Payload Concept Proposal
Gelid Sapphire

Da Vinci Team 2

"Tune into Neptune"

1.0 Introduction

Neptune, the eighth planet from the sun, is not only distinctive because of its bright blue color or its harsh weather conditions, but also because of its extremely unique magnetic field that goes through dramatic changes as it interacts with the solar wind. Due to its complexity, Neptune's magnetic field is still poorly understood. Team *Gelid Sapphire*, in cooperation with UAH, has made it its main objective to research Neptune's truly intriguing magnetic field. Our payload, "The Arrow," was specifically designed to propel from the orbiter provided by the university and determine the strength and direction of the magnetic field.

- Our team name, Gelid Sapphire, is a representation of where our mission will take place, Neptune. The word gelid means icy and extremely cold, which is fitting for Neptune's exceptionally low temperatures. Sapphire is simply a symbol for Neptune as a beautiful, vibrant, blue gem.
- Our slogan, "Tune into Neptune," is a friendly invitation for people to stay informed of the progress of our project and be aware of new findings and research of the planet.

2.0 Science Objective and Instrumentation

Gelid Sapphire's principal science objective is to determine the strength and direction of Neptune's magnetic field. Additionally, we will take advantage of the mission to also conduct research on the upper atmosphere, as it linked well with the focal interest of our mission. We chose this objective because of the unpredictable and peculiar behavior of Neptune's magnetic field. Many aspects of the field and how they affect the planet are still vague or unknown. Conducting research on the magnetic field would serve to give us an insight on the planet's behavior and structure, as well as that of other planets with similar magnetospheres, such as Uranus. Our primary instruments utilized for the magnetic field are the magnetometer and Langmuir probes. One of the biggest challenges our mission poses is being able to accurately obtain data of the atmosphere during a very short period of time. However, due to the fact that our science instruments take measurements almost immediately, we should successfully be able to overcome this barrier. The main instruments used for the atmospheric readings will be the mass spectrometer, pressure transducer, and thermocouple. Based on the challenges posed by our mission, we will need to survive about 13 minutes to successfully complete our readings.

Table 1. Science Traceability Matrix

Science Objective	Measurement Objective	Measurement Requirement	Instrument Selected
Magnetic Field	Determine the strength and direction of magnetic field	Survive a minimum of thirteen minutes to obtain measurements	Magnetometer, Langmuir probe
Atmosphere	Determine the properties and composition of atmosphere	Enter lower atmosphere and begin measurements	Mass spectrometer Pressure Transducer Thermocouple

Table 2. Instrument Requirements

Instrument	Mass (kg)	Power (W)	Data Rate (Mbps)	Dimensions (cm)	Lifetime (s)	Frequency	Duration
Mass Spectrometer	0.230	1.5	22.4000	0.45 x 0.50 x 0.80	140.00	Continuous	N/A
Thermocouple	0.020	N/A	0.0004	2	140.00	Continuous	N/A
Pressure Transducer	0.131	0.04	1.0000	2.2 dia x 8.6 length	140.00	Continuous	N/A
Magnetometer	0.5	1.5	0.0008	2.1 x 1.9 x .8	795.66	Continuous	N/A
Langmuir Probe	0.5	0.5	0.0800	4 antenna, each 0.05 dia x 2.5 length	795.66	Continuous	N/A

Table 3. Support Equipment

Component	Mass (kg)	Power (W)	Data Rate	Other Technical Specifications (mm)
On-Board Computer	0.094	0.4	2 x 2 GB Onboard Storage	96 x 90 x 12.4
Transceiver	0.085	1.7	Up to 9600 Bps down-link; Up to 1200 bps uplink	96 x 90 x 15
Antenna	0.100	0.02	Up to 9600 Bps down-link; Up to 1200 bps uplink	98
Batteries	0.00267 required, using .005	N/A	N/A	Size depends on power required

3.0 Payload Design Requirements

Project requirements place constraints on size and construction, but also provide necessary resources to conduct research. Our payload may not exceed ten kilograms of weight, a volume of 44cmx24cmx28cm; it must provide continuous power, access to data delivery system, and must keep an internal temperature of 294 K. It must be able to contain the instruments needed to conduct our objective and have enough power to sustain them for the time needed to complete it. Although these restrictions placed by the University of Huntsville at Alabama proved to make designing a payload capable of successfully conducting research a difficult task, it allowed team Gelid Sapphire to expand its creativity and strive to create a proper payload. Additionally, we were given functional requirements such as deploying from the spacecraft and housing the payload.

4.0 Payload Alternatives

Initially, Gelid Sapphire came up with three preliminary payload designs for our mission. All three designs were relatively similar and variations of each other. We went through the process of brainstorming and elimination. Each member of the team created a draft for a payload, no matter how absurd the design was. This part of the process allowed us to be creative and innovative, exploring all the options we had while creating our payload. For our first drafts, we used an iOS application called 3D Creationist. Once we had defined ideas, we improved them with a 3D rendering software called Blender. After ruling out several of our ideas, we were left with three choices: "The Firecracker," "Blue Ring," and "The Arrow."

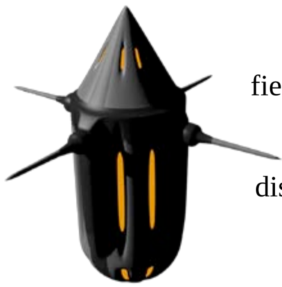


Figure 1. "The Firecracker"

"The Firecracker"

The Firecracker was fashioned to accurately map out Neptune's magnetic field. The Langmuir probes are strategically placed at right angles to determine properties of the plasma and to map out the field. The Firecracker's main mission would be to measure ion current density, and electron energy distribution.

Figure 2. "Blue Ring"

"Blue Ring"

Our second payload, Blue Ring, was designed to have a focus on taking measurements of the atmospheric properties and composition. The cone tip would provide a heat shield capable of withstanding the velocity in order for the payload to obtain data. The unmistakable blue ring around the payload would safely house scientific instruments.

Figure 3. "The Arrow"

"The Arrow"

Our final design, the Arrow, was created to successfully carry out both of our missions, the magnetic field and upper atmosphere, with ease and efficiency. Its simplicity allows for proper weight distribution and safe housing for all the instruments. The cone tip and basic cylinder shape would help direct movement and prevent swaying.

5.0 Decision Analysis

In order to choose the ideal payload to accomplish our science objective, we created a decision matrix. The figures of merit (FOM) provided a model for what was most important in our desired payload. We used this criterion to rate each of our designs. We took into consideration the various functions each design was expected to do and ranked them based on how well they perform said functions. Based on the results from the decision matrix, the concept we chose is "The Arrow." It ranked the highest on the matrix, as it met the criteria better than all of the other design choices and met the six functional requirements the best.

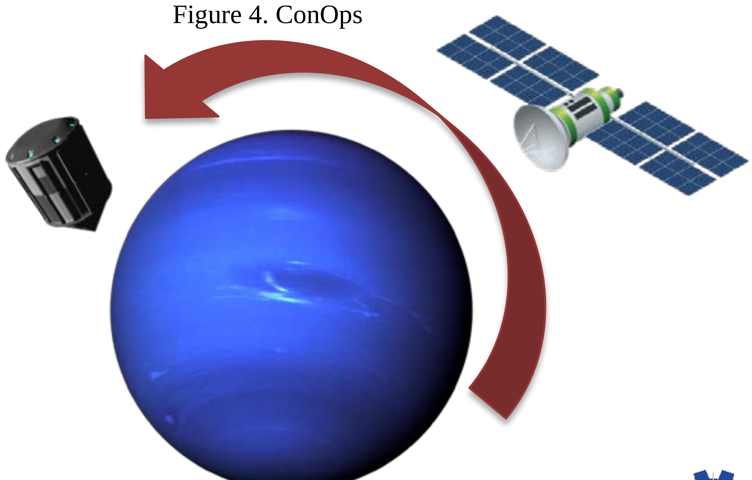
Table 4. Payload Decision Analysis

Figure of Merit	Weight	The Firecracker		Blue Ring		The Arrow	
		Raw Score	Weighted	Raw Score	Weighted	Raw Score	Weighted
Science Objective	9	9	81	3	27	9	81
Likelihood Project Requirement	9	9	81	9	81	9	81
Science Mass Ratio	3	3	9	9	27	3	9
Design Simplicity	1	3	3	9	27	3	3
ConOps Complexity	9	3	27	9	81	9	81
Likelihood Mission Success	9	1	9	3	27	9	81
Manufacturability	1	3	3	9	9	1	3
Longevity	3	1	3	3	9	9	27
Instrument Security	3	1	3	3	9	9	27
Aerodynamics	3	3	9	3	9	9	27
TOTAL			228		306		339

6.0 Payload Concept of Operations

As soon as we deploy via helium propulsion using 6.934*10^7 Pascals of pressure (which results in a deployment velocity of 200 m/s), we will begin operation of instruments and commence readings. We will collect data on the magnetic field throughout the entire mission and begin collection of atmospheric data upon entry of atmosphere. Our entire mission should last roughly 13 minutes from the propulsion of the spacecraft to the conclusion of our readings.

Figure 4. ConOps



7.0 Engineering Analysis

Before we could go any further with our payload, we needed to figure out the usable mass. Since we decided to go with the dropping deployment and the gravity method from the mission trade tree diagram, we agreed that we needed to use the maximum amount of weight, **10 kg**. Additionally, our payload's surface area is approximately 9,170 cm^2, and if we use aluminum-lithium alloy as casing, that is a minimum of **4.897 kg** of the maximum 10. Any extra mass of the 10 that is not used will also be allocated to ballast and housing of the same material.

7.1 Intervals of Operations

In order to better estimate exactly how our payload moves and operates at any given time during the operation, we needed to first make specific intervals for our operations. To explain it simply, our mission consists of a 3,000 km drop until our mission ends. Throughout the course of the mission, multiple variables continually change, including distance from planet and velocity. In order to make a better estimate, we broke up our 3,000 km mission into 30 separate intervals of 100 km.

7.2 Acceleration

In order to determine exactly how our payload accelerates at any given interval, we essentially determined how strong the force of gravity is at that height. To calculate the acceleration due to gravity (*a*), we multiply the Universal Gravitational Constant, or *G*, by the mass of the attracting object, *M*, or in our case the mass of Neptune. After that, we divide by the distance between the object and the center of the attracting object squared, or *r*. This *r* is found by adding the radius of the planet, which is 24,622 km and the altitude at any given interval.

$$a = \frac{(GM)}{(r^2)}$$

When plugged into the equation, these variables will result in the acceleration for our first interval, which comes out to **8.95 m/s²**. These calculations will change the acceleration for every subsequent interval by subtracting 100 km or 100,000 m from the previous *r* value.

$$a = \frac{((6.67 \times 10^{-11} m^3 kg^{-1} s^{-2})(1.024 \times 10^{26} kg)}{(2.7622 \times 10^7 m)^2}$$

$$a = 8.95 m/s^2$$

Table 5. Acceleration Calculations

Altitude (km)	Value used for *r* (m)	Acceleration (m/s^2)
3000	27622000	8.951906731
500	25122000	10.82224516
400	25022000	10.90891985
300	24922000	10.99663999
200	24822000	11.08542245
100	24722000	11.17528445
0	24622000	11.26624358

7.3 Velocity

Velocity is a crucial component to understanding our overall mission time. For this velocity value, we decided to calculate the individual final velocity (or *Vf*) value for each decided interval. An important factor to note is that our payload assumes no drag, as there is no atmosphere for a majority of the mission, and an atmosphere thick enough to create drag for our payload only occupies the last 100 km of our proposed mission. The velocity at the end of any interval is found by taking the square of the initial velocity (*Vi*, this value is 200 for the first interval as that is our deployment velocity, the final velocity value from the last interval calculated for each subsequent interval), 2 times the distance (*d*, or in this case the interval distance, which is 100000 m for every interval) and acceleration (*a*) for the interval, calculated by the previous equation detailed. This is all then square rooted.

$$v = ((Vi^2) + 2ad)^{(1/2)}$$

$$v = ((200m/s^2) + 2(8.9m/s^2)(100000m))^{(1/2)}$$

$$v = 1352m/s$$

When plugged into the equation, our variables give us final the velocity for the initial interval of operation, about **1,352 m/s**. For our next interval of operation, the initial velocity will be the final velocity from our last interval, and using the new acceleration value will also be necessary.

Table 6. Final Velocity Calculations

Altitude (km)	Initial Velocity (m/s)	(m/s^2)	Velocity(m/s)
3000	200	8.951906731	1352.915868
500	7004.789238	10.82224516	7157.619807
400	7157.619807	10.90891985	7308.440687
300	7308.440687	10.99663999	7457.387832
200	7457.387832	11.08542245	7604.585312
100	7604.585312	11.17528445	7750.14675
0	7750.14675	11.26624358	7894.176548

7.4 Time

Now that the final velocity of each interval has been found, we are also able to calculate the time of each interval. This can be used to find the total time of the mission, as well as determine approximately the time our payload enters the area of Neptune sufficient enough for atmospheric data collection, which is at an altitude for around 900 km. Time(*t)* for any interval is equal to our final velocity minus initial velocity, then divided by the acceleration.

$$t = \frac{(Vf - Vi)}{a}$$

After plugging the variables into the time equation, we find that the time for the first interval is approximately 128 seconds. For every subsequent interval, the new variables that are used must be the corresponding initial

$$t = \frac{((1352\,m/s) - (200\,m/s)}{(8.95\,m/s^2)}$$

$$t = 128s$$

velocity, final velocity, and acceleration. After calculating every interval's duration, we found that the total mission time amounts to **795 seconds, or 13.25 minutes, or .22 hours**.

Table 7. Battery Calculations

Beginning Altitude (km)	Time for Interval (s)
3000	128.7899777
500	14.12189122
400	13.8254641
300	13.54478685
200	13.27847275
100	13.02530055
0	12.78418991
Total Time:	795.6623835

7.5 Battery

Now that interval duration is established, we are able to calculate the total battery needed for the mission. First, the instruments must be divided into two sets, one set that operates for the duration of the complete mission, and another set that operates upon entering readable atmosphere in order to collect data. The first set includes all supporting instruments as well as instruments used primarily for measuring the magnetic field, which are the 2 Langmuir probes, magnetometer, onboard computer, transceiver, and the antenna. The second set used for atmospheric readings, which includes the mass spectrometer, pressure transducer, and thermocouple. Total battery consumption per hour must be calculated for both sets. The first set's battery consumption is 4.62 Watts per hour. The second set's consumption is 1.54 Watts per hour. Then, we apply the first set's consumption to the duration of the whole mission, and then apply the second set's consumption for the duration of atmospheric readings, which is each time interval for the last 900 km of operation, which is 140 seconds, or 2.33 minutes, or .0389 hours. The first set will consume 1.01 Watts total, and the second set consumes 0.59 Watts total. Total Watts used over the whole mission will be 1.069 Watts, which results in 2.67 grams of battery mass, as batteries provide 400 Watt-hours per kilogram. 5 total grams of battery mass will be used as backup.

Table 8. Battery Calculations

	Instruments	Operation Time (s)	Power per hour(W)	Total power consumed (W)	Battery mass needed (g)
Set 1	IMU, Onboard Computer, Transceiver, Antenna, 2Langmuir Probes, Magnetometer	795	4.62	1.01	2.52
Set 2	Mass Spectrometer, Pressure transducer, Thermocouple	140	1.54	0.06	0.15
			Total:	1.07	2.67

8.0 Final Design

"The Arrow" will be propelled from the UAH orbiter, which is at an altitude of 3,000 km, and will descend at an initial deployment velocity of 200 m/s, in order to collect data on the magnetosphere and atmosphere. After deployment, it will take continuous measurements of the magnetosphere for the duration of our mission. Once the upper atmosphere is reached, then the second set of instruments will turn on, and begin taking measurements of the atmosphere itself. The ending conditions are unknown, but it is likely that pressure crushes our payload towards the end of the mission.

Figure 5. Instrumentation

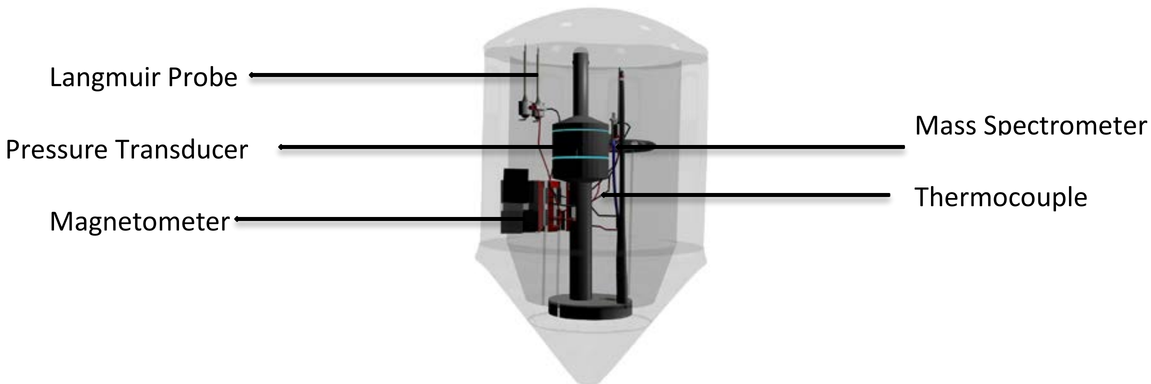


Table 9. Requirements met

Function	Solution
Deployment	Propel from UAH orbiter using helium
Take Measurements	Langmuir probe, Magnetometer, Pressure Transducer, Thermocouple
Collect Data	Mass spectrometer, Onboard Computer
Provide Power	Battery
Send Data	Antenna and Transceiver
Contain/House Payload	Aluminum Lithium Alloy

Table 10. Final Design Mass Table

Function	Components	Mass (kg)
Deploy	IMU	0.013
Measure	Thermocouple, Pressure Transducer, Langmuir probe, Magnetometer	1.131
Collect Data	Mass spectrometer, On board computer	0.324
Provide Power	Space batteries	.005
Send Data	Transceiver, Antenna	0.185
House/Contain Payload	Aluminum-Lithium Alloy	4.897 required, 8.342 used
Total		**10 kg**