PAYLOAD CONCEPT PROPOSAL

Team Vulcan

Grand Forks Central

Grand Forks 1

1. Introduction

Team Vulcan's payload Marco Polo consists of two probes that will deploy from the Neptune Orbiter and a mass spectrometer and inertial measurement unit (IMU) that will be housed on the Triton Lander. Because we will be deploying our payload at three separate locations we named our payload Marco Polo. Just like the story, the three released IMU's will send and receive vibrations to and from each other.

2. Science Objective and Instrumentation

Our two main science objectives will focus around discovering the composition and functionality of the cryovolcanoes located at the South Pole of Triton.

Our first objective is to measure the composition of the cryovolcanic plumes. To perform this objective, we will add a mass spectrometer to the Triton Lander. The mass spectrometer will collect measurements of the elements the cryovolcanoes are emitting. Once the identity of these elements are known, we can determine if they are life supporting. That is, if they contain carbon, hydrogen, oxygen, nitrogen, sulfur, or phosphorous.

Our second objective is focused around discovering the internal structure of Triton. For this, three inertial mass units will be used. One will be added to the Lander, and the others will be released equidistant from each other (Figure A), via our nose cone penetrator probes. The IMU's will then send vibrations through the moon, formulating a comprehensive map of the internal structure of Triton. The vibrations will not be able to travel through liquid, thus indicating to us the possible functionality of these volcanoes and if the core of Triton is liquid.

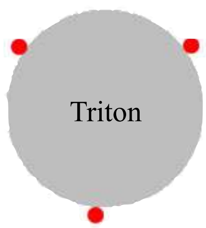

Figure A

These objectives work harmoniously in understanding cryovolcanoes. Because the second objective will determine the internal structure of Triton, we will infer from the collected data how volcanoes with a near absolute zero surface temperature are able to spew out gaseous substances. We can determine this from the data provided because if the vibrations from the IMU's detect a liquid core, then it is highly likely that the inside is hot and that convections are what drive the eruption of the cryovolcanoes. The first objective plays a critical role in identifying the composition of these plumes. Once the elements are known, then we can discover the composition of Triton's interior. These objectives further two important scientific goals; to understand more about Triton, and to determine if it could be life supporting.

Table 1. Science Traceability Matrix

Science Objective	Measurement Objective	Measurement Requirement	Instrument Selected
Composition of Cryovolcanic plumes	Elements	Deploy near the south pole to measure volcano, position measurement	Mass spectrometer, IMU

Internal Structure	Vibrations	Need to be touching the surface of Triton, need to be evenly dispersed across the moon	IMU

Table 2. Instrument Requirements

Instrument	Mass (kg)	Power (W)	Data Rate (Mbps)	Dimensions (cm)	Lifetime	Frequency	Duration
Inertial Mass Unit	0.013	0.22	0.160	2.2 x 2.4 x 0.3	3 months	1 week	400 seconds
Mass Spectrometer	0.23	1.5	22.4	0.45 x 0.50 x 0.80	3 months	1 week	3 months

Table 3. Support Equipment

Component	Mass (kg)	Power (W)	Data Rate	Other Technical Specifications
Antenna	0.100	0.02	N/A	cubesatshop.com deployable antenna system
Transmitter/ Receiver (Transceiver)	0.085	1.7	up to 9600 bps downlink; up to 1200 bps uplink	cubesatshop.com ISIS VHF/UHF Duplex Transceiver
On-board computer (processor with board)	0.094	0.4	2 x 2 GB onboard storage	cubesatshop.com ISIS on board computer 400 MHz, ARM9 processor
Batteries	400 Whr/kg	N/A	N/A	mass calculated by each tea, based on power requirements

3. Payload Design Requirements

As a baseline for this project, each team was given a set of requirements to comply to. For design requirements, our payload was not allowed to exceed 10 kilograms of mass and a volume of 44cm x 24cm x 28cm (29, 568 cm^3). The payload must be unharmed and function autonomously upon and after deployment from the Orbiter.

Functionally, our payload must be deployed from the Neptune Orbiter or be attached to the Triton Lander. It also must be able to provide its own power, take the necessary measurements, collect the data, and transmit this data back to the Motherboard. Our payload must do this while housing its contents safely.

Environmentally, our payload must survive the -391°F surface temperatures of Triton as well as its thin and low pressure atmosphere, which is about 1/12 of the gravitational force on earth. Our payload must also survive the impact with Triton's frozen surface.

4. Payload Alternatives

For our first concept (Figure 1. Concept 1) we created a payload shaped as a rectangular prism to fall to Triton and land on its surface. Two ideas were considered to assist our payload in landing, one involving a parachute landing and the other using a propellant system. Once it landed, it would conduct the necessary science objectives on the surface of Triton. To house the payload, it would be insulated with a durable plastic in order to survive the deployment and Triton's environment. Our instruments, the IMUs and the mass spectrometer would be insulated as well, providing as much protection as possible. In order to provide power, batteries would be included. A computer storage system would process and collect the data for the transmitter to send back to the Orbiter.

Our second concept utilized two nose cone penetrators that would deploy into Triton's crust. The probes would be released from the Orbiter and directly penetrate into the icy surface at a 22.5° angle. Although the key feature of this concept is it's deployment method, it also offers us a better opportunity at another science objective; determining the internal structure of Triton using IMUs. The instruments would be housed at the top of the penetrator cone and the nose would be composed of a heavy strong material to sustain the force of penetration. Insulation within the payload will reinforce the integrity of these instruments and the penetrator upon impact. Once landed, two probes will house only IMUs and the part of the payload attached to the Lander will contain both an IMU and a mass spectrometer. From there, a computer storage system will collect the measured data and a transmitter will send the data back to the Orbiter.

Figure 1. Concept 1

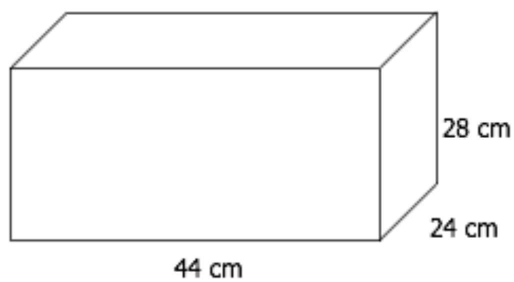

Figure 2. Concept 2

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5. Decision Analysis

In order to objectively weigh the pro and cons of both of our concepts, we performed a decision analysis. For this analysis, we assigned weightings on a 1, 3, or 9 scale to each of the Figures of Merits (FOM). The first seven FOMs were given to us, while the last three were decided upon by our team. Then we decided as a team whether each FOM merited a weight of 1, not very important, 3 moderately important, or 9 very important. Once the weightings of the FOMs were assigned, we scored both concepts on the same scale for each FOM based on our predictions for how well it would meet the objective. These numbers gave us the raw score which we then multiplied to the original weighting, giving us the final weighted score. These scores were then added up for each concept and the results were 336 for Concept 1 and 462 for Concept 2. From doing this, we determined that Concept 2 yielded a higher science to mass ratio, would result in more science despite higher risk, and ultimately would conduct a more effective mission than Concept 1.

Table 4. Payload Decision Analysis

Figure of Merit	Weight	Group 1 Concept		Group 2 Concept	
		Raw Score	Weighted	Raw Score	Weighted
Science Objective	9	3	27	9	81
Likelihood Project Requirement	9	9	81	3	27
Science Mass Ratio	3	3	9	9	27
Design Complexity	1	3	3	9	3
ConOps Complexity	3	3	9	1	27
Likelihood Mission Success	9	3	27	9	81
Manufacturability	3	3	9	9	27
Science to risk ratio	3	3	9	9	27
Ability to measure internal structure	9	9	81	9	81
Ability to measure composition of crovolcanoes	9	9	81	9	81

6. Payload Concept of Operations (Figure B)

Our payload will begin on the Neptune Orbiter and deploy at three different times. The Orbiter will orbit Triton at a velocity of 991 m/s for two years at 100 kilometers above the surface. During those two years, the Triton Lander will deploy from the Orbiter, housing part of our payload, a mass spectrometer and an IMU. Then, the rest of our payload will be released at two separate locations. This part of the payload will feature the nose cone penetrator, which will deploy from the Orbiter at a velocity of 120m/s. Then, the two probes will be launched into the surface of Triton at a trajectory of 1100m/s. Finally, our probes will be equidistant from each other and the Lander at the South Pole to perform the programmed science objectives.

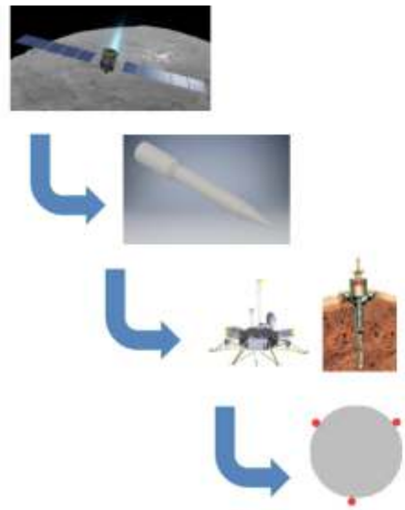


Figure B

7. Engineering Analysis (Figure G)

Beginning with our initial conditions, we started with our givens. Knowing that the radius of Triton is 1453.4 kilometers, the mass of the payload is 8.6 kilograms, the mass of Triton is 2.14×10^{22} kilograms, and the universal gravitational constant is 6.67×10^{-11}, we were able to solve for the Orbiter's initial velocity. We set the equations for the force of gravity and the force of circular motion equal to each other, since they will be moving in tandem. (Figure C)

$$F_c = \frac{mv_i^2}{r} \qquad F_g = \frac{GMm}{r^2}$$

$F_c = F_g$ (Since the payload is in orbit, the force of gravity is equal to the force of circular motion)

$$\frac{mv_i^2}{r} = \frac{GMm}{r^2} \rightarrow v_i^2 = \frac{GM}{r} \rightarrow v_i = \sqrt{\frac{GM}{r}}$$

$$v_i = \sqrt{\frac{(6.67\times10^{-11})(2.14\times10^{22})}{(1453.4)}} = 991\text{m/s}$$

Figure C

Next, we solved for the deployment of our payload. We know the volume of our payload is 1272.35cm^3, the length of our probe is 82cm, the pressure is set to get maximum velocity at 60,000pa, and the mass of each probe is 4.3 kilograms. We used these numbers to find the area affected by pressure, the acceleration of the probe, and the final velocity. The results were 0.64m^2, 8.93×10^3m/s/s, and 120m/s respectively. (Figure D)

$$V = \pi r^2 h \rightarrow r = \sqrt{\frac{V}{\pi h}} \rightarrow r = \sqrt{\frac{(1272.35)}{(\pi)(20)}} = 4.5\text{cm}$$

(h = distance) (Volume equation of cylinder due to cylindrical probe design)

$$A = \pi r^2 \rightarrow A = \pi(4.5)^2 = 0.64\text{m(squared)}$$

$$F = ma \qquad P = \frac{F}{A}$$

$$ma = PA \rightarrow a = \frac{PA}{m} \rightarrow a = \frac{(60{,}000)(0.64)}{4.3} = 8{,}930\text{m/s/s}$$

$v_f^2 = v_i^2 + 2ad \rightarrow v_f = \sqrt{2ad}$ (Initial Velocity is zero because the probe will start at rest)

$$v_f = \sqrt{2(8,930)(0.82)} = 120\text{m/s}$$

Figure D

After deployment, we solved for trajectory. Then using the results we got for the velocity of the Orbiter (991m/s), the deployment velocity (120m/s), and the force of gravity on Triton (0.779 m/s/s, we were able to find the velocity in the y direction, the impact angle, and the resultant velocity. We assumed a drag free flight due to Triton's thin atmosphere, the probe is deployed entirely in the negative y direction, and the probe maintains the Orbiter's x direction velocity during flight. (Figure E)

$$v_y^2 = v_i^2 + 2ad \rightarrow v_y = \sqrt{v_i^2 + 2ad}$$
$$v_y = \sqrt{(120)^2 + 2(0.779)(100,000)} = 410\text{m/s}$$
$$tan\theta = \frac{v_y}{v_o} \rightarrow \theta = tan^{-1}(\frac{v_y}{v_o})$$
$$\theta = tan^{-1}(\frac{410}{991}) = 22.5 \text{ degrees}$$
$$sin\theta = (\frac{v_y}{v_t}) \rightarrow v_t = \frac{v_y}{sin\theta}$$
$$v_t = \frac{410}{sin(22.5)} = 1,100\text{m/s}$$

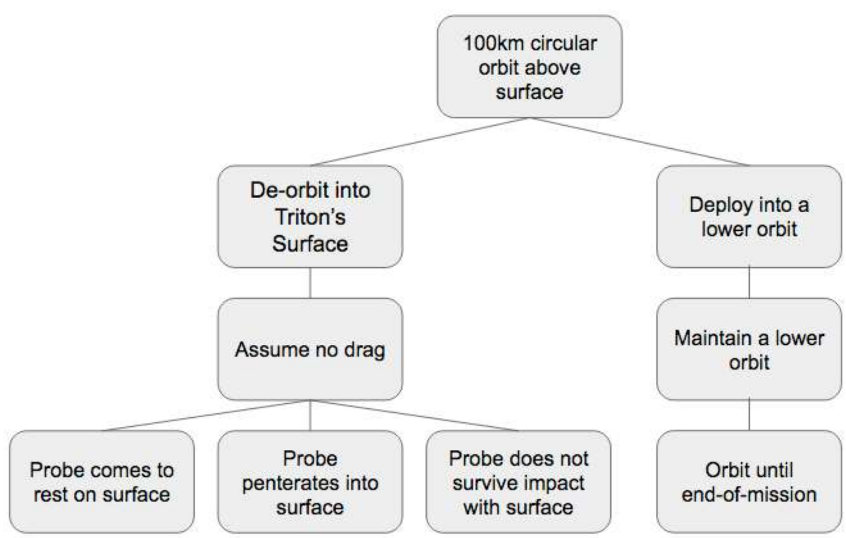
Figure E

Our last step was ending conditions. We knew the penetrability number (assumed value of 10), the nose cone coefficient (assumed value of 0.9), the cross sectional area of the probe (0.64m^2), the mass of the probe (4.3kg), and the velocity on impact (1,100m/s). Then we solved for depth of penetration. (Figure F)

$$D = 0.000018SN(\frac{m}{A})^{0.7}(v - 30.5)$$
$$D = 0.000018(10)(0.9)(\frac{4.3}{0.64})^{0.7}(1,100 - 30.5) = 0.66\text{m}$$

Figure F

Figure G



8. Final Design

The final design, Marco Polo, will feature two nose cone penetrator probes that will contain IMUs and deploy from the Neptune Orbiter. The payload design will also include an IMU and a mass spectrometer that will be housed on the Triton Lander, which will also deploy from the Orbiter and land at the South Pole. This payload will be able to function autonomously with batteries, send data back to the Motherboard with an antenna and transmitter, survive Triton's extreme environment with the high ratio of insulation to instruments, and protect the instruments from harm with the hardened nose cone. Our payload will weigh a total of 9.8kg and be a volume 11,338.68cm^3, both meeting the payload mass and volume requirements which were given at a maximum of 10kg and 29,568 cm^3 respectively.

For our final concept of operations, our nose cone penetrator probes will deploy from the Neptune Orbiter during the two years it will Orbit Triton at a 100km altitude at a velocity of 991 m/s. Then, after deployment at an initial velocity of 120m/s the probes will penetrate into the surface of Triton at an angle of 22.5 degrees at a final velocity of 1100m/s. The other part of our payload will be housed on the Triton Lander which will deploy from the Orbiter and land at the South Pole. For this part of the payload, there will two instruments, an IMU and a mass spectrometer. Once our entire payload has landed on Triton, they will be equidistantly situated from each other. The IMUs in each location will then send vibrations through the moon, collecting measurements on the internal structure, processing this data with a computer storage system, transmitting data back to the motherboard with an antenna/transmitter. The mass spectrometer will measure the composition of the cryovolcanic plumes.

Figure 3. Vulcan's Mission

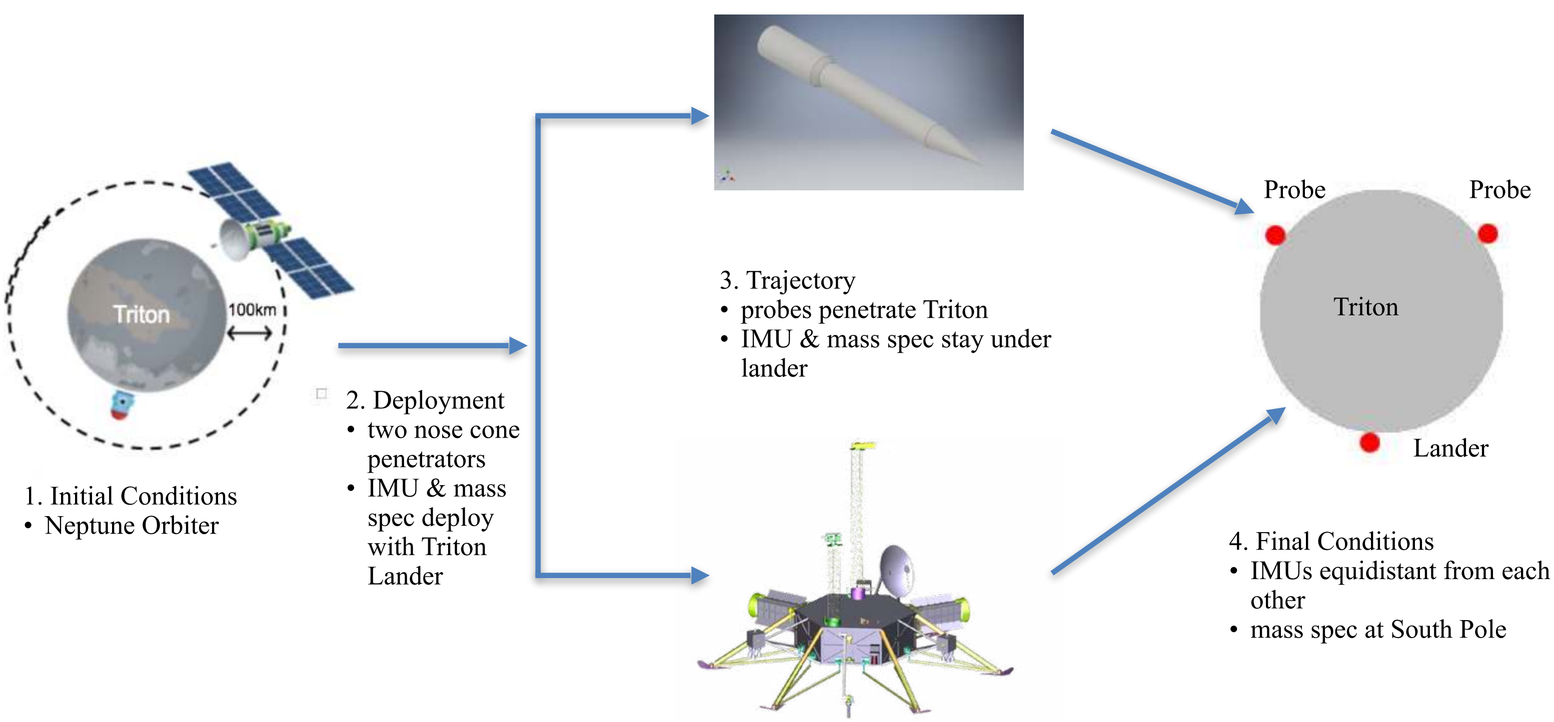


Table 5. Final Design Mass Table

Function	Component(s)	Mass (kg)
Deploy	N/A	0
Measure	IMU (3x), Mass Spectrometer	0.269
Collect Data	Computer (2x)	0.188
Provide Power	Batteries (2x)	0.552
Send Data	Antenna (2x)	0.200
House/Contain Payload	Insulation, Heating, Hardened Nose Cone, Probe Design (All 2x)	8.6
Total		9.8