Landing System for Hypothesized Surfaces

Spring 2024 ME 481 Capstone Design Project

College of Engineering
MICHIGAN STATE UNIVERSITY

Sponsor: NASA/ASU Psyche Mission | Design Group 11

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Problem & Impact

The objective of this project was to formulate a manner by which a future mission may physically land on the asteroid (16) Psyche to conduct further exploration. This process included performing research on past NASA landing systems to not only analyze their application in this case but to invent solutions to Psyche-specific situations and identify critical criteria. Currently, Psyche's actual appearance and geological makeup are unknown and will remain as such until the currently launched Psyche Mission spacecraft comes closer to approaching the asteroid, though there has been a lot of speculation thus far.

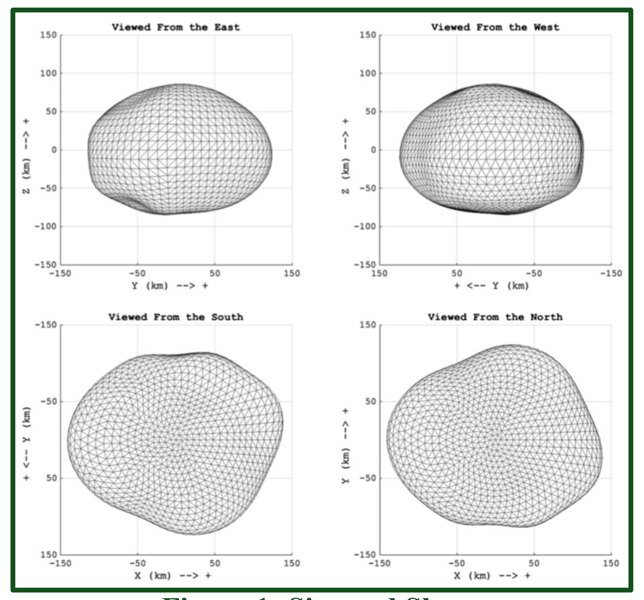

Figure 1: Size and Shape
(Zuber, 2022, p.2)

It is therefore important to research various styles of spacecraft and landing gear to incorporate their relevant aspects into future designs which will be constructed to consider the most likely geological conditions based on what is known today. Considering that nothing like Psyche has ever been examined up close, it is also important to keep in mind the many variables of touching down on a dense, irregularly shaped, low-gravity body when determining the best features to include in a proposed landing system.

Constraints

There is still a large gap in what is understood about the potential planetesimal core, so it is plausible that doing research and mathematical calculations with the information that is already available would be the best course of action. Of course, it is important to keep in mind that the asteroid is unlike any NASA has ever visited in that it is metal-rich and will likely require a new approach regarding physically landing on it because of this among other things. The constraints here are many, as it must be understood that, for example, a harpoon may not be effective due to a potentially very hard surface, or that a parachute will not be of much use considering that Psyche has very low gravity and no atmosphere, compared to Earth where such methods would work well. It is also imperative to remember that there were only a few months that were available to complete the entirety of this project. One may have wished to complete an entire design for a spacecraft, but that was not realistic. In this case, there were hopes to achieve a gravitational and spacecraft dynamics analysis relating to the asteroid to present it alongside research-based information regarding what sort of craft may be most useful.

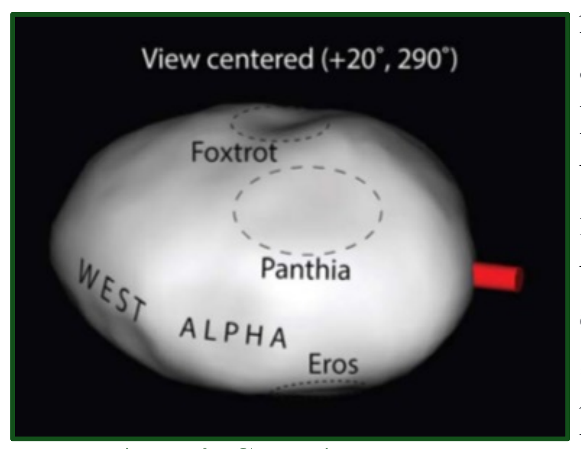

Figure 2: Geological Features
(Shepard, 2021, p.13)

Background Research

Figure 3: Geological Features
("Rosetta-Philae." 2024)

Preliminary research was conducted regarding the conditions on and about Psyche first, involving a general understanding of the asteroid. Initially, an asteroid classification where it was deemed an M-Type (meaning it is made of mostly metal), yearly temperature break-downs, size/shape comparison to other known and traveled to celestial bodies shown in **Figure 1**, and gathering an understanding of Psyche's geological features shown in **Figure 2**. Secondary research was completed on past space missions to other asteroids and similar objects. Past missions like Rosetta-Philae to comet 67P/Churyumov–Gerasimenko shown in **Figure 3**, Hayabusa to asteroid Itokawa, OSIRIS-REx to asteroid Bennu, and Apollo 11 to Earth's Moon, among others.

Code Generation

The Matlab code predicts how the system will function over time, supplying a simulation of landing on the surface. An r-theta coordinate system using longitude and latitude was set to Psyche's surface and used to tell the code how to operate. This system was also used to locate the 2-dimensional sites detailed in **Figure 4** (Vesta) and **Table 2**.

Location	Longitude	Radius (m)	tspan (s)	theta	Low Ft (N)	High Ft Time (s)	High Ft (N)	Starting position
Delta	10	146071	33380	-0.3	-0.05	31960	-9.4	1.687309386
Charlie	130	124185	35460	0.75	-0.05	33690	-10.2	3.644189386
Echo	180	147000	35400	1.4	-0.05	34030	-9.5	4.268029386
Alpha	220	123183	35460	-4.3	-0.05	33670	-10.2	-1.405810614
Bravo	300	120751	35460	-2.6	-0.05	33650	-10.4	0.294189386

Table 2: Initial Input Values

The code forges a trajectory of the lander based on assumptions and given Psyche parameters.

Figure 5 is utilized to match position and omega values to ensure a smooth landing on the surface. The order of graphs from left to right is r-position, theta-position, r-velocity, and omega. A trajectory of what the path would look like to land at location Delta is illustrated in green in **Figure 6**.

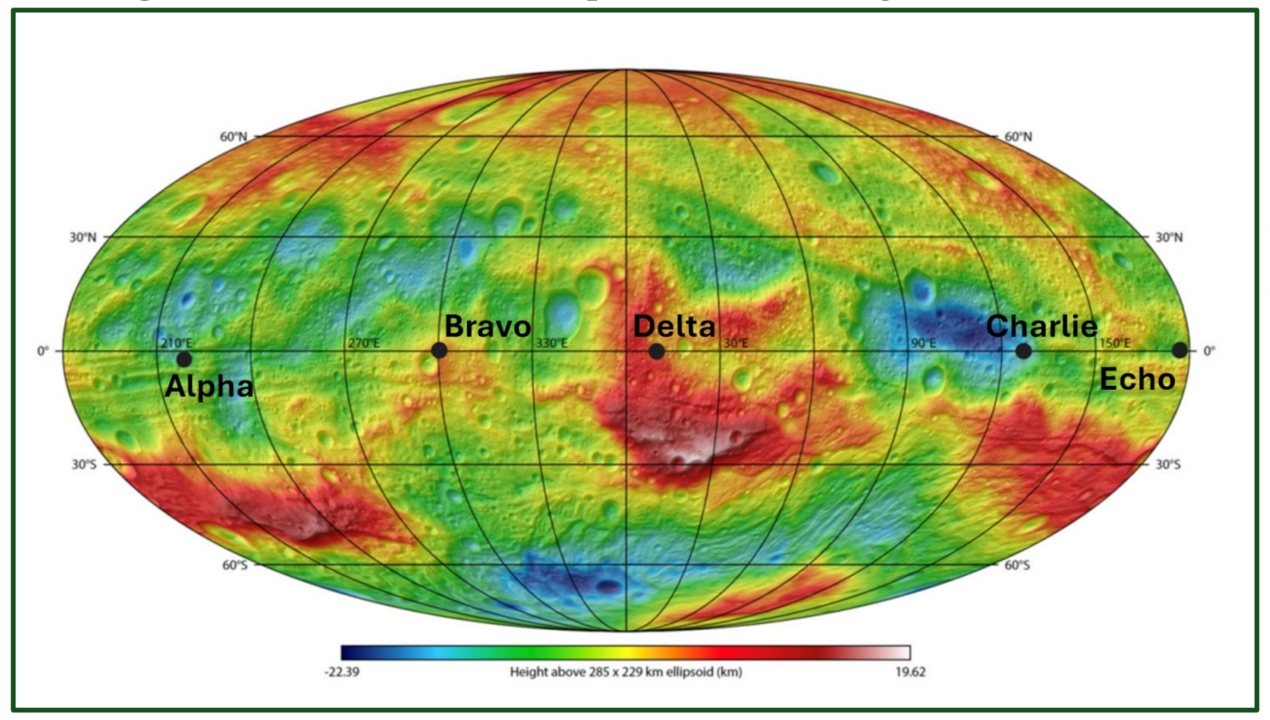

Figure 4: Selected Landing Sites Shown on Asteroid Vesta as a Proxy
(Jaumann, 2022, p.9)

Before the code can be run, a desired coordinate of the landing site must be selected. Then, the corresponding variable from **Table 2** must be input in the script. Then, while running, the code will ask for the desired coordinates. From there, it will ask for a starting theta coordinate from which the spacecraft will begin its descent, low and high thrust force, as well as a timespan during which these forces will act upon the system.

Location	Longitude	Ve (m/s)	Rf (m)	Vf (m/s)	Theta dot final (rad/s)
Delta	10	157.6088	145945	-39.8813	0.000434112
Charlie	130	170.9334	124199	-70.8117	0.000435132
Echo	180	157.11	147013	-38.5688	0.000433813
Alpha	220	171.6273	122786	-72.6968	0.000438892
Bravo	300	173.3476	120647	-76.0922	0.000435341

Table 3: Final Output Values

Following the running of the code, it will provide visuals of the spacecraft's trajectory as shown in **Figure 5**, as well as an analysis of the landing operation as shown in **Figure 4**. These allow the user to determine if landing in such a manner is visually feasible. The final values shown in **Figure 4** are consolidated in **Table 3** for ease of viewing.

The data collected from all five selected landing sites led to the discovery that Delta and Echo locations are the easiest to land at.

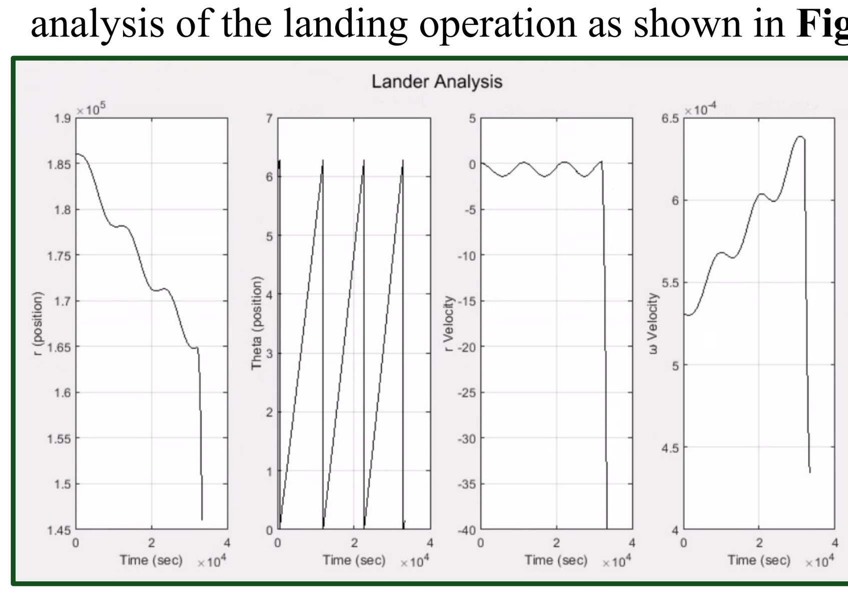

Figure 5: Lander Graph Analysis at Location Delta

It shall be acknowledged that this code does not account for all possibilities within the task of landing on a celestial body in space. Additionally, it does not account for all the unknowns of Psyche.

This code was assembled to function as a building block that can be added upon when more is discovered about the asteroid and can contribute to a control feedback landing system.

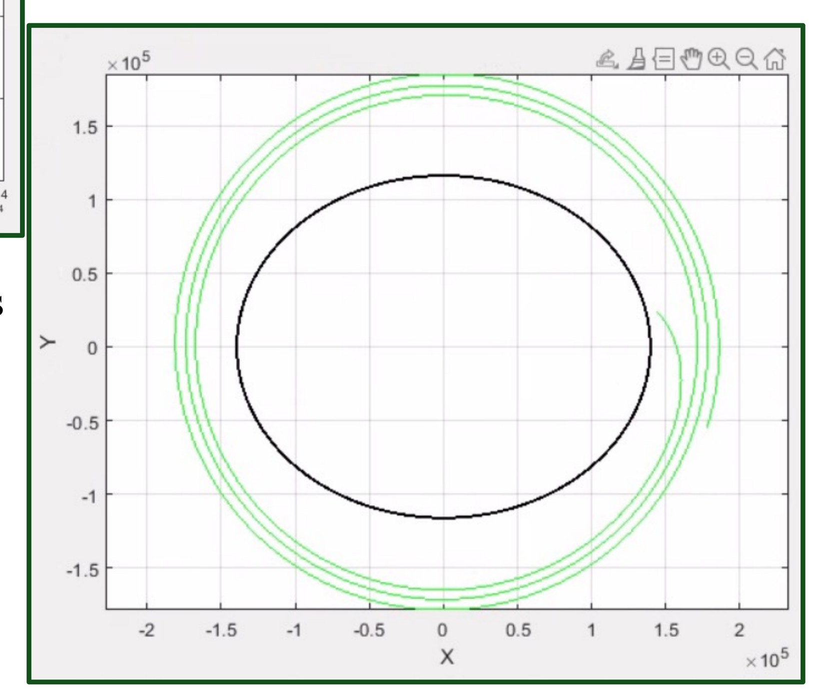

Figure 6: Landing Trajectory at Location Delta in 2D

Mathematical Analyses

Several analyses were conducted to gain a better understanding of what is to be expected on Psyche upon arrival concerning gravity and other extraneous conditions. Preliminarily, after an understanding of the low gravity on the asteroid was ascertained, an analysis of the orbiter traveling about Psyche that would dispense the landing system was performed. Another involved the lander itself and the procedure by which it would land on Psyche. A kinematic analysis of the asteroid was also executed, something that is useful for the logistics of the lander. The final analysis was conducted concerning the lander touching down on Psyche.

$$F_g = mg = \frac{GmM}{r^2}$$

Equation (1)

$$v_o = \frac{2\pi(r+r_f)}{t}$$

Equation (2)

$$r = r_f + 70000$$

Equation (3)

$$v_e = \sqrt{\frac{2GM}{r_f}}$$

Equation (4)

Since there has yet to be up close data gathered, various assumptions were made to aid in some hypothesized calculations. For example, Psyche is rotating about its center and not tumbling, the spacecraft rotates about the equator of Psyche and in the same direction as its rotation, the lander will match the angular velocity of Psyche upon touchdown, the lander will execute a continuous burn of fuel from the thruster, and the surface gravity of Psyche is the mean surface gravity at all points chosen for landing.

- Equation (1) is the force of gravity used at all points.
- Equation (2) is the velocity needed for the spacecraft to be able to orbit Psyche.
- Equation (3) is the total radius from the spacecraft to the center of Psyche.
- Equation (4) is the escape velocity of the lander when on the asteroid.

Location	Longitude	G(m/s^2)	Ve (m/s)	Rf (m)
Delta	10	0.085	157.6088	145945
Charlie	130	0.1176	170.9334	124199
Echo	180	0.084	157.11	147013
Alpha	220	0.1196	171.6273	122786
Bravo	300	0.1244	173.3476	120647

Table 1: Values for Equations

Conclusions

From the many options available, assuming that conditions are as they have been assumed to be up until this point and throughout the analysis, the Apollo 11 Eagle rounded footpad style would be best in the scenario that tipping is a considerable concern, especially knowing that the lander will be autonomous. On the other hand, a sled or one-legged lander style would make more sense when it is desired to utilize the friction of the potential protoplanet while also assuming that Psyche possesses more of a flat surface than is anticipated currently. Lastly, a touch-and-go style would be best in the case that landing permanently on Psyche is deemed unfeasible for whatever reason. Overall, the results of this research and analysis are highly dependent on the hypothesized scenarios presently being implemented. While not everything is theoretical, it is safe to assume that most of the essential particulars will not be fully known until the current mission makes it to Psyche in the coming years.

Fuel is a big concern in limiting waste, money, and mass. For this reason, a hall-effect thruster was chosen for the low thrust force. The high thrust force was found most efficient using hydrazine monopropellant, and the landing force being so large required four hybrid engines.

Location	Longitude	Low Ft (N)	High Ft (N)	Landing Ft (N)
Delta	10	-0.05	-9.4	497.750825
Charlie	130	-0.05	-10.2	913.22445
Echo	180	-0.05	-9.5	496.131675
Alpha	220	-0.05	-10.2	937.47195
Bravo	300	-0.05	-10.4	981.937625

Table 4: Final Landing Locations

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