BERKELEY LAB

LAWRENCE BERKELEY NATIONAL LABORATORY

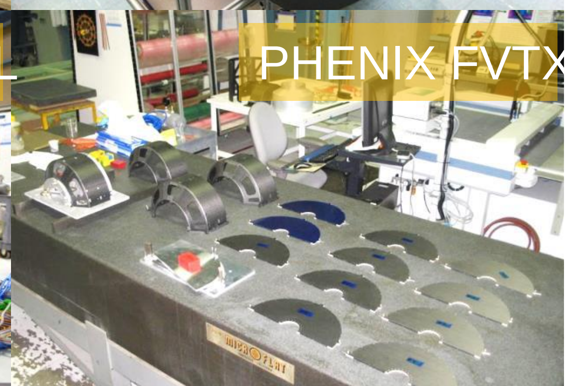
U.S. DEPARTMENT OF ENERGY

Composites Introduction

ESIPAP

March 5 2018

Composites for Detectors



- Overlap of R&D with construction projects is typical for Detectors
- Synergy of project requirements and contiguous R&D allows for bootstrap technology development
- Techniques developed for one detector used on many others
- Composite R&D is related to fabrication capability
- Design and fabrication are interlinked

Detectors are large objects…

- **Design and Fabrication**
- Precision Assembly of large structures (4-8m)
- Fabrication is often limited by equipment
  - Size is an aspect
  - Space for assembly also…
- Process capability (Temp/Pressure) define materials that can be used
  - Equipment defines which materials can be processed
- Broad industry in general Detectors are closest to satellites
  - Vendors with appropriate capability are more rarified…

Composites are materials developed via a fabrication process

- It is impossible to separate material properties from fabrication process in composites
- Ability to close loop on design, fabrication, and test is an important capability to develop and maintain whether in-house or via collaboration with commercial vendor
- It is important to understand aspects of fabrication at all stages, from pre-preg to layup to be able to properly specify design variables
- Over-use of ‘nominal’ values in design is common in our field and is what is taught in typical courses

Part manufacture is material design

Each of the stages of manufacture have some inter-relation and affect the overall product as deviations from ideal

Understanding these deviations allows you to modify the design, tool, and processes to best achieve intent and goals

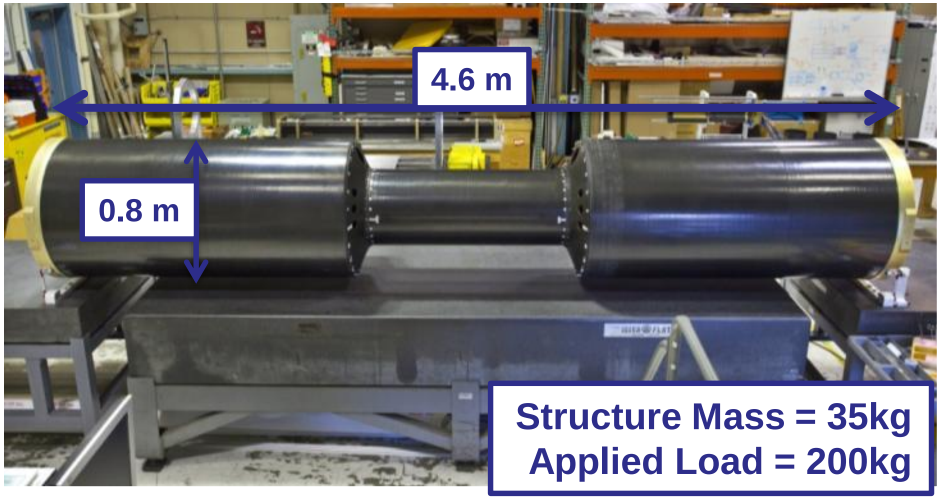
Part and Process Design together are best viewed holistically

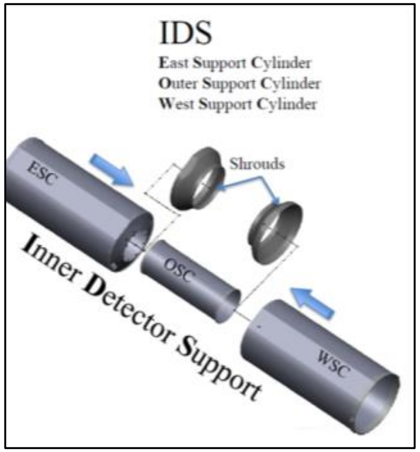
Of course, design of the laminate can have some peculiar ramifications to the manufacturing process…

Aim is to tie design and manufacture together both to show what's easy to do/control and what's difficult

Much of composite fab/design is simple, but tedious…

STAR HFT Inner Detector Support (IDS)

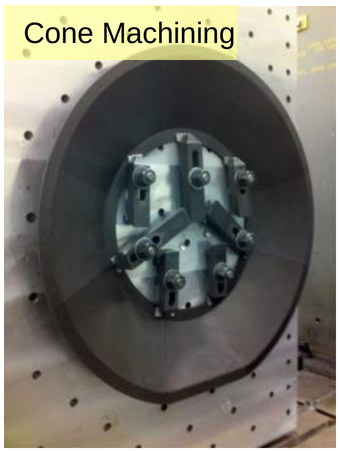


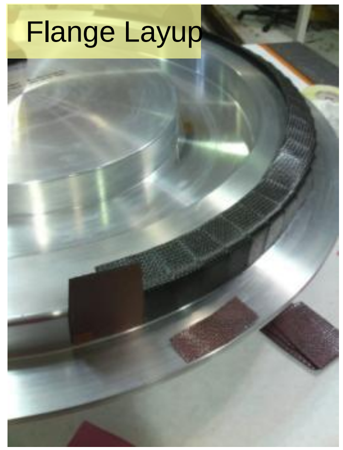

IDS
East Support Cylinder
Outer Support Cylinder
West Support Cylinder
Shrouds
ESC
OSC
WSC
Inner Detector Support

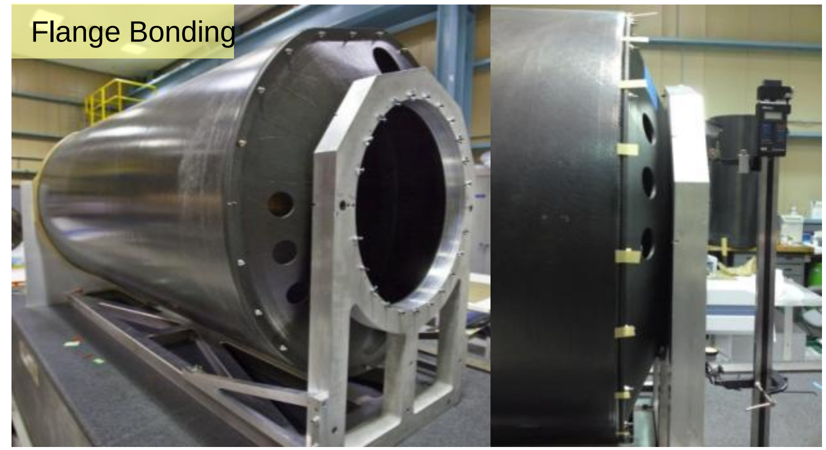

WSC/ESC Mandrel

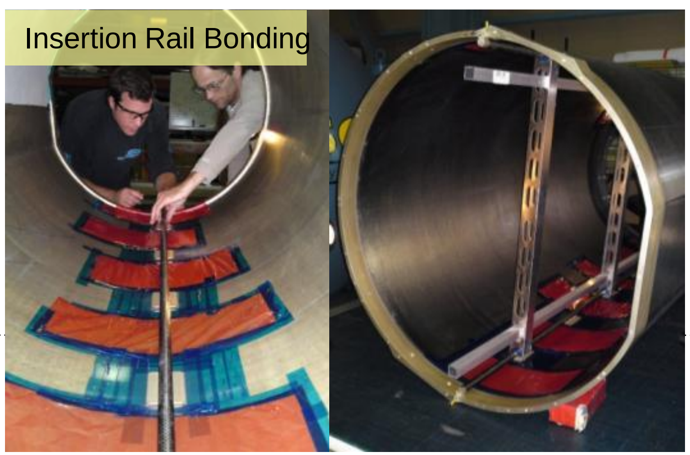

WSC/ESC Layup

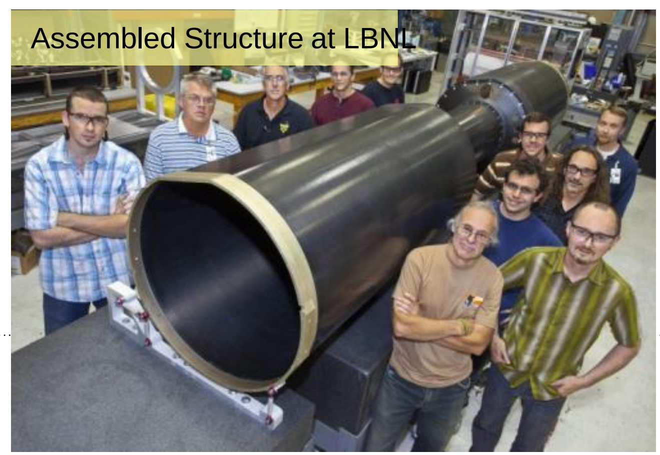

Cone Layup

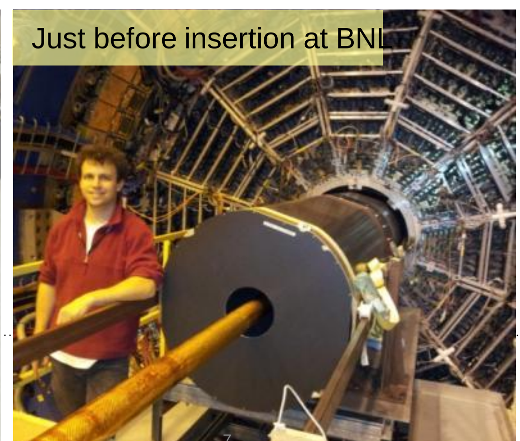

Cone Machining


Flange Layup


Flange Bonding


Insertion Rail Bonding


Assembled Structure at LBNL


Just before insertion at BNL

Generalized Part Fabrication Cycle

Composite parts are generally made from several plies, stacked together with specific fiber orientation and ply shapes.

They require a rigid tooling surface, to give the part form, which must be capable of withstanding compaction forces and cure process without distortion (usually temp, possibly chemical attack)

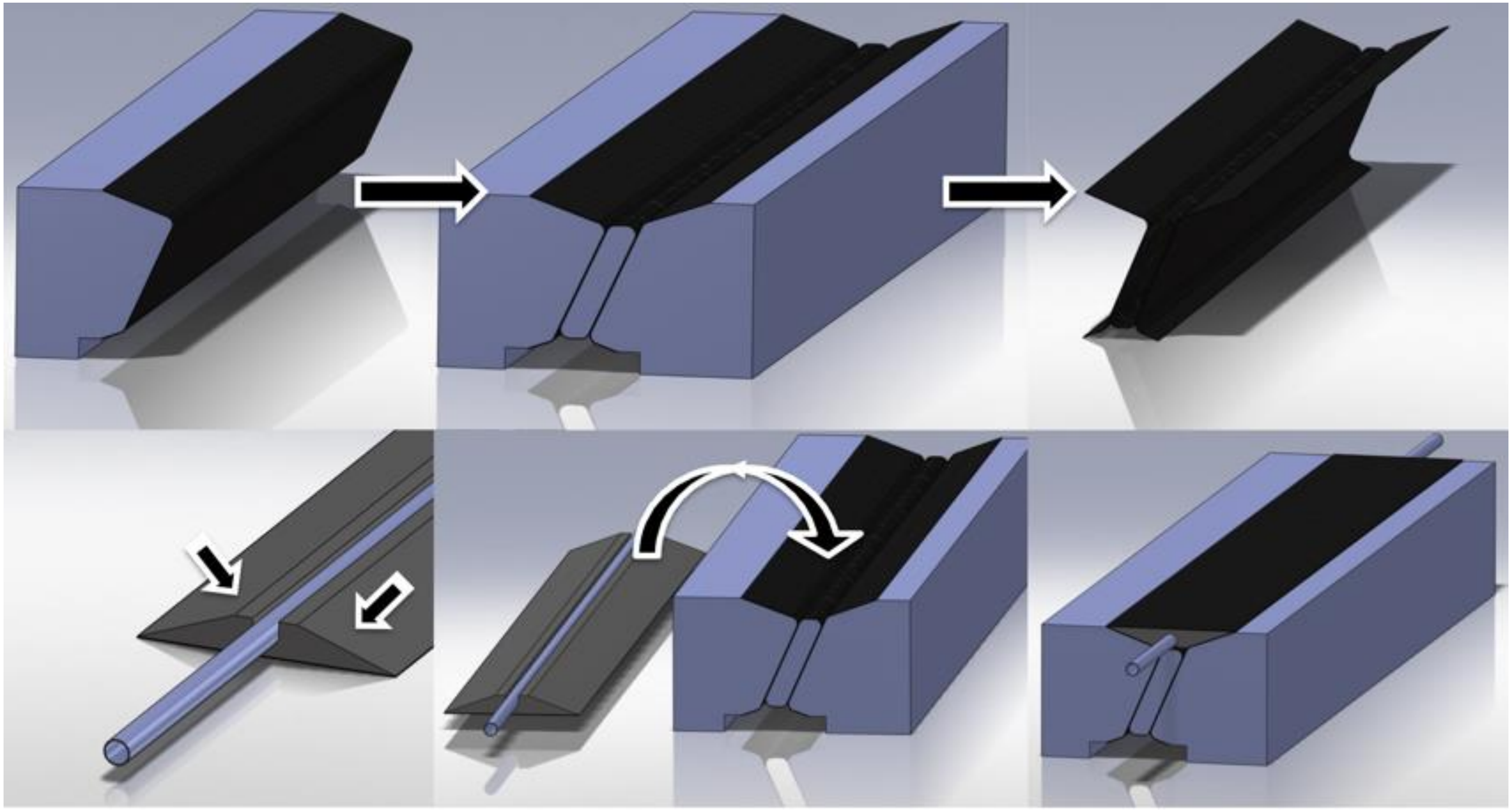
To generate specific properties, these ply stacks must be compacted together removing voids (air bubbles) and excess resin in a controlled manner, which must be maintained through part cure

Part cure can occur at Room Temperature (RT) or elevated temperature depending on the chemistry of the resin system

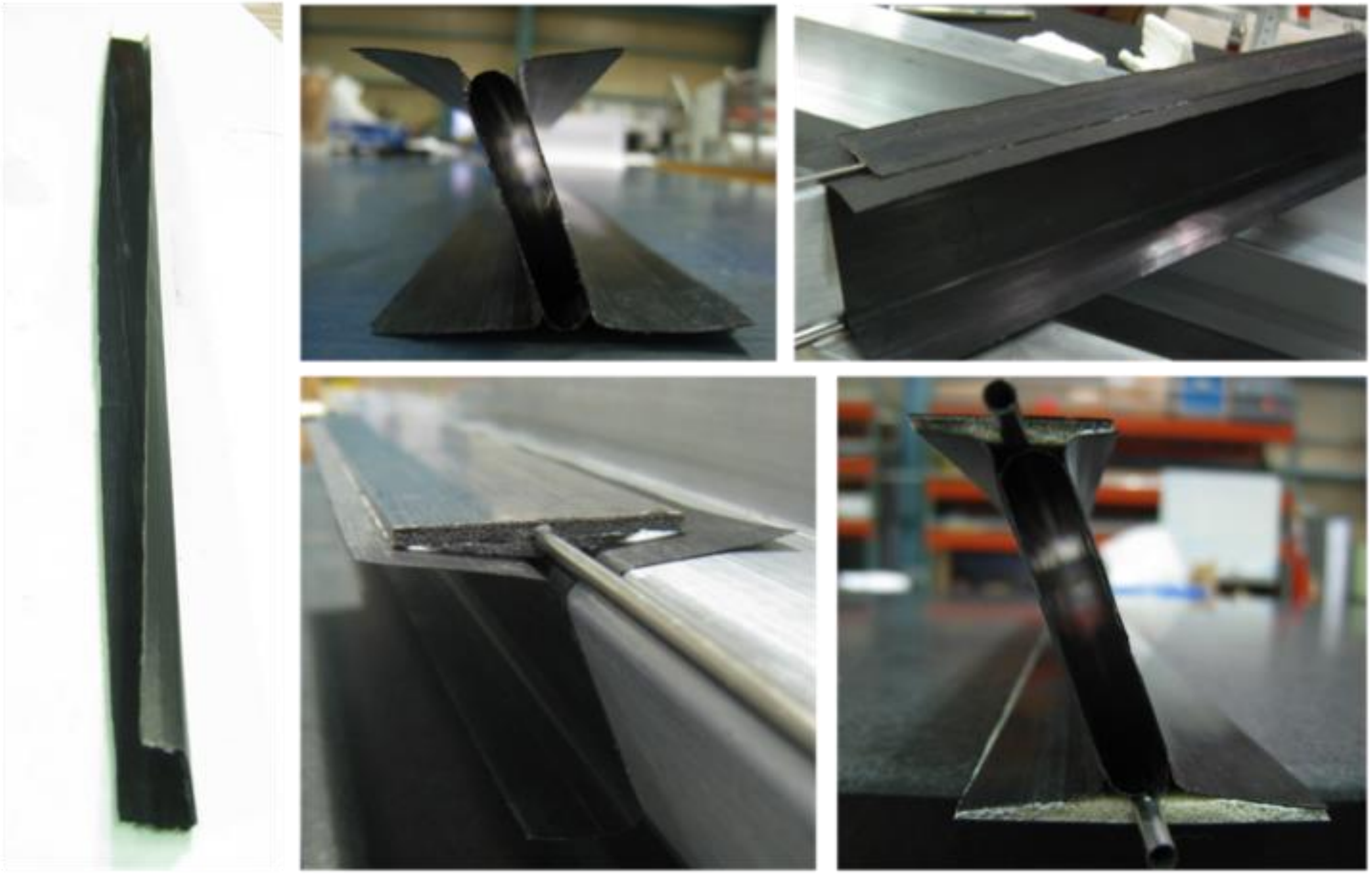
After part cure, the part must be released from the tool, and can subsequently be machined to shape—tool surface integrity is key

Most composite parts are bonded (occasionally bolted) to other components, metal or composite. Preparation involves careful cleaning to remove mold release, and increase surface wettability

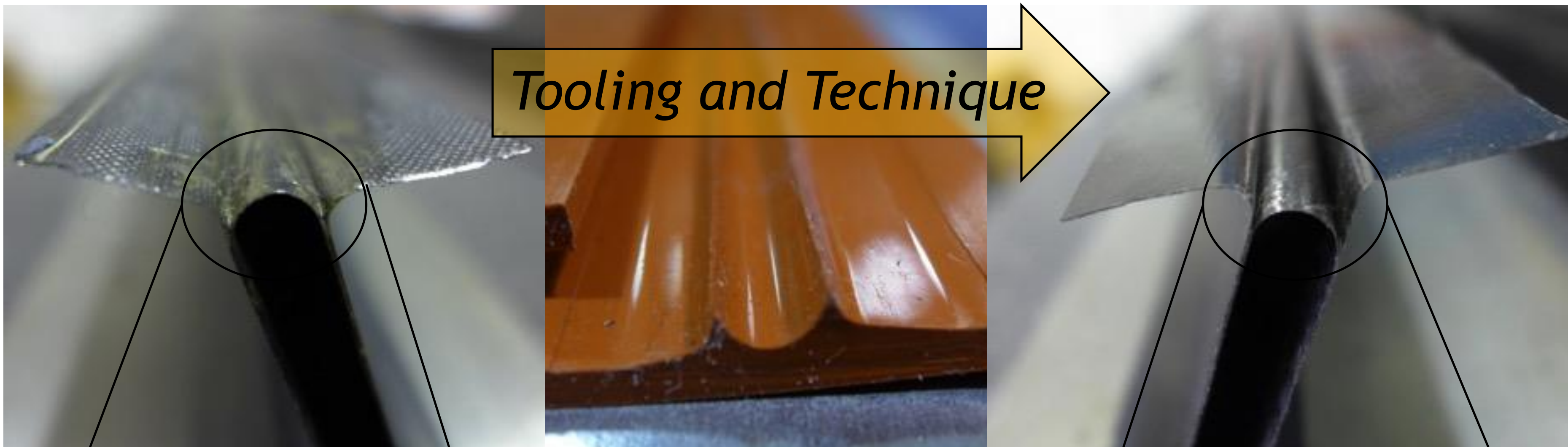
Manufacturing Process

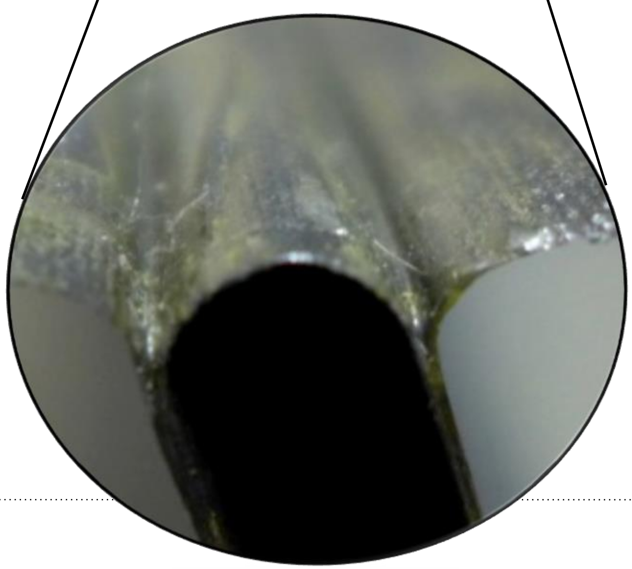


Stages of construction in photos



Co-Cured Assemblies

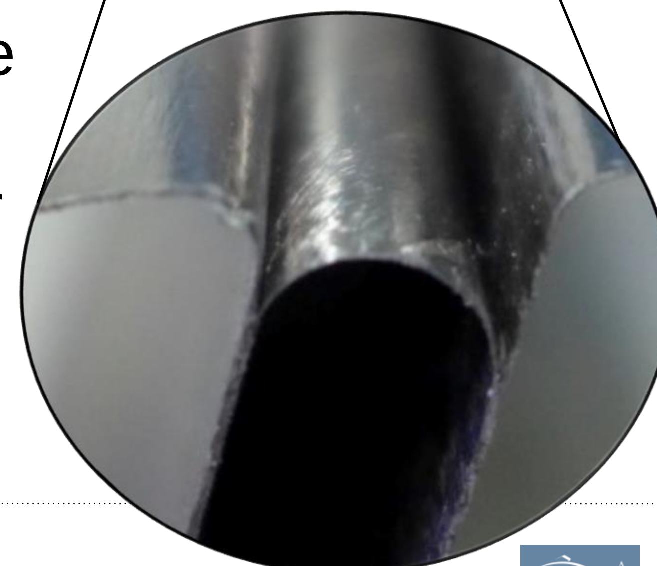




Avoid extra adhesive

48g versus 39g over 1m

Final Co-cured Ibeam < 95g/m



Sounds Rather Complicated…

There are a lot of things that can go awry during a part fabrication

They may have some inter-relation, but each can usually be solved independently

Once a process is defined which yields acceptable parts, the process is highly repeatable

It can take several iterations to nail down such a process

Experience is best, though some aspects can be taught

- This goes for both the Engineers and the Technicians who fabricate the parts

Composite Design and Fabrication are intimately linked—it is important for Engineers to be involved in all stages

Some Design Background

Simple Lever rules can get you 80% of the way to understanding base properties of composite materials, say zeroth order properties like Moduli, Strength and CTE

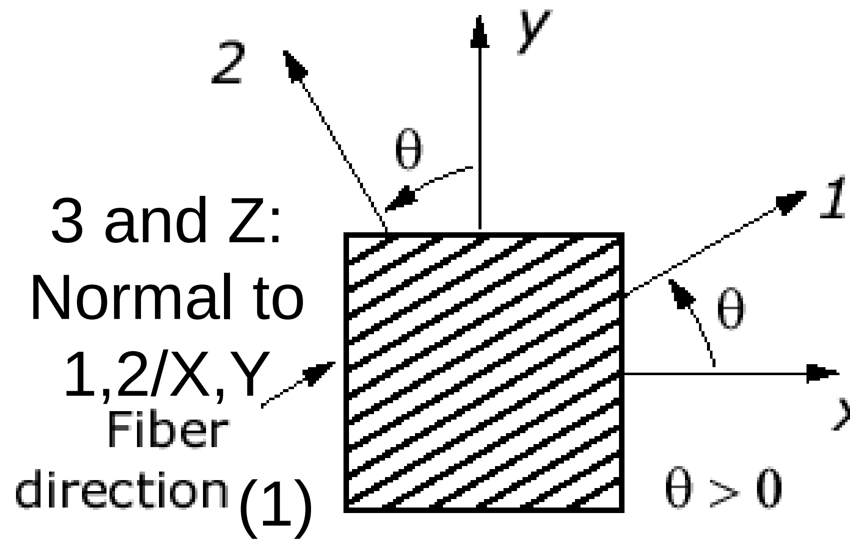
Laminated Plate Theory is the basis for understanding higher order mechanical properties, and response of stresses on the materials

MOST of our laminates are designed ‘Symmetric and Balanced’ and further are designed to be ‘Quasi-Isotropic’

- The sub-class of Symmetric isn’t necessarily Quasi-Isotropic nor Balanced
- Symmetric, Balanced, QI (QIBS) laminates have the special property that many off-diagonal elements of the stiffness matrix are identically cancelled
- Off-Diagonal elements of the stiffness matrix are responsible for ‘anti-clastic’ behavior—bend-twist, and shear-extension coupling of induced strains

Symmetric Balanced Quasi-Isotropic laminates are the easiest to design with, and yield the most predictable parts

Lamination: Additive manufacture



- ‘Carbon Fiber’ material is built layer by layer on a mold
- Each layer has a fiber direction and ‘thickness’ specified by the design requirements (X,Y are Body Coordinates)
- ‘Thickness’ is a function of Fiber Areal Weight and Resin content—typically 55-60% Fiber Volume Fraction

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Part Example: Mount Pad

Plies cut on Automated Ply Cutter

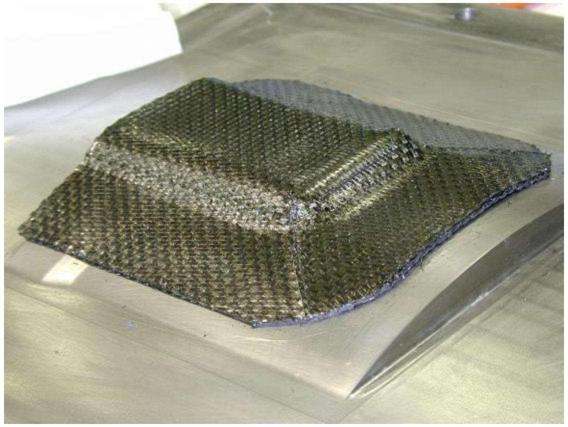
Mount Pad is laid up on tooling produced in YASDA

- Finish straight out of machine required no polishing for part release—reduced cost
- SS material cost almost as much as machining

Part is trimmed on SLA Vacuum Chuck

- SLA allows complicated internal geometry for free

Part takes 3hrs to fabricate, using ~$150 worth of $600/lb material



- **Comparable 'conventional' part with similar properties would be milled Titanium**
  - Material cost for blank slab also around $150
  - Machining cost (each) similar to cost of machining tool ~8hrs
  - Cost per Ti part ~$900 each.
- **Cost per part, ~$400 less for composite component, even with material that costs $600/lb**
- **Composite part production where tooling can be amortized over run can yield parts cheaper than conventionally manufactured parts**

Conclusion

A Very quick overview of the fabrication processes

More detail in later talks about fabrication process (resin control)

Next Talk on Design