Optimum Utilization of Available Space in a Vehicle through Conformable Hydrogen Tanks

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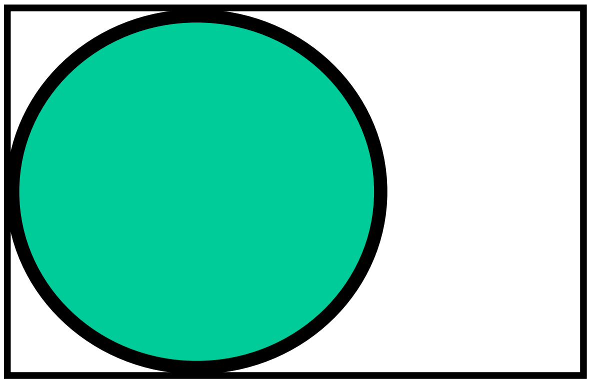
Storage volume is the most critical issue for H_2 vehicles
Objective: reduce overall storage volume by improving the volumetric efficiency of the tanks

Volumetric efficiency of conformable and non-conformable vessels



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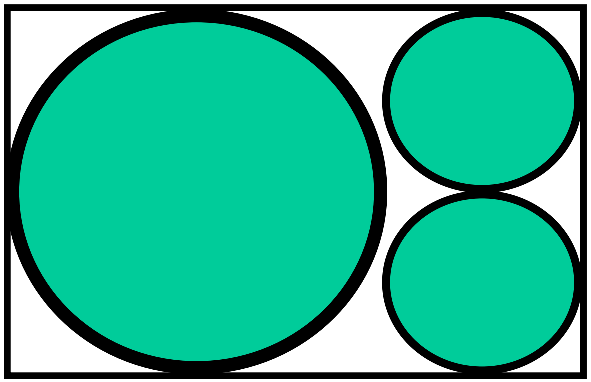

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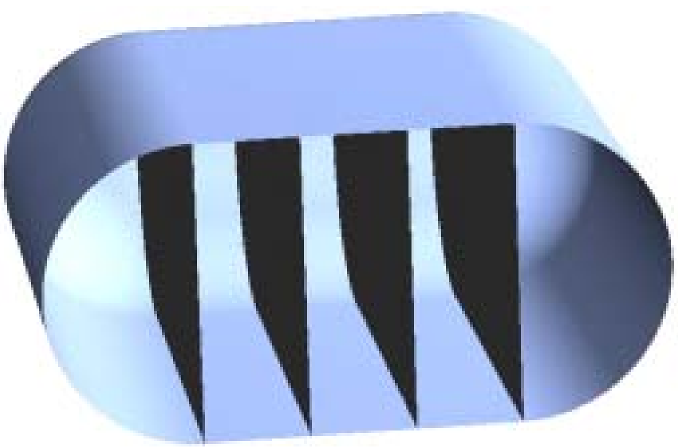

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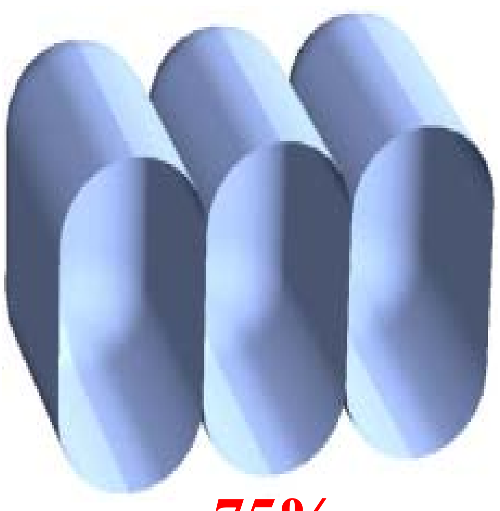

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Budget

$500 k for FY04

new project (no funding in FY03)

Technical barriers and technical targets

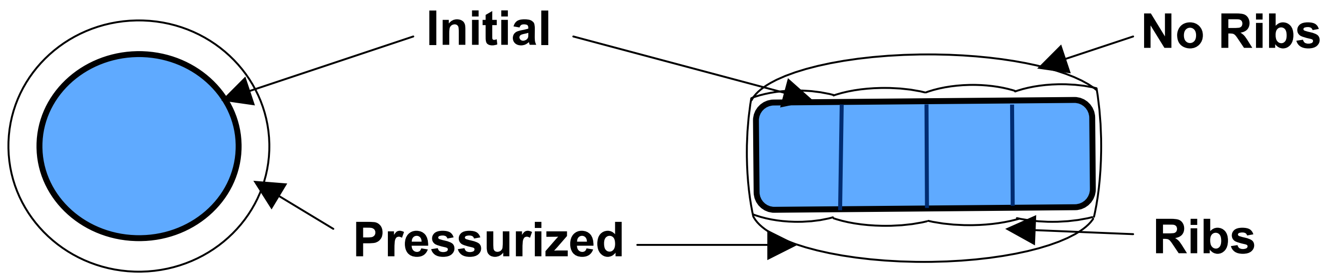
Conformable pressure vessels address the following technical barriers from the Hydrogen Program R&D plan

- **B. Weight and volume, through high performance tanks and better utilization of space**
- **C. Efficiency, low energy for compressing H_2 and using liquid H_2 only when needed**
- **D. Durability, pressure vessels are certified to withstand over 10000 cycles.**
- **E. Refueling time, pressure vessels can be refueled quickly**
- **G. Life cycle and efficiency analysis, we have conducted analysis of system efficiency**
- **H. Sufficient fuel storage for acceptable vehicle range, due to low weight and volume**
- **I. Materials, we are looking into new composites and adhesives**
- **J. Lack of tank performance data, we will test tanks and generate performance data**
- **L. Hydrogen boil-off, reduced boil-off due to high pressure capability**

We are planning to achieve the following technical targets:

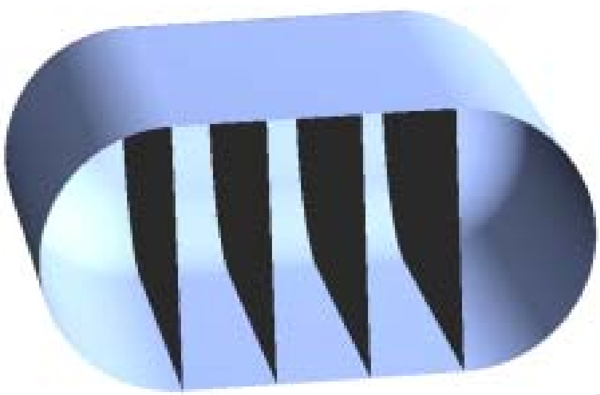
- **2010 weight and 2005 volume targets with compressed hydrogen**
- **2010 weight and volume targets with cryogenic hydrogen**
- **Could achieve the 2015 weight target with cryogenic H_2 and advanced vessels**

Approach: conformable vessels are subjected to bending we are investigating two techniques for reduced bending stress: continuous fiber vessels and vessels made of replicants

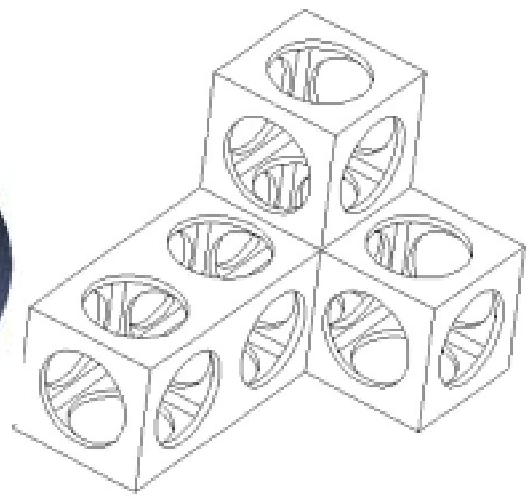


Spherical and cylindrical tanks naturally resist "bending" without internal stiffeners

Conformable tanks require internal stiffeners (ribs) to efficiently support the pressure and minimize bending stresses



Continuous fiber vessels have to be designed to reduce the bending moments



Vessels made of replicants rely on mass-produced parts joined together


Metaphor = architecture not many domes or arches compared to 'endoskeletal' structures built routinely by assembling multi-use parts

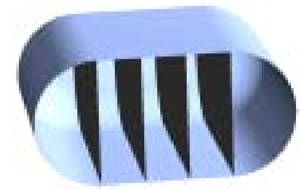
Project safety

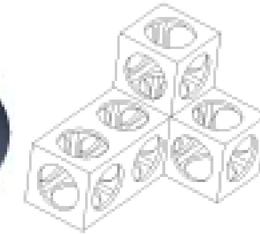
Pressure vessels can explode, releasing substantial energy

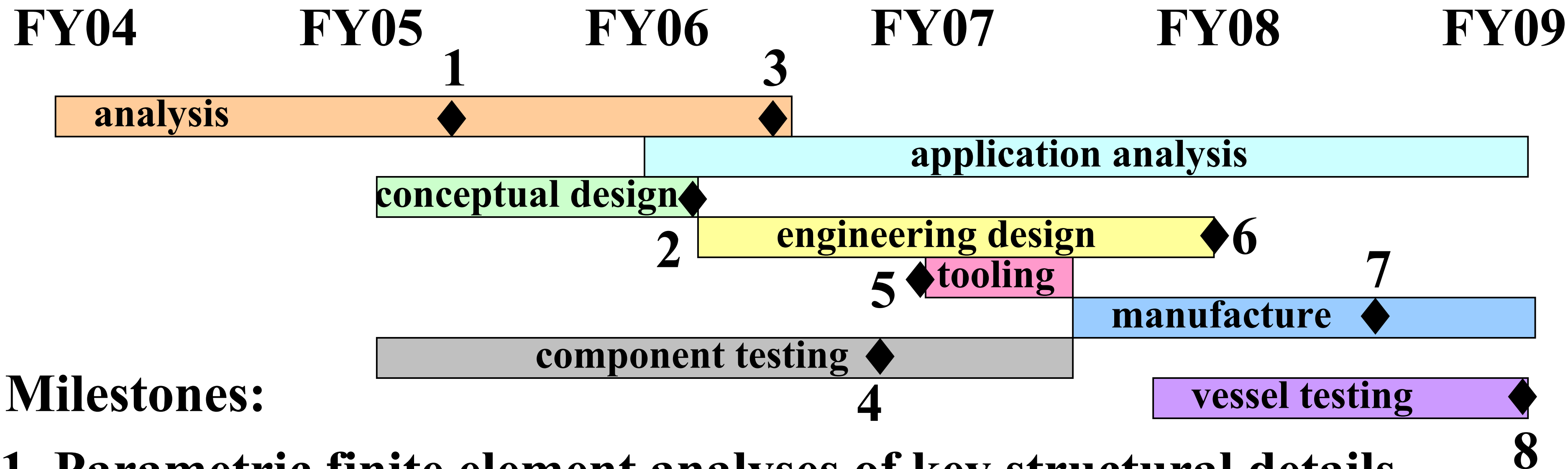
We will address this issue through vessel testing and certification

- **ISO certification for ambient temperature pressure vessels**
- **SAE LNG tests added for cryogenic tanks**
- **Innovative approaches to vessel safety (e.g. turn to dust failure)**

Project timeline: Over the next five years we will analyze, design, manufacture and test two conformable pressure vessel designs



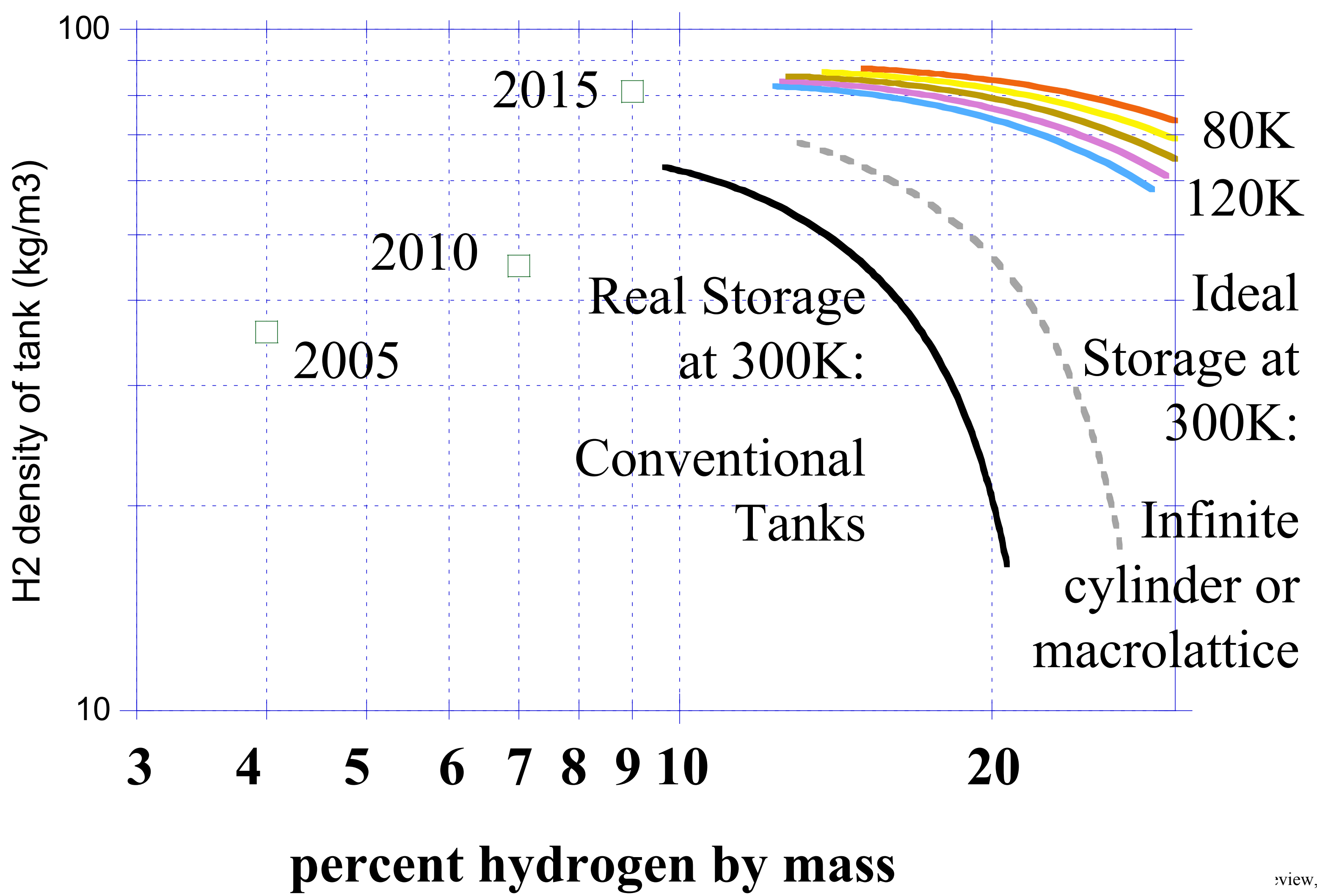




Milestones:

1. Parametric finite element analyses of key structural details
2. Create CAD models of components
3. Select best shapes
4. Verification of structural performance of key components
5. Completion and release of specifications to build components
6. Finalized designs
7. Successful manufacture of conformable test articles
8. Proof of concept with demonstration of adequate burst pressure

Technical Accomplishments and Progress
Analysis of pressure vessel mechanics and PVT properties of H_2 indicates cryogenic vessels can meet volume and exceed weight targets

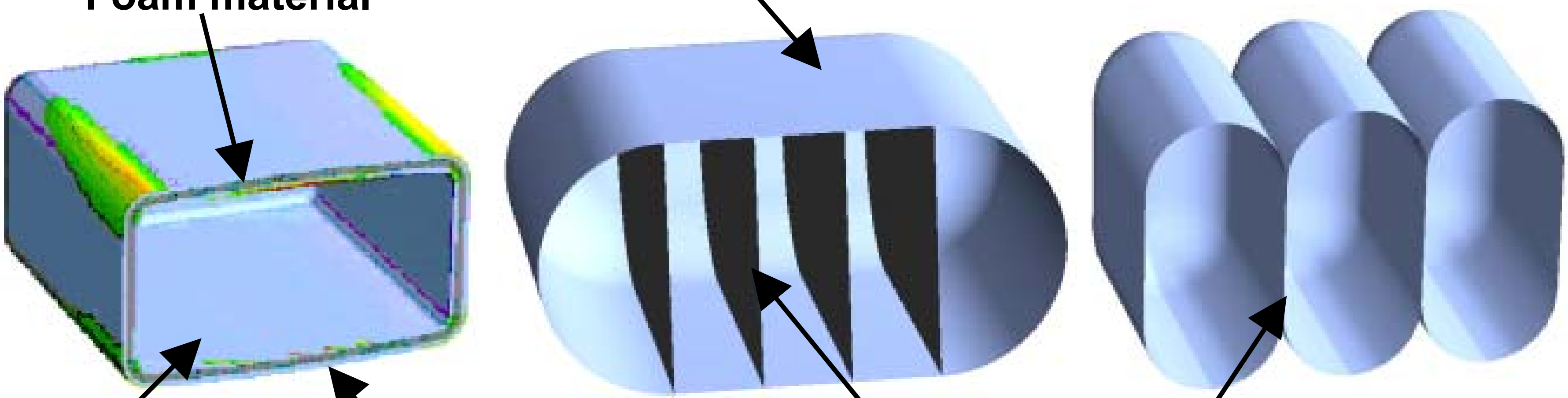


Technical Accomplishments and Progress
We have analyzed three possible designs for continuous fiber conformable pressure vessels

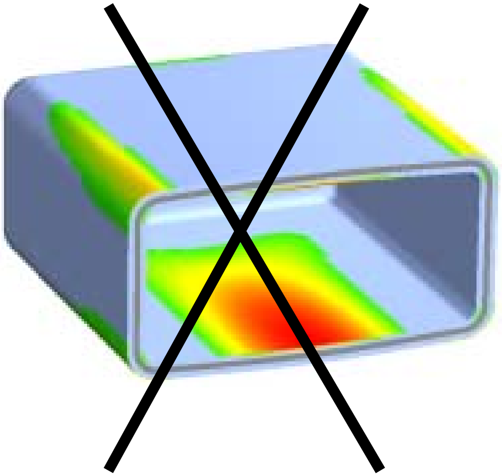
"Sandwich"construction:
Two layers of composite separated by a foam material that transmits shear stresses between the composite layers

Ribbed construction:
Ribs hold the tank together and reduce bending stresses on the composite

"bucking"construction:
uses advantageous geometry in combination with "force cancellation" to control bending



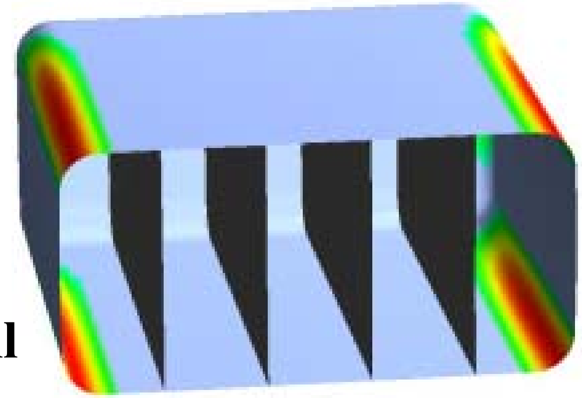
We have used FEA to evaluate and downselect conceptual designs for continuous fiber conformable vessels

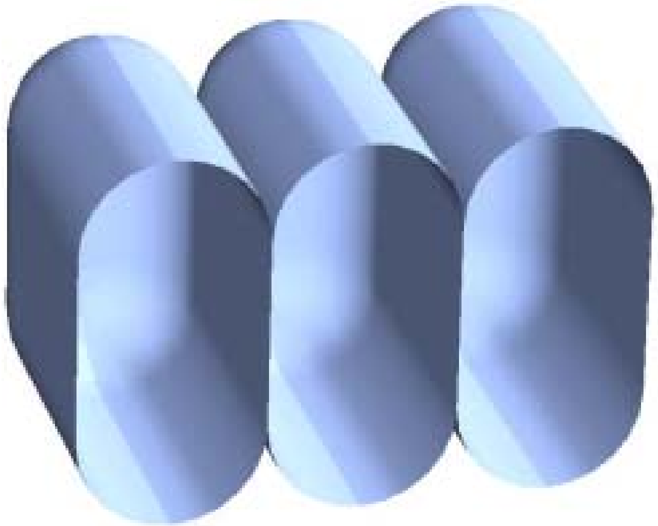


Sandwich structure does not offer clear advantages

Ribs control deflection of flat faces, considerably reducing stresses.

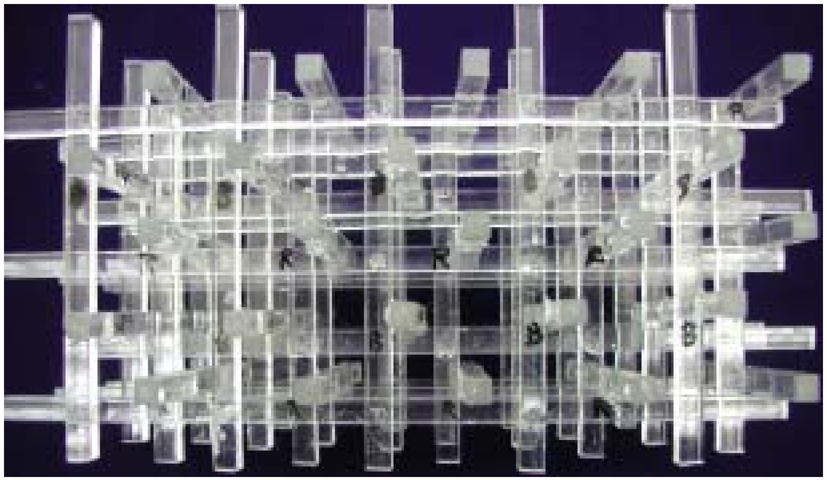
Outstanding issue is how to attach ribs to outer shell



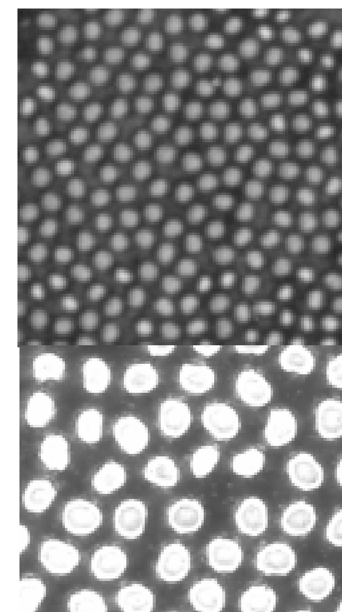


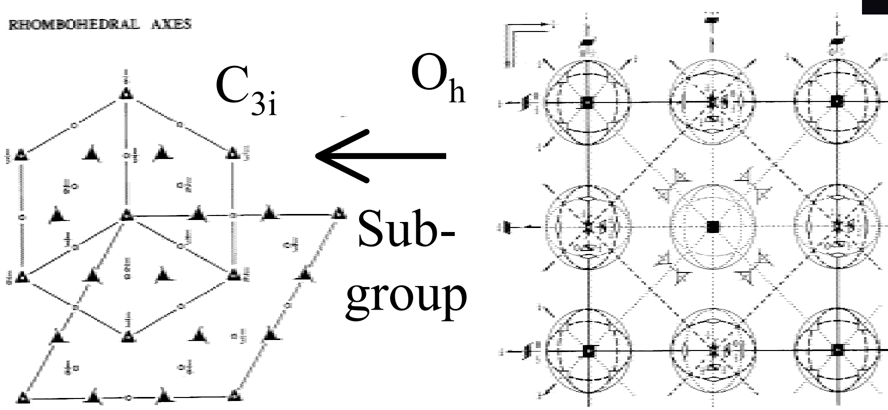
“Bucking” system is very successful in reducing bending stresses, resulting in a very homogeneous stress distribution

Technical Accomplishments and Progress
Geometries, Materials, and Performance for Replicants



Metallography prepared tensile test specimens





Lap joints in thermoplastic composite as tensile test specimens (ASTM D3039)

Found the best macro-lattice geometry for hydrogen fueled motor vehicle replicant tanks

Interactions and collaborations

- Recent CRADA with Automotive Composite Consortium (ACC) on finite element analysis of composites
- Under contract to DARPA to do advanced composite aerospace tank development
- Actively collaborating with the only composite matrix prototype firm (Spencer Composites)
- Long term collaborations with Stanford, Berkeley and Purdue on aerospace pressure vessels

Responses to reviewers' comments
Project is new, but was presented to the DOE/USCAR Technical Team

- **Pursue innovative concepts, such as cryo-compressed hydrogen**
  We are exploiting the entire phase diagram
- **Pay attention to DOE targets and how to get there**
  We are pursuing quantitative strategies in density vs. hydrogen weight fraction
- **Bring in expertise on bonding**
  We are actively working with composite matrix prototype experts
- **Work together on the two approaches to conformability to take advantage of synergies between tasks**
  Working together in analysis and planning

Future work (FY05)

Analysis

Continue conceptual analyses and begin detailed analyses
Replicant skin component modeling
Statistical performance modeling
Applied mathematics (modified group theory) of lattices

Conceptual design

Select most promising geometry for continuous fiber vessels
Engineering requirements for macrolattice components

Component testing

Begin design of component tests for continuous fiber vessels
Statistical testing to failure of replicant struts and connectors

"unique contribution and huge benefit"