PAYLOAD CONCEPT PROPOSAL

Team Glacies

New Century Technology High School

Team #2

"Cooler than the rest"

1.0 Introduction

Team Glacies is a team of high school students participating in UAH's inSPIRESS competition. Over the course of the last few months, we have designed a probe that plans to study the deep atmosphere of Neptune. A compact, rounded cylinder will house the instruments and equipment as it deorbits and falls into the planet. This probe has been nicknamed the Marshmallow Design, and its science objective is to analyze the properties and composition of Neptune's atmosphere. Specifically, it will look for liquid water in the lower parts of the atmosphere, where pressure is very high. The probe was designed to be robust so that it can withstand this pressure as well as other environmental conditions, such as low temperatures and high wind speeds. Altogether, Team Glacies has carefully engineered the Marshmallow to expand our limited knowledge about the interior of Neptune.

We have also developed a strong and competitive team identity. Our slogan, "Cooler than the rest," reflects our drive to go above and beyond in our payload design and other aspects of the competition. Hopefully this payload concept proposal will show this determination for excellence.

2.0 Science Objective and Instrumentation

Our two primary science objectives are atmospheric measurement and water/liquid measurement. The data we retrieve from the atmosphere could allow us to make more successful missions to Neptune by knowing how dense the different sections of Neptune are, how the atmosphere might affect the spacecraft, or even how dangerous the atmosphere of Neptune is to a human. Neptune's atmosphere may even be home to a previously unknown compound that could be analyzed and recreated for study here on Earth. The data that is collected could give insight to the creation of the solar system and might help us know more about what happened all that time ago.

The second objective could allow us to understand more about Neptune's magnetic field. We have learned that one of the few known facts about Neptune is that it has a tilted magnetosphere. This is possibly due to a body of water, or possibly some other liquid. If there is a substantial amount of water found in the atmosphere of Neptune, then we could possibly sustain life far from earth in the outer reaches of the solar system. Since almost nothing is known about Neptune's atmosphere, we believe that these science objectives will help us learn the most with only one trip.

Table 1. Science Traceability Matrix

Science Objective	Measurement Objective	Measurement Requirement	Instrument Selected
Atmosphere	Directly measure temperature, pressure, wind speed, acidity, and electric charge	Probe must withstand pressure, temperature, and winds	Mass spectrometer, thermocouple, pressure transducer, magnetometer
Water/Liquids	Composition, pressure, and temperature of the lower atmosphere	Probe must withstand pressure, temperature, and winds	Mass spectrometer, thermocouple, pressure transducer, magnetometer

Table 2. Instrument Requirements

Instrument	Mass (kg)	Power (W)	Data Rate (Mbps)	Dimensions (cm)	Lifetime	Frequency	Duration
Mass spectrometer	0.230	1.50	22.3	0.045 × 0.50 × 0.80	7.5 hours	5 minutes	1 minute
Thermocouple	0.020	-	1.0×10^{-4}	100 cm long	7.5 hours	continuous	continuous

Pressure transducer	0.031	0.04	1.0	2.2 diameter, 8.6 length	7.5 hours	continuous	continuous
Magnetometer	0.5	1.5	0.0008	21 × 19 × 8	7.5 hours	continuous	continuous
IMU	0.013	0.22	1.60	22.2 × 2.4 × 0.3	7.5 hours	continuous	continuous
Visual image system	2.0	5.0	10.240 per image	10 × 10 × 10	7.5 hours	5 minutes	0.5 minute

Table 3. Support Equipment

Component	**Mass (kg)**	**Power (W)**	**Data Rate**	**Other Technical Specifications**
On-board computer	0.094	0.5	2 × 2 GB	ISIS on board computer 400 MHz, ARM9 processor, 64 MB RAM
Transmitter/receiver	0.085	1.7	9600 bps max for downlink; 1200 bps max for uplink	ISIS VHF/UHF duplex transceiver
Antenna	0.100	0.02	-	Deployable antenna system
Batteries	0.090	-	-	Mass based on power required

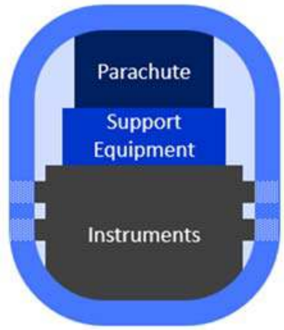
3.0 Payload Design Requirements

To fulfill the science objectives in Neptune, the payload must meet project, functional, and environmental requirements. The project requirements constrain volume to 44 × 24 × 28 cm, limit mass to 10 kg, and prevent the probe from harming the orbiter. The functional requirements determine procedures that need to be executed by the payload while it is conducting the mission. The probe must deploy from the main spacecraft, take measurements, collect data, provide power, send data to the main spacecraft, and house the payload. To reach an area of Neptune where liquid water could be found, the probe must withstand a pressure of 50 bars, fall at a reasonable velocity, have a density that will allow it to dive at least 100 km into the atmosphere, and survive the freezing cold temperatures. We had to be mindful of these constraints as we developed and finalized our design.

4.0 Payload Alternatives

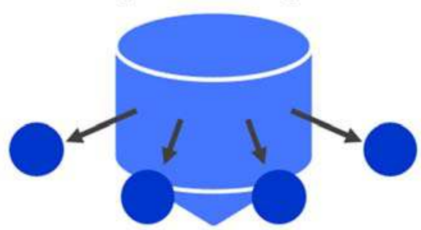
While in the process of developing the payload, the team created two alternative design concepts. Aside from the given constraints, qualities such as resilience and area coverage during the measurement period were considered. Concepts 1 and 2 – nicknamed the "Marshmallow Design" and the "Scatter Design", respectively – comply with these guidelines and approach the scientific objectives in unique manners.

Figure 1. Concept 1



The Marshmallow Design (Fig. 1) includes a cylindrical capsule that contains instruments for data collection and transmission, support equipment, and a parachute that increases drag when necessary. The capsule has a diameter of 20 cm. The rounded edges of the capsule reduce unwanted drag and make the probe more resistant to high pressures. The external walls are wrapped with carbon fiber and the gaps between instruments and equipment are filled with aerogel to insulate the internal systems. Certain instruments (see Table 2) will achieve direct contact with the atmosphere and collect data by extending through open ports on sides of the capsule. These instruments are housed in the lower compartment. The support equipment (see Table 3) will be housed in the central compartment. A 0.09 kg battery will be used to provide power to the entire system; this will also be housed in the central compartment. The parachute is housed in the upper compartment. The payload is launched through a barrel that is 40 cm in length using compressed helium. This design will be able to dive deep into Neptune's lower atmosphere and analyze the properties and composition there.

Figure 2. Concept 2



The Scatter Design (Fig. 2) includes a cylindrical capsule that contains many spherical units that houses instruments for data collection and transmission and support equipment. A conic section has been attached to the bottom of the capsule to improve the aerodynamics of the system. Like the Marshmallow Design, this concept includes thick, insulated exterior walls to increase resistance to the extreme environmental conditions of the planet. Each spherical subunit contains its own instruments for data collection. They are expelled from the capsule through open ports in the exterior walls. The instruments are then deployed from each unit in a similar manner to collect data. Each unit also contains required support equipment (see Table 3) and a 0.09 kg battery to provide power. The entire system is launched through a barrel that is 40 cm in length using compressed helium. Overall, these smaller probes will be able to disperse and analyze the wind patterns of Neptune.

5.0 Decision Analysis

To determine which concept we would use for our final design, we created a decision analysis table. In addition to the provided FOMs, we added three of our own: stability inside atmosphere, structural integrity, and protection during atmospheric entry. The Scatter Design might not be able to reach the depths necessary to find liquid water, so it got a lower score for the likelihood of meeting project requirements and structural integrity. The Marshmallow Design's concept is much less complicated because it does not deploy smaller probes, so it got a higher score for ConOps complexity and manufacturability. The likelihood of mission success is equally high for both concepts because both designs would complete their different tasks. Despite this, the other factors caused the Marshmallow Design to be chosen as the overall winner.

Table 4. Payload Decision Analysis

Figure of Merit	Weight	Marshmallow Design		Scatter Design	
		Raw Score	Weighted	Raw Score	Weighted
Science Objective	3	3	9	3	9
Likelihood Project Requirement	9	9	81	3	27
Science Mass Ratio	9	3	27	3	27
Design Complexity	9	3	27	3	27
ConOps Complexity	3	3	9	1	3
Likelihood Mission Success	9	9	81	9	81
Manufacturability	3	3	9	1	3
Stability Inside Atmosphere	3	9	27	3	9
Structural Integrity	3	9	27	3	9
Atmospheric Entry Protection	3	3	9	3	9
Total			**306**		**204**

6.0 Payload Concept of Operations

The Concept of Operations (ConOps) for the payload consists of four major phases: the Initial Conditions Phase, the Deployment Phase, the Measurement Phase, and the Ending Conditions Phase. Prior to the first phase, the payload will be transported to the planet Neptune via the Orbiter vehicle. The Initial Conditions Phase will begin when the vehicle reaches an altitude of 3000 km above Neptune's "surface" (the point at which the atmospheric pressure of the planet is approx. 1 bar). At this altitude, the Orbiter vehicle will maintain a circular polar orbit around the planet. During this phase, the probe will remain inside a barrel aboard the Orbiter vehicle and all systems will be powered off.

Once the Marshmallow has been authorized to launch, the Deployment Phase will begin. The payload will be oriented towards the bottom of the Orbiter vehicle to ensure proper deployment. The capsule will then be launched from the barrel, whereupon the system will deorbit and fall towards the planet's atmosphere. All instruments will remain unengaged until the probe begins to experience drag from the atmosphere, around 100 km above the "surface".

When the capsule has reached the equator of the planet and has achieved an altitude of 100 km, the Measurement Phase will begin. A parachute will be deployed to reduce speed and all instruments will be engaged. Data relating to atmospheric composition (i.e. acidity, wind speeds, pressure, temperature, and conductivity) and liquid properties (i.e. composition, pressure, and temperature) of the planet will be collected, stored, and transmitted to the Orbiter vehicle during this phase. After the Measurement Phase is complete, the system will eventually enter the Ending Conditions phase, at which point the probe will be crushed 160 km inside the atmosphere by an external pressure of at least 80 bars.

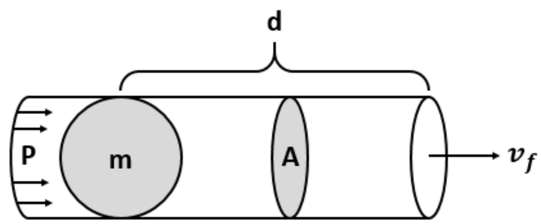
7.0 Engineering Analysis

The details of the payload design can be determined by making some important calculations. In the Initial Conditions Phase, the orbital velocity of the Neptune Orbiter, and the probe onboard, was calculated by combining the equations for the force of gravity and centripetal motion. Velocity would be equal to

$\sqrt{\frac{GM}{r}}$, with G as the gravitational constant, M as the mass of Neptune, and r as the radius of the orbit. Assuming the orbit is perfectly circular with a radius of 3,000 km, orbital velocity would be 15,808 m/s.

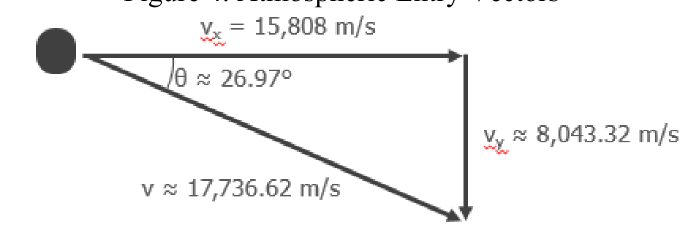
During the Deployment Phase, the probe will be shot out downwards with helium pressure in the barrel (see Figure 3). The equation $v_f^2 = v_i^2 + 2\left(\frac{PA}{m}\right)d$ was manipulated to find the pressure that would be used. Final velocity v_f, the velocity of the probe as it leaves the barrel, must be at least 1% of the orbital velocity, so it was decided to be 158 m/s. Initial velocity v_i is zero because the probe is not moving within the barrel. The cross-sectional area of the barrel A was determined to be 0.03142 m^2 because the radius of the probe is 10 cm. The payload's mass m was approximated to be 7 kg at this stage. Finally, the length of the barrel d will be 40 cm so that it fits within the payload's size constraints. From this information, the pressure P that needs to be used is about 6.95 x 10^6 Pa, or 1,008 psi.

Figure 3. Deployment Barrel



Trigonometry and kinematic equations can be used to find the angle and speed that the probe will enter the atmosphere after falling thousands of kilometers into Neptune (see Figure 4). Horizontal velocity will not change after the probe leaves the Orbiter, so it is the same as the orbital velocity. Vertical velocity, however, increases due to the acceleration of Neptune's gravity. Therefore, after falling from orbit to the altitude of 100 km, the probe will be travelling at 17,737 m/s with an angle of 27°. The time it takes to do this is about 11.79 minutes.

Figure 4. Atmospheric Entry Vectors



A parachute will be used to slow the probe during the Measurement Phase. Its diameter would be equal to $\sqrt{\frac{8mg}{C_D v^2 \rho \pi}}$, with m as the probe's mass, g as the acceleration of gravity, C_D as the coefficient of drag, v as the terminal velocity, and ρ as the density of the atmosphere. The terminal velocity was decided to be 10 m/s. The probe needs to travel to part of the atmosphere with a pressure at least 50 bars, where liquid water would be found, but it is designed to go to 80 bars. So, the average density of the atmosphere to that point will be about 2 kg/m^3. The diameter of the chute was therefore found to be 0.663 m.

After about 7.22 hours of the Measurement Phase, the probe finally reaches the Ending Conditions Phase. To successfully reach this part, the probe's walls need to resist atmospheric pressure up to 80 bars. The equation $P_{CR} = \frac{0.37E}{(r/T)^2}$ can be used to find the wall thickness needed to achieve the crushing pressure P_{CR}. Aluminum (6061-T6) was decided to be the wall material, which has a modulus of elasticity E of 69 GPa. The wall thickness T would consequently be 0.18 cm; however, this equation assumes that the probe is a sphere, so the thickness will be rounded up to 0.2 cm for extra strength. The mass of these walls can be determined now. The probe is a cylinder with a radius of 10 cm and a height of 20 cm, and the density of this kind of aluminum is 2.7 g/cm^3, therefore the mass is approximately 1.038 kg.

Finally, to calculate battery mass, the power required over time by all the instruments and equipment must be determined. The total time of flight is about 7.5 hours, making the required total power 35.85 watt-hours. Space batteries give 400 watt-hours per kg, so our battery will be 0.9 kg.

8.0 Final Design

To summarize all this information, our payload is a cylinder nicknamed the Marshmallow Design. It will deorbit from the Neptune Orbiter and fall about 160 km into the atmosphere of Neptune until it is crushed under 80 bars of pressure. As it falls, its objectives are to measure the properties and composition of the atmosphere and to look for liquid water. In the beginning, this design was merely a concept with little substance; however, as engineering analysis was performed it began to take shape. We found that the pressure needed to deploy from the Orbiter it was about 1,000 psi, the diameter of the parachute should be 66.3 cm, and that the aluminum walls should be 0.2 cm.

The payload meets the project requirements because it has a mass less than 10 kg (see Table 5), fits within the volume constraints, and does not harm the main spacecraft. It deploys with a barrel, takes measurements with various instruments, collects data with its on-board computer, provides power with its battery, sends data with the transmitter/receiver and antenna, and has walls to house itself. To meet the environmental requirements, it can withstand well over 50 bars of pressure, has a reasonable terminal velocity of 10 m/s, and is dense enough to fall below 100 km into the atmosphere. To protect itself from the cold temperatures of Neptune, carbon fiber insulation will be used on the outside of the walls and aerogel will be used to fill voids on the inside. Altogether, this design will be able to successfully fulfill its science objectives, meet requirements, and complete its important mission.

Figure 5. Team Glacies's Mission

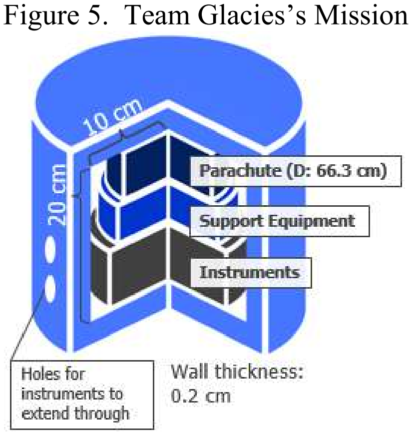


Table 5. Final Design Mass Table

Function	Component(s)	Mass (kg)
Deploy	Barrel, parachute	3.000
Measure	Mass spectrometer, thermocouple, pressure transducer, magnetometer, IMU, visual image system	2.894
Collect Data	On-board computer	0.094
Provide Power	Battery	0.090
Send Data	Transmitter/receiver, antenna	0.185
House/Contain Payload	Walls	1.038
Total		**7.301**