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Resin Infusion/Liquid Moulding: *Technology Advances in Past 35 Years*

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HISTORICAL OVERVIEW

Plastic "Liquid Moulding" Processes Led to RTM & VARTM Methods

- Several "liquid moulding' processes were background to conventional RTM/VARTM:
  - **RIM --- Reaction Injection moulding (and) Resin Injection moulding (NO fibre)**
  - **RRIM --- `reinforced' RIM (Fibre added)**
  - **SRIM --- `structural' RIM (MORE fibre added)**
- Urethane resin technology (1940-1950) added technology
- RTM and VARTM processes grew from various aspects of these technologies

Resin Infusion Patent History

- **RTM** – a grew out of urethane technology developed under the Marco patents in the 1940-1950 time period (pressure feed)
- **VARTM** – grew out of combining "vacuum bag" technology in various 1960-present patent versions (vacuum infusion)
  - ***RFI* – grew out of McDonnell Douglas work in 1980's patents (vacuum infusion, separated materials/resin sheets)**
  - ***SCRIMP* ™ – grew out of Seemann's patents in 1980's and early 1990's (vacuum infusion, flow media)**

Major Developments – Last 15+ Years (Closed Mould, Markets)

- Lots of new infusion resins – PE, VE, Epoxies
- More than existed in the early-mid 1980's
- Excellent high temperature resins (BMI, CE, PI)
- "Heavy areal weight" reinforcement materials
- Various process options (>30+)
- Available "flow media" materials (because of SCRIMP)
- Core materials with induced flow porosity (z-direction flow)
- High performance, complex structural preforms:
  - **Higher fibre volume fractions**
  - **Z-direction reinforcements**
  - **Complex geometries**

MATERIALS

Typical Resin Systems

Polyester	Ambient – 100	Commercial
Vinyl Ester	Ambient - 180	Commercial
Phenolic	140-200	Commercial
Epoxy	180-350	Commercial/Aerospace
Toughened Epoxy	250-350	Aerospace
Cyanate Ester	250-350	Aerospace
Bismaleimide	350-500	Aerospace
Polyimide	350-700	Aerospace
Phenylethynyl Terminated Imides (PETI)	>350	Aerospace

LIQUID MOULDING AND RESIN INFUSION PROCESSES

RTM/VARTM Processes Have ***Numerous*** Variations Today

- Automotive industry utilizes RTM/VARTM liquid moulding (LM) processes
- Other common versions (about 40-50):
  - **VARTM, VARI, VRTM, VIMP, VIP, VIM – vacuum methods**
  - **TERTM, RARTM, CERTM – internal expansion materials**
  - **CIRTM, MIRTM – various injection/infusion methods**
  - **RLI, RFI – liquid and film resin systems**
  - **SCRIMP, UVRTM – flow media and UV systems**
  - **CARTM, RTM LITE – flow media variations**
  - **ETC …..**

Traditional RTM

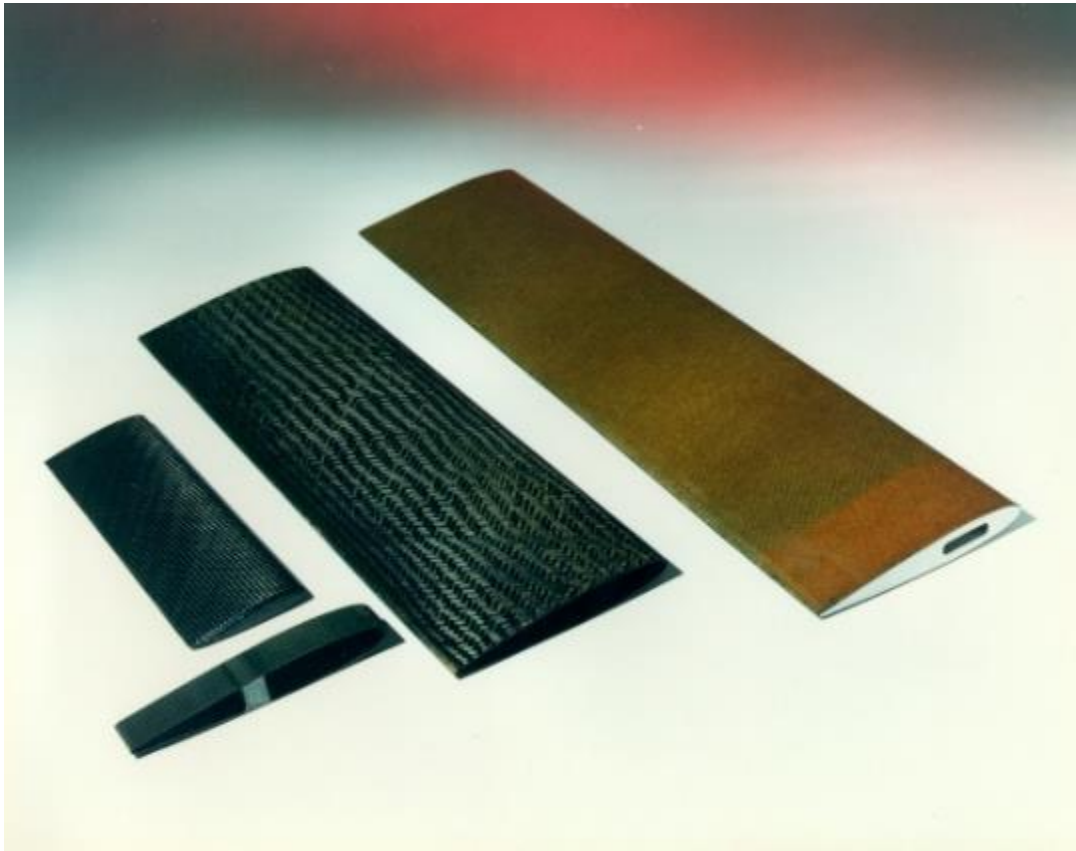
The Key Parameter is Pressure

Resin Transfer moulding (RTM)

- Resin – pressure fed into closed mould
- mould consists of two or more rigid sections
- Excellent dimensional control for part
- Often heated tools (steel, aluminum, Invar)
- Aerospace structures preference
- Pressures upwards of 500 psig (3.45 MPa)
- Higher fibre volumes (>55-65% V_f)

Earliest (1989) RTM Airfoil Structural Parts

- AS4 and IM7 type carbon fibre preforms
- Carbon fabric and braided preforms demonstrated
- Hexcel HBRF-315 toughened resin formulation
- Aerodynamic control surfaces for missile wings
- Moulded-in fittings, closed or open ends, and internal support structures

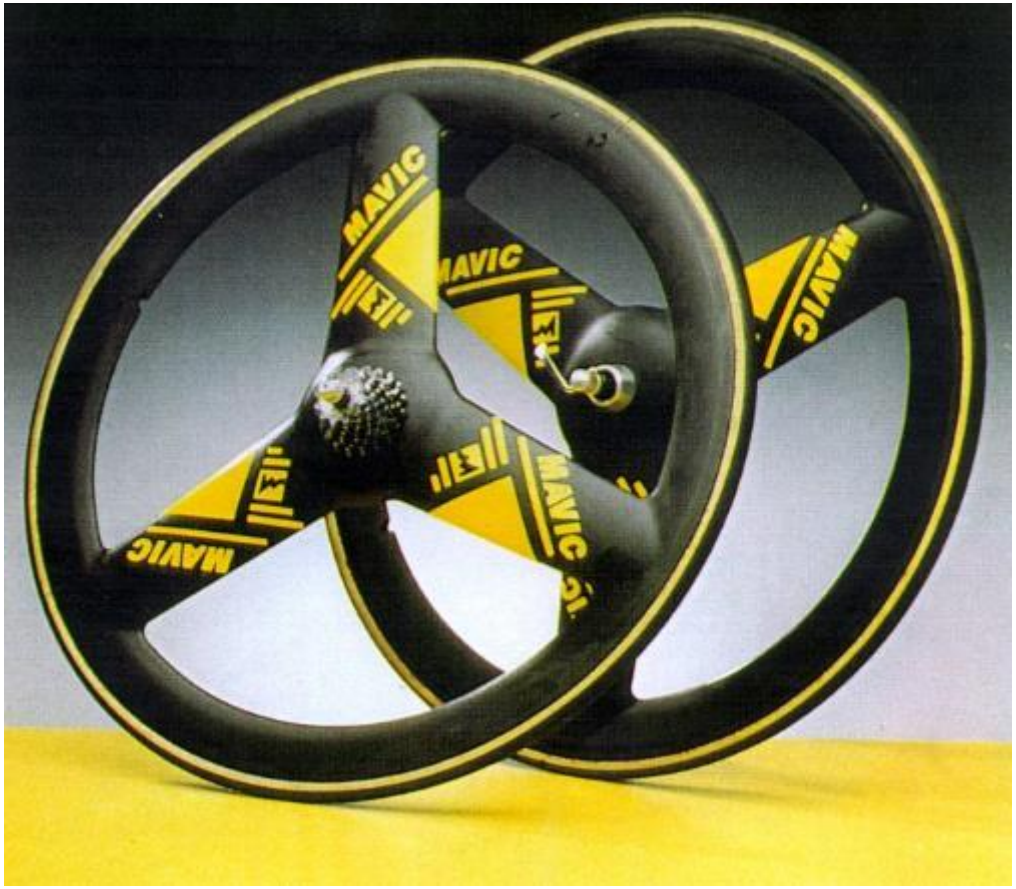


Combination of Materials in RTM Blade

- ATR-72 propeller blade
- Braided carbon and Aramid materials utilized
- One-part epoxy resin
- Aramid provides impact toughness
- Smooth aerodynamic surfaces

High Performance Racing Bicycle Wheels w/Hub Inserts

- RTM process used for racing bicycle wheels
- Carbon fibre preforms
- Epoxy resin RTM processing
- Internal foam core
- Moulded-in fittings



RTM Road Bike Frame Structure

- Carbon/epoxy RTM process
- Lightweight and modern design features
- Monocoque frame, forks, chain-stay
- Complex structure fits RTM process

Carbon Fibre RTM Projectile Sabot

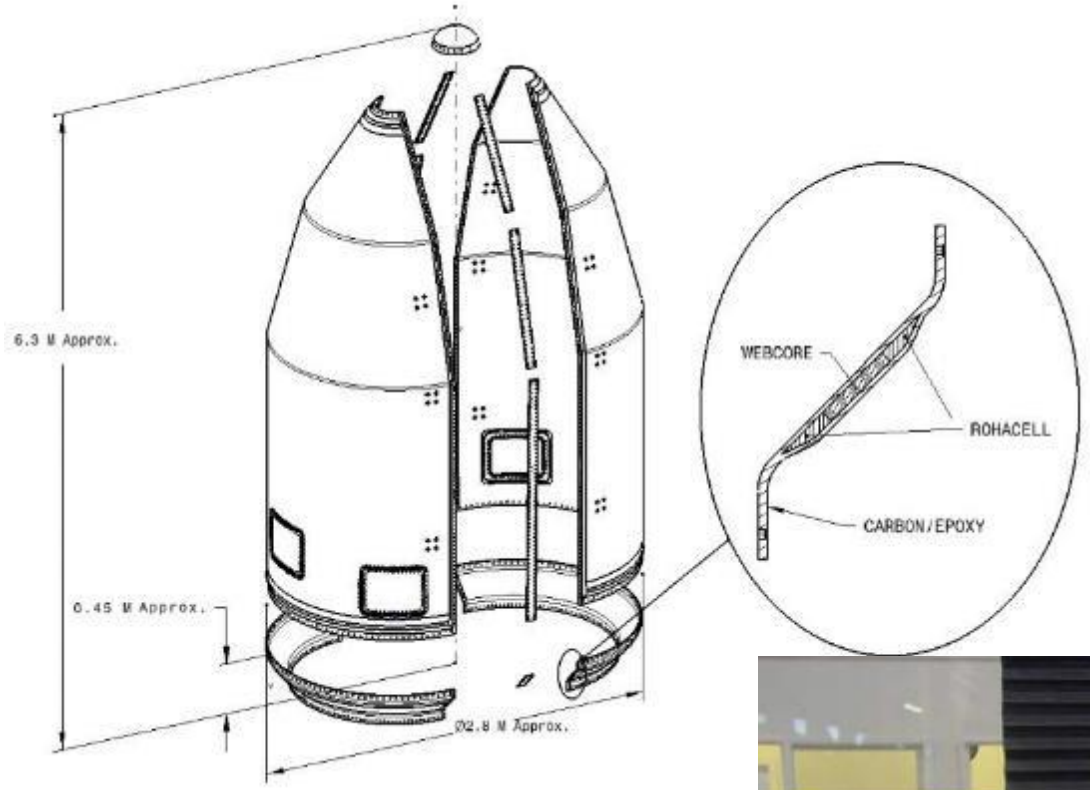
Vacuum-Assisted RTM (VARTM)

The Key Parameter is Vacuum

Vacuum-Assisted RTM (VARTM)

- Resin – pulled in by vacuum (negative pressure) and pressure applied as well at some point in process
- Rigid tool on one side only (could be two sides like RTM)
- Flexible, bagging materials on outside (often)
- Tool surface control on one side only (or two sides if pressure significant)
- No additional pressure added later
- Fibre volumes more like 45-55% V_f
- SCRIMP™ actually a subset within VARTM

VARTM Multiple Port Injection Minesweeper Rudder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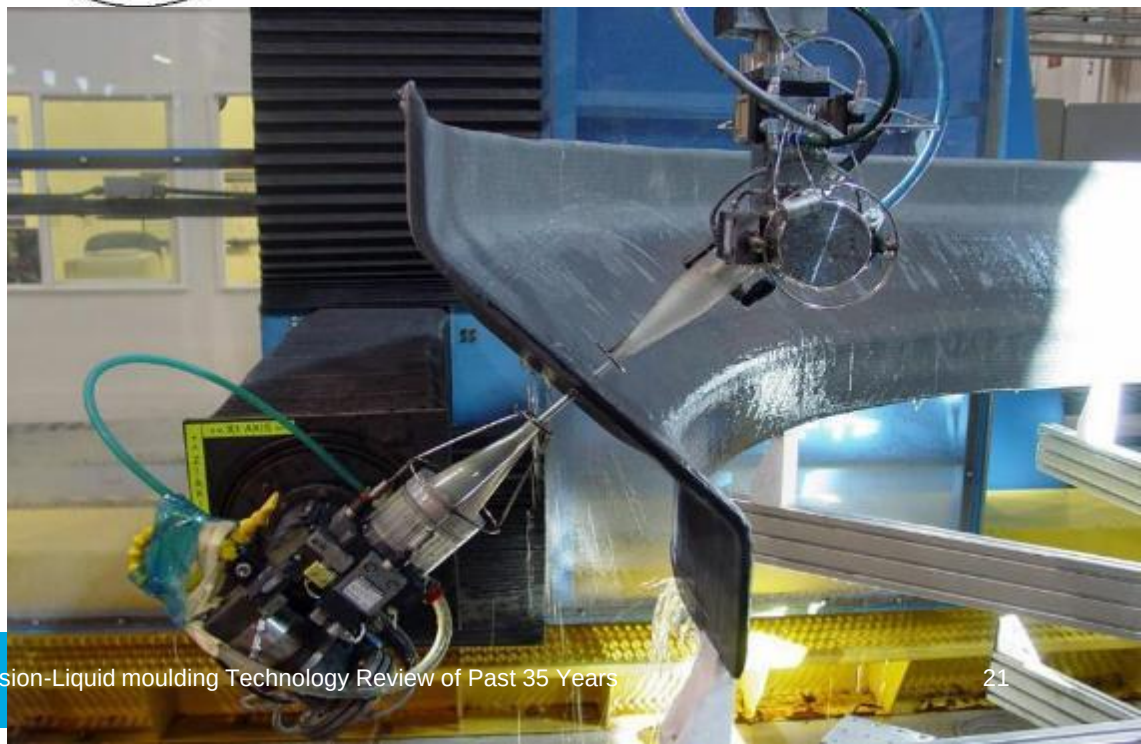
0.45 M Approx.
Ø2.8 M Approx.
WEBCORE
ROHACELL
CARBON/EPOXY

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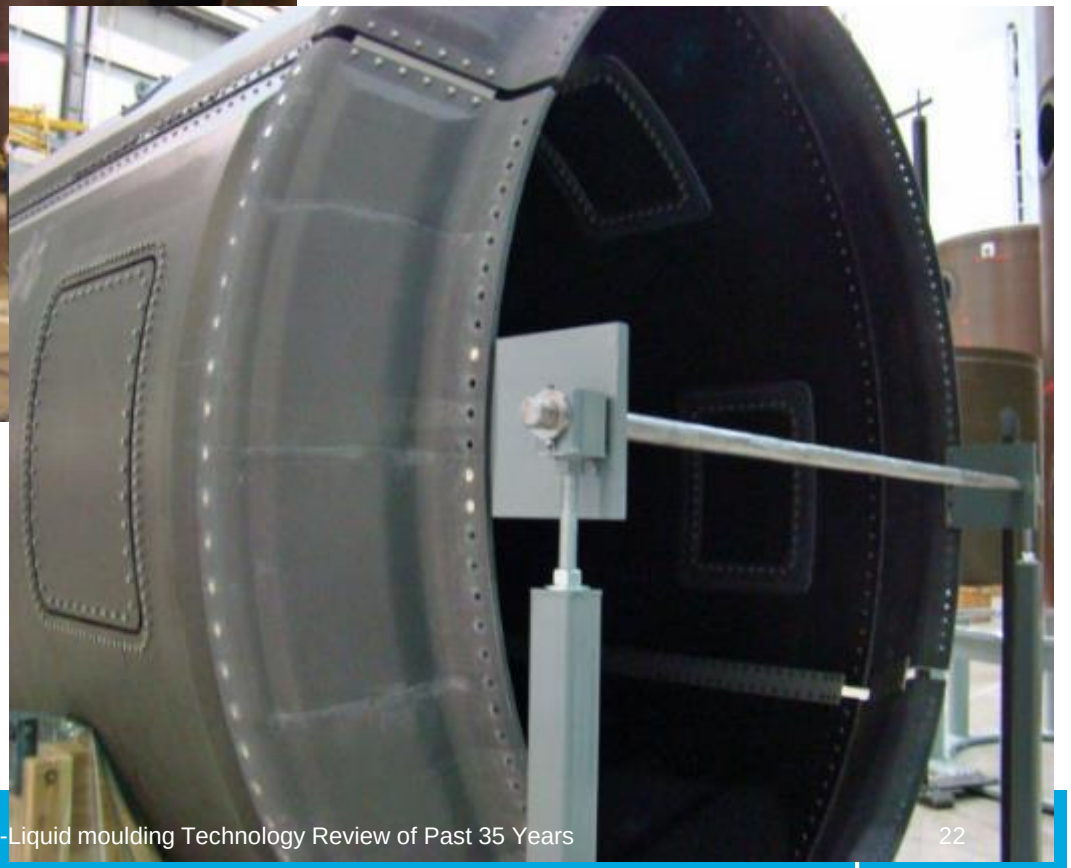


HP-RTM VERSIONS

The Key Parameter is High Pressure

RTM Challenges – Leads to Using HP-RTM as Solution …

Typical challenges and issues of the state of the art RTM process

- Typical injection pressure between 1 and 20 bar

  → Higher pressure disturbs the fiber orientation in the preform

- Permeability of 3D fiber preform influences significantly the injection time

  → Proper impregnation of complex shaped preforms is a challenge

- Required injection time does not allow the use of fast curing resin systems

  → Typically long cycle times due to long injection and curing times

- Additional resin required to push trapped air out of the mold cavity

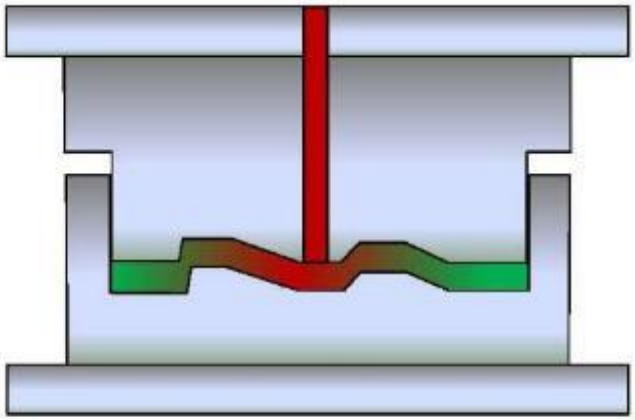
  → Negative economical and ecological impact

- Probable solutions: High Pressure RTM processes

Direct Comparison (Two Versions)

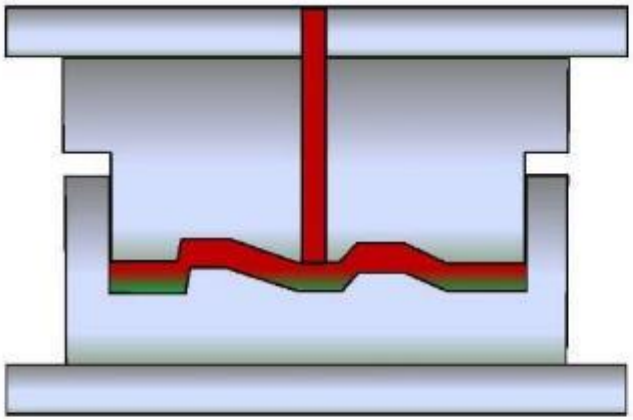
High Pressure RTM Processes

High Pressure Injection Resin Transfer Moulding HP-IRTM



Impregnation of preforms in x- and y- direction

High Pressure Compression-Resin Transfer Moulding HP-CRTM



Impregnation of preforms in x-, y- and z- direction

Preforming Operation BMW i8 Side Frame

BMW i8 HP-RTM Side-frame Moulded Part

Fully Cured Side-Frame Part Moved to Assembly

Integrated HP-RTM Process Line Equipment

SCRIMP

The Key Parameter is Flow Media

SCRIMP™ Process

- Developed, patented by Bill Seemann (1980's)
- Applicable primarily to large surface areal parts
- Incorporates two major features:
  - **Lateral surface resin distribution via open tubes,**
  - **Porous "flow media" in form of netting or screen materials**
- Most efficient for nominal thicknesses in range of 0.5- to 4-inch (12-100 mm) typically
- Fibre volumes often in 45-55% V_f

SCRIMP™ Requires Vacuum Bag Integrity

- Vacuum bag and “medium” integrity critical
- Resin infuses rapidly through “medium” distribution channel
- Resin next spreads out horizontally
- Infusion migrates through preform thickness

SCRIMP™ Infuses 64-ft Yacht Hull

- SCRIMP™ process used on large area products
- Nine (9) injection regions processed at same time
- Resin infused from large catalyzed resin drums
- Process allows rapid preform infusion
- No interface “knitting” problems observed

People Movers (Atlanta, USA Airport)

Resin Film Infusion (RFI)

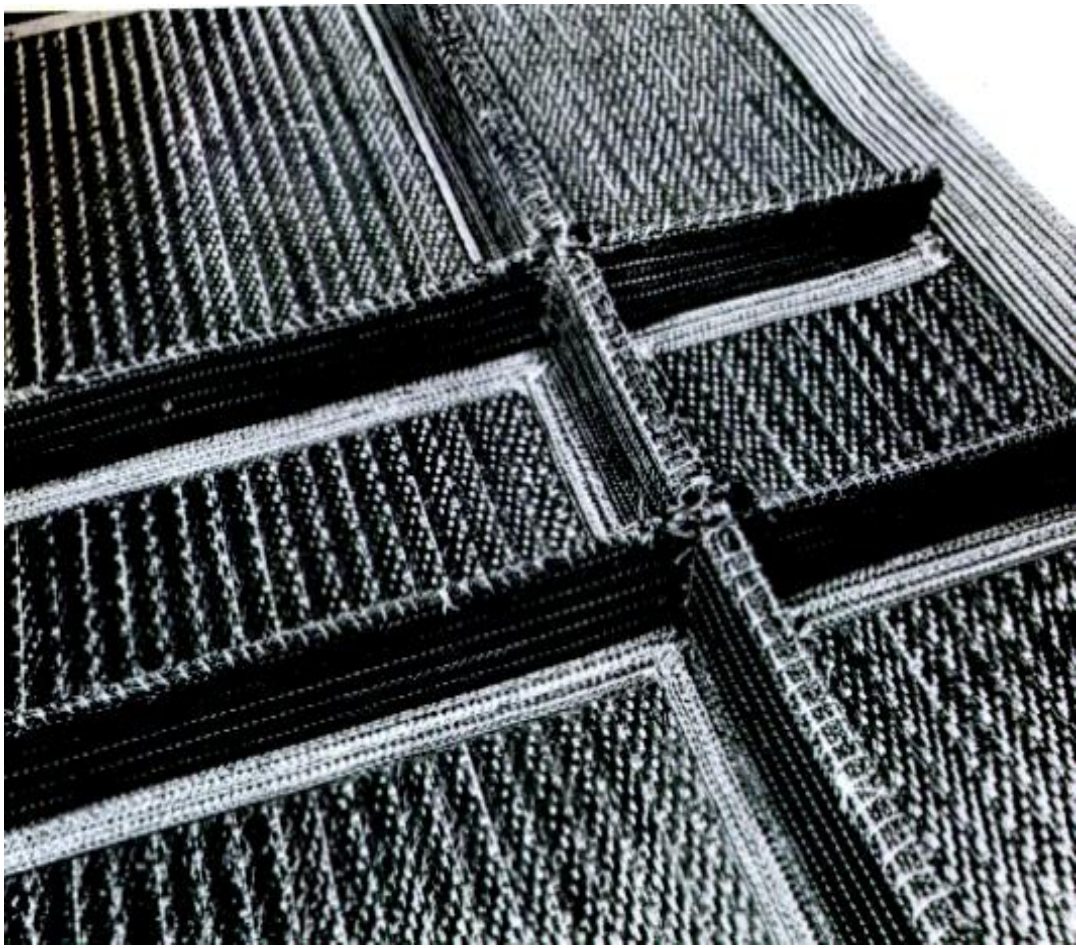
The Key Parameter is Prepreg Resin

Resin Film Infusion (RFI)

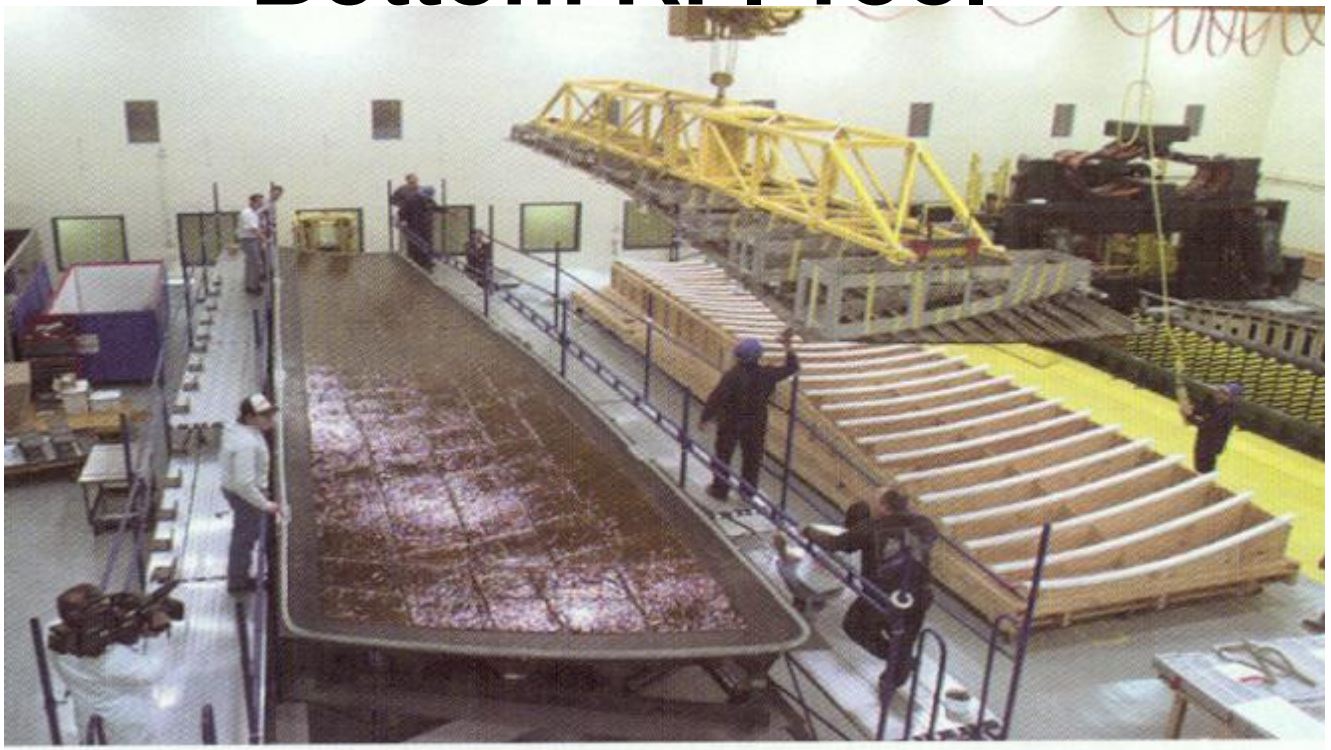
- Resin form very different – prepreg resin plates
- Resin “plates” pre-loaded into rigid female tool cavity
- Complex fibre preforms loaded on top of resin plates
- Mould inserts, tooling pieces loaded into tool
- Flexible bagging installed over assembly
- Resin flows during heat-up and cure cycle – through the “thickness”
- Fibre volumes typically 50-55% V_f

Complex Preforms Required for RFI

- AS4 carbon fibre preforms
- Cross-stiffened, stitched preform for commercial aircraft structures
- Provides complex structure
- Provide de-bulked preform
- Used in resin film infusion (RFI) process



Stitched Preform Lowered Into Bottom RFI Tool

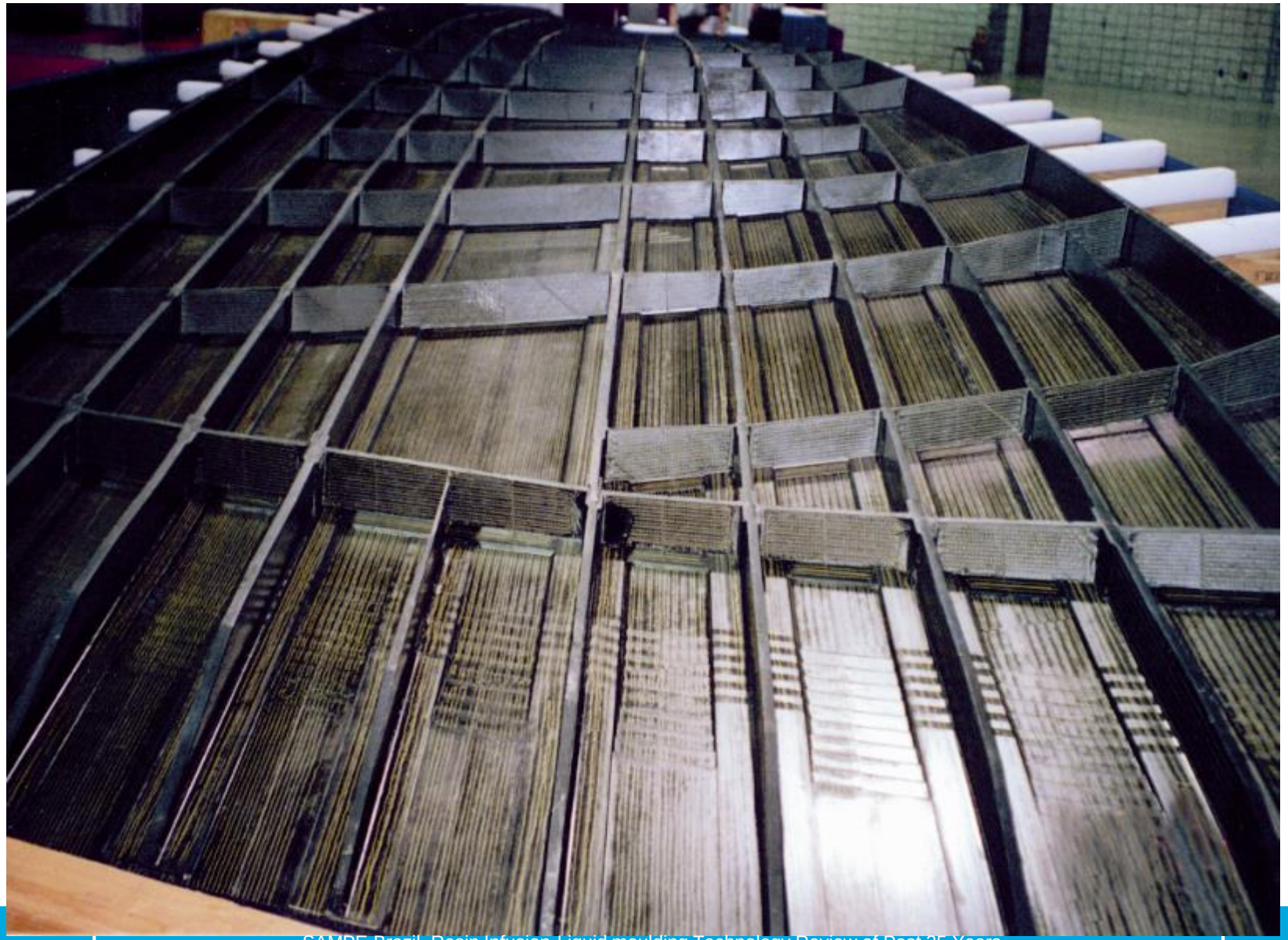


- Bottom mould RFI tool contains:
  - **Hexcel 3501-6 prepreg resin film plates installed**
  - **Stitched carbon preform placed above resin film (being lowered into mould)**

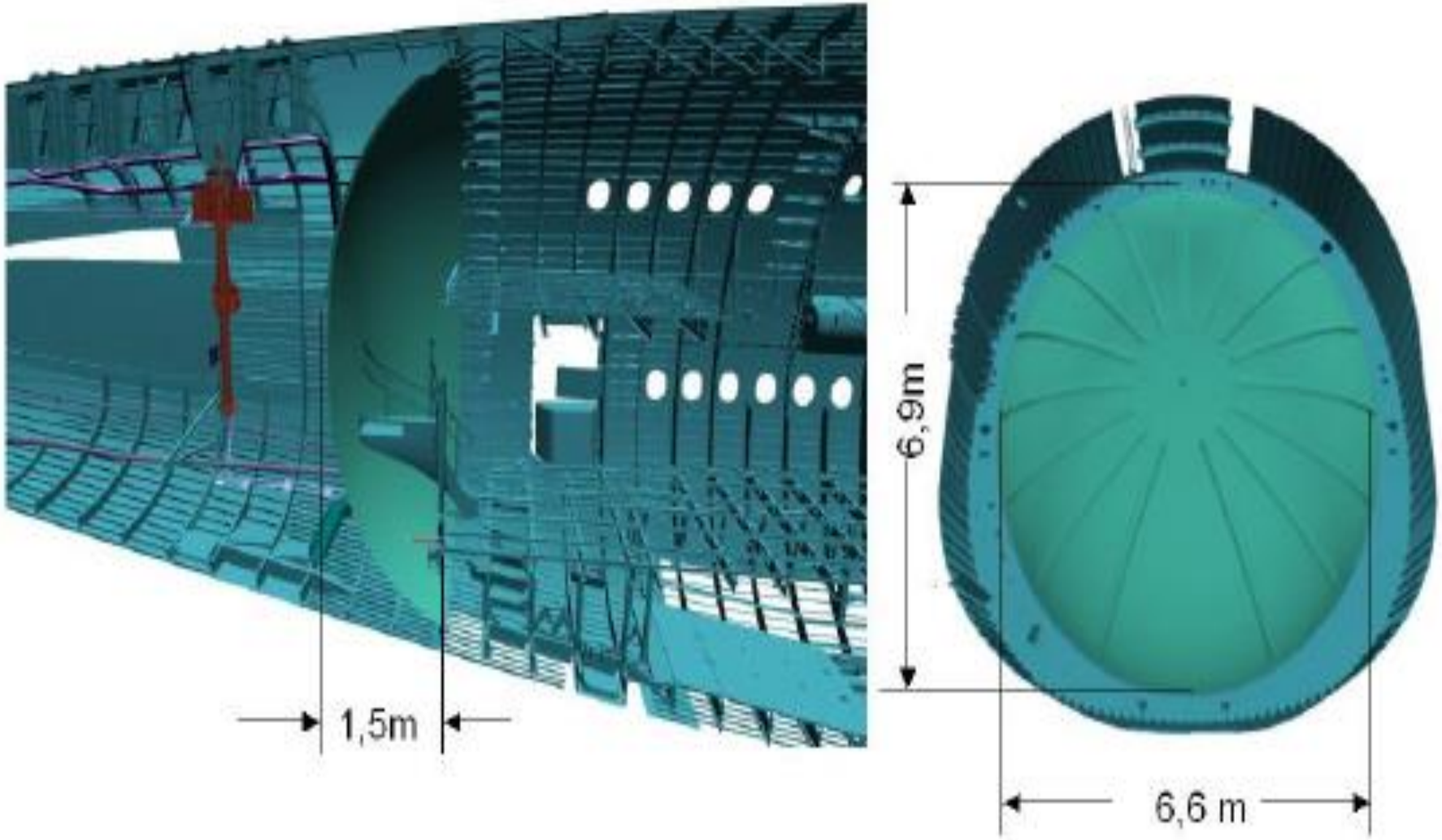
Completed RFI Lower Wing Cover (42-ft, 12.8 m Section)

- 42-ft length
- 8-ft width
- Incorporates damage tolerance features
- RFI technology demonstration
- Reduces `part-count' significantly

RFI Boeing Wing Section (Close-up)



Airbus A-380 Aft Pressure Bulkhead



Completed A-380 Pressure Bulkhead

SQRTM – Same Qualified Resin Transfer Moulding

Key Parameter is Using SAME Prepreg Resin for RTM Infusion

SQRTM Process Uses Prepregs

- Hard tooling is loaded with near-net shape prepreg materials in desired laminate configuration (angles, material stacking, etc.)
- mould is closed and sealed
- Additional prepreg resin is injected along all sides of laminate
- Purpose of “same prepreg resin infusion” is to prevent bleed-out of installed prepreg laminate resin system – not to add additional resin (hence – it acts as a “resin dam”

SQRTM Tooling Assembly w/Prepreg Materials

Assembled SQRTM Tooling Ready for Additional Resin Infusion

SQRTM Manufactured Composite Parts

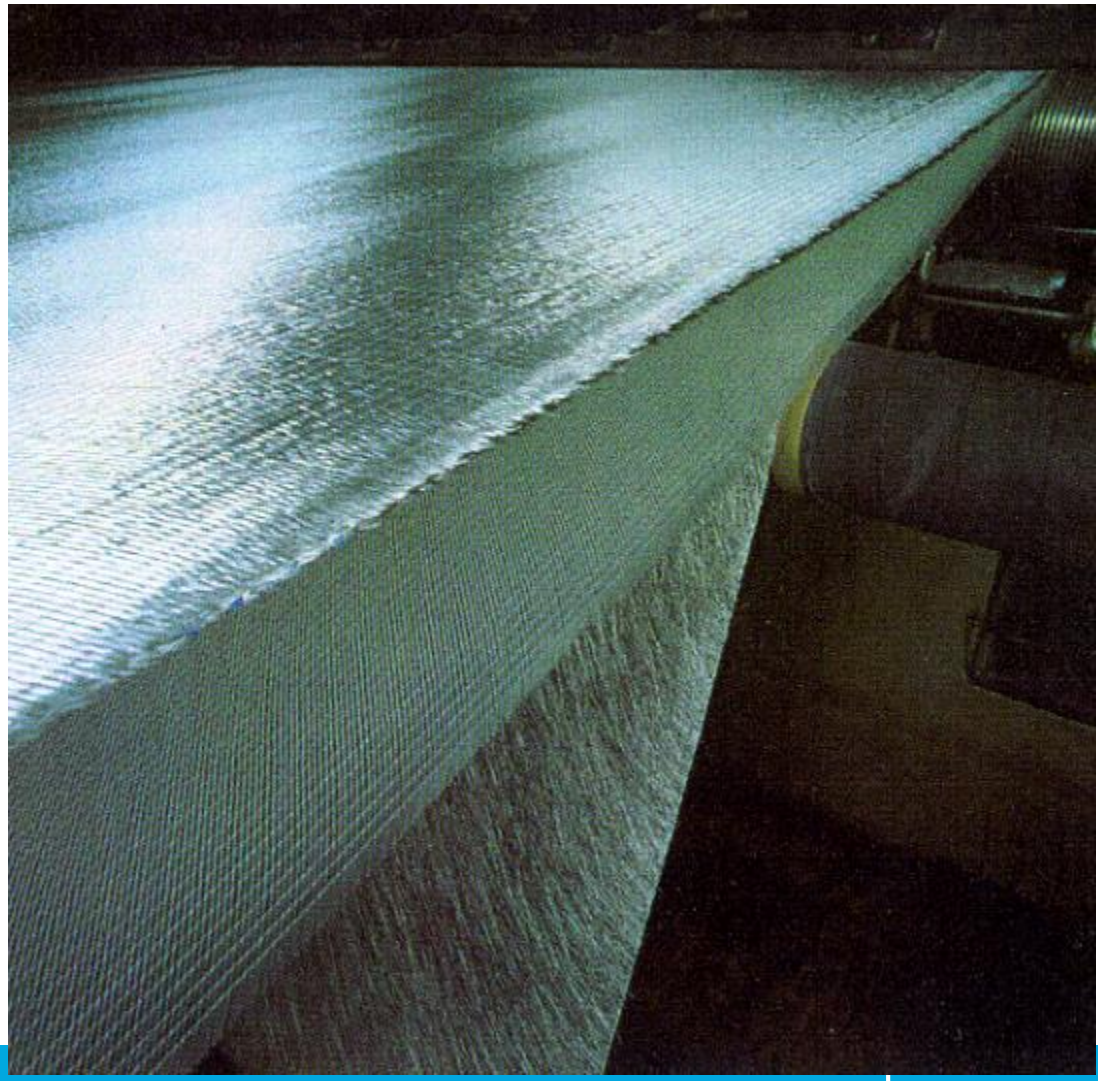
PREFORM TECHNOLOGIES

Utilization of “Fabric” Preforms

Fabric, Preform Type	Percent Industry Utilization (%)
45-Deg, Biased Fabric	14
Multi-Layer Materials	13
Knitted, Stitched	9
Twill Structures	6
Harness Satin Structures (4HS, 5HS)	18
Plain Weave	16
Uni-Tape/Unidirectional	15
Miscellaneous (Other)	10

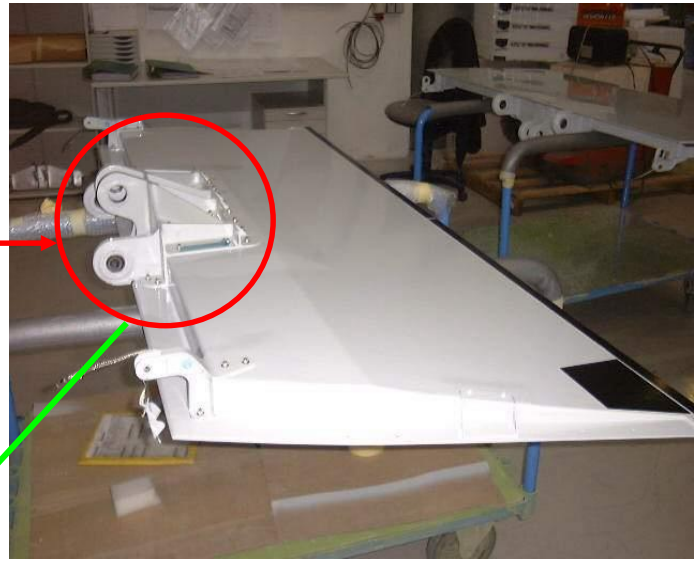
Knitted Fabric Material Example

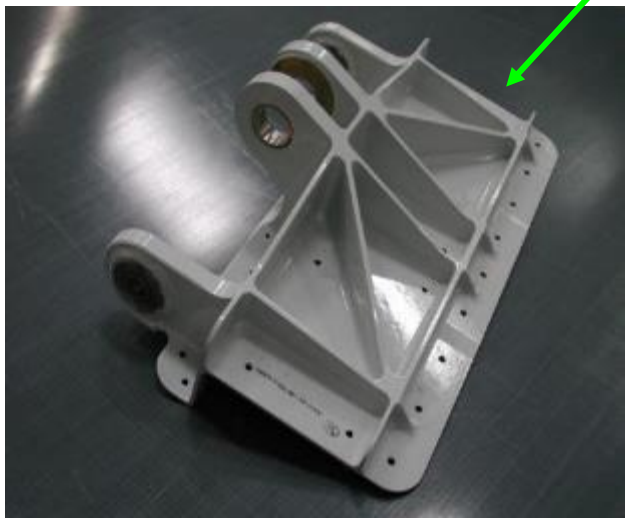
- Continuous preforming process incorporates numerous lay-up options
- Continuous strand material (CSM)
- 0/90° plus continuous mat incorporated
- Knitted together (usually tackified)



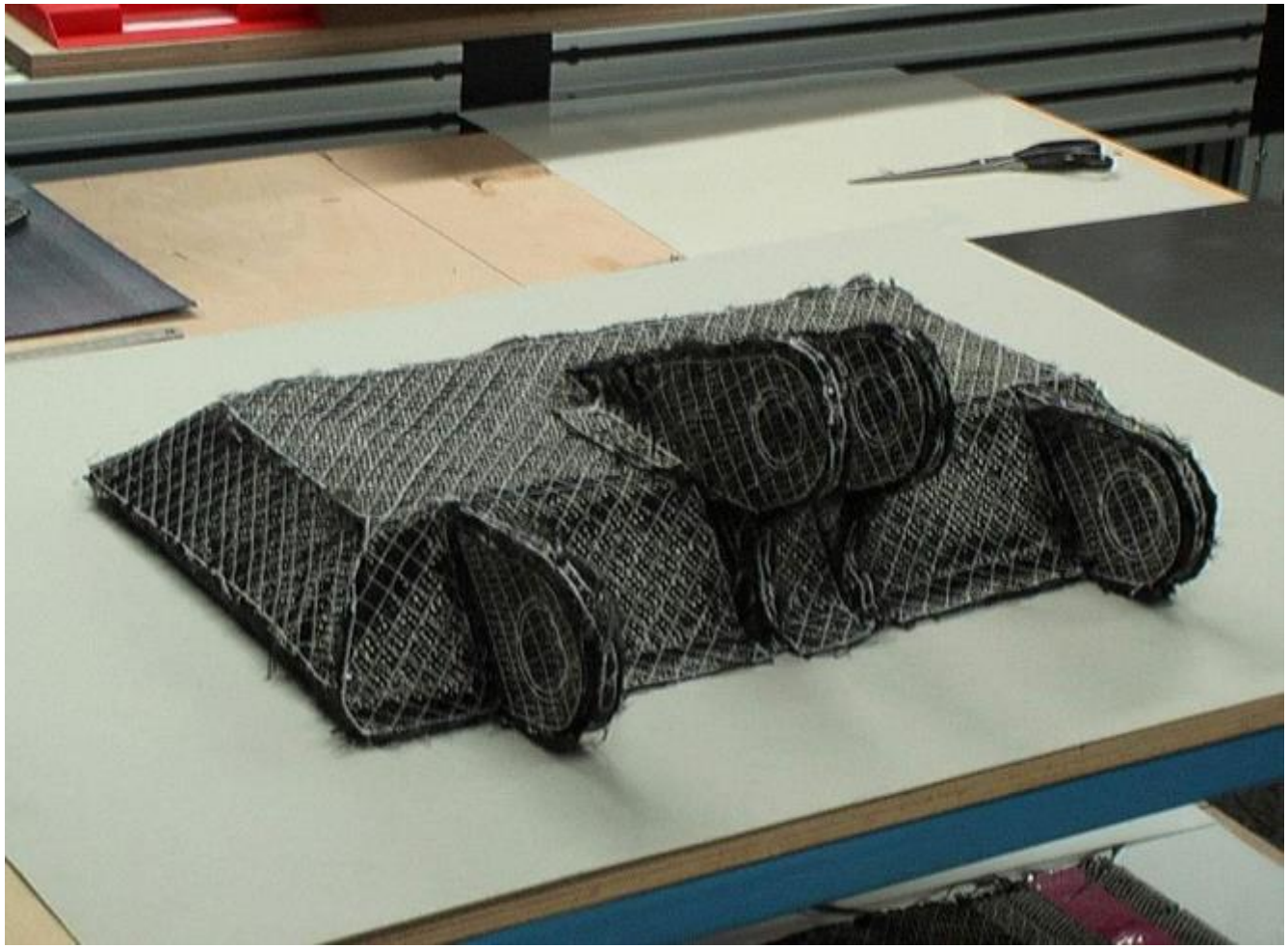
P4 Glass Fibre Automotive Preform (P4-A is Carbon Fibre)

Existing Aluminium Fitting Was Expensive Machined Part Requiring Numerous

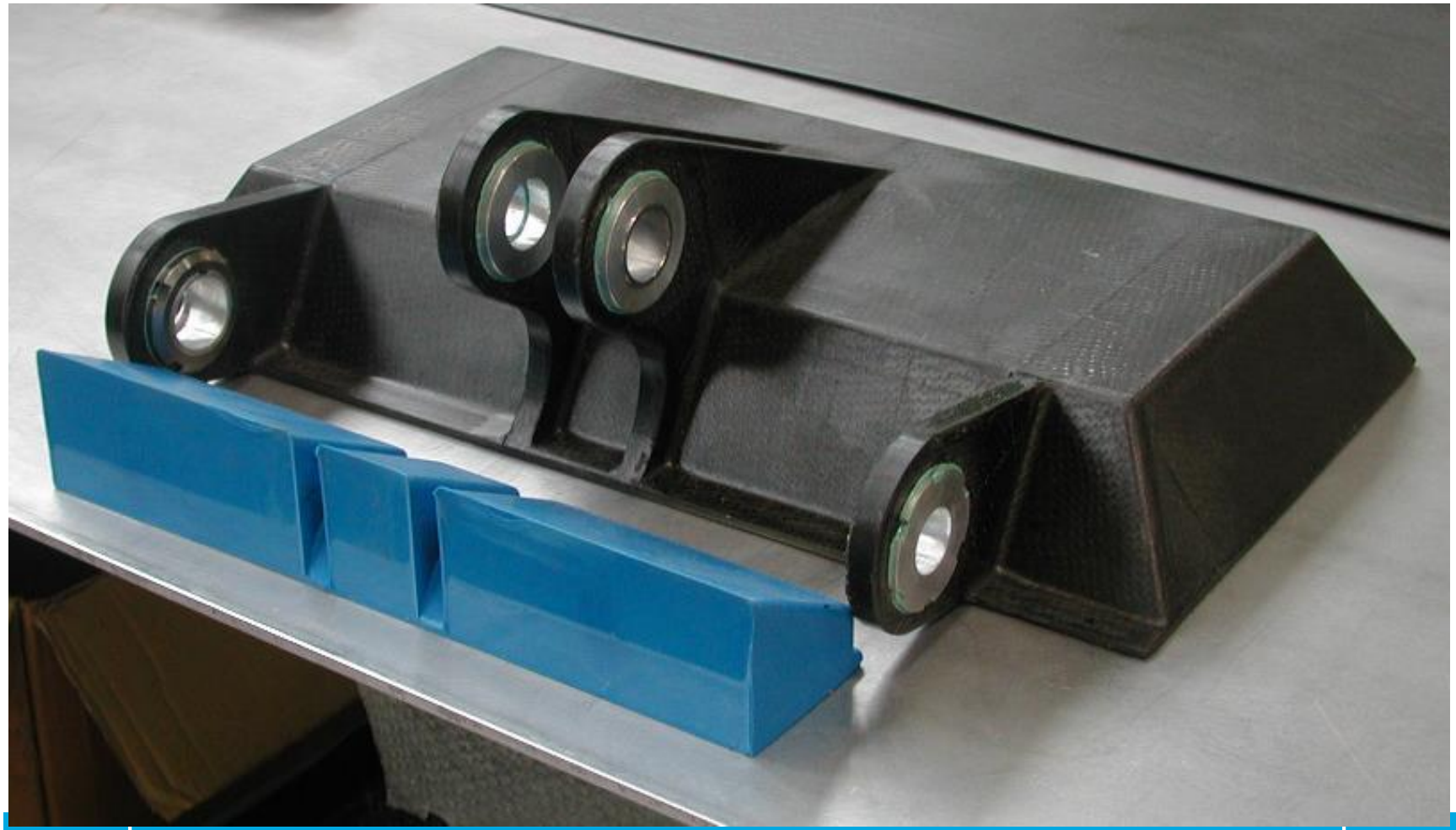




Complete Preform



Completed Center Fitting with Bearings



SUMMARY

Process Comparisons – Part 1

Process & Product Variables	RTM	VARTM	VIP	SCRIMP	RFI
Liquid Molding/Resin "Infusion" Method	Pressure (50-500 psi)	Vacuum (to 29 in Hg) **plus** Pressure	Vacuum (to 29 in Hg)	Vacuum (to 29 in Hg)	Prepreg Resin Plates
Tooling Approach	Rigid, 2 Sides plus Extensive Internal Tooling	1 Side Rigid, Bagging, possible Tooling Enclosure	1 Side Rigid, Bagging	1 Side Rigid, Bagging	Rigid, 1 Side, Tooling Inserts, Autoclave
Nominal Fiber Volume Levels, V_f (%)	55-65+	45-60+	45-55	45-55	50-55
Dominant Market	Aerospace	Aerospace & Commercial	Commercial	Commercial	Aerospace

Process Comparisons – Part 2

Process & Product Variables	HP-RTM	HP-CRTM	RTM LITE	SQRTM
Liquid Molding/Resin "Infusion" Method	Pressure (50-500 psi or much higher, faster)	Pressure (50-500 psi or much higher, faster), **Offset** to Allow Resin Flow	Vacuum (to 29 in Hg)	Prepreg Material **plus** Same Liquid Resin Infused
Tooling Approach	Rigid, 2 Sides Large Areas Possible	Rigid, 2 Sides Large Areas Possible	1 Side Rigid, 1 Side Thin Rigid Structure	Rigid, 2 Sides plus Extensive Internal Tooling
Nominal Fiber Volume Levels, V_f (%)	55-60+	55-60+	45-55	55-65
Dominant Market	Automotive	Automotive	Commercial	Aerospace

Numerous Advances Since Mid-1980‘s

- Significantly more “infusion resin families”
- Automotive developing “snap-cure” resins (60-150 seconds)
- Large number of new infusion processes
- Preforming techniques increased tremendously – arrival of much “heavier” materials for preforms
- Aerospace, Energy, Marine and Automotive markets drive technology

THANK YOU, QUESTIONS ???