PAYLOAD CONCEPT PROPOSAL

A.T.L.A.S.

Scottsboro Team 2

“Dropping our world, Picking up another”

1.0 Introduction

As recommended by NASA's 2006 Solar System Exploration (SSE) Roadmap, the Titan Saturn System Mission (TSSM) has planned a mission to study the diverse and dynamic conditions in the ionosphere where complex organic chemistry begins, observe seasonal changes in the atmosphere, and make global near-infrared and radar altimetric maps of the surface. The TSSM was adopted by InSPIRESS under the name of the Titan Environmental and Atmospheric Measurement (TEAM) mission. In accompaniment to the TEAM mission, the Scottsboro InSPIRESS Team 2 ATLAS (Assessing Titan's Lakes by Air and Sea) was given the task by UAH of aiding the mission by designing a payload probe to accomplish further scientific analysis of the moon. To accomplish this assignment, ATLAS will perform an innovative experiment that would not be redundant to the TEAM mission, while providing results that further the understanding of Titan's hydrocarbon lakes and aid the survivability of future missions. ATLAS developed a straightforward and efficient two-probe mission to compare Titan's largest northern lake, Kraken Mare, and largest southern lake, Ontario Lacus, as well as determine the depths of the two lakes. Identical probes Peary (Kraken Mare) and Amundsen (Ontario Lacus) are designed to 1) Determine lake composition, 2) Measure lake pressure, 3) Measure speed, location, and direction, and 4) Measure lake temperature.

2.0 Science Objective and Instrumentation

Probes Peary (named for Robert Peary, the first man to reach the North Pole on Earth) and Amundsen (named for Roald Amundsen, the first man to reach the South Pole on Earth) have one primary objective and one secondary objective for the ATLAS mission. The primary objective is to compare and contrast Kraken Mare and Ontario Lacus by their composition, pressure, and temperature, which could answer the question of why Ontario Lacus is eroding noticeably while Kraken Mare is not. To compare the composition of the two lakes, a mass spectrometer will take readings as the probes sink in each respective lake. Breaking down the chemical makeup of each lake will provide insight into any potential differences between the two lakes, and possibly explain why Ontario Lacus has a higher erosion rate. A pressure transducer will be utilized to measure pressure within each lake. According to Boyle's Law ($PV = k$), if the pressure on Ontario Lacus is less than that on Kraken Mare, Ontario Lacus will have a higher rate of evaporation. This would explain Ontario Lacus' erosion. Along these same lines, a thermocouple will be employed to measure the temperature of the two lakes. According to Charles' Law, ($\frac{V}{T} = k$), if the temperature of Ontario Lacus is higher than that of Kraken Mare, then Ontario Lacus will have a higher rate of evaporation, again explaining Ontario Lacus' erosion. While each probe is descending into its respective lake, an IMU will be used to measure the speed, location, and direction of the probe to put the measurements into context.

The secondary objective of the ATLAS mission is to determine the depth of both Kraken Mare and Ontario Lacus. This objective serves several purposes. If Ontario Lacus is shallower than Kraken Mare, that would explain the greater erosion and evaporation that Ontario Lacus has experienced. Also, knowing the depth of the two lakes would aid further exploration of Titan. An IMU will track the velocity and location of each probe, and by multiplying the average velocity by the total sinking time the lake depth can be calculated.

Table 1. Science Traceability Matrix

Science Objective	Measurement Objective	Measurement Requirement	Instrument Selected
Compare and Contrast Kraken Mare and Ontario Lacus	Determine composition	Sinking in Kraken Mare and Ontario Lacus for 24 hours (separate probes)	Mass Spectrometer
	Measure pressure in lakes		Pressure Transducer
	Measure speed, location, and direction of probes		IMU
	Measure temperature in lakes		Thermocouple
Determine Lake Depth	Determine depth of Kraken Mare and Ontario Lacus		IMU

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	24 hr	3 hr	2 s
IMU	Primary	0.013	0.22	0.160	24 hr	Continuous	24 hr
Thermocouple	Primary	0.020	6.0 E-6	4.0 E-4	24 hr	3 hr	5 s
Pressure Transducer	Primary	0.145	0.04	5.0	24 hr	3 hr	10 s
On Board Computer	Support	0.094	0.40	N/A	24 hr	Continuous	24 hr
Antenna	Support	0.100	0.02	N/A	24 hr	12 hr	0.5 s
Transmitter/Receiver	Support	0.085	1.7	N/A	24 hr	12 hr	0.5 s
Space Batteries	Support	0.037	714	N/A	24 hr	Continuous	24 hr

3.0 Payload Design Requirements

Probes Peary and Amundsen have several prerequisites they must meet that are separated into three different parameters: project, functional, and environmental. The project requirements stipulated by UAH are 1) No more than 10 kg of mass, 2) Maximum volume of 29,568 cm^3, 3) No harm to the UAH spacecraft, and 4) Compliment TEAM mission. The functional requirements of the probes that are necessary to complete the ATLAS mission are: 1) Deploy from UAH spacecraft, 2) House payload, 3) Provide power, 4) Take measurements, 5) Collect data, and 6) Send data. The environmental requirements of the ATLAS mission are: 1) Survive temperature conditions ranging from 70-180 Kelvin, 2) Subsist in medium of liquid hydrocarbon, and 3) Endure pressure of 1.631 atmospheres.

4.0 Design Choices

The UAH TEAM baseline mission consists of three vehicle elements: a lake lander floating on Kraken Mare that is 200 kilometers from the shore, a balloon and gondola floating 10 kilometers above Titan's surface that is propelled by the wind, and an orbiter that is in a 1000 kilometer circular orbit around Titan. ATLAS determined that in order to deploy into Kraken Mare, probe Peary will drop from the bottom of the lake lander using gravity. This deployment method is simple, requiring no additional mass and avoiding problems with tidal wave motion, and accomplishes the ATLAS mission goal of the probe sinking into Kraken Mare without damaging the UAH lander.

In order to deploy into Ontario Lacus, probe Amundsen will launch backwards from the orbiter using pressurized helium. Launching backwards from the orbiter is necessary because probe Amundsen must achieve de-orbit to land in Ontario Lacus. By launching backwards, the forward velocity of the probe is reduced, allowing Amundsen to descend to Titan's surface. Since probe Amundsen will be descending at an extremely fast velocity due to free fall, a parachute will be deployed when Amundsen is 10 kilometers above Ontario Lacus. The parachute will slow the fall of Amundsen, ensuring that the probe will impact the lake safely.

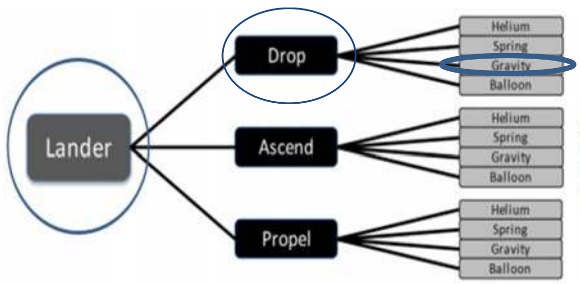

Figure 1. Peary Trade Tree

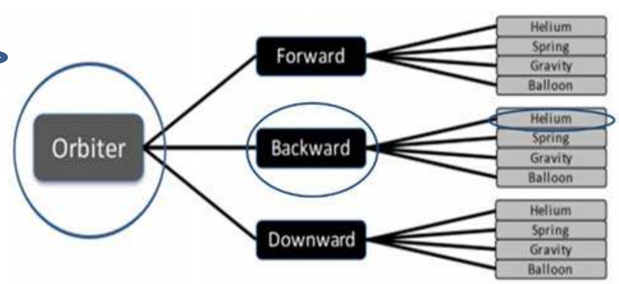

Figure 2. Amundsen Trade Tree

5.0 Preliminary Design

Team ATLAS originally developed two design concepts to accomplish the determined science objectives. The original concept for probe Peary was a glider with a cylindrical fuselage where the instruments would be contained. The spring-loaded wings would be housed in the fuselage while en route to Titan, but when deployed from the muzzle the wings would engage. The concept for probe Amundsen is a spherical shell with an inner cavity to house the instruments. A small hole is located in the middle of the sphere for liquid hydrocarbon to run through while being analyzed by the mass spectrometer. Due to the error potential of the wings failing to engage properly on probe Peary, along with the goal of reducing variance in the mission, the team elected to use the original probe Amundsen concept for both probes.

Table 3. Functional Requirements

Probe	Deploy from UAH Spacecraft	Take Measurements	Collect Data
Amundsen	Muzzle (pressurized Helium)	IMU, Mass Spectrometer, Pressure Transducer, Thermocouple	On-Board Computer
Peary	Drop		

Probe	Send Data	Provide Power	House Payload
Amundsen	Antenna, Transmitter/Receiver	Space Batteries	Technora, Aerogel, Carbon Fiber
Peary			

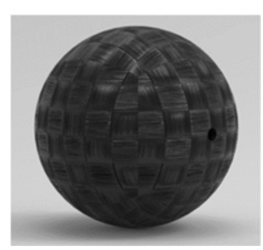

Figure 3. Preliminary Design Concept

6.0 Design Analysis

Upon confirming the spherical concept for both probes, the first issue to address was surviving Titan's environmental conditions. Due to the extreme cold (70-181 Kelvin), it was concluded that a shell of insulation to protect the instruments was necessary. Originally, the shell was planned to be 6 cm in radius, with an outer shell of Technora (1.39 g/cm^3) 1.0 cm thick, a middle shell of Aerogel (0.02 g/cm^3) 4.0 cm thick, and an inner shell of carbon fiber (1.6 g/cm^3) 1.0 cm thick. However, after calculating the mass of the Technora and carbon fiber layers by multiplying their respective volumes by their respective densities, the excessive mass from the two layers was deemed too great, so a thinned layer of 0.5 cm each of Technora and carbon fiber was employed. This allowed greater freedom when designing the rest of the probe in terms of the mass restraint.

After the insulation thickness was finalized, the next question was the radius of the entire probe. Upon consideration that a muzzle would be required to launch Amundsen from the orbiter, ATLAS set the volume of each probe at 13,551.68 cm^3, less than half of the volume limit of 29,568 cm^3. Using the formula for volume of a sphere ($V = \frac{4}{3}\pi r^3$), the calculated radius of each probe was 14.79 cm. With this total radius, the radius of the inner cavity became 9.79 cm. ATLAS then calculated the volume of the inner cavity, 3,930.4 cm^3. The primary and support equipment easily fit within this volume, not exceeding 50 cm^3.

After finding the radius for each probe, the muzzle design was the next priority. Assuming a perfect fit of the probe in the muzzle, the radius of the inner barrel of the muzzle was assigned the 14.79 cm radius value. ATLAS then finalized the radius of the muzzle shell at 0.25 cm, set the length of the muzzle at 20 cm, and determined that the material utilized in the muzzle would be ABS (Acrylonitrile Butadiene Styrene) plastic (1.07 g/cm^3).

With the probe and muzzle designs completed, the orbital velocity 1,584.598 m/s of the orbiter that Amundsen will deploy from was found using the equation $v = \sqrt{\frac{GM}{R}}$. In order to cause Amundsen to de-orbit by decreasing its forward velocity to 1,250 m/s from the orbital velocity, the formula $P = m \cdot \frac{V_F{}^2 - V_i{}^2}{2dA}$ was utilized by ATLAS to calculate the pressure of helium necessary to achieve this velocity, yielding 2,218 psi.

Employing the formula $d_y = v_i t + \frac{1}{2} g t^2$ to find the time Amundsen will take to reach 10 km above the surface (where the parachute will deploy), ATLAS found the elapsed time to be 1,210.16 s. Using this time and 1,250 m/s for the equation $v = \frac{\Delta d}{\Delta t}$, the team calculated the horizontal distance from Ontario Lacus to the required release point from the orbiter to equal 1,512.700 km.

Now that the horizontal distance from the parachute release point was determined, the formula $tan^{-1} = \frac{opposite\ distance}{adjacent\ distance}$ showed that Amundsen's necessary angle of deployment from the orbiter is 33.2°.

To find the area of Amundsen's parachute, the team concluded that the fastest falling velocity for a safe landing was 4.26 m/s. Then, the formula for area of a parachute ($A_p = \frac{2mg}{pC_D V^2}$), was used to find 21.3 cm^2 for the parachute area.

For the battery math, ATLAS determined the Total Power Required (TPR) for each instrument using the formula $TPR = (\frac{Lifetime}{Frequency})(Duration)(Peak\ Power)$. After calculating the TPR for each instrument, the team combined the TPRs and then divided this sum by 400 W·hr/kg to find the total mass of the battery on one probe, 0.0372 kg.

To transmit the data from probe Amundsen, ATLAS will use a conservative 45 degree angle of transmission to the orbiter overhead due to a mountainous region north of Ontario Lacus. Amundsen will make these transmissions twice (every 12 hours) with a window of 8.26 minutes, while sinking in Ontario Lacus at a rate of 21.85 m/s, found using the formula $v = \sqrt{\frac{2mg-2\rho g V_d}{\rho C_D S}}$. Probe Peary will simply transmit its data to the lake lander from which it deployed, from where the data will be stored and then sent to the orbiter overhead.

7.0 Final Design

After weeks of research, mathematical evaluation, and design analysis, ATLAS showed that the spherical probe concept employed in both probes Peary and Amundsen presents the most efficient, effective, and straightforward answer to ATLAS's science objectives. The final design consists of a spherical shell of insulation housing instruments necessary for taking measurements and transmitting data. The probe designs are identical, reducing measurement variance to aid the science objective of comparing and contrasting Kraken Mare and Ontario Lacus. Probe Peary will drop off the bottom of the UAH lake lander on Kraken Mare, minimizing the risk of harming the UAH lander, avoiding the tidal waves on Kraken Mare's surface, and taking up no mass for deployment. The muzzle used to deploy probe Amundsen utilizes Amundsen's shape to effectively launch the probe while conserving mass and volume due to the strength and low density of ABS. The ATLAS probes fit well within the TEAM mission requirements, being able to survive the environment for the duration of the ATLAS mission (24 hours) using a total of 5 cm of insulation, along with using 80% of the allotted mass (8 kg out of 10 kg) and 93.3% of the allotted volume (27,573.97 cm^3 out of 29,568 cm^3).

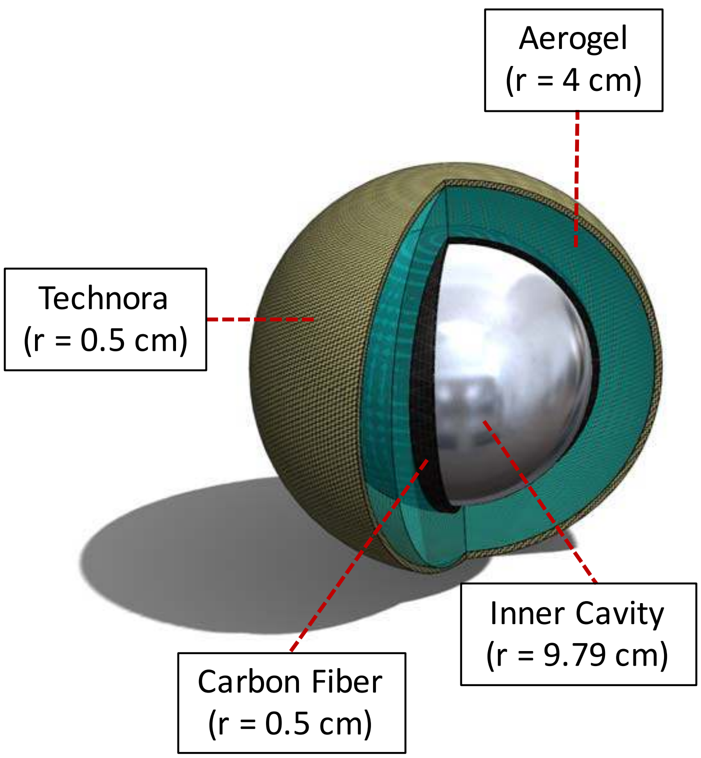

Figure 4. Final Design

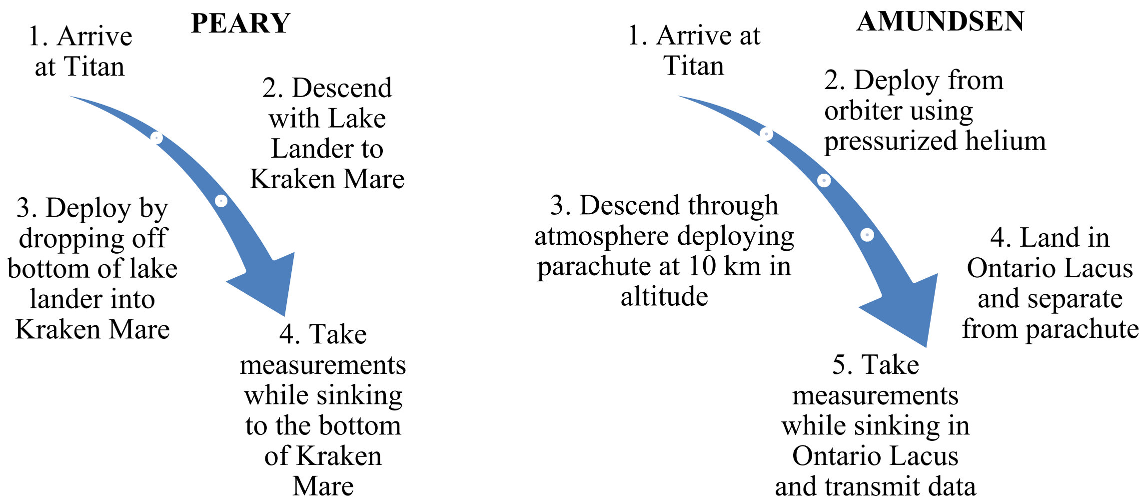

Figure 5. ATLAS's Mission

Table 4. Amundsen Final Design Mass Table

Function	Component(s)	Mass (kg)
Deploy	Muzzle, Parachute	0.501
Measure	Mass Spectrometer, IMU, Thermocouple, Pressure Transducer	0.408
Collect Data	On Board Computer	0.094
Provide Power	Space Batteries	0.037
Send Data	Antenna, Transmitter/Receiver	0.185
House/Contain Payload	Technora, Aerogel, Carbon Fiber	3.026
Total		4.25

Table 5. Peary Final Design Mass Table

Function	Component(s)	Mass (kg)
Deploy	None	0
Measure	Mass Spectrometer, IMU, Thermocouple, Pressure Transducer	0.408
Collect Data	On Board Computer	0.094
Provide Power	Space Batteries	0.037
Send Data	Antenna, Transmitter/Receiver	0.185
House/Contain Payload	Technora, Aerogel, Carbon Fiber	3.026
Total		3.75 Combined: 8