Venera Intrepid Tessera Lander (VITaL)

Alex Ren and Luke Moon

Overview

- VITaL Mission Overview
- Venus Tessera Environment
- Problem Definition
- Analysis
- Failure prediction

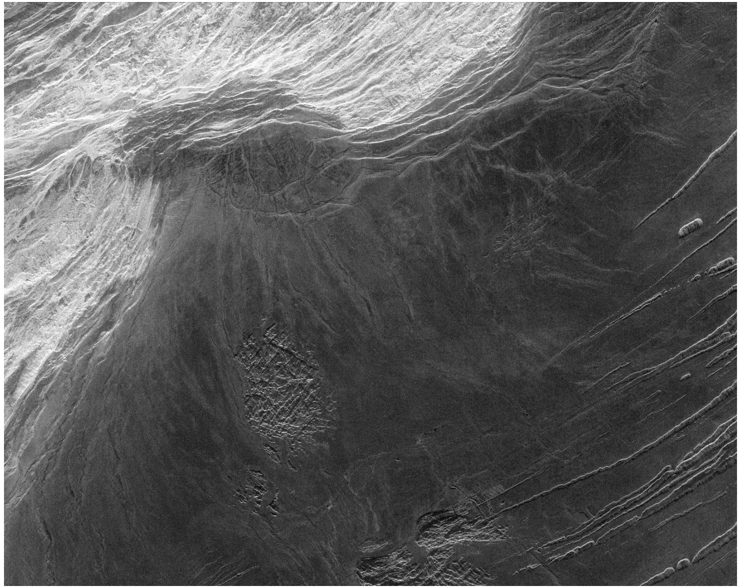
VITal Mission Overview

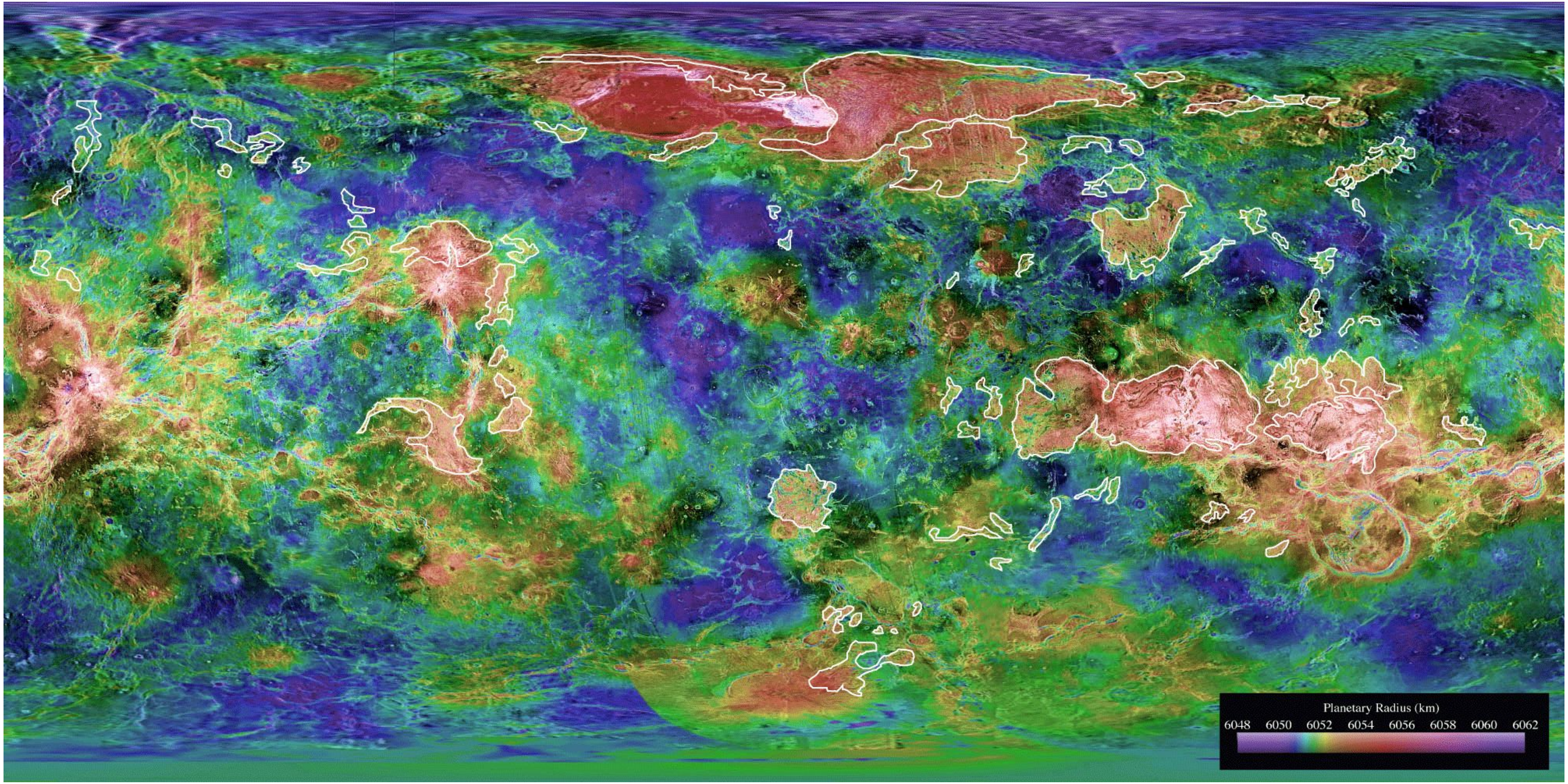
VITaL Mission Goal

- Venera Intrepid Tessera Lander
  - Proposed lander for Venus missions
- Part of proposed ADEPT series of vehicles for interplanetary missions
- Aimed to cover two goals
  - Collect Tessera region samples
  - Collect Venus atmosphere samples

Venus Tessera

- Tectonically deformed regions with unclear formation method/model
- Tessera regions are consistently found to contain the oldest surface materials
  - High chance of accessing rocks from the first 80% of planet's history
- Mission looks to obtain samples from tesserae region

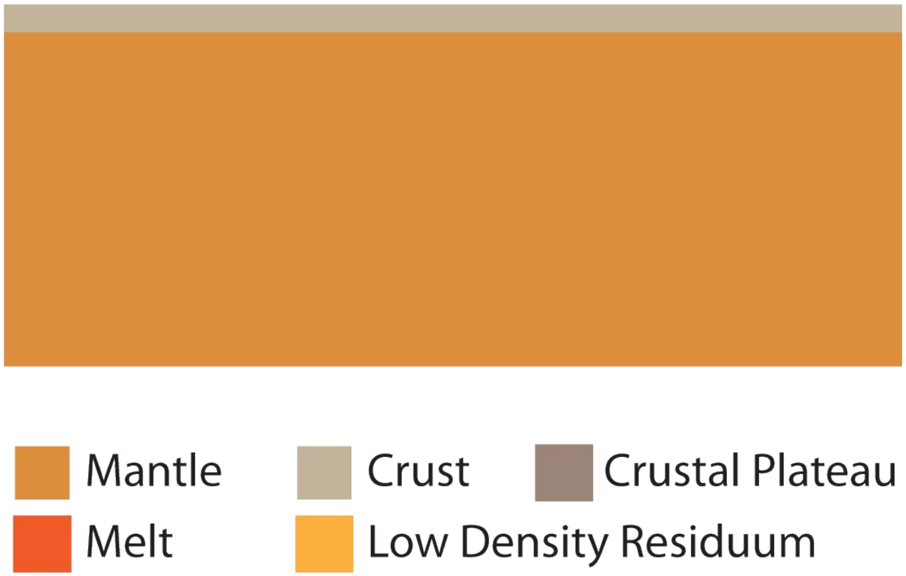




Tessera Interpretive Heatmap

“High” Definition Recreation

Lava Pond vs Giant Impact



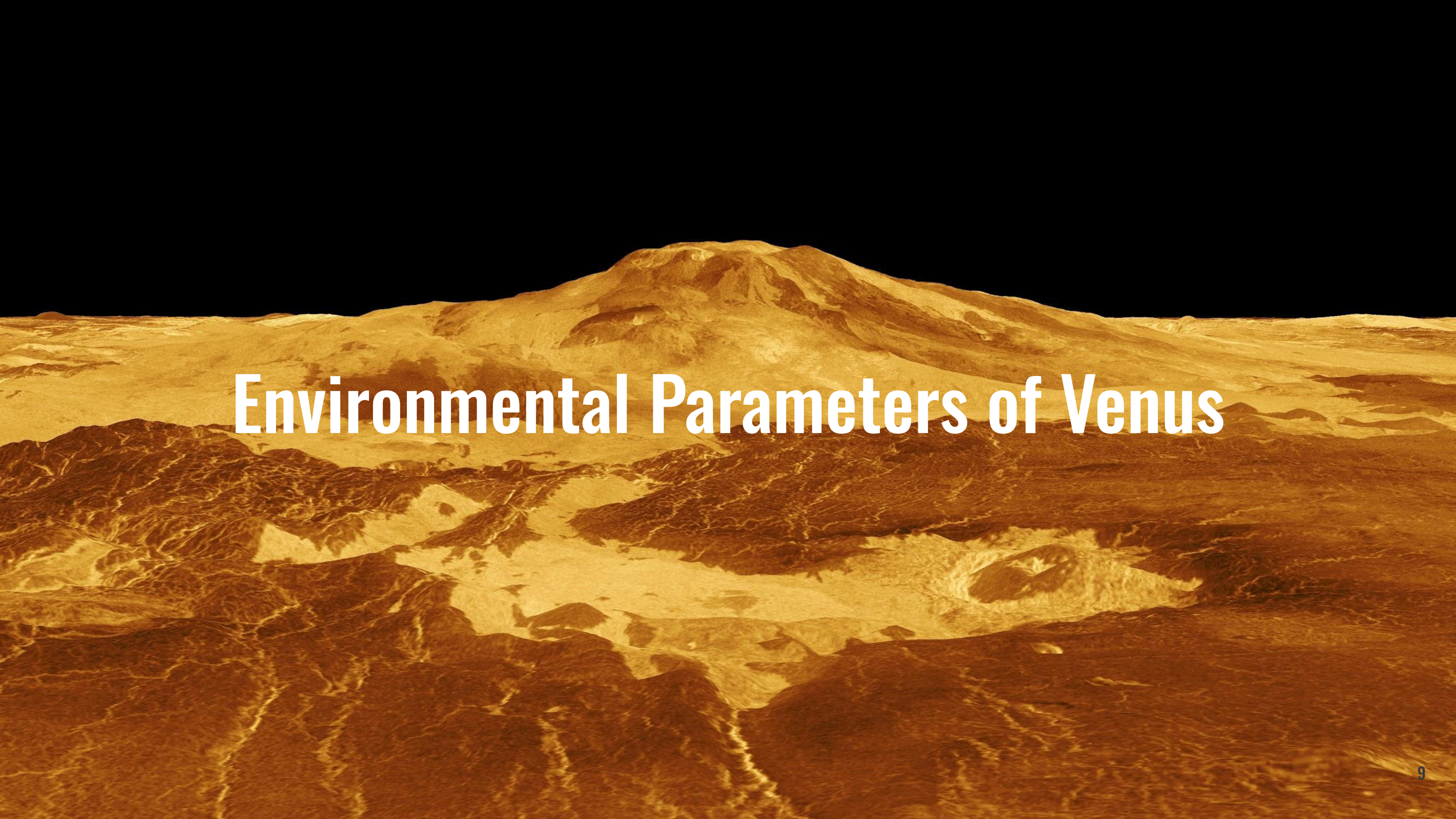
Atmospheric Samples

- Compositional measurements
  - Trace/Noble gasses and isotopes

- Physical parameters
  - Pressure
  - Temperature
  - Wind velocity

- Objective: Improve understanding of surface-atmosphere interactions

Environmental Parameters of Venus

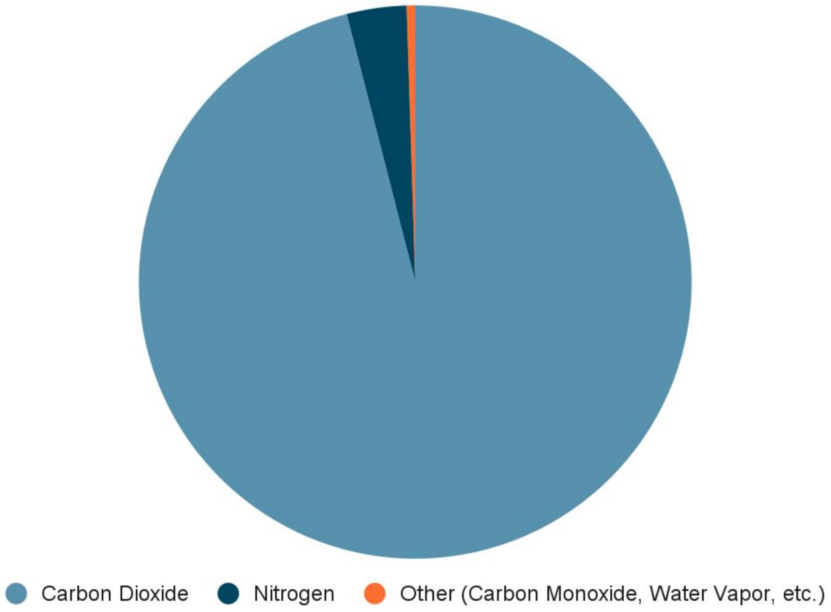


Extreme Temperatures and Pressures

- Average surface temperature of Venus: 467C
- Average surface pressure of Venus: 92 atm
- Estimated temperature in tessera region: 447C
- Estimated pressure in tessera region: 80 atm

Corrosion

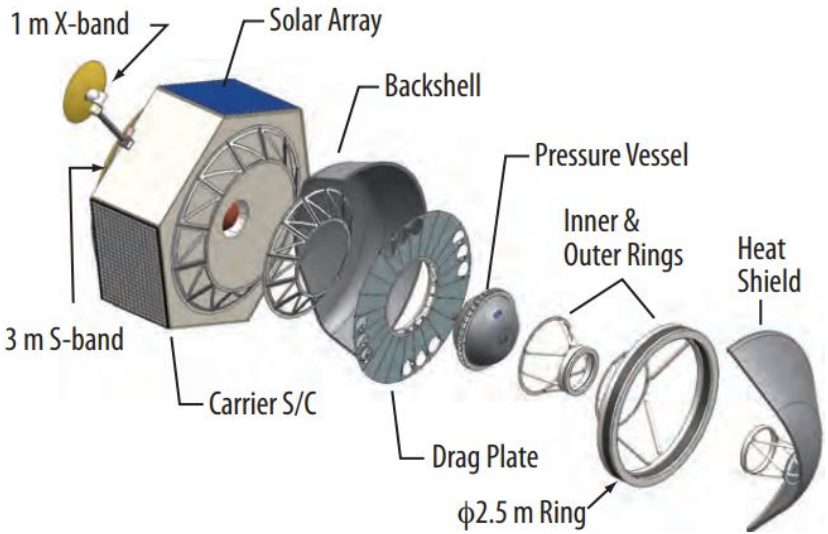
Gas Type	Percentage
Carbon Dioxide	96
Nitrogen	3.5
Carbon Monoxide	<1
Water Vapor	<1
Argon	<1
Sulfur Dioxide	<1



Problem Definition

Lander Design

- Pressure vessel is enclosed in heatshield and impact rings to reduce entry heat or impact damage



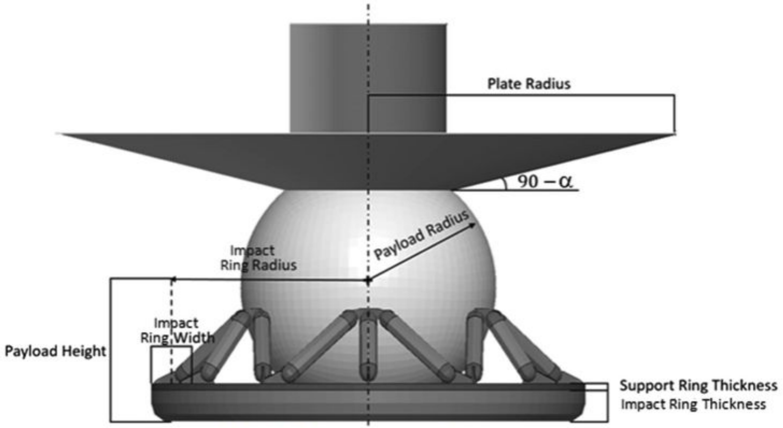


Fig. 4 Primary geometrical design variables.

Pressure Vessel Design from Proposal

- Three shell layers
- Cylindrical cupola
- Extending struts
- Two layers of insulation
- Three windows for camera views
  - Inner and outer window for thermal protection

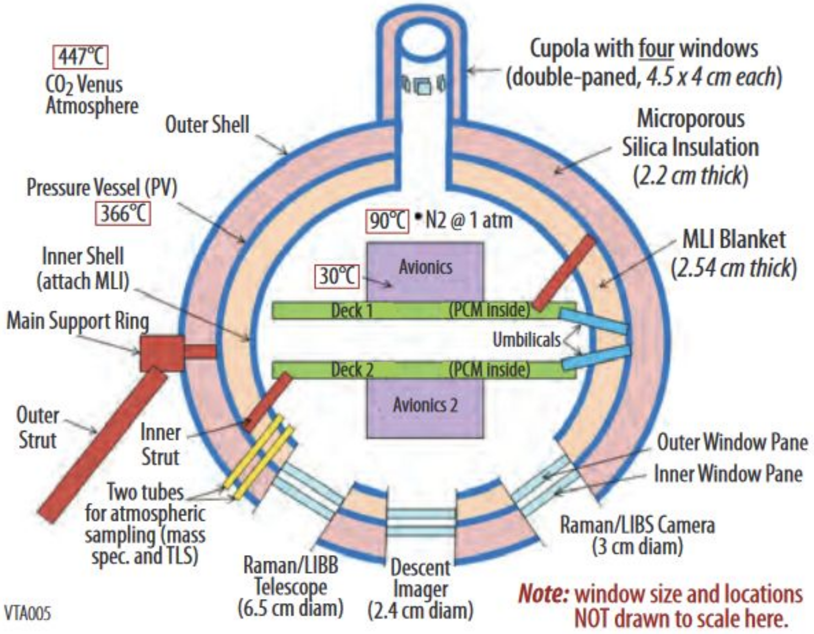


Figure 19: Thermal sketch of lander

Pressure Vessel Dimensions

- Pressure vessel is 0.747 meters diameter
- Thickness is determined by material
- Safety factor of 1.4
- Window dimensions
    - Diameters of 6.5cm, 2.4cm, and 3cm
    - Minimum thickness determined through calculation

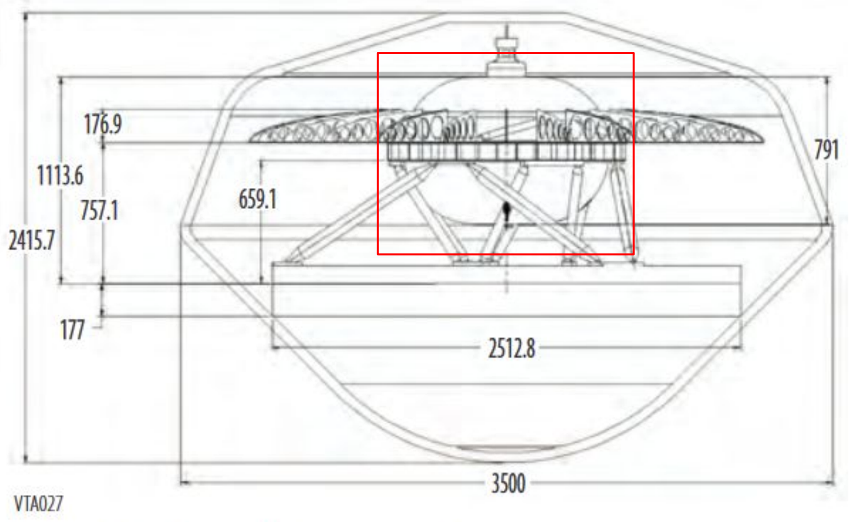
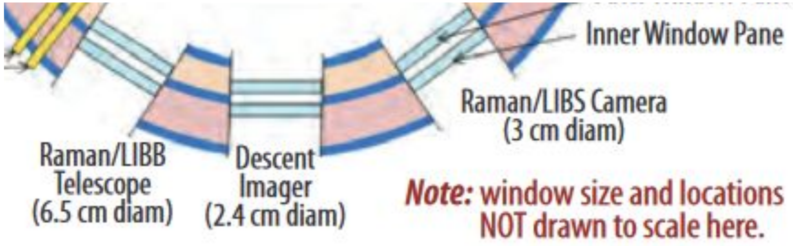
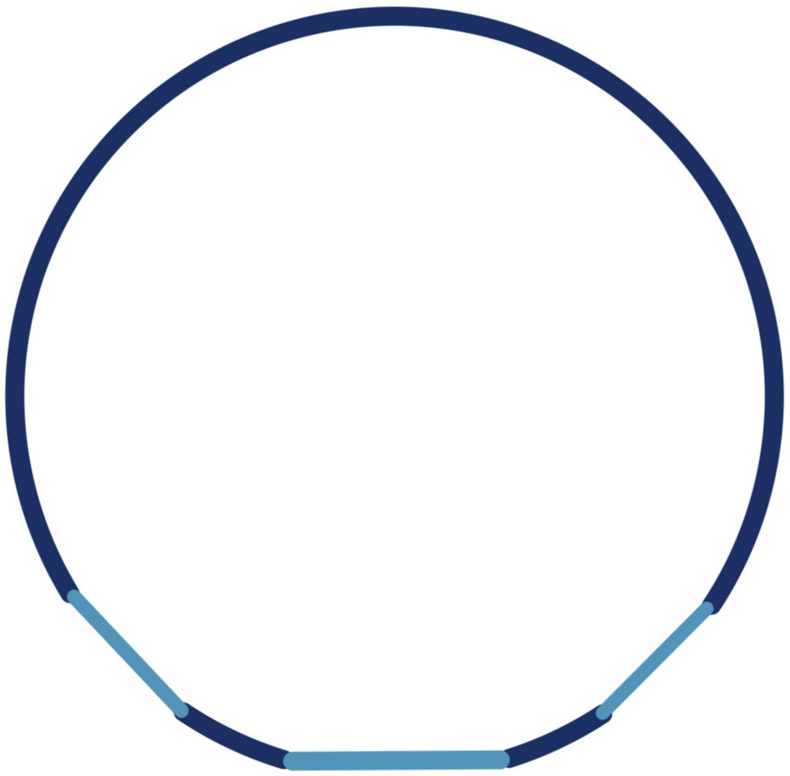


Figure 10: Aeroshell Dimensions (in mm)



Simplified Pressure Vessel Design

- Single shell
  - Assume spherical
- Three windows
  - Single pane
  - No discontinuity between window and shell
  - Windows made of sapphire

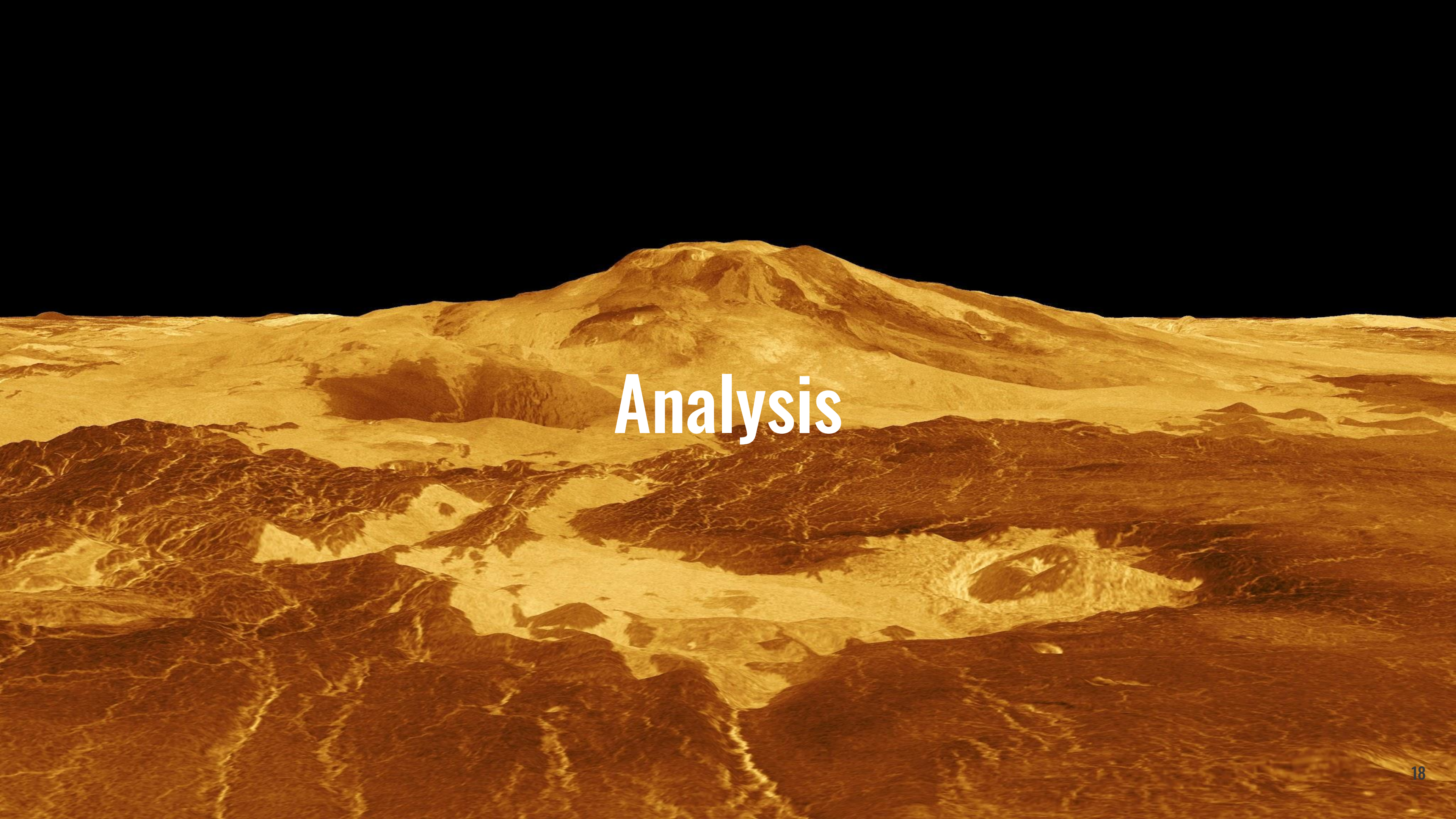


Not to scale

Objectives

- Review potential pressure vessel materials
- Determine required pressure vessel thickness and deflections for each material
- Determine required window pane thickness and deflection

Analysis



Pressure Vessel Materials Survey

Table 3 Material results after exposure to simulated Venus atmosphere

Material	Outcome
Ti	Thin surface oxide; no further reaction
Ti-6Al-4 V	Thin surface oxide; no further reaction
Mo	Thin surface sulfide/oxide layers; no further reaction
Cr	Thin layers of sulfide, carbide, and oxide
Co	Co_xS_y crystals
Pd	PdS layers form and peel off
Zr	Porous ZrO_2 throughout sample
Nb	Nb_2O_5 and disintegrates
Ta	Ta_2O_5 layers that flake off
W	WO_3 layers that peel off

Analysis Method: Pressure Vessel

- Assume thin-walled spherical pressure vessel
- Determine the minimum thickness for the vessel to prevent failure
  - Multiply by safety factor of 1.4
- Calculate displacement due to pressure
- Select a material based on mass

$$\sigma = \frac{(P_i - P_o)r}{2t} \qquad u_r = \frac{(P_i - P_o)r^2(1 - \nu)}{2Et}$$

Pressure Vessel Analysis

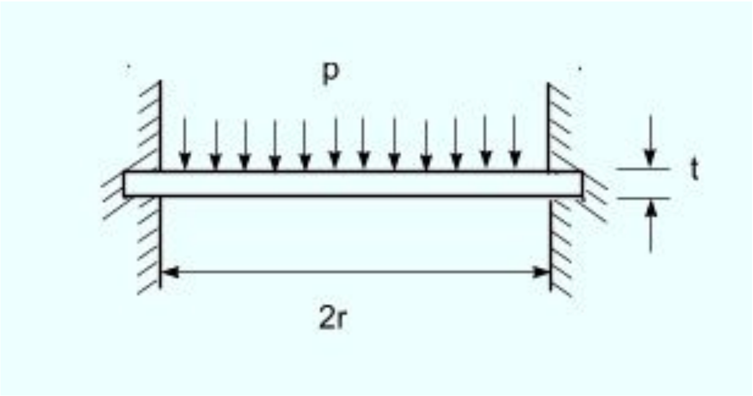
Material	Min. Thickness (mm)	Displacement (mm)	Mass (kg)
Ti (Titanium)	9.5	-0.33	73.1
Ti-6Al-4V (Titanium Alloy)	2.1	-1.5	16.7
Mo (Molybdenum)	4.8	-0.24	84.9

Pressure Vessel Design

- Based on the significantly lower mass of a Ti-6Al-4V vessel, Ti-6Al-4V was chosen as the material
- Due to the large deflection compared to the vessel thickness, the safety factor was adjusted.
- With a safety factor of 5, the resulting thickness is 7.7mm with a -0.41mm displacement.
    - Mass is still less at 58.6kg

Analysis Method: Window

- Bending of thin circular plate
- Uniform load with clamped edges
- Determine maximum allowable stress for sapphire material
- Derive equation for maximum stress in window
- Calculate minimum thickness of window



Window Pane Analysis

- Determine stress-strain relation

$$\begin{bmatrix}\sigma_{rr}\\ \sigma_{\theta\theta}\\ \sigma_{zz}\\ \sigma_{\theta z}\\ \sigma_{rz}\\ \sigma_{r\theta}\end{bmatrix} = \begin{bmatrix} 397.41 & 94.95 & 57.50 & 11.50 & 0 & 0\\ 94.95 & 397.41 & 57.50 & -11.50 & 0 & 0\\ 57.50 & 57.50 & 334.36 & 0 & 0 & 0\\ 11.50 & -11.50 & 0 & 103.46 & 0 & 0\\ 0 & 0 & 0 & 0 & 103.46 & -11.50\\ 0 & 0 & 0 & 0 & -11.50 & 151.23 \end{bmatrix} \begin{bmatrix}\varepsilon_{rr}\\ \varepsilon_{\theta\theta}\\ \varepsilon_{zz}\\ \varepsilon_{\theta z}\\ \varepsilon_{rz}\\ \varepsilon_{r\theta}\end{bmatrix}$$

*GPa

- Determine minimum thickness

$$\sigma_{rr}\big|_{z=h,r=a} = \frac{3qa^2}{16h^2} = \frac{3qa^2}{4H^2}$$

$$t_{rr} = 0.0048\,m$$

$$t_{\theta\theta} = 0.0013\,m$$

Window Pane Analysis

- Determine max displacement

$$w(r) = -\frac{q}{64D}(a^2 - r^2)^2$$

$$w_{z,max} = -0.00004\ m$$

$$D = \frac{Et^3}{12(1 - v^2)}$$

- Determine strain values

Out[11]//MatrixForm=

$$\begin{pmatrix} 0.000698222 \\ 0.0000417236 \\ -0.000127249 \\ -0.0000729725 \\ 0. \\ 0. \end{pmatrix}$$

Failure Prediction

Potential Sources of Failure:

- Camera windows
  - Lower factor of safety means this is most likely to be source of failure
- Corrosion
  - Corrosion in pressure vessel can weaken structure and lead to failure or break hermetic seal
- Landing Impact
  - Improper landing can lead to puncturing of pressure vessel

References

[1] https://www.nature.com/articles/s41467-020-19336-1

[2] http://photojournal.jpl.nasa.gov/catalog/PIA00241

[3] https://en.wikipedia.org/wiki/Tessera_(Venus)

[4] pdf (iop.org)

[5] Venus' Atmosphere: Composition, Climate and Weather | Space

[6] https://arc.aiaa.org/doi/pdf/10.2514/1.A34617

[7] Spherical Pressure Vessel - Radial Displacement (structx.com)

[8] Titanium, Ti (matweb.com)

[9] ASM Material Data Sheet (matweb.com)

[10] Structural Sizing and Synthesis of Venera-Class Landers (aiaa.org)

[11] http://ia800304.us.archive.org/35/items/VenusIntrepidTesseraLanderConceptStudy/03_Venus_Intrepid_Tessera_Lander.pdf

[12] Schott Sapphire Optical Window (matweb.com)

[13] https://dcc.ligo.org/public/0027/T030228/000/T030228-00.pdf

[14] Microsoft Word - 06_PlateTheory_01_PlateTheory.doc (auckland.ac.nz)