Composites for the Aerospace Industry

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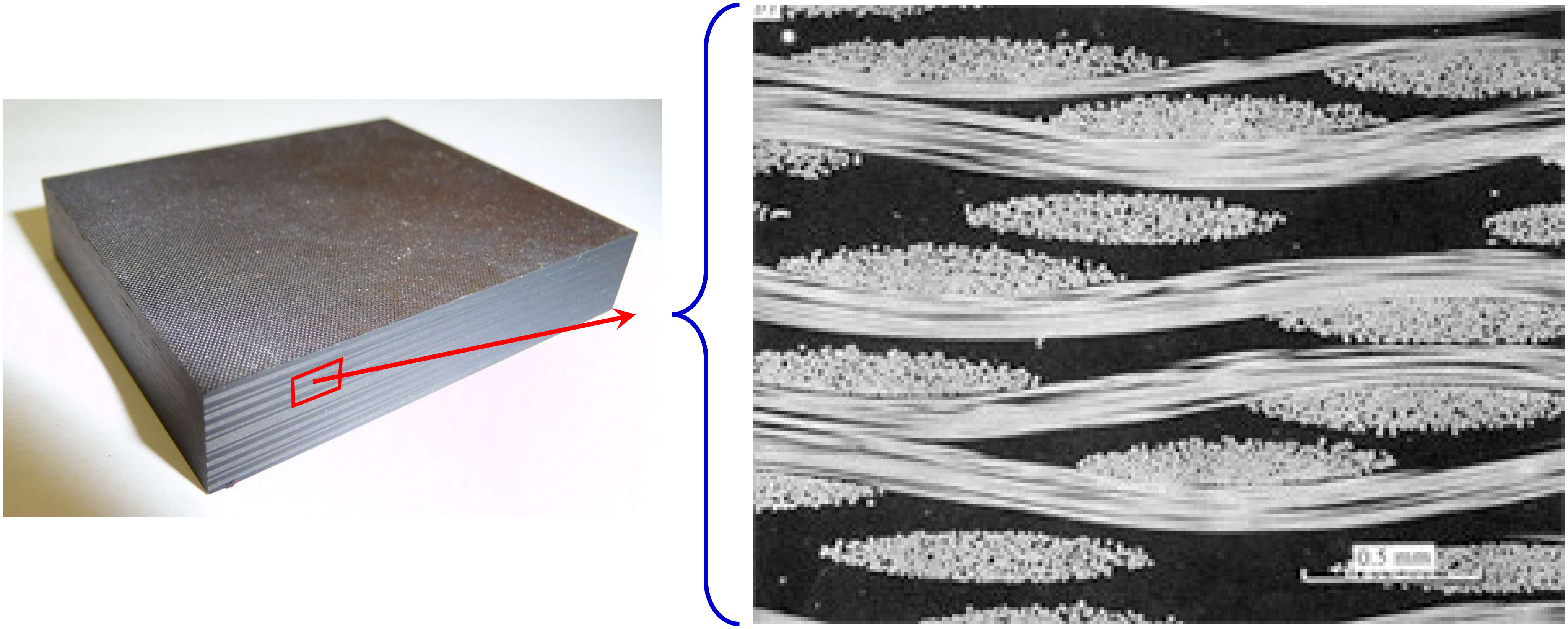
What are "Typical" Aerospace Composites?

- Fiberglass and Carbon (Graphite) Fiber with resin (matrix)
  - Fiber reinforcement determined by structural performance requirements.
  - Resin determined by usage requirements (usually Temperature) and Fab method
  - Other factors can influence (glass for radomes) but these usually dominate.

Composite Part Cross-Sectional Photomicrograph
White is Fiber, Black is Resin Matrix
(Note the various fiber orientations in different plies)



Boeing 787 Aft Fuselage Section

Vought Delivers Aft Fuselage for Boeing 787 Dreamliner

Laminate Structure Versus Honeycomb Sandwich Structure

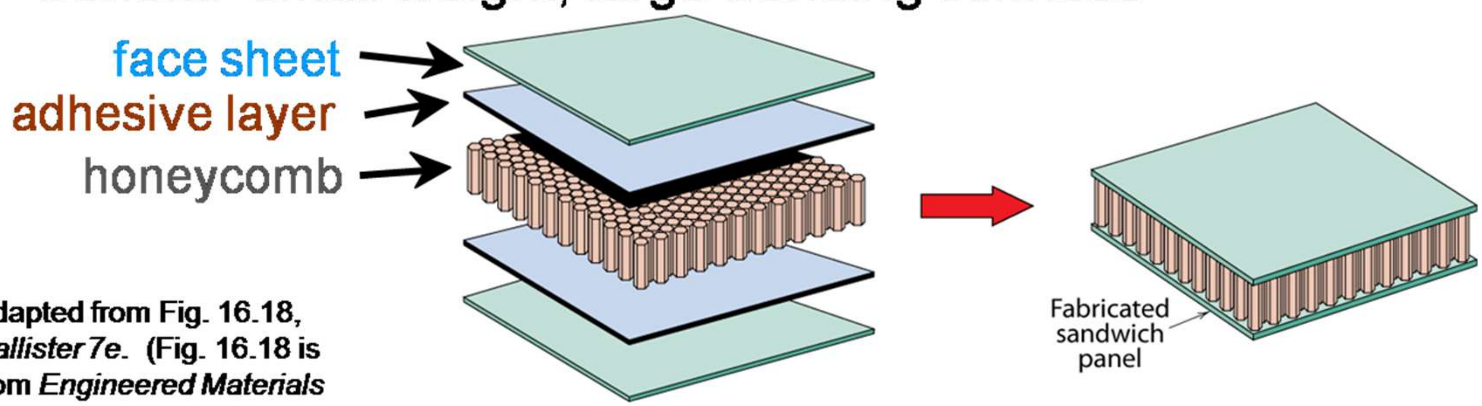
Solid Laminate Structure

- Generally used for primary structure (fuselage, empennage, and wing skins)
- Primarily unidirectional tape
- Maximized tensile/compression
- Superior impact resistance

Honeycomb Sandwich Structure

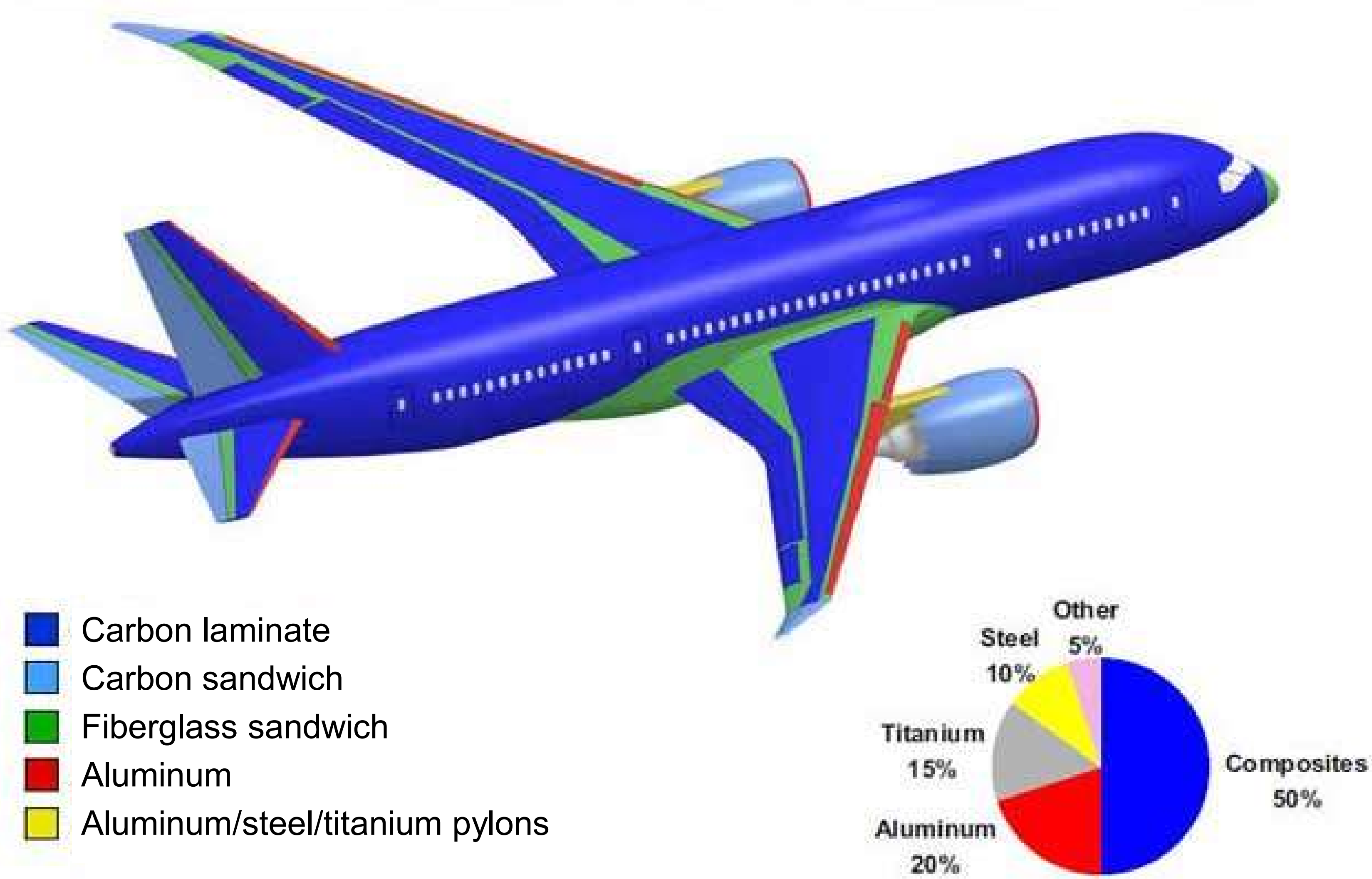
- Generally used for secondary structure (control surfaces, engine cowls, other more lightly loaded structure)
- Maximized stiffness to weight

- Sandwich panels
  - -- low density, honeycomb core
  - -- benefit: small weight, large bending stiffness



Adapted from Fig. 16.18, *Callister 7e*. (Fig. 16.18 is from *Engineered Materials Handbook*, Vol. 1, *Composites*, ASM International, Materials Park, OH, 1987.)

Boeing 787 Material Usage



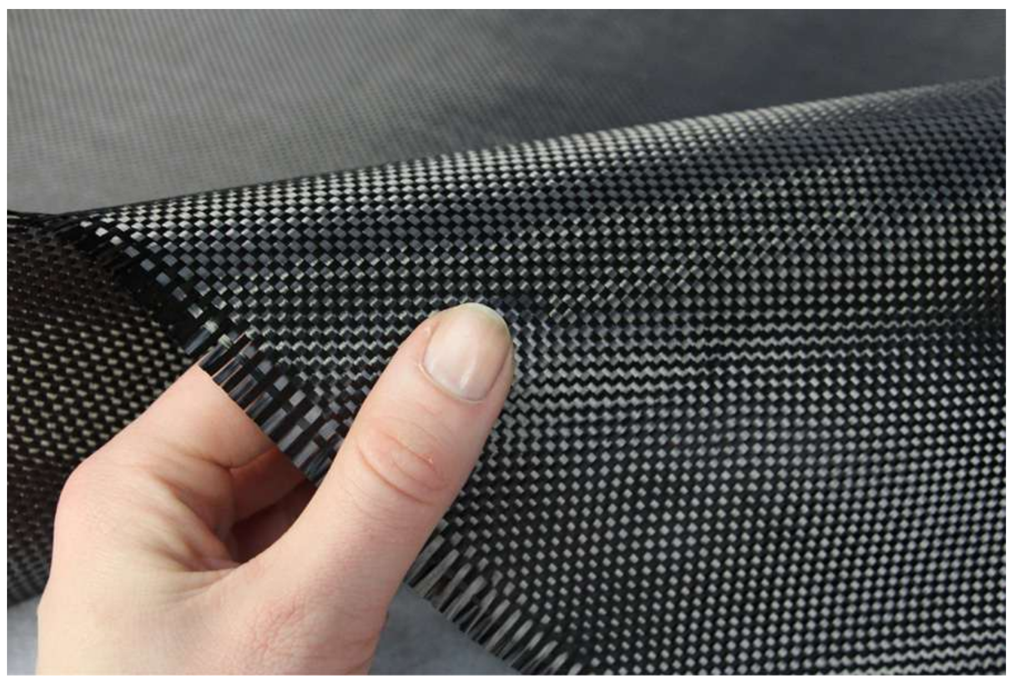
Fibers

- Usually Fiberglass or Carbon (Graphite) – sometimes Kevlar
  - Fibers usually dominate composite structural performance
  - Fiberglass is lower cost but less structural performance than Carbon. (FG modulus about 12 X 10^6 psi and Carbon modulus 30 to 100 X 10^6 psi)
  - Uni-directional tape vs. fabric

Material Forms - Unidirectional Tape Versus Woven Fabric

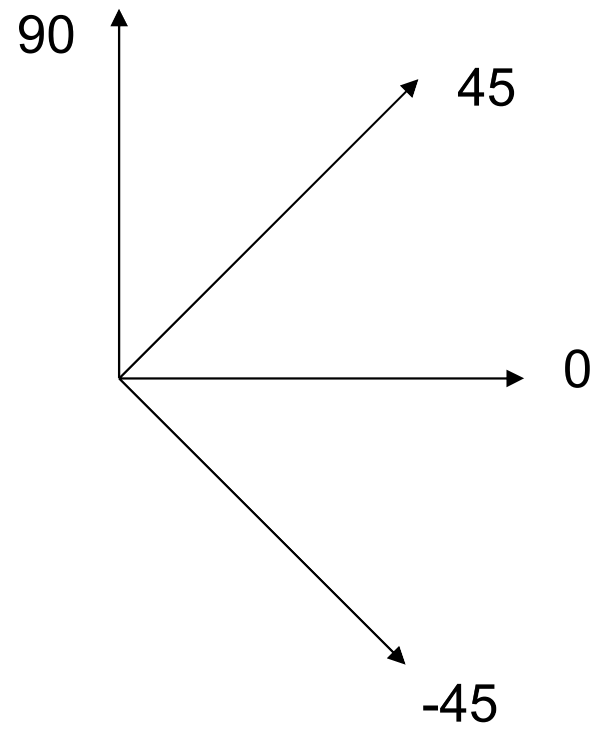
Unidirectional Tape
(maximized strength in fiber direction, used for primary structure)

Woven Fabric
(balanced 0/90 strength, more formable, used for secondary and honeycomb sandwich structure)



Fiber Angles and Stacking Sequence

0
-45
+45
90
+45
-45
0



"Quasi-Isotropic" – similar strength in all directions
Need "balanced and symmetric" to avoid part warpage after cure

Resins

- Thermoset vs. Thermoplastic
  - Thermoset (A resin that undergoes chemical reactions to polymerize and cure)
    - Epoxy, BMI, Polyester, Polyimide, Phenolic, etc.
  - Thermoplastic (A non-reactive resin that is melted to form parts)
    - PEEK, PPS, etc.
  - Process Issues for TS and TP
  - Prepreg vs. Wet resin (TS)

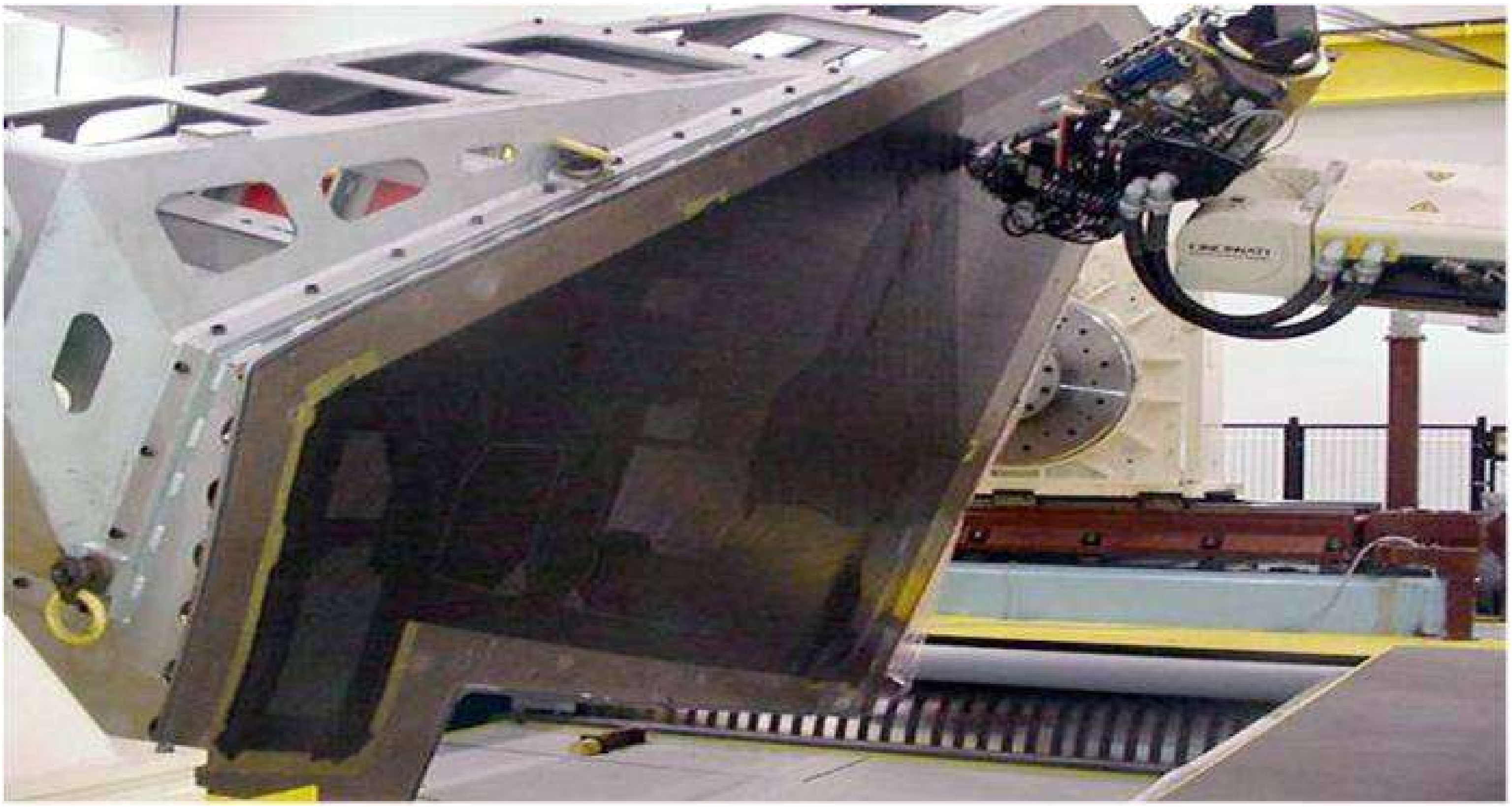
Boeing Airplanes – Material Choice

- Epoxy Resin for Exterior Structural Parts
  – Meet strength/toughness/temperature/etc. req'ts
- Phenolic Resin for Interior Parts
  – Meets Fire/Smoke/Toxicity requirements
- Ongoing interest in Thermoplastic Composites
  – "Melt Resin, Form to Shape" – fast processing

Thermoset Mfg Processes (Prepreg)

- Laydown – Fiber Placement, Hand Layup
- Vacuum Bagging
- Autoclave Cure
- Press
- Filament Winding
- Braiding

Fiber Placement/Autoclave Fabrication
Military Aircraft

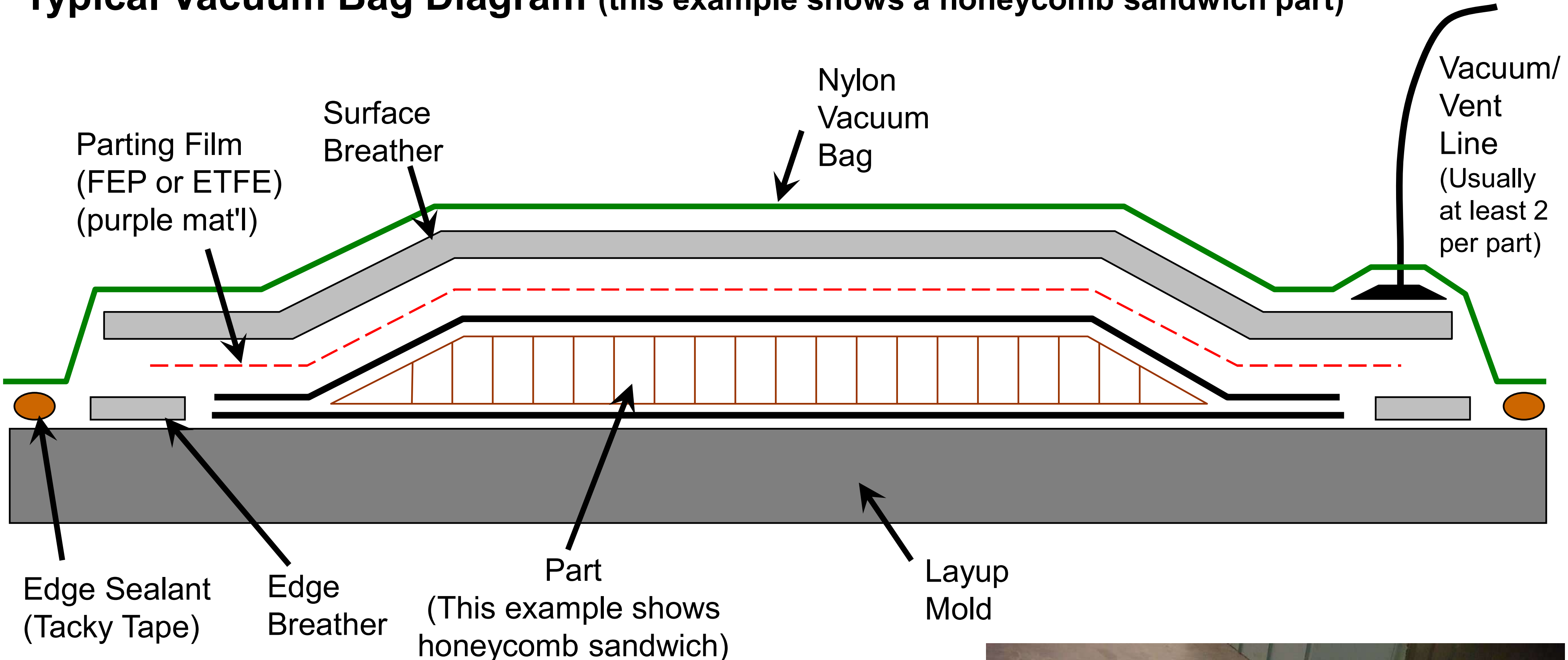


http://www.vought.com/newsFactGallery/releases/2004/081604.htm

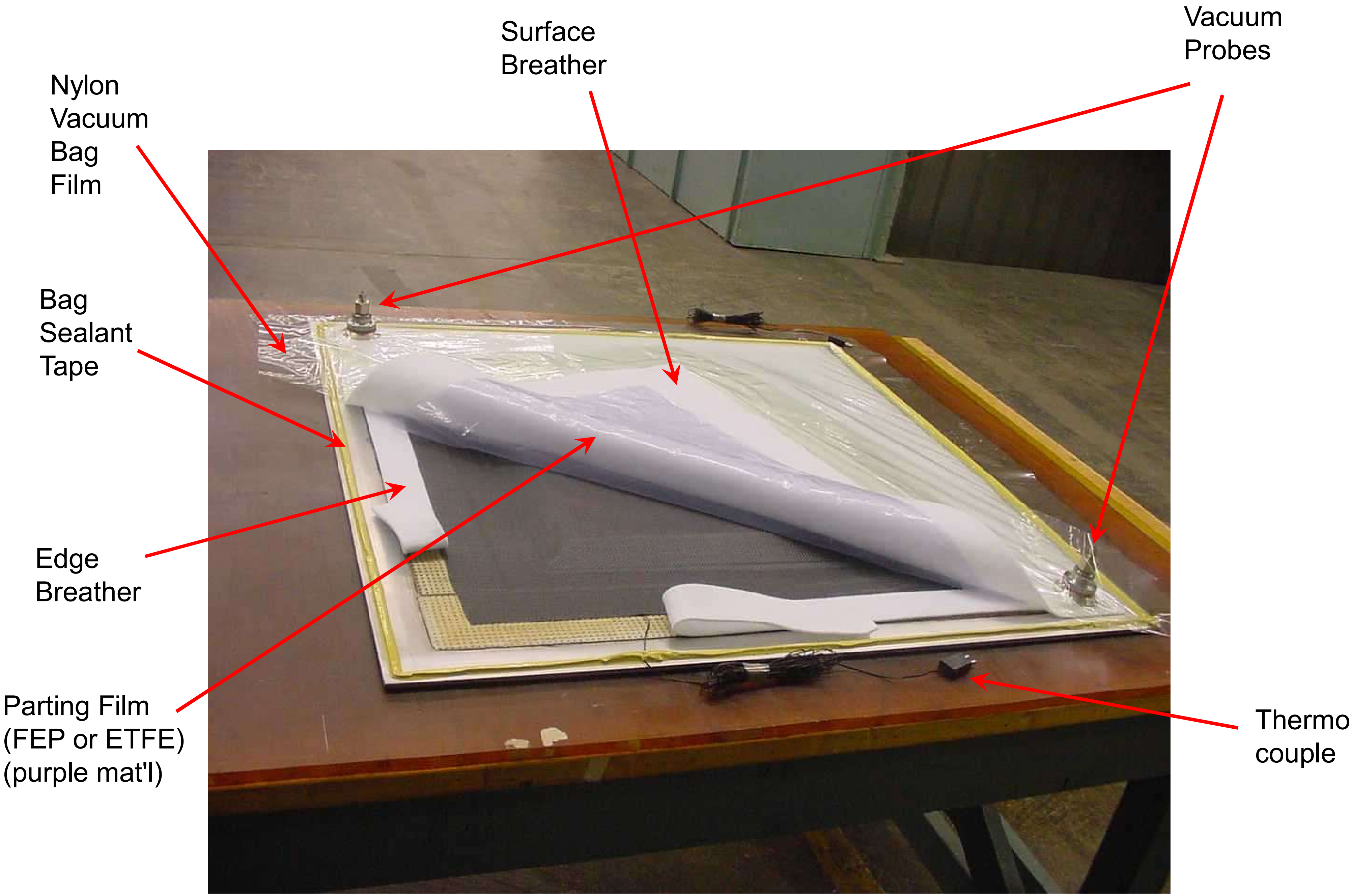
Automated Tape Layup

Hand Layup – Smaller parts, honeycomb sandwich parts

Typical Vacuum Bag Diagram (this example shows a honeycomb sandwich part)

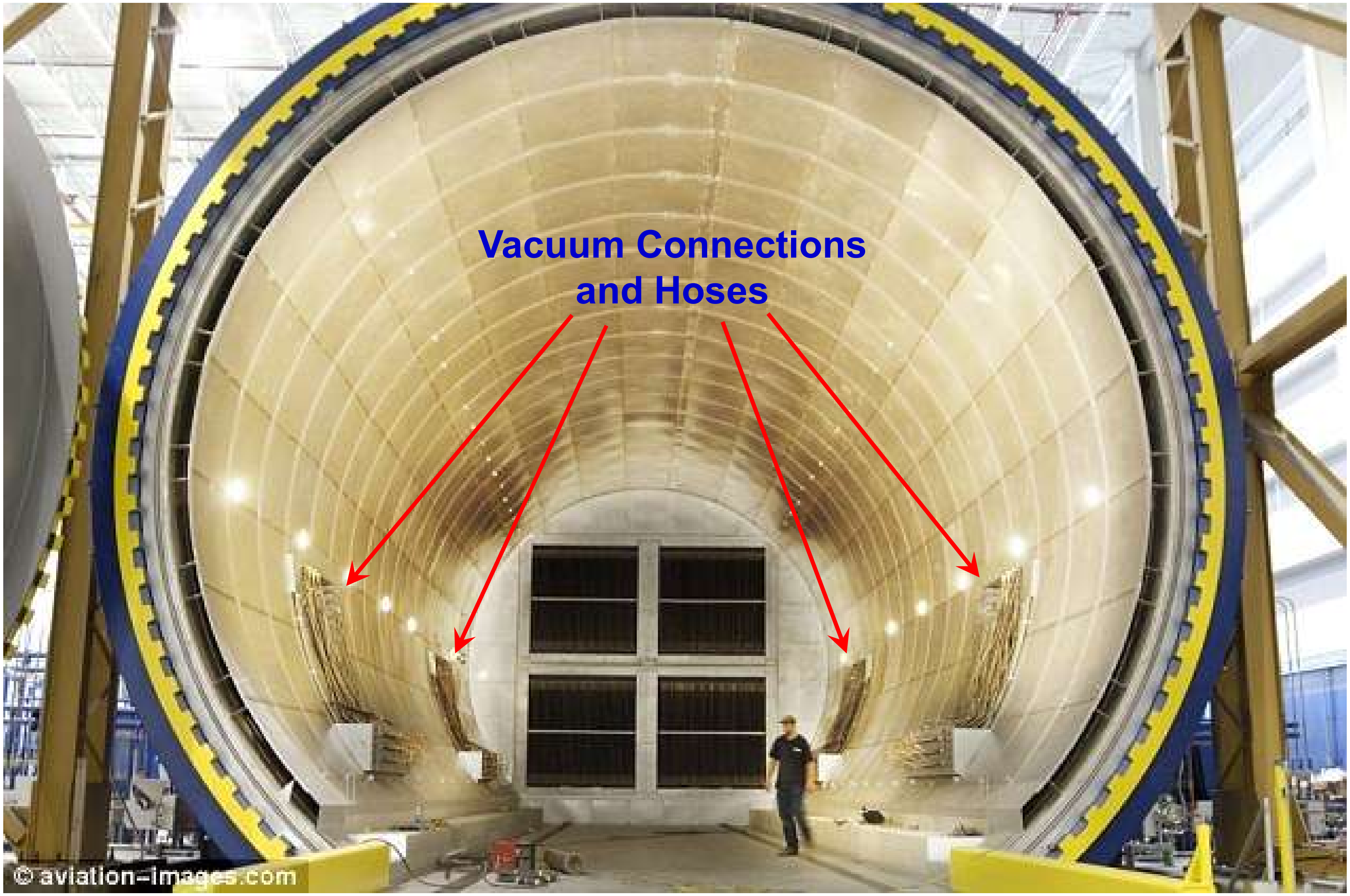


Typical Vacuum Bag

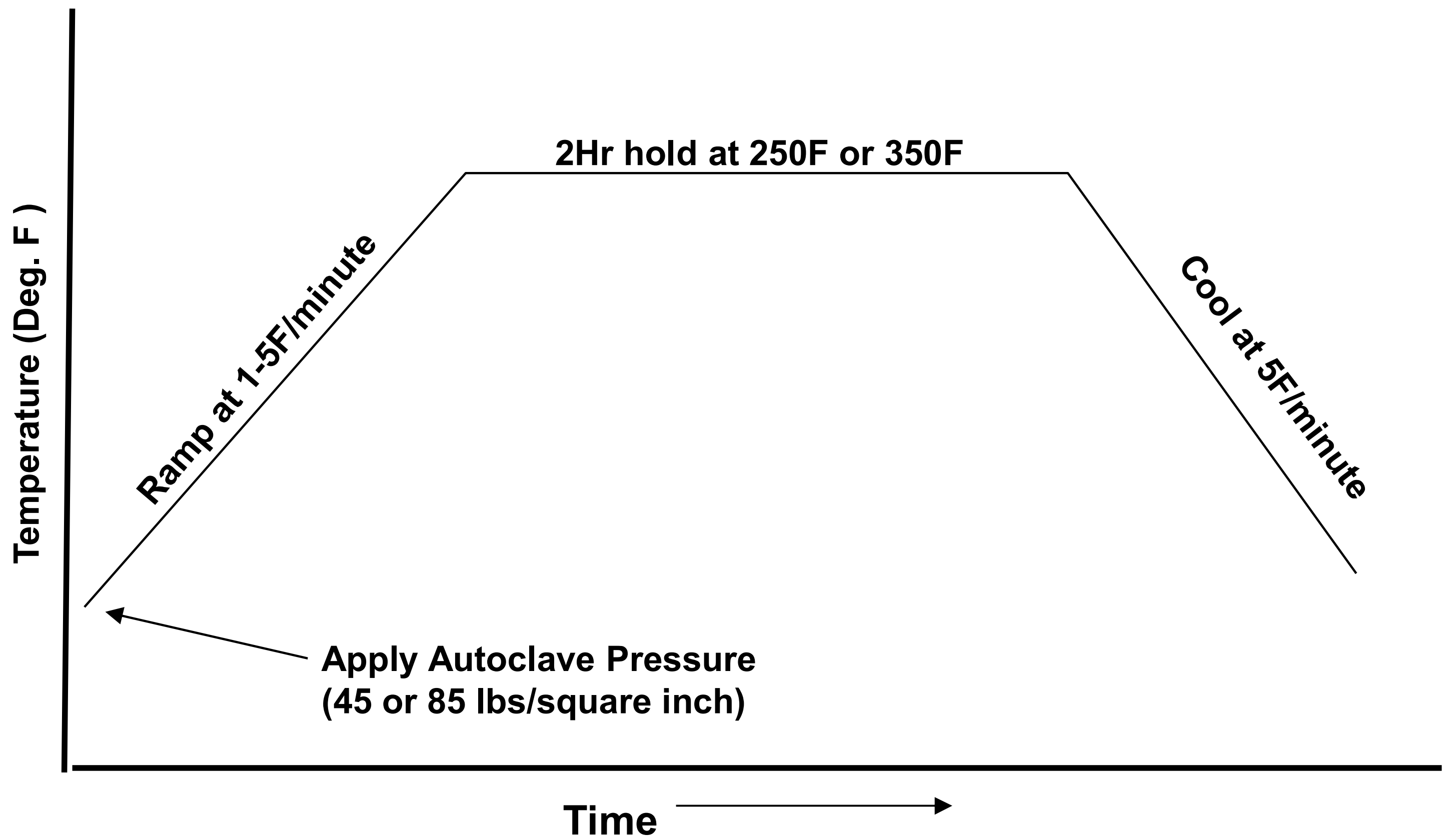


Autoclave

Large-Capacity Autoclave (typically can withstand 100+ psi pressure)



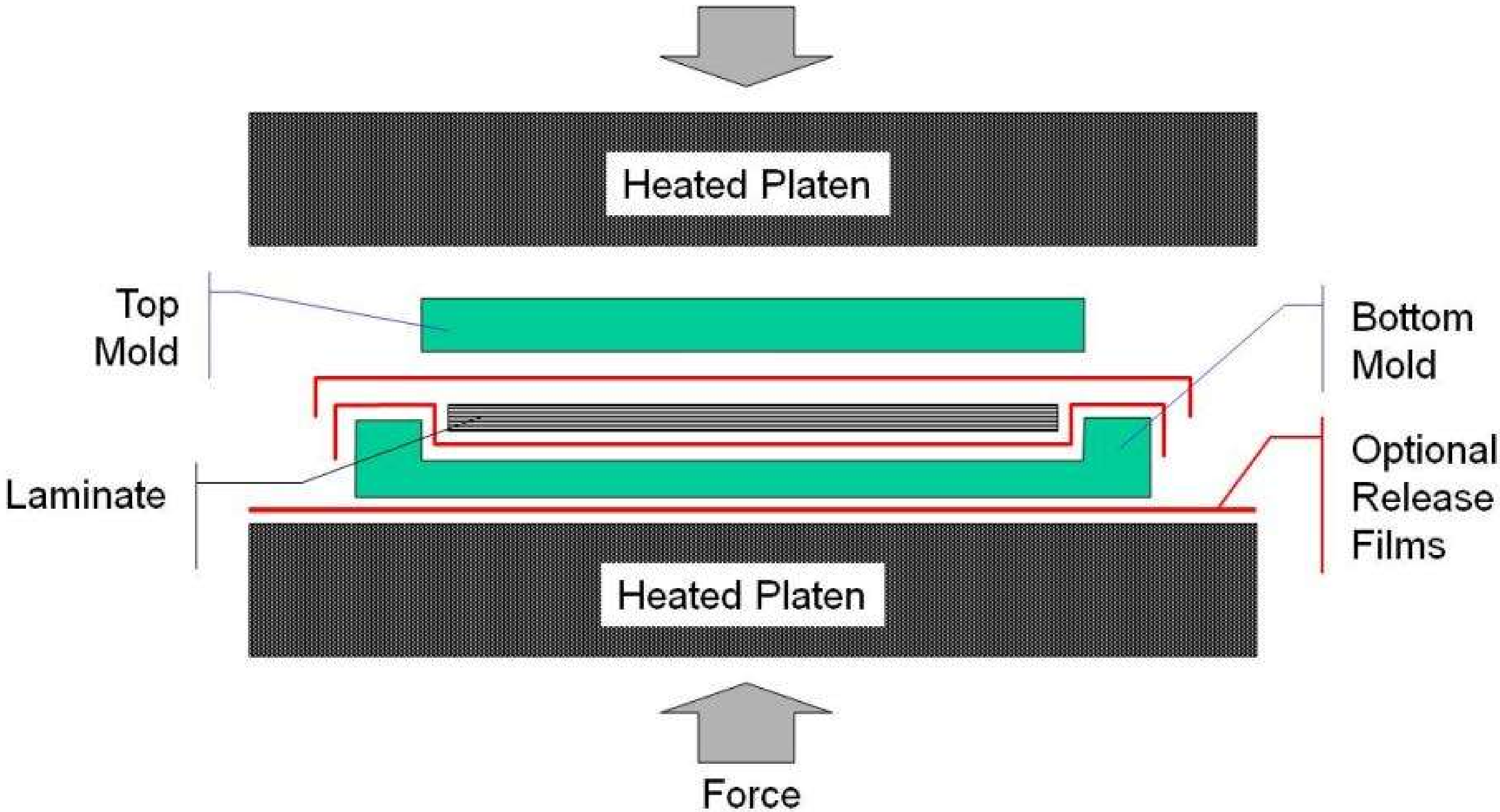
Typical Basic Composite Part Cure Cycle (sometimes there are variations)



Typical Autoclave Cure:

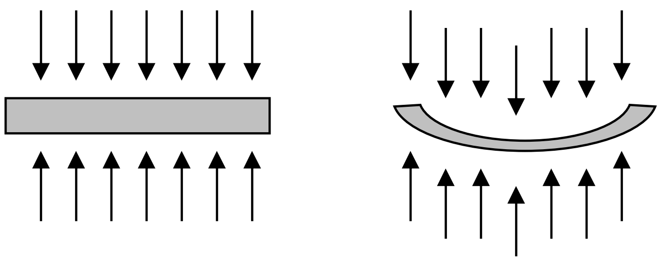
- Stage part in bag under full vacuum before cure
- Connect part in autoclave - draw full vacuum
- Apply 45 or 85 psi pressure at start of cure
- Ramp up to 250F or 350F, hold 2 hours, cool
- Some cure cycles vent the vac bag when autoclave pressure reaches 20 psi

Press Consolidation

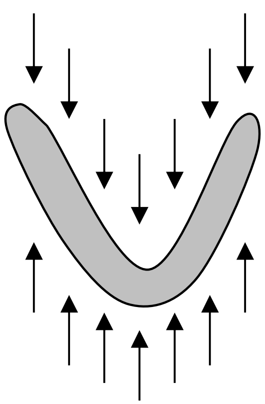


Press Consolidation

Good for flat or almost-flat parts



Not good for sharp curvature

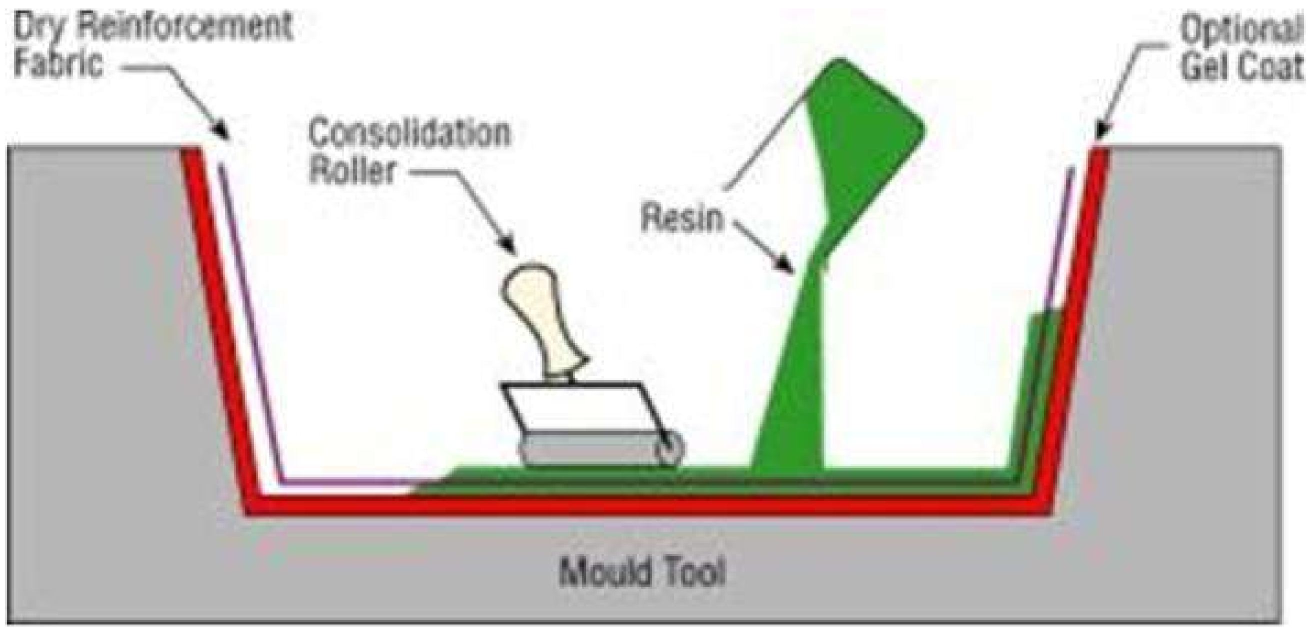


Thermoset Mfg Processes (Wet)

- Wet Lay-up
- RTM
- VARTM
- Filament Winding
- Pultrusion
- Braiding

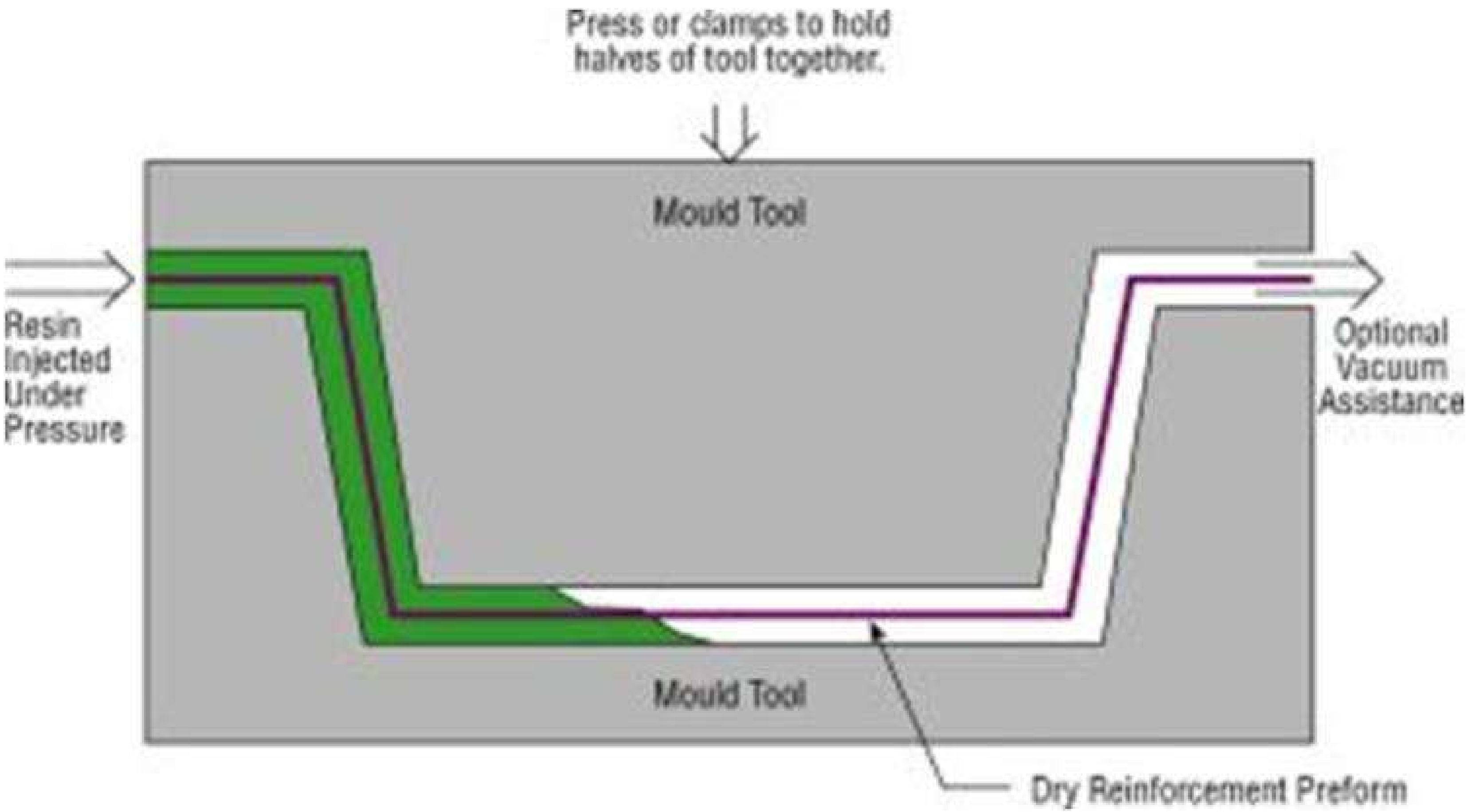
Processes done with dry fibers and liquid resin

Wet Lay-up



Sometimes used in aerospace for repair

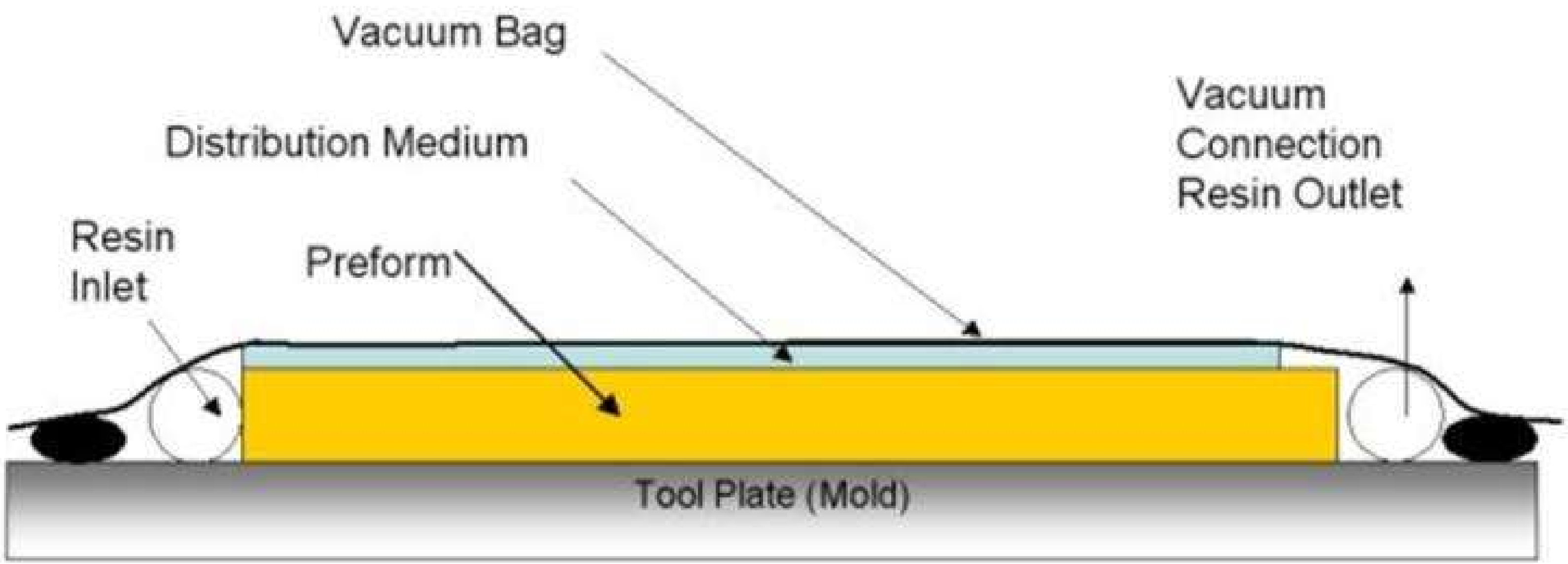
RTM
Resin Transfer Molding



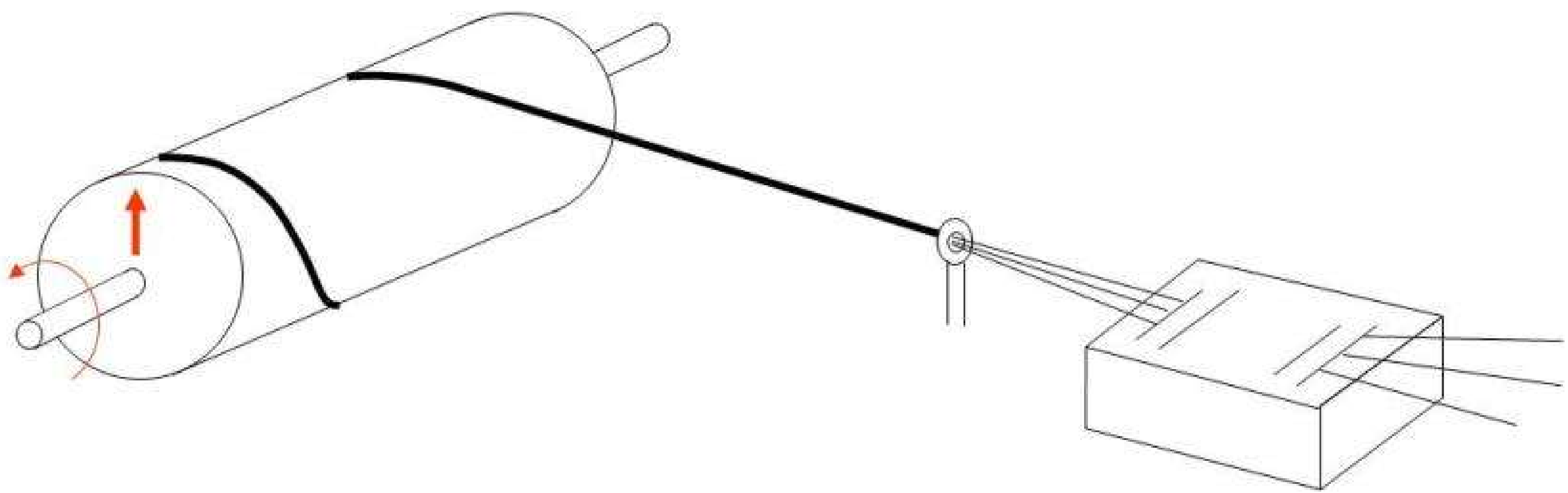
- Matched metal tooling (expensive)
- Precise dimensional control on both sides of part

VARTM

(Vacuum Assisted Resin Transfer Molding)



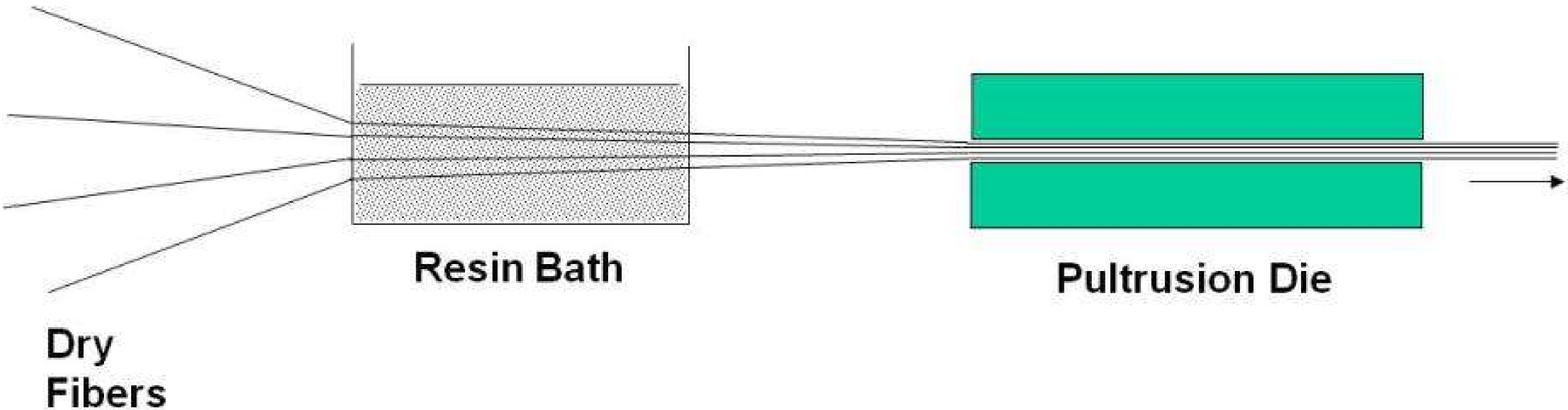
Filament Winding



Filament Winding
Rocket Motor Cases

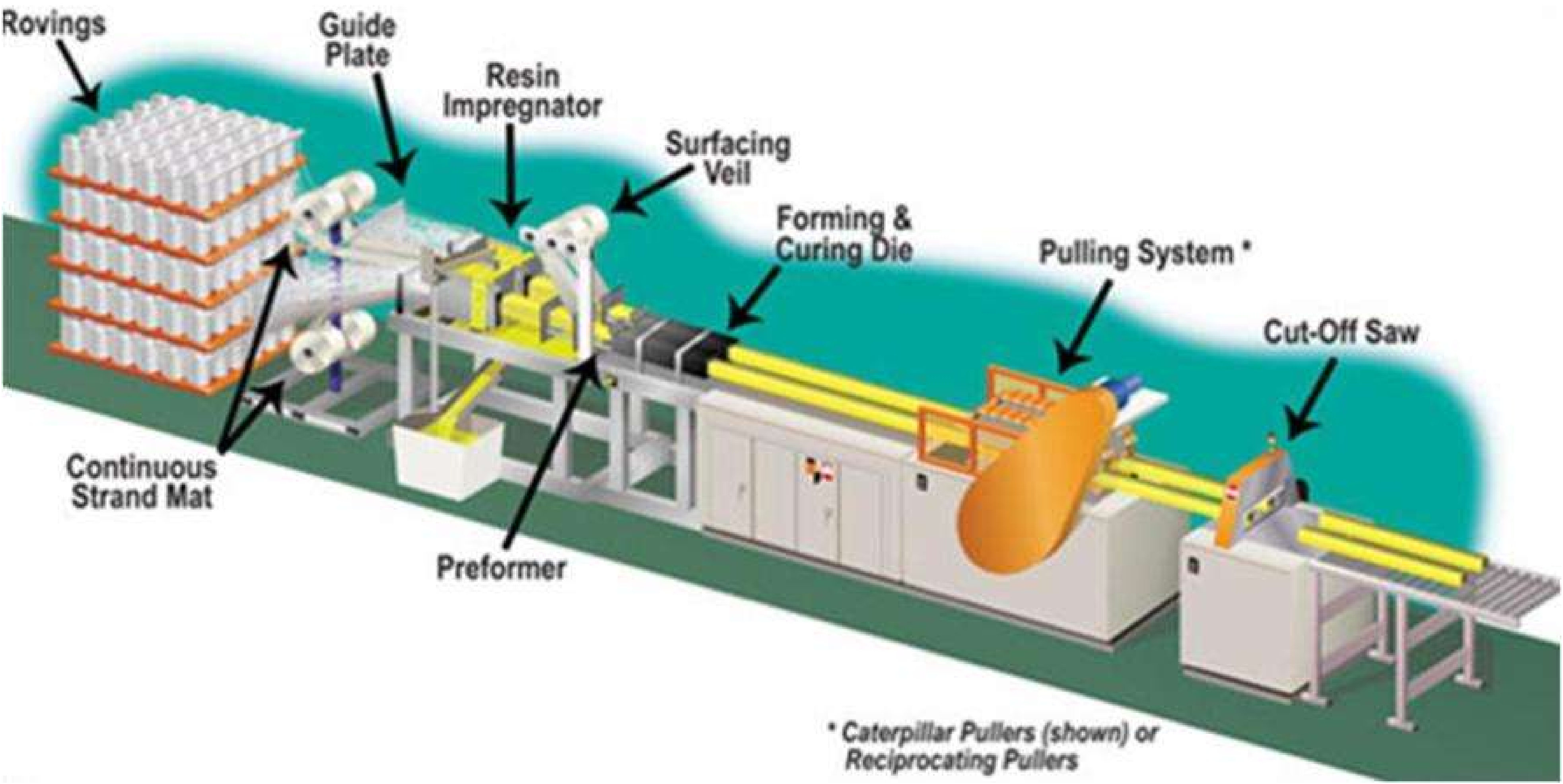
http://www.fas.org/nuke/control/mtcr/text/mtcr_handbook_item6.pdf

Pultrusion



Used for continuous constant section parts

Pultrusion



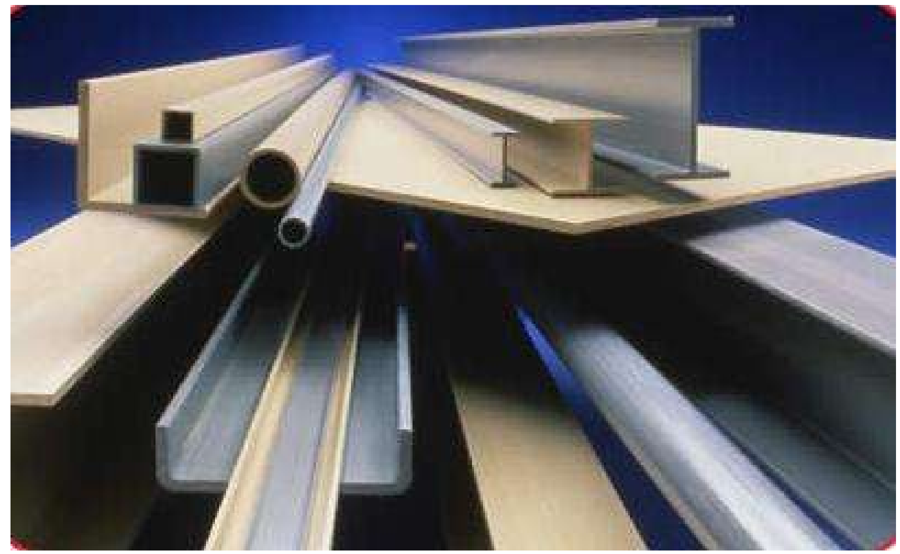
http://www.strongwell.com/pultrusion/

Pultrusion

Dry Fiberglass

Pultrusion

http://www.creativepultrusions.com/custom.html

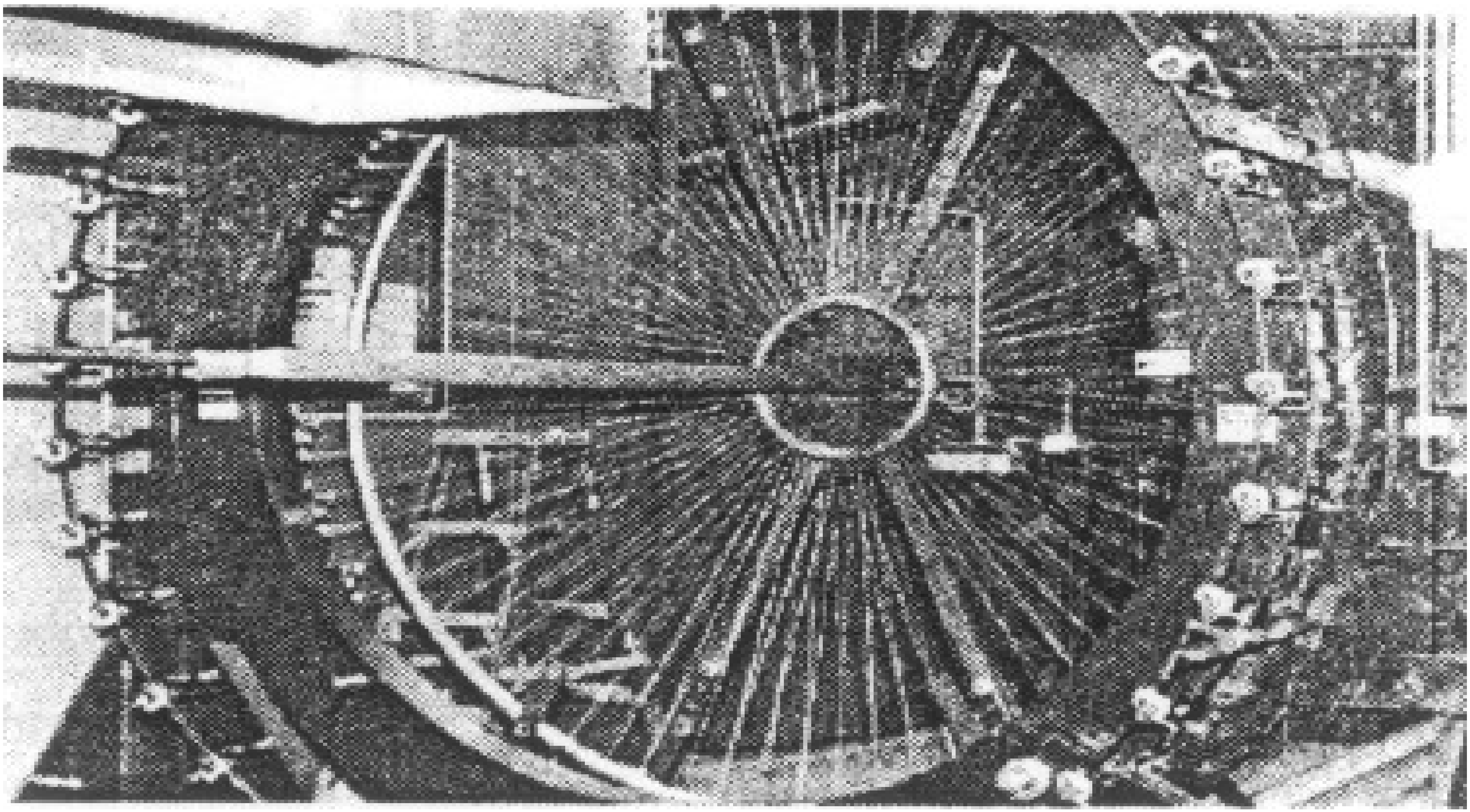


http://www.strongwell.com/products/pultruded_prod/struc_shapes/

Braiding Machine

http://www.omabraid.com/Products/ALL%20MACHINES/240%20FRC/240frc.htm

144 Carrier Braiding Machine



Questions?

Example Material Properties – This is not a complete list

(There will be property requirements for raw fiber, for neat resin, for prepreg, and for cured laminate)

Mechanical Properties

- Tensile strength/modulus
- Compression strength/modulus
- Fracture toughness (G_{IC}, G_{IIC})
- Compression After Impact
- Open Hole Tension
- Open Hole Compression
- In-Plane Shear
- Short Beam Shear

(several others)

Physical Properties

- Resin content
- Fiber tensile strength
- Fiber/resin areal weight
- Resin flow
- Prepreg volatile content
- Fiber orientation

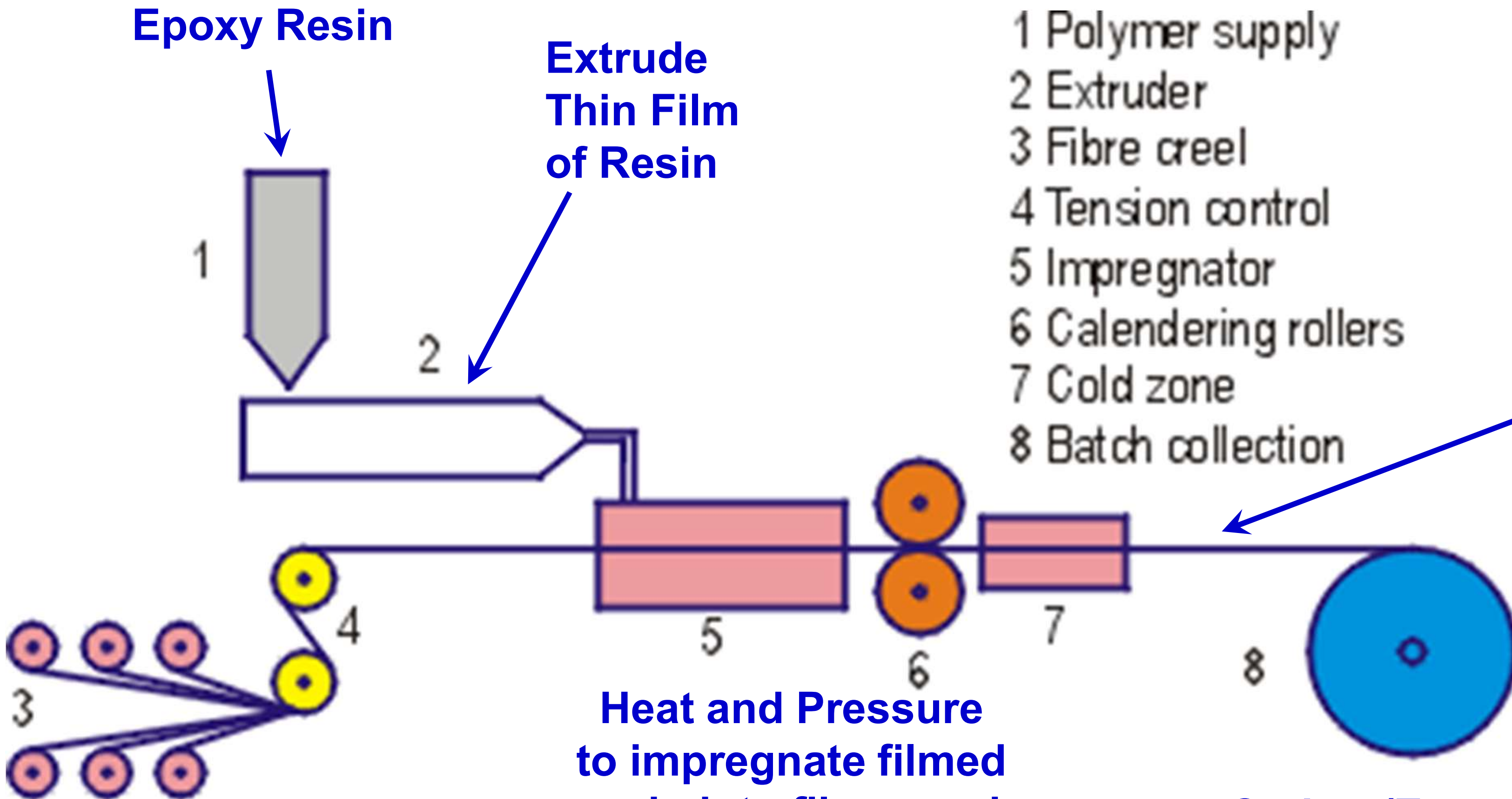
Chemical Evaluations

- Glass transition temperature
- Chemical fingerprint
- Solvent/chemical resistance
- Viscosity curve
- Degree of cure
- Cured ply thickness

Processibility

- Tack
- Automated tape layup compatibility
- Formability (drape)
- Tendency to wrinkle
- Tendency for porosity

Basic Schematic of Hot Melt Impregnation Process (Usually for Uni Tape)

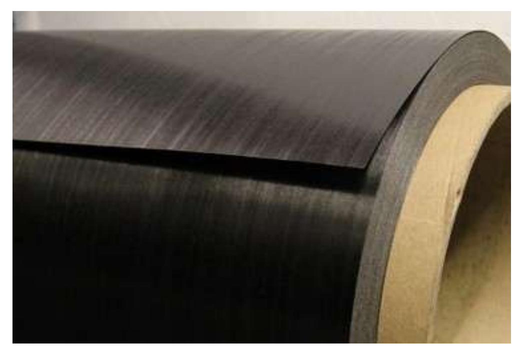


Heat and Pressure to impregnate filmed resin into fibers and partially cure ("B-Stage") the resin to appropriate tack level

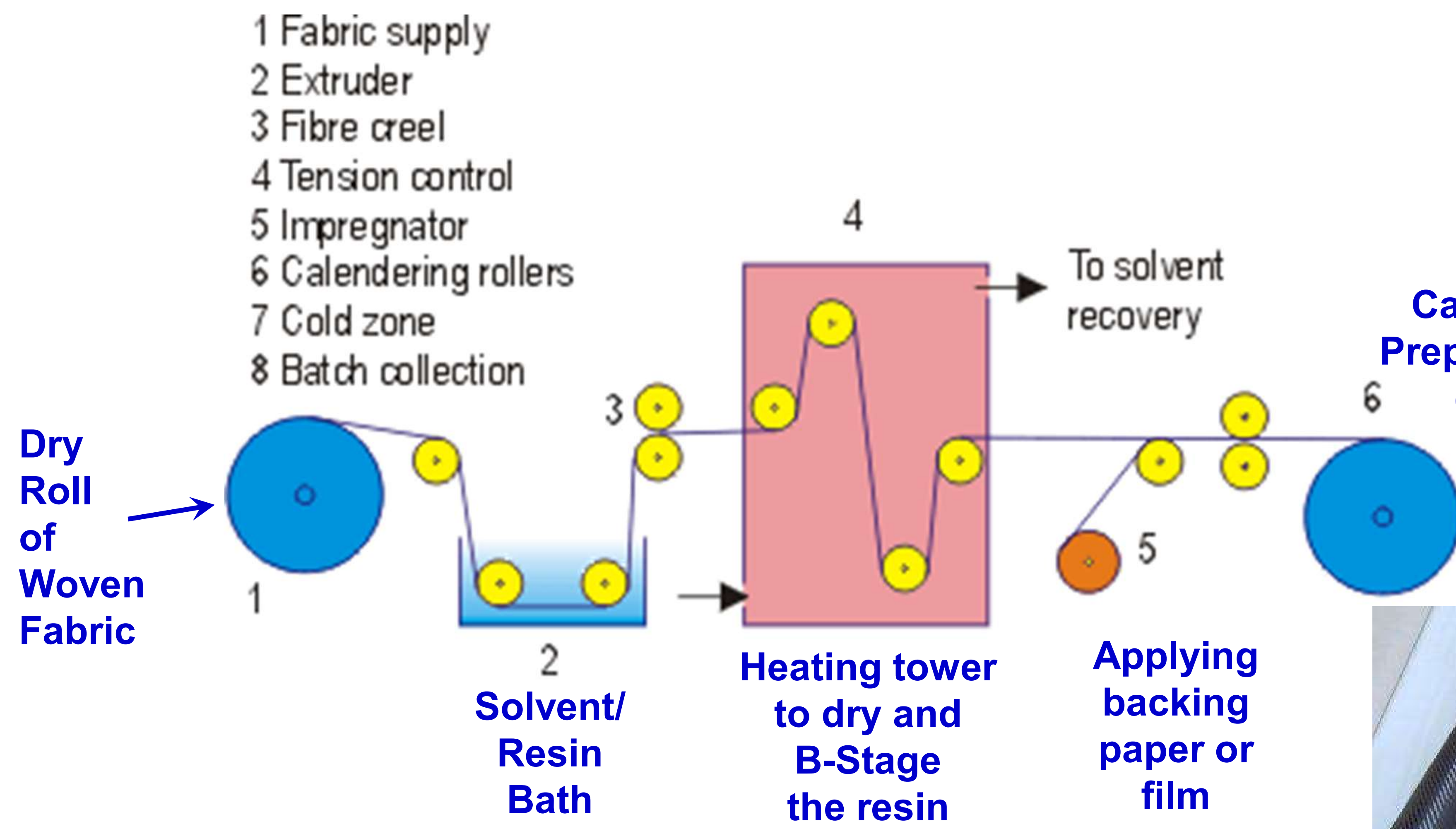
Carbon Fiber Creels (Many)

Example Photo of Creels

Carbon/Epoxy Prepreg is wound onto rolls and frozen

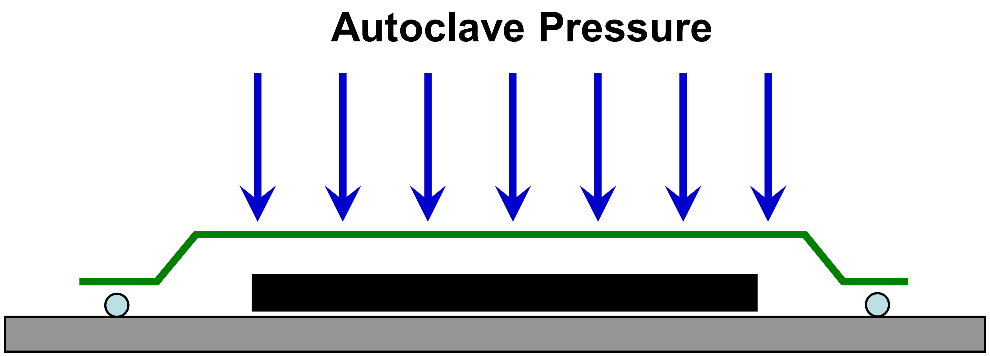


Basic Schematic of Solvent Dip Impregnation Process (Usually for Woven Fabric)

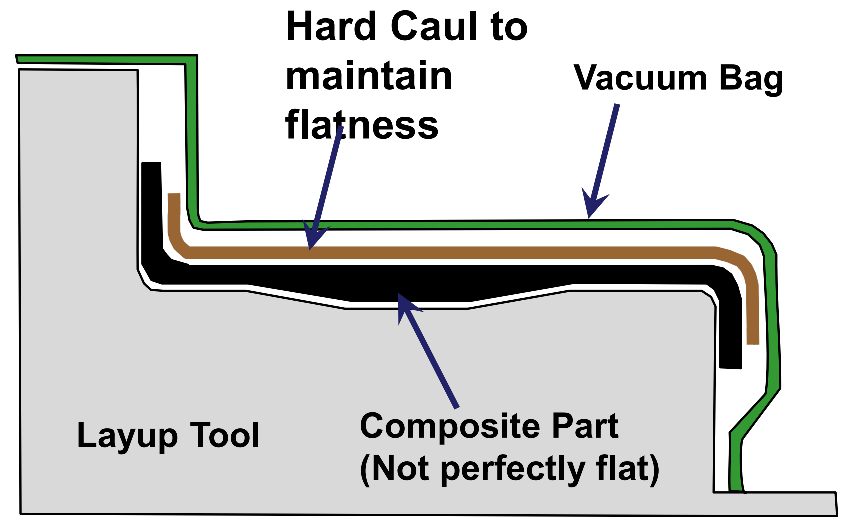


Is Resin Pressure Equal to Applied Autoclave Pressure?

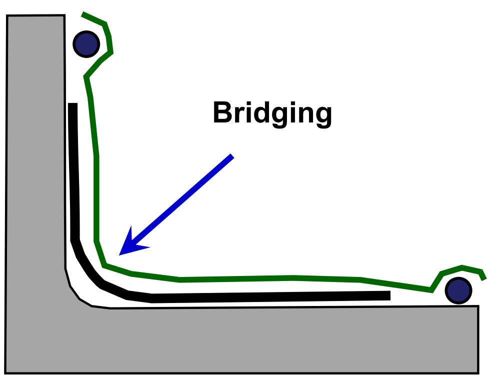
NEVER! – Unless We Are Making Flat Parts (which we aren't)



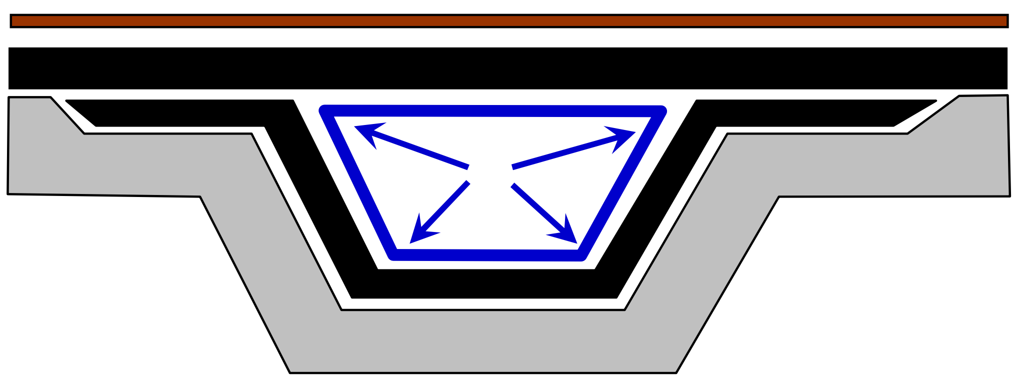
Flat Part – perfect pressure transfer
(There are approximately ZERO structural parts like this)



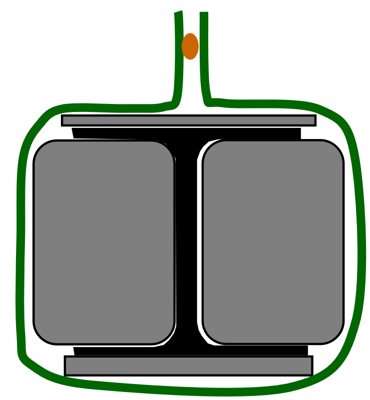
Hard Caul – won't conform to part
Inhibits pressure transfer to part



Sharp Concave Radius



Hat Stringer with Internal Pressurized Bladder



I-Beam Stringers
Part is trapped inside hard tooling