PAYLOAD CONCEPT PROPOSAL

Mission Magneto

Muscle Shoals High School

Team 2

“ The scientific superheroes of tomorrow, today!”

1.0 Introduction

Saturn's magnetosphere remains to be one of the most curious characteristics of Saturn. As seen on no other planet, Saturn's magnetic field and axis of rotation align axis symmetrically. Our team *Mission Magneto,* composed of 8 students from Muscle Shoals High School, designed the payload *Octavius* to explore Saturn's magnetosphere and provide further insights on Saturn's unique system. The name Octavius was derived from its 8-sided structure that was inspired by NASA's Magnetospheric Multiscale Mission that explored Earth's magnetosphere. Octavius will be transported to Saturn via the UAH orbiter Cleopatra that was designed by UAH students.

2.0 Science Objective and Instrumentation

We have determined that the main science objective of Mission Magneto is to explore Saturn's magnetosphere, primarily studying the influence on Saturn's magnetic field of different sets of plasma composition around Saturn and Enceladus. We decided on this particular science objective in our initial research of Saturn's magnetosphere when we noticed how the plasma in the solar wind was repelled by Saturn's magnetosphere, but the plasma coming from Enceladus was actually pulled into Saturn's rotation before being ejected out of the magnetotail. These opposite reactions between different plasmas and the magnetosphere led us to want to discover exactly how plasma all around Saturn could possibly be influencing Saturn's magnetic field in different ways. In order to meet this science objective, we identified three sets of data that we would need to measure with our payload: hot plasma, energetic particles, and magnetic fields. We utilized an internal mass spectrometer to collect data on the plasmic composition, a Langmuir probe to record electron densities, and two fluxgate magnetometers to detect disturbances in the magnetic field (one as a control, and the other as a source of measurement). These instruments coupled with an inertial measurement unit will provide us with information on plasmic interaction within the magnetosphere at certain locations around both Saturn and Enceladus.

Table 1. Science Objective Trade Study

Figure of Merit	**Weight**	**Magnetosphere**		**Composition of Plumes**		**Internal Structure and Heat Flow**	
		Raw Score	Weighted	Raw Score	Weighted	Raw Score	Weighted
Interest of Team	9	9	81	3	27	1	9
Applicability to other science fields (broadness)	1	3	3	3	3	3	3
Mission Enhancement	1	1	1	3	3	3	3

Measurement Method (easy to obtain)	9	1	9	3	27	9	81
Understood by the Public	9	3	27	3	27	3	27
Creates excitement in the public (wow factor)	3	9	27	3	9	1	3
Ramification of the answer	3	9	27	3	9	1	3
Justifiability (nice, neat package), (self-enhancement)	1	9	9	9	9	3	3
			184		108		152

Table 2. Science Traceability Matrix

Science Objective	**Measurement Objective**	**Measurement Requirement**	**Instrument Selected**
Hot Plasma	Plasmic Composition	During orbit with Saturn, shoots lasers into plasma	Mass Spectrometer
Energetic particles	Electron Density	Probes slide out in plasma, during orbit	Langmuir Probe
Magnetic Fields	Sense disturbances in magnetic fields	Isolate it, 2 coils, during orbit	Fluxgate Magnetometer

Table 3. Instrument Requirements

Instrument	**Mass (kg)**	**Power (W)**	**Data Rate (Mbps)**	**Dimensions (cm)**	**Lifetime**	**Frequency**	**Duration**
Mass Spectrometer	0.230	1.5	22.4	0.45 x 0.50 x 0.80	2 years	1 month	1 hour
Langmuir Probe	0.5	0.5	0.08	0.05 x 2.5	2 years	1 month	1 hour
Flux Magnetometer	0.05	1.5	0.0008	2.1 x 1.9 x 0.8	2 years	1 month	1 hour
Inertial Measurement Unit (IMU)	0.013	0.22	0.160	2.2 x 2.4 x 0.3	2 years	1 month	1 hour

Table 4. Support Equipment

Component	Mass (kg)	Power (W)	Data Rate	Other Technical Specifications
On-board Computer (processor with board)	0.094	0.4	2 X 2 GB onboard storage	ISIS On Board Computer 400 MHz, ARM9 processor
Transmitter/ Receiver (Transceiver)	0.085	1.7	Up to 9600 bps downlink; up to 1200 bps uplink	ISIS VHF/UHF Duplex Transceiver
Antenna	0.100	0.02	N/A	Deployable Antenna System
Batteries	400 Whr/kg	N/A	N/A	Mass Calculated by each team, based on power requirements.

3.0 Payload Design Requirements

In designing our team´s payload, there were many requirements that we had to consider in order to make this mission achievable. First and foremost, UAH provided us with size and project requirements that had to be met. Those included a mass of no more than 10 kg and a volume of no greater than 44x24x28cm. Also, our payload could not do any damage to the main UAH spacecraft when deploying.

Along with project requirements, the team was challenged to also meet certain functional requirements; the payload we designed would have to accomplish certain tasks set by the InSPIRESS team. These included deploying from the UAH spacecraft, collecting data autonomously, and transmitting that data back, all while providing its own power source and protection from the environment.

Finally, we had to ensure that our payload would survive the cold environment of Enceladus's atmosphere. Since we are deploying around Enceladus, our payload must be able to survive temperatures of -210℃ and be in working condition to collect and send data, all while withstanding speeds of 154.444 m/s in order to maintain a lower orbit.

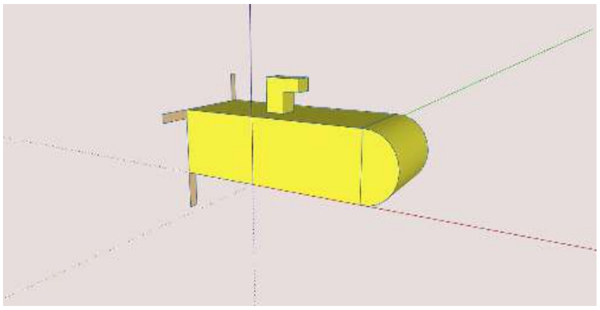
4.0 Payload Alternatives

In order to brainstorm as many ideas as possible for our payload design, we separated into two groups. Concept one, *The Yellow Submarine,* was derived from the group that was led by our chief engineer. Their goal was to design a payload that met our science objective at a more simplistic basis. Concept 2, *Octavius,* was led by the project manager and was tasked to be more complex. We believed these two separate approaches would give our group more developed options for our final design.

4.1 Concept 1

Our first concept, The Yellow Submarine, was designed to be a simple, bare-bones concept meeting the basic needs of our science objective. The payload had a single fluxgate magnetometer in the front to measure changes in Saturn's magnetosphere. This concept used an external mass spectrometer to obtain fly-by compositions of plasma, and a Langmuir Probe in the rear for determining electron density. All components necessary for the operation of the payload(i.e. IMU, On-Board Computer, Antenna, and Transceiver) were housed in the interior of the payload.

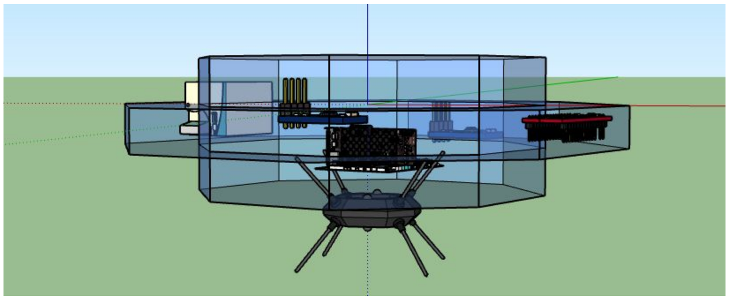
Figure 1. Concept 1



4.2 Concept 2

Concept 2, entitled Octavius, was a payload that the team specifically designed to obtain as many sets of data on plasma´s influence within the magnetosphere as possible. His octagonal shape, inspired by NASA's Magnetospheric Multiscale Mission, allows for many instruments to have direct access to the atmosphere. Octavius is essentially composed of two main sections. The first section we entitled as the Main Processing Unit. This is the inner area of Octavius that houses the On-Board Computer, the antennae, the transceiver, batteries, and one of the fluxgate magnetometers (control). The other section we labeled as the instrument bay. This is the area that hangs around the middle of Octavius and provides access points for the main instruments to have contact with the atmosphere. Included in the instrument bay are our internal mass spectrometer, another fluxgate magnetometer, a Langmuir probe, and our inertial measurement unit. These instruments were selected based on their abilities to deliver data on the plasmic composition, magnetic fields, and electron densities all at specific locations around the magnetosphere.

Figure 2. Concept 2



5.0 Concept Selection Trade Study

In order to perform an accurate assessment of which payload best suited our science objective, our team used seven Figures of Merit given to us by UAH and three Figures of Merit that the team thought were important in settling on a final design. These three figures we created were Data Precision, Power Source Reliability, and Deployment Method. Data Precision was important to our science objective because the team´s main goal was to compare how the measured data was different around the magnetosphere. Even small differences in composition would be crucial to our mission. Power Source Reliability was crucial because we needed to ensure that our payload would be able to collect data for the full two years we were deployed. Finally, Deployment Method was chosen because an efficient deployment that fit into the mass requirement would be vital to our payload collecting data from around Enceladus.

Table 5. Payload Concept Selection Trade Study

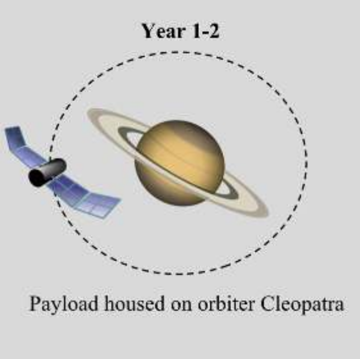
Figure of Merit	**Weight**	**The Yellow Submarine**		**Octavius**	
	Weight 1, 3, 9	**Raw Score**	**Weighted Score**	**Raw Score**	**Weighted Score**
Science Objective	9	3	27	3	27
Likelihood Project Requirement	3	9	27	3	9
Science Mass Ratio	1	3	3	1	1
Design Complexity	3	3	9	9	27
ConOps Complexity	9	3	27	9	81
Likelihood Mission Success	9	3	27	3	27
Manufacturability	1	3	9	1	1
Power Source Reliability	3	1	3	9	27
Data Precision	9	3	27	9	81
Deployment Method	1	3	3	3	3
			164		284

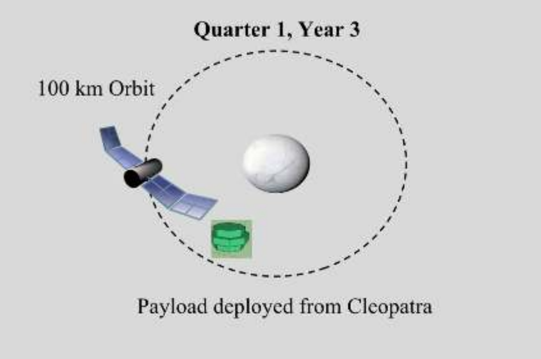
From the Concept Selection Trade Study, it became extremely apparent that the payload Octavius would better reach the goals set forth by our team. While Octavius is a more complex design and will be more difficult to fit into the project requirements, we judged that his ability to take extremely precise sets of data coupled with his Conops complexity gave him the cutting edge needed to fulfill our science objective.

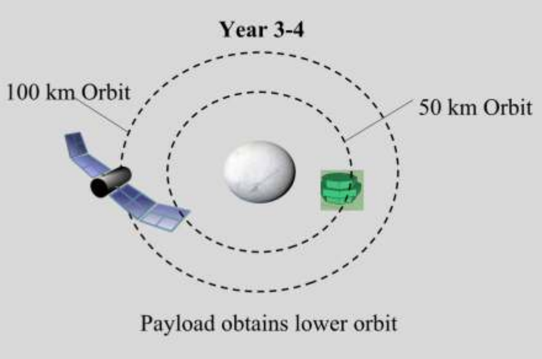
6.0 Payload Concept of Operations

The basis for our concept of operations was to design our mission to measure as many data sets on plasma´s interaction within Saturn's magnetosphere. This led us to want to incorporate the data taken from the UAH Primary Missions as efficiently as possible. Knowing that we have full access to the data from the UAH Primary Missions, we chose to deploy in quarter 1 of year 3 around Enceladus in order to optimize our data bank. We chose to deploy at

Enceladus for two main reasons. One of them being that the plumes located at the south pole of Enceladus eject large amounts of plasma, and the other being that disturbances in Saturn's magnetic field around Enceladus have already been represented in data from NASA´s Mission Cassini. From our deployment off of the UAH orbiter Cleopatra, Octavius will obtain a 50 km circular orbit around Enceladus and will take measurements for the remaining two years of the mission. We will then take the data we have collected and compare it to the data derived from the UAH orbiter Cleopatra who took similar measurements both around Saturn and a 100 km circular orbit around Enceladus. This, overall, will give us three different sources of measurements relating how different plasmic compositions interact with the magnetosphere in different ways, hopefully providing a better insight on the irregularities witnessed in Saturn's magnetosphere.







7.0 Engineering Analysis

Upon completing the Concept of Operations, we next had to ensure that the payload we developed would have the necessary means to achieve our research goals within the four stages of engineering analysis.

First, in our assessment of Initial Conditions, we had to find the extremely specific mass of Octavius by performing a battery analysis. We summed our battery mass by taking the amount of power required to power our instruments and multiplied by the operational time. This gave us our total power in W*hrs which we in turn divided by 400 W*hr/kg to determine our battery mass of 0.4154 kg. This mass, along with the total mass of instruments and housing, gave us the correct total mass of Octavius that would be used in subsequent calculations, 4.0414 kg. The next goal in Initial Conditions was to calculate the initial velocity of our payload. Knowing that the orbiter is in stable orbit, we calculated the velocity by taking the square root of the gravitational constant multiplied by the mass of Enceladus and dividing by our orbital radius ($V_i = \sqrt{(GM/r)}$). This gave us an initial velocity of 143.055 m/s.

After determining our initial conditions, we designed our deployment tube and calculated both the final velocity and acceleration needed to reach our goal of 50 km orbit. The deployment tube is 30 cm long, has on an octagonal shape slightly bigger than Octavius, and has an area of 176 cm². Because we are seeking a lower orbit of 50 km, we calculated that the final velocity we would need to achieve was 154.444 m/s. This number came from using the same calculation method as the initial velocity; however, the team now used a 50 km orbital radius rather than a 100 km ($V_f = \sqrt{(GM/r)}$). The next task came in determining the needed acceleration to deploy at this velocity and the pressure required to achieve it. We achieved this velocity by accelerating $166.67 m/s^2$ through 5.5 psi of helium gas in the same direction as the initial velocity of the orbiter. Since we are changing from a 100 km orbit to a 50 km orbit, the increase in velocity through forward propulsion allows us to change our trajectory and allow for a continual lower orbit. Once this lower orbit is achieved, we will maintain the orbit and take measurements for one hour every month for the two-year orbital period. All calculations are given in the table below.

To go along with engineering analysis, the payload we designed needed to be able to achieve these 4 stages of operation while also surviving the environment. Because the temperatures around Enceladus are extremely cold, we designed a layer of aerogel to fit inside the main processing unit of Octavius to better allow our instruments to work in the extreme environment. The outer shell of Enceladus was created using Aluminum which gives Octavius the support and protection required to operate at high speeds while still being lightweight.

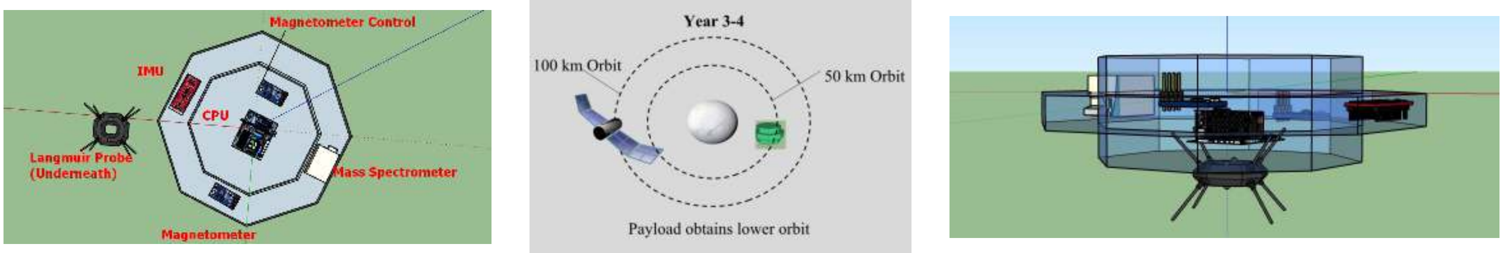
Aspect of Design/Deployment	**Calculation Method**	**Result**
Initial Orbital Velocity	$V_i = \sqrt{(GM/r)}$; 100 km radius	143.055 m/s
Final Orbital Velocity	$V_f = \sqrt{(GM/r)}$; 50 km radius	154.444 m/s
Pressure Required	$V_f^2 = V_i^2 + 2(P*A/m)*d$	5.5 psi
Acceleration	$a = (P*A/m)$	$166.67 m/s^2$
Trajectory	Forward Propulsion	50 km Circular Orbit

- d = length of deployment tube in meters; 0.3 m
- A = area of the deployment tube in m^2 ; $0.0176 m^2$

8.0 Final Design

The final design of our payload is essentially an orbiter that has been specially equipped with specific instrumentation to assess 3 certain sets of data: hot plasma and its composition, energetic particles, and magnetic fields. The team's payload Octavius uses an internal mass spectrometer to measure the composition of the plasma, a langmuir probe to determine electron density, and two fluxgate magnetometers to detect disturbance in the magnetic field (one as a control and the other as a source of measurement). These instruments coupled with an inertial measurement unit will provide data on how Saturn's magnetosphere interacts differently with separate sets of plasma all around Enceladus. By deploying into Enceladus's atmosphere and obtaining a lower orbit, Octavius will be in a prime position to take the needed data to meet our science objective. For the two years after deployment, Octavius will use the calculated battery mass to power all the instruments for 1 hour every month for 24 months, essentially providing 24 different sets of data for comparison. We then will take the data we have collected and compare it to the data received from the UAH primary missions in order to effectively draw conclusions on Saturn's magnetosphere and achieve our science objective.

Figure 3. Mission Magneto's Mission



Aerial View of Octavius

ConOps Summary

Side View of Octavius

Table 6. Final Design Mass Table

Function	Component(s)	Mass (kg)
Deploy	Aluminum Launch Tube	5.18
Measure	- Mass Spectrometer - Langmuir Probe - Flux Magnetometer (x2) - IMU	- 0.230 - 0.5 - 0.05 (x2) - 0.013 Total: 0.843
Collect Data	On-board Computer (processor with board)	0.094
Provide Power	Batteries	0.4154
Send Data	- Transmitter/Receiver (Transceiver) - Antenna	- 0.085 - 0.100 Total: 0.279
House/Contain Payload	Aluminum Shell, Aerogel layer	2.41
Total		9.2214

Table 7. Design Compliance Table

Requirement	Payload Design Component
No more than 10 kg	9.22 kg < 10 kg
Fit within a 44 cm x 24 cm x 28 cm box	14 cm x 15.7 cm x 15.7 cm
Survive Environment	Aluminum housing and Aerogel insulation
No harm to spacecraft	Use a pressurized deployment