Payload Concept Proposal

Neptune Orbiter and Triton Explorer Mission

Spring 2017

Good Hope High School

Team 2

ATLANTIS

Analysis of **T**riton's **LA**ndmass and **N**eptune's **T**ropopause and **I**nternal **S**tructure

"Mobilis in Mobili"

1.0 Introduction

Team ATLANTIS is a group of seven students enrolled in a physics class at Good Hope High School. The team has been challenged by UAH and the class's teacher to create a payload that will travel aboard a spacecraft that UAH has designed for their Neptune Orbiter and Triton Explorer (NOTE) Mission. The payload for Team ATLANTIS, "*Ned Lander",* is named after Ned Land, a character from Jules Verne's *Twenty Thousand Leagues Under the Sea*. ATLANTIS's slogan is "Mobilis in Mobili," which roughly translates from Latin to, "moving within the moving element."

ATLANTIS decided to make references to this novel concerning the payload name and slogan due to the fact that Triton is named after the Greek god known as the messenger of the sea. The team will travel to Triton, Neptune's largest moon, aboard the Lander with the intentions of studying surface composition, atmospheric properties, and subterraneous structure at the south pole.

2.0 Science Objective and Instrumentation

The primary science objective for "*Ned Lander"* is to measure the composition and properties of Triton's surface with a mass spectrometer and a thermocouple. Measuring the composition of Triton offers a unique opportunity to examine Triton's origin from the Kuiper Belt. This will allow the team to gain more insight on dwarf planets such as Pluto and other celestial bodies within and beyond the Kuiper Belt.

The second science objective is to measure atmospheric properties and composition. The "*Ned Lander"* will use a mass spectrometer and a thermocouple for this objective as well. By measuring Triton's thin and tenuous atmosphere, the payload could explain how Triton developed such an atmosphere and further explain regions of the Kuiper Belt. The third and final objective that ATLANTIS decided to pursue is to examine subterraneous structure. The "*Ned Lander"* will determine the internal structure and heat flow of Triton by using an inertial measurement unit (IMU) and thermocouples. This objective is especially important to develop a more clear picture of the inside of Triton.

Table 1. Science Traceability Matrix

Science Objective	Measurement Objective	Measurement Requirement	Instrument Selected
Surface Composition	Composition of and variations in Triton's surface	– Multiple samples – Payload able to withstand impact	Mass spectrometer and thermocouple
Atmospheric Measurement	Composition and properties of what makes up Triton's atmosphere	– Multiple samples – Incremented measurement	Mass spectrometer and thermocouple
Subterraneous Structure	Inner geologic structure and heat flow of Triton	– Minimum 3 IMUs – Stay on surface – 4 hours lifetime – Continuous measurement	IMUs and thermocouples

Table 2. Instrument Requirements

Instrument	Mass (kg)	Power (W)	Data Rate (Mbps)	Dimensions (cm)	Duration (sec)	Frequency	Lifetime
Mass Spectrometer	0.230	1.5	22.4	0.45 x 0.50 x 0.80	320 s* / 10 s	Continuous * / Once	6 minutes
Thermocouple	0.002	N/A	1.0 E -4	10	90 days	Continuous	90 days
IMU	0.013	0.22	0.16	2.2 x 2.4 x 0.30	320 s / 2 minutes	Continuous * / 10 days	90 days

*frequency during flight

Table 3. Support Equipment

Component	Mass (kg)	Power (W)	Data Rate	Dimensions (mm)	Other Technical Specifications
Computer	0.094	0.4	2 X 2 GB onboard storage	96 x 90 x 12.4	400 MHz, ARM9 processor
Transceiver	0.085	1.7	Up to 9600 bps downlink; up to 1200 bps uplink	96 x 90 x 15	ISIS VHF/UHF Duplex Transceiver
Antenna	0.100	0.02	(see above)	98	Deployable Antenna System
Batteries	2.29	N/A	N/A	1.75 x 7 x 0.5	Mass calculated by power requirements

3.0 Payload Design Requirements

Before designing the payload, ATLANTIS was given multiple requirements. The first set was the project requirements, those designed by the InSPIRESS program that ensure economic efficiency and guarantee safety for all the projects involved in the NOTE mission. These requirements are as follows: the payload must not exceed 10 kg, the payload must fit within a 44 cm x 24 cm x 28 cm volume, the payload must survive the trip to Triton and its environment, and the mission cannot cause harm to the UAH spacecraft and must complete the mission within the allotted 90 days.

The second type of requirements given pertain to the payload and its functions. These are known as the functional requirements. There are six: deploy from the UAH spacecraft, house and contain the payload and instrumentation, provide power, collect data, analyze data, and transmit the results of the mission.

The third set of requirements given to ATLANTIS is environmental requirements, which are set to ensure the payload can survive the environment of Triton. The payload must survive pressures ranging between 1.4 to 1.9 P, temperatures ranging from 38K to 100K, and an assumed surface gravity of 0.779 m/s^2.

4.0 Payload Alternatives

Concept 1: Nautilus

ATLANTIS's first concept was a payload to Neptune named the "*Nautilus*." The concept was designed to measure the atmospheric composition, properties, as well as the radiation of Neptune. The spherical design was intended to help the payload survive the harsh conditions of Neptune. The concept of operations involve launching from the Orbiter, falling through the atmosphere while taking atmospheric data, landing in a possible liquid ocean, and taking radiation measurements after impact. The positives of this concept include gaining insight to Neptune's storms and its internal radiation. A negative would be power constraints and furthermore mass constraints because the scintillation counter requires a great deal of power.

Concept 2: Ned Lander

ATLANTIS's second concept is the payload headed to Triton named the "*Ned Lander*." Its objective is to take atmospheric measurements and study the surface composition and internal structure of Triton. The sharp, cylindrical design was created to help the payload break through the surface of Triton on impact. The concept of operations for this payload is to launch three "*Ned Landers"* from the UAH Lander by rotating 120° three times, take atmospheric measurements during flight, penetrate the surface of Triton, collect data from the surface of Triton and its internal structure, and finally send all data collected. The positives of this concept include acquiring information of Triton's origin, learning more about the Kuiper belt (where Triton is theorized to have originated), and gain insight on Triton's atmospheric abnormality. Negatives would be mass constraints because the payload would be required to penetrate Triton's surface.

Concept 3: Nautilander

Team ATLANTIS's ideal, initial concept was a combination of concepts one and two, and it was called the "*Nautilander"*. It was meant to take several payloads to Neptune and Triton, therefore increasing the amount of science data collected. While calculating battery mass, concept of operations complexity, and mass of the total equipment needed, ATLANTIS came to the realization that "*Nautilander"* would be the least feasible concept because it sacrificed too many necessary components of the other concepts to be a successful mission. In the end, ATLANTIS realized it would better to specialize in either Triton or Neptune.

Figure 1 Concept 1

Figure 2 Concept 2

5.0 Decision Analysis

Originally, ATLANTIS planned to deploy at both Neptune and Triton from the Neptune Orbiter in a combination of the "*Nautilus*" and "*Ned Lander*" concepts as denoted in the "*Nautilander*" concept; however, upon conducting a decision analysis, the ATLANTIS team realized that a combination concept would not be possible with the given dimensional and mass constraints. ATLANTIS then turned to the individual "*Nautilus*" and "*Ned Lander*" concepts.

The two concepts were weighted against each other on ten figures of merit (FOMs). Seven of these FOMs were given through the InSPIRESS program, and three were created by the ATLANTIS team. The seven FOMs given were as follows: Science Objective, Likelihood Project Requirement, Science Mass Ratio, Design Complexity, ConOps Complexity, Likelihood Mission Success, and Manufacturability. The three that ATLANTIS created are Durability, Power Consumption, and Data Transmission. These additional FOMs were chosen because the concept selected would have to survive the dense atmosphere of Neptune or the virtually nonexistent atmosphere of Triton – not to mention both of these concepts would have to survive impact if surface science was to be conducted.

To conduct the decision analysis, all of these FOMs were categorized based on if the concept needed more or less of the FOM. Each FOM was given a weight of 1, 3 or 9, denoting how important it was to the overall mission. Each concept was given a raw score of 1, 3 or 9 based on how well the concept met each FOM. All of the raw scores were multiplied by their respective weights, and these weighted scores were totalled to give an overall assessment of each concept.

After concluding the decision analysis, the "*Ned Lander*" concept was the overall victor with a score of 188 negating where the concepts weighted scores were equal. This was mainly due to the scores received on the Likelihood Project Requirement and Power Consumption FOMs. Interestingly enough, these two FOMs were somewhat tied together. The "*Nautilus*" concept made use of a Scintillation Counter while the "*Ned Lander*" concept did not. With a power rate of 7.5 watts, the Scintillation Counter significantly cut into power supplies and in turn the allotted mass of 10 kilograms. This edge was even enough to overcome the "*Nautilus*'s" durability advantage as the "*Nautilus*" did not have to penetrate the surface whereas the "*Ned Lander*" concept did to conduct surface science.

Table 4. Payload Decision Analysis

FOM	Weight	Nautilus		Ned Lander		Nautilander	
		Raw Score	Weighted	Raw Score	Weighted	Raw Score	Weighted
Science Objective ↑	~~9~~	~~9~~	~~81~~	~~9~~	~~81~~	~~9~~	~~81~~
Likelihood Project Requirement ↑	9	3	27	9	81	1	9
Science Mass Ratio ↑	3	3	9	3	9	1	3
Design Complexity ↓	3	1	3	3	9	1	3
ConOps Complexity ↓	3	9	27	9	27	3	9

Likelihood Mission Success ↑	9	3	27	3	27	1	9
Manufacturability ↑	1	1	1	3	3	1	1
Durability ↑	3	3	9	1	3	3	9
Power Consumption ↓	3	1	3	9	27	1	3
Data Transmission ↑	~~9~~	~~3~~	~~27~~	~~3~~	~~27~~	~~3~~	~~27~~
TOTAL			**106**		**188**		**48**

6.0 Payload Concept of Operations

The Concept of Operations (or ConOps) is a plan the payload will execute in order to perform a successful mission. The decision analysis helps determine the priorities and the concept paints a clear picture as to what the payload should do and how it should do it. The "*Ned Lander*" ConOps includes five phases:

1st Phase - Three "*Ned Lander*" payloads will be loaded into the muzzle. Then, they will be launched from the lander at varying angles by rotating every 120°. Each payload will impact the surface at different locations to acquire data from different regions on Trition.

2nd Phase - The payload will collect atmospheric data while it is in flight. Because of the surplus of power provided from the battery, the equipment will be taking readings for the entirety of the flight of the payload. The equipment will be turned off during impact in order to keep the data intact.

3rd Phase - The payload will penetrate the surface of Triton. The "Penetration equation" was used to calculate the depth at which the "*Ned Lander*" would penetrate. During this phase the equipment will be turned off and the payload will be at an approximate depth of 0.157 meters.

4rd Phase - The payload will collect surface and subterraneous data while inside Triton. This phase will be in operation for two minutes every ten days for a total of ninety days. The equipment that will be taking measurements are the mass spectrometer, thermocouple, and IMU.

5th Phase - The payload will send all the data that it has collected to the Lander. Finally, the payload will run out of power and die without causing harm to neither Triton nor the Lander.

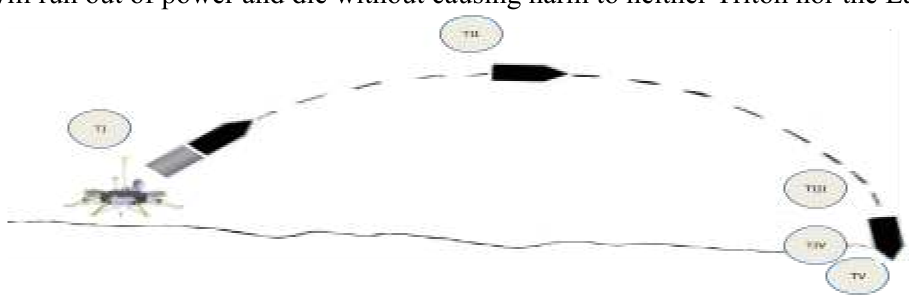


Figure 3 Concept of Operations

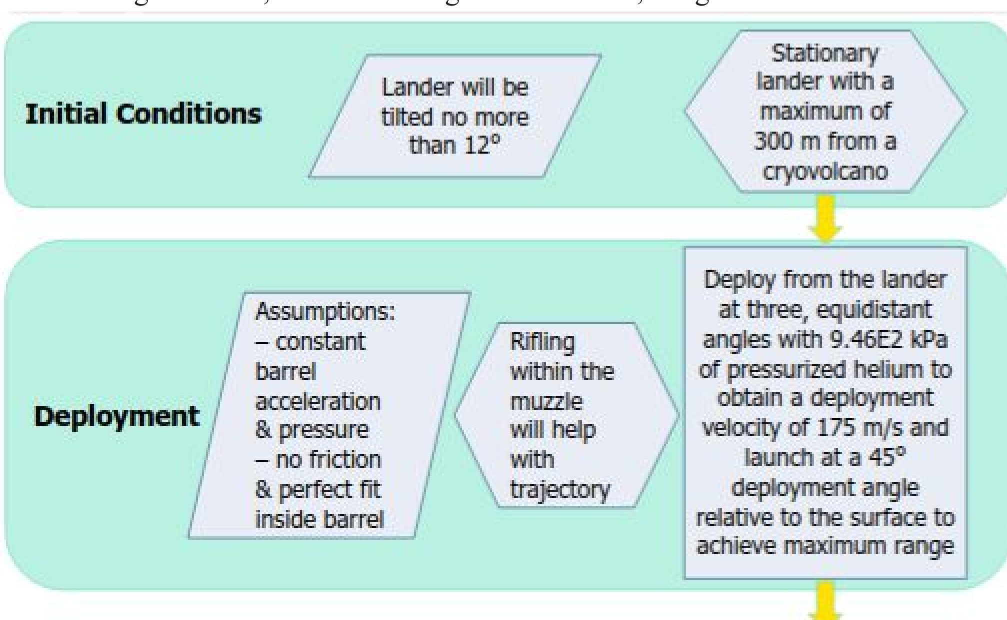
7.0 Engineering Analysis

To ensure ATLANTIS's mission would succeed, a mathematical analysis was required. This analysis was divided into four phases: Initial Conditions, Deployment, Trajectory, Ending Conditions. The first phase, Initial Conditions, was already given as the "*Ned Lander*" would be part of the UAH NOTE mission up until the Deployment phase.

In calculating the Deployment phase, several assumptions had to be made: constant barrel acceleration, constant barrel pressure, no friction inside the barrel, and the payload would fit perfectly inside the muzzle. To deploy safely from the UAH lander, the "*Ned Lander*" will utilize 946 kPa of pressurized helium to obtain a deployment velocity of 175 meters per second; the "*Ned Lander*" also will deploy at 45° relative to the surface to achieve a maximum range of approximately 41 kilometers from the UAH Lander. This distance exceeds the required 10 meters designated in the mission. To assist with the Trajectory phase of the engineering analysis, the muzzle will use rifling to spin-stabilize each payload.

With a total flight time of 318 seconds, several more assumptions had to be made: no drag while in flight, the lander height would be negligible, and gravity would be constant throughout the trajectory. Initially, ATLANTIS planned to deploy from the Orbiter 100 kilometers above the surface of Triton to increase the distance between each "*Ned Lander*" thereby helping to collect a wide range of data; however, after many failed attempts to reconcile an overwhelming g-load, ATLANTIS decided that deploying from the Lander, although this approach would not gather as much data, would be the best approach for the overall success of the mission.

Assuming a nose cone coefficient of 1.0 and a penetrability number of 10 allowed the "*Ned Lander*" to penetrate at a depth of 0.157 meters. The given values for the penetrability number range from 2.5 to 3.5; however, 10 was assumed because of the fact that no extensive studies have been done on nitrogen ices and the fact that the surface of Triton is constantly sublimating. Bringing the engineering analysis to a conclusion, at an impact velocity of 175 meters per second, the "*Ned Lander*" will experience an overall g-load of 9,940 which is right under the 10,000 g threshold.



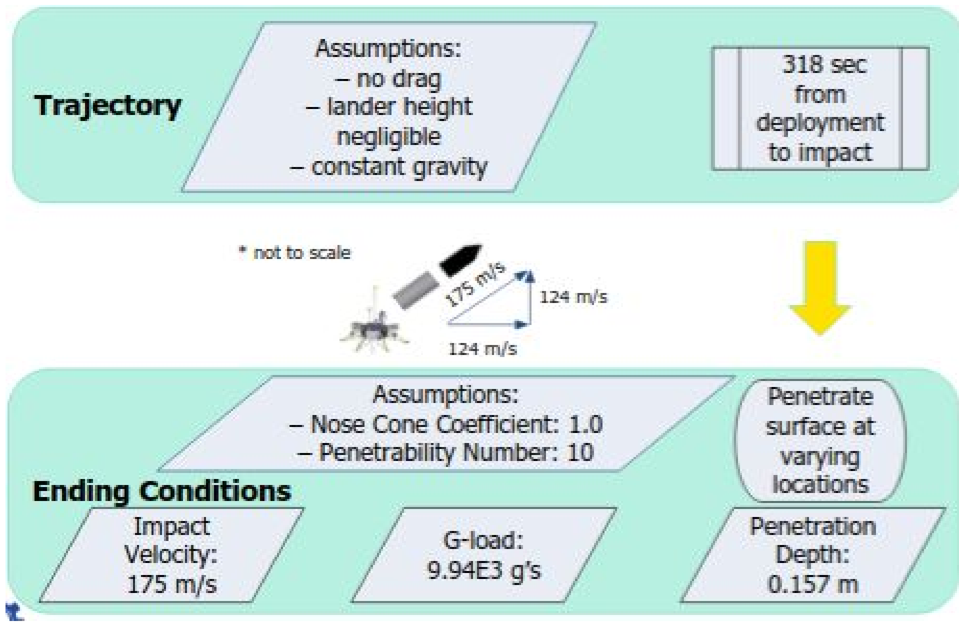


Figure 4 Engineering Analysis Flow Chart

8.0 Final Design

The final design for the "*Ned Lander*" has been modified extensively in order to survive the impact on the surface of Triton. The main feature of the payload is the cone, because it is composed of multiple materials. The cone is primarily composed of titanium alloy, the tip is composed of diamond, and the interior is formed with lead. Titanium alloy was chosen because it is a sturdy metal. Diamond was chosen because of its ability to "penetrate" most substances. Lead was included in the interior to weigh down the tip of the payload to help the payload penetrate as much as possible. The interior equipment is configured in such a way that the area of the payload is as small as possible, thus allowing the payload to experience less Gs and penetrate farther into the surface of Triton. The support equipment is also positioned in optimal locations so the data can be transmitted properly.

Legend
Yellow: Mass spectrometer
Blue: Battery
Green: IMUs
Orange: Transceiver
Purple: On-board Computer
Grey: Antenna

Figure 5 Final Payload Design

Table 5. Mass Table by Function

Function	Instrument(s)	Mass (kg)
House Payload	*Ned Lander*	0.278
Provide Power	Batteries	2.29
Take Measurements	Mass Spectrometer, Thermocouple, & IMU	0.258
Collect Data	On-Board Computer	0.094
Send Data	Transceiver & Antenna	0.185
Mass per *Ned Lander* : **3.11 kg**		
Deploy	Muzzle	0.622
TOTAL	@ **3** *Ned Land(er)s*	**9.95**

Table 6. Requirement Compliance

Requirement	Requirement Met?	Payload Design
Stayed within 10 kg of mass	✓	9.95 kg mass
Stayed within 44 cm x 24 cm x 28 cm	✓	Muzzle dimensions are 6.0 cm diameter and 45 cm length
Survives environment	✓	Titanium alloy is stable, a diamond tip will help with penetration, and lead will weigh down the nose
Does not harm UAH spacecraft	✓	Deploys safely away from the lander
Collect data	✓	Mass spectrometer, thermocouples, and IMU
Deploy	✓	Deploy from lander with pressurized helium