Toroidal tank development for upper-stages

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Background

• Past interest in upper stages
  – Orbit transfer vehicle programs; toroidal tanks were under study
    • Compact LOX Feed System Study  AFRL TR-86-045

• Current interest
  – SLI architecture studies
  – JPL satellites

• Potential Benefits
  – Packing efficiency
  – Weight savings

• Challenges
  – Manufacturing methods
  – Fluid acquisition
Why are we building toroidal tanks?

- **CDDF (Center Director’s Discretionary Fund)**
  - SLI 2nd and 3rd gen programmatic interest
  - Manufacturing hurdles challenged before architecture is defined
- **Joint IR&D**
  - New pressure vessel technologies developed by MSFC
  - Conformal CNG tank technology developed at THIOKOL
  - Combined effort to leverage results
MSFC IR&D Effort

• Development of tank and pressure vessel concepts for upper stages
  – Address permeation issues with pressurant gasses (Helium)
  – Develop processes adaptable to conformal tanks
  – Consider lined and unlined composite tank concepts
    • Liner development based on contained fluids
  – Produce ultra-light vessels that are suitable for satellites and scalable to upper stages
  – Develop technology that may be transferred to industry
MSFC IR&D Effort
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THIOKOL Conformal Tank Technology Development
Aluminum Propane Tank Product Overview

- Cylindrical tanks provide near-optimum pressurized fuel storage
- Cylinders often do not fit well within the available vehicle space
- Conformable concepts adapt to the available vehicle space
- New technology propane fuel storage tanks
  - Interlocking aluminum extrusions reduce the number and criticality of longitudinal welds in the assembly
- Unit cost is more than cylindrical tank, but offers significant advantages
  - Extends vehicle range: up to 50%
  - Reduces weight: aluminum construction
  - Reduces system complexity:
    - Eliminates “ganged cylinders”
    - Lowers overall system cost
- Complete family of ASME certified tanks available as commercial products
Composite Tank Product Overview

- Composite tank development has been completed using Department of Energy funding
  - Both tanks are for gaseous fuel storage
    - CNG at 3,600 psig
    - Hydrogen at 5,000 psig
  - Both tanks are made using aluminum polar bosses, plastic liners, and TCR composite over wrap
  - Both tanks have been designed to fill Ford P2000 envelope (13 in. x 22 in. x 28 in.)
- Tanks are in the process of certification to industry standards
  - CNG tank has completed commercial NGV2-1998 certification testing
  - Hydrogen tank will also complete all certification testing by June 01 to modified NGV2-1998 standard
  - Next step is to address specific OEM test criteria
- Significant interest in both CNG and hydrogen tanks from after market and OEM customer base
Approach To Producing Toroids

• Continuous circular toroid
  – Tooling
  – Materials
  – Design
  – Advantages and challenges

• Conformal/segmented toroid
  – Tooling
  – Materials
  – Design
  – Advantages and challenges
Continuous Composite Toroidal Tank fabrication

• Several methods approached to consider:
  – Scalability
    • What is the representative size that may be needed
    • Are the processes adaptable
  – Manufacturability
    • Tooling methods to be developed
    • Automation vs. hand-layup
  – Operational environment
    • Operational pressures
    • Fluid management, slosh
    • Chemical compatibility of fluid and permeability of gasses
Continuous Composite Toroidal Tank fabrication

- Tooling, materials, design
  - Rotationally molded thermoplastic liner/mandrels
  - Liner pressurized while over-wrapped and cured
  - Lower temperature cured graphite epoxy over-wrap
  - Nylon end fitting machined and bonded
  - 1/3 scale version of what could fit in delta 4 fairing
Continuous Toroidal Tank fabrication
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Continuous Toroidal Tank fabrication
Continuous Toroid Traits

- 60 inch outside diameter, 16 inch cross section
- 5 inch diameter port 180 degrees on the opposite side of 1 inch port
- The composite toroid weighed less than 40 lbs.
- It contained 120 gallons of water, 27,793 cubic inches
- Total weight slightly more than 1,000 pounds, full
- Predicted burst pressure 375 psi
- Actual burst pressure 425 psi
- Area of highest strain, inner radius
- Packing efficiency (38% more volume than multiple spheres constrained by the same space)
Inspection and test of continuous toroid

• Vessel was inspected with thermography
  – No surface wrinkles, very minor de-bonds
• Triaxial strain gauges used to help predict burst
Inspection and test of continuous toroid
Segmented Composite Toroidal Tank fabrication

• Several methods approached to consider:
  – Scalability
    • What is the representative size that may be needed
    • Are the processes adaptable
  – Manufacturability
    • Tooling methods to be developed
    • Automation vs. hand-layup
  – Operational environment
    • Operational pressures
    • Fluid management, slosh
    • Chemical compatibility of fluid and permeability of gasses
Segmented Composite Toroidal Tank fabrication

- Tooling, materials, design
  - Machineable wax mandrel outfitted with end fittings and copper plated
  - Graphite epoxy over-wrap
    - Each segment filament wound with graphite/epoxy
  - Conformal tank geometry proprietary
  - Slightly less volume than continuous toroid; however, higher pressure applications likely
  - Process being scaled and modified
  - Sub-scale assembly useful for demonstrating concept
Segmented toroid
Segmented toroid
Segmented toroid
Segmented toroid
Segmented toroid
Potential advantages of segmented toroid

- Management of fluid acquisition
  - Slosh modes unique to toroids
- Packaging of oxidizers and fuels
  - Alternate tanks to control center of gravity
  - 10-20% more efficient than cluster of cylindrical tanks
- Replacement of damaged unit in the assembly
- Adaptable to very long toroid assemblies
- Customize to propulsion system requirements
  - Pressure fed system vs. pump fed
Where next?

• Continue development of segmented toroid
  – High cycle testing of assembly
  – Investigate application to SLI architecture or commercial applications

• Fabrication of additional circular toroids
  – Consider additional burst test or flow studies
  – Investigate slosh management
    • Positive expulsion bladder

• Consider partnerships if appropriate