Damage Arresting Composites Using Interlaminar Stitches

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April 29-30, 2015

Outline

- Background
- Value of through-the-thickness stitching
- Current structural concept
- Panel fabrication methodology
- Assembly into test article and structural performance

Participants

- Stitched structure development was initiated under the Advanced Composites Technology (ACT) Program between NASA and McDonnell Douglas Company in the 1990's
- Continued development with the Boeing Company (Boeing) and the Air Force Research Lab (AFRL) in the early 2000's when the current structural concept was born
- New partnership formed in 2007 between NASA and Boeing which continues today under the Environmentally Responsible Aviation (ERA) Project
- Federal Aviation Administration (FAA) has also contributed to the current activity
- Under ERA, NASA and Boeing have worked together on design, analysis and testing, but all fabrication has been done by Boeing Research and Technology

Goals of the ERA Project

- Develop technology for commercial transport aircraft to simultaneously reduce:
  - Fuel consumption
  - Pollution
  - Community noise
- Develop technologies supporting conventional aircraft and new aircraft configurations
- Aim for technologies that could be implemented in the 2025 to 2030 time period
- Run the Project over 2009-2015

Composites for Aircraft

- Reducing aircraft weight allows for smaller engines which will burn less fuel
- Stiffer structure allows for aerodynamic advantages with stiffer and/or longer wings
- Composite materials allow for more opportunities for tailoring

Full advantage of opportunities provided by composite structures have not been realized

Stitched Composites Project Objective

Develop technology to reduce aircraft weight by 10 percent over state-of-the-art composites while maintaining safety margins and supporting advanced aircraft configurations

Design with Stitched Structure

- Stitching provides through-the-thickness attachment that can reduce or eliminate the need for fasteners
- Removing holes for fasteners removes the need for build-ups in the regions of fastener holes
- Stitching provides through-the-thickness reinforcement to prevent delamination, turn cracks, and minimize the spread of damage, which changes the design space by suppressing failure modes
- By removing the possibility of delamination between plies or between flanges and skin, repeated buckling cycles and pressurizations do not trigger failures
- Suppressing the skin-flange separation failure mode caused by repeated pressure cycles on nearly flat panels as found in the center section of a Hybrid Wing Body (HWB) vehicle means that stitching is enabling technology for HWB center section

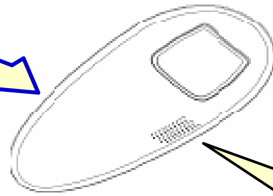
Development Path for Stitched Composites

NASA/Boeing ACT Technology

Ended in 2000

Lightly Loaded Secondary Structure

Production

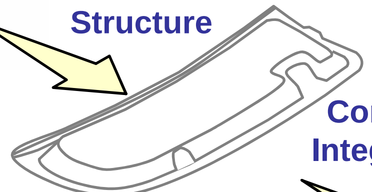


LAIRCM Fairing

Fairing First Flight 2003

Moderately Loaded Structures

Unitized Structure



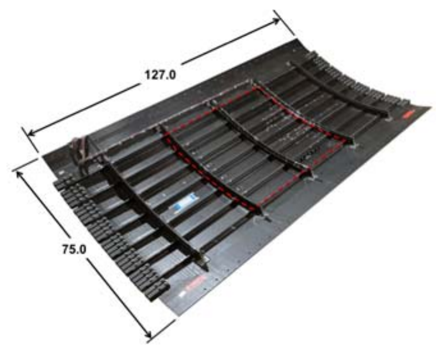
Gear Doors

C-17 Production Main 2006

Highly Loaded Structures

Complex Integration

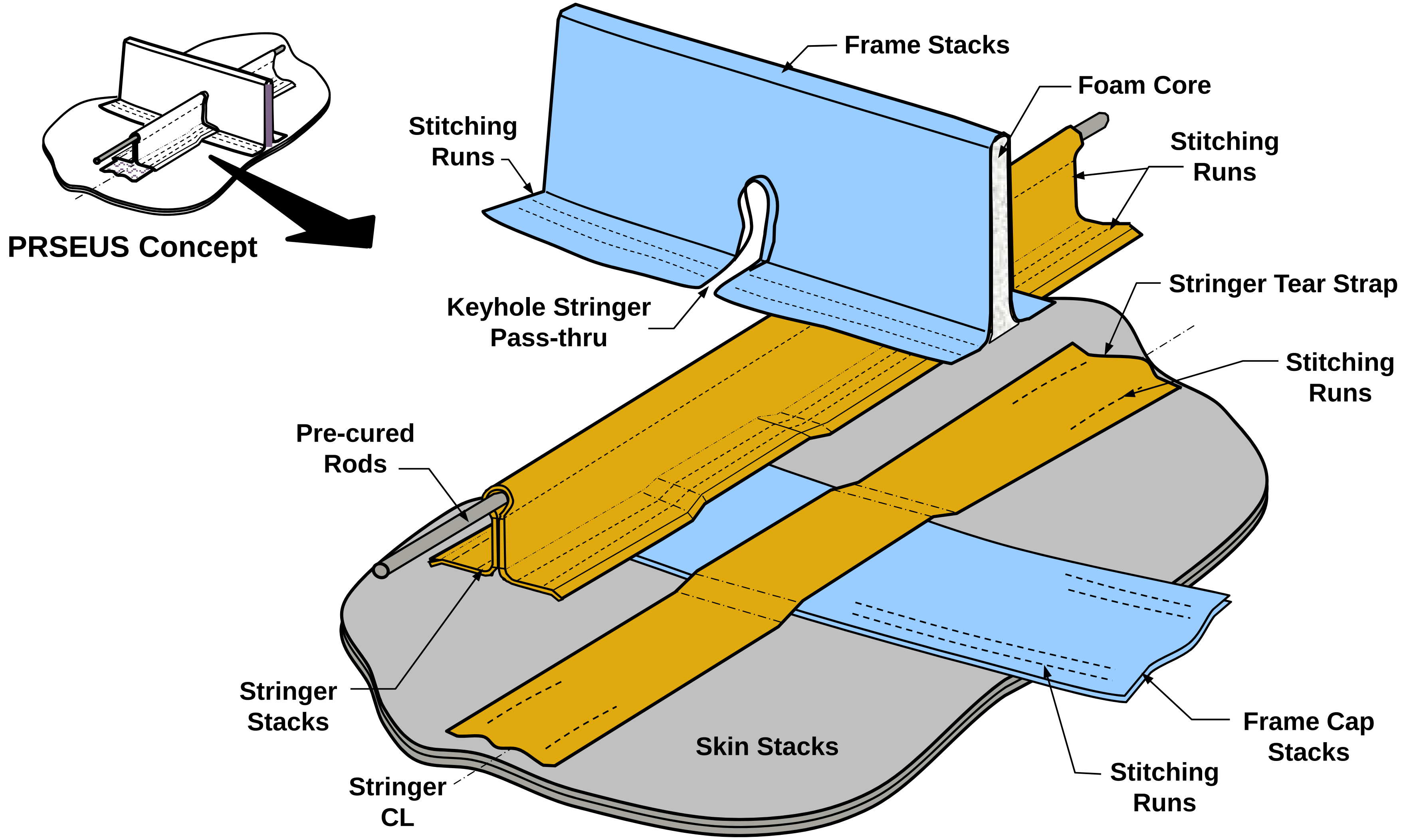
Curved FAA-NASA Panel 2010



Large Panel AF Contract 2006

Wing and Fuselage Structures

Pultruded Rod Stitched Efficient Unitized Structure



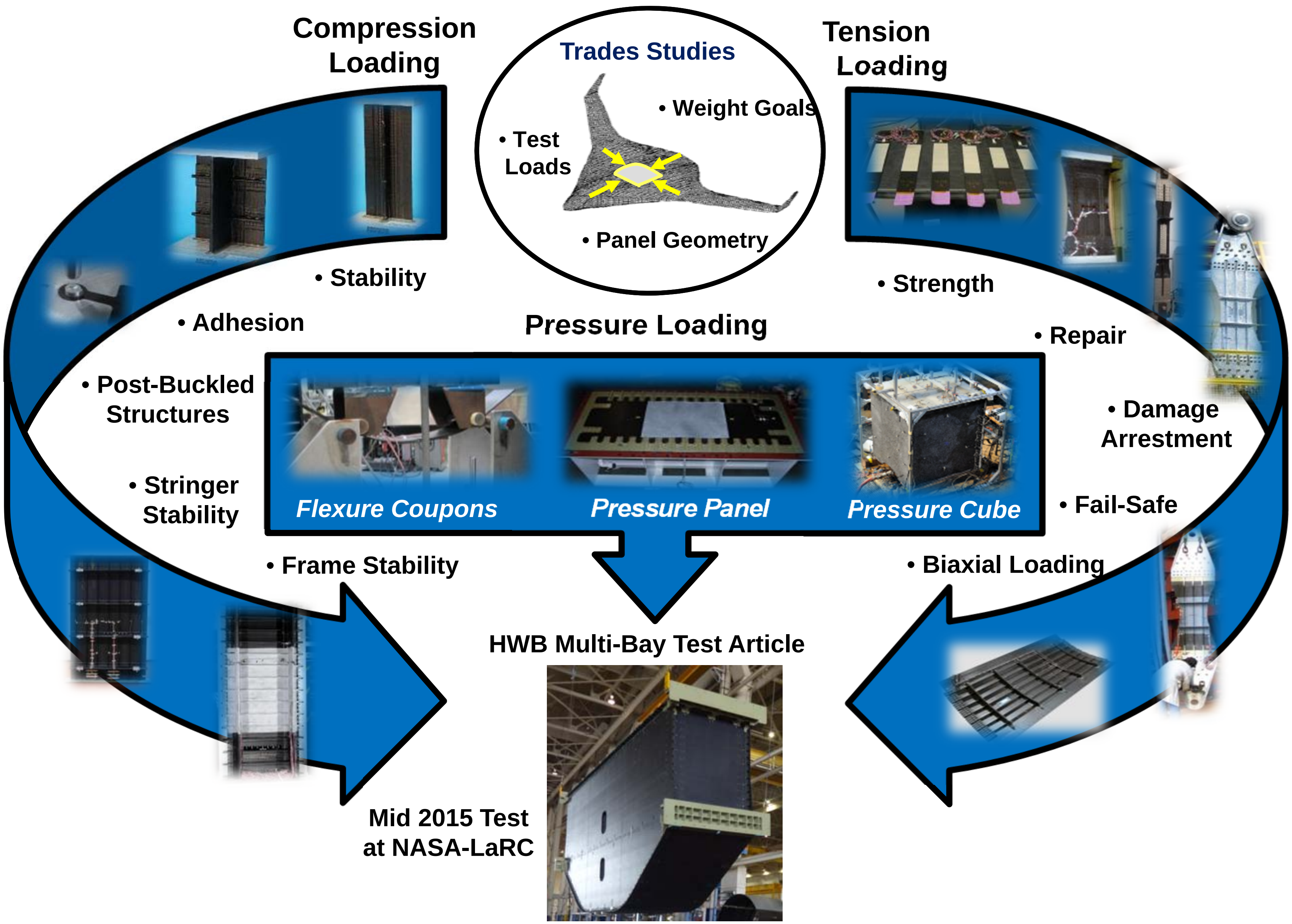
Exploded View of PRSEUS Panel Concept

Stacks of 44/44/12 percent 0/45/90 lay-up
0.052 in. thick

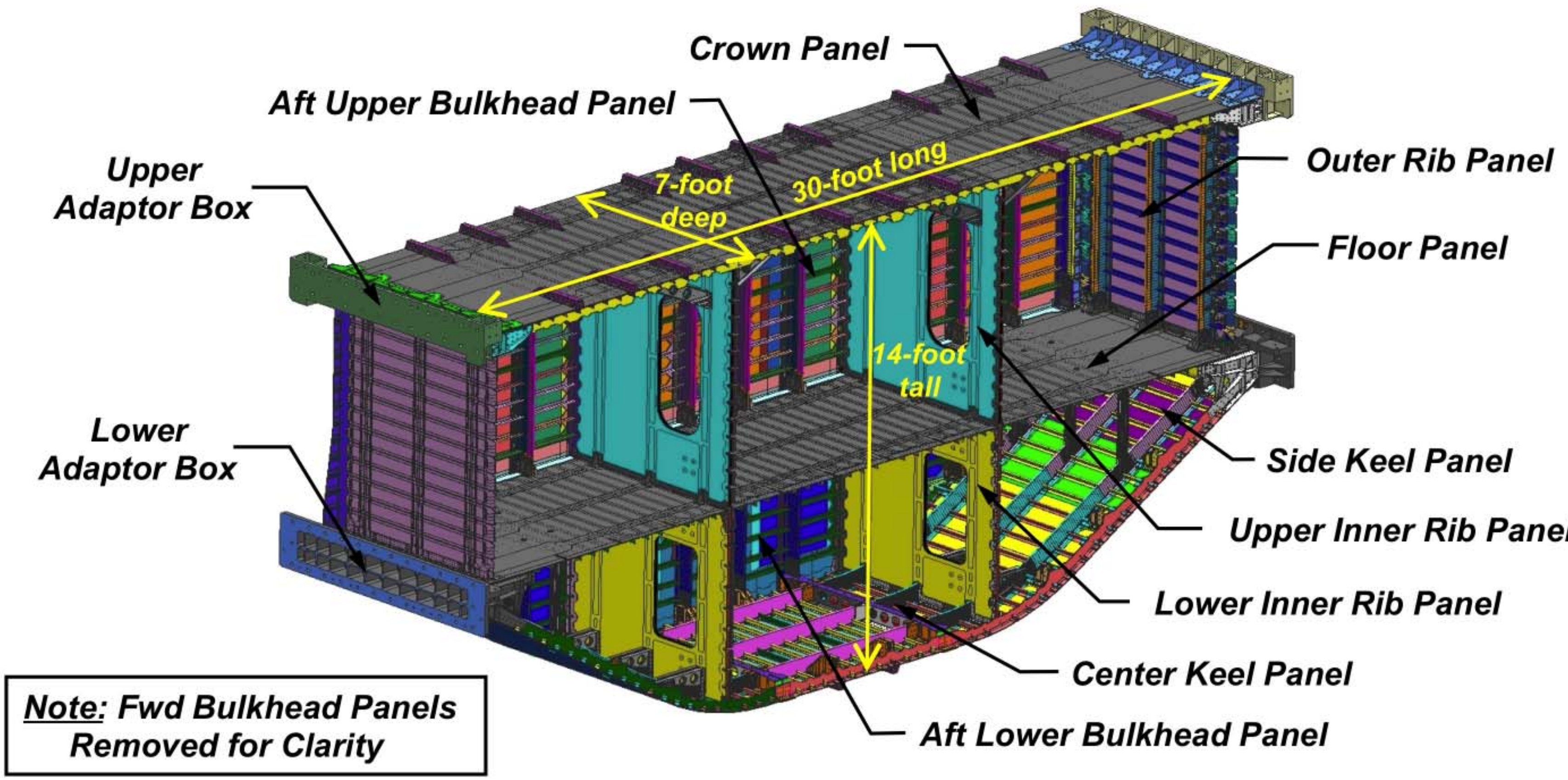
Unitized Stitched Structures

- Large integral components
- Out-of-autoclave process (oven with vacuum pressure only)
- Dry fabric removes out time issues associated with prepreg
- Fabricate entire wing cover panel or entire upper section of fuselage in one cure
- Hard metal tooling on outer moldline (OML) only
- Simplified bagging process for inner moldline (IML)

Building Block Testing

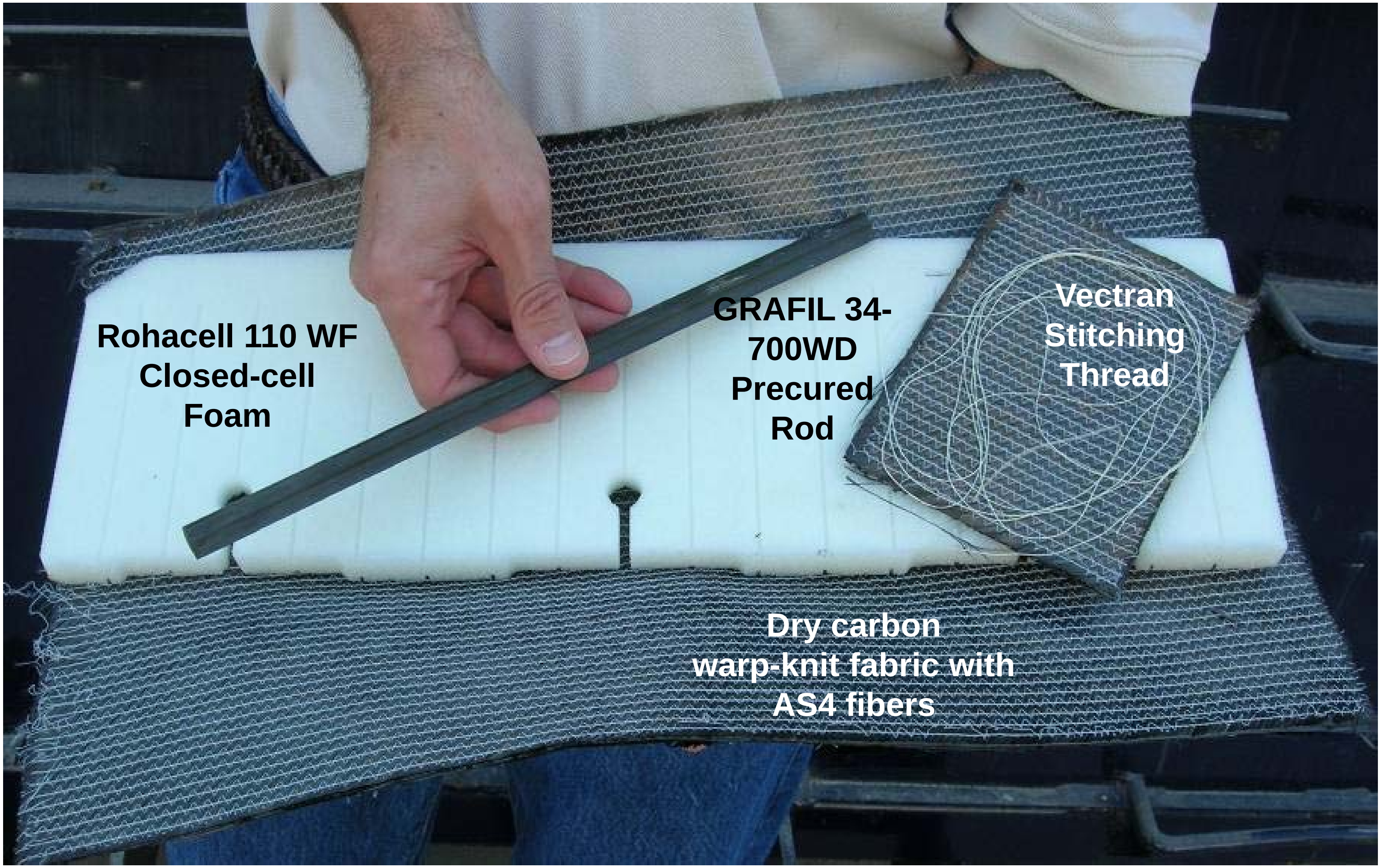


Multi-Bay Pressure Box Test Article

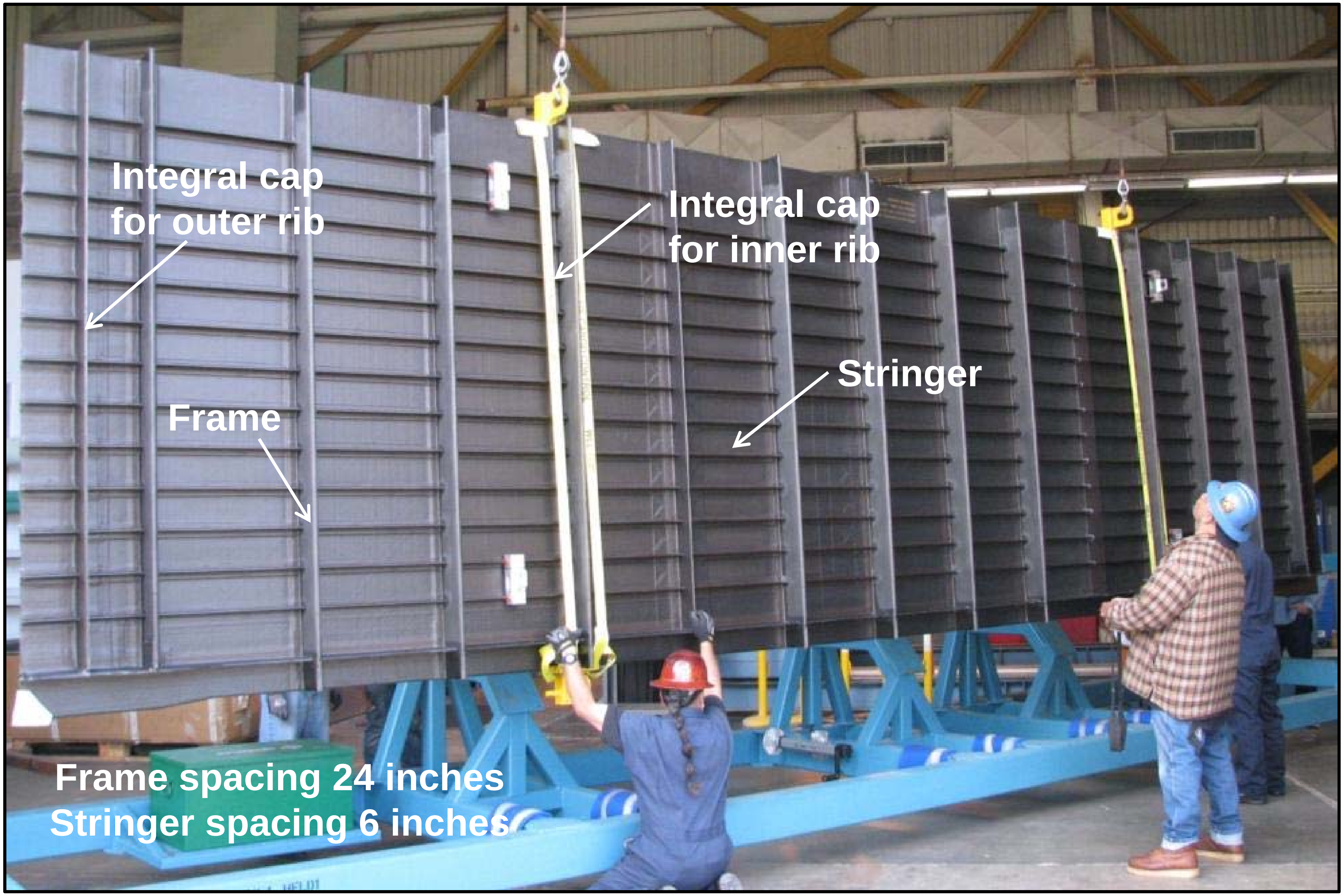


- 11 PRSEUS panels
- 4 sandwich panels
- Metal fittings and load introduction hardware

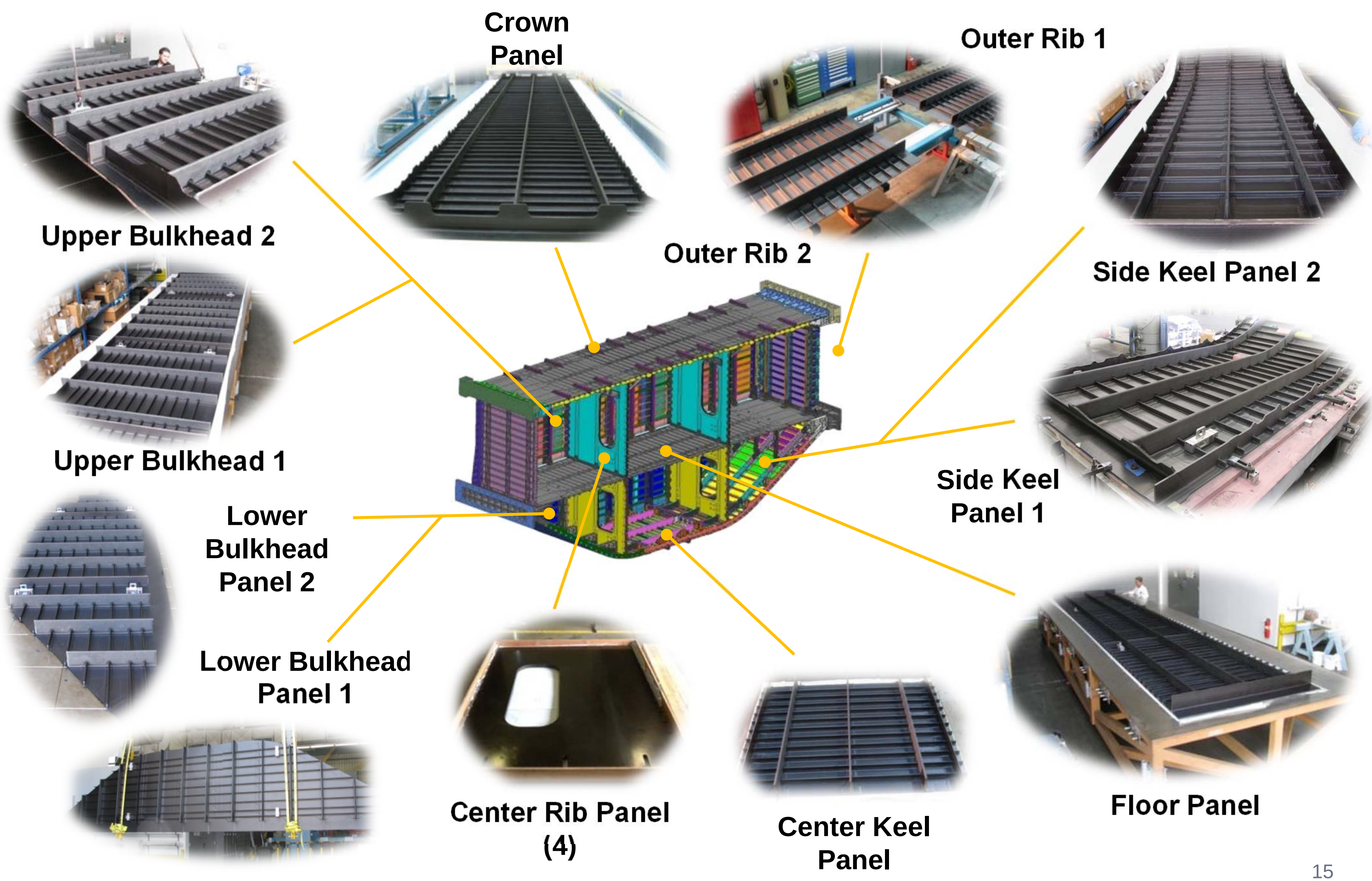
PRSEUS Components



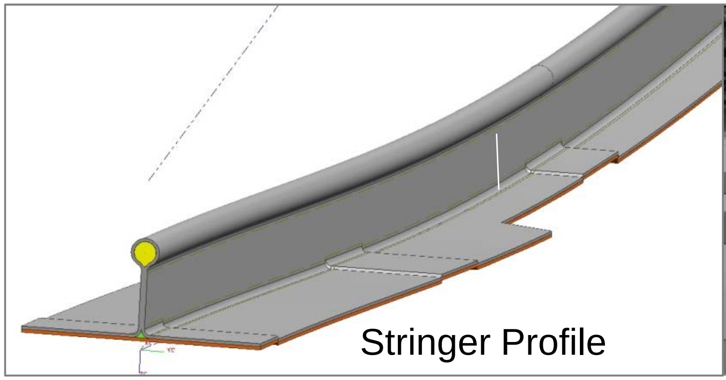
PRSEUS Bulkhead Panel

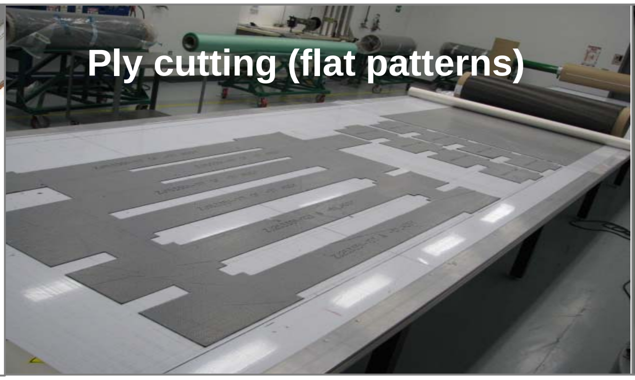


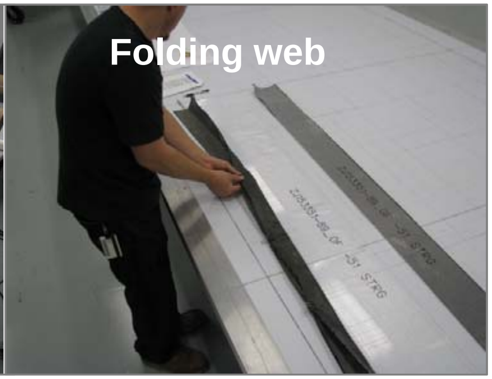
Panels for the Multi-Bay Pressure Box

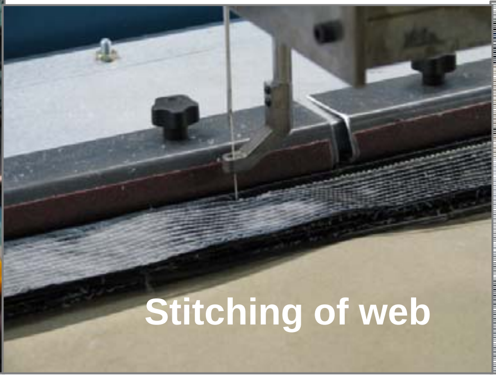


Stringer Preforms



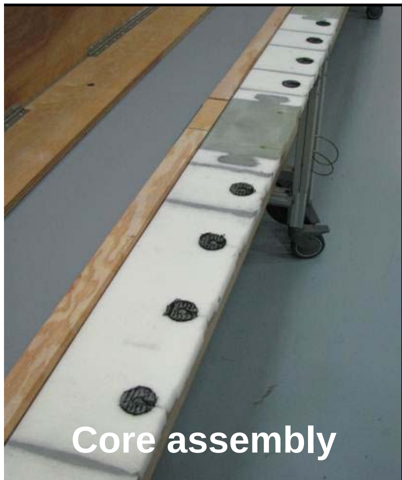


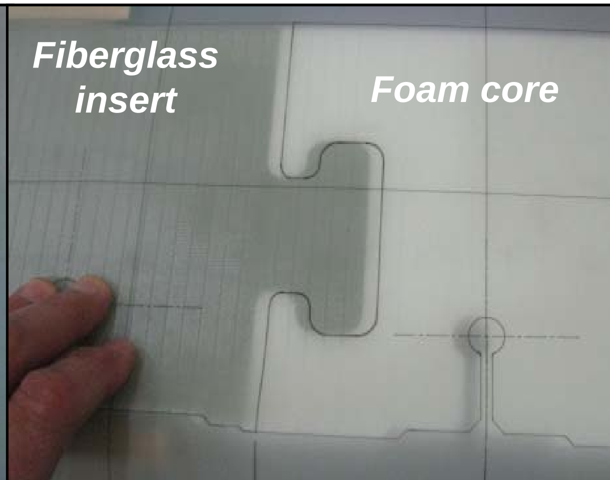


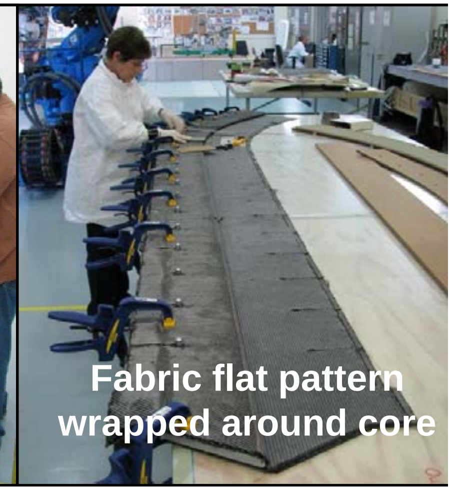


- Stringer blanks produced
- Stitching creates a “pocket” for the rod to be later inserted
- Leader wire in pocket to keep stringer flat and allow rod insertion later
- Flanges formed and fillet installed later

Frame Preforms

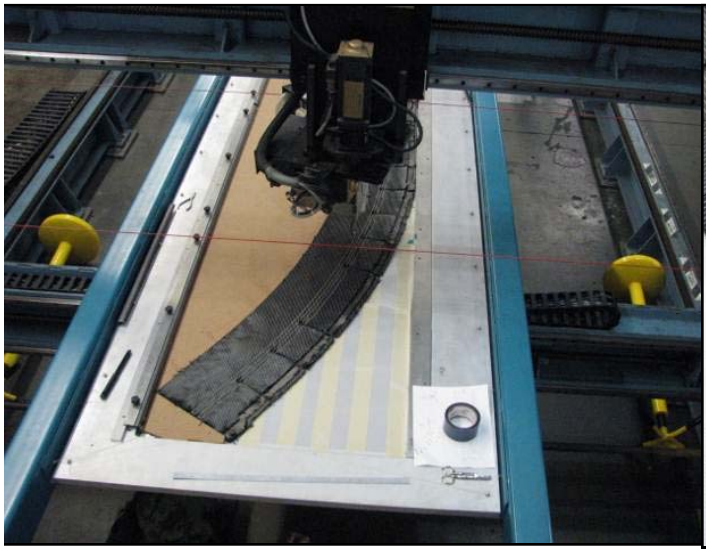




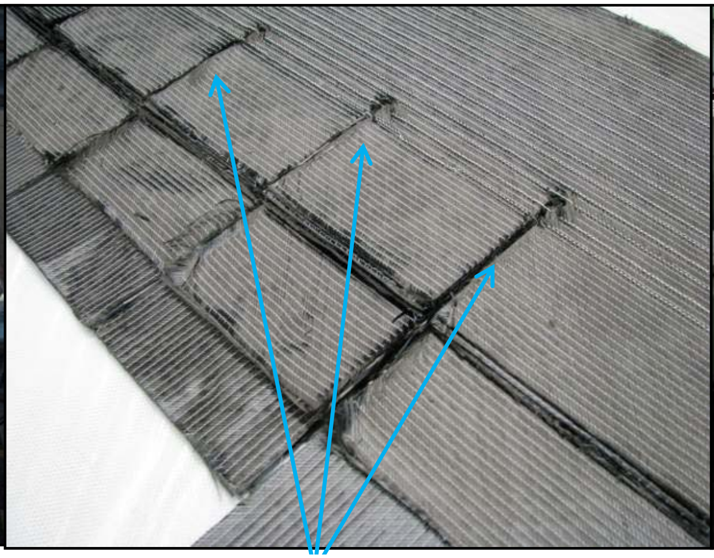


- Fiberglass included at frame ends
- CNC machined foam and fiberglass core assembly
- Flat patterns net sized (no subsequent trimming)
- Fabric wrapped around and stapled to core
- Flanges formed in panel assembly jig

Bulkhead and Rib Cap Preforms



Stitching of web



Keyhole for stringer pass through

Locally extended flange (tabs)

- Bulkhead and rib cap blanks produced off-line
- Flat patterns net sized (no subsequent trimming) with “keyhole” slot
- Flanges formed and fillet installed in panel assembly jig

Panel Preform Assembly Jig (Stitch Tools)


- Position and hold near net shape preforms for subsequent assembly stitching
- CNC machine foam blocks and wood details
- Pinned and bolted to steel base in robot cell

Frame and Cap Installation

Center frame inserted

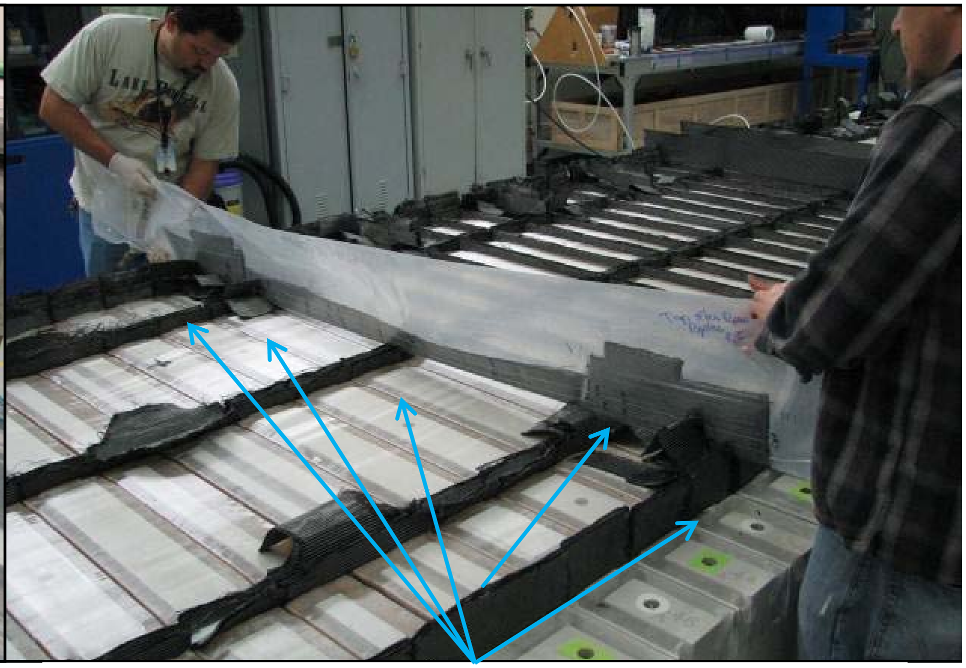
Bulkhead caps inserted

- Thin fiberglass layer on tool allows near edge stitching
- Frames and caps inserted down into tool cavity
- Flanges protrude outward from assembly jig at this stage

Frame, rib & bulkhead cap installation

Stringer Installation

Vacuum bagged stringers



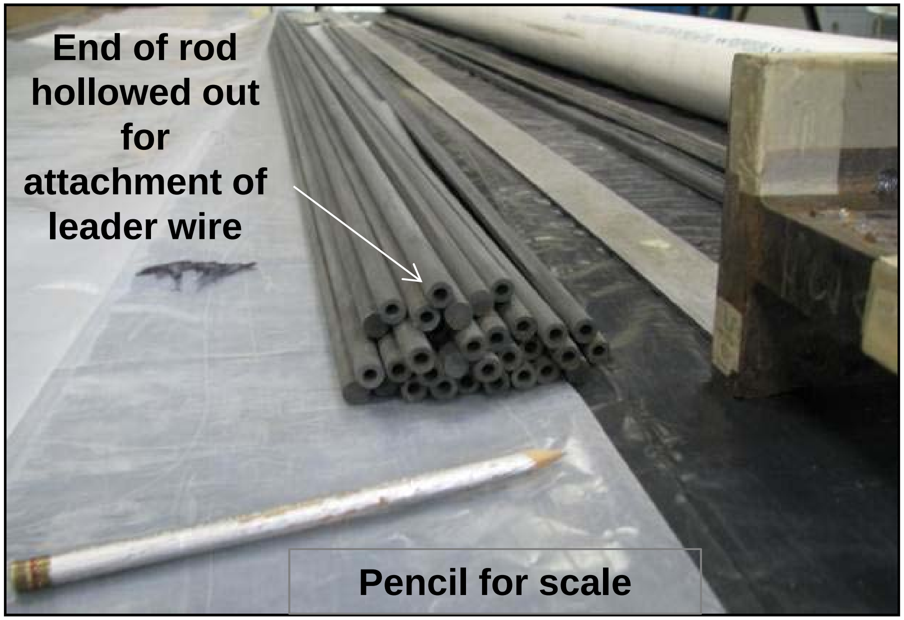
Web of stringer preform inserted into keyhole slot in frames and caps

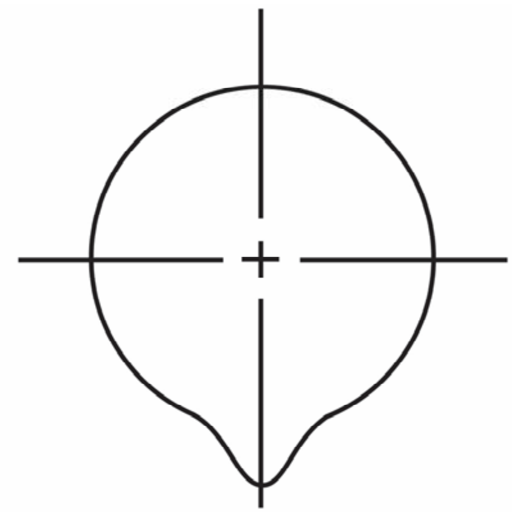
- Stringer installed in collapsed condition
- Vacuum bag is removed
- Bulb feature formed not yet formed (pocket still flat)

Forming of Flanges

- Dry soft fabric is folded down against tool surface by hand to form flanges of frames, cap, and stringers

Pultruded Rods

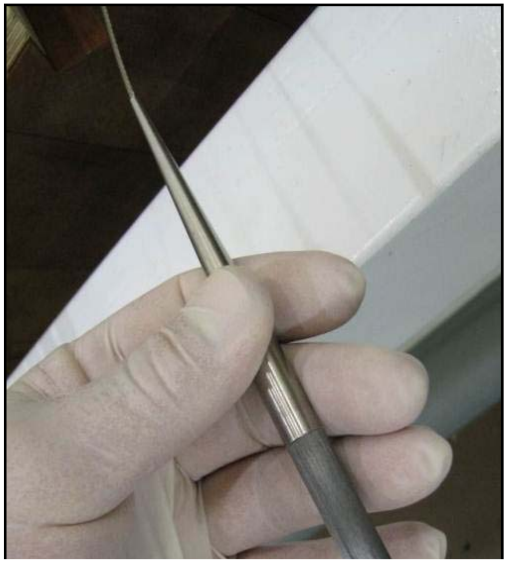




Pultruded rod
Nominal diameter 0.375 in.

- Carbon fiber rods
- Pultruded cross section with integral fillet feature
- Cut to length and end drill for attachment of leader wire
- Grit blast and deionized water rinse surface preparation
- Installed into stringer during panel preform assembly

Rod and Fillet Installation



Rod-to-leader adapter

Rod installation

Fillet installation

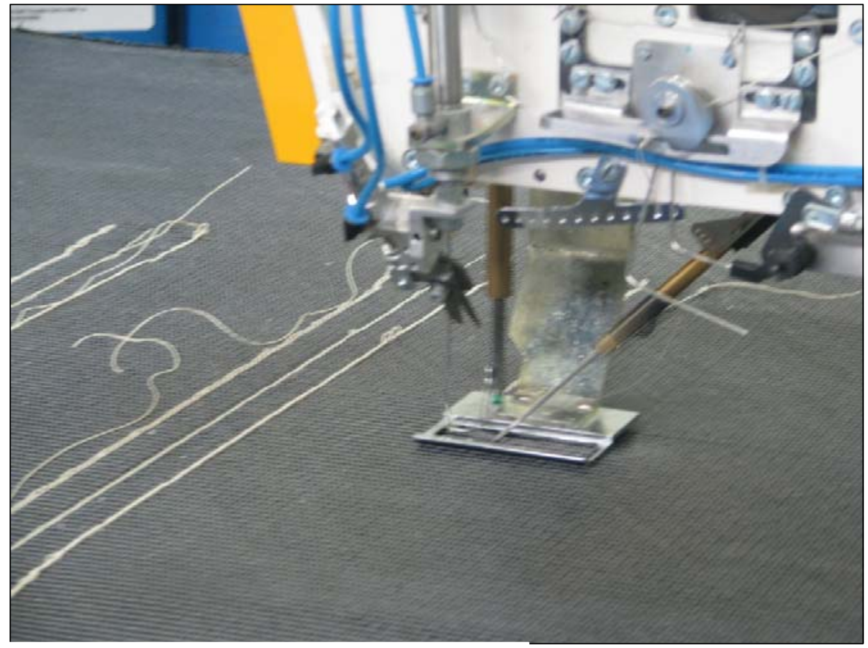
- Leader wire used to pull rod into stringer pocket
- Rod installation
  - Forms bulb feature of stringer web
  - Interlocks bulb of stringer into frame and cap webs
- Fillets tack stitched in place

Tear Strap and Skin Lay-Up

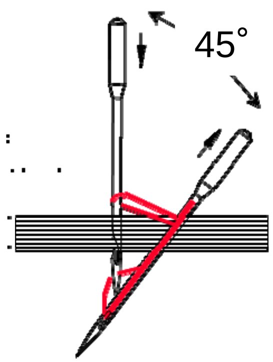
Skin ply stack lay-up

- Lay down each tear strap
- Roll out skin stacks

Single Sided Robotic Stitching



Stringer flange-to-skin seam installation



← **Single thread two needle system**

- Program robot for each seam
- Stitch using single sided stitching
- One needle straight down and one needle angled

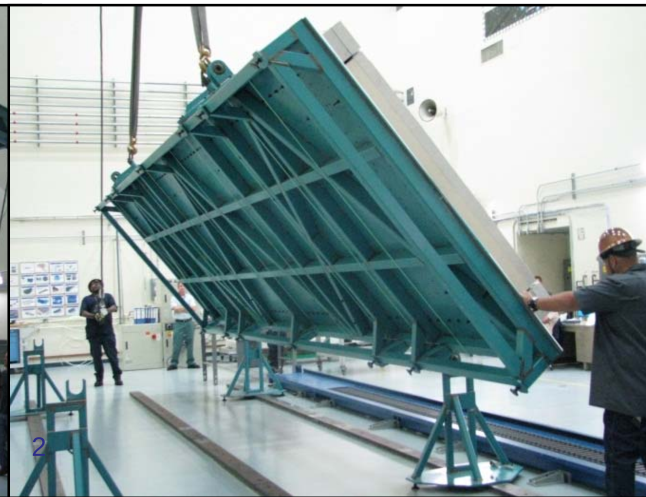
Stitching Seams

Crown panel stitching complete

Stringer flange-to-skin seam installation

- Location and amount of stitching dictated by out of plane loading requirement

Preform Transfer to Mold Tool



- Preform is banded down against assembly jig
- Jig with preform is rotated over and placed onto mold tool surface
- Stitch tool base is unbolted and removed, leaving preform with foam block tooling on mold

Removal of Stitch Tooling

Steel table removed

Row of base blocks removed

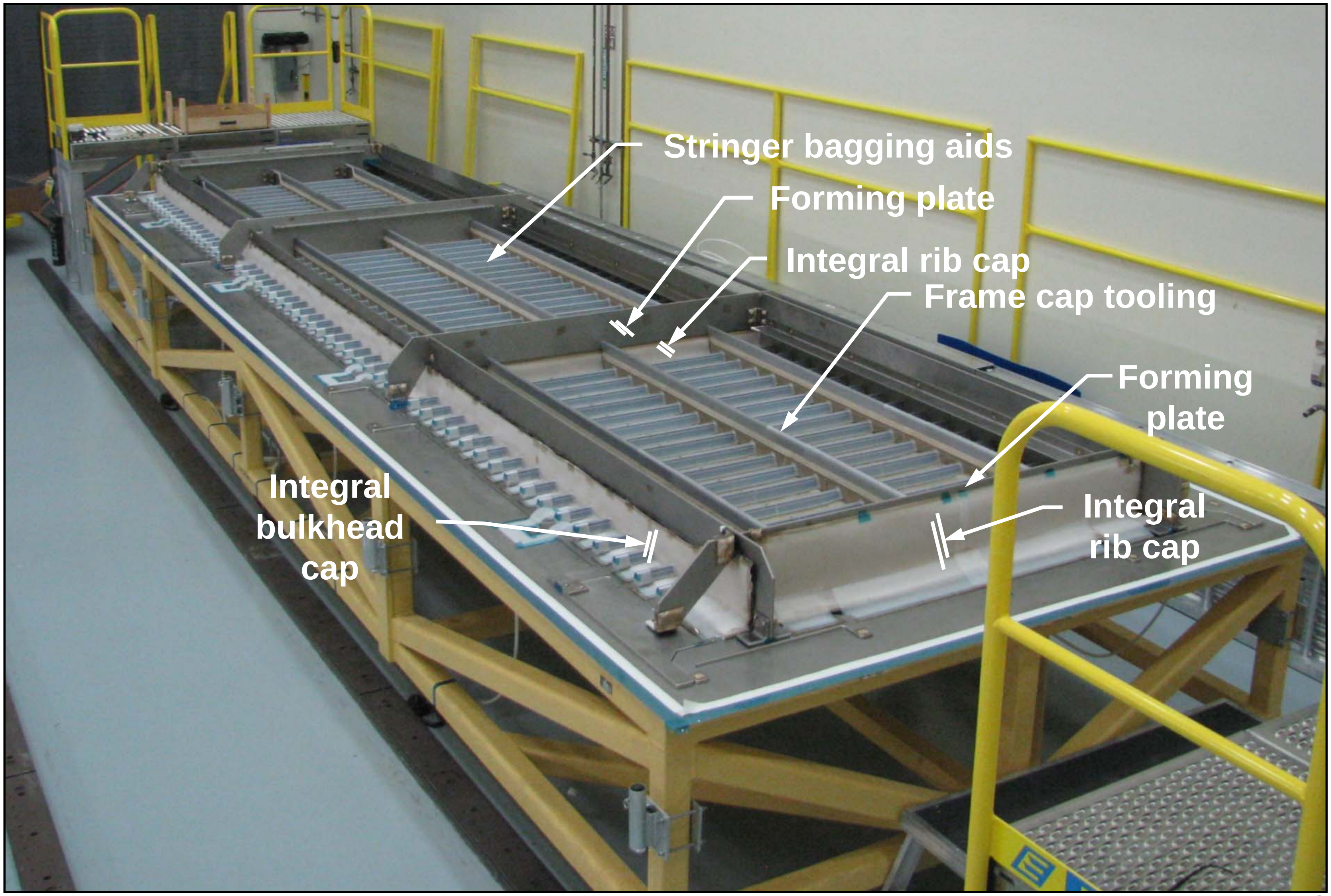
Stitching tool sets exposed

Wood frame removal

Stitched Preform Crown Panel

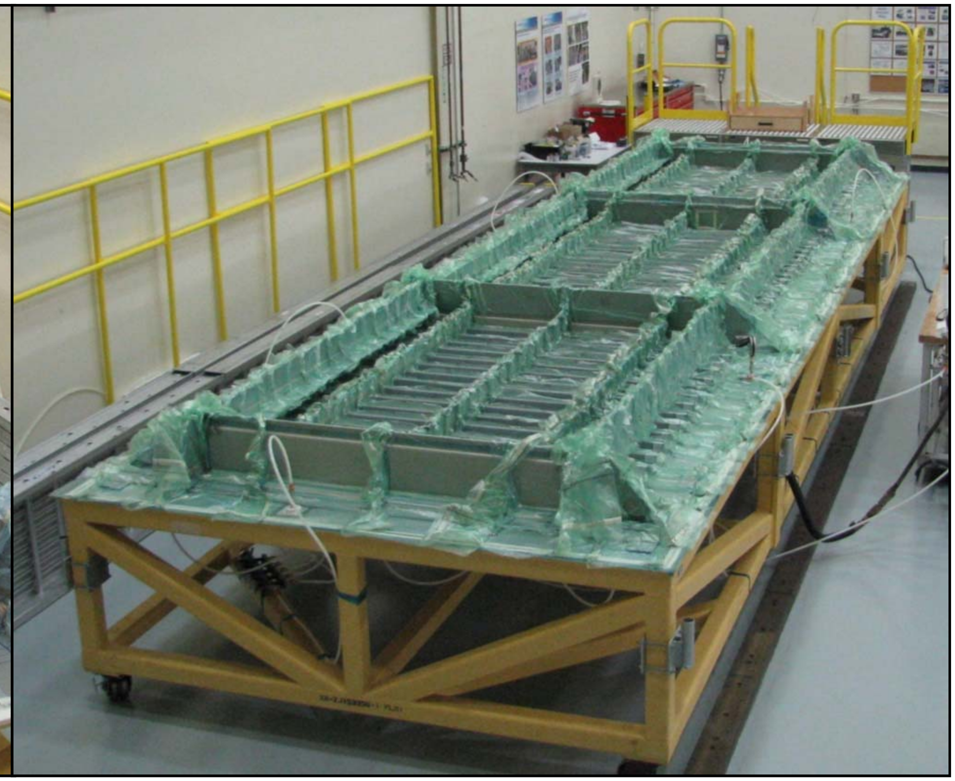
51 stringers
2 bulkhead caps
2 outer rib caps
2 inner rib caps
3 frames
skin

Under-Bag Tooling on Crown Panel



Vacuum Bag System

Pleated primary vacuum bag



Textured secondary vacuum bag

- Double vacuum bag system
- Conventional nylon bag film

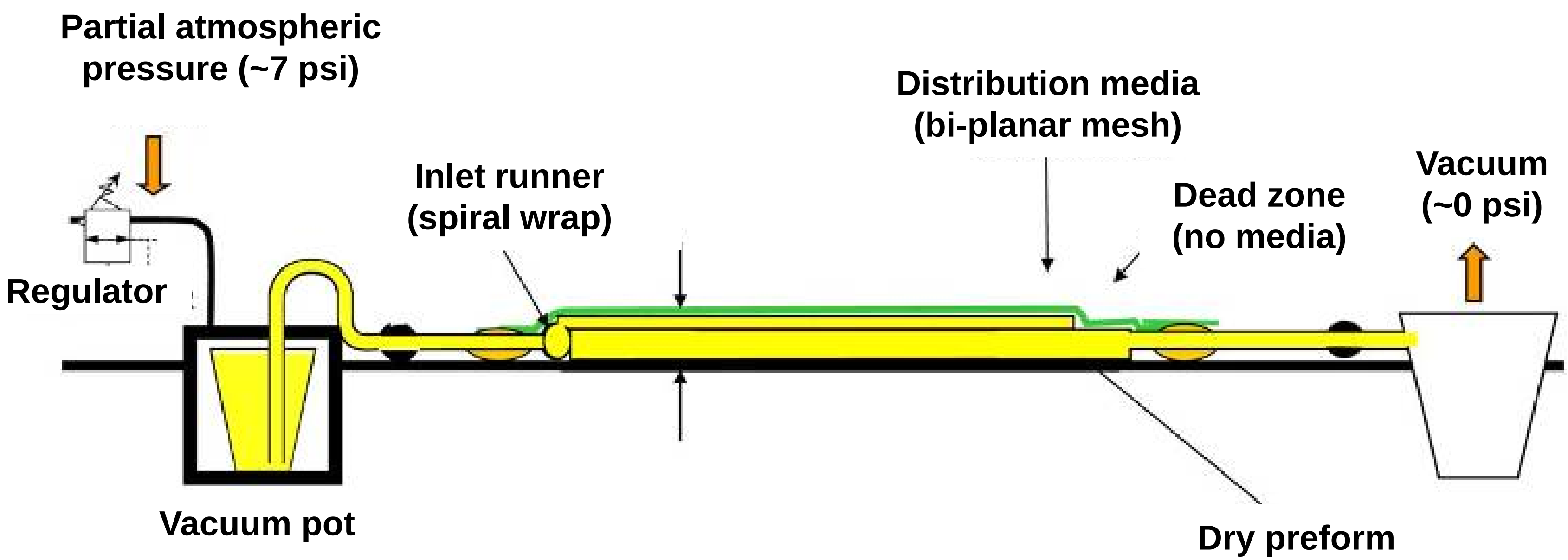
Preform with Cure Tool Moved to Oven

Crown panel preform move to oven

Crown in oven

Resin Infusion Details for Crown Panel

- Controlled Atmospheric Pressure Resin Infusion Process (CAPRI)
- Two component epoxy resin (Hexflow VRM34)
- Advanced Process Technology - Servo Rotary Dispensing (SRD) machine
  - Heats & thin film degasses resin components in separate holding tanks
  - Automatically delivers properly degassed, metered and mixed material on demand to the mold at the specified temperature and pressure
- Volume of resin: 44 liters
- Infusion time: 45 min. @ 140°F
- Initial cure @ 200°F with free standing final cure @ 350°F



Infused and Cured Part in Oven

Vacuum Bag Removal

Secondary bag removal

Primary bag after infusion

- Remove secondary bag
- Remove primary bag
- Remove tools and bagging aides
- Return to oven for free standing post-cure

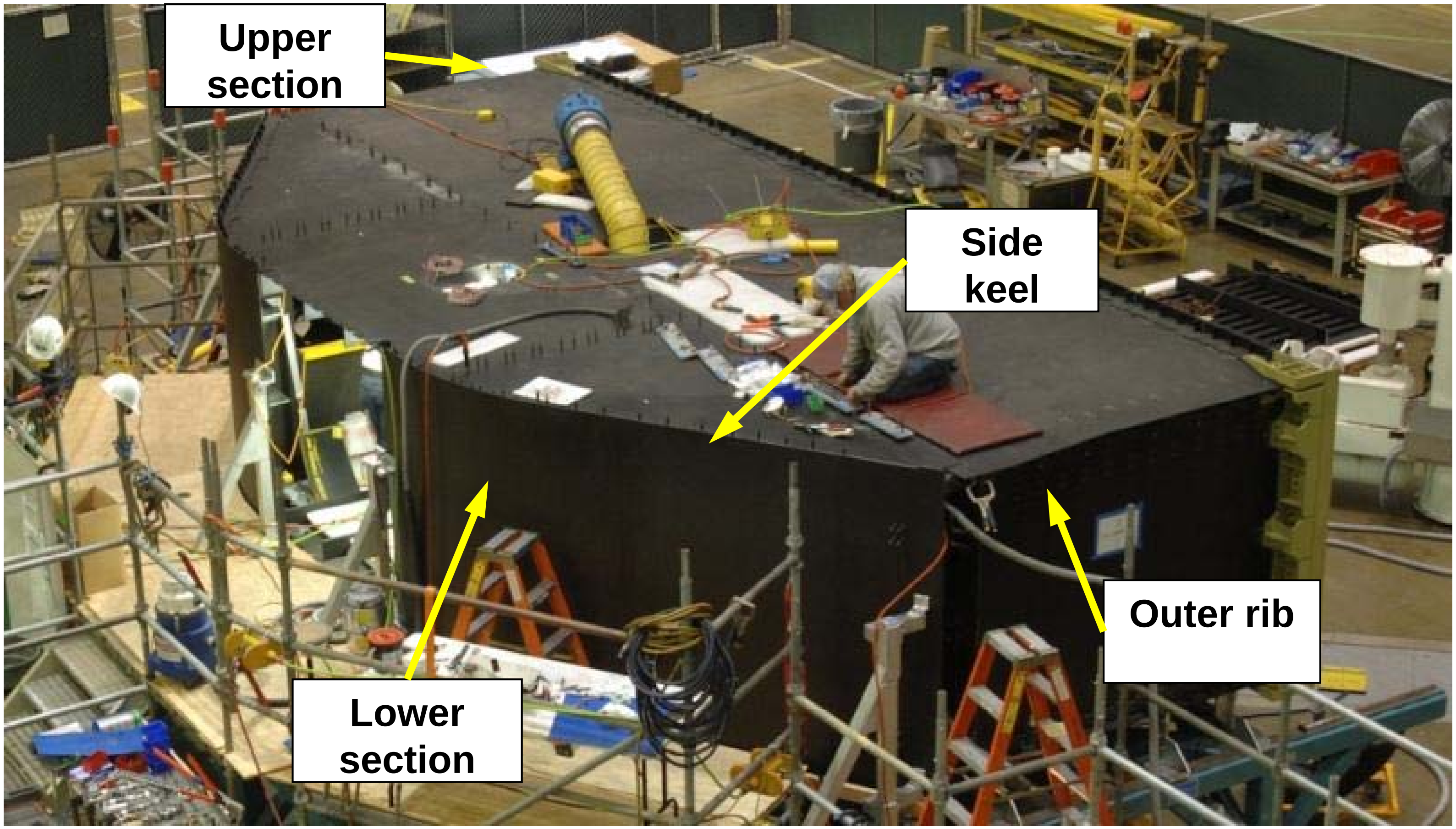
Cured Panels

Upper bulkhead panel

Side keel panel

- Cured panels sent out for periphery trim
- Top of integral cap webs machined to profile
- Determinant assembly pilot holes installed

Test Article Assembly



Multi-Bay Pressure Box Rotated Upright

Load introduction hardware

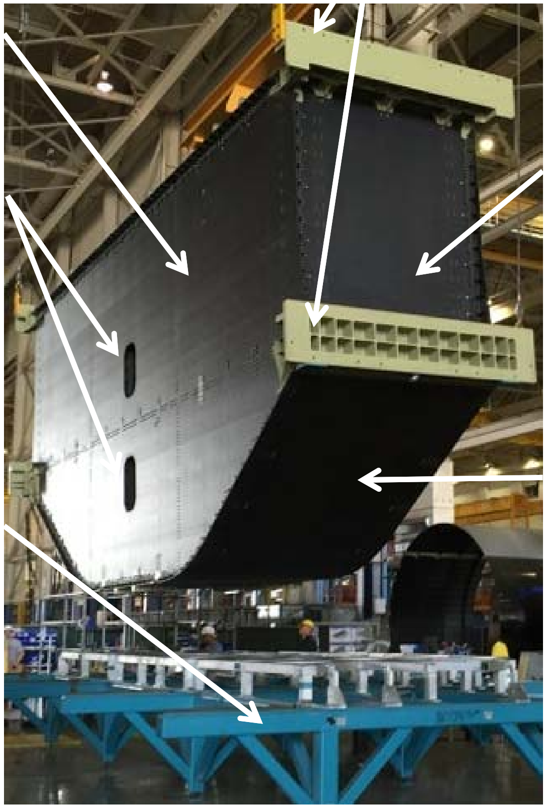
Bulkhead

Access door opening

Assembly jig

Outer rib

Side keel



Transport from Assembly Site in CA to Test Site at NASA Langley Research Center in VA

NASA Super Guppy Aircraft at Long Beach airport

Placed in holding fixture and loaded onto aircraft

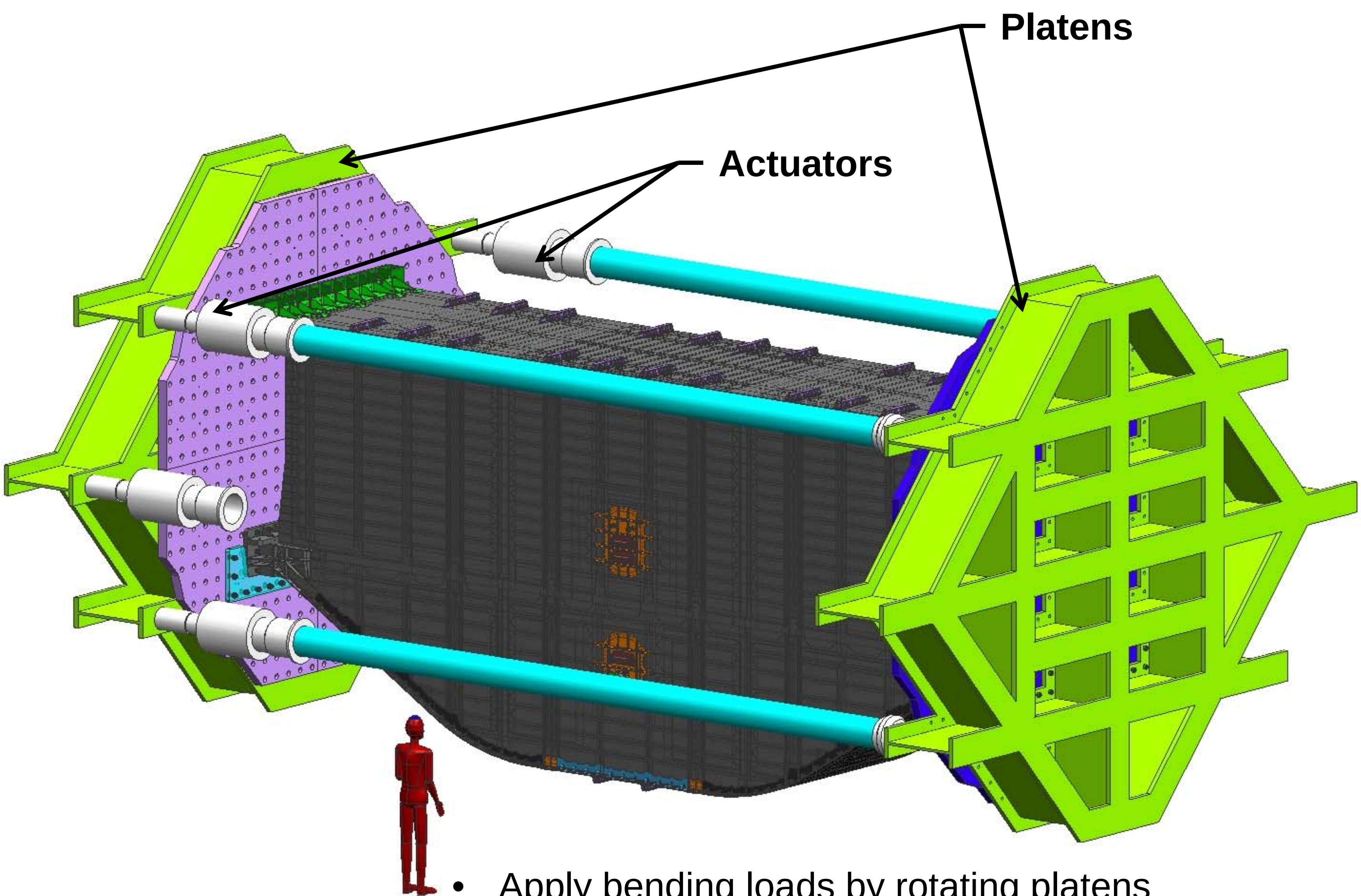
Delivered to NASA Langley

Inside the NASA hangar

Lifted off the loader/mover

Inside the test facility specimen preparation area

Test Article Installation in Combined Loads Test System (COLTS) Facility

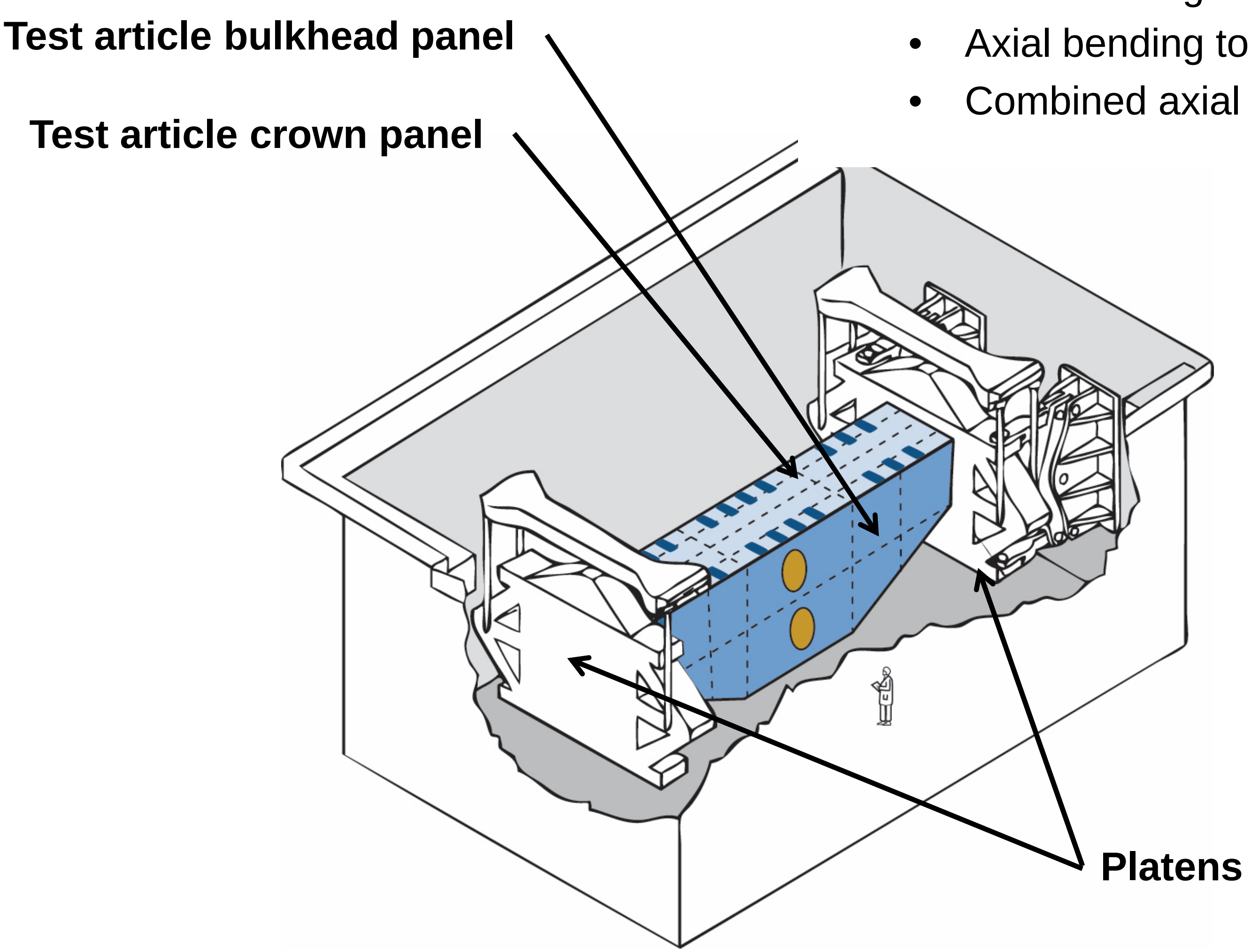


- Apply bending loads by rotating platens
- Internal pressure to simulate cabin pressure

Loading Conditions for Design Ultimate Load

Test conditions

- Pressure loading to 2P (18.4 psi)
- Axial bending to 2.5G
- Axial bending to -1G
- Combined axial loading and 1P (9.2 psi)



Moving into Test Chamber

Testing Sequence

- Load pristine structure to design ultimate load in five conditions
- Inflict barely visible impact damage to exterior and interior of structure
- Repeat loading to design ultimate load in five conditions
- Take structure past design ultimate load to failure

Summary of PRSEUS Development

- PRSEUS development supported by NASA, Boeing, FAA and AFRL
- Building block approach moving from small elements through large-scale structure
- Stitching is used to suppress interlaminar failures, arrest damage and turn cracks
- Unitized structure simplifies final assembly
- Out-of-autoclave processing allows for cheaper fabrication and quicker and easier changes to designs
- Successfully fabricated 11 large PRSEUS panels and assembled into 30-foot-long multi-bay box representing the center section of a HWB vehicle
- Testing with applied bending loads and internal pressure

Acknowledgement

- The panel fabrication effort described herein was led by Patrick Thrash from Boeing Research and Technology at the Marvin Dow Stitching Center at Boeing Huntington Beach CA

Primary References*

- NASA Contractor Report 2104-218149 (final report for contract NNL13AA11C)
- CAMX SAMPE paper “Manufacturing of a Stitched Resin Infused Fuselage Test Article” from October 13-16, 2014.
- Controlled Atmospheric Pressure Resin Infusion Process, Patent EP 1507647 B1

*Publically available