PAYLOAD CONCEPT PROPOSAL

Neptune Orbiter and Triton Explorer Mission

Spring 2017

Excelsior

"Upward and Onward to Greater Glory"

Grand Forks Central High School Team #2

1. Introduction

Upward and onward to greater glory, Excelsior! We consider our team identity to be representative of our goals within the InSPIRESS project. As a team we define our success as gaining any new information about the enigmatic Triton and accumulating excitement for STEM fields within our community. We are excited to share our accomplishments with you. For the InSPIRESS project, **Team Excelsior** was tasked with designing and sending a payload to explore either Neptune or Triton on one of the Neptune Orbiter and Triton Explorer (NOTE) baseline mission vehicles. We chose to deploy our payload, **Pandora's Box**, from the NOTE Orbiter onto the South pole of Triton and perform our science objectives from there. One of the reasons we chose Triton over Neptune is because of unique characteristics on Triton including the only form of cantaloupe terrain in our solar system. This effect could be a result of Triton's unique geysers and the dispersal of its particles, a factor we are going to explore as part of our mission. Our developed payload is named Pandora's Box for the story of its namesake and its connection to the Excelsior mission. The story of Pandora's Box originates from the ancient greek story Works and Days written by the poet Hesiod. As the tale goes, the box was created and given to Pandora, the first woman on Earth. Enclosed was all of the evils in the world, and she was warned that if opened all the evils would escape and only hope would remain. We chose this because of the risk involved with our mission's impact and the hope we would have that it would gain and transmit back information even if the payload encounters problems with its landing. Overall our mission should take 45 days to complete and successfully discover more about Triton.

2. Science Objective and Instrumentation

After researching Neptune's largest moon, Team Excelsior chose the **science objective of exploring the rejuvenation of Triton's surface in relation to geysers, seismic activity and atmospheric versus surface composition.** Findings from our science objective could affect scientists, engineers, and even the average person. As a human race we are extremely interested in learning more about everything—particularly space. Successfully finding information on Triton, whether it be taking thermal pictures, discovering more about the components of the moon's atmosphere and surface composition, or testing the particles emitted by geysers could lead to new revelations and breakthroughs on Earth and throughout our solar system. The instruments we chose to complete of our science objective were an Inertial Measurement Unit (IMU), an infrared (IR) imaging system, and a Mass Spectrometer. We will have four Inertial Measurement systems that deploy separately from our payload to measure and triangulate seismic activity without the potential of losing experimental data from one system landing in a shadow zone. The Mass Spectrometer and the infrared imaging system will be housed in the payload to measure geyser particle dispersal and surface composition. The support instruments we will need to complete our mission are an on board computer system, transmitter/receiver, battery, and antenna. These will power our mission and allow for the discovery and transmission of the data we collect to be sent back to the main spacecraft.

Table 1. Science Traceability Matrix

Science Objective	Measurement Objective	Measurement Requirement	Instrument Selected
Explore Triton's Geological Surface Processes	Seismic Activity/ Vibrations	• Minimum of 3 probes • 45 day lifetime • Measurements every twelve hours	Inertial Measurement Unit (IMU)
	Geyser Particle dispersal and Surface Composition	• One probe • 45 day lifetime • Continuous pictures • Measurements of soil and geyser particles	IR Imaging System Mass spectrometer
	Atmospheric Composition	• One probe • 45 day lifetime	Mass Spectrometer

Table 2. Instrument Requirements

Instrument	Mass (kg)	Power (W)	Data Rate (Mbps)	Dimensions (cm)	Lifetime	Frequency	Duration
IMU	0.013	0.22	0.160	2.2 x 2.4 x 0.3	45 days	12 hours	30 minutes
IR Imaging System	2	5	10.240 per image	0.45 x 0.50 x 0.80	As Payload falls/lands	Continuous	Continuous
Mass Spectrometer	0.230	1.5	22.4	0.40 x 0.50 x 0.80	45 days	5 hours	5 scans

Table 3. Support Equipment

Component	Mass (kg)	Power (W)	Data Rate	Other Technical Specifications
On board computer	0.094	0.4	2 x 2 GB On board Storage	96 x 90 x 12.4 mm
Transmitter/ Receiver	0.085	1.7	Up to 9600 bps Downlink—up to 1200 uplink	96 x 90 x 15 mm
Battery	400 Whr/kg	N/A	N/A	10 batteries 88 x 95 x 14 mm
Antenna	0.100	0.02	Up to 9600 bps Downlink—up to 1200 uplink	98 mm

3. Payload Design Requirements

There were a plethora of requirements we had to take into consideration when designing our payload. Some of these requirements, such as project and functional requirements, were given to every group participating in the InSPIRESS project. Others, like environmental requirements were dependent on whether we chose to conduct research on Neptune or Triton. We chose Triton and thus focused entirely on the aspects of the moon that would impact the payload. One of the payload design or **project** requirements, for the mission was having a collective mass of 10 kilograms or less. This affects how much equipment the payload can house and what materials can be utilized in crafting our payload. The payload we were tasked with creating had to be capable of being housed within a volume of 44 cm by 24 cm by 28 cm. This further restricted the size and shape of our payload and what could theoretically fit inside it. The payload also had to be capable of deploying from the main spacecraft without causing harm to it, and remain autonomous once deployed, therefore we had to provide enough battery space to run the payload. The **functional** requirements we had to contemplate when creating our design was that the payload had to be capable of deploying from the main spacecraft, taking measurements, collecting data, providing power, and housing the payload. These all affected our decision to ensure we complete the payload within the given requirements. We chose the South pole of Triton as the destination for our payload, so the **environmental** requirements imposed upon us consisted of our payload being capable of withstanding the extreme cold. The temperature can get as low as seven degrees Kelvin on Triton. We also had to take into account the pressure, which is roughly 14 micro-bars, and the wind, believed to be anywhere from 5-15 m/s. This meant our payload would have to be properly insulated and built to sustain the icy impact.

4.0 Payload Alternatives

Using the requirements given to us, our Excelsior team outlined and designed two concepts to appropriately test the scientific requirements and handle the environment our payload would be facing during this mission. The concepts differed in the ways they completed our science objective. From these two concepts, a final payload design emerged.

4.1 Concept 1: Pandora's Box (Figure 1.)

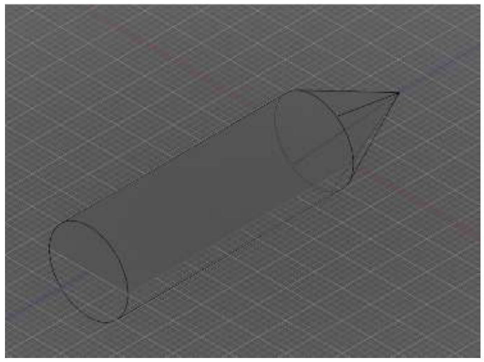
Our first concept was a square box that houses specific scientific instruments, including the Mass Spectrometer, IR Imaging System and support equipment inside the payload, with IMUs on the outside. The Mass Spectrometer and the IR Imaging System would be able to test surface composition and atmospheric composition, as well as photograph the surface through holes in the box on the descent. The IMU's that are housed in spheres will test the vibrations and seismic activity on the satellite's surface. Originally the design was to have four IMUs connected to the outside, but still partially inside the payload, and released by electromagnets. This is a beginning aspect of the Pandora's Box design.

Figure 1. Pandora's Box

4.2 Concept 2: Orion (Figure 2.)

The second concept developed by our team we decided to name Orion due to the shape of the design—which looks like a spear similar to the one depicted in the constellation, Orion. It was designed this way to maximize the landing techniques we envisioned for it. Orion is a penetrating lander that would bury itself into the surface of Triton in order to test the surface composition upon impact, as well as after. It would also deploy the aforementioned spheres from the rear of the cylinder to test vibrations on the surface, while the head of the spear would house the Mass Spectrometer, IR Imaging System, and support equipment. More important equipment like the Mass Spectrometer and IR Imaging System would be stowed in the tip to receive optimal pictures while falling, whereas the support equipment would fit as much in the head as possible with overflow sitting in Orion's shaft. Upon careful consideration several problems arose with the Orion design.

Figure 2. Orion



5. Decision Analysis

When analyzing our two designs, Pandora's Box and Orion, we put a lot of emphasis into how efficient each design was in fulfilling the design requirements. We were given Figures of Merit (FOMs) by UAH for evaluating our payload concepts, and were then tasked with devising several of our own. The FOMs we created for analyzing our designs were reaction to the environment, power usage/battery, and landing on Triton. Triton has an extremely cold environment that would require our payload design to be properly insulated. We also wanted to weigh which design would best utilize and fit our batteries because our mission requires a great deal of power to run the instruments we chose. And finally we wanted a design that would have the most success when landing on Triton to successfully carry out aspects of our science objective. During our analysis we found a major advantage of Pandora's box to be it's extreme space efficiency given the design requirements. Conforming our shape to that of the design requirements elicits a gargantuan difference in the amount space for insulation, equipment, and batteries. With Orion, a major issue would have been providing ample space for instruments within our volume as equipment was moved further and further down the shaft. However with Pandora's Box our only true restraint would be mass, which greatly facilitates the design process. Rectangular prisms are much more realistic to manufacture and the Pandora's box design introduces fewer environmental risks as we consider landing and ease of insulation. For these reasons Pandora's Box lead in points by a substantial margin and was chosen by Team Excelsior for the Neptune Orbiter and Triton Explorer Mission.

Table 4. Payload Decision Analysis

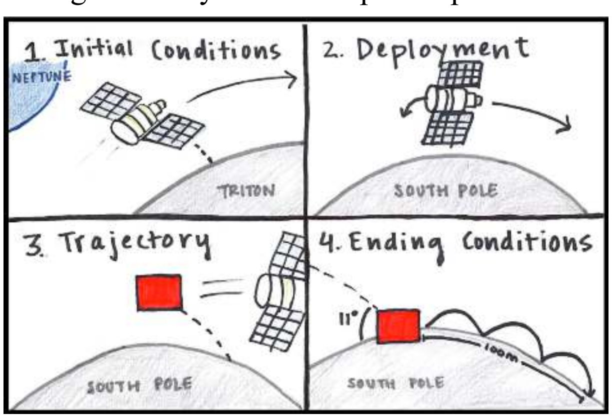
Figure of Merit	Weight	Group 1 Concept		Group 2 Concept	
		Raw	Weighted	Raw	Weighted
Science Objective	9	3	27	3	27
Likelihood Project Requirement	9	3	81	3	27
Science Mass Ratio	1	9	9	1	1
Design Complexity	9	3	27	1	9

ConOps Complexity	1	3	3	3	3
Likelihood Mission Success	3	3	9	3	9
Manufacturability	9	9	81	1	9
Reaction to Environment	9	3	27	3	27
Power Usage/Battery	9	9	81	3	27
Landing on Triton	3	9	27	3	9
Total		Sum	372	Sum	148

6. Payload Concept of Operations (Figure 3.)

Our Pandora's Box payload will travel to Triton on the NOTE mission by hitching a ride on the main spacecraft as it travels 7 Earth years to reach Neptune. Pandora's Box will be held in the Orbiter which orbits around Neptune for two years at an altitude of 3000 kilometers, and then Triton at an altitude of 100 kilometers for an additional two years. On the Triton Orbiter the payload will have access to environmental data, in reference to the atmospheric composition, which will be tested on the descent to land on Triton's surface. (1) In the initial conditions the payload, housed in the Orbiter, will be orbiting Triton at roughly 992 m/s at an altitude of 100 kilometers above the surface. (2) The payload will then deploy backwards, in the opposite direction of the spaceship's path, off of the main spacecraft. We will be exiting from an airtight shaft using helium at an acceleration of 12.5 m/(s^2). The pressure will be 2.11 Pa. (3) The payload will then fall forward from its deployment at a relatively slow initial velocity of 10 m/s to land on the South pole of Triton, testing atmospheric composition as it goes. The payload will also release the 4 spheres containing the IMU's at the same time, hoping to get enough of a spread for triangulating data, even if one of the spheres is destroyed, or if the payload encounters shadow zones on Triton similar to that of those on Earth. The payload will fall for approximately 507 seconds before impact. (4) In the ending conditions the payload will impact the South pole of Triton at a small angle of 11 degrees at a speed of 395 m/s. We anticipate that the payload will skip across the surface like a stone on water for 100 m before coming to rest on the South pole. From there the payload will remain stationary as it conducts measurements and collects data about the surface composition and vibrations.

Figure 3. Payload Concept of Operations



7.0 Engineering Analysis

When figuring out the calculations of our mission there were aspects that we were given, and then those that we had to assume. The table below outlines the work we did in solving for parts of the initial conditions, deployment, trajectory, ending conditions and required battery mass.

7.1 Initial Conditions

We are choosing to store our payload on the Triton Orbiter because we will have more access to environmental data to test the composition of the atmosphere as the payload falls. The payload will be safely housed in a tube on the back end of the Orbiter, ready to eject out of the NOTE mission. We altered the shape from an irregular box with semi-circles to a rectangular prism in order to maximize space and create a tighter fit in the tube with a more efficient discharge. After taking into account constant velocity we determined that the Orbiter will be orbiting around Triton using the equation $v = \sqrt{(GM/r)}$ at 992 m/s. Therefore we decided to deploy backwards from the NOTE Orbiter to minimize the final velocity when the payload hits the surface.

7.2 Deployment

After comparing our calculations with the requirements, we decided to use an applied helium force to discharge our payload as a more reliable option than that of spring deployment. As previously stated, the design team chose to deploy backwards to better prepare the payload structure for a softer final impact. We used the equation $V_f = V_i + 2ad$ and assumed the slowest possible velocity we could for exiting the air tight tube—10m/s. The payload will then fall gradually forward with an initial speed in the x direction of 1000m/s. In the y direction the initial velocity of 10 m/s will slowly increase due to acceleration of gravity as the payload falls with no drag toward the surface of Triton.

7.3 Trajectory (Figure 4.)

For the trajectory of our payload, we took into consideration the obvious curve of the circular moon and worked using calculus to better assume the distance of our trajectory, rather than relying on just trigonometry. This would be a very easy procedure assuming a constant vertical velocity but, unfortunately, because of the acceleration due to gravity the velocity is always increasing during the projectile's descent. Integrals were used to find the average height of descent in order to take into account the acceleration due to the $0.779 m/(s^2)$ of gravity on Triton. The integral utilized (Figure 5.) is the equation used to find the height of the projectile in the seconds after deployment over the interval between the deployment and the total time that it takes for the projectile to make impact. The integral was divided by the total time necessary to find the average height, instead of simply the area under the curve. Using this method our calculations were greatly altered from those we found using trigonometry. Although our angle didn't change by more than a degree, the change in distance from our results using the previous method was approximately 12,000 meters. This is a big deal when we consider landing in an exact location, as we are on the South pole of Triton.

Figure 4. Trajectory

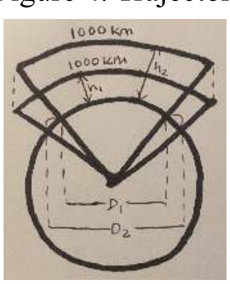


Figure 5. Equation for our Trajectory Calculations

$$2\pi r_1 \left(\frac{V_x\sqrt{2gh}}{2gh\left[\left(\frac{g\int_0^{\frac{\sqrt{2gh}}{g}} \left(h - \frac{gx^2}{2}\right)dx}{\sqrt{2gh}}\right)+r_1\right]} \right)$$

7.4 Ending Conditions

The ending conditions of Pandora's box will occur on the South pole of Triton where it will be able to properly test the surface and geyser particles, as well as relay information from the IMUs and itself back to the NOTE Mission. Our payload will hit Triton's surface at an angle of 11 degrees and then skip across the surface before coming to a stop approximately 100 m after impacting with a velocity of 350 m/s. Using our versatile design and proper insulation the payload will be safe no matter what side it stops on.

7.5 Battery Mass

It was very important to find the mass of the battery because it could take up a substantial part of our weight requirement. After several calculations on battery mass for a 45 day mission we decided to run the support instruments as little as possible and send data once a day—which significantly lowered the amount of battery mass we had to account for.

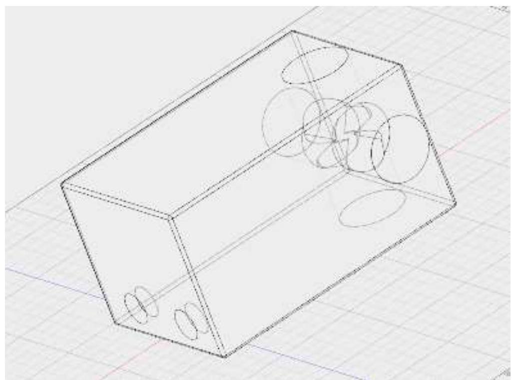
Table 5. Engineering Analysis

	Equations and Given	Assumptions	Calculations
Initial Conditions	√(GM/r) G=6.67 x 10^-11m^3kg^-1s^-2	r=1.450x10^6m M=2.14x10^22 kg	v=992 m/s
Deployment from the UAH Vehicle	a=PA/m A=59.2m^2 Vf=Vi + 2ad	d=100 km m=10kg Vf=10m/s P=?	P=2.11 Pa a=12.5 m/s^2
Payload's Trajectory	Vf = Vi+ at Vi=0 a=0.779m/s^2	t=? Vf=?	t=507 s
Ending Conditions	Vf^2=Vi^2 +2ad Vi=O a=0.779m/s^2	D=100km Vf=?	Vf=395 m/s Angle=11 degrees
Required Battery Mass	Kg of Bat.=TW/Hr / 400 W/hr per KG 30 day lifetime		Weight of Batteries =1.3 Kg

8. Final Design

Pandora's Box is a rectangularly shaped box with six openings. Each opening has a specific purpose, correlating with the scientific instruments we chose to use. The two openings on the front lower half of the payload will house the IR Imaging System and Mass Spectrometer in order to correctly test surface composition and atmospheric composition as well as photograph the surface on the payload descent. The four openings towards the rear of the payload will deploy the IMUs that are housed in spheres to test the vibrations and seismic activity on the satellite's surface. There are four spheres in an attempt to reduce the possibility of a IMU landing in a shadow zone, or place where it cannot triangulate vibrations in order to find the epicenter. This number of IMU's will also reduce the chance that one will land in a place that it will not be able to communicate with the payload once on the surface. Pandora's Box is made out of titanium with a honeycomb design inside to stabilize the instruments in the interior and provide impact protection. Crumple zones will also provide impact protection to the payload and its internal instruments when the payload lands on the South pole of Triton. Slightly curved edges to the outside of the payload will also hopefully provide it protection as it impacts and skips along the South pole. Pandora's Box will be slightly top heavy in the hopes that when it lands it will most likely hit on a specific upright flat side of the payload, protecting the instruments. The payload will contain aerogel to insulate the instruments. The spheres housing the IMU's will be wrapped in a carbon fiber shell in order to provide a layer of impact protection and insulation outside of the titanium sphere. Pandora's Box will conform with the project requirements by fitting directly within the payload space requirement and being made of light materials. The IMU spheres and batteries are housed inside to protect them from the environment. Many of the safety features like the crumple zones, as well as insulation like the aerogel, will protect the payload and its instruments.

Figure 6. Excelsior's Mission



We define success as exploring and obtaining as little, or as much, relevant information as possible about Triton during our payload mission. And with Pandora's Box complying with all of the requirements given to us by UAH for the Neptune Orbiter and Triton Explorer Mission we believe we will be successful in gaining a more holistic view of Triton. By obtaining more information on atmospheric and surface composition, geyser particle dispersal, and seismic activity as well as understanding the appearance of Triton we plan to contribute to exploring and learning more about Triton's geological surface processes and the universe beyond.

Table 6. Final Design Mass Table

Function	Component(s)	Mass (kg)	Total
Measure Data	• IMU • External Mass Spectrometer • IR Imaging System	0.013 x 4=0.052 kg 0.23 kg 2 kg	9.9 kg
Provide Power	Lithium Ion Batteries	1.18 kg	
Send/Collect Data	On Board Computer, Transceiver, Antenna	0.279 kg	
House the Payload	Outside of box, Insulators	6.2 kg	