TEAM RUAUMOKO

"SPEARING THE SUBSURFACE"

SCOTTSBORO HIGH SCHOOL

NOTE Mission
Payload Concept Proposal

1.0 Introduction

As recommended by NASA's Solar System Exploration Roadmap, the Rapid Mission Architecture (RMA) Neptune-Triton-KBO study has planned a mission to explore the dynamic and diverse conditions on Triton, Neptune, and several Kuiper Belt objects. The RMA was adopted by InSPIRESS under the name of the Neptune Orbiter and Triton Explorer (NOTE) mission. In accompaniment to the NOTE mission, the Scottsboro InSPIRESS Team 1 RUAUMOKO (Revealing Undiscovered Atmospheric and Underground Measurements while Observing a Kuiper belt Object) was tasked by UAH with complementing the mission by designing a payload to accomplish further scientific analysis of Neptune or Triton. To accomplish this task, RUAUMOKO will conduct an originative study of Neptune's moon Triton, providing non-superfluous information furthering the understanding of Triton's atmosphere, Triton's subsurface activity, and aid in the survivability of future missions. RUAUMOKO developed a direct and efficient four-probe mission to study Triton's atmosphere and subsurface at the North and South poles and two points along the equator. Identical probes Zhang (North Pole), Richter (South Pole), Williamson (Equator), and Adams (Equator) are designed to 1) Determine atmosphere composition 2) Measure temperature of atmosphere and subsurface 3) Measure pressure of atmosphere and subsurface 4) Measure seismic activity of subsurface 5) Measure location and direction.

2.0 Science Objective and Instrumentation

Probes Zhang, Richter, Williamson, and Adams (all named for contributors to seismology) have one primary objective and one secondary objective for the RUAUMOKO mission. The only mission that has observed Triton in close proximity is the Voyager 2 flyby. The primary science objective is the study of Triton's subsurface seismic activity. This study should reveal the causes to Triton's unique features such as: geysers, resurfacing, tectonic shifting, internal heating, and internal structure. To measure the subsurface activity of Triton, an inertial measurement (IMU) unit and piezoelectric accelerometer (PA) will be used in conjunction. The piezoelectric accelerometer will register a seismic event activating the IMU. The IMU will register shear waves (S-waves) and pressure waves (P-waves). The frequency and duration of these seismic waves will provide insight to geysers and resurfacing. The strength of the S-waves and P-waves will indicate the internal structure and heat flow of Triton.

The secondary objective for the RUAUMOKO mission is to determine the composition and measure the temperature and pressure of the atmosphere on Triton. This objective would determine the composition of the atmosphere possibly determining why the geysers shift their trajectory 90 degrees at an altitude of eight kilometers in the atmosphere. Measuring temperature and pressure in varying locations could also provide additional information as to the behavior of the geysers and the atmosphere.

Table 1. Science Traceability Matrix

Science Objective	Measurement Objective	Measurement Requirement	Instrument Selected
Study the subsurface activity of Triton	Study seismic and subsurface activity of Triton	North Pole South Pole Equator	Mass Spectrometer, Pressure Transducer, Thermocouple, IMU
Study the Atmospheric composition	Determine composition	On free fall from orbiter	

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Table 2. Instrument Requirements

Instrument	Type	Mass (kg)	Power (W)	Data Rate (Mbps)	Lifetime	Frequency	Duration
Mass Spectrometer	Primary	0.230	1.5	22.4	100 seconds	1	100 seconds
IMU	Primary	0.013	0.22	0.160	(min) 9,575 Seismic events	1.994 hours	30 seconds
Thermocouple	Primary	0.020 /meter	0.000006	0.0004	(min) 9,575 Seismic events	1.994 hours	30 seconds
Pressure Transducer	Primary	0.145	0.04	5.0	100 seconds	1	100 seconds

Table 3. Support Instrument Requirements

Instrument	Type	Mass (kg)	Power (W)	Lifetime	Frequency	Duration
On Board Computer	Support	0.094	0.4	(min) 9,575 Seismic events	1.994 hours	30 seconds
Antenna	Support	0.100	0.02	4 months	2.401 hours	9.481 minutes
Transmitter/ Receiver	Support	0.085	1.7	4 months	2.401 hours	9.481 minutes
Space Batteries	Support	3.00	TBD	4 months	n/a	n/a
Piezoelectric Accelerometer	Support	0.076	Self – Powered	4 months	per event	30 seconds

3.0 Payload Design Requirements

The four identical probes Richter, Adams, Williamson, and Zhang are restricted under several parameters of three different categories including project, functional, and environmental requirements. The project requirements stipulated by UAH are 1) No more than 10 kg of mass 2) Maximum volume of 29,568 cm^3 (44cm x 24cm x 28cm) 3) No harm to the UAH spacecraft 4) Complement NOTE Mission. The functional requirements of the probes that are necessary to complete the RUAUMOKO mission are: 1) Deploy from UAH spacecraft 2) House Payload 3) Provide Power 4) Take measurements 5) Collect Data 6) Send Data. The environmental requirements of the RUAUMOKO mission are: 1) Survive temperature conditions of 35 Kelvin, 2) Survive free-fall through an atmosphere with a pressure of 1.38×10^{-5} atmospheres, 3) Subsist in a medium of frozen nitrogen.

4.0 Payload Alternatives

After determining the requirements, Team RUAUMOKO broke into two teams and developed two possible concepts to effectively complete the mission and the atmospheric and subsurface science objectives. Concept 1 utilizes a simplistic sleek penetrator design to increase penetration depth. In addition, Concept 1 is capable to complete the mission but its lack structural integrity and would have a very high impact force focused on a single point of impact.

Concept 2 entails a tetrahedron shape with a truncated nose that encompasses a housing for a penetrator that breaks through a diaphragm upon impact. The shape of the tetrahedron increases air resistance, which decreases impact velocity and force, while maintaining structural integrity. It has an integrated muzzle therefore taking up less volume and mass. However, Concept 2 lacks the desired amount of simplicity.

Figure 1. Concept 1 (Penetrator)

Figure 2. Concept 2 (Tetrahedron)

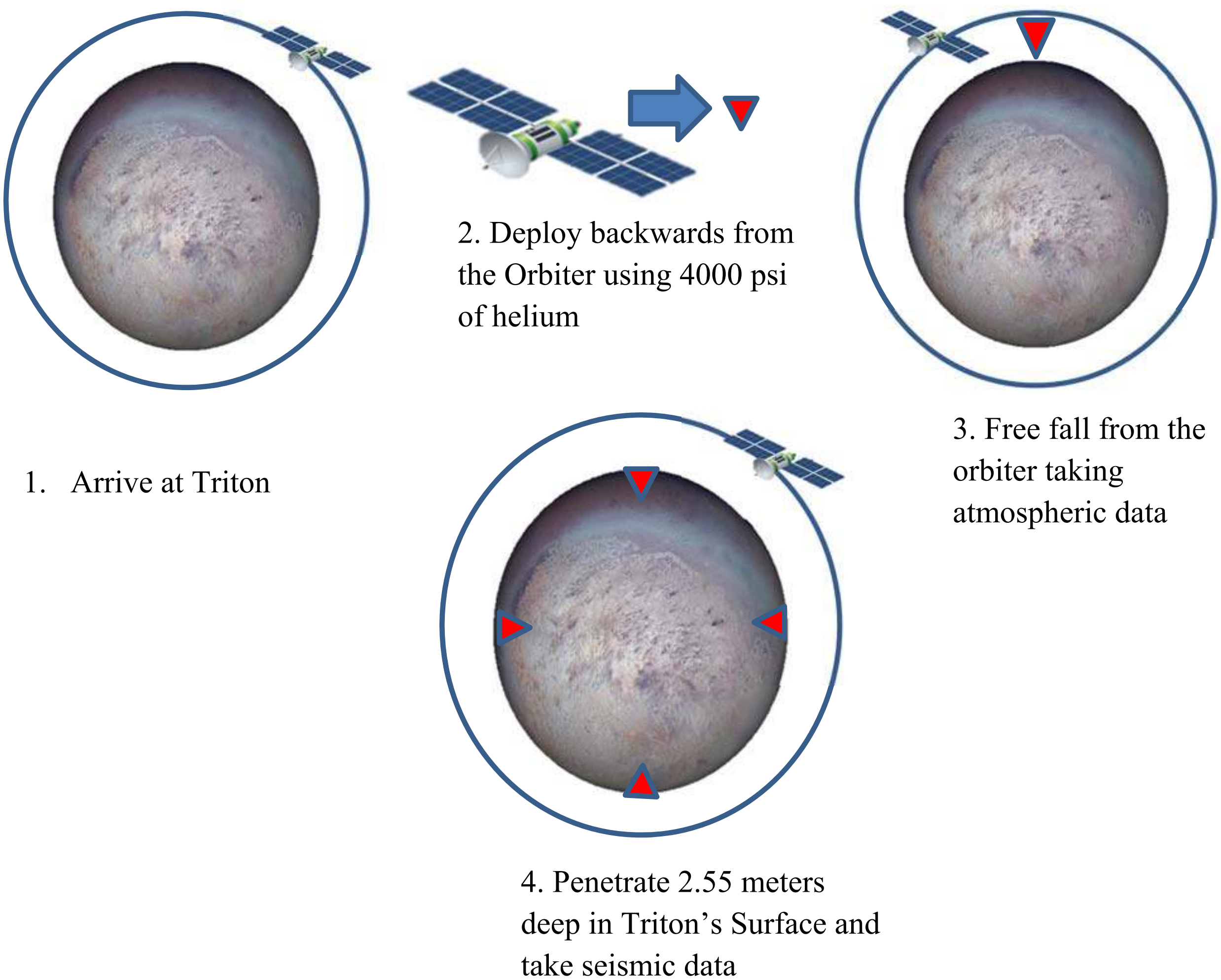
5.0 Decision Analysis

After developing the two original concepts, team RUAUMOKO completed a Figure of Merits chart for each concept to determine the most effective way to complete the mission. Three figures of merit were added to the original seven supplied by InSPIRESS. Penetration, Deployment, and Mission Success were three integral figures for the selection of the final design. Once the Figures of Merit chart was completed, a combination of the two probes was chosen due to their exceedingly close total, within two percent of each other. The final concept will utilize the best parts of each design alternative.

Table 4. Payload Decision Analysis

FOM	Weight	Penetrator		Tetrahedron	
		Raw Score	Weighted	Raw Score	Weighted
Science Objective	9	9	81	9	81
Likelihood Project Requirement	9	9	81	3	27
Science Mass Ratio	3	1	3	1	3
Design Complexity	3	9	27	3	9
ConOps Complexity	3	1	3	1	3
Likelihood Mission Success	9	3	27	9	81
Manufacturability	1	1	1	1	1
Penetration	9	9	81	9	81
Deployment	3	3	9	9	27
CEA Compatibility	3	1	3	3	9
TOTAL		**316**		**322**	

6.0 Payload Concept of Operations



7.0 Engineering Analysis

Upon determining a tetrahedral shape for all four probes and the volume of the instruments, the first issue was to survive Triton's environmental conditions. Due to the temperatures, as cold as 35 degrees Kelvin, it was concluded that a shell of insulation was imperative. Originally a shell of insulation 5 cm thick was planned to be used, an outer shell of carbon fiber (3.4 g/cm^3) 1.0 cm thick and an inner layer of aerogel (.002 g/cm^3) 4.0 cm thick. However, after multiplying their respective densities by their respective volumes it was determined the probes would be too massive to fulfill the design requirement of less than 10.00 kg mass. To conform to this constraint the insulation layers were halved (0.5 cm carbon fiber and 2 cm aerogel) to allow more freedom in designing the remainder of the probe concerning the mass constraint.

After the thickness of the insulation was finalized, the volume of the probes had to be determined. Upon consideration that all four probes had to be launched from the orbiter with a muzzle, a volume of 404.8 cm^3 (1 Probe) was decided. Using the formula for volume of a tetrahedron ($V = \sqrt{3}\frac{h^3}{8}$), the calculated height of each probe with all the insulation layers was 12.32 cm. With the total height, the height of the instruments was determined to be 7.32 cm allowing the instruments to fit easily in the inner volume of 84.86 cm^3. The primary and support equipment fit easily in this volume, not exceeding 80.00 cm^3 in volume.

After determining the height of the probe, the muzzle was the next priority. Assuming a perfect fit of the probe within the muzzle, the inner height was assigned the 12.32 cm value and an edge length of 15.088 cm. RUAUMOKO set the thickness of the of the muzzle to 0.5 cm, set the length at 0.50 m as to stay within the mass constraints and determined that half of the muzzle thickness would be an inner .25 cm of ABS plastic (1.05 g/cm^3) and the outer .25 cm would be carbon fiber (1.6 g/cm^3).

With the probe and muzzle designs completed, the orbital velocity 992 m/s of the orbiter that all four probes will deploy from was found using the equation $v = \sqrt{\frac{GM}{R}}$. In order to deorbit a sufficient amount without destroying the instruments a value of 1000 psi was selected. Using the formula $P = m \cdot \frac{V_F{}^2 - V_i{}^2}{2dA}$ the deorbit velocity found was 804 m/s.

The lifetime of the mission was determined by looking at the seismic data of Earth and it was decided that a minimum of four months would be necessary to get an in-depth look at the subsurface features of Triton. For the battery math, the Total Power Required (TPR) was determined for each instrument using the formula $TPR = \left(\frac{Lifetime}{Frequency}\right)(Duration)(Peak\ Power)$. After calculating the TPR for each instrument, the TPRs were summed and then divided by 400 W·hr/kg to find the total battery for one probe, 0.75 kg.

To transmit the data from the probes RUAUMOKO will use a conservative 90-degree angle of transmission to the orbiter overhead due to penetrating into the surface. The probes will transmit data every 2.4 hours. Each probe has a transmission window of 320 seconds (5.3 minutes). Finally, to determine the penetration depth the formula d = 0.000018(S)(N)($\frac{m}{A}$)$0.7(v - 30.5)$ was used to yield a penetration depth of 2.55 meters.

8.0 Final Design

After weeks of research, mathematical evaluation, and design analysis, RUAUMOKO showed that a combination of both the penetrator concept and the tetrahedron concept presents the most efficient, effective, and straightforward solution to accomplish RUAUMOKO's science objectives and meet the project, functional, and environmental requirements. The final design is a culmination of the best components of each design alternative. The final design consists of a tetrahedron housing the instruments necessary for completing and supporting the mission. All four probe designs are identical, reducing measurement variance to aid the science objective of comparing the composition at each four locations on the South pole, North pole, and two points along the equator. Probes Richter, Adams, Williamson, and Zhang will deploy, each having their own muzzle, using the same method of firing off the back of the orbiter using 1,000 psi of compressed helium. RUAUMOKO's probes fit well within the NOTE mission requirements, being able to survive the environment for the duration of RUAUMOKO's mission (minimum of 4 months) using 2 centimeters of aerogel insulation and 0.5 centimeters of carbon fiber along with using only 91.28% (9.128 kilograms of 10 kilograms) of the allotted mass and 73.06% (21,602 cm^3 of 29,568 cm^3) of the allotted volume.

Figure 3. Final Design

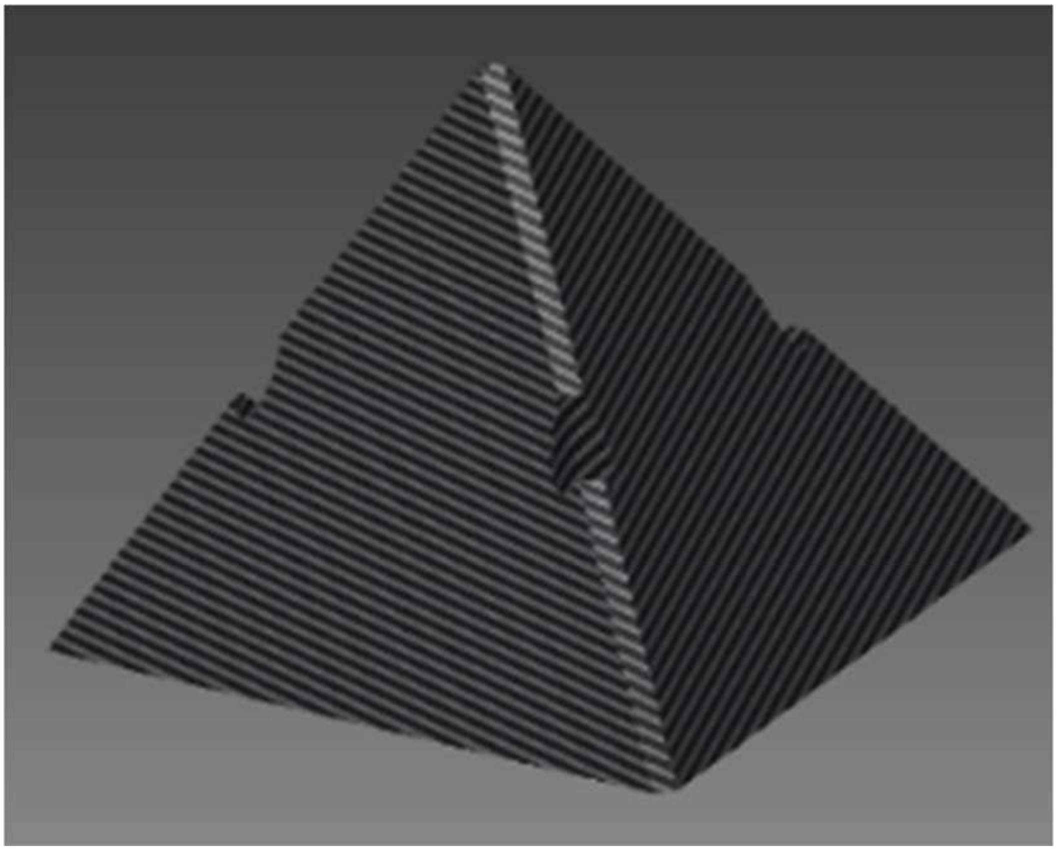


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Table 5. Final Design Mass Table

Function	Component	Mass (kg)
Deploy	Muzzle (Carbon Fiber, ABS)	0.460
Measure	IMU, Mass Spectrometer, Pressure Transducer, Thermocouple, Piezoelectric accelerometer	0.484
Provide Power	Space Batteries	0.75
House/Contain Payload	Carbon Fiber, Silica Aerogel	0.309
Collect Data	On Board Computer	0.094
Send Data	Antenna Transmitter/Receiver	0.185
Total:		2.282 kg

Figure4. RUAUMOKO's Mission