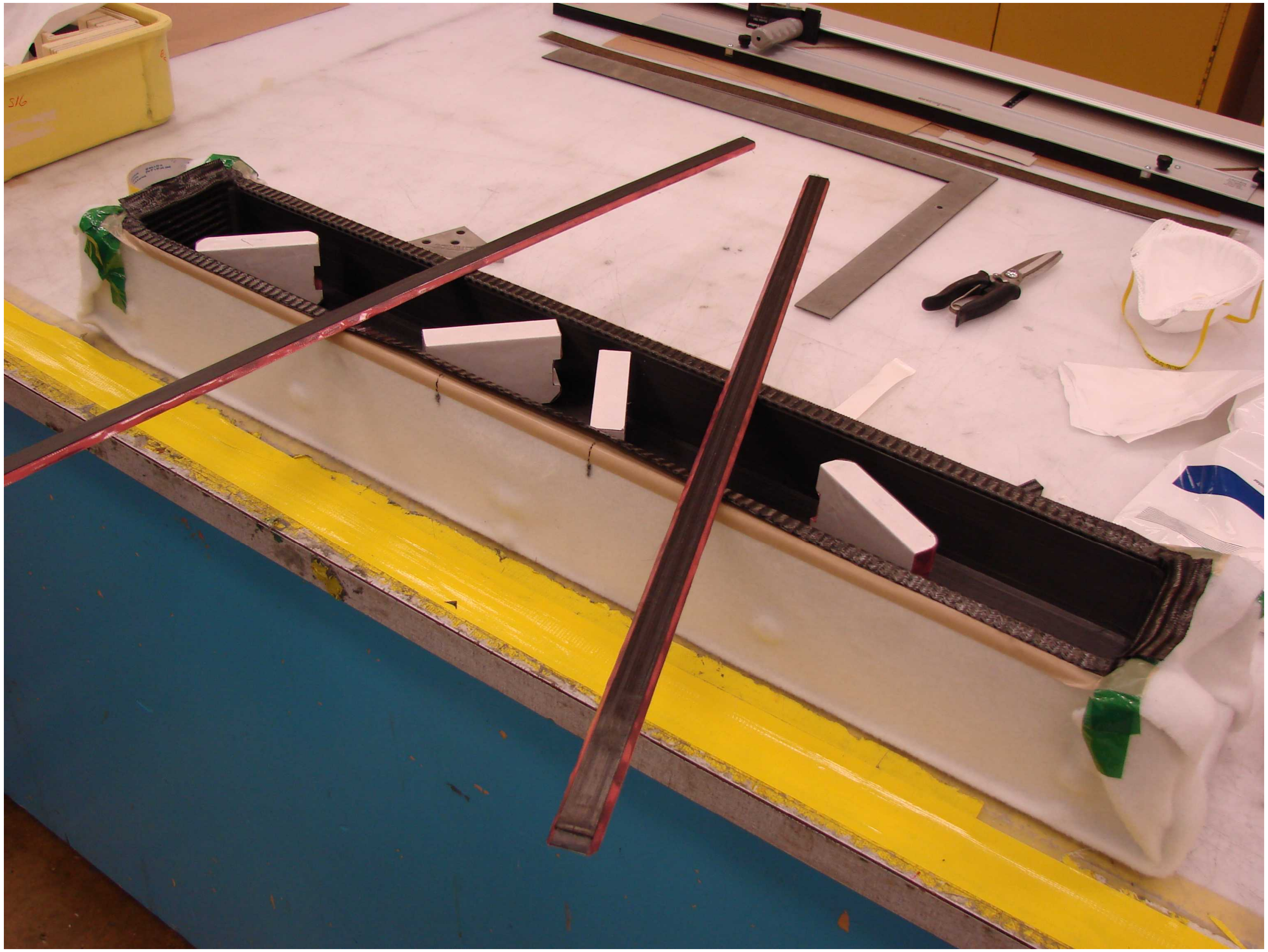




Sandia National Laboratories

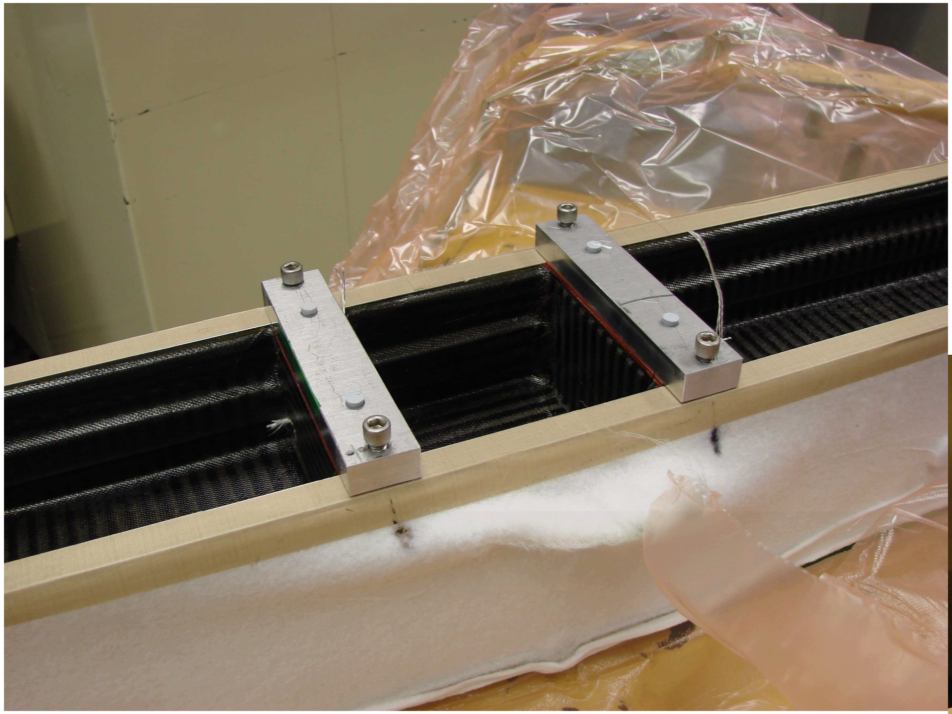
Uni Floor

Transom / Ribs



Inner Twill Shell

Transom Locators

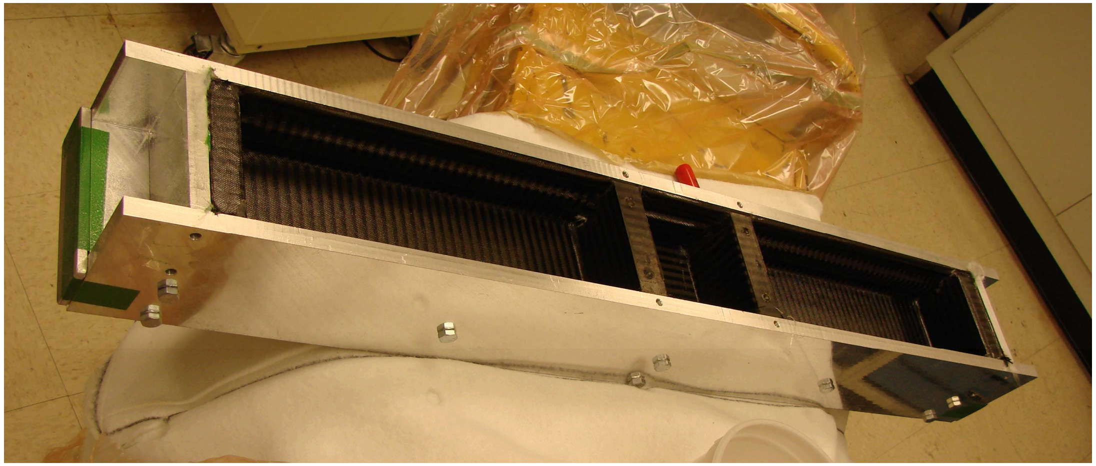


Vacuum Bag

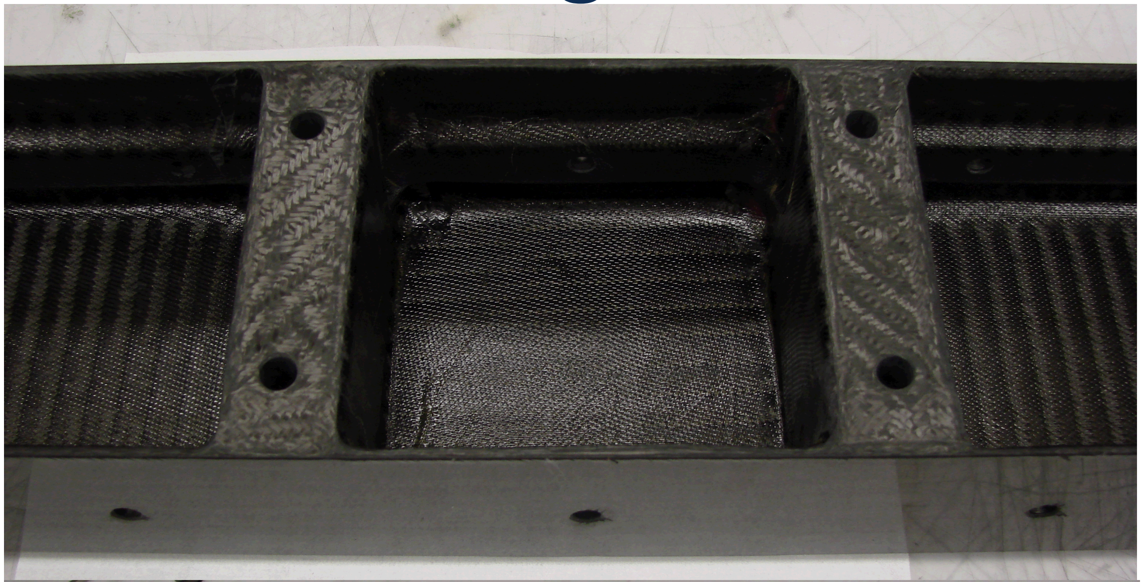
Autoclave

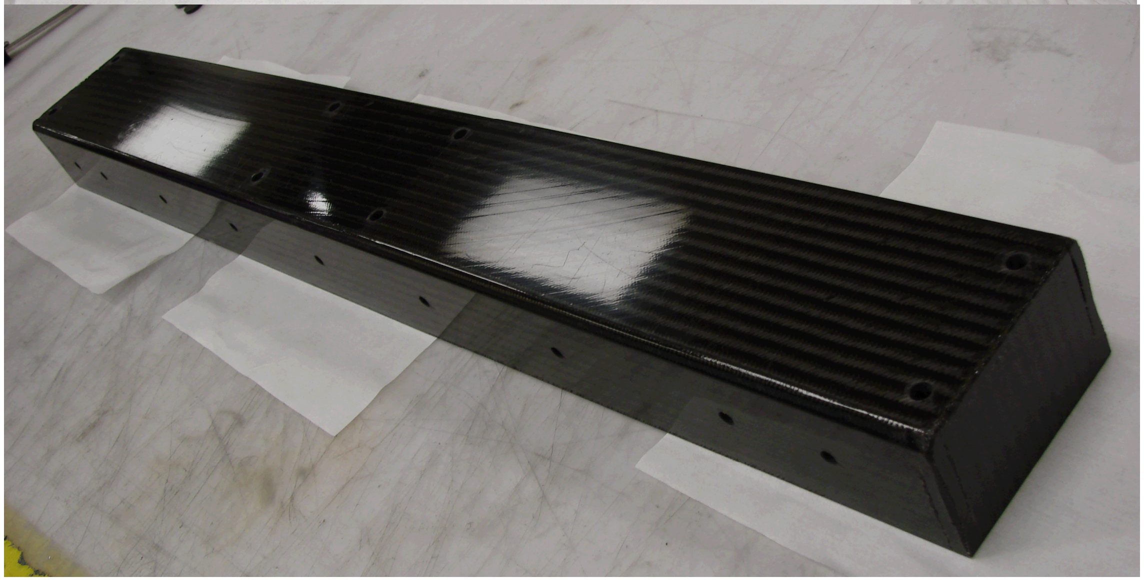
- Baron Autoclave
- 100 PSI @ 160 °F for 16 hours

Demold

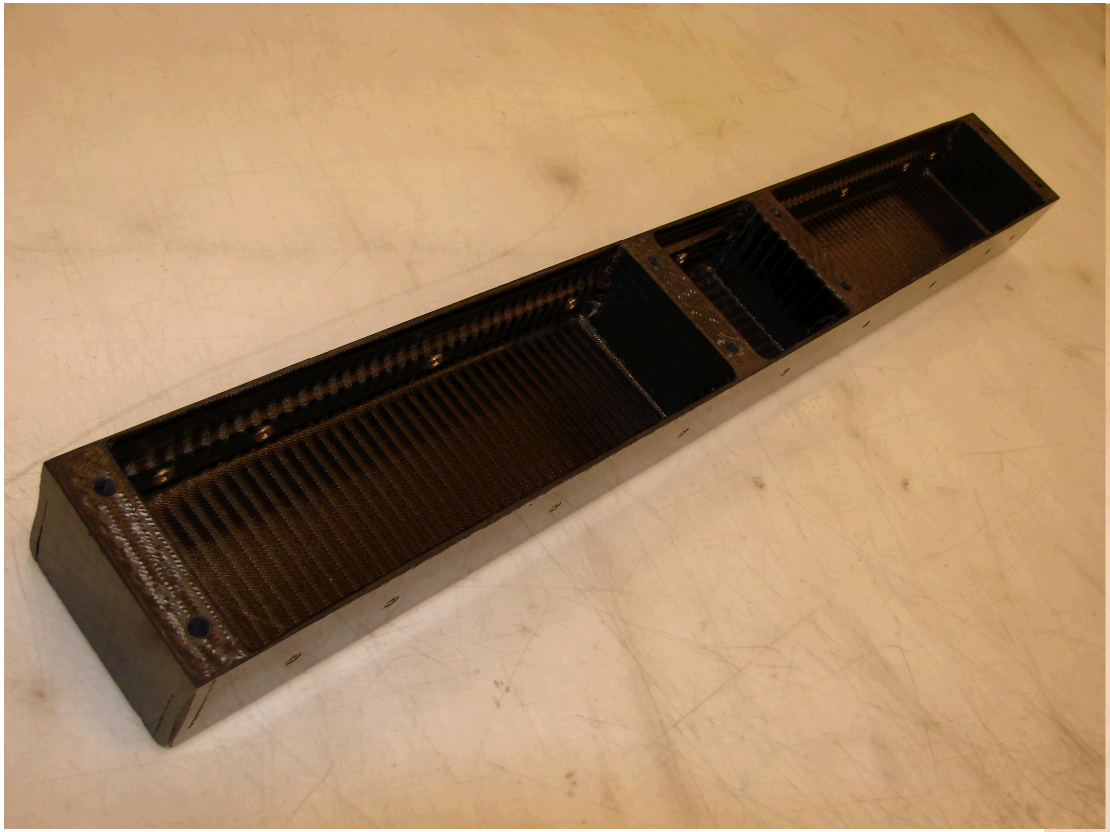


Machining





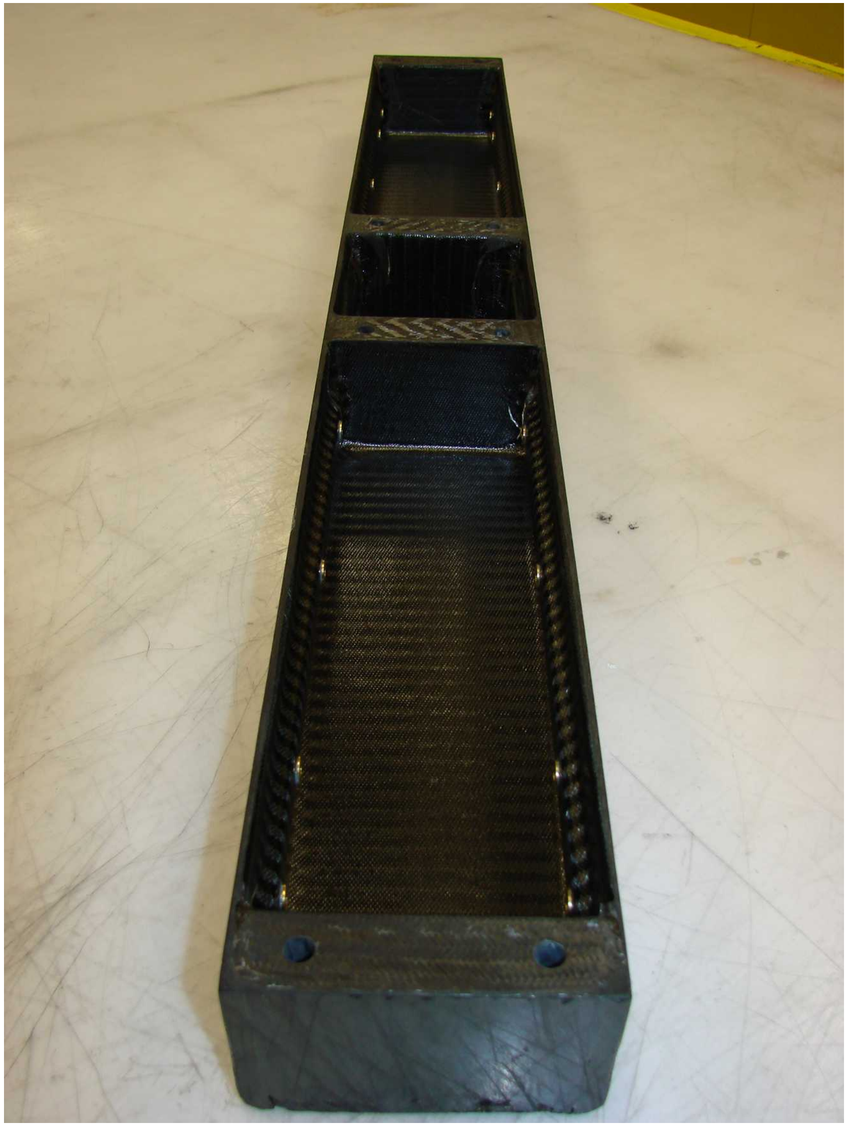
Inserts



Flange 10-32 brass inserts (for attachment of the Invar rails) mounted from inside-out

Bonded with Hysol 9394 structural adhesive

Final Assembly

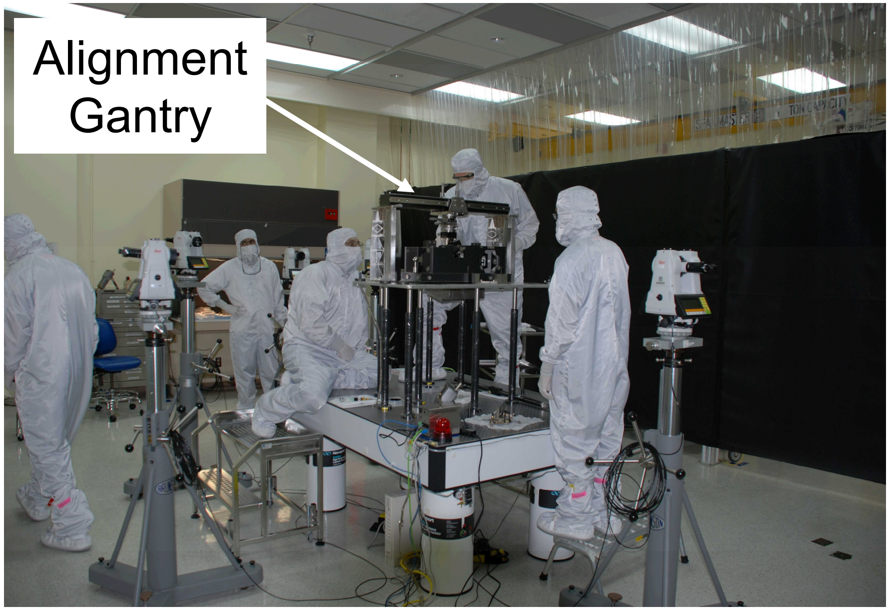


Final weight - 5 pounds (minus the Invar rails)

Well within the customer specification of 20 pounds

Far below the original design estimate (for Invar) of approximately 80 pounds

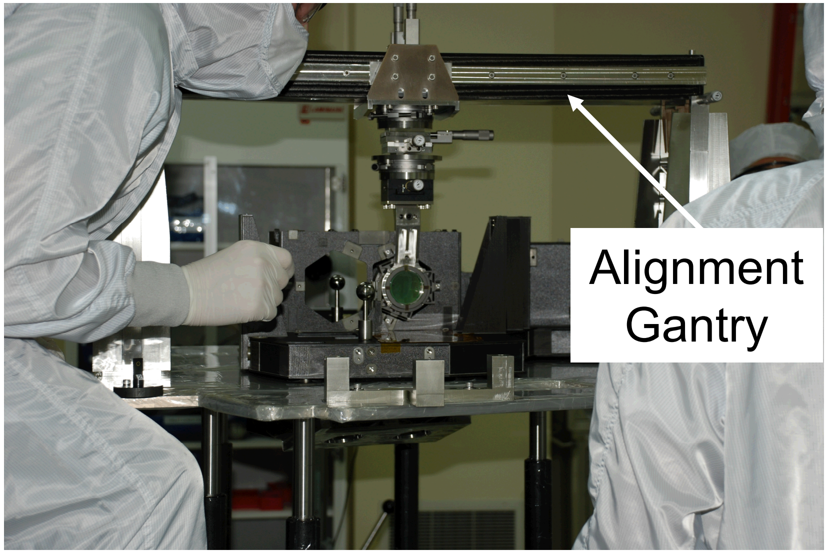
Conclusions



We developed and built a composite gantry beam for precise alignment during optics assembly.

The gantry has drastically reduced the time required to align the optical component elements (4 hours *vs.* 1 week).

The optics engineers also report it is much more accurate than they have ever seen in such a mechanism.



Conclusions

- We partner with engineering groups throughout Sandia (and elsewhere) to understand their project goals
  - Wind Energy, Solar Energy, National Security, other
- We have significant expertise and work to keep projects efficient and economical (*e.g.*, we often work with models – not drawings)
- We do mechanical design, materials callouts, fabrication, in-house machining, inspection, and form/fit/function testing for our encapsulation, adhesive, and composite projects
- We work with a variety of different processes and unique materials, including (but not limited to):
  - VARTM – vacuum assisted resin transfer molding
  - SMC – sheet molding compounds
  - BMC – bulk molding compounds
  - CF – carbon fiber laminates
- We team with other Sandia organizations for materials characterization and testing

Backup Viewgraphs

We fabricated prototype composite hardware for a satellite payload R&D program


Aluminum mold


Lay-up process


Vacuum bag cure


Completed shell

Harvester Overview for International AMS Technical Exchange

Joe Sanders

April 2016

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Outline

- Harvester Mission Overview
- Brief review of Harvester development history
- System and Capabilities Overview

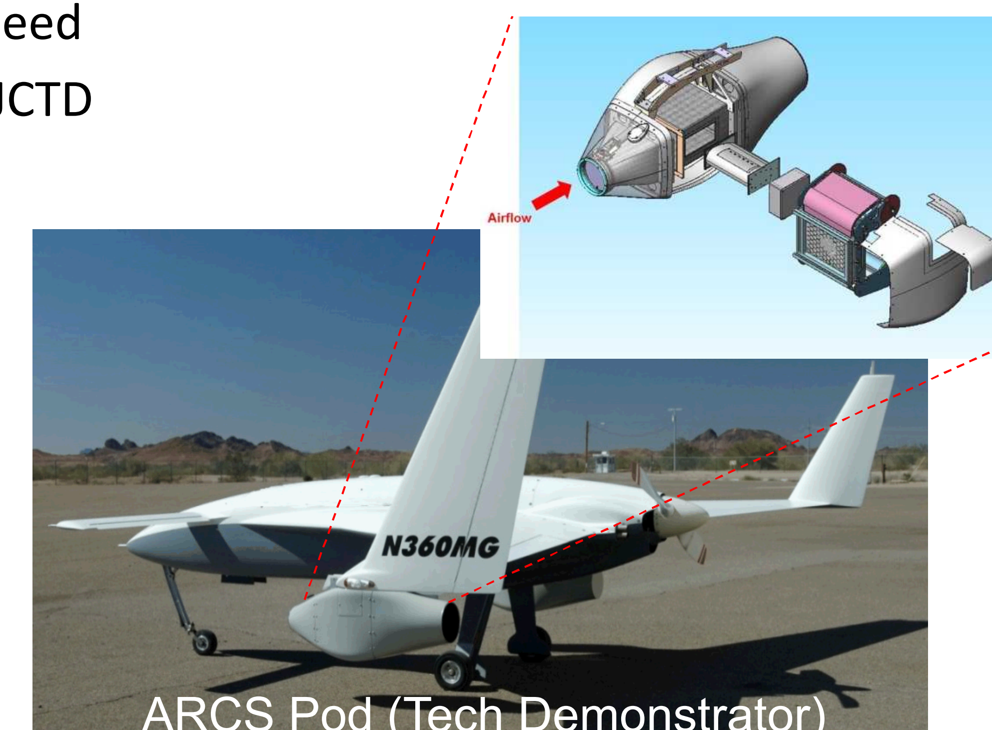
Harvester Mission Statement

Harvester is designed to collect debris released from a nuclear explosion, enabling subsequent detailed forensic analysis of the samples, and consists of two particulate sampling pods with real-time radioisotope identification capability, a high sensitivity gamma directional sensor that enables the aircraft crew to vector the aircraft toward the direction of peak plume radiation intensity, and an operator control workstation. An important attribute of Harvester is its modular design, allowing rapid integration onto designated aircraft models so that specific aircraft tail numbers do not need to be dedicated to support the mission. Harvester has been integrated and successfully flight tested on three aircraft platforms to date: MQ9 UAS, C-130H, and C-130J. It is also being considered for other USAF platforms.

Harvester History

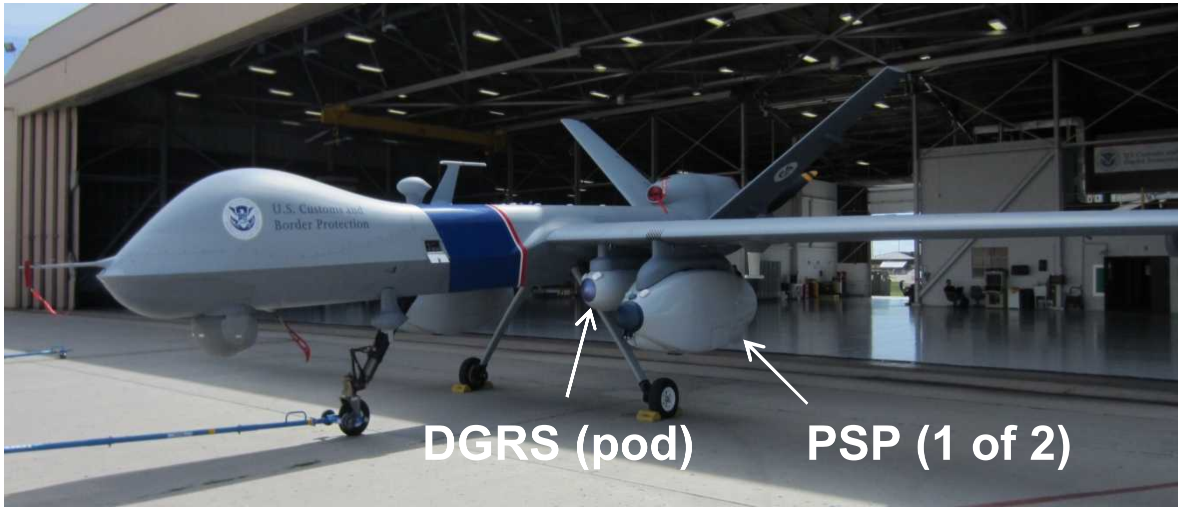
- Genesis of modularity occurred during AARE development – Is it possible to avoid mission-dedicated aircraft?
- R&D support through NA-22, DTRA, USAF
  - ARCS "tech demonstrator" pod flown on multiple aircraft
  - R&D to Harvester included scale-up, advanced rad modeling, flow/filter studies
- Close engagement with US DOD system operators and maintainers helped ensure users get what they want/need
- Harvester part of successful NTNF JCTD

AARE system



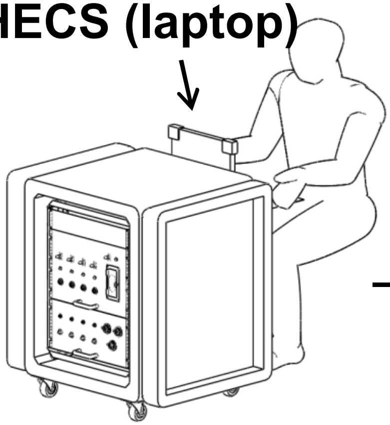
ARCS Pod (Tech Demonstrator)

Harvester Integration & Testing on MQ9



Harvester C-130 Configuration

HECS (laptop)

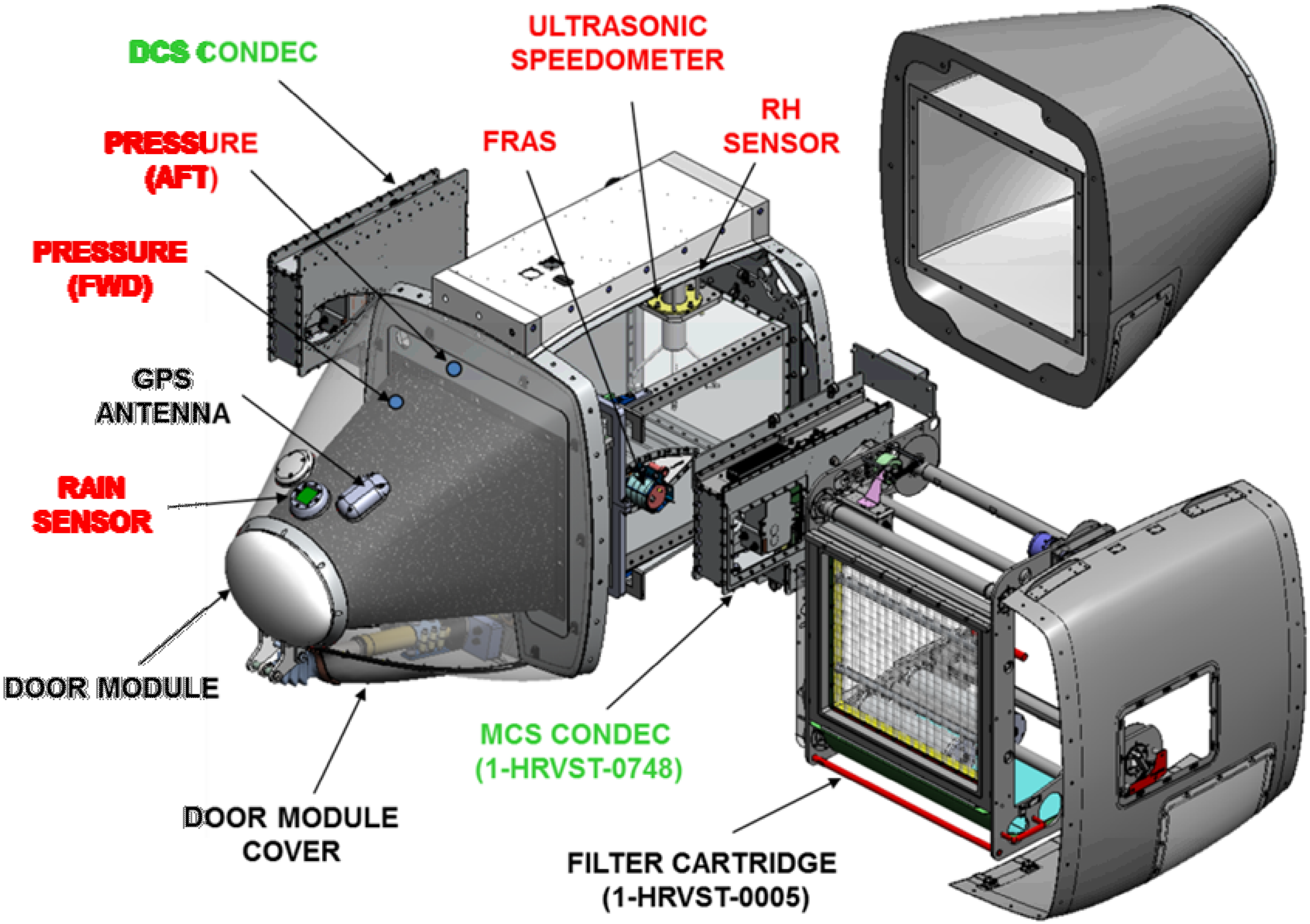


HFCU

Created a ruggedized control and power distribution system
- Central power/comm distribution

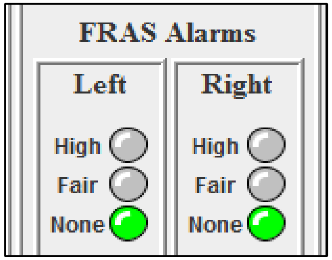
DGRS sensor array repackaged from pod to pallet

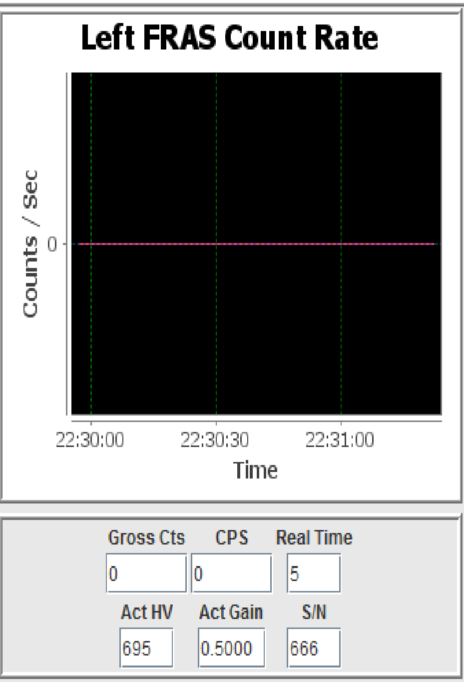
Particulate Sampling Pod (PSP)



Filter Radiation Analysis System (FRAS)

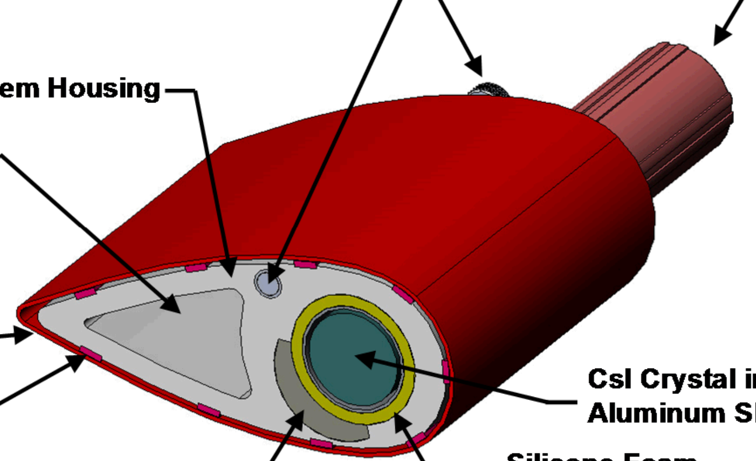
- Real-time spectral measurement of debris on filter
- IDs radioisotopes





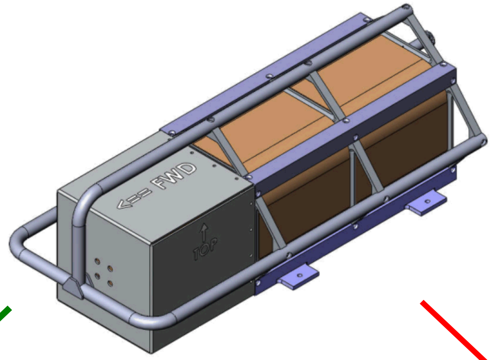
Isotope Data

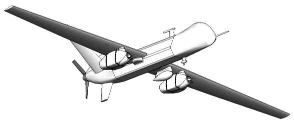
Isotope	Isotope
Sr91	I132
Zr95	I133
Zr97	Cs134
Nb97	IXM135
Mo99	Xe135
Tcm99	Cs136
Ru103	Ba140
Ru105	La140
I131	Ce141
Rh105	Ce143
Te132	Ce144
Cs137	Na22
Th232	Ba133
Be7	Bi214
Pb212	Pb214

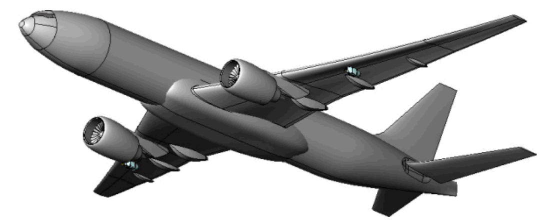


It is straightforward to change the radioisotope library – ours was optimized for a nuclear explosion occurring within hours to days

Directional Gamma Radiation Sensor (DGRS)

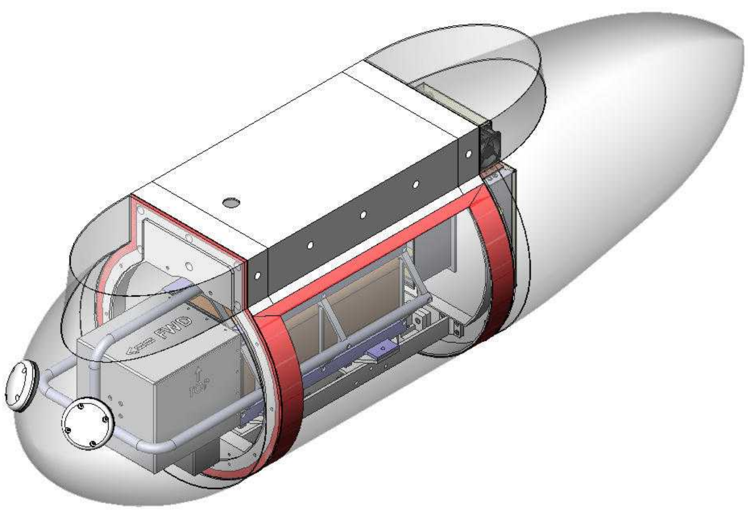


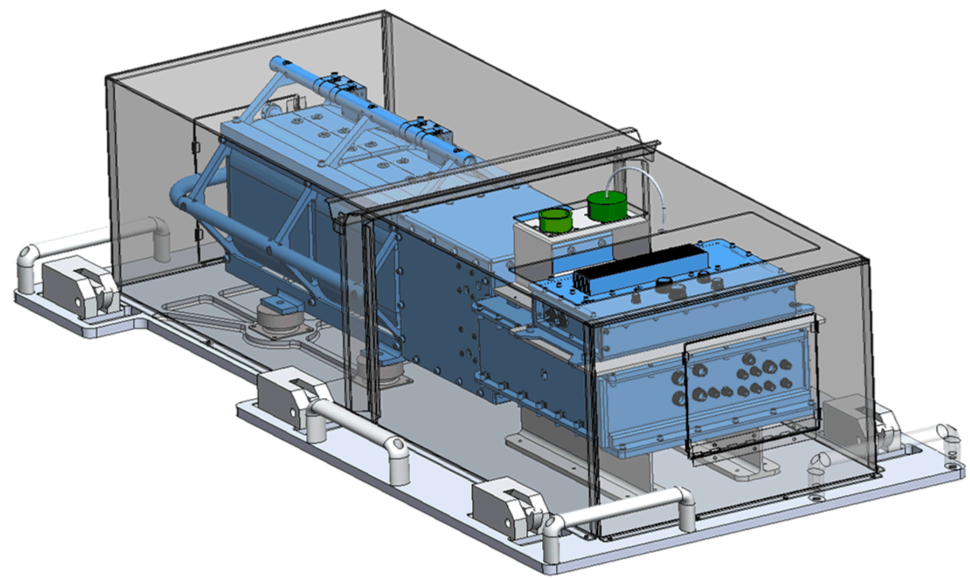




DGRS, In-Pod Version

DGRS, In-Fuselage Version





Harvester Software

- Operation via HECS (ruggedized laptop)
- Distributed architecture with computers in PSPs and DGRS communicating with HECS via ethernet
- Autonomous operation (originally intended primarily for UAS use)
- Significant software updates throughout process based on user feedback