Pressure Vessel Technology Developments

4th International Planetary Probe Workshop
Pasadena, CA

Mike Pauken, PI
Elizabeth Kolawa, Ram Manvi, Witold Sokolowski, Joseph Lewis

June 29, 2006

Outline

- Why Pressure Vessels Need Development
- Historical Perspective
- Design Guidelines
- Some Candidate Materials
- Material Down-Selection
- Various Manufacturing Methods
- Moving Forward

Why Pressure Vessels Need Development

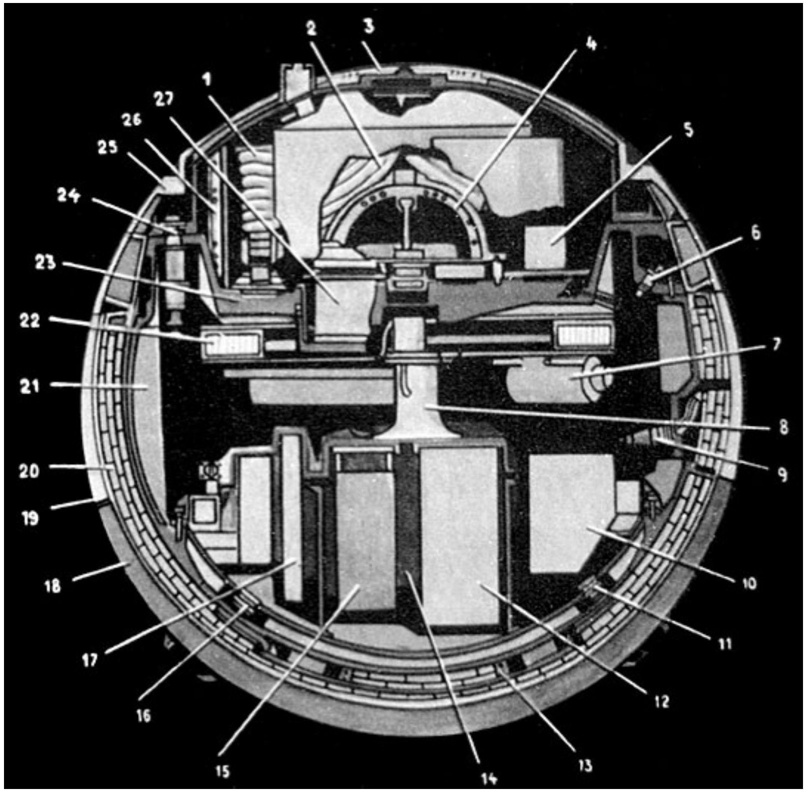
- Decadal Survey identifies Venus Lander, Jupiter Deep Probes as 2 of 6 highest priority missions
- Present state-of-the-art pressure vessel technologies are not adequate for the mass requirements of these missions
- The pressure vessel represents one of the single largest mass elements in a Venus Lander or Deep Atmospheric probe
- It appears that pressure vessel mass could be reduced by up to 50% of a Titanium shell

Historical Perspective

- Soviets began Venus exploration program with launch of Venera 1 in 1961. Program ended in 1984 with VEGA 1 and 2.
- NASA launched Pioneer Venus Probes in 1978

Mission	Launch Year	Pressure Rating
Venera 3	1965	5 bar
Venera 4	1967	20 bar
Venera 5,6	1969	25 bar
Venera 7	1970	150 bar Titanium
Venera 8-14	1972-1981	100 bar Titanium
Pioneer Large Probe	1978	100 bar Titanium
Pioneer Small Probe	1978	100 bar Titanium

Venera 5 Descent Module

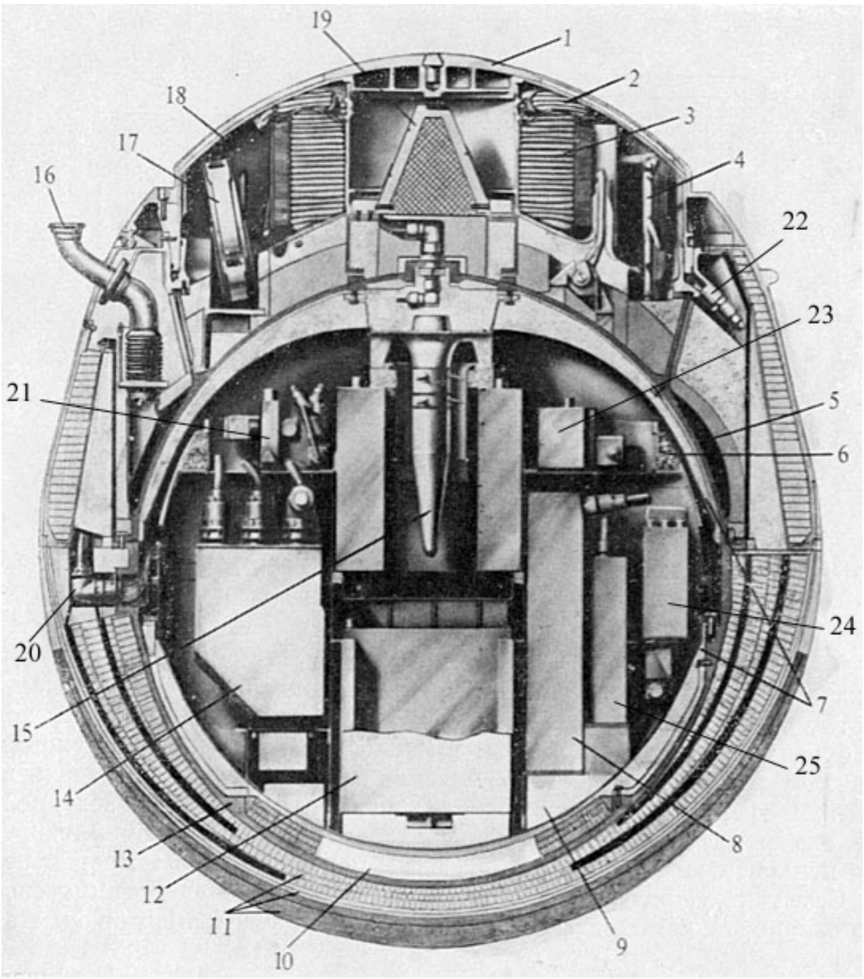


All systems, including instruments, were protected by pressure vessel and passive thermal control

The layout of the Venera-5 descent vehicle:

1. drogue parachute
2. main parachute
3. explosive bolts of cover
4. transmitter antenna
5. gas density gauge
6. grooving charge valve
7. dehumidifier
8. circulation fan
9. electrical umbilical
10. commutation unit
11. accelerometer
12. transmitters
13. anti-vibration damper
14. power unit
15. onboard transmitter
16. accelerometer
17. program timing unit
18. heat shielding
19. heat shielding
20. external insulation
21. internal insulation
22. temperature control system
23. lid of instrument compartment
24. explosive bolt
25. cover of parachute compartment
26. radio altimeter antenna
27. gas analyzer

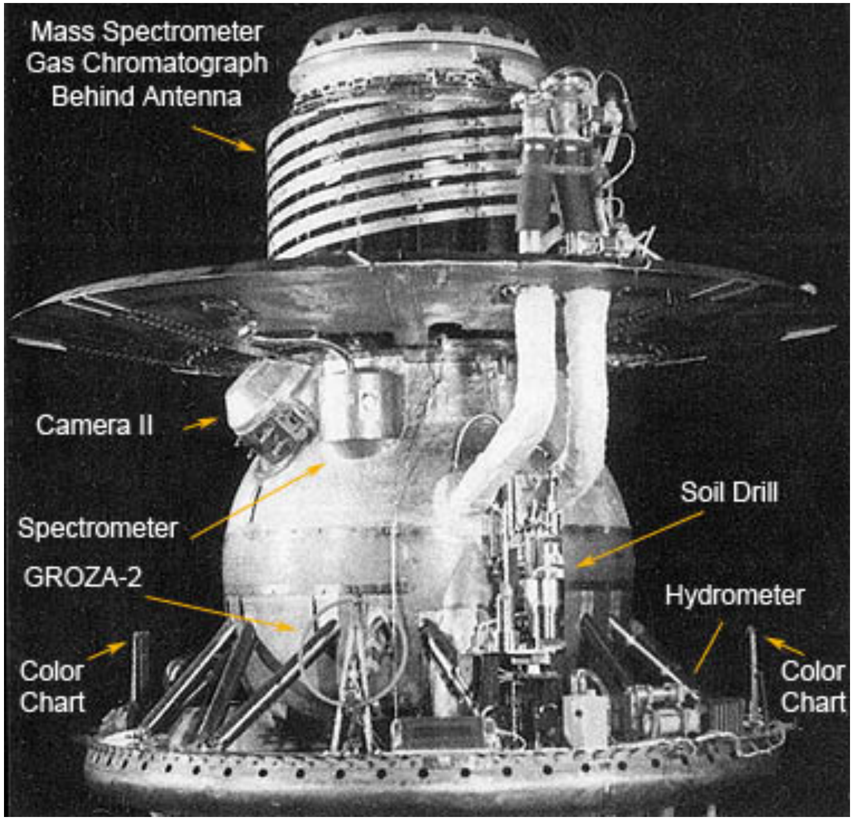
Venera 8 Descent Module



Venera 8 descent module:

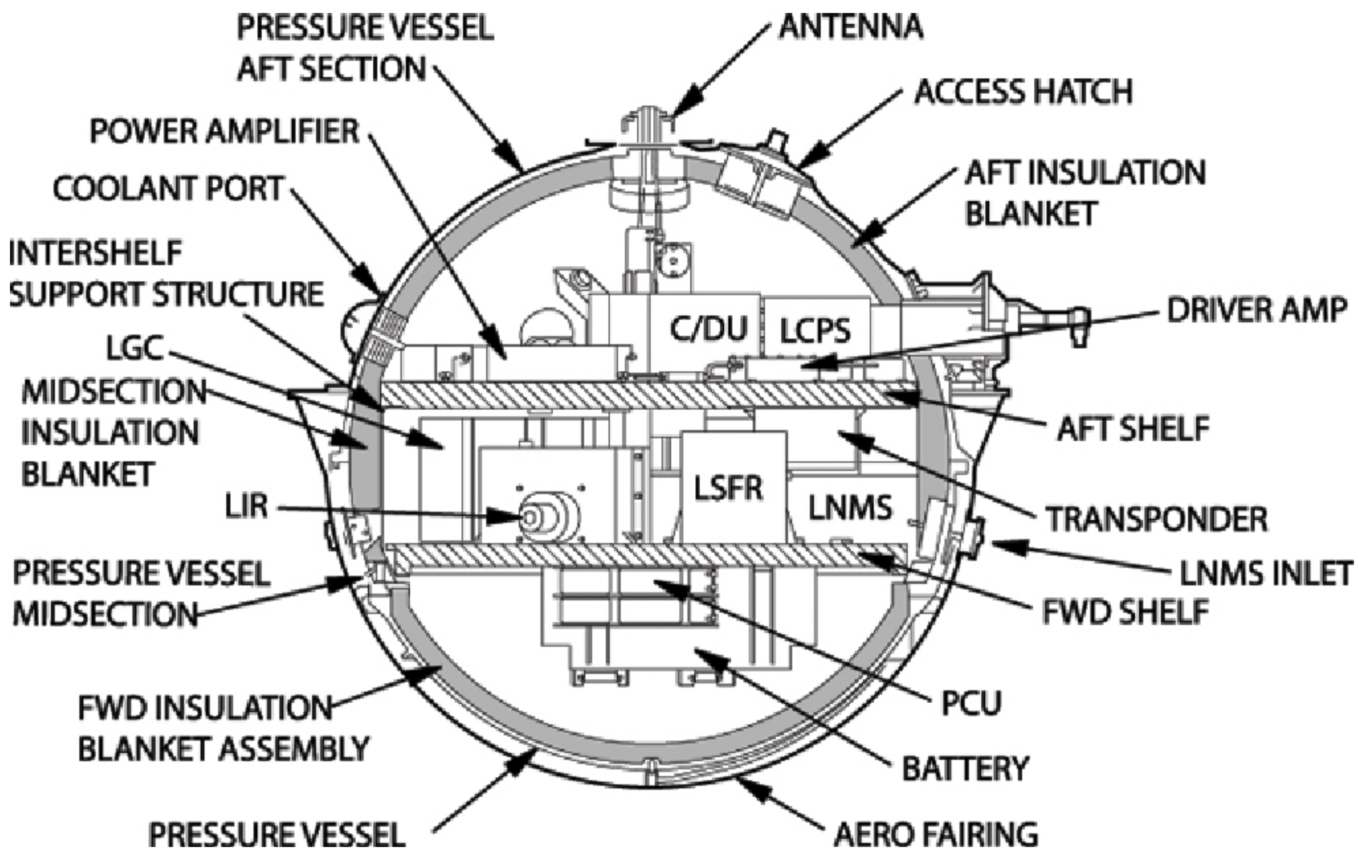
1. cover of parachute housing
2. drogue parachute
3. main parachute
4. altimeter antenna
5. heat exchanger
6. heat accumulator
7. internal thermal insulation
8. program timing unit
9. heat accumulator
10. shock absorbing damper
11. external thermal insulation
12. radio transmitter
13. spherical instrument compartment
14. commutation unit
15. circulation fan
16. cooling conduit from bus
17. ejectable secondary antenna
18. parachute housing
19. primary antenna
20. electrical umbilical
21. antenna feeder system
22. explosive bolts of cover
23. telemetry unit
24. stabilized quartz oscillator
25. commutation unit

Venera Instruments



Venera 13. A number of instruments were placed outside the pressure vessel.

Pioneer Venus Probe



Pioneer Venus Large Probe inside view of pressure vessel.

Pressure Vessel Design Guidelines

- Buckling @ ultimate load of 150 atm pressure and 500ºC
  - –use standard NASA specified knockdown factor of 0.14 for pressure vessels (0.3 is commonly used in industry).
- Yielding @ proof load of 125 atm pressure at 500ºC.
- Creep at 500ºC limit allowable total strain at 10 hours to 0.5%.
- Impermeable to gases
- Low thermal conductivity at 500ºC
- Compatible with Venus environment

Required Material Properties at Temperature

- Tensile/compressive yield strength
- Tensile elongation
- Shear strength
- Tension/compression modulus
- Fracture toughness
- Thermal conductivity
- Specific heat capacity
- Thermal expansion
- Creep rupture time
- Creep rate (in compression/bending)

Some Candidate Materials

- Metallic materials:
  - Titanium: Ti-6Al-4V alloy and Beta S
  - Nickel-chromium alloys: Inconel 718, Inconel X or Haynes 230
  - Nickel-chromium-cobalt alloys: Haynes 188
  - PH stainless steels: 17-7 PH or 15-5 PH
  - Beryllium I-220H
- Advanced composite materials:
  - SiC reinforced titanium matrix composites
  - B fiber reinforced titanium matrix composites
  - Inorganic Sialyte based composite
  - Aluminum/Sapphire and aluminum/silicon carbide metal matrix composites
  - Polymer Matrix Composite

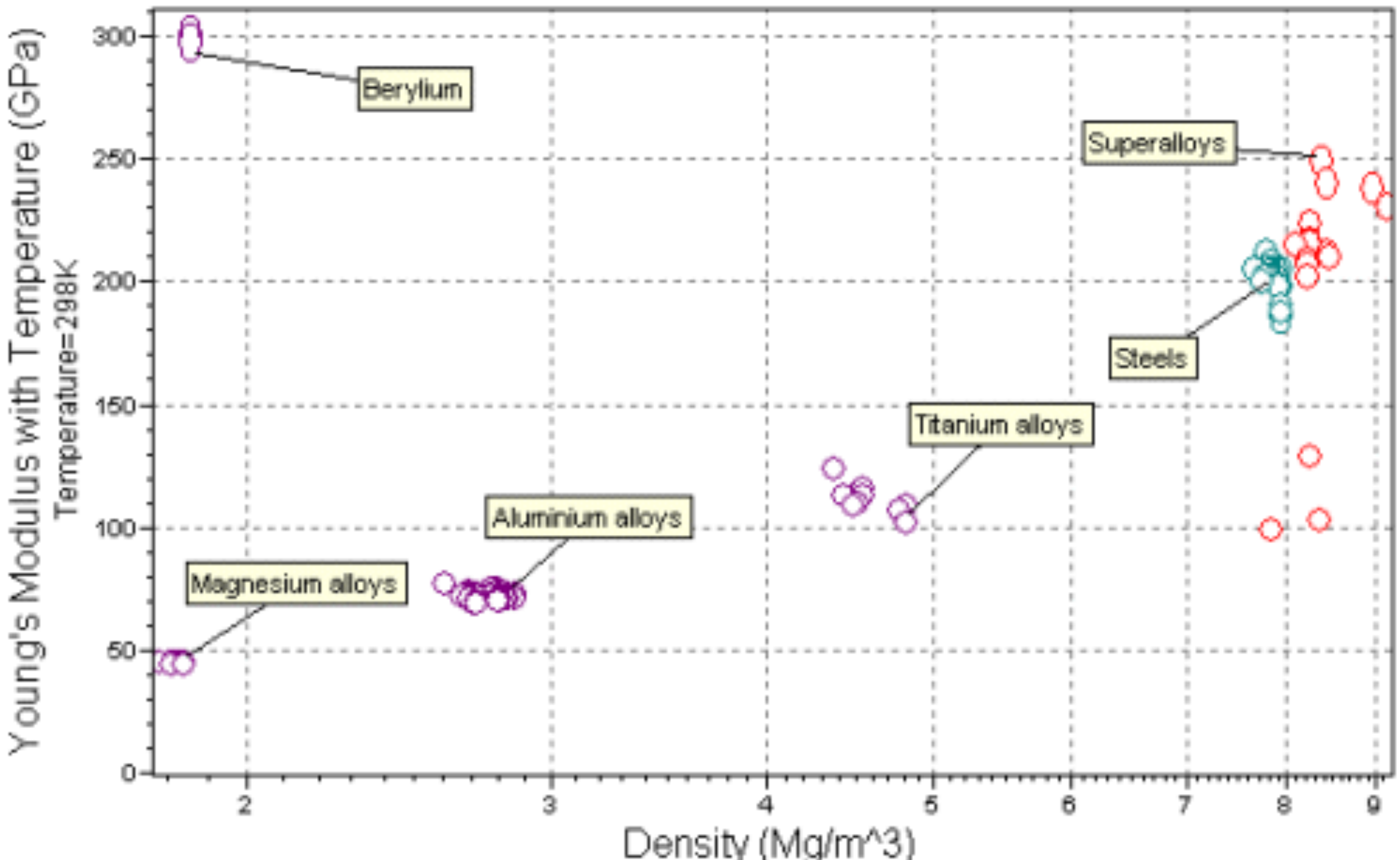
Material Down-Selects

- Inconel 718: best performance in both creep and tensile property comparisons
  - primary metallic candidate for the pressure shell using honeycomb structure.
- Ti-6Al-4V: second best performer in creep and tensile comparisons also has low thermal conductivity.
  - State-of-the-art material on previous missions with monolithic shell.
- Haynes 188 has superior creep properties at high temperature. Performs best in 900C to 1100C range. At 500C it is no better than Inconel 718. Haynes 188 was not retained for further consideration.

Material Down-Selects

- 15-5 PH showed reasonable creep properties at 500C, but creep resistance falls very rapidly above 500C leaving little margin. 15-5 PH was not retained for further consideration.
- Creep data was not available for 17-7 PH. However it is not expected to perform significantly better than 15-5 PH and was not retained for further consideration.
- SiC/Ti matrix composite has superior strength/density performance compared to other materials. Creep resistant at 500C.
- Beryllium is lightweight and has high elastic modulus, high thermal conductivity and high specific heat and low creep resistance in tension.

Material Down-Selects



Young's Modulus against density for various materials at room temperature. At 500C the Magnesium and Aluminum alloys drop out.

Various Manufacturing Methods

TYPICAL HONEYCOMB FABRICATION

- Facesheets
  - Bulge-form Beta S titanium or Inconel 718 sheet to hemispherical shape.
- Honeycomb
  - Corrugate Beta S titanium or Inconel 718 sheet.
  - Diffusion bond corrugated sheet to form honeycomb block.
  - Slice honeycomb to desired thickness.
  - Bulge-form honeycomb to hemispherical shape.
- Assembly
  - Assemble facesheets, TICUNI braze alloy or BNi-8 alloy, and honeycomb in hemispherical braze fixture
  - Vacuum furnace braze assembly.

Bulge Form Tooling

Vacuum Braze Furnace

Various Manufacturing Methods

Composite Wrapped Tanks

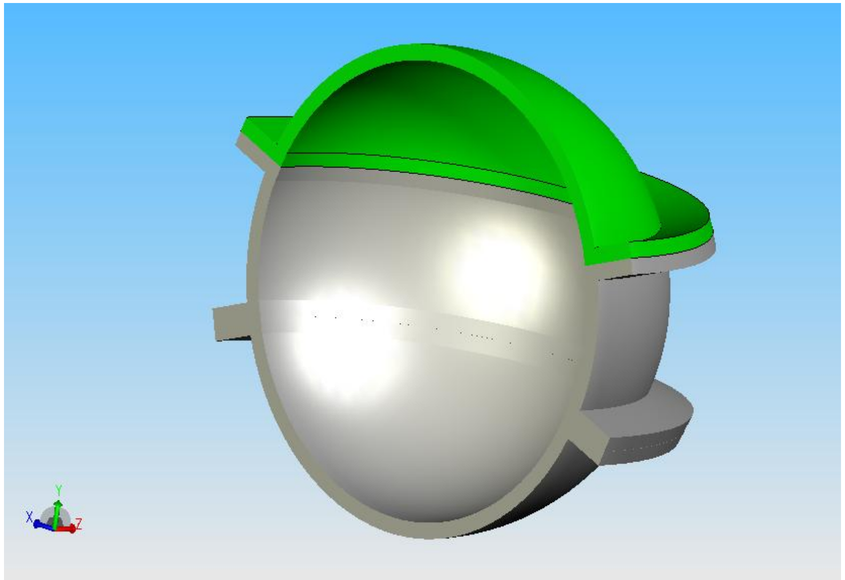
- Composite tanks using Aluminum/Sapphire or aluminum/silicon carbide or Polymer Matrix Composite
- Wrap matrix runs through wet adhesive such as molten aluminum or epoxy.
- Wetted matrix is wrapped around mandrel.
- Composite wound tank is cured at elevated temperature.
- Need to work out details of adding flanges, view ports, feed-throughs etc.

Linerless Composite Tanks by Composite Technology Development Inc.

Various Manufacturing Methods

Monolithic Shells

- Titanium or Beryllium can be fabricated into monolithic shells.
- Titanium hemispheres can be shaped using spin forming.
- Flanges, windows, feed throughs, brackets etc can be welded onto the shell.
- Beryllium hemispheres must be machined from billets.
- Flanges, windows etc must be machined into parent shell out of the original billet



Cut-Away sectional view of 3 piece monolithic shell

Moving Forward

- Develop more detailed manufacturing engineering plans for leading candidate materials.
- Estimate comparative fabrication costs for the different manufacturing technologies.
- Obtain samples/prototypes of shells from leading candidate materials.
- Perform testing on prototypes under Venus-like environmental conditions for temperature and pressure for survivability.