Perpetual Motion - *"The Power to do More"*

Payload Concept Proposal

Perpetual Motion

Palmetto Scholars Academy

Team #3

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Titan Environmental and Atmospheric Mission (TEAM)

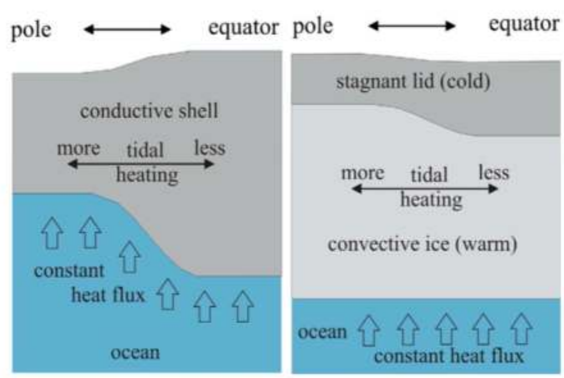
1.0 Introduction

Perpetual Motion chose their team name because they recognize that change is constant and must be studied for the advancement of science and technology. As a result, they chose the slogan: "The Power to do More.". The logo features a Kraken in Kraken Mare, a point of interest on Titan, holding an overbalanced wheel to represent perpetual motion. Perpetual Motion's chosen payload design is an orbiter named "Coeus" after the Titan of intellect, representing the inquisitive mind which parallels Perpetual Motion's attitude and the payload's corresponding science objective. The primary science objective is to study observed gravitational anomalies on Titan. Perpetual Motion's Coeus payload includes two main components intended to aid in the Titan Environmental and Atmospheric Measurement (TEAM) Mission, which was delivered by UAH Point of Contacts Matt Turner and PJ Benfield: a Radio Science Subsystem (RSS) and a Radar Altimeter to study gravity and topography, respectively.

2.0 Science Objective and Instrumentation

The primary science objective of the payload will be to study Titan's observed gravitational anomalies. A group of scientists at the University of California, Santa Cruz used data gathered by Cassini instrumentation to develop models of Titan's topographical features. When flying over a mountain on Earth, an increase of gravity (positive gravitational anomaly) is expected due to the excess mass. On Titan, however, this is not the case. Over Titan's elevated features there is a negative correlation between gravity and topography. It is theorized that small bumps on the surface may have deep "roots" beneath it like an iceberg extends beneath the surface. The iceberg floating in water is in equilibrium, its buoyancy balancing out its weight. The roots beneath Titan's surface would extend much further below which would push them up against the surface, developing small, raised bumps. Weathering and erosion would keep these anomaly features minimal.

If large roots are the cause of this negative gravitational anomaly, Titan's ice shell would be very thick and rigid to keep it submerged. If convection occurs, however, the rigid portion would likely be thin and weak. Thus, these two models are not compatible with a geologically active, low rigidity ice shell. This means Titan's moment of inertia is possibly higher and less centrally condensed than previously thought (less solid substance, more ice). This would make it difficult to produce ice volcanoes, which have been theorized to replenish the abundance of methane present in the atmosphere. This objective would further indicate internal structure, ice shell properties (size, rigidity, thickness), and cryovolcano feasibility. Therefore, determining the existence of cryovolcanoes is a science objective inherent within Coeus' mission.



Douglas Hemingway and Francis Nimmo at UC Santa Cruz "A Rigid and Weathered Ice Shell on Titan"

For Titan to house cryovolcanoes, the subsurface would have to be warming up enough to melt parts of Titan's interior and send volatiles through an opening in the surface. The best proof of cryovolcanism on Titan is the region of Sotra Facula, a destination of interest. Sotra Facula is comprised of two peaks more than 3,000 feet tall. In addition, the finger-like flows named Mohini Fluctus and a depression 5,600 feet deep and 20 miles wide named Sotra Patera are other topographical features that suggest the process of cryovolcanism. This leads scientists to believe cryovolcanism is the best explanation for these features. Although scientists have not confirmed whether or not cryovolcanism occurs on Titan, it is the best current explanation for certain land features.

Science Traceability: Through a decision analysis process, Perpetual Motion chose to base their payload off of a Radio Science model. To fulfill the science objective, the measurement objective is set, the requirements necessary to take that measurement, and the measurement objective are displayed in the Science Traceability Matrix.

Table 1. Science Traceability Matrix

Science Objective	Measurement Objective	Measurement Requirement	Instrument Selected
Geophysics - Internal Structure	Measure surface composition and internal structure.	-Face Titan's surface while positioned between Titan and Earth -Outside of Payload Housing	Radio Science Subsystem (RSS)
Topography - External Features	Determine height of surface features.	-Face Titan's surface -Outside of Payload Housing	Radar Altimeter

Instrument Requirements: The total mass of the instruments and mission support equipment is 4.402 kg (not including battery mass or housing). Due to the 10 kg project requirement, 3 kg of batteries (400 Whr/kg) was decided in order to leave mass for housing the payload. The total duration of the TEAM Mission that UAH and Perpetual Motion are part of determined Coeus' Mission lifetime. The UAH orbiter operates for twenty months (approximately 28 Titan Sols). The frequency and duration that each instrument operates are set to maximize the success/data collected by the mission-- Mission Supporting instruments (MS) operate as necessary and the RSS and Altimeter begin operation once Coeus has deployed from the UAH orbiter, the payload has sustained a stable orbit, and Titan is located between Earth's Deep Space Networks (DSN) and the payload.

Table 2. Instrument Requirements

Instrument	Type	Mass (kg)	Power (W)	Data Rate (Mbps)	Size (cm)	L (Titan Sol)	F (s)	D (s)
RSS	P	2	80.7	N/A	7 x 20 x 21	38	45	0.05
Altimeter	P	2	50	0.00058	8 x 8 x18	38	45	0.05
OBC	MS	0.094	0.4	N/A	20 x 10 x 1	38	300	15
Storage	MS	0.010	2	12000	2.2 x 6 x 0.2	38	300	0.1
Transceiver	MS	0.085	1.48 Tx/ 0.21 Rx	0.0012	5 x 5 x 3	38	300	15
IMU	MS	0.013	0.160	0.160	0.45 x 0.50 x 0.80	38	300	0.1
Batteries	MS	3	400 Whr/kg	N/A	20 x 10 x 13	N/A	N/A	N/A
Housing	MS	2.206	N/A	N/A	3060	Full	Full	Full

*P (Primary Instrument) **MS (Mission Supporting) ***Lifetime
****Frequency *****Duration

3.0 Payload Design Requirements

InSPIRESS has four major requirements, three of which are displayed in Table 3: Project Requirements, Environmental Requirements, and Functional Requirements. The fourth component is the Science Requirement: Does your payload comply with all other components, and is it designed to accomplish its objective? Perpetual Motion's payload, Coeus, meets all InSPIRESS requirements (as shown by table 4).

Table 3. Payload Design Requirements

Project Requirements:	**Environmental Requirements:**	**Functional Requirements:**
1. *Autonomy* - Payload is autonomous. 2. *Environment* - Payload studies environment and is equipped to survive potential conditions. *3. Science* - Payload performs science. 4. Ride aboard UAH spacecraft. *5. Mass*: 10 kg, *Volume* when stowed: 44 x 28 x 24 cm. *6. No harm to main spacecraft.*	1. Temp.: -179 °C / -290 F (surface) 2. Pressure (air): 1.5 atmospheres 3. Gravity: 1.352 m/s^2 4. Radiation: low due to thick atmosphere 5. Chemistry: 98.4% nitrogen, 1.4% methane, 0.2% hydrogen 6. Wind: 400 km/hr (250 m/hr) - Huygens; more tame nearer surface ~1-2 km/hr	1. Deploy from UAH spacecraft 2. Take measurements 3. Collect Data 4. Provide power 5. Send Data 6. House the Payload

4.0 Design Choices

UAH provides 3 methods of transport: Orbiter, Lander, and Balloon; 3 directions of deployment: Forward, Backward, Downward; and 4 methods of deployment: helium, gravity, spring, balloon.
Orbiter - *1000 km* altitude for *20 months* maximum.
Balloon - *10 km* altitude for *6 months* maximum.
Lake Lander - On *Kraken Mare, 200 km* from shore for *30 day* maximum.
Perpetual Motion chose to deploy their payload from the UAH orbiter.

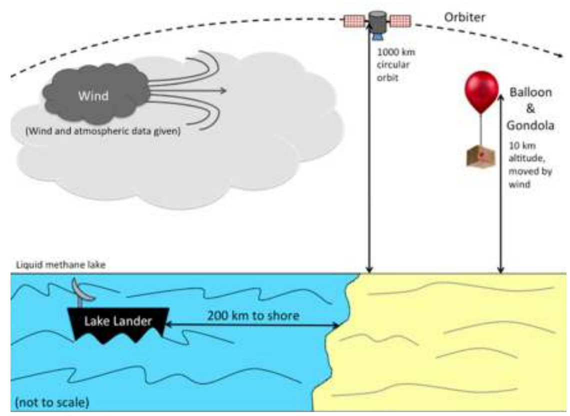


Figure 1: **GRACE Satellite Configuration**

5.0 Preliminary Design

Concept 1: RSS Model

A radio transmitter sends radio waves through Titan's surface and then to the Deep Space Network (DSN). Using the Doppler effect, changes beneath the surface can determine composition of the surface and layers beneath.

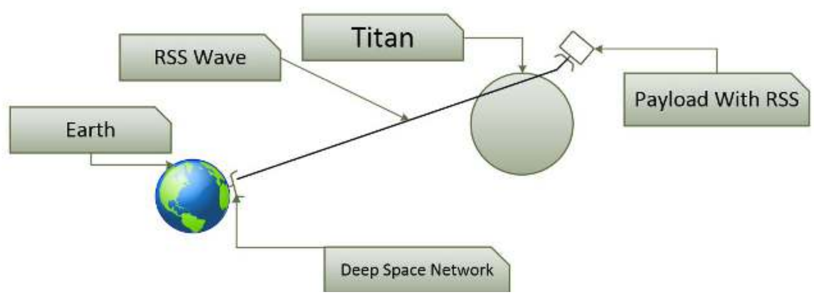


Figure 2: **GRACE Satellite Configuration**

Concept 2: GRACE Model

A set of twin satellites travel next to each other in orbit, using high accuracy microwave range finding link to distance variances to the nanometer. As the satellites orbit around a planet, positive gravity anomalies cause the first satellite to lower slightly, and vice-versa for a gravity decrease. Two measurements are recorded (one for each satellite) in order to accurately map gravitational fields.

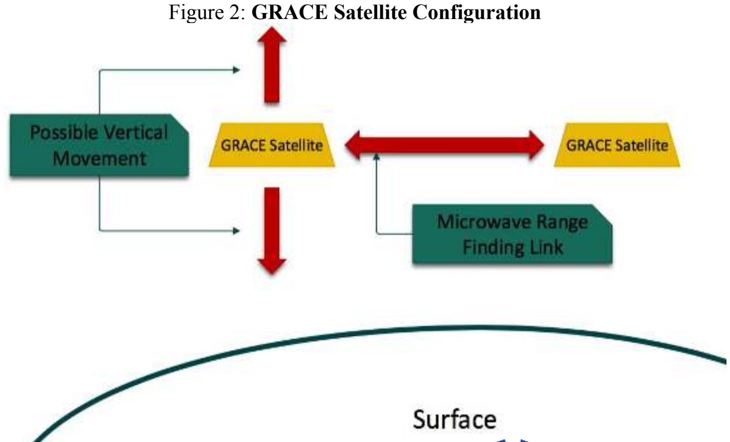


Table 4: Decision Analysis and Mission Compliance Table

FOMs	Summary	Preference	Weight	RSS Model	x_1	GRACE Model	x_2
Perpetual Motion Preferences							
Measurements	Data Accuracy / Amount	Precise Data Collection	~~3~~	~~9~~	~~27~~	~~9~~	~~27~~
Science	Performs Objective	Gathers Best Data	3	9	27	3	9
Stable Orbit	Orbit Stability	Stable	~~1~~	~~9~~	~~9~~	~~9~~	~~9~~
UAH InSPIRESS Requirements							
Project	Autonomy	Fully Autonomous	9	3	27	9	81
Environmental	Prepared For Environment	Rides Spacecraft	~~9~~	~~9~~	~~81~~	~~9~~	~~81~~
Functional	Within Constraints Set By UAH	Under Mass / Volume Constraints	9	9	81	1	9
Totals:				252		216	

Decision Analysis Methodology:

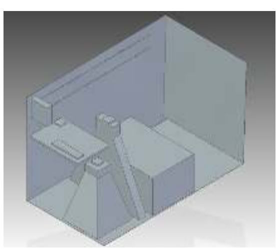
Figures of Merit (FOM) are divided by team preferences and InSPIRESS requirements, which are weighted highest. This aims to produce the most compliant design. The team gave each model a score:

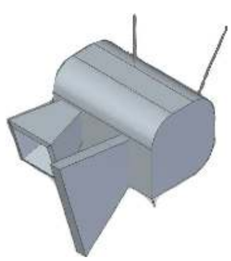
- 1 - low,
- 3 - medium, and
- 9 - high likeliness

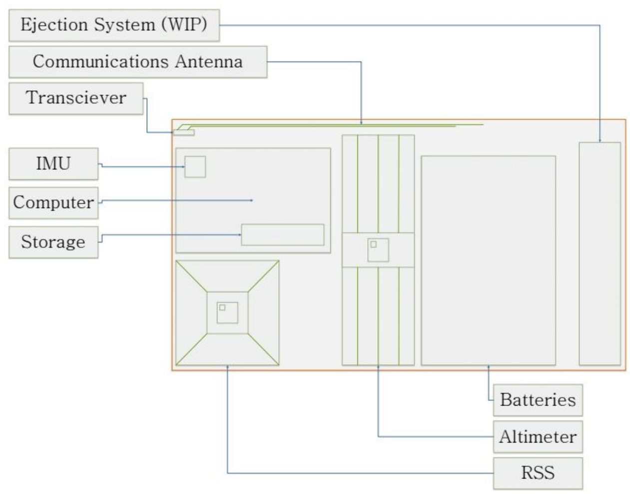
Weights are multiplied by the scores, and the sum of ranks to each respective design results its total score.

Highest total is chosen as design: RSS Model.

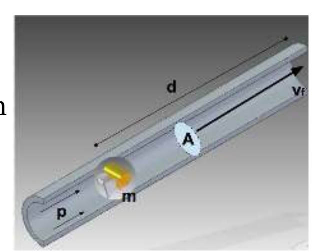
These are a few of the preliminary design concepts Perpetual Motion modeled. The bottom two 3D CAD models were developed with Solid Edge during the early design process and were manipulated further as the design was more defined.The 2D layout was an initial model to determine position and location of the different instruments. Figure 3. Prelim. Internal and External







6.0 Design Analysis - There are three main sets of calculations for this mission: orbit conditions and helium deployment.



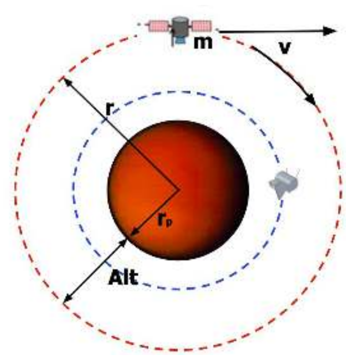
Helium Pressure Deployment System: A final velocity and distance were chosen in order to keep the payload close to Titan. Instead of solving for final velocity acceleration we solved for acceleration. InSPIRESS assumptions for calculations: payload is perfect fit within system, pressure is constant, and no friction.

Orbit Conditions: The force of gravity is set equal to the force of the payload's circular motion (centripetal force) around Titan and is used to determine orbital velocity. The closer to the mass, the higher the orbital velocity will be. It is recommended by InSPIRESS that muzzle velocity be 1% of orbital velocity. The sum of these two velocities is Coeus' payload velocity. Algebraically, we can use the orbital velocity equation to determine orbital radius and the muzzle velocity equation to solve for payload acceleration through deployment. InSPIRESS Calculation Assumptions: Circular Orbit and no drag

Measurements: After deployment, Coeus will take 121.80 seconds to reach stable orbit. Coeus will activate the altimeter for a duration of 0.05 seconds once in correct alignment. Immediately after, the RSS will be activated for a duration of 0.05 seconds. This process will repeat itself every 45 seconds. After 152 activations of the RSS, both instruments will shut down for a grace period of 6878.56 seconds while the payload is not in optimal alignment. Another 152 activations will occur using the same frequency and duration followed by another grace period. This process will continue for the entirety of the mission for a total of 5808 measurements.

Table 5. Calculations Table

Design Stage	Variable and Item	Equation	Calculation	Result
Initial Conditions	Fc, Centripetal Force	$Fc = \frac{mv^2}{r}$	$\frac{(9.608)(1584)^2}{(3576*1000)}$	6.74 N
	Fg, Force of Gravity	$Fg = \frac{GMm}{r^2}$	$\frac{(6.67x10^{-1})(1.3452x10^{23})(9.608}{3576^2}$	6.74 N
	v, Orbital Velocity	$\therefore v = \sqrt{\frac{GM}{r}}$	$\sqrt{\frac{(6.67x10^{-1})(1.3452x10^{23})}{3576}}$	1584 m/s^2
Deployment	Vf², Muzzle Velocity	$Vf^2 = Vi^2 + 2ad$ $a = \frac{1}{2}(\frac{d}{Vf^2})$, $P = \frac{F}{A}$	$15.84 = 2(\frac{1}{2}(\frac{0.4}{15.84}))$	15.84 m/s^2
	Pv, Payload Velocity	$Vp = v + Vf^2$	1584 + 15.84	1599.84 m/s^2
Trajectory	r, Radius of Orbit	$r = \frac{GM}{v^2}$	$\frac{(6.67x10^{-1})(1.3452x10^{23})}{1584^2}$	3505.53 km

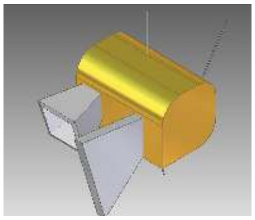


Payload Velocity	Orbit Radius	Above Surface	Orbit Difference
1599.85 m/s²	3505.53 km	929.53 km	70.46 km

Variables and Values Table

M, mass of Titan	1.3452 x 10^{23} kg
rp, radius of planet	2576 km
G, gravitational constant	6.67 x 10^{-11} m^3 kg^{-1} s^{-2}
m, mass of orbiter	9.6086 kg
v, orbital velocity	1584.01 m^2
Alt, orbit altitude	929.54 km
r, Alt + rp	3505.54 km

7.0 Final Design



Housing - Coeus will be shielded by carbon nanotube material sheets and MLI, a common multi-layer insulation for payloads in vacuo, in order to keep the gondola thermally controlled throughout the mission. MLI has three layers: one to trap heat, a perforated layer to allow air passage, and another to protect from the environment.

Gravity Gradient Stabilization - For the primary instruments to operate effectively, the payload antenna must face the surface of Titan with Earth on the other side. Coeus has a gravity gradient stabilization system that will deploy to ensure the antenna is always facing Titan's surface. The force of gravity is stronger the closer an object is to the mass. One side of the satellite will feel this force more than the other. If the difference between the forces is great enough, the satellite will become tidally locked, and the side sustaining the greater force will remain facing the body of mass.

Table 6. Final Design Mass Table

Function	Component(s)	Mass (kg)
Deploy	Helium Pressure	N/A
Take Measurements	RSS / Radar Altimeter / IMU	2 / 2.2 / 0.013
Collect Data	OBC /Storage	0.094 / 0.01
Send Data	Transceiver	0.085
Provide Power	Batteries	3
House Payload	MLI	2.206
Total Coeus Orbiter Payload Mass		9.608

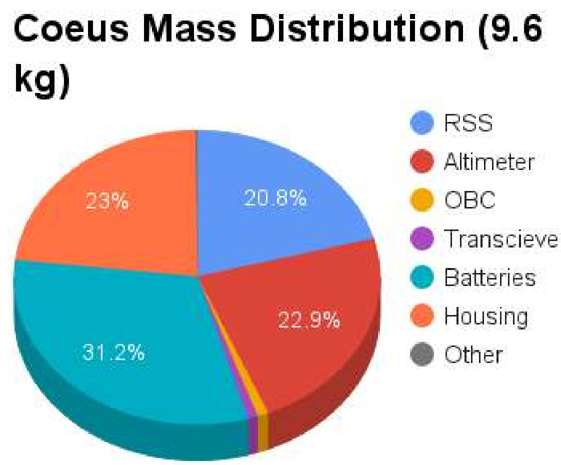
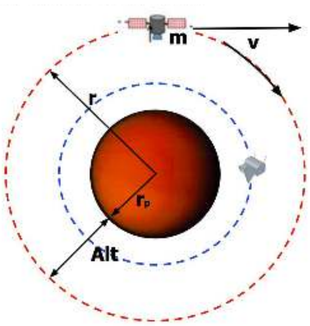


Figure 4.: Mass Distribution



Concept of Operations: Phase 1: Coeus accelerates at 0.13 m/s² in order to exit the deployment system at 15.84 m/s (muzzle velocity) and deploys from the UAH Orbiter. **Phase 2:** Payload stabilizes in orbit around Titan at 1599.85 m/s². **Phase 3:** RSS and Altimeter begin taking measurements approx. 2 minutes after deployed. Data is collected and transferred. **Phase 4:** Finalize data transfers. Turn off payload. **Mission Conclusion:** Analyze data received by DSN to fulfill its science objective and mission.

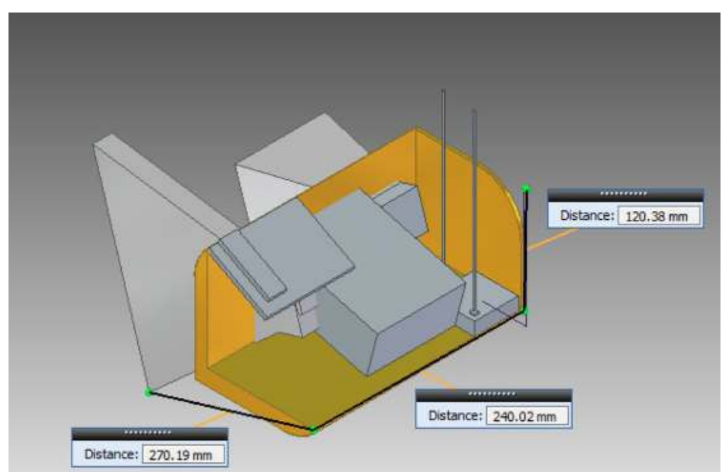


Figure 5. Perpetual Motion's Mission