Payload Concept Proposal

Aquanauts
Da Vinci School for Science and the Arts
Team 1

"Diving through the big blue."

1.0 Introduction

Neptune is the eighth planet in the solar system, and it also one of the most vibrantly colored ones, displaying a bright blue hue. Neptune is mainly composed of hydrogen, helium, methane, and trace amounts of other gases, although it has been theorized that water may exist somewhere in Neptune's atmosphere. Our team, the Aquanauts, will send payloads to Neptune to conduct research for our scientific objectives. Our team's payload, The Orbital Drop Instrument of Neptune (O.D.I.N.), is an ellipsoid-shaped device that was partly based off of a NASA astronaut capsule that has been modified in order to meet our specifications. It has been made as compact as possible in order to house all of the scientific instruments necessary to complete our science objectives.

2.0 Science Objective and Instrumentation

We have decided to have three science objectives: To determine the cause of Neptune's vibrant blue color, to explore the possibility of water in Neptune's lower atmosphere, and to record the atmospheric properties and composition. The team decided to go with three science objectives because all of this information is very similar in the manner of data collection. Having more information on a planet could allow us to determine similarities between discovered planets and newfound planets. From the sustainability of the atmosphere to the possible origins of the vibrant blue-causing agent, having data on all of these factors is important when learning about the multiple creations of the universe.

To find results for all of our science objectives, we must use mass spectrometers, thermocouples, inertial measurement units, and pressure transducers. To determine the composition of Neptune's atmosphere, the payload will be equipped with mass spectrometers. Thermocouples are to measure the temperature of the surrounding environment. The IMU tracks our payload's velocity and gravitational forces. The last instrument necessary to record data is the pressure transducer, which measures Neptune's atmospheric pressure.

Table 1. Science Traceability Matrix

<table>
<tr><th>Science Objective</th><th>Measurement Objective</th><th>Measurement Requirement</th><th>Instrument Selected</th></tr>
<tr><td>Explore the possibility of water on Neptune</td><td rowspan="2">Determine the atmospheric properties and composition</td><td rowspan="3">Take measurements at different altitudes at a constant rate</td><td rowspan="3">Mass Spectrometer
Thermocouple
Pressure Transducer</td></tr>
<tr><td>Learn about Neptune's atmosphere</td></tr>
<tr><td>Learn about Neptune's color</td><td>Determine why Neptune is blue</td></tr>
</table>

Table 2. Instrument Requirements

Instrument	Mass (kg)	Power (W)	Data Rate (Mbps)	Dimensions (cm)	Lifetime (mins)	Frequency	Duration (mins)
Mass Spectrometer	0.230	1.5	22.4	0.45 x 0.50 x 0.80	13.267	Continuous	13.267
Thermocouple	0.020/meter	N/A	0.0001	Length TBD	13.267	Continuous	13.267
Pressure Transducer	0.131	0.04	1.0	2.2 cm dia x 8.6 cm length	13.267	Continuous	13.267
Inertial Measurement Unit (IMU)	0.013	0.22	0.160	2.2 x 2.4 x 0.3	13.267	Continuous	13.267

Table 3. Support EquipmentB

Component	Mass (kg)	Power (W)	Data Rate	Other Technical Specifications
On-Board Computer	0.094	0.4	2 x 2 GB Onboard Storage	400 MHz, power efficient ARM9 processor
Transceiver	0.085	1.7	9.6 to down-link 1.2 to uplink	ISIS VHF/UHF Duplex Transceiver
Antenna	0.100	0.02	Same as Transceiver	Deployable antenna system
Space Batteries	400 Whr/kg		N/A	Based on power requirements

3.0 Payload Design Requirements

In order for the Aquanauts to successfully complete the NOTE mission, our payload must meet certain requirements. For instance, our payload must deploy properly from the UAH orbiter, record data autonomously, transmit data, provide its own power, and protect itself from environmental damage.

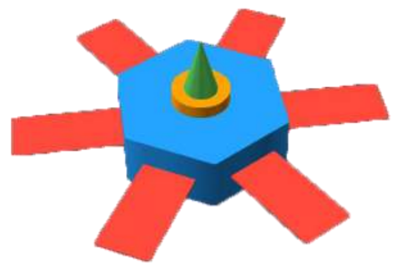
The team's payload must also meet the project requirements, which include a volume limit of 44 x 24 x 28 centimeters, have a mass limit of 10 kilograms, have an internal temperature of 294 K (70°C), and the prevention of damage to the main spacecraft.

The environment also places constraints on how our payload operates. Neptune's environment is a dangerous one, as its average temperature is -214°C and it is home to the strongest winds in the solar system (clocking in at up to 2,100 kilometers per hour). Its atmosphere is also one of the thicker ones in the solar system, as it is one of the gas giants. Atmospheric pressure increases as an object descends through Neptune, with the lower troposphere layer ranging from one to five bars (100 – 500 kPa). Temperature also changes with altitude, as it increases with altitude in the stratosphere and decreases in the thermosphere.

4.0 Payload Alternatives

The Aquanauts have designed three payload concepts: the Galvanized Empirical Atmospheric Reader (G.E.A.R.), the Orbital Drop Instrument of Neptune (O.D.I.N.), and Scorpio. All of these concepts would contain the same scientific instruments to record the same measurements, and it would just be the housing that differentiates each payload. All of the concepts were designed to house the same scientific instruments and undergo the same Concept of Operations, and, in this case, it would be to drop from the UAH orbiter and descend into Neptune's atmosphere.

Figure 1. Concept 1: G.E.A.R.



Our first concept, G.E.A.R., is a gear shaped probe with panels surrounding the payload and a protruding conical shape, which houses the supporting equipment. The panels are used to increase air resistance to keep the payload in Neptune's atmosphere for a greater duration and prevent it from being crushed by the atmospheric pressure too quickly.

Figure 2. Concept 2: O.D.I.N.

The second concept, O.D.I.N., is based off a NASA astronaut capsule that has been modified to suit our project requirements. It is an ellipsoid shape to prevent volume waste. O.D.I.N. is bottom-heavy, preventing it from tipping over during its descent. Because of its shape, O.D.I.N. is very aerodynamic, making it the payload that will fall the fastest.

Figure 3. Concept 3: Scorpio

Our final concept, Scorpio, is a combination of both of our previous payloads, but they will be scaled down. It will have a good amount of air resistance (from G.E.A.R.), as well as more protection for the scientific instruments (from O.D.I.N.).

5.0 Decision Analysis

In order for our team to choose the best possible payload design, we created a decision matrix. We took into account multiple figures of merit that affect the chances of a successful mission, such as the likelihood of the payload meeting the project requirements and the chance of completing the science objectives.

Table 4. Payload Decision Analysis

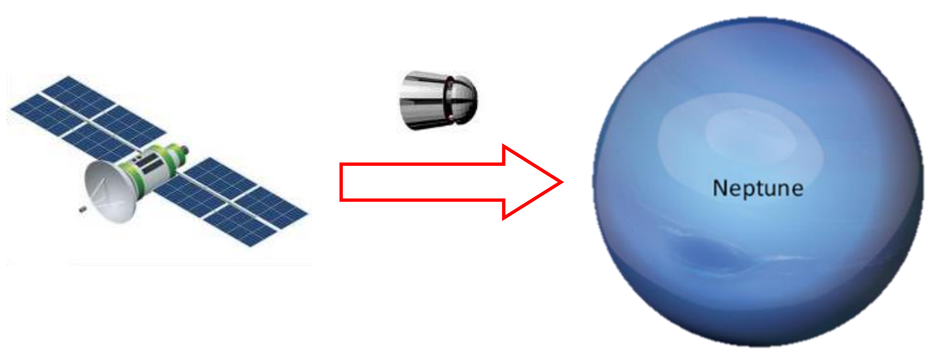
Figure of Merit	Weight	G.E.A.R.		O.D.I.N.		Scorpio	
		Raw Score	Weighted	Raw Score	Weighted	Raw Score	Weighted
Science Objective	9	9	81	9	81	9	81
Likelihood Project Requirement	9	3	27	9	81	9	81
Science Mass Ratio	3	3	9	9	27	9	27
Design Simplicity	3	9	27	9	27	3	9
ConOps Complexity	9	9	81	9	81	9	81
Likelihood Mission Success	9	3	27	9	81	3	27
Manufacturability	1	9	9	9	9	3	3
Environment Sustainability	9	1	9	9	81	9	81
Aerodynamics	3	9	27	1	3	9	27
Instrument Security	3	1	3	9	27	3	9
TOTAL			300		**498**		426

6.0 Payload Concept of Operations

To begin our mission, O.D.I.N. will be deployed from the UAH orbiter, but there won't be just one payload. Four other O.D.I.N. payloads will deploy at different locations across Neptune. Payloads will be forcibly evacuated from the spacecraft at a constant interval every 31,120 kilometers of Neptune's surface the spacecraft travels.

After deployment, all O.D.I.N. payloads will descend towards Neptune's atmosphere and begin to record atmospheric data, but more precisely, the composition of the gases. The payloads will continuously record data with every scientific instrument until they are all destroyed by the atmospheric pressure.

Figure 4. O.D.I.N. ConOps



7.0 Engineering Analysis

Before we could go any further with our payload, we needed to figure out its weight, dimensions, and volume. Since the instruments we chose are very light in weight, we already knew we were going to make more than one payload. After playing around with the weight and volume of our payload, we decided to make each payload **2kg** and have a volume of **1,209cm^3**, which is a total mass of 10kg and 6,045 cm^3. Our payload is in the shape of an ellipsoid, a 3-D ellipse. Towards the bottom of our payload you will find out that it is consisted of mass spectrometers, ballast weight, pressure transducer, and a thermocouple. This is because we want to keep all of our instruments low and together. Then towards the top you will find our supporting instruments, which are the space batteries, on-board computer, transceiver, and antenna. Our dimensions of our payloads are 13cm by 18.6cm by 5cm.

7.1 Orbital Velocity

In order to calculate our orbital velocity we had to use the Universal Gravitational Constant, mass of Neptune, and the radius of Neptune. After researching for each of the values for each variable, we plugged them in and solving for our orbital velocity. We ended up getting **15,724m/s**.

$$v = \sqrt{\frac{GM}{r}}$$

$$v = \sqrt{\frac{(6.67 \times 10^{-11} m^3 kg^{-1} s^{-2})(1.024 \times 10^{26} kg)}{(27{,}622{,}000m)}}$$

$$v = 15{,}724.8m/s$$

7.2 Initial Velocity

After calculating our orbital velocity, we had to make our initial velocity at least 1% or more than our orbital velocity, which is anything faster than roughly 157m/s. Once we found that out, we began to change up our numbers and we decided to go with **200m/s** as our initial velocity.

7.3 Helium Pressure

In order for us to launch at a velocity of 200m/s, we had to figure how we wanted to propel our selves out of the barrel. We had the choice of helium pressure or spring. We ended up choosing helium pressure. After calculating and finding the values for each variable, we inserted them into the equation and solved for our pressure, which gave us **500,000Pa**.

$$v_f^2 = v_i^2 + 2\left(\frac{PA}{M}\right)d$$

$$200m^2/s^2 = 2\left(\frac{P(0.02m^2)}{2kg}\right)(0.4m)$$

$$P = 500{,}000Pa$$

7.4 Values Relative to Descending

As we mentioned earlier our initial velocity will be 200m/s and our velocity of our payload will rapidly increase and will reach a final velocity of 7750.1m/s. Our payload will hit Neptune's atmosphere when it passes **25,522,000m** in altitude. It will take us approximately **655 seconds** to reach the atmosphere. That means we will hit Neptune's atmosphere at **6,370.1m/s**, which will allow us to record data for around **140 seconds**. Our total mission time for each individual payload will be **795.66 seconds**. Our acceleration will range from 8.95m/s^2 to 11.26m/s^2 as we begin to propel from the orbiter.

7.5 Battery Size

In order to find our total battery mass, we looked up the power required for each of our instruments using the provided materials. We then calculated the total operational time by multiplying our lifetime time and our total duration of each instrument. After calculating the total operational time for each instrument, we added them all up to get our total power required, which is 5.38 W·hr. We then used the battery mass formula to calculate our battery mass, which is $m_{batt} = ((\text{total power required})(W \cdot hr))/(400W \cdot hr/kg)$. After solving for the battery mass, our final battery mass is **0.002kg**.

Table 5. Values Relative to Descending

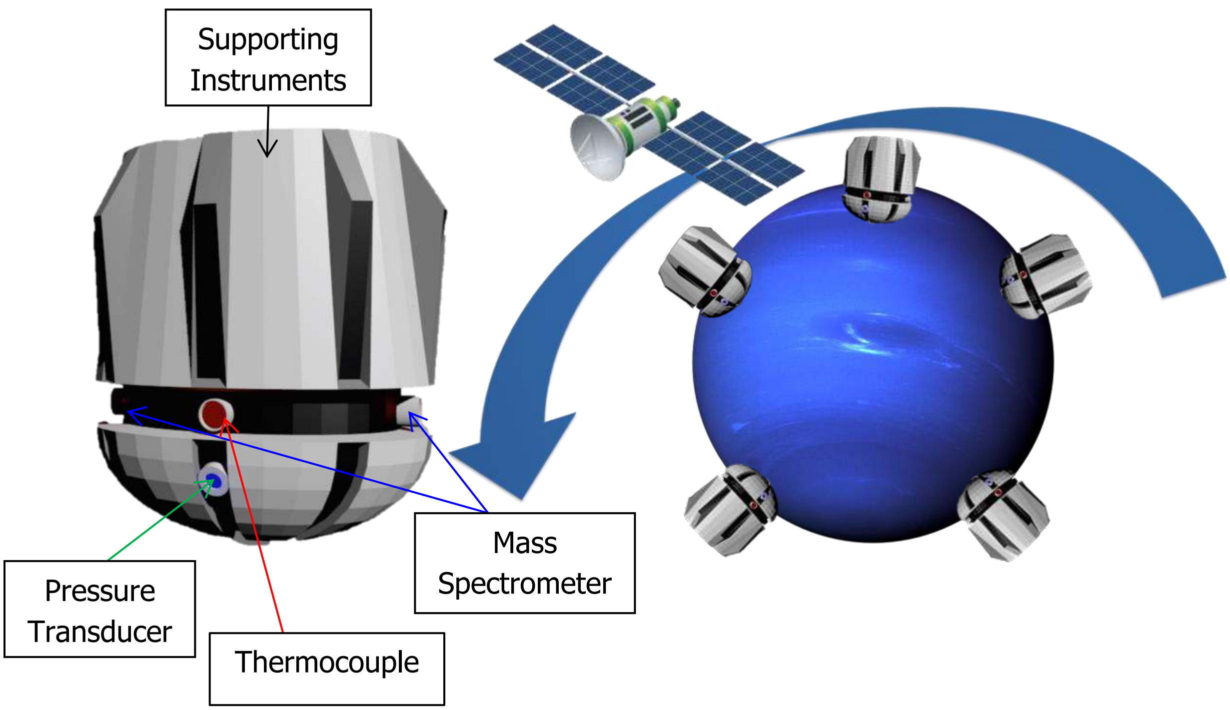
Velocity Final (m/s)	Velocity Initial (m/s)	Acceleration (m/s²)	Altitude (m)	Time (sec)
1352.9	200.0	8.95	27622000	128.78
1906.3	1352.9	9.01	27522000	61.36
2334.6	1906.3	9.08	27422000	47.16
2698.2	2334.6	9.14	27322000	39.73
3020.5	2698.2	9.21	27222000	34.97
3313.7	3020.5	9.28	27122000	31.57
3584.9	3313.7	9.35	27022000	28.99
3838.7	3584.8	9.42	26922000	26.94
4078.6	3838.7	9.49	26822000	25.26
4306.7	4078.5	9.56	26722000	23.85
4524.9	4306.7	9.63	26622000	22.64
4734.6	4524.9	9.70	26522000	21.59
4937.0	4734.6	9.78	26422000	20.67
5132.7	4937.0	9.85	26322000	19.86
5322.8	5132.7	9.93	26222000	19.12
5507.6	5322.8	10.00	26122000	18.46
5687.8	5507.6	10.08	26022000	17.86
5863.8	5687.8	10.16	25922000	17.31
6035.9	5863.8	10.24	25822000	16.80
6204.6	6035.9	10.32	25722000	16.33
6370.1	6204.6	10.40	25622000	15.90
6532.6	6370.1	10.48	25522000	15.50
6692.4	6532.6	10.56	25422000	15.12
6849.7	6692.4	10.65	25322000	14.76
7004.7	6849.7	10.73	25222000	14.43
7157.6	7004.7	10.82	25122000	14.12
7308.4	7157.6	10.90	25022000	13.82
7457.3	7308.4	10.99	24922000	13.54
7604.5	7457.3	11.08	24822000	13.27
7750.1	7604.5	11.17	24722000	13.02
7894.1	7750.1	11.26	24622000	12.78

8.0 Final Design

O.D.I.N. is the concept that the Aquanauts have chosen based off the results from the decision matrix. Each O.D.I.N. will have a volume of 13cm by 18.6cm by 5cm, which is far below the volume limit we were given (44cm x 24cm x 28cm). Also, each payload will weigh at about two kilograms, so only 5 O.D.I.N.s can be used due to mass constraints. They are an ellipsoid shape to conserve volume while housing all our necessary equipment. With this compact design, the payload can protect our scientific instruments from critical damage when entering Neptune's environment.

Five of these payloads will be propelled from the UAH orbiter down towards Neptune at different points around the planet and will begin recording data with their science instruments (Mass Spectrometers, Pressure Transducer, Thermocouple, and IMU). As the O.D.I.N. payloads descend through Neptune's atmosphere, the mass spectrometers will determine the atmosphere's molecular makeup, while the pressure transducers and thermocouples will record atmospheric pressure and temperature, respectively. The payloads will be deployed at different locations to acquire multiple points of data. This is done to determine if the atmosphere all over Neptune is the same.

Figure 5. Final O.D.I.N./The Aquanauts' Mission



Each payload will approximately weigh in at two kilograms, and our team must design it to house everything necessary for the success of our mission and keep the total mass less than 10 kilograms. Also, we had to make sure our payload had solutions to the functional requirements given to us. For example, we have to have a strong housing material in order for our payload to withstand the Neptunian elements, but it also had to be light enough to meet the mass requirement. The equipment that makes up this mass is listed on *Table 6*.

Table 6. Final Design Mass Table

Function	Components	Mass (kg)
Deploy	N/A	N/A
Measure	Mass Spectrometers, Thermocouple, Pressure Transducer, and IMU	0.624
Collect data	On-board Computer	0.094
Provide power	Space Batteries	0.002
Send data	Transceiver and Antenna	0.185
House payload	Aluminum Lithium Alloy	0.980
Ballast Weight	Extra weight	0.115
Total		**2**

The Aquanauts have taken into account all of the requirements our payload needs to abide by, and in this case, they are the project, functional, and environmental requirements. Following these will allow us to increase the chances of having a successful mission. All of our compliances are displayed on *Table 7*.

Table 7. Requirements Compliance Table

Project	Environmental	Functional
2 kg of mass (10 kg total)	Payload reinforced by aluminum lithium alloy	Deployed by free falling from orbiter
Continuous power by the usage of space batteries	Multiple payloads to increase mission success likelihood	Measure with Mass Spectrometer, Thermocouple, Pressure Transducer, and IMU
V = 13 cm x 18.6 cm x 5 cm	Low mass allows for a slower descent	Collect data in On-board Computer
Aerogel insulation to keep internal temp. at 294 K		Provide power with Space Batteries
Does not harm UAH spacecraft		Send data with Transceiver and Antenna
		House payload with Carbon Fiber Matrix