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Ionization of Excess Propellant

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Ionization of Excess Propellant

by

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Abstract

This project aims to assess the performance and behavior of Mirco-Electromechanical Digital Thrusters (MDTs) in space. The experiment's primary objectives include evaluating individual MDT performance, assessing MDT panel integrity, examining fratricide effects, and analyzing the performance of an entire MDT panel. The experiment will take place on an external pallet on the International Space Station (ISS). However, one of the main constraints provided by NASA is that the experiment shall not be a pressure chamber at launch and should be able to vent air out. This poses as a challenge when on the ISS external pallet because excess propellant shall not be released in space for environmental concerns and the safety of projects and the ISS itself. The proposed solution for this problem is an Electro-Static filter (ESF) as well as a torturous path that the propellant will go through. While this isn't the only constraint that is part of this project it is a major concern and the use of an electro-static filter in space needs to be researched and examined. This paper will briefly examine the proposed solution for the testing of MDTs in space and research the probability of using an electro-static filter in space to collect excess propellant.

Introduction

The MDT Experiments and Systems Analysis (MESA) project was designed to develop a design concept to assess the performance of MDTs in space. The experiment will be mounted on an external pallet of the International Space Station, providing the opportunity to conduct testing of MDTs in microgravity. MDTs have emerged as a promising solution for maneuverability in space, but it is important that their behavior and performance in space is assessed as it is essential for future missions. However, there are a few challenges when conducting experiments on the ISS. One of the main challenges imposed by NASA is that the experiment must not be a pressure chamber at launch and should be capable of venting air out. This poses the challenge of containing excess propellant as it cannot be released due to environmental concerns and safety concerns. This paper will briefly examine the proposed solution for the MESA project and further examine the use of an electro-static filter to collect excess propellant.

Constraints

The constraints below come from the MESA ISS External Pallet Experiment Mission Academic Announcement of Opportunity, which serves as an outline for MAE-491.

The requirements and constraints placed on this project are as follows.

1. The maximum volume for this experiment shall be 30 cm (length) by 30 cm (width) by 60cm (height).
2. The total mass of the experiment shall not exceed 30 kg.
3. The nominal power draw for the experiment shall not exceed 60 W.
4. The experiment shall be totally enclosed to meet NASA safety standards. (Launch vehicle venting requirements allowed.)
5. Total material cost of one experiment shall not exceed $200,000.
6. The following measurements shall be collected for each firing of the MDT(s).
    a. Thrust generated (threshold)
    b. Thrust misalignment (objective)
    c. High speed optical evidence of a firing (visible – threshold; IR - objective)
    d. Evidence of a successful/unsuccessful firing from the firing chain of command
7. The following measurements should be collected throughout the entire lifetime of the experiment while on board the ISS.
    a. Temperature inside and outside the experiment enclosure (threshold)
    b. Radiation inside and outside the experiment enclosure (objective)

Threshold – required data that must be collected.

Objective – optional data that can be collected.

Science Investigation

MESA is a proposed science payload meant to access the performance of MDTs in low earth orbit. MESA will be mounted on an external pallet on the outside of the ISS. MDTs are small arrays of solid rocket propellant that are mounted onto an electronic circuit board. These induvial propellant cells can be electronically activated to produce small, controlled bursts of thrust. In order to collect this data for the mission, four science objectives will be used to guide the science operations for this experiment. The MDT panel that will be used for this experiment is shown below in figure 1.

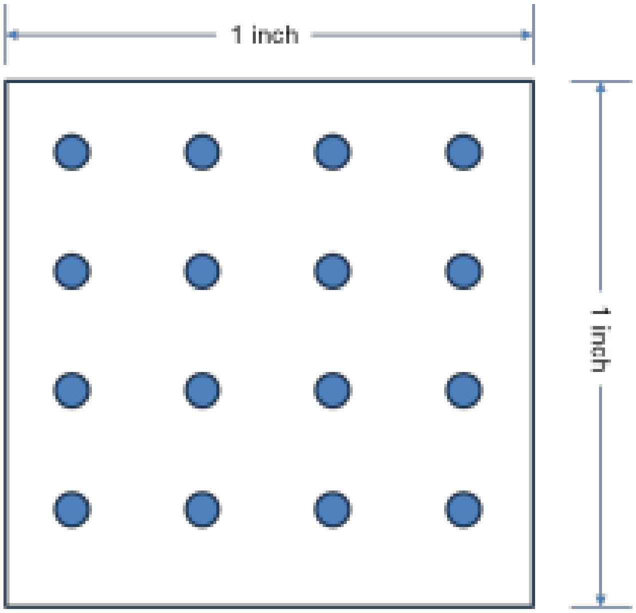

Figure 1. MDT Panel

Each blue dot in figure 1 represents a single MDT, so for each panel there are 16 MDTs. The following four objectives below come outline the purpose of each objective and how many panels will be allocated for each one. The four objects come from the MESA ISS External Pallet Experiment Mission Academic Announcement of Opportunity.

Individual MDT Performance: objective #1 concerns determining the performance of individual MDTs when they are commanded to fire. This objective is accomplished by commanding an individual MDT to fire every two weeks during the experiment operation in orbit. Two MDT panels will be dedicated to this objective.

MDT Panel Performance: objective #2 concerns determining the performance of an MDT panel. The plan is to fire multiple (2-3) MDTs at once to determine if the panel's integrity holds. We will fire pairs of MDTs, first across one fuse and then across two fuses. Each column of MDTs is on a dedicated fuse. Five boards are dedicated to this objective and will be fired every three months in the same MDT order.

Fratricide Performance: objective #3 concerns determining if the proximity of an MDT firing affects any others around it. We plan to fire an entire fuse of MDTs (either a row or column with a total of four MDTs firing) every month throughout the experiment's lifetime. A total of three MDT panels will be dedicated to this objective. D.4 Objective #4: Entire Panel Performance

Entire Panel Performance: objective #4 concerns determining the performance of an entire panel being fired at once. All 16 MDTs will be commanded to fire. This objective will be conducted immediately upon experiment operations starting at 6 months into the mission, and at 12 months. A total of three panels are dedicated for this objective.

Experiment Operations

The following data will be collected with the proposed solution: thrust generated, thrust misalignment, successful/unsuccessful firing, temperature/optical evidence. Figure 2 below shows the general layout of the different objects as described above in the science investigation.

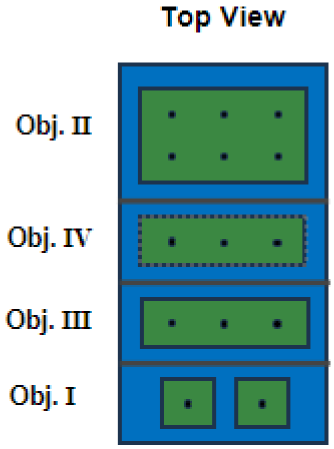

Figure 2. Layout of Science Objectives

Figure 2 serves as a basis for how each objective will be laid out within the experiment. The CAD model of the solution and where this layout plays a role in the experiment will be explored later in this report. Each green square and its respective dot represents a MDT panel.

Thrust Generated and Thrust Misalignment

To measure the thrust of the MDTs a button load cell will be used under each panel. Thrust misalignment will be measured only on the objective one and diaphragm strain gauges are to be used to measure the directional forces of the single MDT. The load cells used in objective one will serve to also double check the forces registered from the diaphragm strain gauges because the sum of those forces will equal the resultant normal vector that will be read by the load cell. Figure 3 below shows the layout of how thrust misalignment and thrust generated will be measured specifically for objective 1. For each other objective the same layout will be used just without the strain gauges.

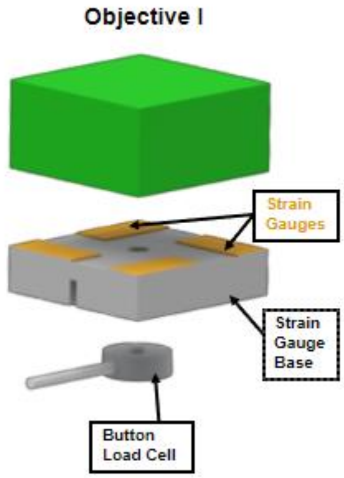

Figure 3. Thrust Misalignment and Thrust Generated Configuration for Objective 1

The MDT panel is shown in figure 3 as a green box and the gray plate below serves as an aluminum base that will have a slot underneath for the button cell to rest in and will allow for the diaphragm strain gauges to be mounted.

Infrared Radiation (IR) System

To have a visual representation of each firing, a microbolometer sensor package is to be used to collect IR imaging data of the system. A bolometer measures radiant heat by absorbing infrared radiation, which changes the sensors electrical resistance. Microbolometers are the sensor packages that are used in thermal imaging cameras. While there is a lot of analysis required to come up with the correct microbolometer package for the experiment Focal Plane Array, such analysis is outside the scope of this paper. Figure 4 below shows how the microbolometer will be oriented with respect to figure 2.

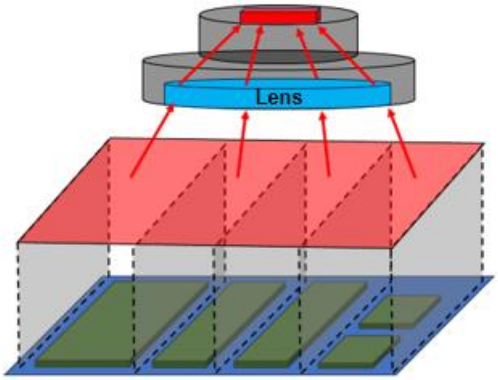

Figure 4. MDT Object Place

The microbolometer (illustrated by a red box at the top) will be mounted above the plane where the MDT panels will lay. Each time an MDT fires the microbolometer will be able to measure the change in temperature and a successful firing will be able to be recorded. If a firing were to be sent by the chain of command and the microbolometer does not read the change in temperature, then this will show that there was a misfire, and something went wrong. The IR system as seen in figure 4 above will be able to provide IR imaging of the experiment and be able to detect a successful/unsuccessful firing.

Temperature

The temperature of the interior and exterior of the system will be recorded using an SRTD-1 RTD Surface Sensor. One sensor will be mounting inside the experiment to measure the interior conditions of the system and ensure that it is being insulated properly. Another sensor will be mounting on the outside of the system to monitor the temperature of the space environment. Figure 5 below shows how the sensor will be mounted to the outside of the experiment.

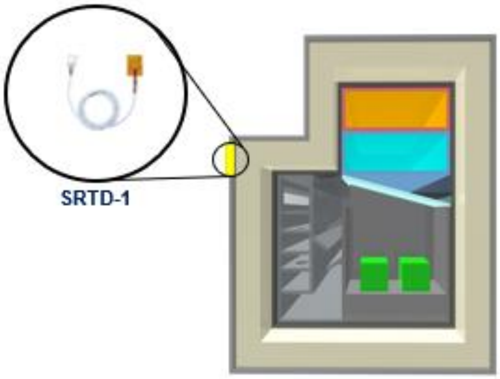

Figure 5. Temperature Configuration

MESA Solution Overview

The experiment operations served as a basis for how the required data would be collected. The solution overview section will examine how each of these components would be configured into a single system that could have each one of these sub-systems operating all together. Figure 6 below shows the cross-section ISO view of the proposed solution for the MESA experiment.

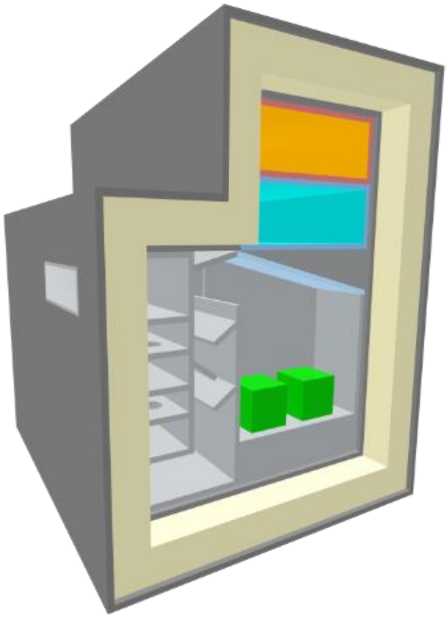

Figure 6. Cross Section ISO View

Each subsystem is color coded accordingly:

- Orange – On Board Computer (OBC)
- Teal – IR System
- Green – MDT Panel
- Grey – Aluminum 2024-T6
- Biege – NCFI 24-124 Spray-On Foam Insulation
- Sky Blue – Infused Silica Panel

Each component of each subsystem was chosen to survive the conditions of low earth orbit. The analysis for each component is outside the scope of this report. This report will further examine the potential of using an electrostatic filter to collect any excess propellant that could harm other experiments or potentially affect the MDT experiment itself.

Excess propellant

To meet the venting requirements of NASA on board the ISS and at launch a vigorous/torturous path was implemented for any excess propellant. Figure 7 below shows the pressure flow of the excess propellant and the path that was implemented to try and stop excess propellant from leaving the system.

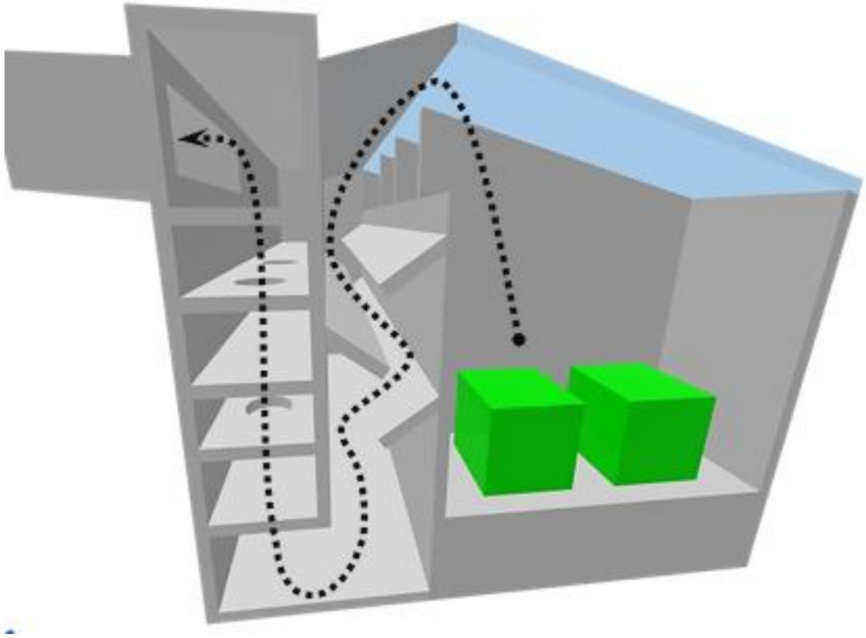

Figure 7. Pressure Flow of Excess Propellant

As shown above, when the propellant is fired the force of the “explosion” would shoot the propellant up and it would be reflected off the infused silica shield into the left “S” trap. The slanted aluminum pieces serve as a potential catch trap for the propellant but if it were to make it past that section the excess propellant would be directed up the 5 different plates on the far-left side of figure 7. The small holes are there because of the venting requirements set by NASA. If the holes were not there then the project would be a pressure vessel when launching and the experiment would explode. If some of the propellants were not to be launched up into the “S” trap, then that’s where the electro-static filter would catch any excess propellant in the firing chamber.

Electro-Static Precipitator

An electrostatic precipitator (ESP) is a device that uses electrostatic forces to remove particles in a gas. Figure 8 below shows the diagram of how an electrostatic precipitator is configured.

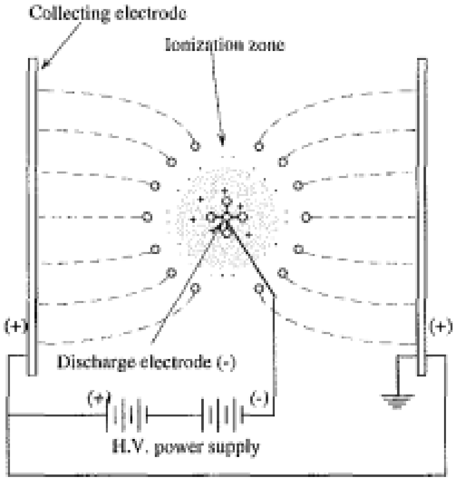

Figure 8. Schematic of an Electrostatic Precipitator

As shown in figure 8, “ESPs are configured by taking a high voltage power supply and positively powering the electrodes and negatively charging the gas. By doing this the negatively charged particles in the gas will be attracted to the positively charged electrodes. The particles are charged in the air by the attachment of ions that are produced by corona discharge” (A Mizuno, 2005). Corona Discharge is caused by a conductor that is carrying high voltage and is the electrical discharge that is caused by the ionization of the surrounding gas. In this case, the wire coming from the negative terminal of the power supply is ionizing the gas in between the positively charged electrodes. Figure 9 below shows the configuration for the electro-static precipitator or electro-static filter as referenced before.

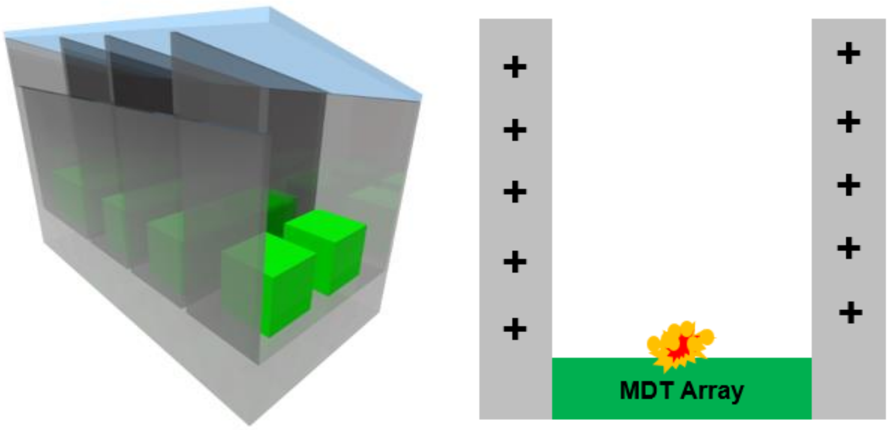

Figure 9. MDT Firing Chamber

On the left, the MDT firing chambers for each objective are shown and on the right is the front view of each MDT firing chamber. For any propellant that were to be floating in the firing chamber the gas would be negatively charged to ensure that the particles were attracted to the positively charged walls. The theory behind electrostatic precipitation is about as far as the senior design group analyzed when constructing this design.

Further Examination / Results

One of the components of electro-static precipitation that was failed to be considered was the power supply. In order to ionize the gas that is in the MDT chamber a power supply that could output 3kV – 5kV would be needed. When examining the market for high voltage power supplies (HVPS) there is a lack of existing modules that would fit with this design. However, there are currently strides being made to design a HVPS for in space experiments by The Space High Voltage Power Supply team at Los Alamos National Laboratory. They are designing a compact modular HVPS for a CubeSat mission (J. Deming, 2023). Testing would need to take place with this power supply in vacuum conditions to ensure that enough voltage is being produced to ionize the surrounding gas.

To implement such a design in this system further testing must be done in vacuum conditions. Further analysis using theoretical equations cannot be done in this case because of the nature of the experiment. The size of the propellant is proprietary information and would be useful in trying to calculate the voltage required and the efficiency of the electrostatic precipitator. This is the main reason why no equations are present within this paper. This paper serves as a further examination and guide that Northrop Grumman would need to do to try and implement the electro-static filter design mentioned above.

Conclusion

This paper outlined the design and objectives of the MESA ISS External Pallet Experiment, which aims to assess the performance of Micro-Electromechanical Digital Thrusters (MDTs) in space. The experiment is designed to collect various data points, including thrust generated, thrust misalignment, high-speed optical evidence of firing, temperature, and radiation levels inside and outside the experiment.

One of the main challenges with this experiment is ensuring that any excess propellant is contained within the experiment while also not being a pressure chamber at launch. The experiment must follow NASAs venting requirements. The proposed solution involves implementing an electrostatic precipitator or electro-static filter (ESF) and a torturous path for the propellant to follow. Furthermore, the paper discusses the configuration of each sub-system, and they collect the required data for the mission. Also, the paper expands on the analysis of the ESF and the feasibility of using it to collect any excess propellant in the firing chamber. However, it is noted that further testing and analysis is required, particularly concerning the power supply needed to ionize the gas in the firing chamber.

Overall, the MESA experiment represents an approach to test propulsion systems in space, aiming to advance the understanding of MDT performance in space. This experiment served as a valuable contribution to Nortrup Grumman in their future testing of propulsion technologies in space and aboard the International Space Station.

Reference List

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