Finite Element Analysis of (L)H_2 Cryogenic Capable Pressure Vessel Designs

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QuickTime™ and a TIFF (Uncompressed) decompressor are needed to see this picture.

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Introduction:

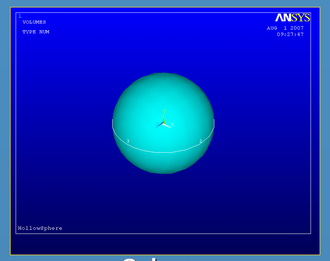
1. Cryogenic Capable Pressure Vessel

QuickTime™ and a TIFF (LZW) decompressor are needed to see this picture.

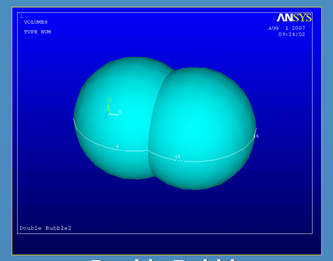
2. Hydrogen powered Toyota Prius

- There are four technologies suitable for vehicular hydrogen storage: compressed gas, metal hydride materials, carbon-based materials, and cryogenic liquid
- Each technology has a weakness: weight, volume storage efficiency, compression or liquefaction demand, or boiling loss
- LLNL's research efforts involves the usage of a cryogenic capable pressure vessel (CCPV)
- CCPV Advantages: long range, compact, eliminates LH_2 evaporation, flexible refueling

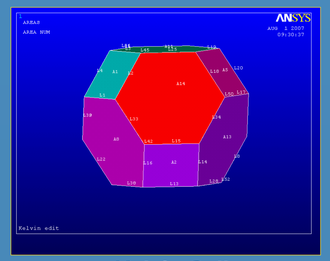
Pressure Vessel Designs:



Sphere



Double Bubble



Kelvin Cell

3. Cryogenic Capable Pressure Vessel Designs

Methodology:

- Finite element model of each design was created using Aluminum 6061 and subjected to various internal pressures
- Each model was analyzed with and without an outer carbon fiber/epoxy composite laminate layer
- A program was created to generated the elastic properties of the carbon fiber/epoxy composite laminate
- The model calculates the properties using three different micromechanics models: Rule of mixtures, Concentric cylinder, and Halpin-Tsai

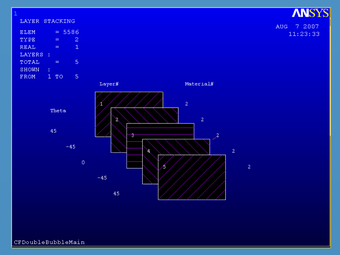
Elastic Properties Model:

T300/BSL914C composite laminate stiffness matrix

140.6233	4.6844	4.6844	0	0	0
4.6844	12.5003	4.2297	0	0	0
4.6844	4.2297	12.5003	0	0	0
0	0	0	5.5000	0	0
0	0	0	0	4.1353	0
0	0	0	0	0	5.5000

T300/BSL914C composite laminate compliance matrix

0.0072	-0.0020	-0.0020	0	0	0
-0.0020	0.0909	-0.0300	0	0	0
-0.0020	-0.0300	0.0909	0	0	0
0	0	0	0.1818	0	0
0	0	0	0	0.2418	0
0	0	0	0	0	0.1818



4. Carbon Fiber Layup

Rule of Mixtures Model

Ec11 = Ef11*Vf+Ee11*Ve
NUc12 = NUf12*Vf+NUe12*Ve
Ec22 = 1/((Vf/Ef22)+(Ve/Ee22))
Gc12 = 1/((Vf/Ge12)+(Ve/Ge12))

Concentric Cylinder Model

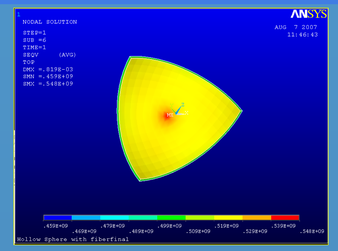
Ec11 = Ef11*Vf+Ee11*Ve+TT1
NUc12 = NUf12*Vf+NUe12*Ve+TT2
Gc12 = Ge12*(Gf12*(1+Vf)+Ge12*(1-Vf))/((Ge12*(1-Vf))+Ge12*(1+Vf))
Gc23 = Ge23*(1+(1+B1)*Vf/(P Vf*(1+3*(B1^2)*(Ve^2)/(A*(Vf^3)+1))))
Ec22 = 4/(1/Gc23+1/Kc23+4*(NUc12^2)/Ec11)
NUc23 = Ec22/(2*Gc23)-1

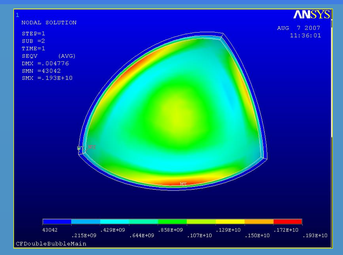
Halpin-Tsai Model

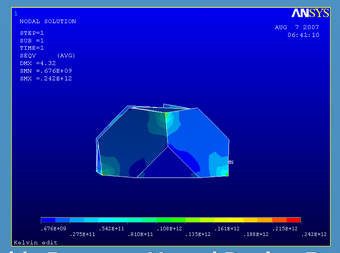
Ec11 = Ef11*Vf+Ee11*Ve
NUc12 = NUf12*Vf+NUe12*Ve
Gc12 = Ge12*(1+EPS_G12*ETA_G12*Vf)/(1-ETA_G12*Vf)
Ec22 = Ee22*(1+EPS_E22*ETA_E22*Vf)/(1-ETA_E22*Vf)
Gc23 = Ge23*(1+EPS_G23*ETA_G23*Vf)/(1-ETA_G23*Vf)

Results:

- Due to the symmetry of the pressure vessel designs, full models of the designs were not required to properly analyze each design.
- The spherical design experienced the least stress of all the designs with or without carbon fiber
- The Kelvin Cell design experienced the most stress and displacement at 5000 psi
- The usage of carbon fiber on the designs reduced the stress experienced by each pressure vessel.



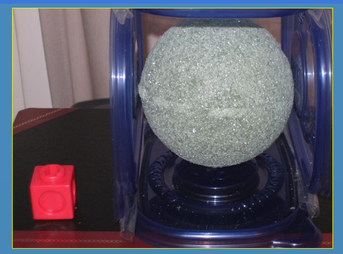




5. Cryogenic Capable Pressure Vessel Design Results with carbon fiber

Discussion:

- The kelvin cell design has excellent packing characteristics, but it fails at high pressures
- The usage of a different material such as stainless steel 304 could increase the kelvin cell design resistance to failure
- The double bubble design uses the least area to enclose two equal volumes
- At 5000 psi, the carbon fiber wrapped spherical vessel design's von mises stress was 28.394% less than the double bubble
- Given the stress experienced by the spherical design, it is feasible to create a modular cubic cryogenic capable pressure with a spherical inner vessel and a cubic vacuum outer jacket.



6. Cubic Cryogenic Capable Pressure Vessel

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