Composite Tanks and Pressure Vessel Development

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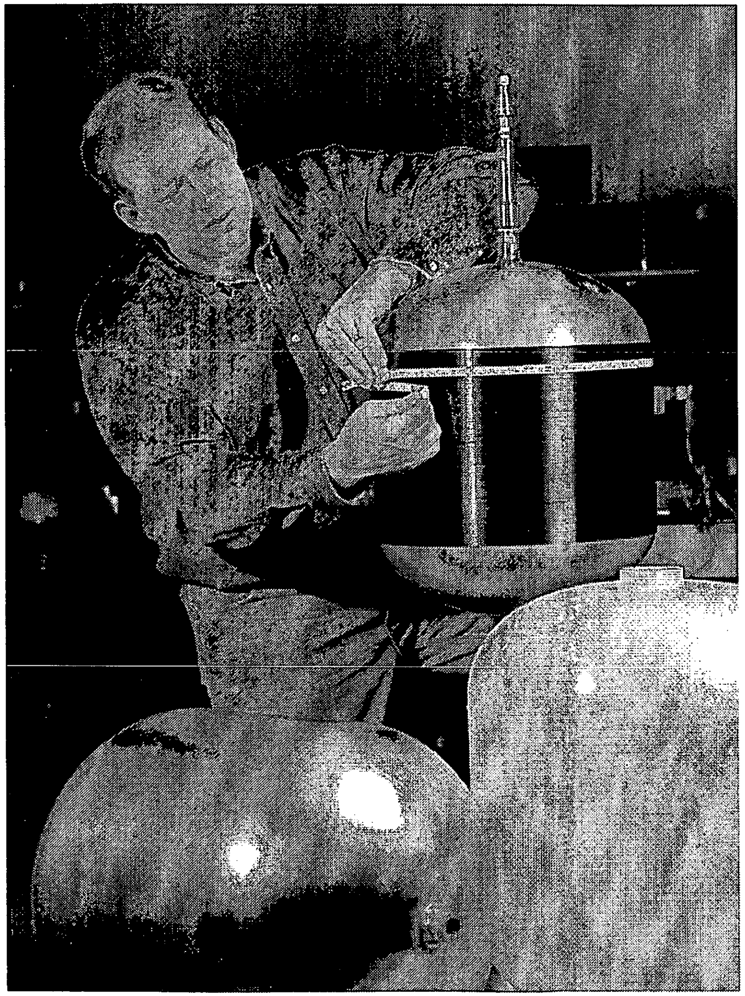


- Technology crosscutting to many industries
- Adaptable to specific applications
- Scalable
- Easily adaptable to design changes
- Applicable to conformal tank configurations

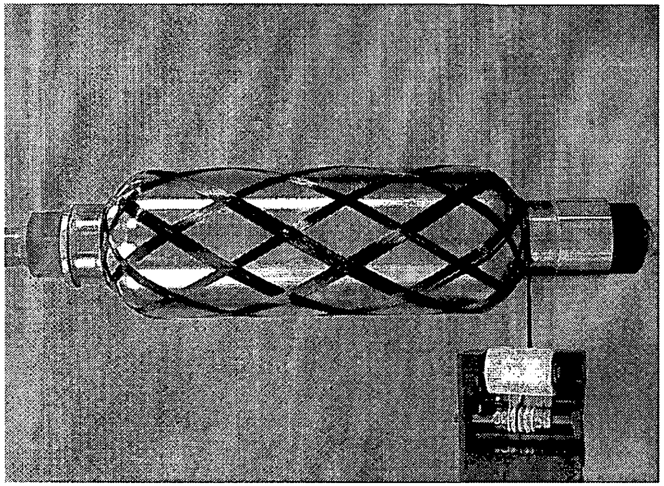
Historical Background

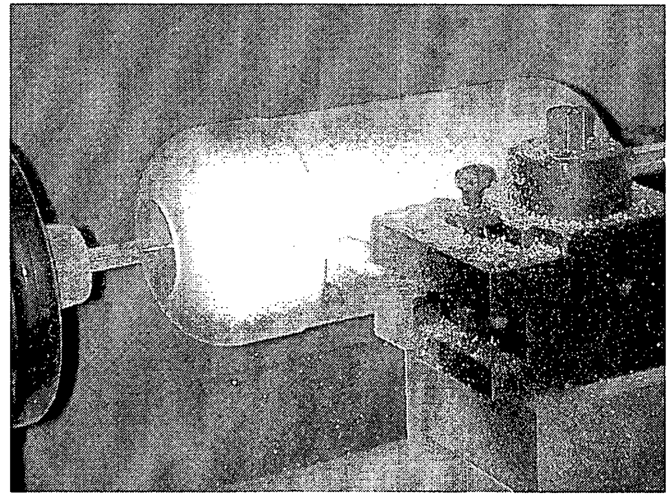
- Pressure vessels and Tanks are vital to NASA missions
  - —Significant effect on launch vehicle performance
    - ♦ Tanks need to be lightweight and perform under the operational environments
  - —Design and material limitations make it difficult to contain the fuels and oxidizers
    - ♦ Recent interest in 90% Hydrogen Peroxide adds to the challenge of containment
  - —The majority of current tank technologies are not easily adaptable to conformal shapes
  - —The cost of tooling-up for large tanks are magnified by sudden design changes
  - —New launch vehicle concepts may require tanks and pressure vessels of a non-standard configuration

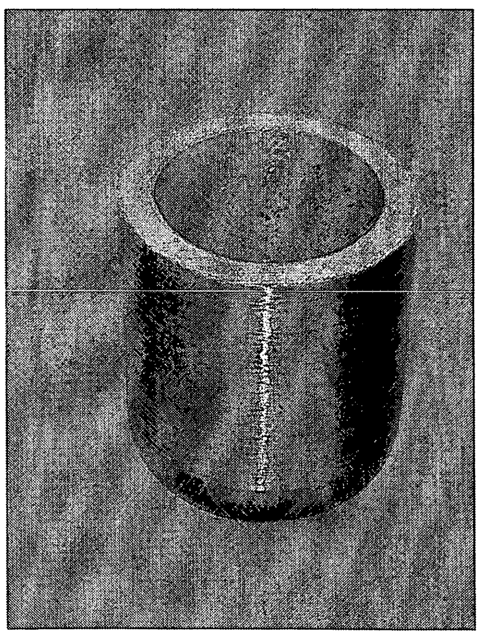
R&D Status

- Scaled versions of new tanks have been fabricated
- Testing has begun
  - LN2 fill & drain, pressurized to 2,000psi followed by leak test
  - Testing with LH2 soon
  - 6,000 psi Helium tank will be tested soon
  - Testing with 90% hydrogen peroxide undecided
- Refinements in design,processing and selection of materials
- Partnerships developing with JPL
- Potential partnerships and joint R&D under discussion
- 2nd and 3rd generation launch vehicle decisions will effect the path of R&D

Layered Vessels

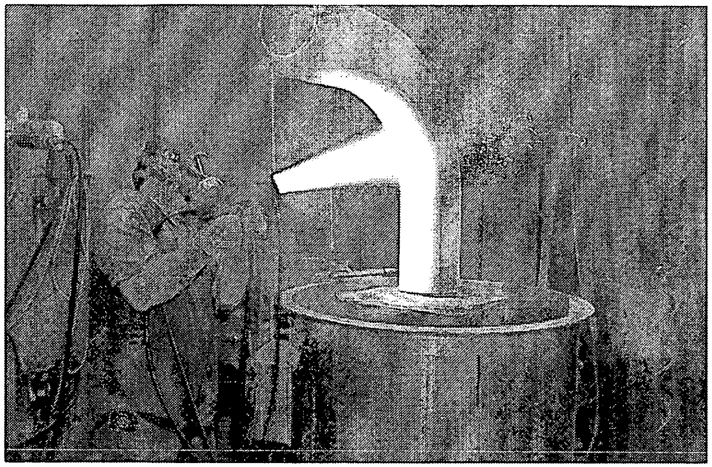




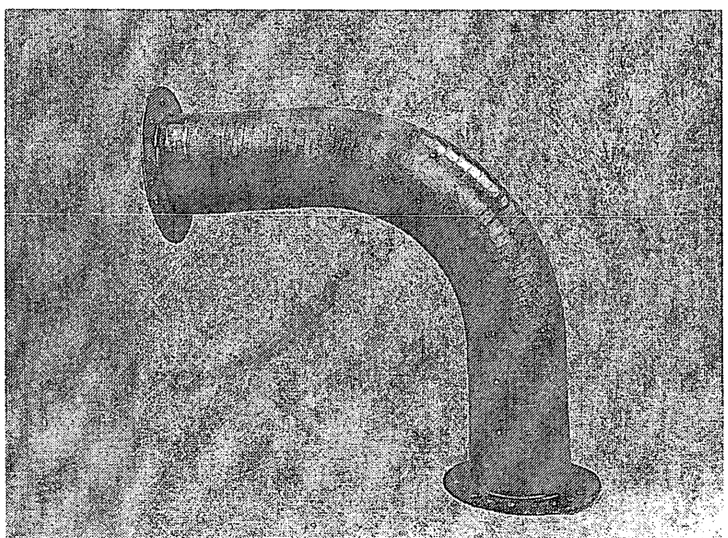


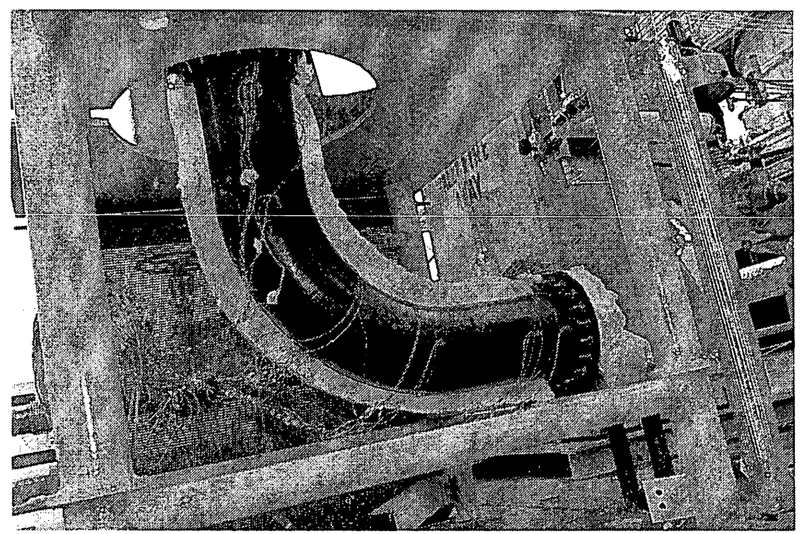
- Multi-layered approach
  - — Scalable
  - — Easily changed
    - ♦ Material substitutions
    - ♦ Machined insulation
  - — Impact resistance
  - — Cryogenic applications
  - — Fire resistant
  - — Fuel cell applications

Composite Ducts



- Processes for tanks can apply to ducts
- Composite ducts have been tested
  - LH2, 10 cycles at 100 psi
  - Leak checked with Helium
  - Proof test near 700 psi
- Lined/layered duct planned for development and testing

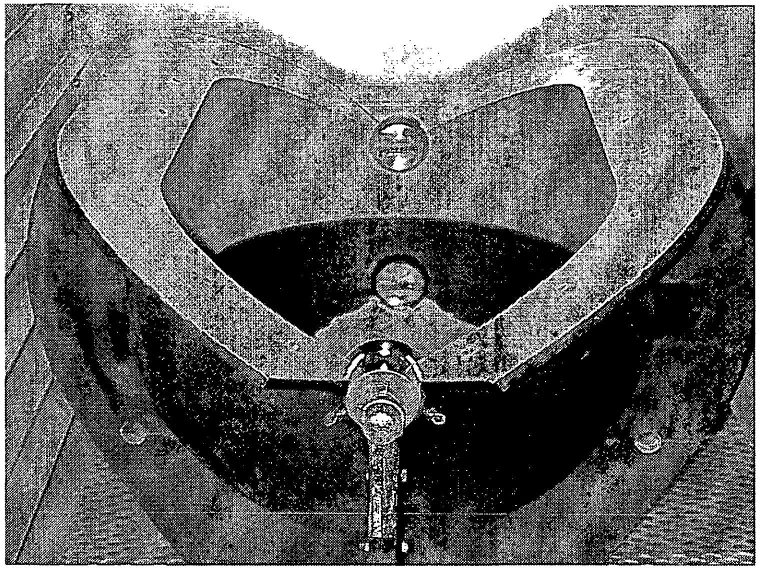


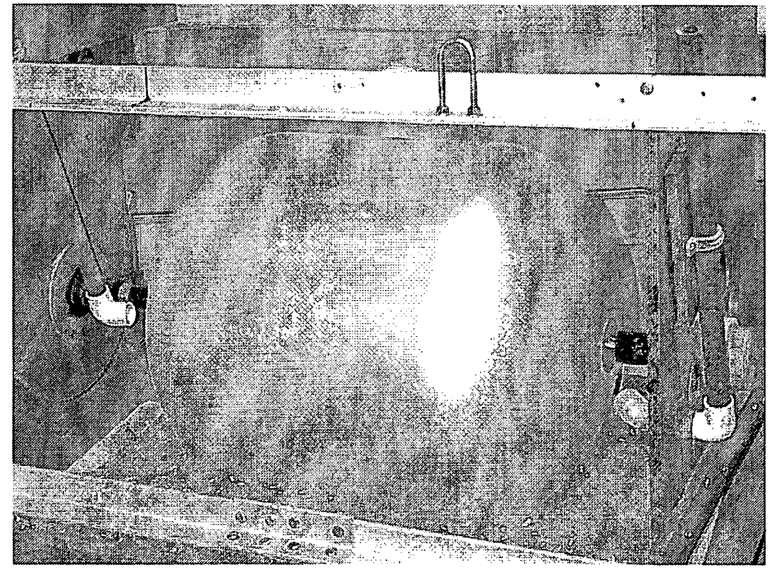


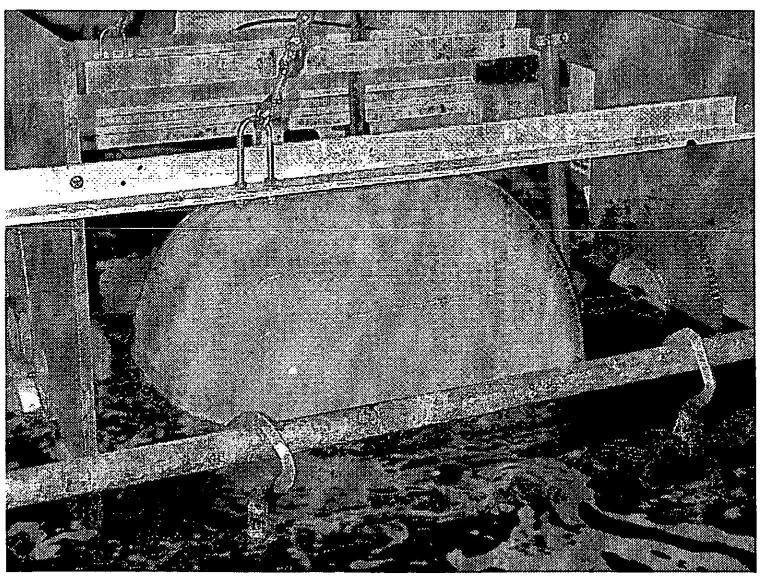
Electro-formed liner fabrication

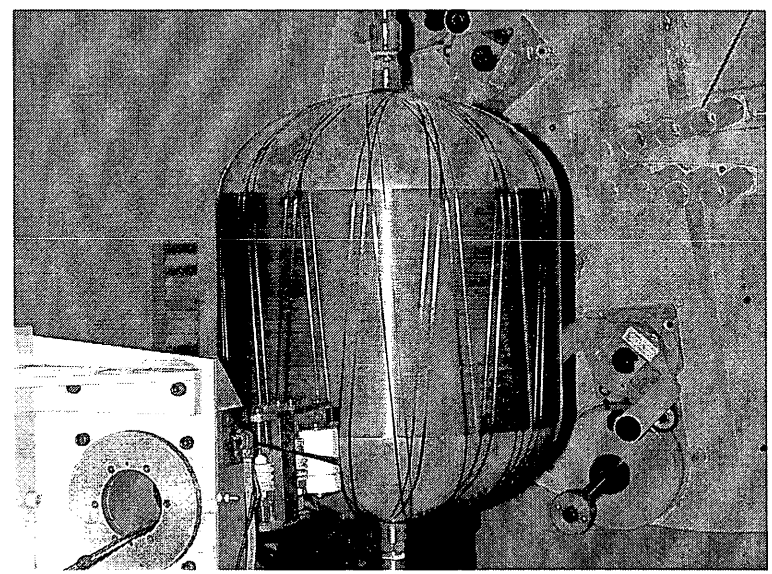
- Water soluble and melt-out mandrels
  - —Eutectic salt
  - —High temperature wax
    - Additives and fillers to stabilize wax
- Mandrel is removed from liner
- Liner is pressurized during the winding of the composite over-wrap and during oven curing
  - —Pressure of the liner is increased after progressive layers
- Plated liners can adapt to conformal tanks
- Permeability of different metals and alloys to be studied

Liner fabrication

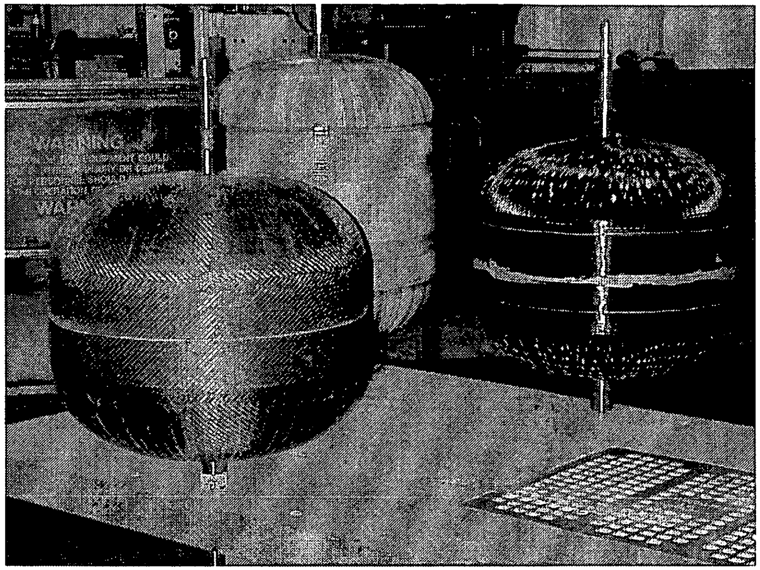


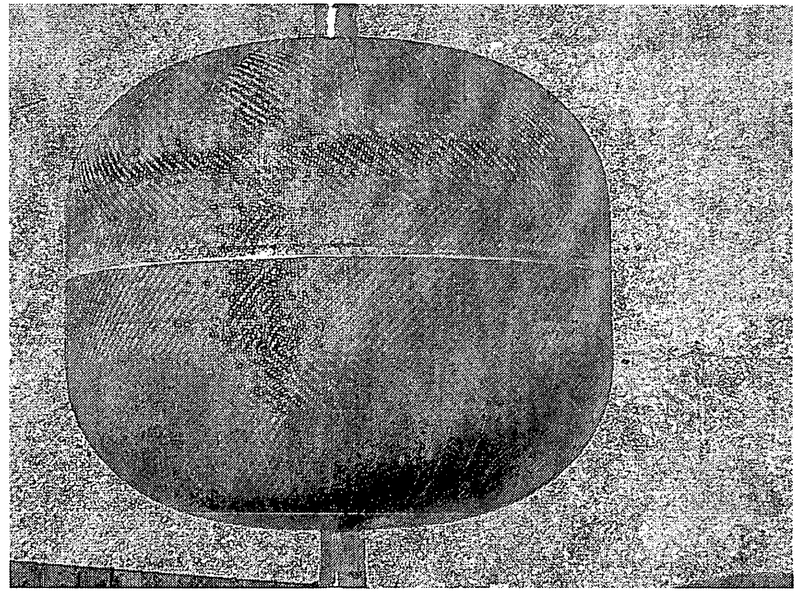


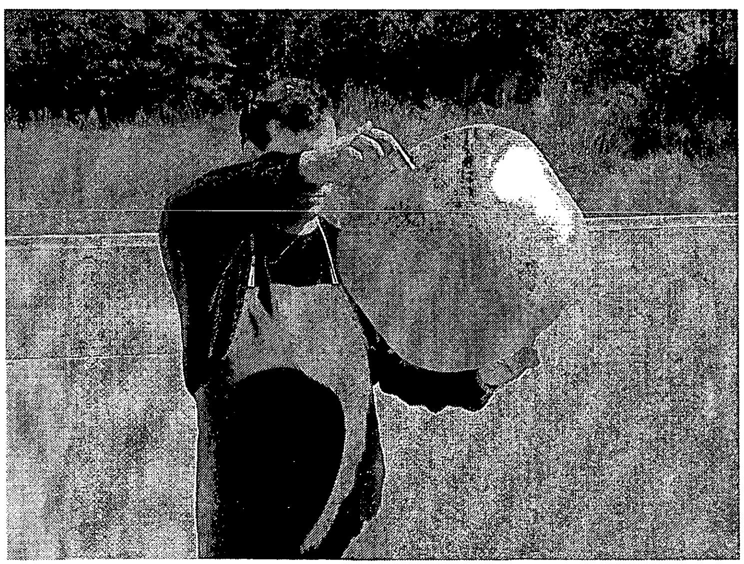




Pressurant/fuel cell vessels

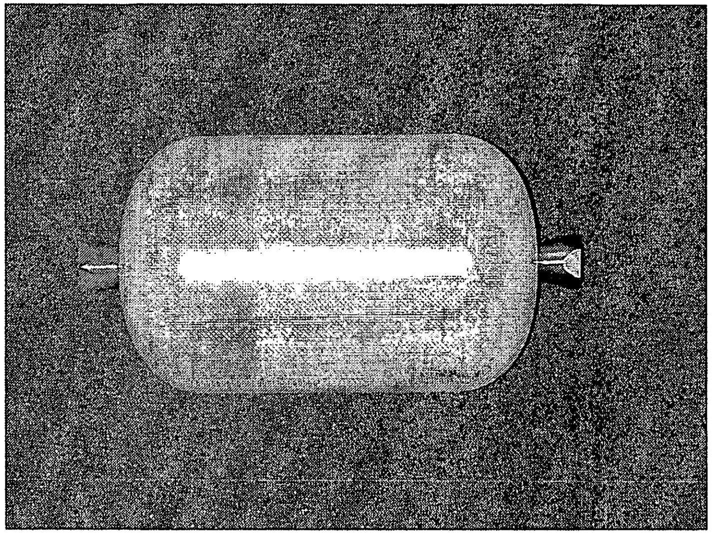


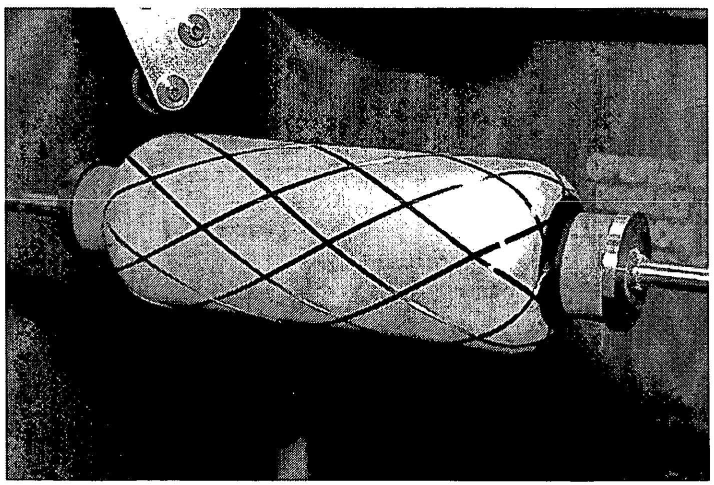




- Composite mandrel
  - — Easily modified
  - — Light weight
  - — Low CTE
  - — Plated with permeation barrier(copper/nickel)
  - — Over-wrapped with composites

Thermoplastic liners



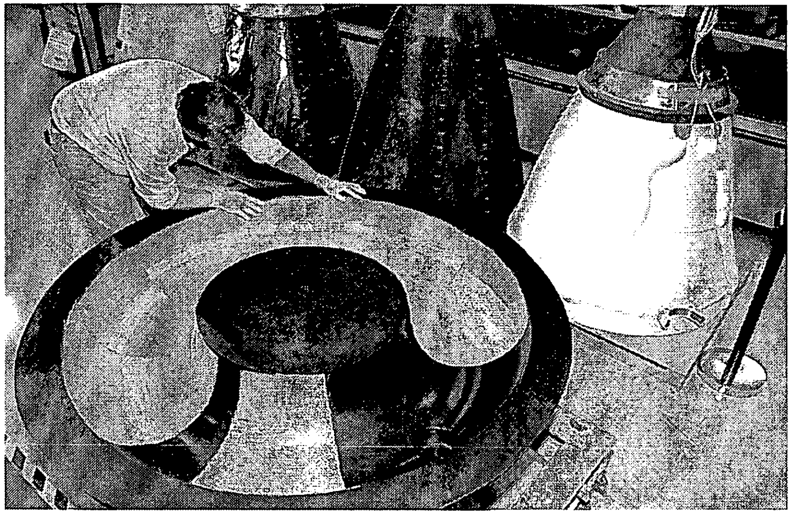


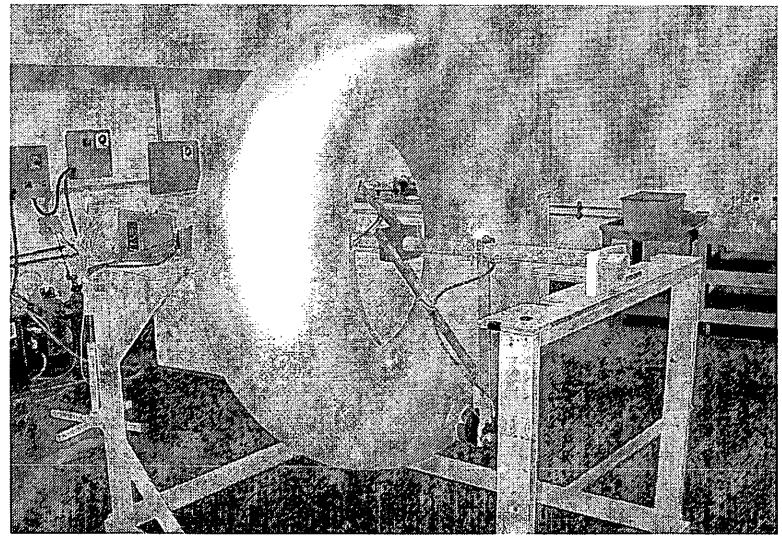
- Rotational molded liners are rather inexpensive and adaptable to material changes
- Thermally sprayed liners can be rather thin if mandrel can be removed
  - — Properties of liner can be enhanced with over-wrap
- Permeability of liners to pressurant gasses(Helium) not adequate
- Application of permeation barriers to plastic liner under research
- Additional work on conformal tanks is proposed for more study

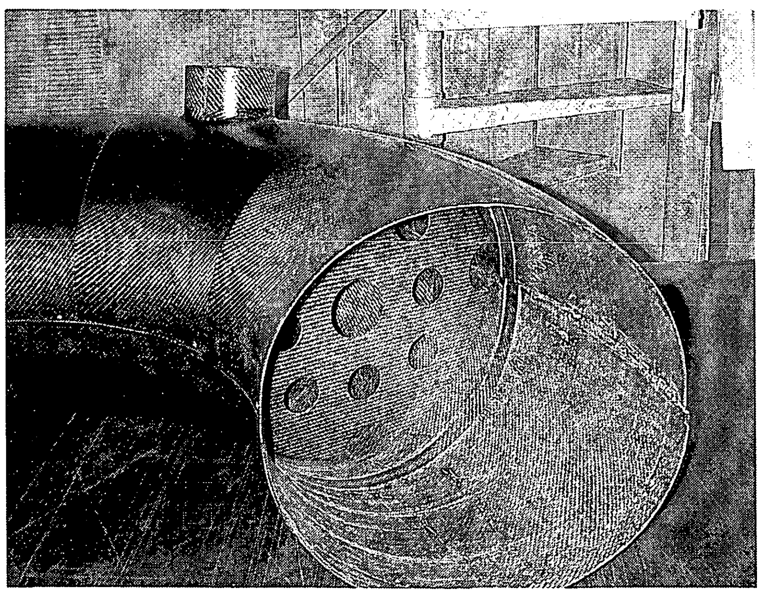
Toroidal tank development

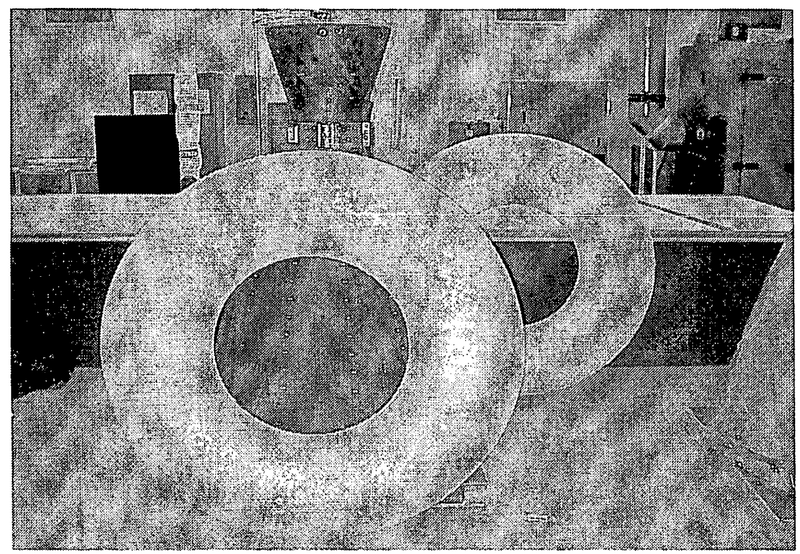
- Toroidal tanks are under study for upper-stage applications because of the potential for space and weight savings
  - Toroids have manufacturing challenges
    - Propellant management
- Several different tanks are being fabricated by different methods
  - All-composite
  - Metal lined, or plated permeation barriers
  - Plastic lined
- Slosh baffles and support structures under development

Toroidal tank development

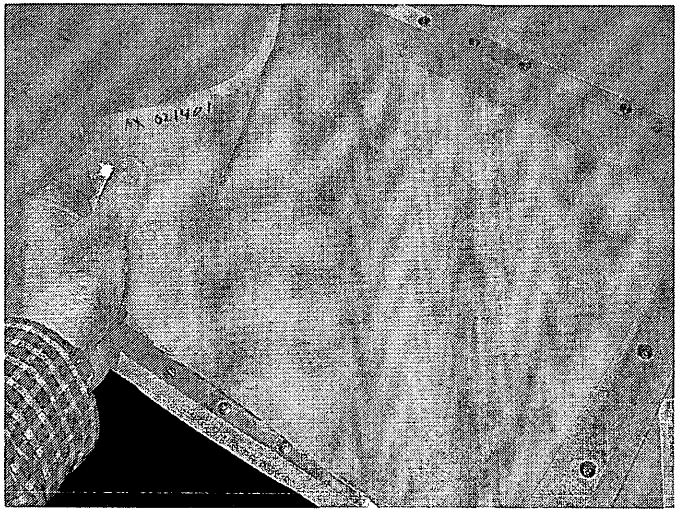


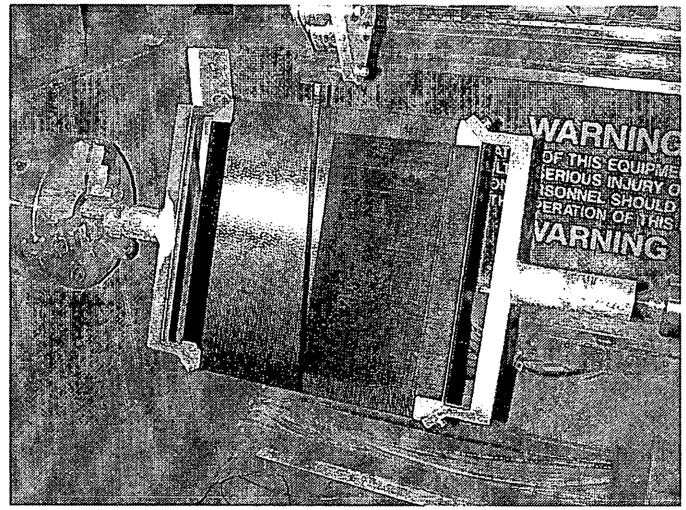


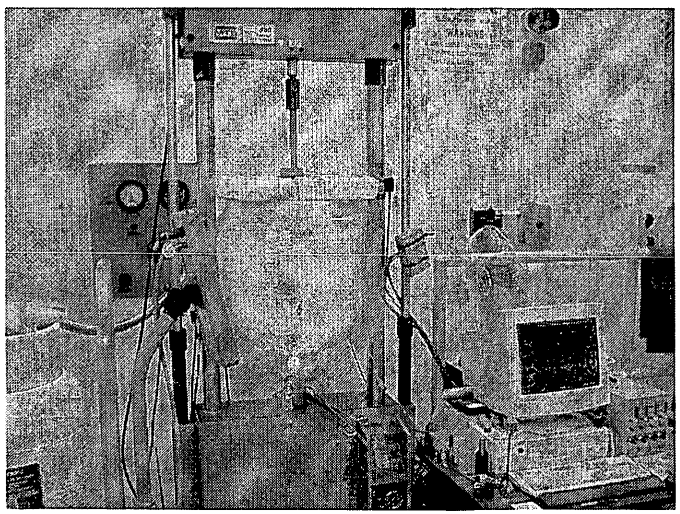


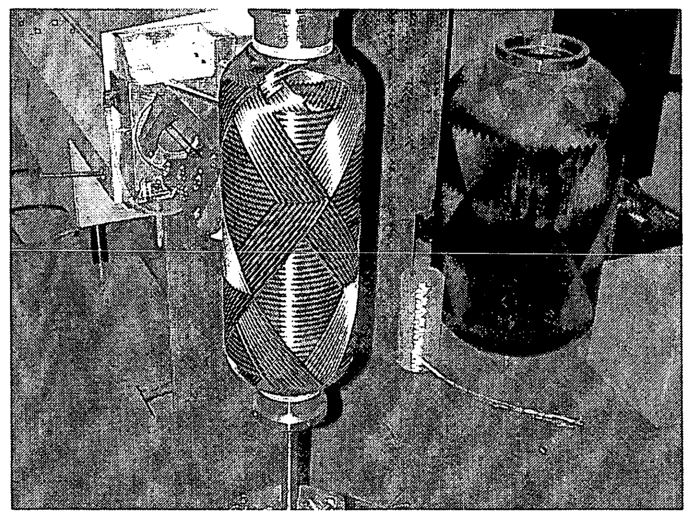


Material test and development









Material test and development

- Materials are being screened for cryogenic applications
  - —Samples from vendors are being supplied
  - —New materials are being developed internally
  - —Micro-cracking and permeability under study
  - —Tensile testing of composite laminates and resins at ambient and cryogenic temperatures
- Materials for Hydrogen Peroxide compatibility
  - —Few composite materials have shown promise
  - —Liner material appear vital
    - Near pure Aluminum alloys and Fluorinated polymers show the most promise

Material test and development

- Fiber/resin systems for pressurant tanks being evaluated
  - —Aluminum liners used to evaluate performance of materials (delivered fiber strength etc.)
- Hybrid laminates planned for further evaluation
  - —Performance of PBO , T-1000 carbon combined in the filament winding process
  - —Application to long term storage at high pressures
  - —Impact/damage tolerance studies
- Material development for impact resistance and fire protection for pressure vessels

Future Activities

- Fabrication and test of toroidal tanks
- Composite over-wrap of very thin Aluminum lined tanks
  - —Demonstration of larger scaled Aluminum lined tanks
  - —Testing with LH2
  - —Hydrogen Peroxide tank development for long term storage
- Conformal tank R&D
- Material development and testing for cryogenic tanks
  - —Micro-cracking and permeability studies
- Development of unlined composite tanks
- Demonstration of full-scale(50) composite 6,000 psi Helium pressurant tank
- Additional refinement of fuel cell pressure vessels