UNIVERSITY OF COLORADO - BOULDER
DEPARTMENT OF AEROSPACE ENGINEERING SCIENCES
ASEN 4018

PROJECT DEFINITION DOCUMENT (PDD)

Micro-Particle Uni-Directional Sensor for Ice Collisions (M.U.S.I.C.)

Approvals

	Name	Affiliation	Approved	Date
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Course Coordinator	Chris Muldrow	CU/AES		

I. Project Customer

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II. Team Members

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III. Problem or Need

Little is known about the water under the icy crust of Saturn's moon Enceladus. This global ocean separates the rocky core from the thick ice surrounding the body, and at the south pole the water erupts in icy geysers. The flash-frozen droplets from these geysers can provide much information about the environment under the ice, and a glimpse into one of the few places in the solar system that may house the proper conditions for life. This mission will meet the need to characterize these ice geysers by orbiting very low through the plumes and capturing data from the collisions. By analyzing the acoustic signature of the impacts, this sensor will be used in tandem with other onboard sensors to classify the size and composition of the particles, and their probability for containing micro-organisms.

IV. Previous Work

Detecting and characterising particulates using acoustic methods is not an unknown field. For example, NASA developed DRAGONS (Debris Resistive/Acoustic Grid Orbital Navy-NASA Sensor) for the purpose of detecting micrometeoroids and space debris particulates at various orbits around the Earth. The sensor had a resolution of roughly 50μm under ideal conditions. It made use of a 1m^2 sensor composed of two layers: A first layer that is punctured by the particles, and a second layer where the particulates are annihilated and their energy measured. This study provides interesting insight into ways to measure particles, however due to the destructive nature of the process to the sensor, and the fact it measures particles moving significantly faster than the ones anticipated for this project, simply replicating the same sensor will not prove satisfactory.
Flybys of Enceladus have been done before. NASA's Cassini spacecraft flew over the icy moon three times, once at an altitude of only 30 miles above the surface as it gathered data on the ice plumes [1]. The Cosmic Dust Analyzer onboard was used to analyze the material of the plumes, finding salt water and simple organic molecules [2]. Cassini also indirectly studied the plumes by measuring how the force of the particles altered its orbit.

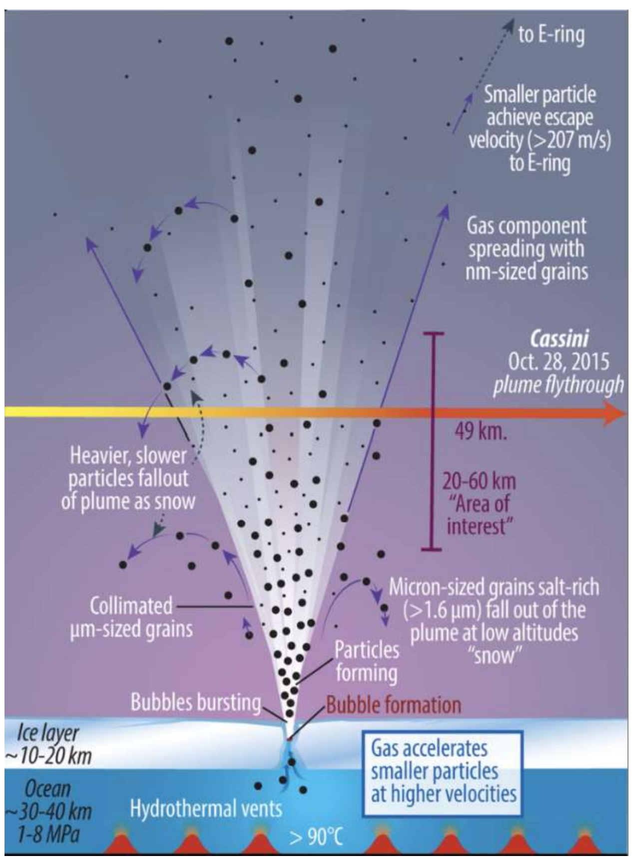

Fig. 1 Cassini Flyby

This project will continue the research that Cassini started, by flying through the ice plumes at much slower speed with sensors purpose built for analyzing the plumes.

V. Specific Objectives

Based on the issue to be addressed and from meetings with the customer, the project as a whole can be broken down into three levels of specific objectives:

Level I	The sensor shall, over a given window of time, report the average number of impacts
Level II	The sensor should be able to resolve individual impact events.
Level III	The sensor should be able to identify the mass and velocity of individual impact events.

Level I represents the minimum level of success for this project. Level II would be considered total fulfillment of objectives, and Level III requirements are objectives put forth by the customer that are not expected to be met but would further satisfy customer needs.
The final deliverables for this project will be twofold: a summary of the teams findings, and acoustic impact data. The team will conduct research into the concept and develop mechanical and software solutions for noise reduction, impact detection, and data analysis. During development, the team will find a reliable way to measure the perturbations in the sensor surface, and will test ways to characterize the vibrations induced by nearby sounds or small particle collisions through simple tests. Once a functional prototype is completed, operational conditions will be simulated in a vacuum chamber where ice particles are accelerated to high speed and collide with the sensor.

VI. High Level Functional Requirements

A. Mission Requirements

Requirement	Rationale
The sensor shall be capable of integration with the satellite.	Ultimately the sensor will be part of a larger system, and must integrate properly. This will be out of the scope of the project as we are simply validating that an acoustic sensor is a viable option.
The sensor shall be able to withstand a launch.	The final design will experience vibrations and stresses, which is a consideration for material choices. This is outside the scope of the project as our prototype will not be launched.

B. Sensor Requirements

Requirement	Rationale
The sensor shall fit inside a 10x10x10 cm volume.	This is to ensure that the sensor fits inside the vacuum chamber to be used for testing.
The detection hardware shall be capable of operating in a vacuum.	This ensures that the portion of the sensor where the particles will collide can survive the environment of space.
The sensor shall be able to detect ice particle impacts ranging from 0.5 to 4μm (CR).	This is the range of particles of interest in the plumes.
The sensor shall be able to detect ice particle impacts ranging from velocities between 100 and 300m/s (CR).	This is based on the orbital velocity of the spacecraft around Enceladus.
The sensor shall be able to survive repeated impacts from small ice particles.	This will allow the sensor to be repeatedly tested and improved, and demonstrate its ability to operate in mission conditions.
The vacuum portion of the sensor shall not use more than 1W of power (CR).	This ensures there will be no overheating.
The sensor shall mitigate vibrations inside the vacuum chamber.	This will reduce noise and ensure actual impacts can be detected.
The sensor should be able to detect distinct impacts in cases of multiple impacts.	for instance, if two particles hit the sensor at the same time it should be able to identify that there were two impacts. This enables a more detailed analysis of impact statistics.

C. Software Requirements

Requirement	Rationale
The sensor design shall be based in a computational model of the impacts.	Understanding and predicting the physics of the impacts is an important aspect of characterizing actual data.
The system shall be able to provide data over a given window of time to the user.	The aggregate number of impacts or the average number over time is important in understanding the plume characteristics.
The system shall be able to measure the noise floor and be able to take this into account when measuring impacts.	Reducing the noise floor is critical to distinguishing very small particles from noise.
The system shall be able to determine the rate of impacts.	Similar to determining the average, this is important for discovering where the plumes are more numerous and dense.
The system should be able to determine individual impact characteristics.	This would provide data on the finer details of the plume characteristics.

Note: CR = Customer Requirement

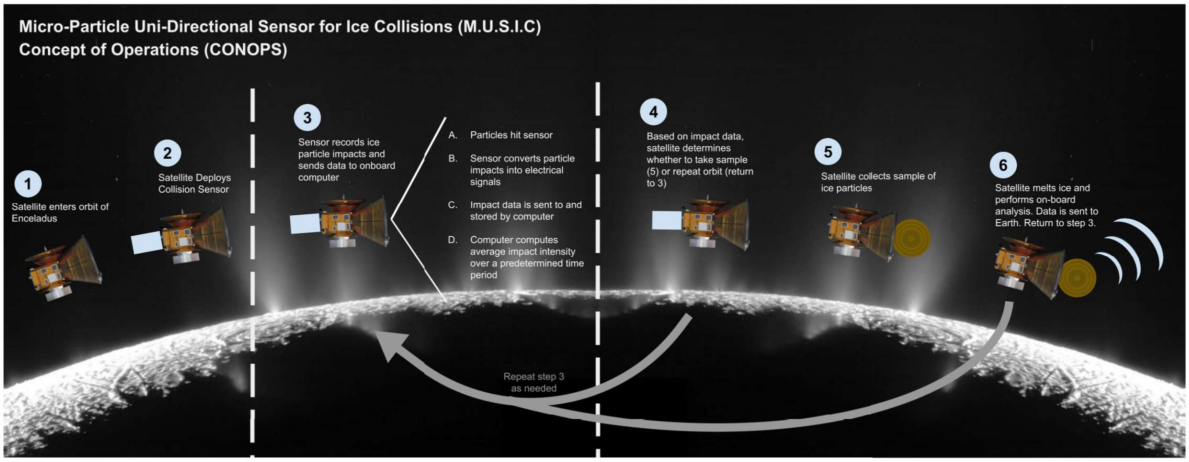

Fig. 2 Concept of Operations (CONOPS)

The mission-level Concept of Operations (CONOPS) diagram is displayed in the figure above. The mission profile breaks down into distinct stages:

1) The satellite enters an orbit around Enceladus.
2) The satellite deploys the sensor.
3) The satellite performs a flyby through one of Enceladus' plumes. During this, the sensor records impact data and transmits it to the onboard computer. The computer calculates an aggregate measure of impact intensity over a predetermined time period.
4) Based on the impact data, the satellite decides whether to collect a sample or conduct a different flyby.
5) The satellite opens its collection system and collects a sample of ice particles.
6) The satellite melts the sample and uses its microscope to record data. This data is then sent to earth and another flyby is conducted.

VII. Critical Project Elements

CPE No.	Critical Project Element	Reasoning
1.	Vacuum Chamber	Access to the testing chamber restricts testing and validation.
2.	Sensor	A means to detect acoustic signals will need to be developed to meet project requirements. This includes the acquisition of specific parts, as well as both mechanical and electrical assembly.
3.	Data Analyzer	The system shall be able to differentiate particle impacts from background noise, otherwise it will not be able to meet minimum requirements.
4.	Testing / Simulation Software	The creation of a computation/analytical model will assist in the validation of our design before manufacturing, which will constrain prototyping.

VIII. Sub-System Breakdown and Interdependence

Subsystem No.	Subsystem	Dependencies
1.	System Simulation	None
2.	Data Acquisition	1, 5
3.	Data Analysis	1, 2, 4
4.	Prototyping	1, 2
5.	Electronics	1, 2, 4
6.	Structural Design	2, 4, 5

IX. Team Skills and Interests

Critical Project Element	Team member(s)	Associated skills/interests
Vacuum Chamber	Bradley Bishop, Cyrus Nichols, Sophia Trissell	Mechanical and Electrical Interfaces, Test Plan/Procedures, CAD Modelling
Sensor	Jarrett Bartson, Bradley Bishop, Riley Gordon, Alec Macchia, Timothy Shaw, Sophia Trissell	CAD Modelling, Stress/Failure Analysis, Electronics, RF Engineering (Noise Mitigation/Detection, RF Shielding), Materials Science, Assembly/Physical Manufacturing (soldering, 3D printing, etc.)
Data Analyzer	Garrett Lycett, Alec Macchia, Timothy Shaw	Statistics, Data Analysis, Coding (MATLAB, C++, Python), Electrical Interfaces
Testing/Simulation Software	Jarrett Bartson, Riley Gordon, Garrett Lycett, Cyrus Nichols, Tyler Schwinck, Timothy Shaw	CAD Modelling, FEM (Finite Element Analysis), Stress/Failure Analysis, Systems Engineering

X. Resources

Critical Project Elements	Resource/Source
Vacuum Chamber	Vacuum Chamber to test sensor (currently located in California), personnel to run vacuum chamber
Sensor	Soundproof chamber to test before vacuum chamber tests
Data Analyzer	Background research, from technical documents.
Testing/Simulation Software	N/A

References

[1] Planetary Sciences Communications Team. “Enceladus: Ocean Moon.” NASA Science Solar System Exploration, NASA Jet Propulsion Laboratory, 25 Sept. 2018, https://solarsystem.nasa.gov/missions/cassini/science/enceladus.

[2] Planetary Sciences Communications Team. “Cosmic Dust Analyzer (CDA).” NASA Science Solar System Exploration, NASA Jet Propulsion Laboratory, 4 Sept. 2018, https://solarsystem.nasa.gov/missions/cassini/mission/spacecraft/cassini-orbiter/cosmic-dust-analyzer/.

[3] Ann and H.J. Smead Aerospace Engineering Sciences; "Project Definition Document (PDD) Assignment." University of Colorado Boulder, 22 Aug. 2021.

[4] Stradling, G.L., Idzorek, G.C., Shafer, B.P., Curling Jr, H.L., Collopy, M.T., Blossom, A.H. and Fuerstenau, S., 1993. Ultra-high velocity impacts: cratering studies of microscopic impacts from 3 km/s to 30 km/s. *International Journal of Impact Engineering*, 14(1-4), pp.719-727.

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