SOLAR CAR CONFERENCE | FEBRUARY 3-5, 2017 | OVERLAND PARK, KS

COMPOSITES

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FEB 4, 2017

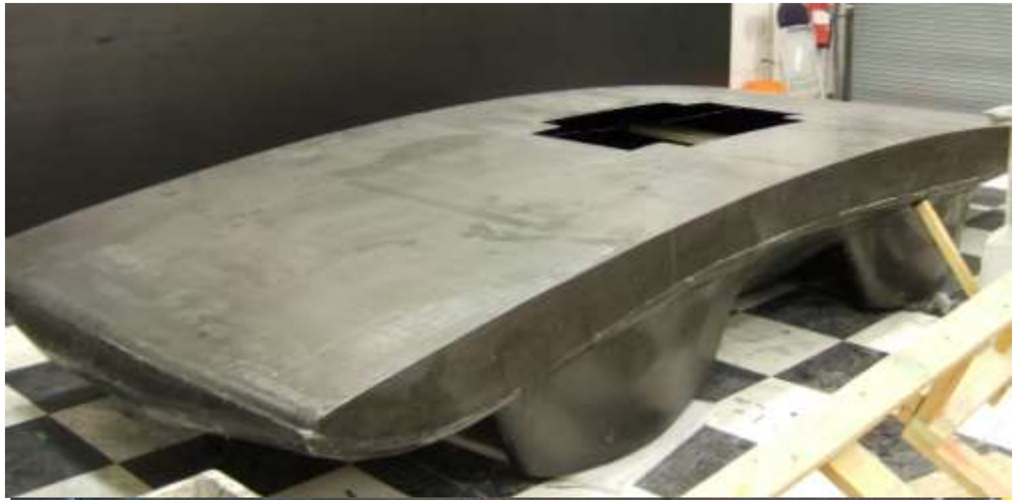
CONTENTS

COMPOSITE INTEGRATION

- **Body**
- **Frame**
- **Enclosures**
- **Suspension/Other**

BODY

- **Aerobody**
  - Thin sandwich structure with large unsupported areas, low loads
  - Supports the solar array – electrical pass-throughs, conductivity
  - Functional for tilting and removal by team members
- **Fairings**
  - Sandwich or thin laminate panel, low loads
  - Dynamic or static
  - Could take damage from road

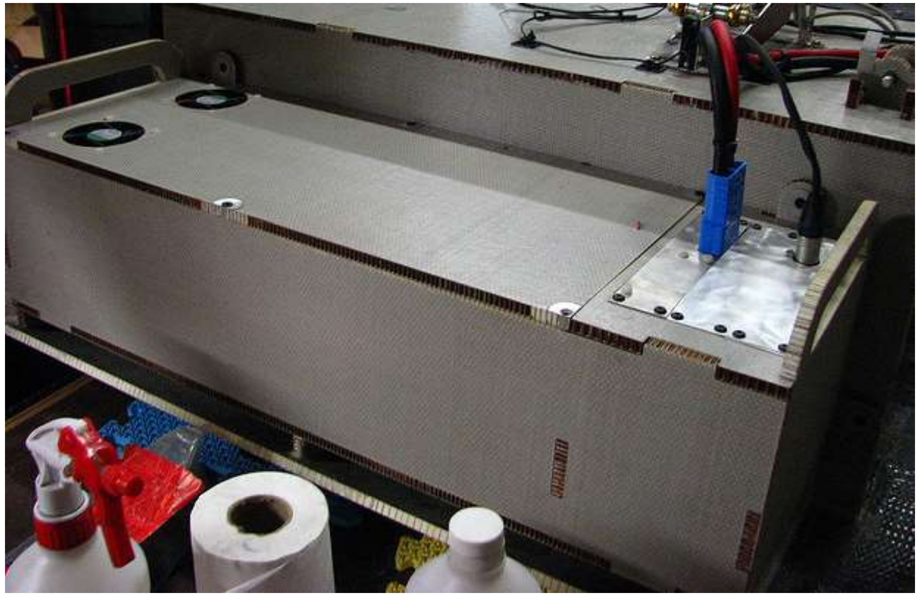


FRAME

- Thicker sandwich panels – takes suspension loads and impact loads
- Integrated with body
- Many cutouts and attachment points
- Bonded components
- Stiffeners

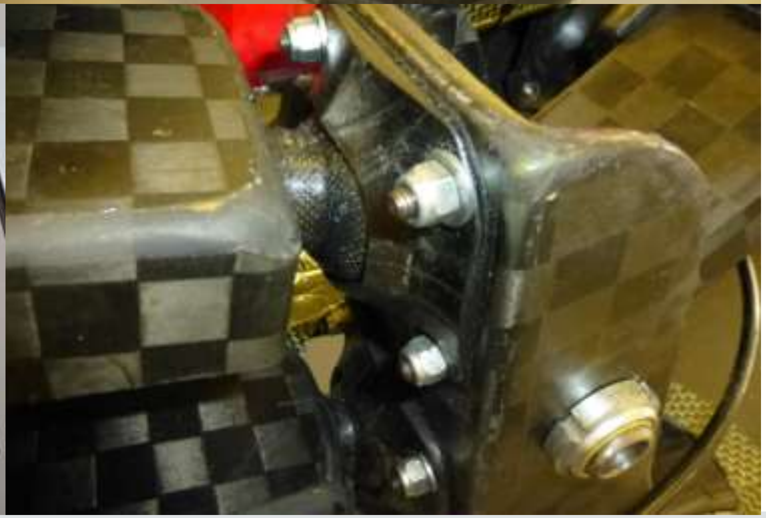
ENCLOSURES

- Battery/electronics box – conductivity, cutouts, durable, environmental seal
- Instrument covers – lightweight, cutouts, conductivity, environmental seal, aesthetics



SUSPENSION/OTHER

- Wishbone links – tensile & compressive loads, nodes, connections
- Steering column & rack extensions – tensile & compressive loads on rack, torque loads on steering column
- Uprights – tensile, compressive, torque, and very dynamic loads
- Frame attachments



COMPOSITE MATERIALS

- **Material Selection**
- **Mechanical Properties**
- **Design for Manufacturability**

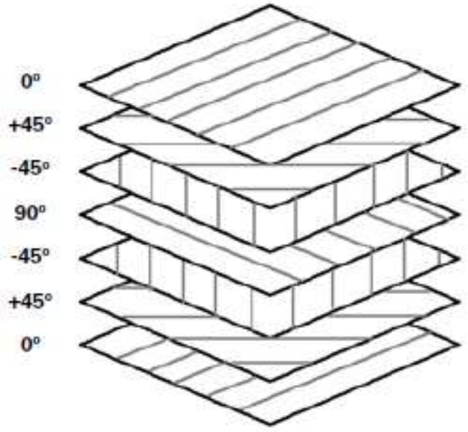
MATERIAL SELECTION

Material	Fiberglass	Carbon Fiber	Aramid (Kevlar)
Cost	Lowest	Highest	Middle
Density	Highest	Middle	Lowest
Tensile Strength	Middle	Highest	Middle
Modulus	Lowest	Highest	Middle
Conductivity	Nonconductive	Conductive	Nonconductive

MECHANICAL PROPERTIES* (ADDED)

Fabric based composite materials are non-isotropic

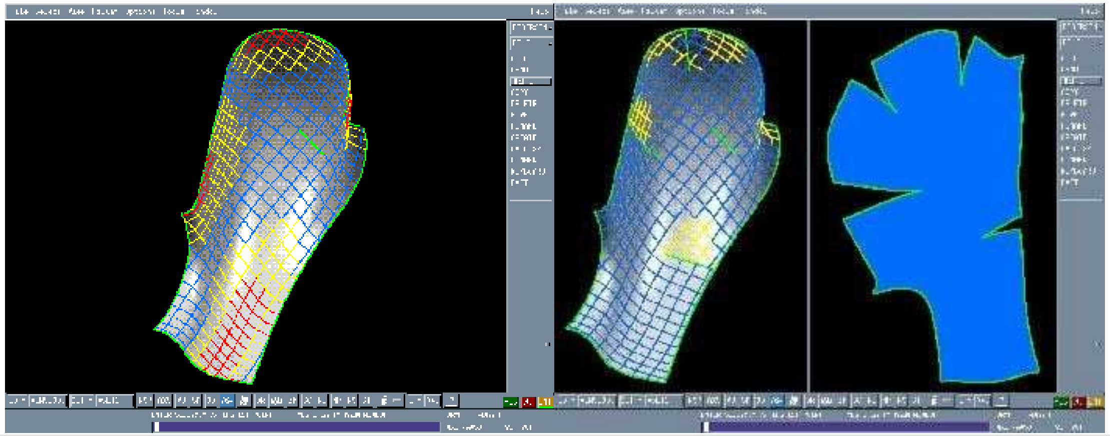
- This is caused by the directionality of the fibers
  - Fibers in dry fabrics are typically woven or stitched with a primary (0°) direction along the length of the fabric roll
    - Woven fabrics typically have an equal amount of fibers in the bias (90°) direction perpendicular to the direction of the fabric roll
    - Stitched non-crimp fabrics can have any amount of bias fibers in almost any direction, typically 90°, ±45°, or ± 30°
  - Fibers in prepregs can be woven or unidirectional
    - Unidirectional prepregs have fibers only in the 0° direction and are held together by the resin matrix
    - Woven prepregs typically have equal amounts of fibers in the 0° and 90° directions
- Unidirectional fabrics have flexural and tensile strength only in the direction of the fibers
  - Two layers can be laminated together at 0° and 90° to have equal strength in both directions (this is typically the lamination schedule on the skins of sandwich panels)
  - Multiple layers in incremental directions of 0°, ±45°, and 90° creates a quasi-isotropic panel (when made of carbon fiber this is referred to as "black aluminum" due to its similar mechanical properties in all planar directions)
- Woven or stitched fabrics have equivalent flexural and tensile strength in the directions of the fibers, however the maximum strength in either direction is less than that of a unidirectional fabric
- For structural components the direction of the load should guide the fiber direction of the panel to make the most efficient and lightest part. Fibers in unnecessary directions are added weight

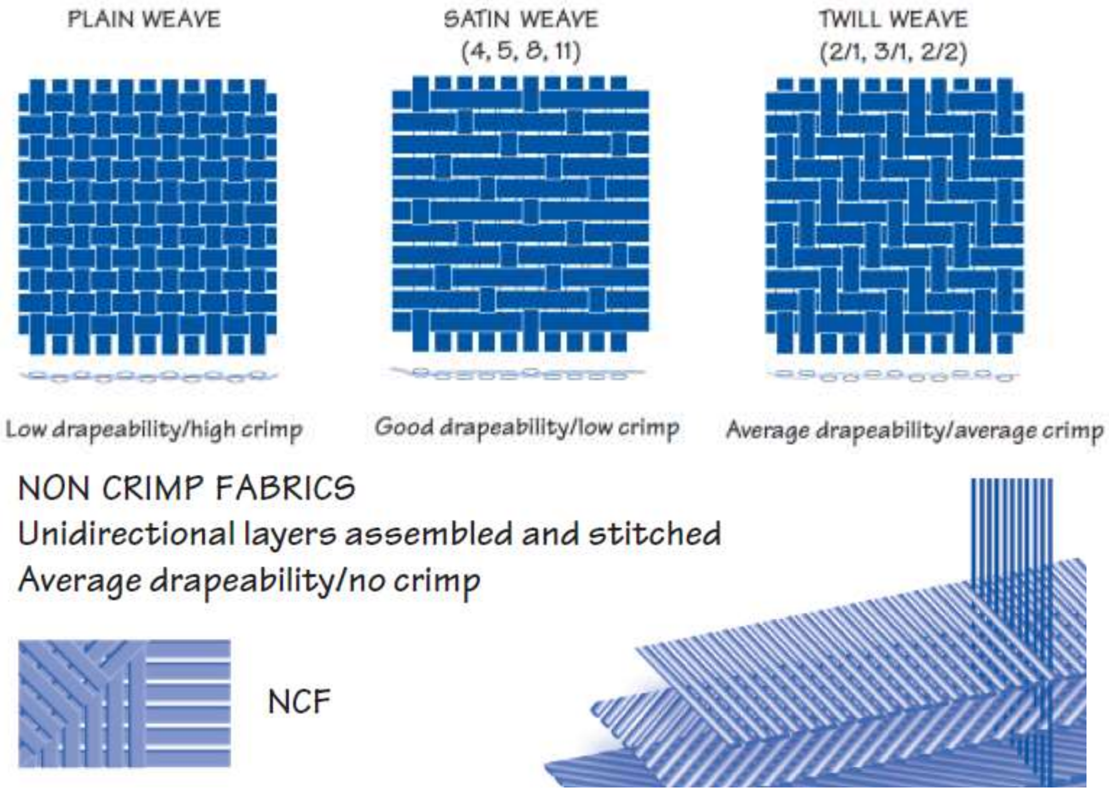


Starting at the top surface (0/+45/-45/90/-45/+45/0)

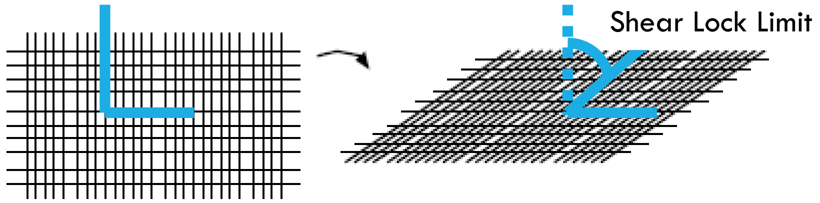
DESIGN FOR MANUFACTURABILITY

- Highly contoured surfaces require drapapble fabrics
- Manufacturability can be tested in FiberSim, Catia PLM/CPD, NX Composites Tool, or PAM-FORM
  - These programs provide a map of where the fiber can go before cutting or darting is required
  - This allows you to avoid bridging or wrinkling
  - You can also export the flat pattern and have it cut on a CNC cutter or print a template
  - The primary input for this software is the Shear Lock Limit angle (or the extent to which the fabric can be stretched in-plane)





Source: Hexcel Composites: Hexply Prepreg Technology



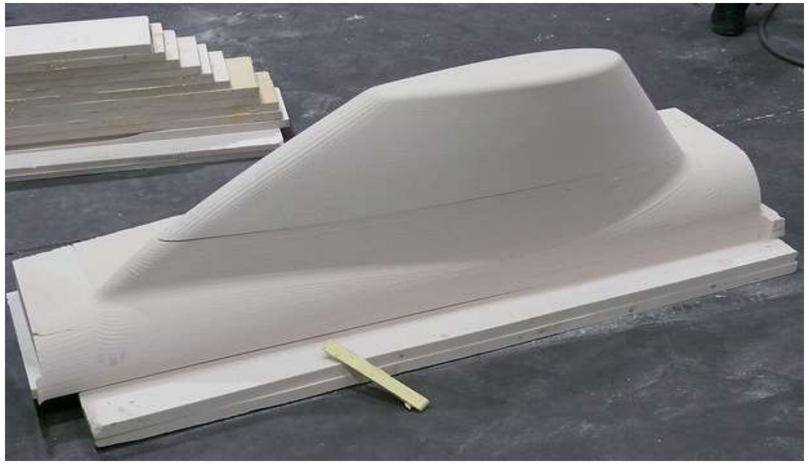
Source: Gurit Guide to Composites

FABRICATION METHODS

- **Molds**
- **Process Selection**
- **Wet Layup**
- **Infusion**
- **Prepreg**

MOLDS

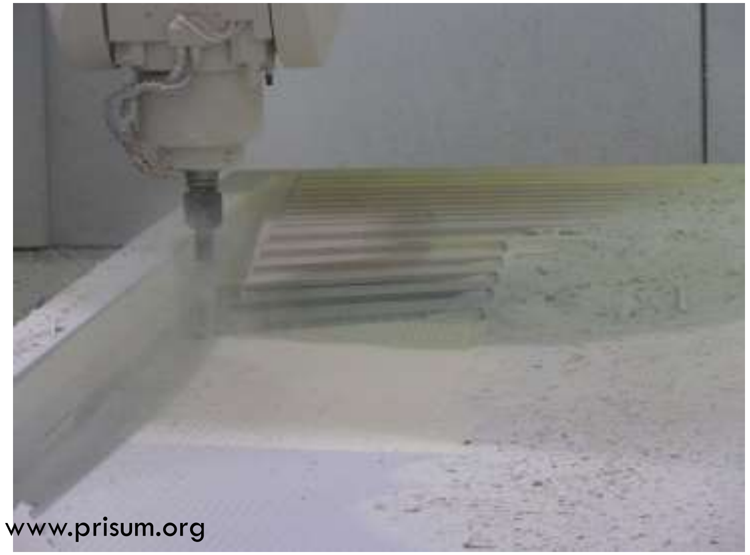
- Molds have an "A" surface (in contact with the mold) and a "B" surface (on the bag side)
  - The "A" surface will have a smoother finish with minimal to no wrinkles
  - The "B" surface will be rougher from the breather and susceptible to wrinkles and resin flash
  - The exterior of the vehicle should be the "A" surface, the "B" surface is also better for bonding
- Molds can be either male/plug/positive (the interior volume of the part) or female/negative (exterior volume around the part)
  - To create a part with an "A" surface exterior a female mold must be used
  - A male mold is usually used to cast the female mold but not typically for making a part



Source: www.prisum.org

MOLDS

- Constructing a female mold can be done in one or two steps
  - The mold can be machined from foam, wood, etc.
    - Advantages: faster, cheaper, suitable for low temp cures under vacuum pressure
    - Disadvantages: harder to machine deep cavities, cannot typically go to cure temps of 180C(350F) (High density urethane*, EPS, wood), cannot withstand high pressure, susceptible to cracking. *some urethanes can go to 300F
  - A male mold can be machined, which is easier, and the female is cast from it with a composite layup
    - Advantages: easier to machine external features, composite female mold can go to higher temps and pressures, stronger
    - Disadvantages: more time and labor intensive (making two molds), more expensive



Source: www.prisum.org

PROCESS SELECTION

Layup Type	Wet Layup	Infusion	Prepreg
Cost	Lowest	Middle	Highest
Material Life	Unlimited	Unlimited	Limited (store @ -18°C)
Ease of Layup	Worst (resin mixing/wetting)	Middle (resin mixing)	Best
Complexity of Processing	Lowest	Middle (infusion plumbing)	Highest (autoclave)
Volatile Exposure	Highest	Middle	Lowest
Cure Type	Exothermic (Room temp)*	Exothermic (Room Temp)*	Endothermic (120-180°C)
Max Consolidation Pressure	1 Bar(14.5psi), vacuum pressure	1 Bar(14.5psi), vacuum pressure	7 Bar(100psi)+, autoclave
Core Options	Foam**	Foam	Honeycomb or high temp foams
Core Compression	Lowest (foam)	Lowest (foam)	Highest (honeycomb)
Fiber Volume Fraction	Lowest	Middle	Highest
Laminate Consistency	Lowest	Middle	Highest

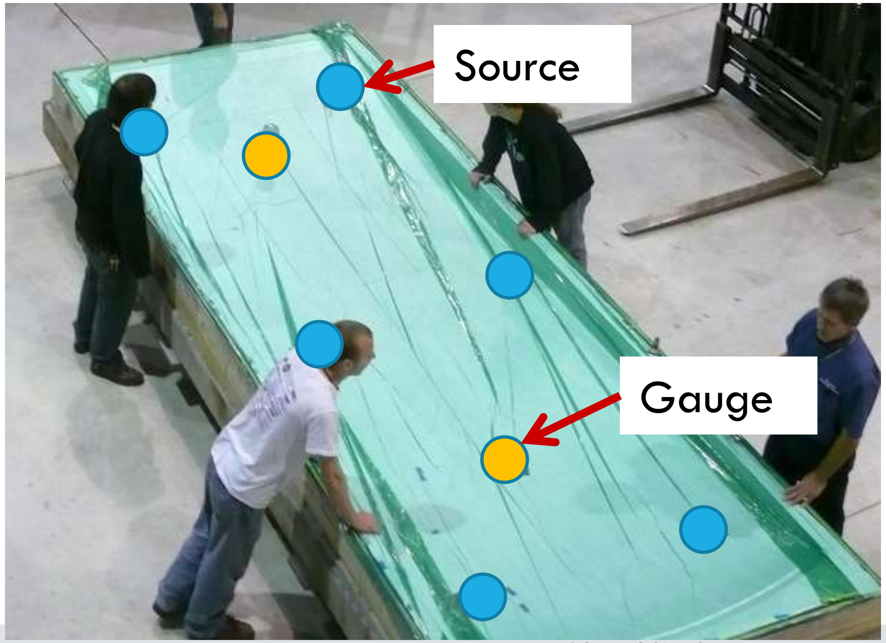
*Elevated temperatures can decrease cure time and increase laminate properties

**Honeycomb is possible if careful processing is done, however the part will have additional resin weight

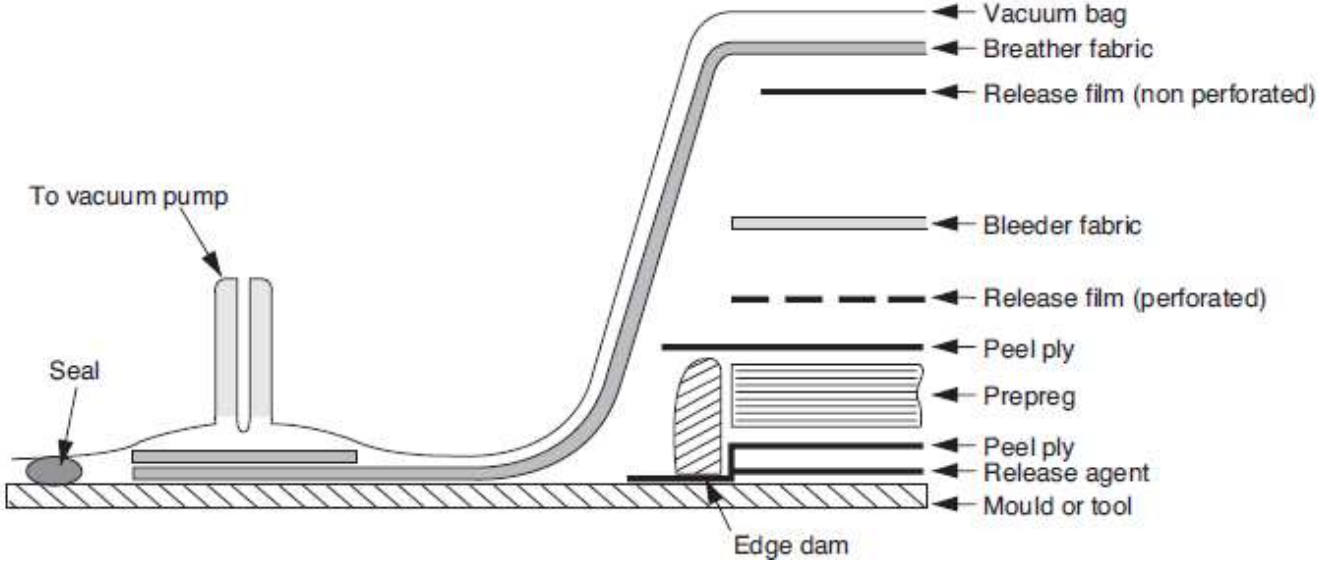
PROCESS SELECTION

All process types

- Use mold release but be sure to follow the directions carefully
- Vacuum bag pleats (use liberally) need to be aligned with elevation changes
- Maintain a consistent vacuum, a 1inHg/min drop maximum after source removal
- The vacuum gauge probe should be far from the source probe
- Maintain pressure on the part until the temperature is as low as possible, this reduces residual stress and spring-back
- Always use the appropriate PPE



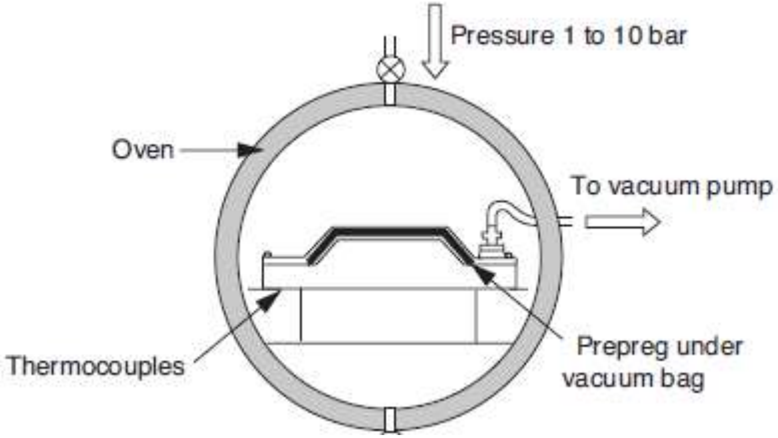
WET LAYUP



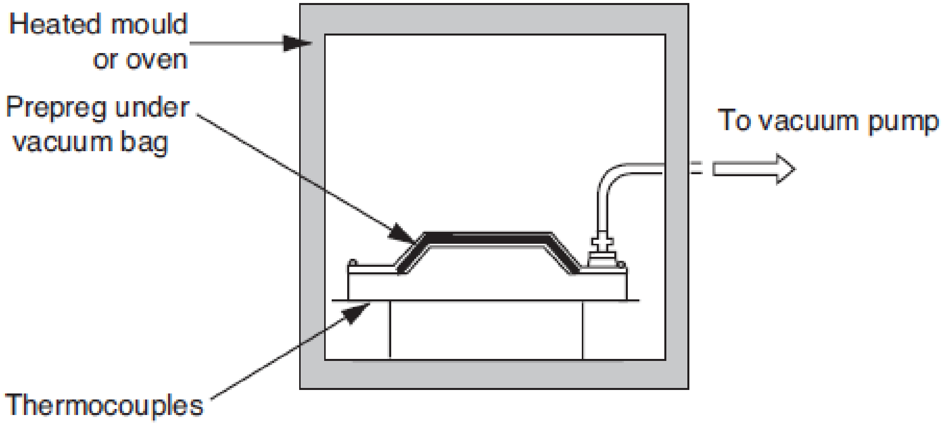
- **Release Agent** — Allows release of the cured prepreg component from the tool.
- **Peel Ply (optional)** — Allows free passage of volatiles and excess matrix during the cure. Can be removed easily after cure to provide a bondable or paintable surface.
- **Bleeder Fabric (optional)** — Usually made of felt or glass fabric and absorbs the excess matrix. The matrix flow can be regulated by the quantity of bleeder, to produce composites of known fiber volume.
- **Release Film** — This layer prevents further flow of matrix and can be slightly porous (with pin pricks) to allow the passage of only air and volatiles into the breather layer above.
- **Breather Fabric** — Provides the means to apply the vacuum and assists removal of air and volatiles from the whole assembly. Thicker breathers are needed when high autoclave pressures are used.
- **Edge Dam** — Contains resin flow and component shape
- **Vacuum Bag/Sealant Tape** — Provides a sealed bag to allow removal of air to form the vacuum bag.

Source: Hexcel Composites: Hexply Prepreg Technology

PREPREG



Autoclave cure – application of vacuum, heat, and pressure

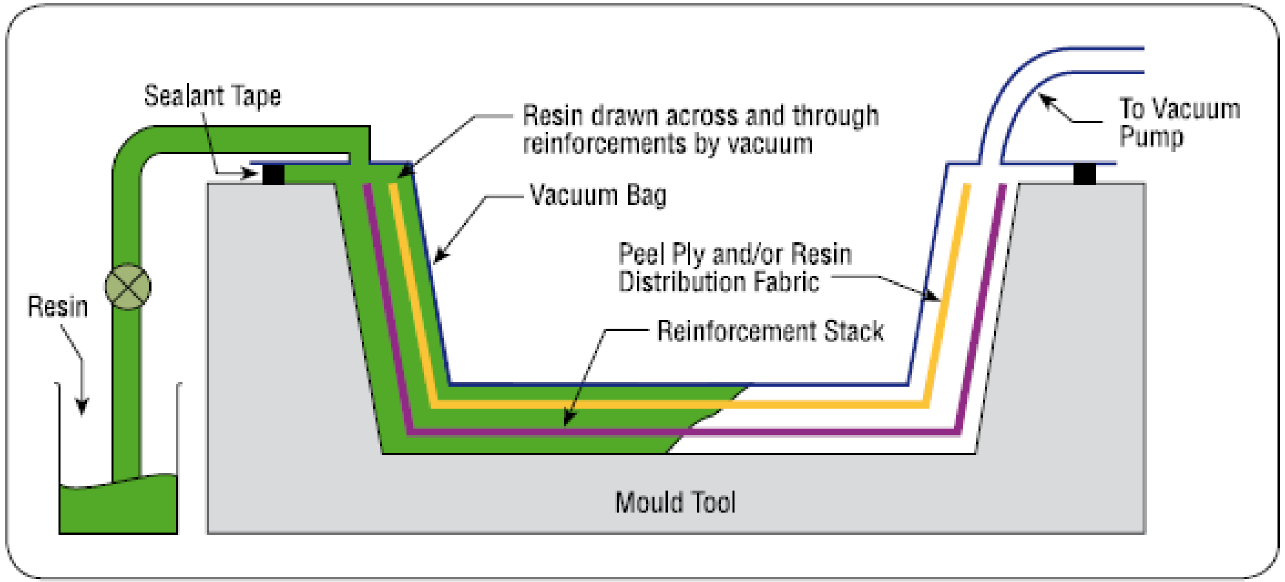


Oven cure – application of vacuum and heat

Source: Hexcel Composites: Hexply Prepreg Technology

RESIN INFUSION

- **VARTM? Infusion? SCRIMP?**



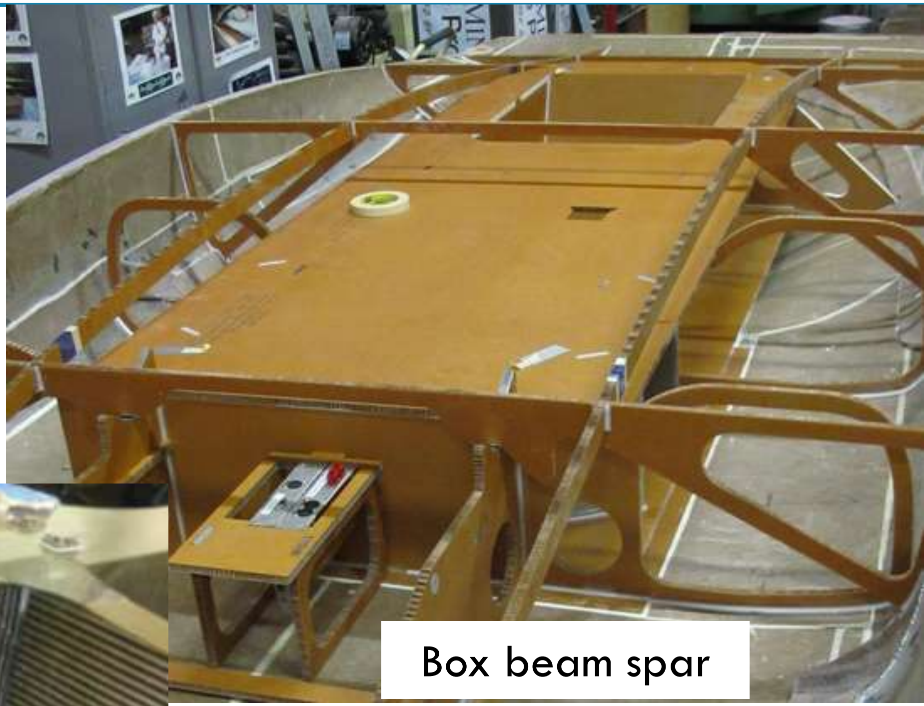
Source: Gurit: Guide to Composites

DESIGN PRACTICES

- **Composite Chassis Design**
- **Panels**
  - **Stiffening**
  - **Bonding**
- **Suspension**
- **Frame Attachment**

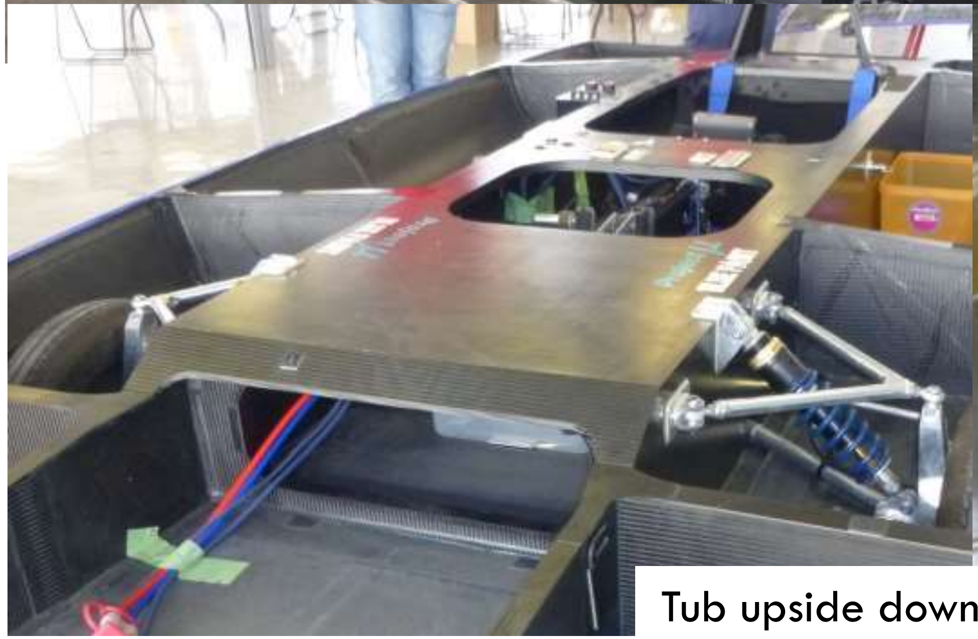
COMPOSITE CHASSIS DESIGN

Open beam spar

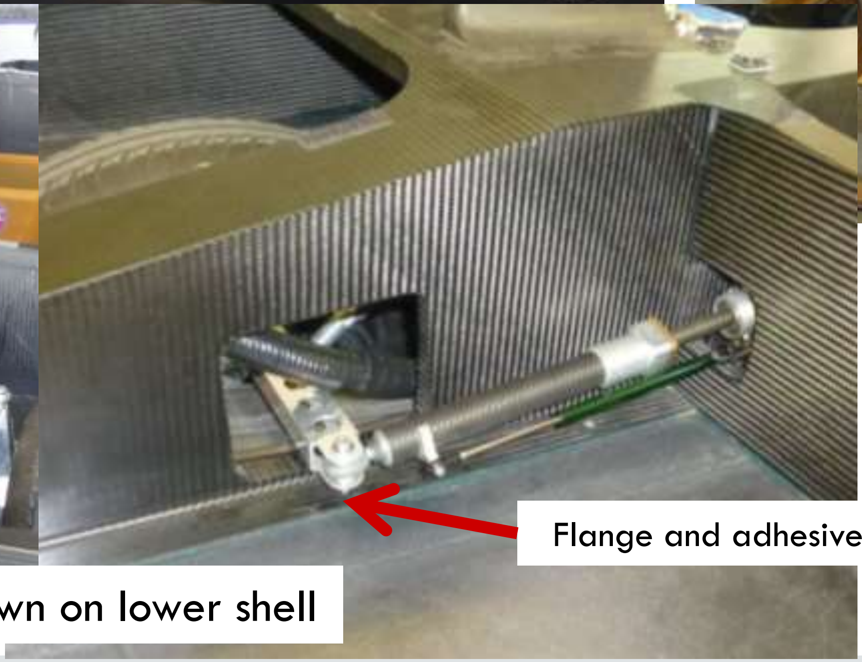


Box beam spar

Source: https://www.flickr.com/photos/theholymacintosh



Tub upside down on lower shell



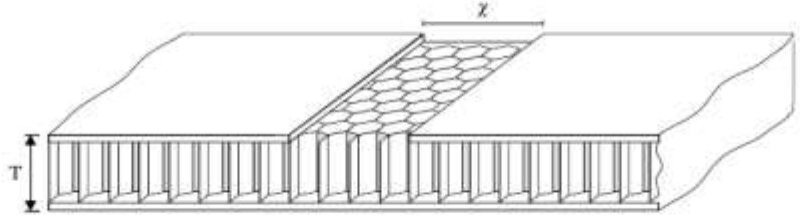
Flange and adhesive

PANELS

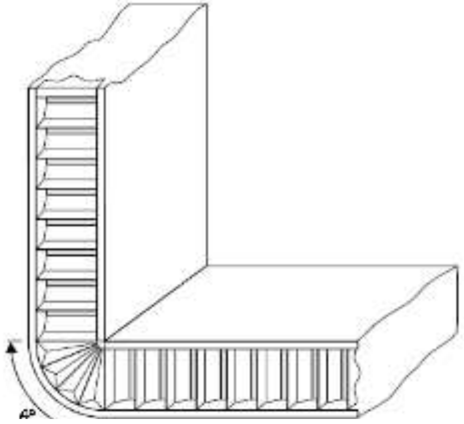
- Outer surface skin of unidirectional [0,90]n plies, this can be optimized
- Core of honeycomb (aramid, Nomex, aluminum, plastic) or foam of various thicknesses
- Honeycomb can't be used with infusion, wet layup if you are careful
- Foam core is typically weaker and heavier than Nomex
- These can be bought premade and laser or waterjet cut
- Dry after waterjet
- Seal all edges

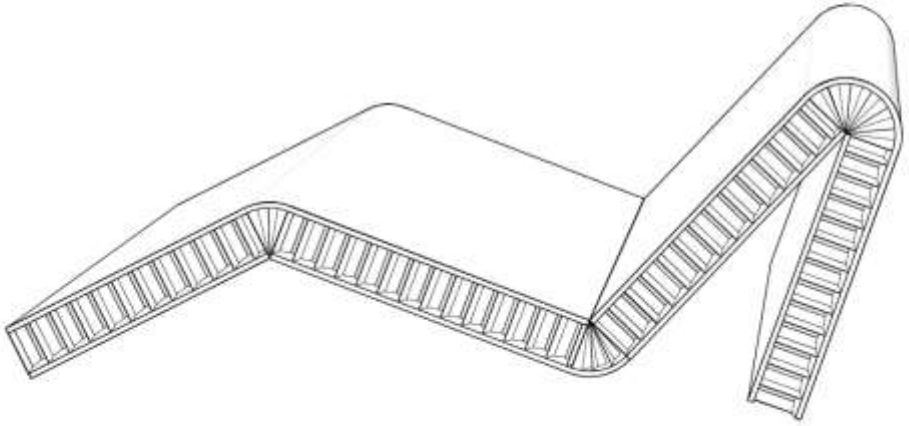
	Solid Material	Core Thickness t	Core Thickness 3t
Stiffness	1.0	7.0	37.0
Flexural Strength	1.0	3.5	9.2
Weight	1.0	1.03	1.06

Source: Hexcel Composites: Sandwich Panel Fabrication Technology



$$x = \frac{2\pi \times T \times \theta^{\circ}}{360}$$

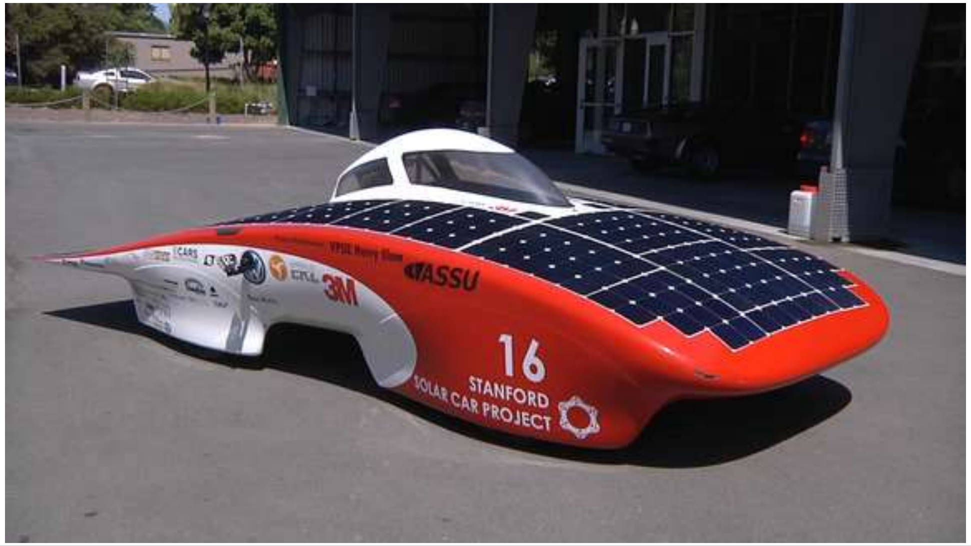




STIFFENING

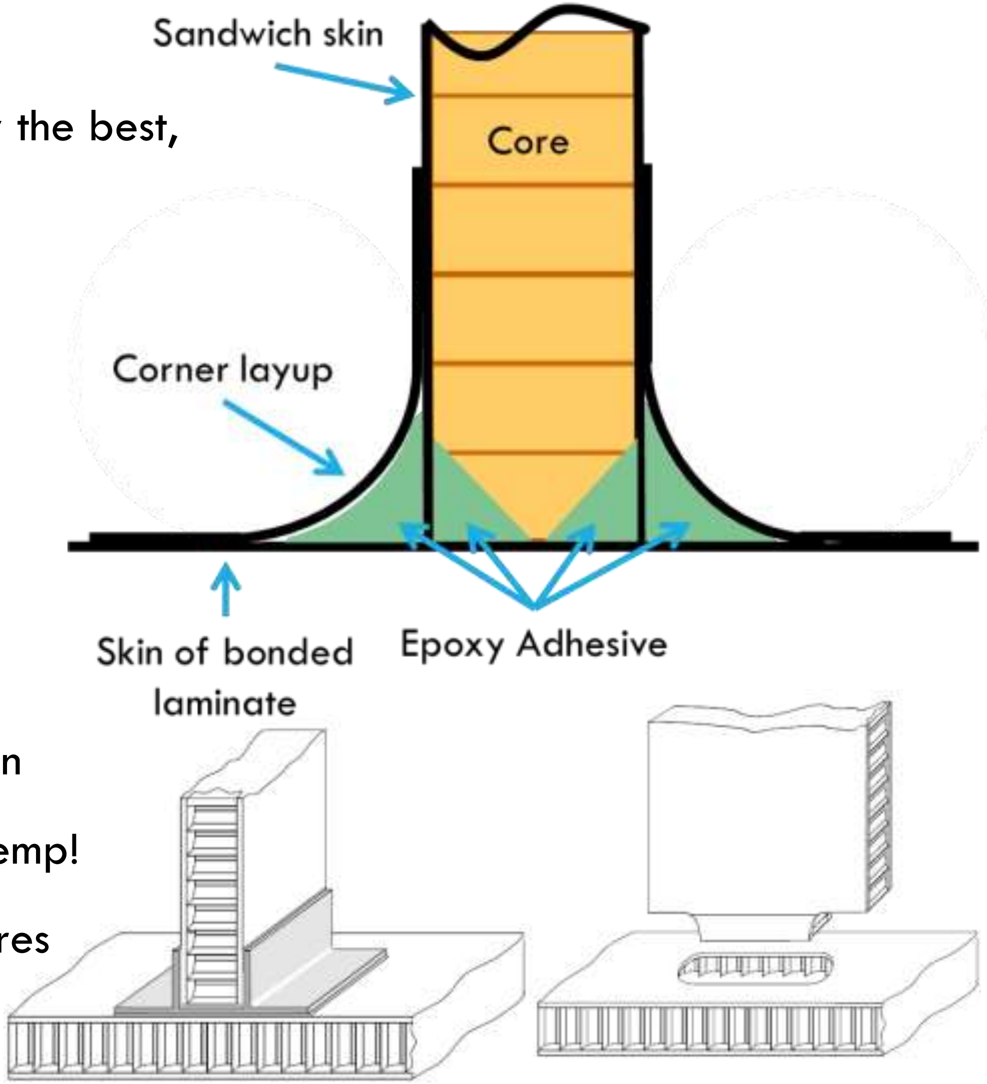
- Stiffening (increased moment of inertia) can typically be created in several ways
  - Increasing the laminate or core thickness
  - Adding stiffening sections (“C”-channel, hat, etc.) or ribs
  - By designed curvature
- Stiffening can also be improved by adding higher modulus plies

Source: https://www.flickr.com/photos/theholymacintosh



BONDING

- Quality bonds are critical to maximizing strength
- Use appropriate adhesive (compatible with composites), epoxies are usually the best, PU and acrylics can also work
  - 3M DP460NS – epoxy, strongest for most applications
  - 3M 8115 – epoxy, automotive panel bonding
  - ProSet 176/276 – epoxy, automotive
  - Plexus – methacrylate
- Surface must be properly prepped and cleaned
- Adhesive must be inserted on the inside of the sandwich
- Adhesive on the outside must be masked and filleted
- Outer wet layups can be added for additional strength and crack prevention
- Closely follow the instructions of the material, bond line thickness and cure temp!
- Adhesive can be bulked and bondline controlled by adding glass microspheres
- Panels bonded in this way are designed to be loaded in shear only

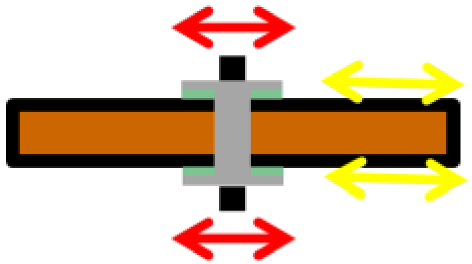


Source: Hexcel Composites: Sandwich Panel Fabrication Technology

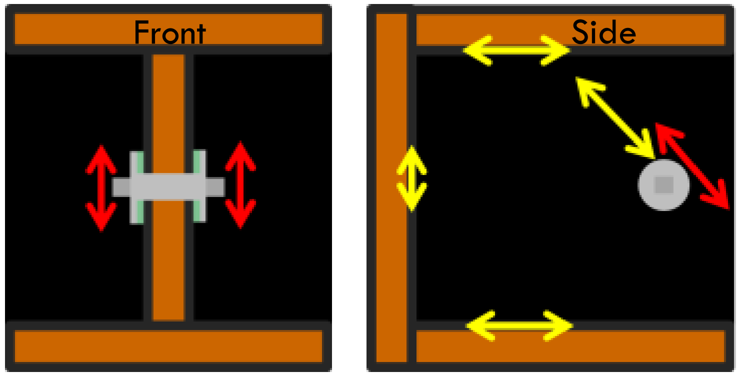
SUSPENSION ATTACHMENT

Loads should be transferred in in-plane shear only

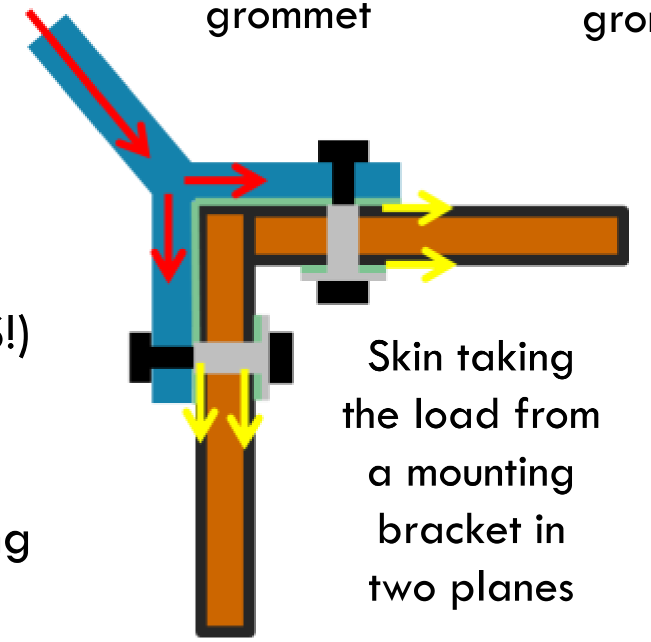
- Let the skins do the work!
- Load is transferred from grommet or bracket through the adhesive bond to the skins
- In-plane shear transfer of loads allows for very lightweight robust attachments
- Loads should be transferred to as many planar skins as possible
- Out-of-plane bending loads are a last resort and often require heavy reinforcement
- Do not rely on Out-Of-Plane Strength (OOPS!)
- Attachments should ***never*** be placed in <u>unbonded</u> bearing loads
- Shear loading does require extensive planning and alignment



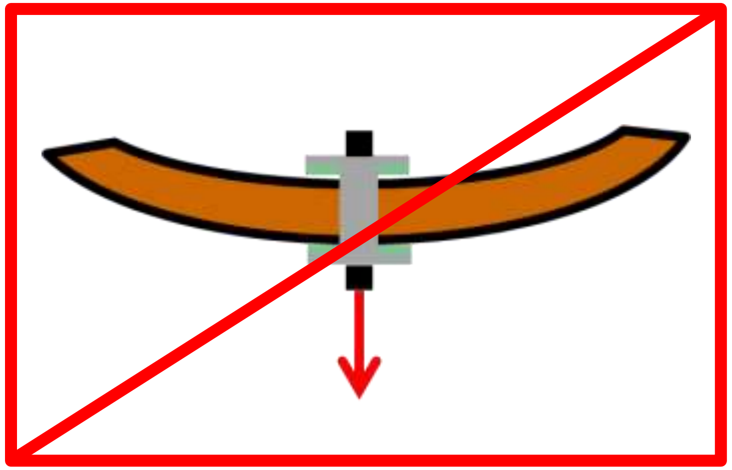
Skin taking the load from a bonded grommet



Skin taking the load from a bonded grommet and transferring to other planes



Skin taking the load from a mounting bracket in two planes

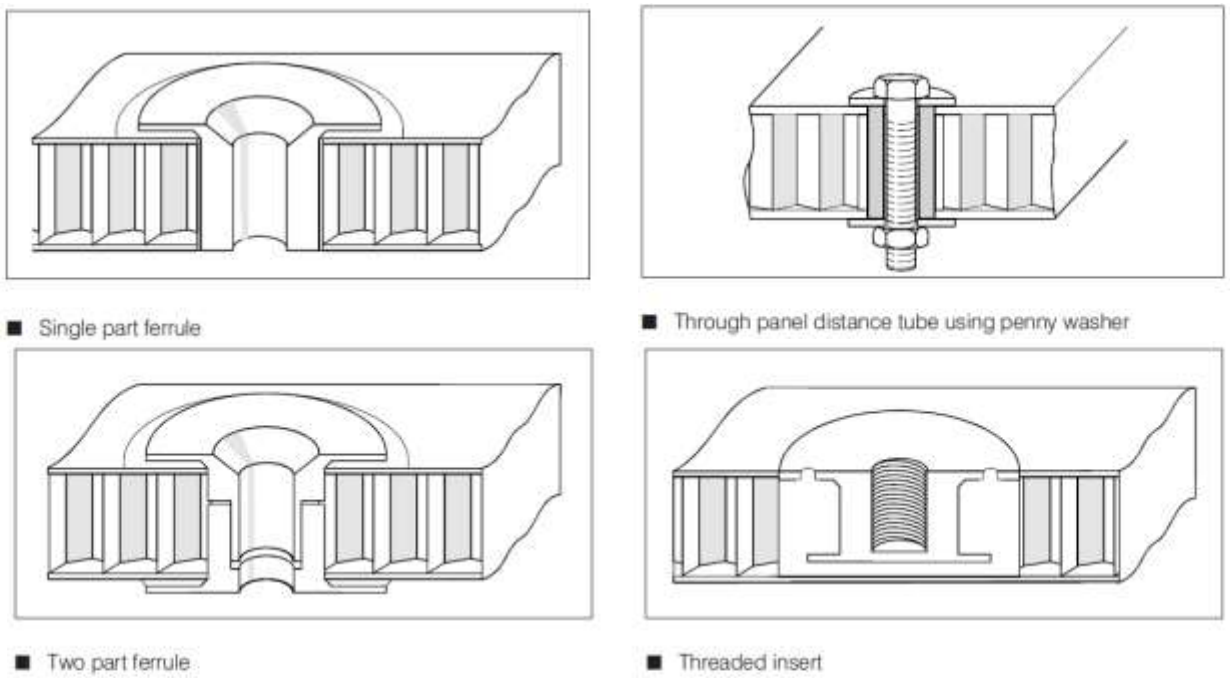


Load relying on panel bending stiffness is undesirable

SUSPENSION ATTACHMENT

Grommets

- Grommets are a lightweight and effective way of transferring load to the skin of the panel
- You can estimate how much load a grommet will support by taking the rated sheer strength of your glue (usually in psi) and multiplying it by the bonding area on the flanges of the grommet
- Sources
  - ClickBond
  - Young Engineers
  - Grommet Installation

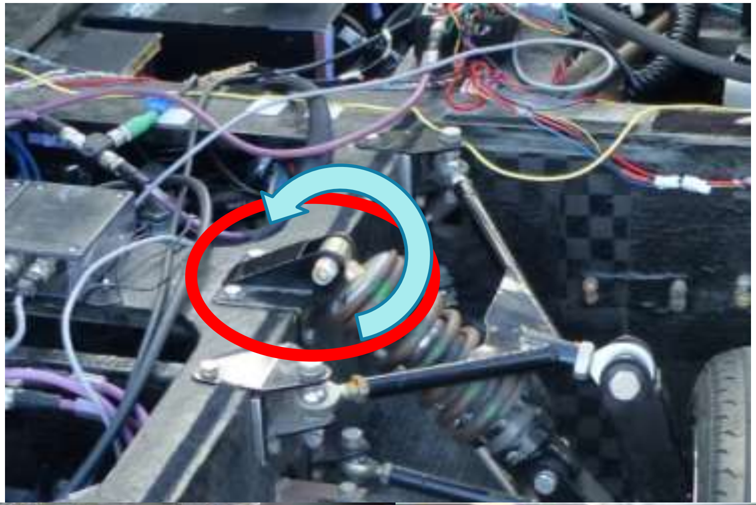


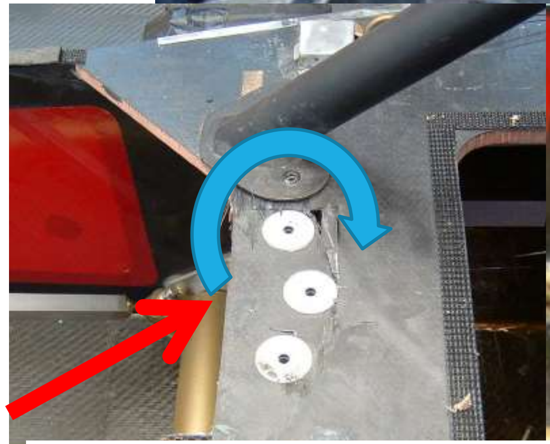
Source: Hexcel Composites: Sandwich Panel Fabrication Technology

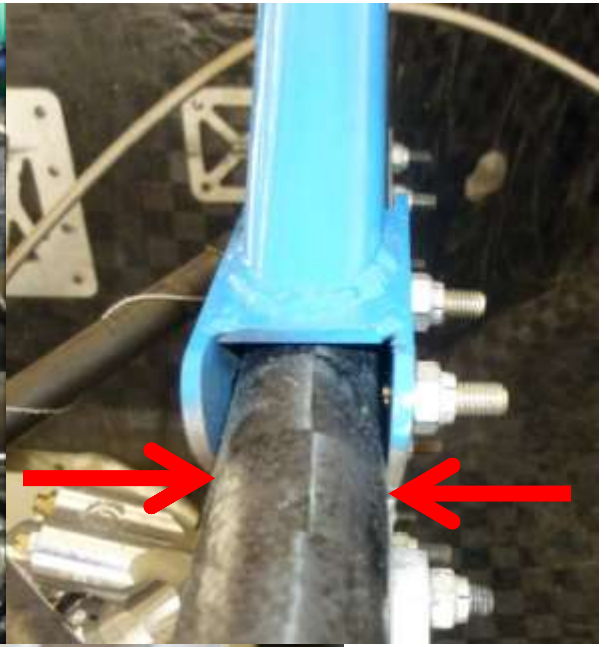
Source: http://solarcar.wikia.com/wiki/UMNSVP_Composite_Chassis_Design

SUSPENSION ATTACHMENT

Incorrect attachment techniques



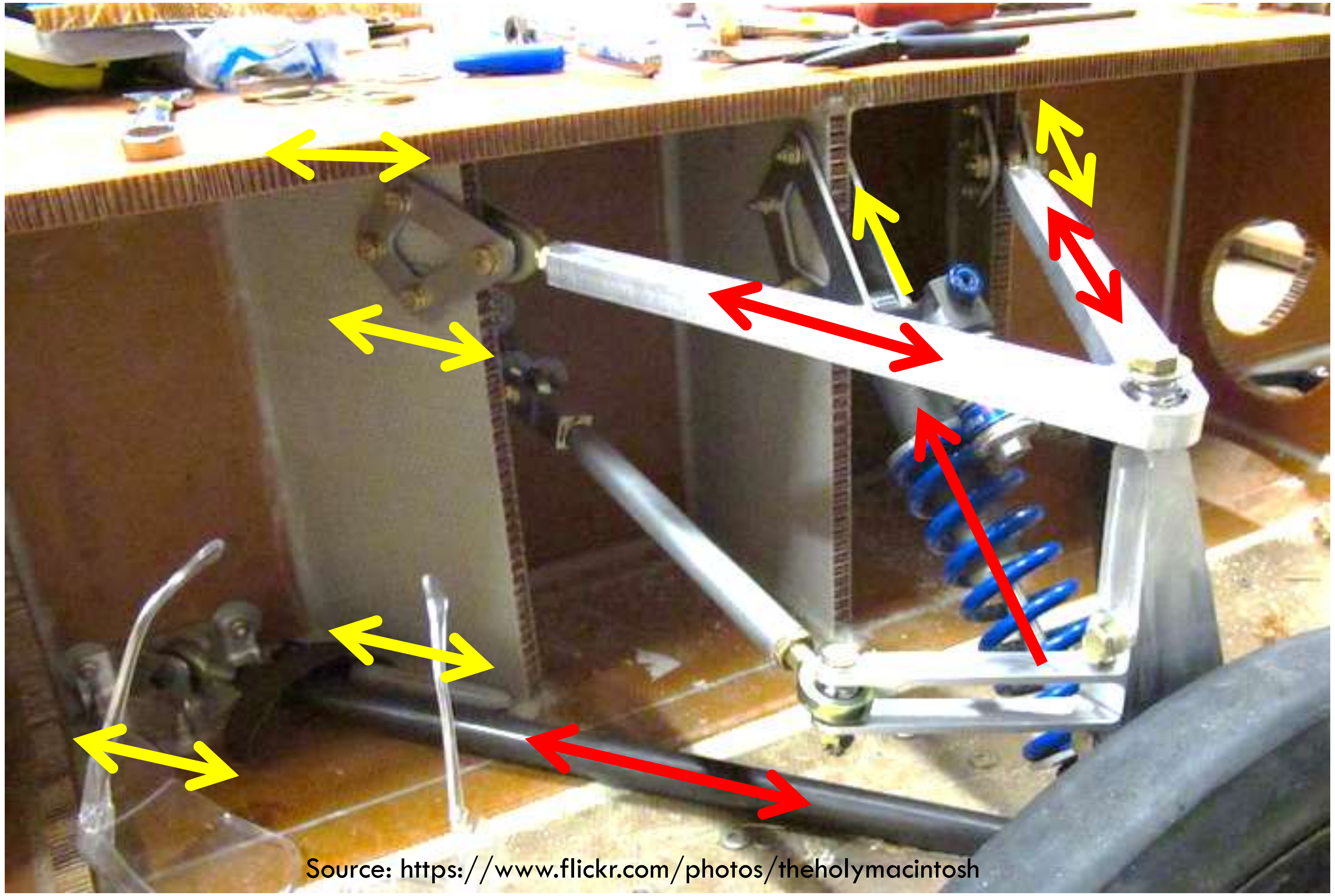


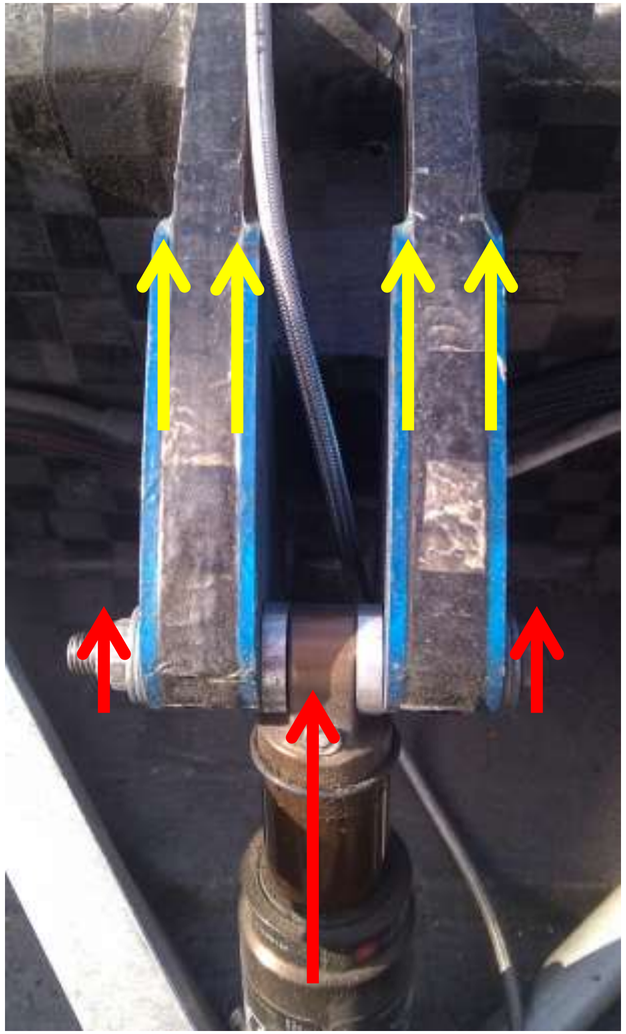


Source: http://solarcar.wikia.com/wiki/UMNSVP_Composite_Chassis_Design

SUSPENSION ATTACHMENT

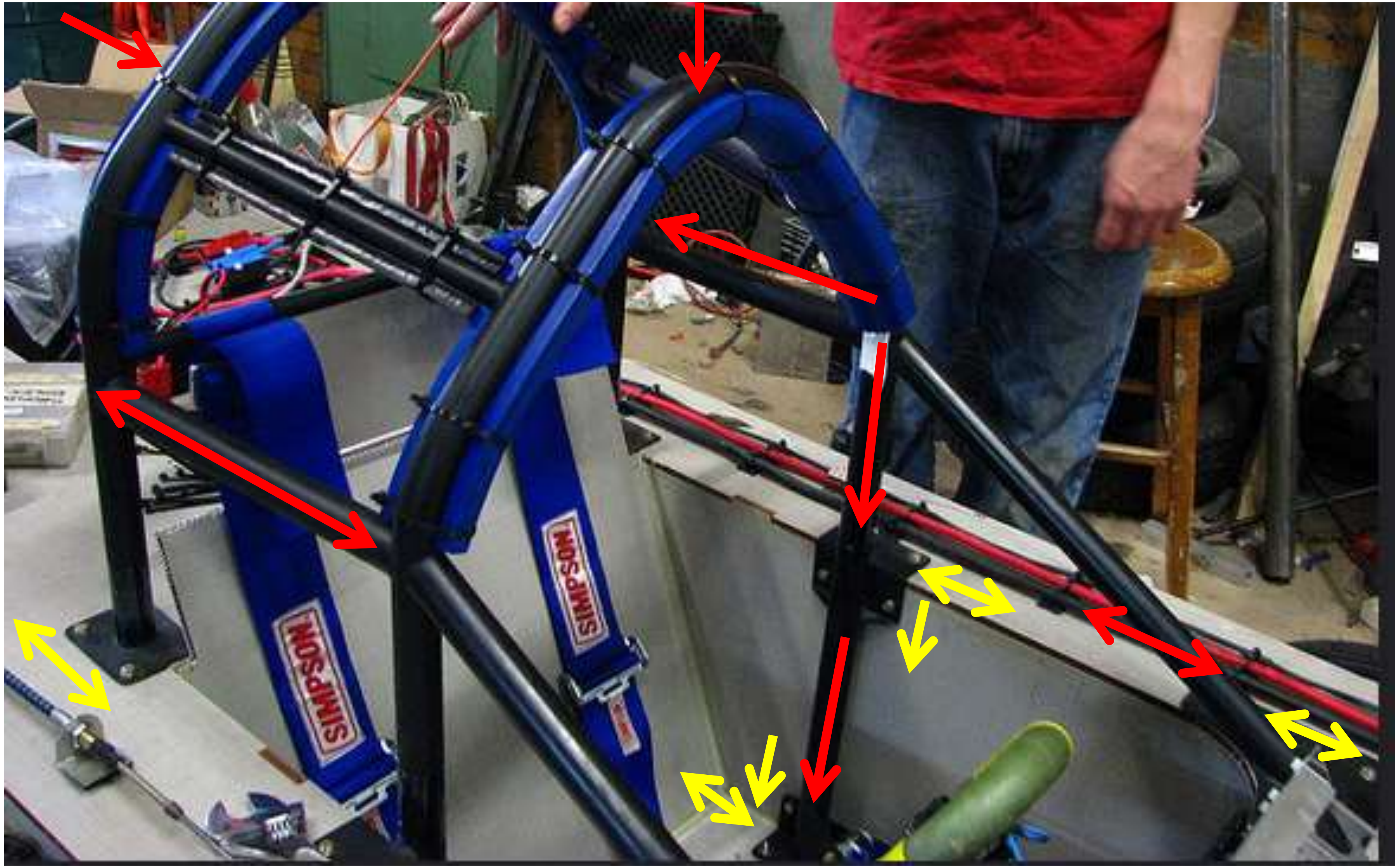
Correct Suspension Installation





FRAME ATTACHMENT

Correct Frame Installation



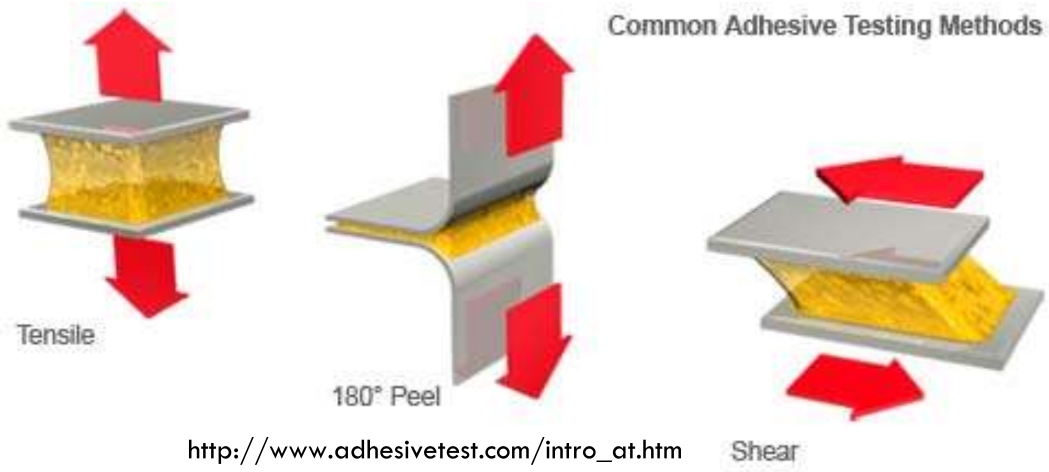
Source: https://www.flickr.com/photos/theholymacintosh

TESTING

- **Coupons**
- **Subcomponents**
- **Full Scale**

COUPONS

- Types of tests done at coupon level
  - Tensile
  - Compression
  - Shear
  - Flexural
  - Peel



http://www.adhesivetest.com/intro_at.htm

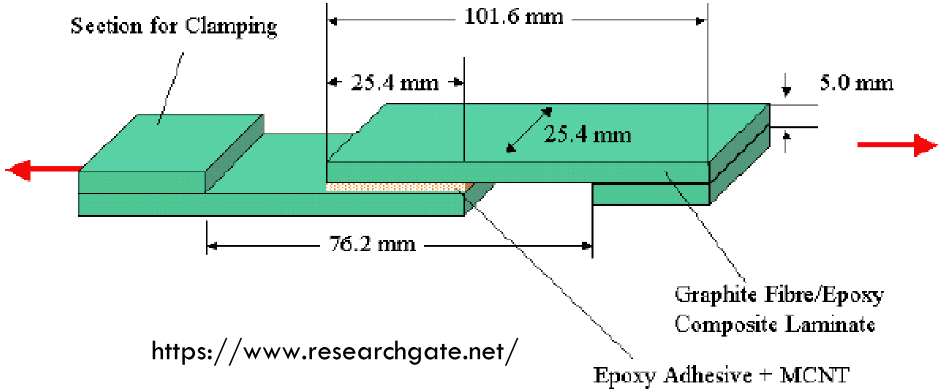
- Published mechanical properties can be used but should include knock downs and a safety factor in calculations and FEA
- Coupon testing is needed to quantify the effect of manufacturing deficiencies, this provides a knock down factor
- Statistical analysis of the coupons gives a basis for the safety factor

COUPONS

ASTM Volume 15.03 Space Simulation; Aerospace and Aircraft; Composite Materials

- C273 – Shear Properties of Sandwich Core Materials
- C297 –Flatwise Tensile Strength of Sandwich Constructions
- C363 – Node Tensile Strength of Honeycomb Core Materials
- C364 – Edgewise Compressive Strength of Sandwich Constructions
- C365 – Flatwise Compressive Properties of Sandwich Cores
- C393 – Core Shear Properties of Sandwich Constructions by Beam Flexure
- D7264/D790 – Composite Flexural Properties
- D903 – Peel Strength of Adhesive Bonds
- D905 – Shear Strength of Adhesive Bonds
- D950 – Impact Strength of Adhesive Bonds
- D5573 – Failure Modes of Composite Joints
- D5868 – Lap Shear Bond Strength
- D7205 – Tensile Strength of Composite Bars
- D3039/D638 – Tensile Strength

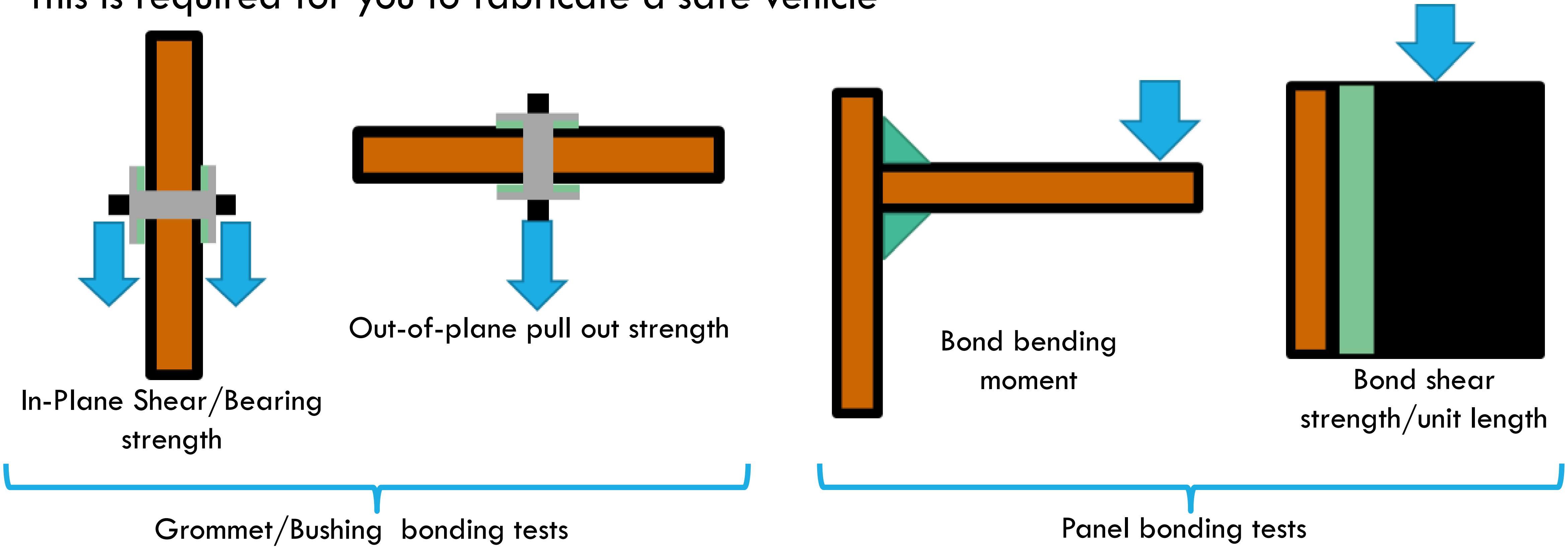
http://www.ecs.csun.edu/hpv/csun2010dp_materialstest.html



https://www.researchgate.net/

SUBCOMPONENT

- Subcomponent testing is especially useful for mechanical and bonded joints
- Fabricate the designed joint and add a load
- This is required for you to fabricate a safe vehicle



FULL SCALE

- https://www.youtube.com/watch?v=j18YnzFdn6Q?t=50s

REFERENCES AND RESOURCES

- MIL-HDBK-17-3F - COMPOSITE MATERIALS HANDBOOK, VOLUME 3. POLYMER MATRIX COMPOSITES: MATERIALS USAGE, DESIGN, AND ANALYSIS
- *Gurit Guide to Composites*, www.gurit.com/-/media/Gurit/Datasheets/guide-to-compositesv5webpdf.ashx
- *Hexcel Hexply Prepreg Technology*, www.hexcel.com/Resources/DataSheets/Brochure-Data-Sheets/Prepreg_Technology.pdf
- Hexcel Sandwich Panel Fabrication Technology, www.hexcel.com/Resources/DataSheets/Brochure-Data-Sheets/Sandwich_Panel_Fabrication_Technology.pdf
- Hexcel HexWeb Honeycomb Sandwich Design Technology, www.hexcel.com/user_area/content_media/raw/Honeycomb_Sandwich_Design_Technology.pdf
- University of Minnesota Solar Vehicle Project Wiki http://solarcar.wikia.com/wiki/UMNSVP_Composite_Chassis_Design
- Composite Materials Fabrication Handbook #1, #2, #3: #1-Materials and wet layup, #2-Vacuum bagging, #3-Mold making and some FEA

MATERIAL SUPPLIERS

http://www.aircraftspruce.com/ - hardware and composite supplies

http://www.clipnuts.com/products/press-fit-inserts.html - grommets

http://www.youngengineers.com/ - grommets

http://clickbond.com/ - grommets

http://www.airtechintl.com/ - vacuum bagging materials and composites

http://www.cytec.com/businesses/industrial-materials/process-materials/products - vacuum bag

http://www.fibreglast.com/ - composite supplies

http://www.compositesone.com/ - composite supplies

http://www.westsystem.com/ - resin

http://www.compositesworld.com/suppliers - every supplier to the composite industry

QUESTIONS?