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Venus Lander Design

Garon Morgan
Virginia Commonwealth University

Brian Rodrigues
Virginia Commonwealth University

Dhruv Sachani
Virginia Commonwealth University

Jason Scott
Virginia Commonwealth University

MECHANICAL & NUCLEAR ENGINEERING

Venus Lander Design

MNE 510 **Team members:** Garon Morgan, Brian Rodrigues, Dhruv Sachani, and Jason Scott | **Faculty adviser:** Mr. James G. Miller | **Sponsor:** NASA | **Sponsor adviser:** Dr. Juan R. Cruz

CAPSTONE DESIGN EXPO 2017

The Mission

The students were tasked to design an Entry, Descent, and Landing (EDL) system for a lander to reach the surface of Venus. The project's design requirements included specified landing location, maximum acceleration, time of descent, etc. Using a combination of 3D modelling and programming the students designed the EDL within given constraints under specific tolerances.

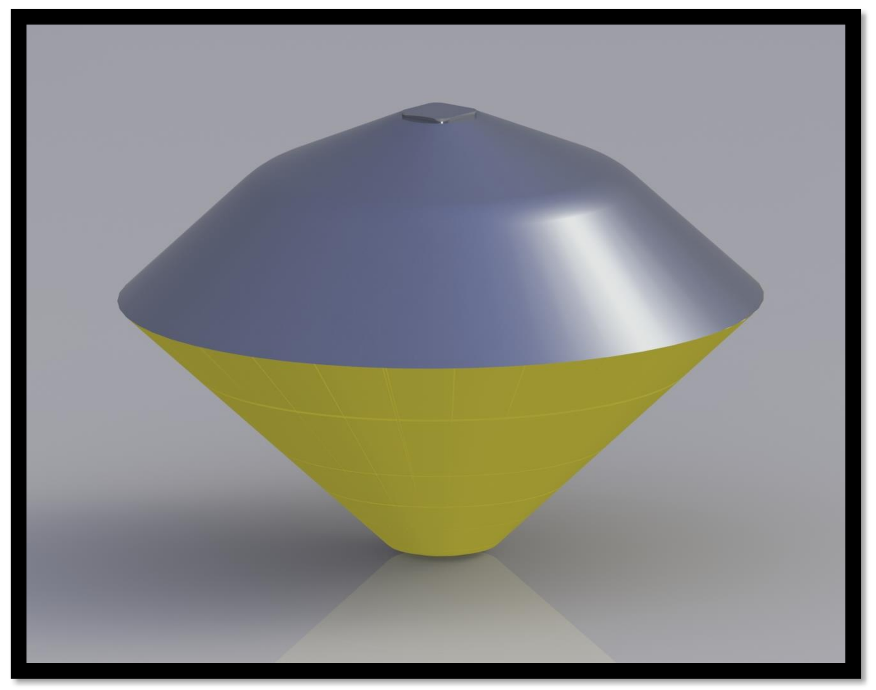

Figure 1: The graphic above is a rendered image of the aeroshell (the casing that protects a payload during re-entry). The yellow region is made of carbon phenolic, a material used to support the large heat load.

Inspiration

Lander missions to any planet can provide useful insights. One potential insight that could be gained by studying Venus is a deeper understanding of the runaway greenhouse effect. This understanding could be critical in the mitigation of a similar fate on Earth.

Environmental Challenges

Exploring Venus poses many challenges, such as extremely high pressures (~90 Earth atmospheres at the surface), high temperatures (>450 C), volcanic activity, sulfuric acid clouds, uneven terrain, etc.

The Plan

The team decided to break the descent into three phases (as seen in the graphic below). In order to understand how the motion through the atmosphere takes place, the lander's descent through the atmosphere was modeled by a set of six simultaneous differential equations.

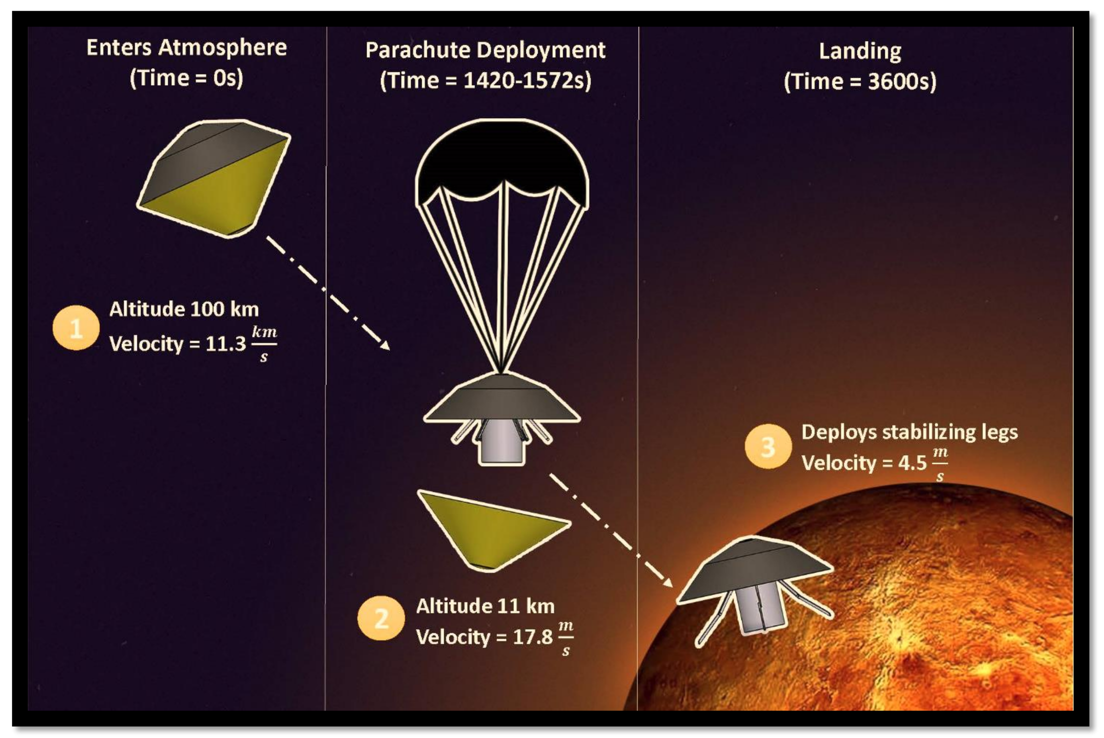

Figure 2- Design of Operation: For Stage 1 (entry), the physics model considered the weight of the entire vessel, and aerodynamic values associated with the geometry of the heat shield (yellow section). During Stage 2 a parachute is released, and the subsequent drag force removes the heat shell. Thus, only the back shell of the aeroshell is considered in the model. During Stage 3 the parachute is removed and the lander reaches the surface.

The State Variables

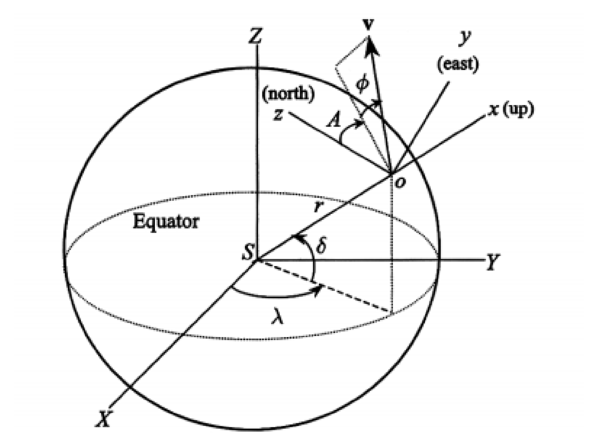

Fig. 12.1. Planet-fixed and local horizon frames for atmospheric flight.
(Source: Tewari, p. 285)

State Variables

v	planet-relative velocity
ϕ	flight path angle with respect to the local horizontal; positive above the horizon
A	flight path angle with respect to north (positive clockwise)
r	geocentric radius
δ	latitude (positive north)
λ	longitude (positive east)

The Simulation

Since all six state variables (velocity, radius, pitch, yaw, latitude and longitude) are dependent on each other, they must be solved simultaneously at each stage, at each time step. The size of the time step will determine the accuracy of the model. The following plots were obtained to highlight key features of the EDL:

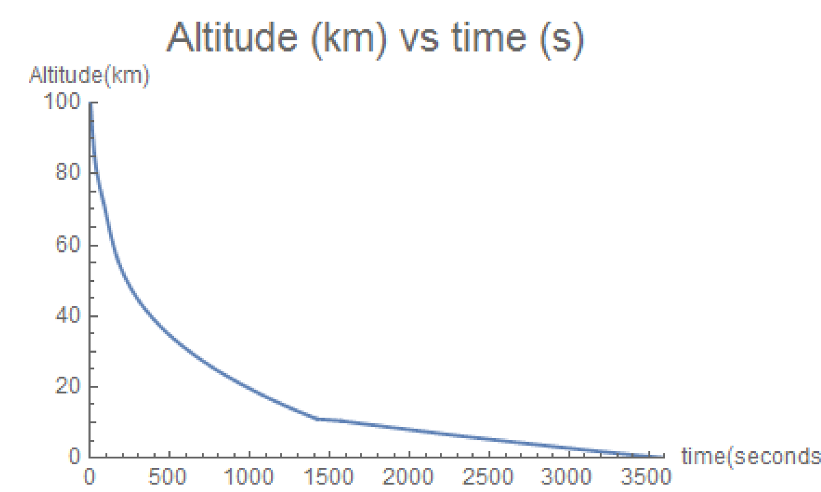

Figure 3: This graph depicts the relationship between altitude and time.

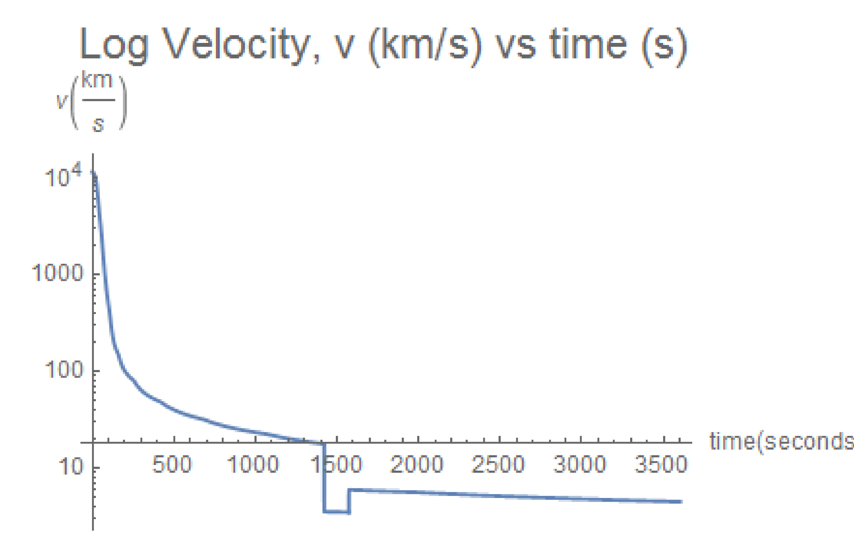

Figure 4: This graph depicts the relationship between log velocity and time. At t=1420s the parachute is released causing a sudden decrease in velocity.

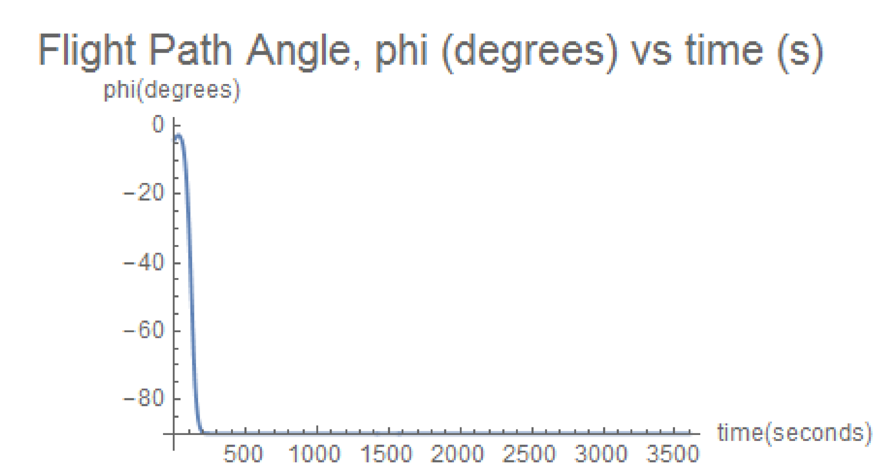

Figure 5: This graph depicts the relationship between flight path angle (phi) and time. At t=287s the flight path angle converges to 90°.

Aeroheating

During the entry stage, the velocity is significant (11.3$\frac{km}{s}$). This causes heat generation to the aeroshell due to convective heat and radiative heat.

$$\dot{Q}_{\text{total}} = \dot{Q}_{\text{convective}} + \dot{Q}_{\text{radiative}}$$

Equation 1: Equation for the total heat rate.

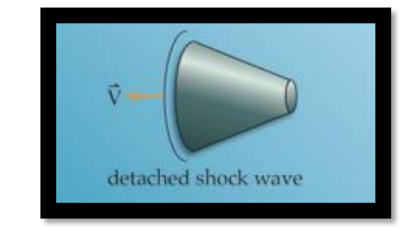

Figure 6: Shockwave example. (faa.gov)

Convective and radiative heat both depend on air density, vehicle velocity, and nose radius. When an entry vehicle travels at high speeds air molecules bounce off of the front of the vehicle and collide with oncoming air molecules, resulting in a shockwave. The resulting shockwave impacts further air molecules in front of the vehicle, heating the air around it. This convective heat is the primary source of heat transfer. The shockwave also dissociates atmospheric gas into asymmetric diatomic molecules. The molecules reform into diatomic molecules in the shock layer. These new molecules have a high vibrational temperature that transforms the energy from vibrational to radiative (radiative heat transfer).

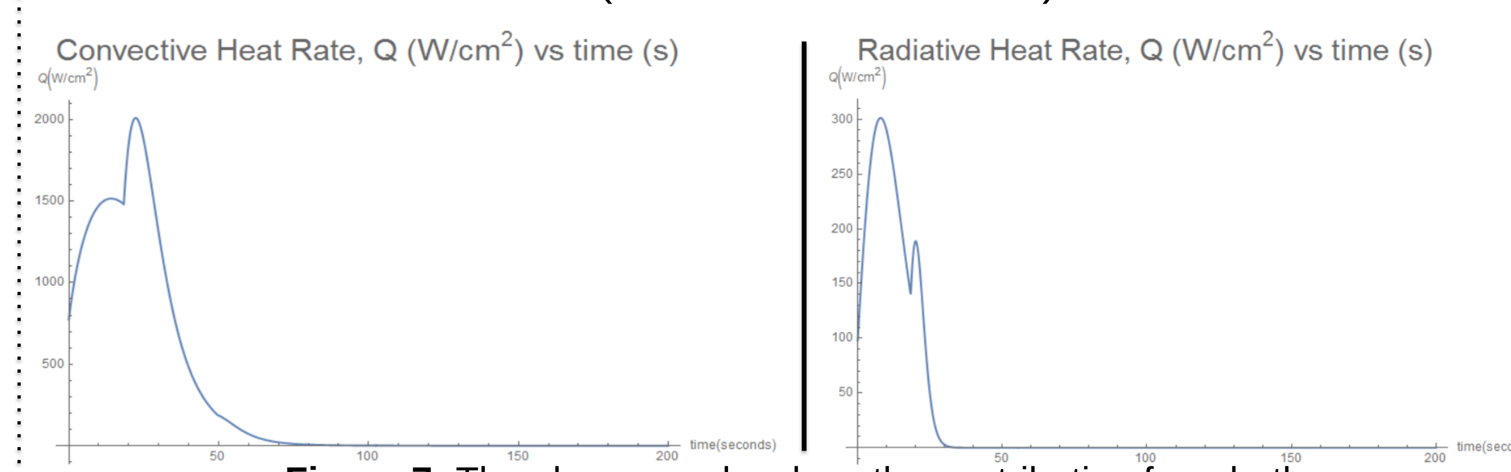

Figure 7: The above graphs show the contribution from both types of heat. It can be seen that convective heat contributes more heat per unit area opposed to radiative heat.

Landing Considerations

When landing on the planet, the vehicle is travelling at 4.5 m/s. A cylindrical crush plate is used to minimize the force of impact on the spherical payload. Additionally, to design for steep landing conditions, stabilizing legs were implemented in the design to maintain proper orientation.

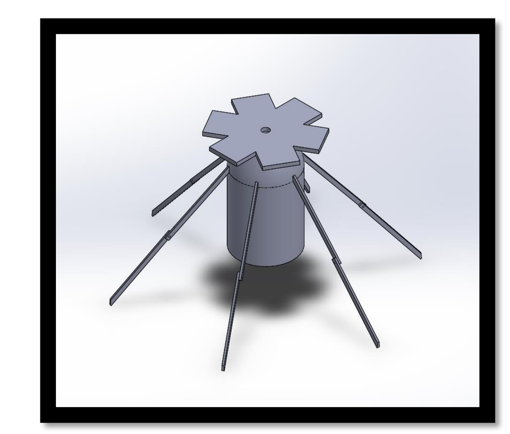

Figure 8: Lander Model

Special Thanks

The team would like to express their gratitude to Dr. Juan Cruz without whose time, patience, and assistance the completion of this project would not have been possible.