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Advanced Composite Manufacturing for the Orion Program

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Why Composites?

<u>Advantages</u>

- Reduced structure weight - this is by far the biggest driver
  - Graphite/epoxy density is 40 percent less than aluminum
  - Actual weight savings depends on the application and number of joints but usually varies between 15% and 30%
- Reduced part count
  - Lower assembly costs
- Tailoring of material thickness is easy
- High corrosion resistance and fatigue capability

Why Composites?

Advantages

- Special advantages in special situations, e.g...
  - The use of low thermal conductivity glass/epoxy
  - The use of low thermal expansion material in satellites
  - The use of very high modulus material to minimize deflections
  - The use of low dielectric materials in radomes
- Tailoring of material properties is possible
- Wide variety of materials and forms to suit specific needs

Why Composites?

Disadvantages

- Larger scatter in material properties
- Sensitivity to manufacturing processes
- Complex analysis required
- Material cost
- Lack of material databases
- Sensitivity to moisture and elevated temperature
- Repairability

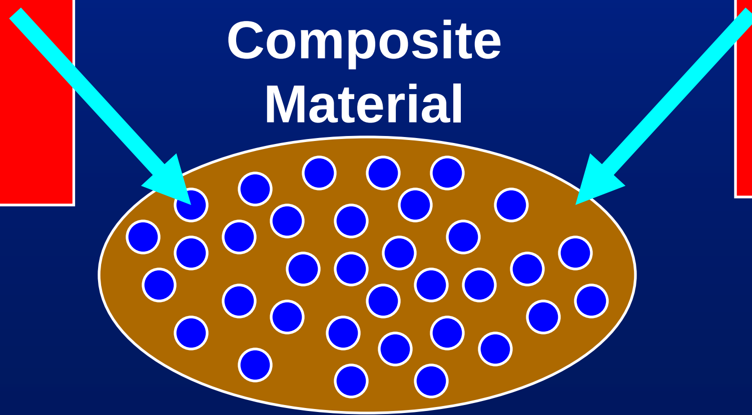
What are Composites ?

- Composites are non-homogenous, reinforced, matrix bound materials that usually exhibit some desirable structural characteristics such as high strength, great stiffness, or low density.

- The reinforcing filaments may be boron, graphite, glass, etc., and the binding matrix is usually an epoxy, polyester, or polyamide resin, but may be a metal, ceramic, or glass.

Reinforcement
- Fibers
- Whiskers
- Particulates
- Flakes

Composite Material

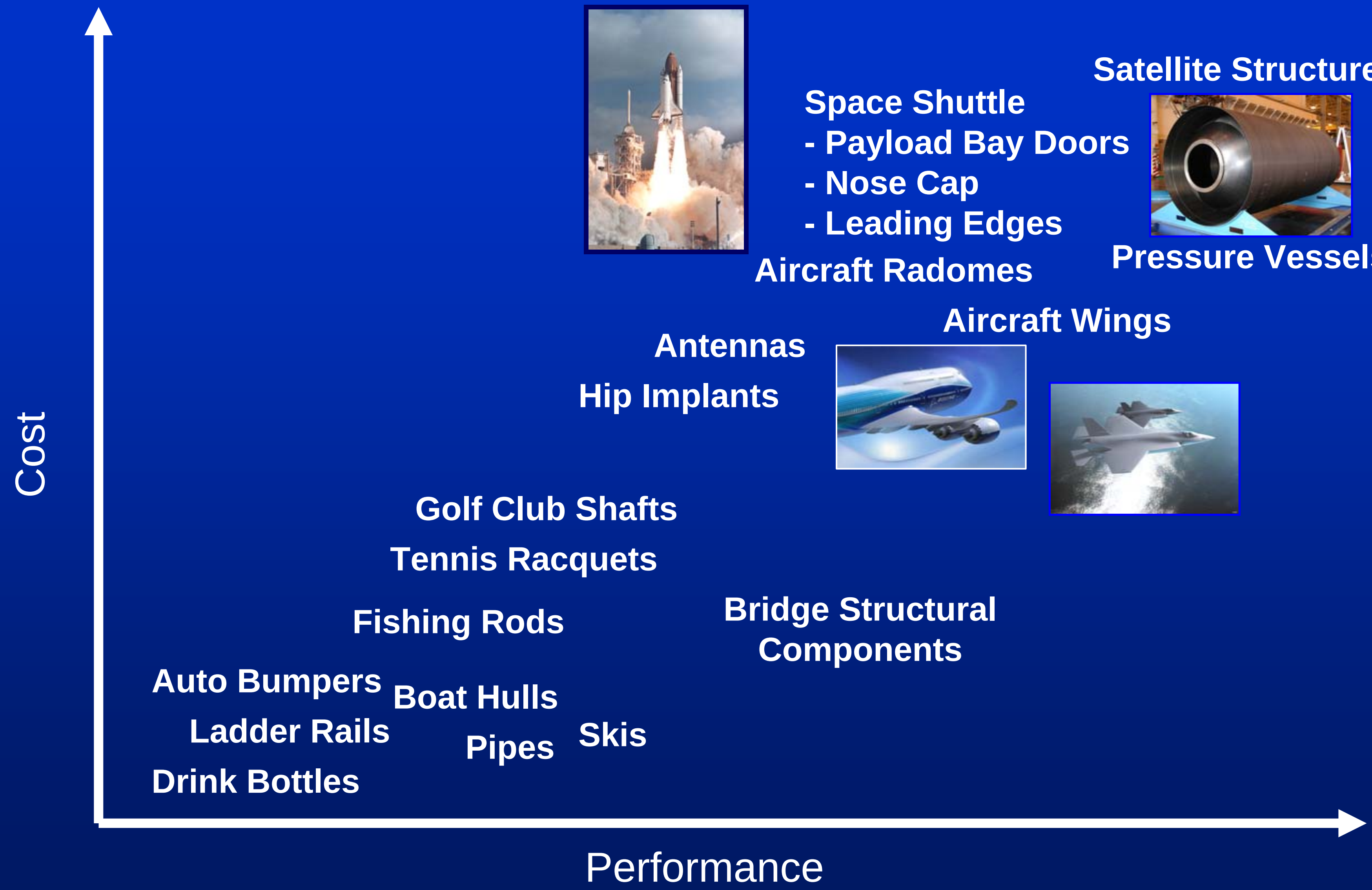


Matrix
- Resin/Polymers
- Metal alloys
- Ceramics

History of Fibrous Composites

- Wood
- 800 B.C Straw and Mud Bricks (Adobe)
- 700 B.C Laminated Bow with Animal Tendons, wood, silk
- 1910 Doped Fabric and Wood A/C Structure
- 1935 Owens-Corning Fiberglass Corp.
- 1940 Plywood A/C Structure
- 1943 FRP Aircraft Structure
- 1947 First Commercial Epoxy
- 1953 Corvette FRP Production Body
- 1958 First Carbon from Rayon
- 1959 Texaco announces Boron
- 1961 First Graphite from Pan
- 1964 Carbon Fibers from Pan
- 1965 Boron Fibers Available
- 1969 F-4 Boron-Epoxy Rudder
- 1970 F-14 Boron/Epoxy Horizontal
- 1973 Kevlar 49
- 1985 Spectra

Current Applications of Composites



Advanced Composites Manufacturing

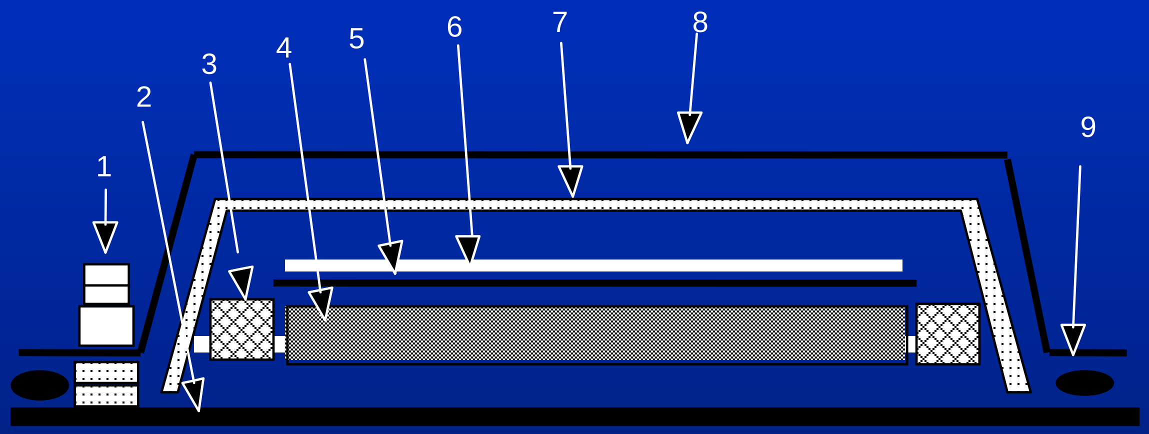
- Focus on thermoset polymer matrix composites
- Focus on advanced composite structures
  - Resin matrix (epoxy, phenolic, bismaleimide, polyimide)
  - Reinforced with continuous fibers (carbon, glass, aramid, quartz)
  - Multiple plies with varying orientations
  - Used on highly loaded structures
  - High fiber to resin ratio (55-65% fiber by volume)
  - Low void content (<2% by volume)
  - Use temperature of 120°C or higher

Example Bagging Sequence for Cure

Vacuum bagging:

– Forms and consolidates the laminate

– Allows outgassing in the laminate during cure



1. Vacuum port*
2. Tool*
3. Edge dam
4. Laminate*
5. Peel ply
6. Release film*
7. Breather*
8. Nylon vacuum bag*
9. Sealant tape*

* needed for debulks

Manufacturing Methods

- Manual methods
  - Hand layup
  - Resin infusion methods
    - Resin transfer molding (RTM)
    - Vacuum assisted resin transfer molding (VARTM)
    - Resin film infusion (RFI)
- Automated methods
  - Filament winding
  - Automated tape laying
  - Advanced fiber placement

Hand Layup

- Process Description
  - Hand place reinforcement onto tool
  - Vacuum bag layup
  - Oven or autoclave cure

Tool

Prepreg

- 2 Basic Methods
  - Prepreg lay up - unitape and fabric
  - Wet lay up
    - Lay down dry fabric, pour or brush resin into the fabric
    - Pre-wet dry fabric then lay up on mold

Hand Layup

- Consolidation Methods
  - Intermediate debulks during layup
  - External pressure (vacuum bag or autoclave) during cure

- Tooling
  - Composite, Invar, aluminum, steel
  - Must be able to withstand cure temperatures and pressures

Hand Layup

- Application Considerations
  - Material compatibilty - unlimited combination of fiber and resin
  - Part geometry - complex parts, small to moderate size
  - Equipment requirements - oven or autoclave
  - Material scrap - high
  - Labor cost - high
  - Material lay down rates - low
  - Repeatability - low
    - Improved with automated ply cutters and laser ply projection systems
  - Good process for small part size, small number of units, and parts with complex shapes

Hand Lay Disadvantages

Fabricating prepreg laminate structures* can be accomplished many ways:

- Hand operations
  - Typically limited to fabric
  - Used extensively in prototype and small to medium size parts
  - Several advantages
    - No capital investment in equipment
    - Simpler less expensive setup and operation
    - Can do complex contoured surfaces
  - Several disadvantages
    - Limited through put/productivity
    - Quality issues
      - Limited accuracy/repeatability
      - Human error
    - High material scrap factors
      - Materials remaining after pattern nesting and cutting

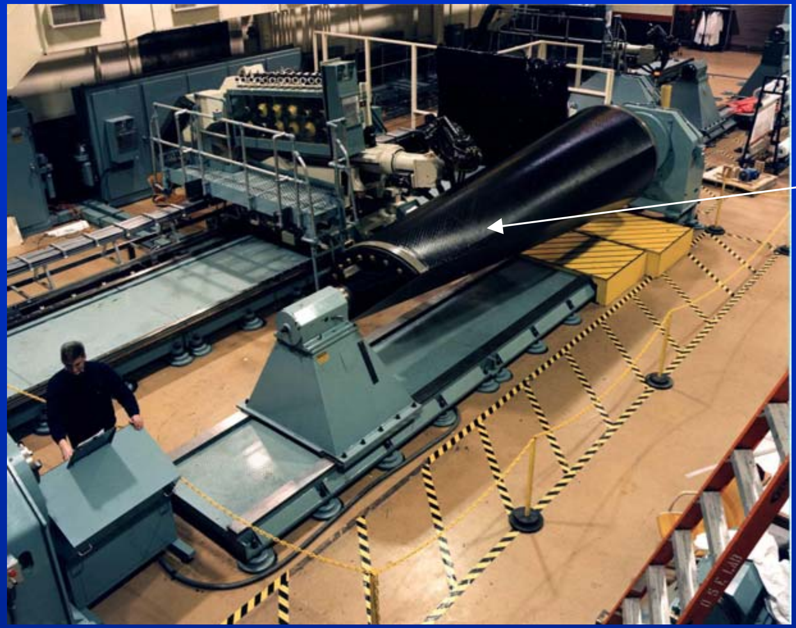
**** This does not consider dry fiber fabrication processes such as filament winding and resin infusion***

Advanced Fiber Placement

- Process Description
  - Automated machine places multiple unitape prepreg tows on mandrel
  - Placement up to 32 tows, tows are usually 1/8” wide
  - Tows can be added, dropped, and added again at any time during the lay down process
  - Vacuum bag layup to the tool
  - Oven or autoclave cure

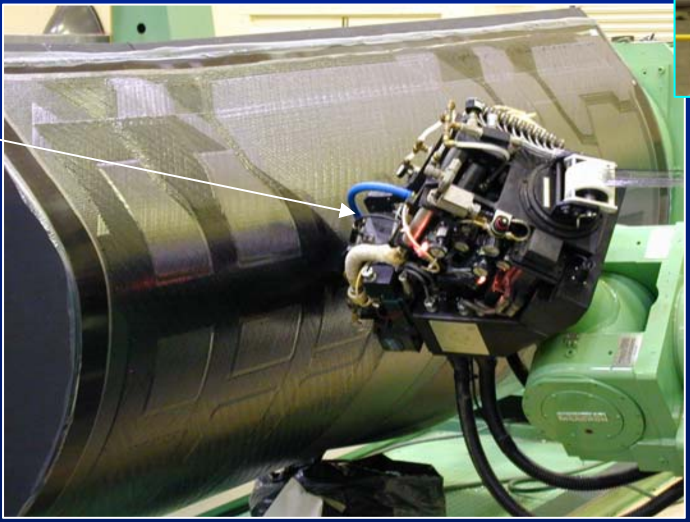
- Consolidation Methods
  - Compaction by appplying pressure and heat at roller in placement head
  - Intermediate debulks during layup
  - External pressure (vacuum bag or autoclave) during cure

Advanced Fiber Placement



rotating
mandrel

multi-axis fiber
placement head



Advanced Fiber Placement

- Tooling
  - Composite, Invar, aluminum, steel
  - Must withstand head pressure, cure temperatures, and cure pressures

- Application Considerations
  - Material compatibility - unitape only
  - Part geometry - moderate to large parts with complex contours
  - Equipment requirements - fiber placement machine, autoclave
  - Material scrap -low
  - Labor cost - low
  - Material lay down rates - high
  - Repeatability - high
  - Good process for large parts with complex surfaces

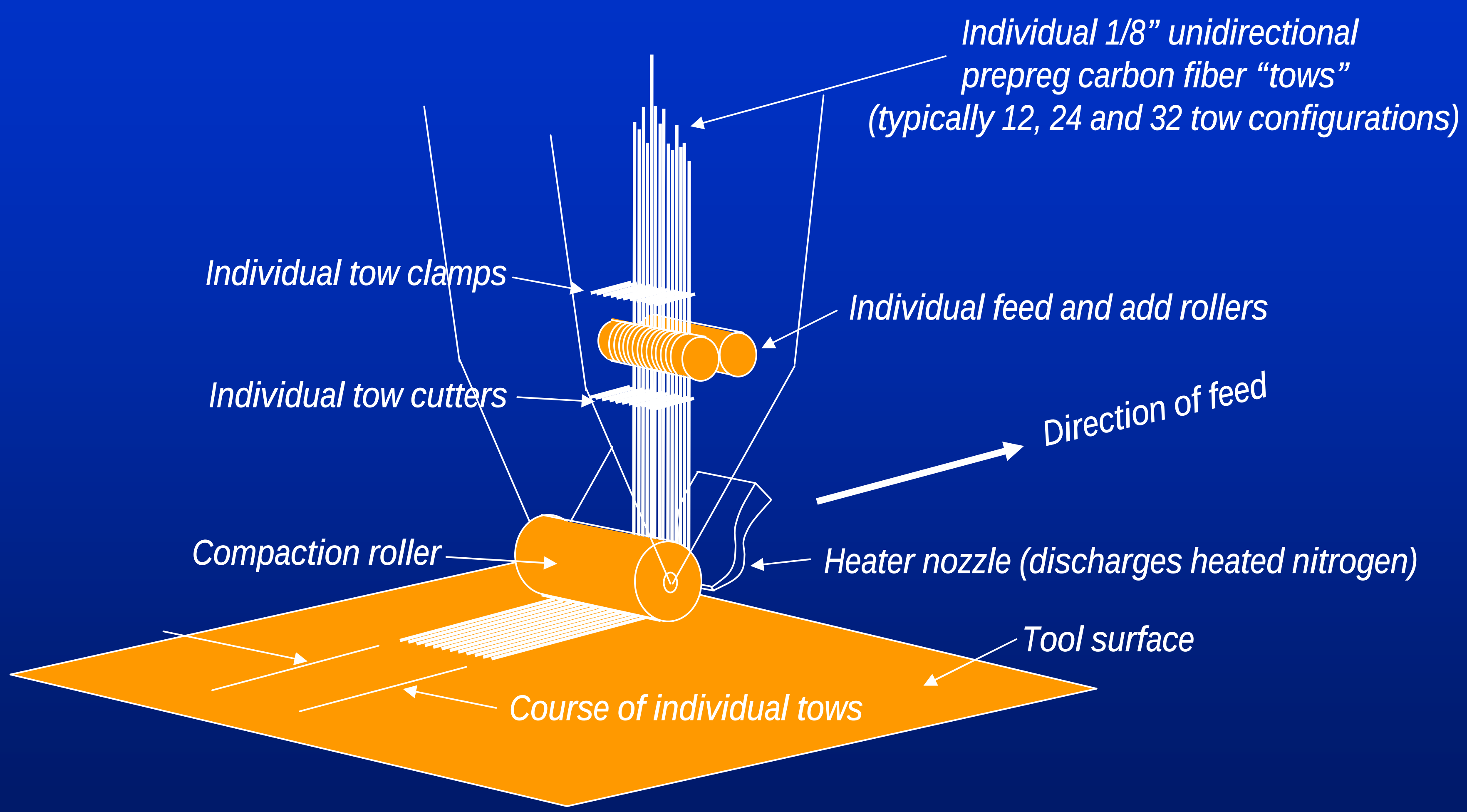
Advanced Fiber Placement

Fabricating prepreg laminate structures* can be accomplished many ways:

- Automated operations
  - •Fiber placement
    - Process originated from tape laying
    - Places multiple "tows" of narrow unidirectional prepreg tape on a tool surface typically in quasi-isotropic ply build ups (0°. +/- 45° and 90° fiber orientations)
    - Several advantages
      - • High productivity (high lbs./hr. lay down rates)
      - • High accuracy/repeatability
      - • Can lay on relatively complex curved tool surfaces
      - • Cutting and adding tape has a very low scrap factor
        - Narrow 1/8" tows create very fine saw tooth pattern for near net shape ply boundaries
    - Disadvantage
      - • Capital investment

Why Fiber Placement

Process diagram:



Orion Composites

- Fiber Placement chosen as primary composite manufacturing process on Orion
  - Composites consist of greater than 30% of primary structure (~130 parts/vehicle)