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System Management Tactics for CubeSat Design

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System Management Tactics for CubeSat Design

by

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Systems Engineering Management Plan

MEMS Digital Thrusters Technology Demonstration Mission
MDTTDM

____ _____________

Designated Governing/Technical Authority Date

Alencia Hall 04/21/23
Program/Project Manager Date

Rebekah Clark 04/21/23
Chief Engineer Date

By signing this document, signatories are certifying that the content herein is acceptable as direction for engineering and technical management of this program/project and that they will ensure its implementation by those over whom they have the authority.

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1.0 Purpose and Scope

1.1 Purpose

The purpose of this SEMP is to develop a basis for implementing and communicating the technical effort of the MEMS Digital Thruster Technology Demonstration Mission which is focused on researching how MDT technology affects the efficiency of each subsystem of the CubeSat the thrusters are applied to, as well as the effectiveness of the thrusters themselves.

1.2 Scope

To determine the overall effectiveness of the MEMS digital thrusters as specified by the Missile Defense Agency and the Northrop Grumman Corporation, the UAH senior design team will research and design a CubeSat using as much COTS technology as possible to develop a plan intended to measure the efficiency of each subsystem, due to the addition of the thrusters, as well as the effectiveness of the thrusters themselves. The designed system will comply with CubeSat Design Specifications, Revision 14, and will be accomplished in no larger than a 3U CubeSat. The project will have a current-year design budget of $500,000 and a completion date of May 2023. After May of 2023, Northrop Grumman and the Missile Defense Agency will review the project design and make changes where necessary. They will establish control of the project until launch in May 2025. From there, the CubeSat will obtain at least six months of continuous on-orbit operations, controlled by a ground station at The University of Alabama in Huntsville.

1.3 Content

This document has been organized according to the table of contents found on page two of this document.

2.0 Applicable Documents

The following documents listed here were used as a reference for this document. Please refer to them for detailed information not included herein:

2.1 NASA Documents/Regulations

GSFC-STD-7000A
NASA CubeSat Handbook
SMC-S-016

2.2 Contractor-Provided Information/Requirements

20-1724 Technology Briefing Rev 1
CDS+REV14_1+2022-02-09
Communication Window Calculations
Northrop Grumman MDT Data Sheets

2.3 The University of Alabama in Huntsville Information/Requirements

IPT AAO for MDTTDM Fall 2022
DAC 1 Overview and Kickoff
DAC 2 Requirements MDT
DAC 2 Science Requirements
DAC 3 Leadership Tasks
DAC 3 Overview and Expectations
DAC 3 Spacecraft Tasks
DAC 3 Systems Tasks
DAC 4 Overview and Expectations
Project Constraints REV 1
Team Charter

2.4 American National Standard Mass Properties Control for Space Systems Regulations

ANSI/AIAA S-120A-201X

3.0 Technical Summary

3.1 System Description

The purpose of this project is to develop a design that can test the success of integrated MEMS Digital Thruster (MDT) Technology. The team's design will focus on discovering how the MDT technology affects the efficiency of each subsystem as well as the effectiveness of the thrusters; thus meeting the requirements of the Missile Defense Agency and the Northrop Grumman Corporation. The Missile Defense Agency and Northrop Grumman Corporation have expressed interest in MEMs Digital Thrusters technology and how they affect a CubeSat, the overall effectiveness of the thrusters, and what impact the thrusters have on the eight subsystems. The companies have provided the UAH senior design class with a total design and test budget of $500,000 to test these objectives. The team is made up of a three-member leadership team and eight single-member subsystems: Systems Integration, Payload, Communications, Structures, Thermal, Power, Attitude Determination and Attitude Control, and Communication and Data Handling. Each subsystem will be integrated into the final product (CubeSat). The payload will consist of a Crystal Space Micro Camera and MEMS. These items will allow the goals of the mission to be carried out specifically by the monitoring capability of the camera and the function of the thrusters which is the study of the mission. The communications subsystem will consist of a PULSAR-XTX X-Band Transmitter and a PULSAR-XANT X-Band Antenna. The transmitter and Antenna will be used in the CubeSat to communicate with and send data to the ground station. The structure subsystem will consist of an EnduroSat 3U CubeSat Structure made of Aluminum 6082. This structure will be the base of support for the entire CubeSat. Thermal subsystems are relying on a passive heat transfer system. This subsystem will utilize: matte white paint, thermal switches, Copper Cabled thermal straps, and temperature sensors to keep the CubeSat within operating temperatures. The power subsystem will consist of an EnduroSat EPS ll which is a two-piece battery that includes a Power Distribution Module (PDM) and the battery pack itself. The power subsystem will also use an EnduroSat 3U Solar Panel to ensure power operations are always available. The ADCS subsystem is likely the most complex as well as one

of the most mission-critical subsystems for this project. The subsystem will consist of a Cube ADCS (3-axis) which has a power cycling ability vital to the purpose of this mission since ADCS will be powered off in order to accurately measure the effects of the MEMs. The last critical subsystem is C&DH. This subsystem will be made up of an Isis Onboard Computer which will store data until it can be dropped down to the ground station. Overall, Payload, Communications, Structures, Thermal, Power, ADCSl, and C&DH will all interface with each other to perform the mission. Specifically, there will be direct interfaces between power, communications, and C&DH. There will also be direct interfaces with Power and ADCS. The only human interface required for the mission will be the operators at the ground station who will collect the data and give commands to the CubeSat to perform the necessary functions for a successful mission. The CubeSat will also interface with the P-Pod before being loaded for launch. All of these interfaces must be cohesive to ensure a healthy mission outcome.

3.2 System Structure

The base product layers are identified as the subsystem components that will be integrated together to form the CubeSat. Each subsystem is managed by a lead engineer. The next tier is the leadership team. The leadership team shall oversee each lead engineer. The leadership team of UAH shall be responsible for presenting a completed preliminary design to the Northrop Grumman Corporation and the Missile Defense Agency. The UAH leadership team shall also provide a bill of materials (BOM), schedule, and technical risk matrix. UAH, NGC, and MDA shall designate members of the MDTTDM project from their companies to form the CCB. The CCB will vote on each of the KDPs and also be presented with the findings of each critical meeting (PDR, CDR, SRR, etc). The WBS demonstrates each of these responsibilities in Figure. The specifications of the individual subsystems have been taken into account and will be tested against the specifications found in GSFC-STD-7000A, NASA CubeSat Handbook, and SMC-S-016. The system will be developed starting from the CubeSat structure. Then each subsystem will be built and added to the structure one at a time. After all subsystems have been added to the structure testing shall begin until all requirements and specifications are verified.

3.3 Product Integration

The UAH Senior Design Team is responsible for the preliminary design of the 3U CubeSat. The design will be presented to course instructors before students graduate in May. The project will then be managed by MDA and the Northrop Grumman Corporation for further design, research, and development, testing, etc. The Northrop Grumman Corporation has specifically provided the data for the communications subsystem as well as the MEMS thrusters. The responsibilities of each organization will be developed after the preliminary design of the students is completed and the companies decide how to move forward. The design will be comprised of all subsystems previously mentioned in section 3.1 and the integration of these subsystems will be the responsibility of the project's sponsors. At this time, that decision will not be made until the preliminary design is completed.

3.4 Planning Context

The project faces numerous challenges from the planning perspective due to multiple factors. The project will undergo a total management shift after the preliminary design is delivered in April to the professors at UAH and the sponsors at MDA and Northrop Grumman. It will ultimately be up to the management teams at MDA and Northrop Grumman to finish assigning task work once the shift is made. However, there are other planning constraints known to exist that can be managed to ensure a smooth transition of management and ultimately project completion. The senior design team will deliver the preliminary design no later than April 19, 2023. This design will then go to review with the sponsors. The schedule in **Figure 1** depicts the timeline of the mission.

CubeSat Project Launch Plan

	Task Name	Status	Health	Start Date	End Date	Description	Duration	% Complete
1	**MEMS Digital Thrusters CubeSat**			**08/17/22**	**05/31/25**		**63d**	**1019d**
2	**Pre-Phase A: Concept Studies**			**08/17/22**	**09/21/22**		**51d**	**36d**
3	Project Proposal	Complete	●	08/17/22	09/11/22	Project Requirements were given and described to teams	26d	26d
4	DAC 1 Review/ KDP: A	Complete	●	08/17/22	09/21/22	Background research was performed to gain insight into challenges as well as items that could be replicated for a more successful mission.	26d	36d
5	**Phase A: Concept and Technology Development**			**09/21/22**	**05/31/23**		**7.75d**	**253d**
6	DAC 2 Review	Complete	●	09/21/22	12/07/22	Possible parts and subsystem design were discussed	4.75d	78d
7	DAC 3 TIM	Complete	●	01/09/23	02/01/23	Senior Design Team began to solidify a design and presented this to the board	2d	24d
8	DAC 3 Review	In Progress	●	01/09/23	03/08/23	Senior Design Team solidifies subsystem parts and begins to compile system as a whole		59d
9	DAC 4 TIM	In Progress	●	03/08/23	03/22/23	Senior Design Team Solidifies a Design complete with all specified requirements for review		15d
10	DAC 4 Review	In Progress	●	03/22/23	04/17/23	Senior Design Team Turns in Final Preliminary Design and MDA/Northrop Grumman will take over		27d
11	SRR	In Progress	●	04/17/23	05/01/23	MDA/Norththrop verify research and requirements performed by senior design team in order to move forward to Phase B		15d
12	SDR	In Progress	●	05/10/23	05/25/23	System Definition Review to ensure System has been properly Defined		16d
13	KDP: B			05/25/23	05/31/23	CCB will convene and verify that all is ago to move to next phase		7d
4	**Phase B: Preliminary Design and Technology Completion**			**05/23/23**	**06/04/23**		**30.75d**	**13d**
5	PDR	In Progress	●	05/31/23	05/31/23	MDA/NG Solidifies a Prelimnary Design complete with all specified requirements for review	7d	1d
6	KDP: C			05/23/23	06/04/23	If Design is approved Team will then move into Phase C		13d
7	**Phase C: Final Design**			**06/30/23**	**09/30/23**		**2d**	**93d**
8	CDR	In Progress	●	06/30/23	09/30/23	Critical Design Review may be repeated several times before all is ago	1d	93d
9	PRR	In Progress	●	07/01/23	09/30/23	Production readiness review will coinside heaviley with CDR to ensure product is feasibly built		92d
0	KDP: D			07/25/23	07/31/23	Once the Final design is approved and built then Phase D may be begun		7d
1	**Phase D: System Assembly, Integration, Test, Launch**			**07/23/23**	**05/31/25**		**12d**	**679d**
2	Vibration/Shock Testing	In Progress	●	07/25/23	12/25/23			154d
3	Temperature Control Testing	In Progress	●	11/02/23	06/01/24			213d
4	TRR	In Progress	●	07/23/23	03/01/25	Test Results Will be Evaluated and changes made where necessary, if faults are discovered team may go back to the drawing board and still have plenty of time to deliver a working product to the launch vehicle that has been retested.	~0	588d
5	Delievery To Launch Vehicle Integrator	In Progress	●	03/01/25	05/05/25	Vehicle will be assembled and ready to transport to Launch Integrator		66d
6	Launch	In Progress	●	05/01/25	05/31/25	Launch will occur during the month of May	~0	31d
7	KDP: E			05/01/25	05/31/25	If vehicle launches successfully team can then move to phase E/		31d
8	**Phase E: Operations and Sustainment**			**07/23/23**	**05/31/25**		**12d**	**679d**
9	CubeSat Collects Data	In Progress	●	05/01/25	05/30/26	CubeSat will operate for one year as required		395d
0	**Phase F: Closeout**			**07/23/23**	**05/31/25**		**12d**	**679d**
1	CubeSat is Decommisioned	In Progress	●	05/01/26	05/30/26	CubeSat will then be instructed to perform a controlled Deorbit		30d
2	SAR	In Progress	●	05/01/26	06/30/26	Summary will be reviewed and findings discussed		61d

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Figure 1: Schedule

As shown the final design must be completed and built by July of 2023. Testing must also be completed by February 2025. The vehicle must be stable and ready for transport by March 1,

2023. The launch will take place in May 2025. The CubeSat will then perform normal operations and orbit for at least six months before a controlled deorbit occurs to decommission the spacecraft.

3.5 Boundary of Technical Effort

The mission aims to test the productivity of MEMs digital thrusters. However, there is no known knowledge as to how these thrusters will affect the CubeSat systems operations. The MEMs produce an initial jolt of current that will run through each of the subsystems. Therefore, each subsystem must be designed to handle this temporary increase in current. The team can test all subsystems to ensure that there will be no breakdown due to an overload. The team shall also test the ADCS subsystem to identify any issues in suspending power operations. ADCS must be turned off when the MEMs are fired, if it is still operating during the fire the test could be void. The team should keep these concerns in mind in regard to finalizing part options and making any changes to the parts designated in this document as they have been carefully selected with these concerns in mind. Failure to heed these concerns could result in failed testing scenarios and push the team behind schedule. The CubeSat will become operational once orbit is obtained, assuming its launch vehicle is successful and orbit is attainable. After the CubeSat has completed its six-month mission sequence the team will evaluate its condition and if it can sustain more testing then data will continue to be gathered. If all data necessary for the mission has been obtained or the CubeSat is nearing non-functionality then the team will perform a controlled deorbit and the CubeSat will be disposed of.

4.0 Technical Effort Integration

4.1 Responsibility and Authority

For the duration of Pre-Phase A, the project will be co-directed by Matt Turner and P.J. Benfield at the University of Alabama in Huntsville. They will assign all requirements of the project to the senior design team at the University of Alabama in Huntsville in coordination with feedback received from the project sponsors, MDA, and the Northrop Grumman Corporation. The design team will be structured as follows: A project manager whose primary responsibilities will be to serve as the operational manager, provide task management, coordinate schedules and timelines, maintain team morale and efficiency, and approve overall presentation slides/reports. A chief engineer who will serve as a resource for team members, solve technical problems through team collaboration and provide industry contacts for advice, and approve technical specifications for designs. There will also be a lead systems engineer who will serve as a systems integrator to guarantee that all components of the system can function cohesively and efficiently, provide support to each subsystem lead, and oversee the planning, design, and implementation of the project in order to ensure that the requirements are met and that the system life cycle is feasible. These three positions will form the leadership team and will be overseen by Matthew Turner and P.J. Benefield directly. The leadership team will then oversee each subsystem engineer. Each engineer has been assigned to a specific portion of the CubeSat and will be responsible for the functions of the designated subsystem. There will be a Payload Engineer responsible for defining

the payload requirements and interfaces with the spacecraft, as well as the operational requirements of the thrusters. The Communications Engineer will be responsible for determining the communications requirements of the spacecraft (i.e. data sent to and from), and designing a system that can accommodate those requirements. Also responsible for determining how to transmit the required data within the communications window. The Structural Engineer will oversee the structure of the CubeSat design and effectively integrate the structural components with the system's electrical and other mechanical aspects. There will also be a Thermal Engineer who will develop a method for controlling and monitoring the temperature and thermal environment of the CubeSat's hardware within a predefined range. The Power Engineer will develop a power production, management, and distribution system for the CubeSat and its subsystem. Then the ADCS Engineer will determine the orientation, pointing, slewing, and slewing requirements of the CubeSat and design a way to accomplish these requirements. The C&DH Engineer serves as the lead for command and data handling for the mission and ensures that the C&DH system interfaces correctly with other CubeSat subsystems. Each of these engineers answers directly to the management team. **Figure 2** has been provided below for reference.

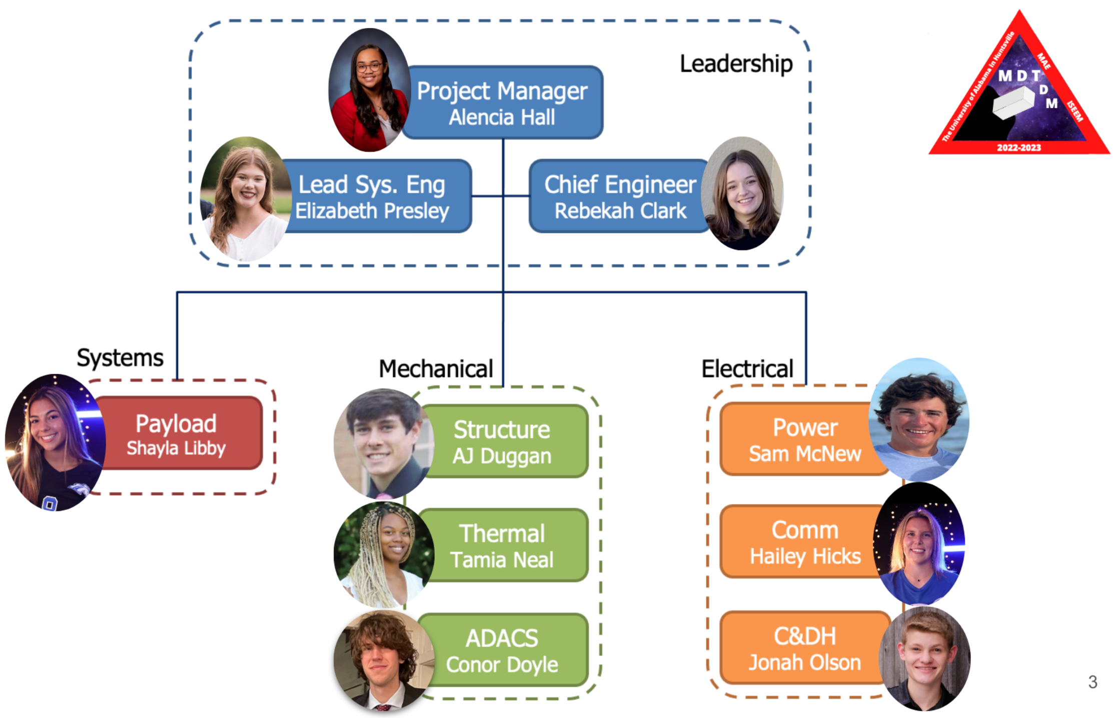


Figure 2: Work Organization

Once the project has completed pre-phase A it will be in the control of the sponsors and the co-directors to adjust to a new management system. It is recommended that a similar structure be followed for management of the project and each subsystem be given an engineer to primarily focus on its designated function. This will ensure a smooth transition and keep the project on

course for launch. It is also pertinent that a change control board (CCB) be appointed immediately to secure proper lines of communication. The CCB should consist of one member of each subsystem and two members at large from the project's sponsors to ensure that their requirements are continually met. The project's technical expertise is attainable and able to be staffed by a level 1 or beginning engineer, however, it must be approved by a level 3 or advanced engineer to ensure all requirements and functions are met before the CubeSat is shipped for launch. Following a systems engineering approach ensures the project is carefully considered from cradle to grave. This project specifically will benefit by ensuring a lead systems engineer is always designated and can validate the project's integration.

4.2 Analytical Tools that Support Integration

The project will ultimately utilize a variety of tools to support the integration process. At this time, Computer Aided Design (CAD) has been the primary source used. Specifically, Solid Edge was used to produce a preliminary design of the CubeSat. The design included all subsystems and aided in verifying measurement requirements. The design can be seen below in Figures: **3** and **4. Figure 3** depicts an isometric view while **Figure 4** depicts a side view. After the completion of pre-phase A, sponsors will then utilize the tools they have at their disposal to continue the project.

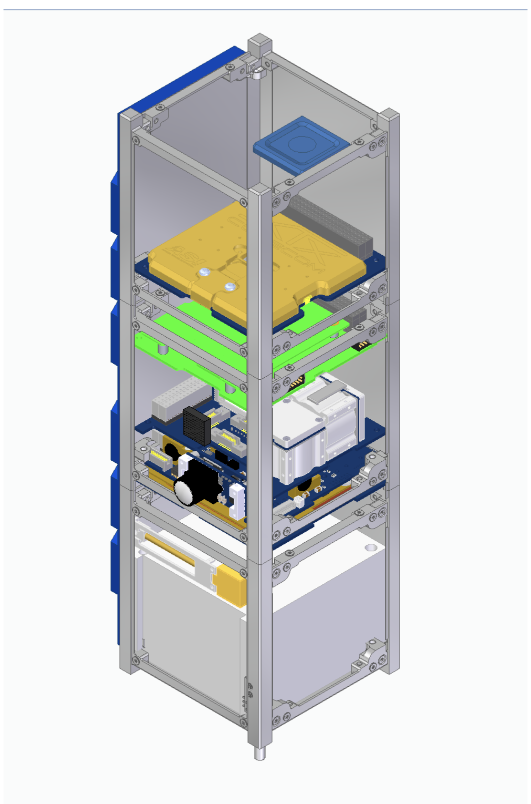


Figure 3: Isometric View

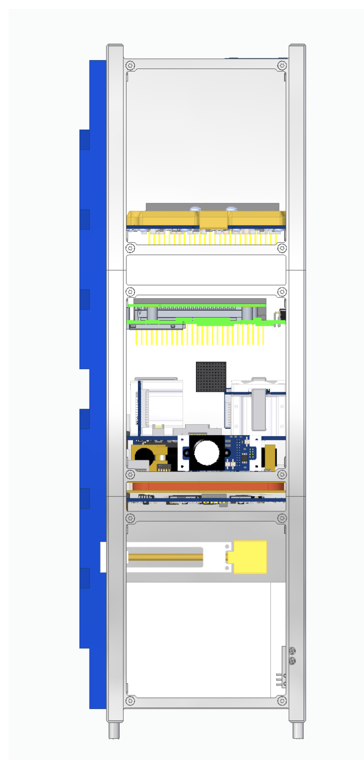


Figure 4: Side View

5.0 Common Technical Processes Implementation

5.1 Stakeholder Expectations

The UAH senior design team will research and design a CubeSat using as much COTS technology as possible to develop a plan intended to measure the efficiency of each subsystem, due to the addition of the thrusters, as well as the effectiveness of the thrusters themselves. The designed system will comply with CubeSat Design Specifications, Revision 14, and will be accomplished in no larger than a 3U CubeSat. The project will have a current-year design budget of $500,000 and a completion date of the design from the senior design team of May 2023 with a launch set for May 2025.

5.2 Technical Requirements Definition

The mass margin for all hardware shall be no less than 15% and the power margin for the project shall be no less than 16 W and no greater than 21 W. The test sequence will occur once every two orbital periods. Since the testing sequence is every 3 hours, and the communications window has 8 passes the data shall be communicated to the ground station once every orbit or every 1.5 hours. Any data produced during the 9 non-testing hours will not be stored. Tests must use limits according to the standards given in. These specifications will be used to verify all systems meet the criteria for launch.

5.3 Logical Decomposition

The mass margin limit is identified to ensure that once the CubeSAt design has been fully realized there is still room if necessary. The 15% window allows room for items that possibly weren't in the first concept drawing and also to allow changes to other COTS if needed. The power margins have been set to comply with the capabilities of the subsystems. The minimum power required is 15.755 W which is why the minimum power requirement is 16 W so the CubeSat is not without power. The max power is set so that no complications will arise from the level of power produced in the CubeSat. The max power is also below the final testing mark which gives extra protection concerning what will be known as to how it can/will perform under different power conditions. The data shall be communicated to the ground station once every 1.5 hours to create more storage on the onboard computer. If the data were being stored longer, there would be a risk for having to dump data before it can be transmitted. This is also the reason that any data collected during the 9 non-testing hours will not be gathered. The GSFC-STD-7000A and SMC-S-016 specifications are to be used during testing to ensure that all components are NASA compliant and that there will be no issues getting approval for launch.

5.4 Design Solution Definition

The mission's components have been chosen based on the requirements of the project. The mass margin limit is identified to ensure that once the CubeSAt design has been fully realized there is still room if necessary. Currently, the design for the project has 27% unallocated which meets and surpasses the recommended 15% minimum. The power margins have been set to comply with the capabilities of the subsystems. The minimum power required is 15.755 W which is why the minimum power requirement is 16 W so the CubeSat is not without power. The max power is set so that no complications will arise from the level of power produced in the CubeSat. The max power is also below the final testing mark of 21.255 W which gives extra protection concerning what will be known as to how it can/will perform under different power conditions. The OBC is also equipped with a 32-bit ARM9 processor that can process 400MHz and has the memory capacitance of 2X2GB for payload data. More memory is also available upon request, up to 32GB which ensures that the CubeSat can store data long enough to transmit to the ground station at the appropriate times. The tests are also designed with the specifications in mind to produce a quality CubeSat that meets the specification limits.

5.5 Product Implementation

The mission utilizes COTS technology in all subsystems. Products shall be further researched by the Northrop Grumman Corporation and then purchased from the supplier. The Northrop Grumman Corporation can then assemble the product in-house and utilize engineers to build the cabling for the CubeSat. All requirements are met if the recommended design by the senior design team is chosen. If changes are required, a requirements traceability matrix must be redone to ensure new components fully meet the requirements.

5.6 Product Integration

Each individual component in the subsystems have been tested and meet the current stakeholder and technical requirements. Before assembly of the CubeSat, each subsystem must be tested as its own complete subsystem before integrating into the final design. This will help to eliminate unidentified errors in addition to checking the total performance of the system before it is a part of the whole system. After each subsystem is tested, it can be added to the CubeSat.

5.7 Product Verification

Given that the mass margin for all hardware shall be no less than 15%, the CubeSat mass shall be measured to verify that this requirement is met. The power margin for the project shall be no less than 16 W and no greater than 22 W. When testing of the power system begins, the team will test 3 W above and 3 W below the marginal range to show the effects of higher or lower power supply. However, when orbit begins the power levels will be consistently monitored to ensure that power never goes above or below the power margin. The resultant data from the power sensors will be provided to verify that this requirement is met. The test sequence will occur once every two orbital periods. Since the testing sequence is every 3 hours, and the communications window has 8 passes the data shall be communicated to the ground station once every orbit or

every 1.5 hours. This will be verified through the data logs that will be kept at the ground station. These logs will be provided to stakeholders on a bi-weekly basis. Any data produced during the 9 non-testing hours will not be stored. This will also be verified utilizing the data logs. Tests must use limits according to the standards given in. These specifications will be used to verify all systems meet the criteria for launch. This requirement can be met through the testing records provided by the testing company.

5.8 Product Validation

The UAH senior design team will research and design a CubeSat using as much COTS technology as possible to develop a plan intended to measure the efficiency of each subsystem, due to the addition of the thrusters, as well as the effectiveness of the thrusters themselves. The sponsors of the project will be provided a list of each subsystem with the specific parts that will be integrated into the CubeSat. This comprehensive parts list will designate where the technology was obtained from and will validate to the stakeholders that the system does utilize as much COTS as is feasible. The designed system will comply with CubeSat Design Specifications, Revision 14, and will be accomplished in no larger than a 3U CubeSat. The CubeSat will be measured to prove to stakeholders that the CubeSat meets the size requirements for a 3U CubeSat. The tests for the completed CubeSat will also be measured according the specifications of CubeSat Design Specifications and Revision 14 and the test results will be shown to stakeholders to validate the requirement is met.The project will have a current-year design budget of $500,000 and a completion date of the design from the senior design team of May 2023 with a launch set for May 2025. The bill of materials will be provided to the stakeholders to demonstrate that the requirement for the budget is correct and the senior design team will give a presentation at the end of DAC 4 to showcase the preliminary design of the project thus satisfying the May 2023 requirement. The launch date will be scheduled by Northrop Grumman, MDA, and NASA for May of 2025 but this requirement is to be fulfilled by Northrop Grumman, MDA, and NASA and is except from the UAH senior design team given that their role is completed before launch takes place.

5.9 Product Transition

The product shall advance according to the schedule. Before the next step is taken, the KDP must be validated. If all requirements for the KDP are met the product shall advance to the next stage. There are five total KDP laid out in the schedule. There must be a review conducted and the CCB must approve the KDP. Once approved, the product shall continue into the next phase.

5.10 Technical Planning

Each technical planning process has been given its own set of criteria, as seen in each subsection of section 5. The management of each planning process will be the responsibility of the owner of the process. If there is a change to the stakeholder requirements, the stakeholders shall notify the CCB of the change they wish to make. If the change is feasible according to the current schedule then it will be implemented. If the change shall impact the schedule's end date, stakeholders must be made aware and will vote on the change. If there is a change in the technical requirements the

same process will be followed. All processes evolving the individual subsystems will be the responsibility of the lead engineer of that subsystem to address.

5.11 Requirements Management

As mentioned above, changes in the requirements must be voted on by the CCB. In addition to a vote, a new requirements traceability matrix must be performed to ensure that the requirements translate throughout each product level from top to bottom. If a requirement is found to not be traceable through the system, the requirement must be re-evaluated or the design must be changed. This process ensures that there are no unnecessary requirements as well as making sure that the necessary requirements are fully met.

5.12 Interface Management

There are three separate entities advancing the efforts of this mission. The Northrop Grumman Corporation, Missile Defense Agency, and UAH are responsible for all aspects of the project. To ensure communication is kept between each entity, a bi-weekly stakeholders meeting will be held under the direction of the program manager. In reference to the technical interfaces of the project, before assembly of the CubeSat, each subsystem must be tested as its own complete subsystem before integrating into the final design. After each subsystem is tested, it can be added to the CubeSat.

5.13 Technical Risk Management

Risk is a factor associated with any mission. To mitigate any risk factors and to increase the chances of a correct risk response, risk mitigation strategies will be written for each technical risk associated with the project. The risk mitigation tactics will be approved by the lead engineer. Program manager, and CubeSat operator to ensure clear communication is had between all parties and everyone is educated on the risks associated with the mission. The stakeholders shall also be briefed on what the risk factors are associated with this mission as well as the plans in place to ensure that despite the risk factors at hand there will still be a successful mission in the end.

5.14 Configuration Management

The Change Control Board (CCB) will serve as the prime source of configuration management for the duration of the project. The CCB will comprise one member of each subsystem and two members at large from the project's sponsors to ensure that their requirements are continually met. The CCB shall meet on a biweekly basis to vote and discuss concerns. Any actionable request can not be fulfilled until the board has convened, discussed, and voted on said item. If a new risk is identified, it must be brought before the CCB and added to the risk matrix if it is found to be a threat. There must also be a review conducted and the CCB must approve a KDP that has fullfill all its criteria before continuing into the next phase. Any decision made by the CCB shall be written down in the "CCB Updates" document. This document will keep a running

total of the date, reason why, and what specifically was changed. This document will be visible to all members working the project. If a request is made by the stakeholders at the bi-weekly stakeholder meeting then this request will still be voted on by the CCB since each stakeholder also has a member who is a part of the CCB.

5.15 Technical Data Management

To accurately capture lessons learned, cost data, trade studies, and technical analysis of the mission, a team will be built to monitor all data produced from the project. The team will be equipped with employees capable of performing the necessary functions to accurately analyze the data the project produces. There will be a quarterly report provided by the CubeSat analyst team that will provide the current cost trends, lessons learned, and any applicable trade studies for the project at that point in time. This report will be provided to every member of the project.

5.16 Technical Assessment Management

Throughout the lifecycle of the project, the technical competency of the CubeSat will be measured through the KDPs as mentioned previously. /In order to advance to the next technical level of the project, the CubeSat must effectively complete all requirements of the previous phase. These KDPs were developed with the end goal in mind of producing a stable and effective CubeSat.

5.17 Decision Analysis

If any decision made in consideration of the project is found to be void, an alternative shall be given to the CCB. The alternative must first be analyzed by the lead for the subsystem and approved before going to the CCB.

6.0 Technology Insertion

Assuming that the CubeSat enters orbit in May of 2025, there will be no further updates to the system after May of 2025, excluding software updates that may be required for regular maintenance. Prior to shipping for launch, the CubeSat may be updated with new technology provided that it is a necessary change or provides a significantly greater contribution to the project. Given that the CubeSat will deorbit, it is unnecessary to update the model after launch. However, the data acquired from this mission should be utilized in future projects to incorporate newer and better features to future CubeSats where applicable. If a subsystem proves to be inadequate after further examination, then the team will re-evaluate and move forward utilizing other COTS options. This project was tailored to COTS technologies and as such provides many benefits to the sponsors given that if one does not work as intended there are multiple options that can. All components will be integrated into the CubeSat before July 31, 2023. After the integration is complete and the CubeSat is assembled testing will commence according to the specified standards of the project.

7.0 Additional SE Functions and Activities

7.1 System Safety

The MEMs digital thrusters CubeSat is utilizing COTS technology meaning many of the components have an established flight heritage as well as thorough testing. A risk matrix has been performed of the current operational and system risks to the CubeSat depicted below in **Figure 5** .

Project Name:	Project Manager	Date
MDTTDM	Alencia Hall	3/8/23

Risk Matrix		Severity				
		Insignificant	Minor	Moderate	Major	Severe
Likelihood	Almost Certain					
	Likely					
	Possible					B
	Unlikely			D		A, E
	Rare				C	

A: MDTs have adverse reaction on equipment
B: ADACS will not turn off as intended
C: OBC is unable to interface with other components in CubeSat as intended
D:Temprature can not be stabilized due to heat leaks or improper cooling
E: Battery cell fails causing low voltage, which could lead to a failed mission

Figure 5: Technical Risk Matrix

While there are several risks with major to severe consequences the likelihood of these is low and can be brought lower through additional testing measures. In addition to operational/system risks, there are other known risks associated with the mission. As space exploration has continued to grow, the amount of rocket launches associated with these missions has been known to cause damage to the ozone layer. However, for a singular rocket the consequences to the environment would be categorized as insignificant. The risk to the public is insignificant as well as precautionary measures are already in place to minimize any threat to society. Since the CubeSat will deorbit and be incinerated upon re-entry the debris remaining will be minimal to nonexistent and comply with NASA standards.

7.2 Engineering Methods and Tools

The CubeSat will complete its preliminary design phase at the University of Alabama in Huntsville. Upon approval of the sponsors, the project will move forward under the direction of the Northrop Grumman Corporation with the Missile Defense Agency supervising. Northrop Grumman will then proceed to build and test the CubeSat according to the standards and requirements of the project as stated in the requirements document “DAC 2 MDT Requirements Doc”. If requirements have a necessary change to be made or updated, it must pass through the CCB before any action is taken moving forward. Northrop Grumman shall also construct a

model of the system using MBSE software to gain a clear perspective of the overall system. This model will be presented to MDA before testing of the system begins to ensure that changes can be made if needed. Testing facilities will be required to meet all requirements of the CubeSat. If neither sponsor has the necessary testing equipment and/or facilities, then the testing will be outsourced to an agreed upon agency. Engineers supporting the project should have training pertaining to system oriented thinking as well as the technical knowledge necessary for the component insertion in addition to the operational standards of the CubeSat.

7.3 Specialty Engineering

Below in **Figure 6** is the WBS for the duration of the project.

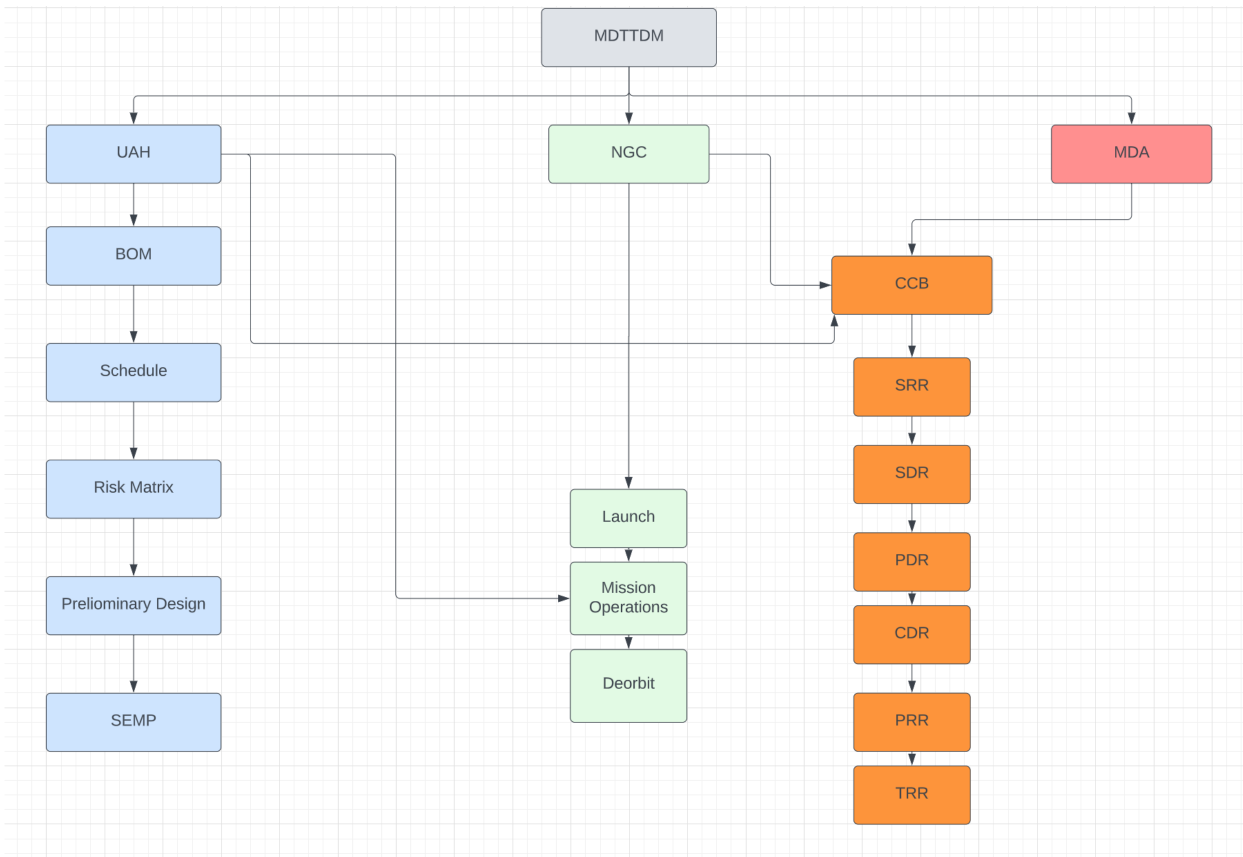
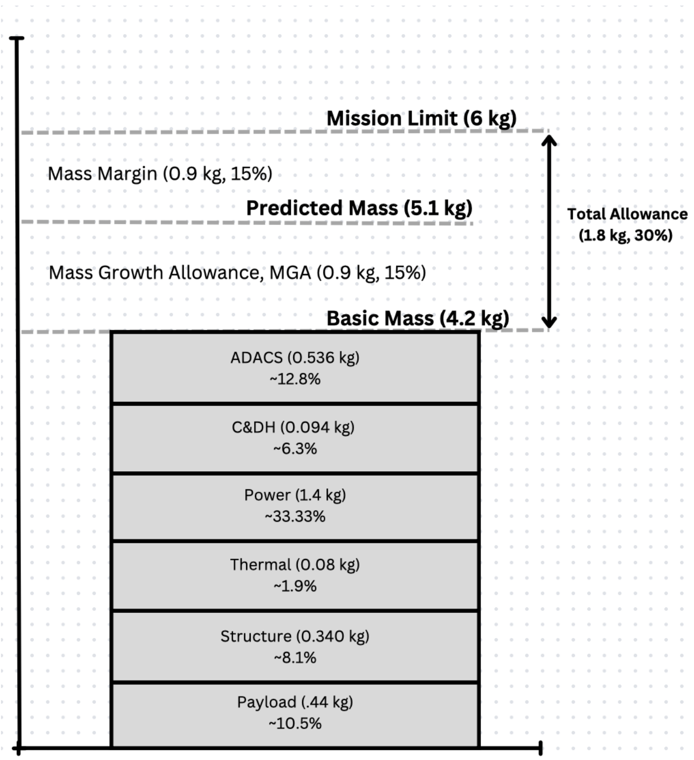


Figure 6: WBS

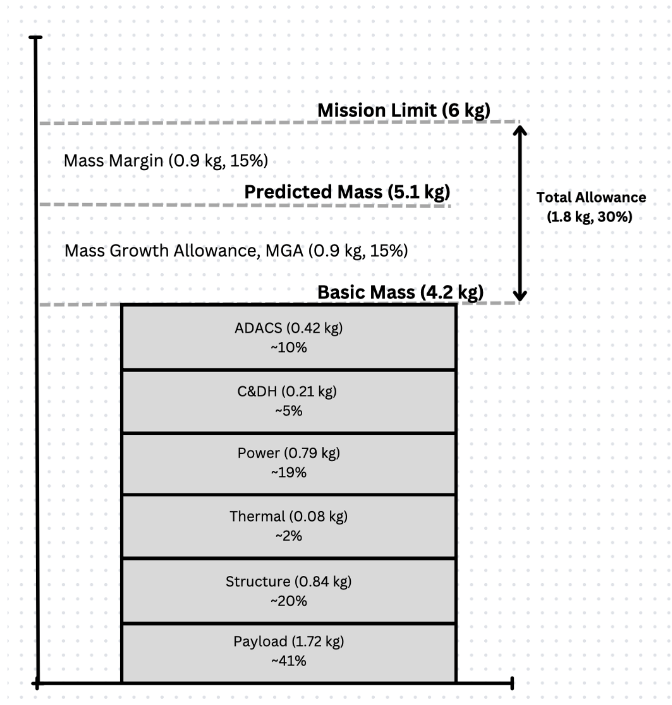
For the success of the mission, employees with a background in planning for safety, reliability, human factors, logistics, maintainability, quality, operability, and supportability shall be integral parts of the team. The WBS above indicates the primary work components for every stage in the project and designates which group the responsibility shall fall to.

7.4 Technical Performance Measures

Many factors have been carefully considered to maintain a successful mission. The mass stack allocations of the CubeSat can be seen below in **Figure 7** .



Current Mass Allocation



SMAD Recommendation

Figure 7: Mass Allocations

The current mass allocation is 73% of the basic mass meaning it satisfies both SMAD and NASA recommendations. This allocation leaves plenty of margin for cabling, sensors, and any other materials that will need to be added in the final design of the CubeSat. The power subsystem will consist of an EnduroSat EPS ll which is a two-piece battery that includes a Power Distribution Module (PDM) and the battery pack itself. The power subsystem will also use an EnduroSat 3U Solar Panel to ensure power operations are always available. All components have been chosen to reflect the power supply that is available. Below in **Figure 8**, you can see each of the power requirements and the specific masses of each component.

Instrument	Mass (kg)	Dimensions (cm)	Power (W)	Data Rate (kbps)	Lifetime (min)	Frequency	Duration
Accelerometer	0.00992	0.762 x 2.54 x 2.16	0.025 to 0.16	1.5	6 months	Before, During, and After MDT Firing Sequence	2.0 s
Gyroscope	0.055	4.475 x 3.860 x 2.0	1.5	0.5	6 months	Continuous	Continuous
Current Sensor	0.025	2.65 x 1.80 x 1.28	1.8	7.0	6 months	Continuous	Continuous
Voltage Sensor	0.038	4.57 x 2.90 x 2.60	1.2	100	6 months	Continuous	Continuous
Star Tracker	0.275	4.5 x 5.0 x 9.5	1.4	0.01	6 months	Before, During, and After MDT Firing Sequence	2.0 s

Instrument	Mass (kg)	Dimensions (cm)	Power (W)	Data Rate (kbps)	Lifetime	Frequency	Duration
IMU	0.026	3.4 x 3.9 x 2.4	1.4	4.8	6 months	Continuous	Continuous
Digital Temperature Sensor	0.011	0.4 x 0.4 x 0.085	1.2E-5	0.024	6 months	Before, During and After Firing Sequence	2.0 s
Optical Sensor	0.05	4.5 x 2.5 x 4.5	0.075 to 0.24	1000	6 months	Before, During and After Firing Sequence	3.0 s

Figure 8: Science Traceability Matrix

The mass margin for all hardware shall be no less than 15% and the power margin for the project shall be no less than 16 W and no greater than 22 W. The project, at this time, has undergone DAC 1, DAC 2, DAC 3, DAC 4. The next action item will be the SRR and SDR. After these action steps are completed the project will move along with the schedule as shown in figure. To accurately measure the effects of the MEMs digital thrusters, a series of tests will be performed. The test sequence shall span a 30 minute interval, occurring every 3 hours, happening 5 times per day. There shall be a 9 hour recovery time utilized for charging after the 5 rounds of testing are completed. When the test occurs, CubeSat function will be monitored for adverse effects. The purpose of the mission is to gain a better understanding of these effects, so there will be no TPM for the adverse effects themselves besides keeping the CubeSat in operating conditions. The CubeSat must remain operable, but tests must be performed to gain the necessary information of the negative effects meaning that although the tests may degrade the operations it is acceptable to continue provided the CubeSat can still function. The data gathered shall be transmitted to the

ground station. There is an assumed 10.899 minute communications window based on a given height of 400 km and an orbital period of 1 hour 32 minutes 33 seconds. This will allow around 8 passes a day with phase shift of 23 degrees. The test sequence will occur once every two orbital periods. Since the testing sequence is every 3 hours, and the communications window has 8 passes the data shall be communicated to the ground station once every orbit or every 1.5 hours. Any data produced during the 9 non-testing hours will not be stored. The current cost of the project is $203,194.19. As seen below in **Figure 9**.

Part Name	Quantity	Unit Cost	Total Cost	
Structure				
EnduroSat 3U CubeSat Structure	1.00	$4,100.00	$4,100.00	
Thermal				
AZ-93 White Thermal Control Paint	TBD	TBD	TBD	
Thermal Switch	TBD	TBD	TBD	
Copper Cabled Thermal Straps	1.00	$800.00	$800.00	
Digital Temperature Sensor	1.00	$4.29	$4.29	
ADACS				**Total:**
CubeADCS	1.00	$37,000.00	$37,000.00	**$203,194.19**
Star Tracker	1.00	$37,112.00	$37,112.00	
Accelerometer	1.00	$720.00	$720.00	
Tensor Tech CMG-10m Control Moment Gyroscope	1.00	$20,000.00	$20,000.00	
IMU	1.00	$9,020.00	$9,020.00	
Power				
EnduroSat EPS II+ Battery Pack	1.00	$40,200.00	$40,200.00	
EnduroSat 3U Solar Panel	1.00	$6,200.00	$6,200.00	
Current Sensor	1.00	$45.00	$45.00	
Voltage Senor	1.00	$6.90	$6.90	
C&DH				
PULSAR-XTX X-Band Transmitter	1.00	$23,500.00	$23,500.00	
PULSAR-XANT X-Band Antenna	1.00	$4,100.00	$4,100.00	
ISIS Onboard Computer	1.00	$7,261.00	$7,261.00	
Payload				
Optical Sensor	1.00	1000*	$1,000.00	
Testing				
Vibration Estimate	1.00	$1,250.00	$1,250.00	
Standard Shock Estimate	1.00	$750.00	$750.00	
Thermal Leak Estimate	1.00	$1,500.00	$1,500.00	
Thermal Qualification Estimate	1.00	$8,625.00	$8,625.00	

Figure 9: BOM

This current estimate is for parts and testing only. The cost is estimated to trend upward as the CubeSat is integrated and more concepts become fully realized. The current schedule allows a wide margin of error in the event of any set back to the mission timeline. When the testing begins for the completed CubeSat, it is imperative to test according to the standards given in GSFC-STD-7000A and SMC-S-016. These specifications will be used to verify all systems meet the criteria for launch. To ensure proper communication is continued throughout the duration of the project, progress reports will be provided to the program manager at the end of each work week before 5:00 pm. Each subsystem lead is required to complete a progress report for their

specified subsystem. The reports will include what stage the team is currently in and the key activities needed before the next stage can commence. The report will also include the phase the team should be in according to the schedule. If the team is on time no extra justification is required. If a team is behind, barriers to entry are required to be included on the report. This will ensure the team is proactively working to stay on schedule and if for some reason are behind they have a plan to move forward. As discussed previously a CCB shall be in place to make any changes to the project. The CCB shall meet on a biweekly basis to vote and discuss concerns. Any actionable request can not be fulfilled until the board has convened, discussed, and voted on said item.

7.5 Heritage

Given that the mission utilizes COTS technology, many of the parts chosen have a proven flight heritage. The Crystal Space Micro Camera has flight heritage and allows the goals of the mission to be carried out specifically by the monitoring capability of the camera. The communications subsystem's PULSAR-XTX X-Band Transmitter and PULSAR-XANT X-Band Antenna both have extensive flight heritage as well. The transmitter and antenna will be used in the CubeSat to communicate with and send data to the ground station. The structure subsystem will consist of an EnduroSat 3U CubeSat Structure made of Aluminum 6082 that has obtained flight heritage. This structure will be the base of support for the entire CubeSat. Thermal subsystems components that have flight heritage are the matte white paint and thermal switches. These will keep the CubeSat within operating temperatures. The power subsystem's EnduroSat 3U Solar Panel ensures power operations are always available and has proven flight heritage. The ADCS subsystem is likely the most complex as well as one of the most mission-critical subsystems for this project. The subsystem will consist of a Cube ADCS (3-axis) which has a power cycling ability vital to the purpose of this mission since ADCS will be powered off in order to accurately measure the effects of the MEMs. This particular ADCS has f;ight heritage as well. Lastly, C&DH will be made up of an Isis Onboard Computer which will store data until it can be dropped down to the ground station. This OBC has proven flight heritage since 2014. While each of these components have heritage and individual testing, it is imperative that the CubeSat be tested as a unit once all integration has been completed. Tests should be conducted according to the GSFC-STD-7000A and SMC-S-016 specifications.

8.0 Integration with the Project Plan and Technical Resource Allocation

Risk will continuously be monitored throughout the project. If a new risk is identified, it must be brought before the CCB and added to the risk matrix if it is found to be a threat. If a risk is identified as severe and likely, a full team meeting is required with at least 70% of the team present. The risk must be thoroughly discussed and a plan must be made to mitigate said risk. If the risk level is unable to come down to possible, it is recommended that another option be supplied by the technical team to the CCB if there is another viable option. Any decision made by the CCB shall be written down in the "CCB Updates" document. This document will keep a

running total of the date, reason why, and what specifically was changed. This document will be visible to all members working the project. There are also weekly reports being filed with the program manager as mentioned in section 7.4. There will be a bi-weekly stakeholders meeting where the findings of the reports will be discussed with all stakeholders by the program manager. The stakeholder meeting shall consist of three members from each entity of UAH, Northrop Grumman, and the Missile Defense Agency. During the stakeholders meeting the CCB Updates document will also be reviewed in addition to the weekly reports. The design of the CubeSat was influenced by extensive research on what is available for COTS on the market as well as lessons learned from other missions. It is imperative that lessons learned be provided at the end of this mission so future projects can make educated decisions on their mission goals.

9.0 Compliance Matrices

Complaince Matrix	
Requirement	**Compliance Indicator**
The mission shall be accomplished with no larger than a 3U CubeSat	Compliant
The mission shall comply with the CubeSat Design Specification (1U-12U), Revision 14, CP-CDS-R14	Compliant
The mission shall be designed with a ground station located at The University of Alabama in Huntsville	Compliant
The mission shall cost (parts only) less than $500,000 (current year dollars)	Compliant
The mission shall launch by May 2025	
The mission shall have continuous on-orbit operations for at least six (6) months	Compliant
The mission shall incorporate as much COTS technology as possible	Compliant
The test sequence shall span a 30 minute interval	Compliant
The test sequence shall occur every 3 hours.	Compliant
The test sequence shall occur 5 times per day.	Compliant
There shall be a 9 hour recovery time utilized for charging after the 5 rounds of testing are completed.	Compliant
The mass margin for all hardware shall be no less than 15%.	
The power margin for the project shall be no less than 16 W.	Compliant
the power margin for the project shall be no greater than 22 W.	Compliant

Figure 10: Compliance Matrices

Appendices

CubeSat Project Launch Plan

#	Task Name	Status	Health	Start Date	End Date	Description	Duration	% Complete
1	**MEMS Digital Thrusters CubeSat**			**08/17/22**	**05/31/25**		**63d**	**1019d**
2	**Pre-Phase A: Concept Studies**			**08/17/22**	**09/21/22**		**51d**	**36d**
3	Project Proposal	Complete	●	08/17/22	09/11/22	Project Requirements were given and described to teams	26d	26d
4	DAC 1 Review/ KDP: A	Complete	●	08/17/22	09/21/22	Background research was performed to gain insight into challenges as well as items that could be replicated for a more successful mission.	26d	36d
5	**Phase A: Concept and Technology Development**			**09/21/22**	**05/31/23**		**7.75d**	**253d**
6	DAC 2 Review	Complete	●	09/21/22	12/07/22	Possible parts and subsystem design were discussed	4.75d	78d
7	DAC 3 TIM	Complete	●	01/09/23	02/01/23	Senior Design Team began to solidify a design and presented this to the board	2d	24d
8	DAC 3 Review	In Progress	●	01/09/23	03/08/23	Senior Design Team solidifies subsystem parts and begins to compile system as a whole		59d
9	DAC 4 TIM	In Progress	●	03/08/23	03/22/23	Senior Design Team Solidifies a Design complete with all specified requirements for review		15d
10	DAC 4 Review	In Progress	●	03/22/23	04/17/23	Senior Design Team Turns in Final Preliminary Design and MDA/Northrop Grumman will take over		27d
11	SRR	In Progress	●	04/17/23	05/01/23	MDA/Norththrop verify research and requirements performed by senior design team in order to move forward to Phase B		15d
12	SDR	In Progress	●	05/10/23	05/25/23	System Definition Review to ensure System has been properly Defined		16d
13	KDP: B			05/25/23	05/31/23	CCB will convene and verify that all is ago to move to next phase		7d
4	**Phase B: Preliminary Design and Technology Completion**			**05/23/23**	**06/04/23**		**30.75d**	**13d**
5	PDR	In Progress	●	05/31/23	05/31/23	MDA/NG Solidifies a Prelimnary Design complete with all specified requirements for review	7d	1d
6	KDP: C			05/23/23	06/04/23	If Design is approved Team will then move into Phase C		13d
7	**Phase C: Final Design**			**06/30/23**	**09/30/23**		**2d**	**93d**
8	CDR	In Progress	●	06/30/23	09/30/23	Critical Design Review may be repeated several times before all is ago	1d	93d
9	PRR	In Progress	●	07/01/23	09/30/23	Production readiness review will coinside heaviley with CDR to ensure product is feasibly built		92d
0	KDP: D			07/25/23	07/31/23	Once the Final design is approved and built then Phase D may be begun		7d
1	**Phase D: System Assembly, Integration, Test, Launch**			**07/23/23**	**05/31/25**		**12d**	**679d**
2	Vibration/Shock Testing	In Progress	●	07/25/23	12/25/23			154d
3	Temperature Control Testing	In Progress	●	11/02/23	06/01/24			213d
4	TRR	In Progress	●	07/23/23	03/01/25	Test Results Will be Evaluated and changes made where necessary, if faults are discovered team may go back to the drawing board and still have plenty of time to deliver a working product to the launch vehicle that has been retested.	~0	588d
5	Delievery To Launch Vehicle Integrator	In Progress	●	03/01/25	05/05/25	Vehicle will be assembled and ready to transport to Launch Integrator		66d
6	Launch	In Progress	●	05/01/25	05/31/25	Launch will occur during the month of May	~0	31d
7	KDP: E			05/01/25	05/31/25	If vehicle launches successfully team can then move to phase E/		31d
8	**Phase E: Operations and Sustainment**			**07/23/23**	**05/31/25**		**12d**	**679d**
9	CubeSat Collects Data	In Progress	●	05/01/25	05/30/26	CubeSat will operate for one year as required		395d
0	**Phase F: Closeout**			**07/23/23**	**05/31/25**		**12d**	**679d**
1	CubeSat is Decommisioned	In Progress	●	05/01/26	05/30/26	CubeSat will then be instructed to perform a controlled Deorbit		30d
2	SAR	In Progress	●	05/01/26	06/30/26	Summary will be reviewed and findings discussed		61d

Figure 1: Schedule

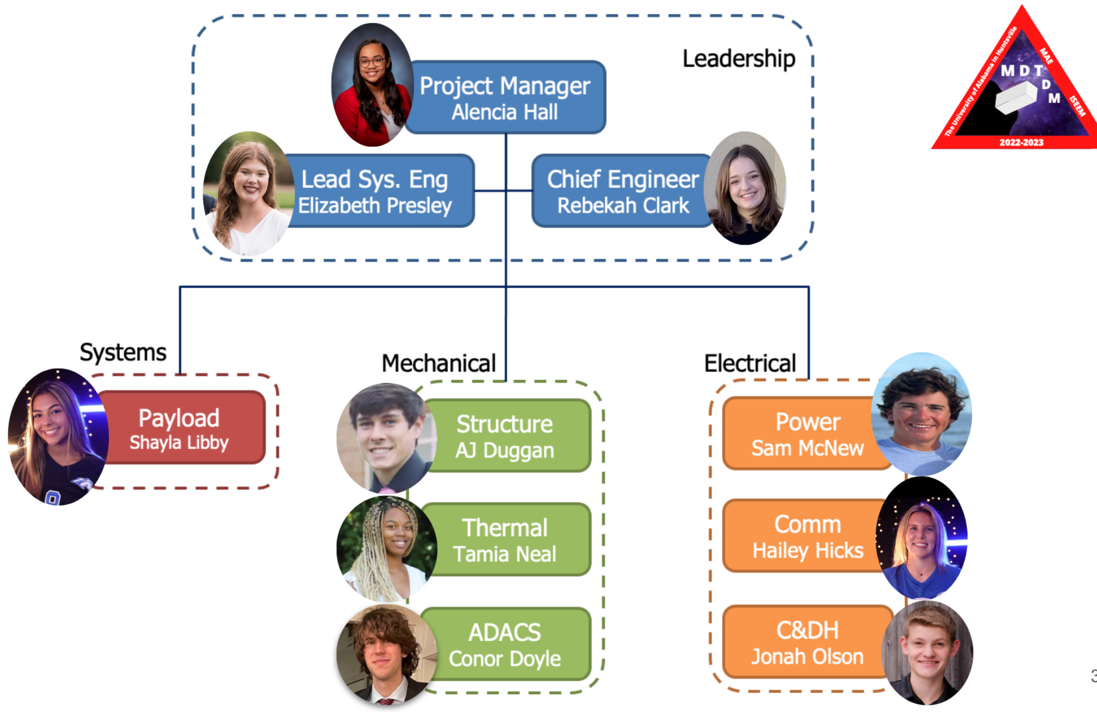


Figure 2: Work Organization

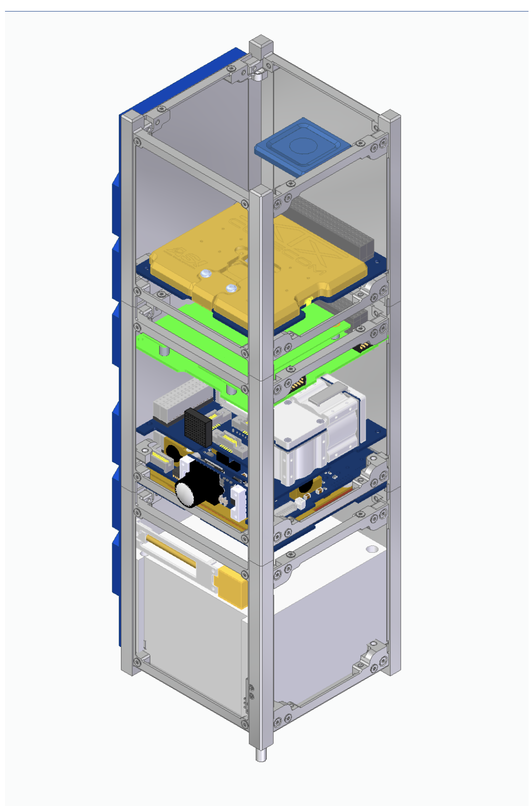


Figure 3: Isometric View

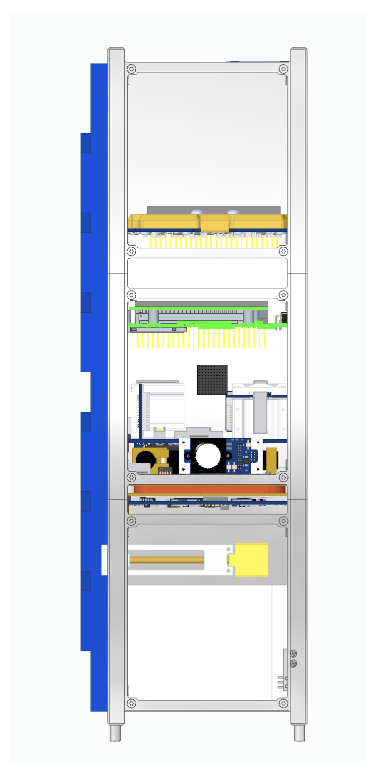


Figure 4: Side View

Project Name:	Project Manager	Date
MDTTDM	Alencia Hall	3/8/23

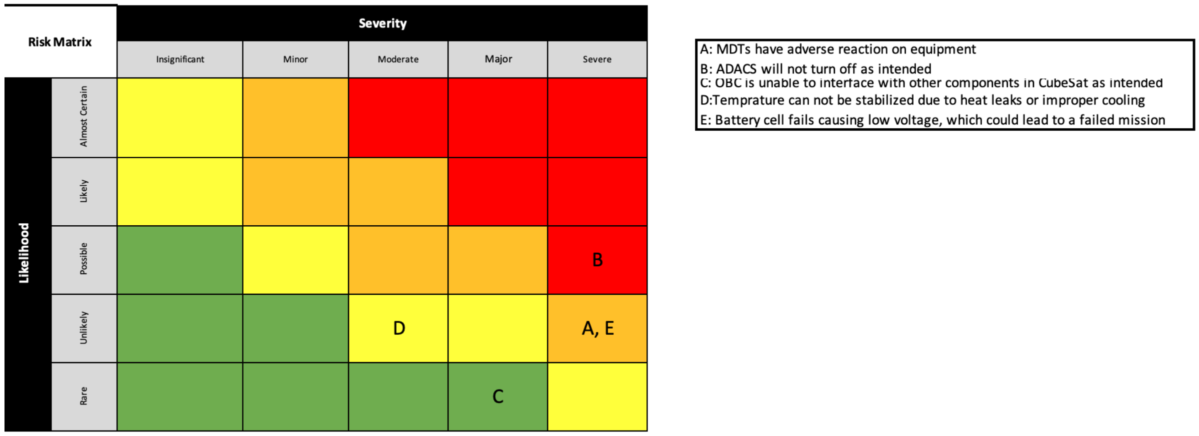


Figure 5: Technical Risk Matrix

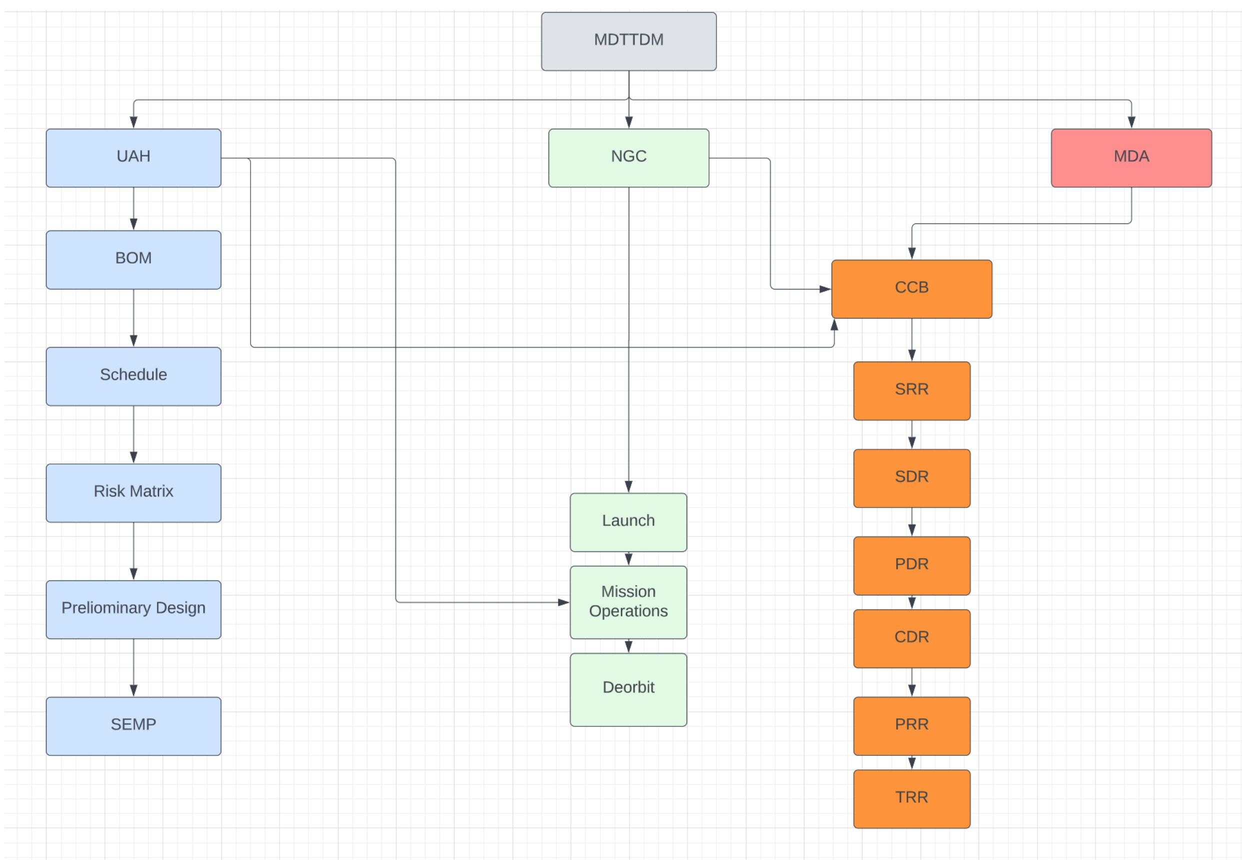
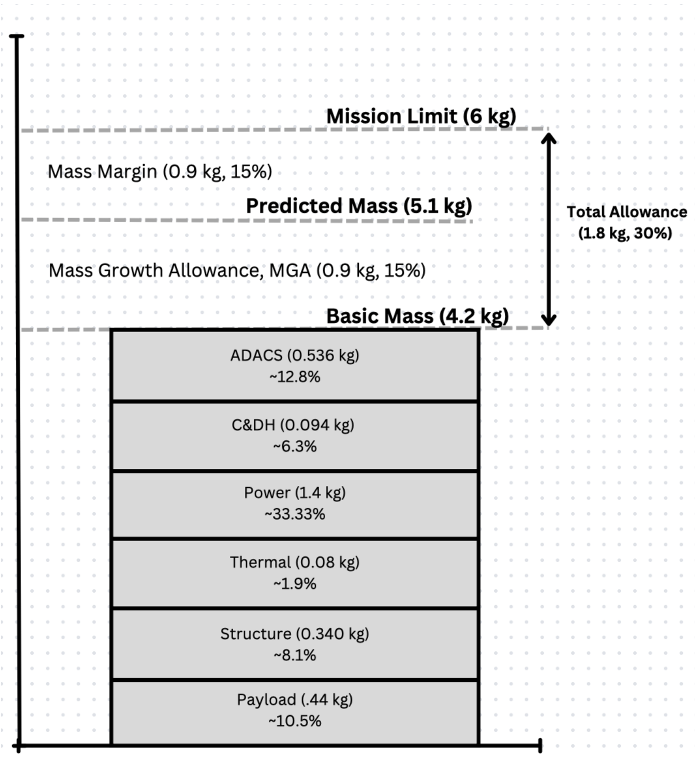
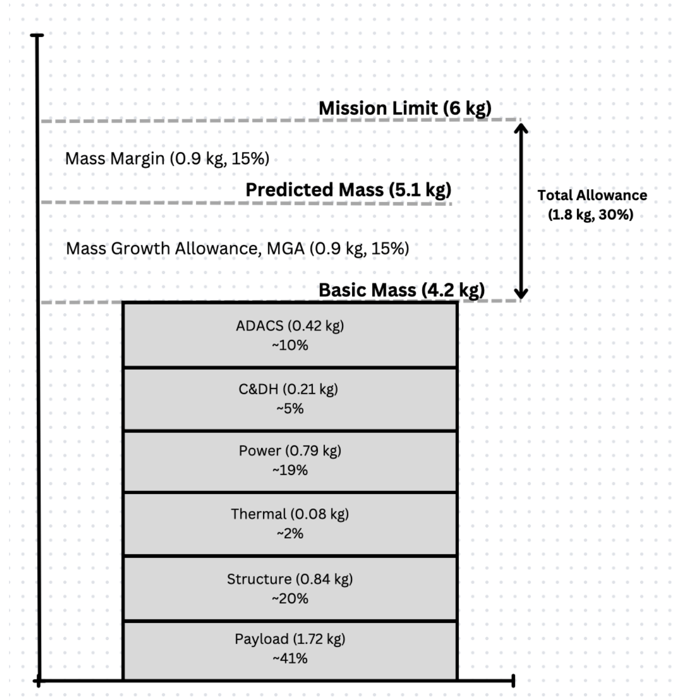


Figure 6: WBS



Current Mass Allocation



SMAD Recommendation

Figure 7: Mass Allocations

Instrument	Mass (kg)	Dimensions (cm)	Power (W)	Data Rate (kbps)	Lifetime (min)	Frequency	Duration
Accelerometer	0.00992	0.762 x 2.54 x 2.16	0.025 to 0.16	1.5	6 months	Before, During, and After MDT Firing Sequence	2.0 s
Gyroscope	0.055	4.475 x 3.860 x 2.0	1.5	0.5	6 months	Continuous	Continuous
Current Sensor	0.025	2.65 x 1.80 x 1.28	1.8	7.0	6 months	Continuous	Continuous
Voltage Sensor	0.038	4.57 x 2.90 x 2.60	1.2	100	6 months	Continuous	Continuous
Star Tracker	0.275	4.5 x 5.0 x 9.5	1.4	0.01	6 months	Before, During, and After MDT Firing Sequence	2.0 s

Instrument	Mass (kg)	Dimensions (cm)	Power (W)	Data Rate (kbps)	Lifetime	Frequency	Duration
IMU	0.026	3.4 x 3.9 x 2.4	1.4	4.8	6 months	Continuous	Continuous
Digital Temperature Sensor	0.011	0.4 x 0.4 x 0.085	1.2E-5	0.024	6 months	Before, During and After Firing Sequence	2.0 s
Optical Sensor	0.05	4.5 x 2.5 x 4.5	0.075 to 0.24	1000	6 months	Before, During and After Firing Sequence	3.0 s

Figure 8: Science Traceability Matrix

Part Name	Quantity	Unit Cost	Total Cost	
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EnduroSat 3U CubeSat Structure	1.00	$4,100.00	$4,100.00	
Thermal				
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Thermal Switch	TBD	TBD	TBD	
Copper Cabled Thermal Straps	1.00	$800.00	$800.00	
Digital Temperature Sensor	1.00	$4.29	$4.29	
ADACS				**Total:**
CubeADCS	1.00	$37,000.00	$37,000.00	**$203,194.19**
Star Tracker	1.00	$37,112.00	$37,112.00	
Accelerometer	1.00	$720.00	$720.00	
Tensor Tech CMG-10m Control Moment Gyroscope	1.00	$20,000.00	$20,000.00	
IMU	1.00	$9,020.00	$9,020.00	
Power				
EnduroSat EPS II+ Battery Pack	1.00	$40,200.00	$40,200.00	
EnduroSat 3U Solar Panel	1.00	$6,200.00	$6,200.00	
Current Sensor	1.00	$45.00	$45.00	
Voltage Senor	1.00	$6.90	$6.90	
C&DH				
PULSAR-XTX X-Band Transmitter	1.00	$23,500.00	$23,500.00	
PULSAR-XANT X-Band Antenna	1.00	$4,100.00	$4,100.00	
ISIS Onboard Computer	1.00	$7,261.00	$7,261.00	
Payload				
Optical Sensor	1.00	1000*	$1,000.00	
Testing				
Vibration Estimate	1.00	$1,250.00	$1,250.00	
Standard Shock Estimate	1.00	$750.00	$750.00	
Thermal Leak Estimate	1.00	$1,500.00	$1,500.00	
Thermal Qualification Estimate	1.00	$8,625.00	$8,625.00	

Figure 9: BOM

Complaince Matrix	
Requirement	**Compliance Indicator**
The mission shall be accomplished with no larger than a 3U CubeSat	Compliant
The mission shall comply with the CubeSat Design Specification (1U-12U), Revision 14, CP-CDS-R14	Compliant
The mission shall be designed with a ground station located at The University of Alabama in Huntsville	Compliant
The mission shall cost (parts only) less than $500,000 (current year dollars)	Compliant
The mission shall launch by May 2025	
The mission shall have continuous on-orbit operations for at least six (6) months	Compliant
The mission shall incorporate as much COTS technology as possible	Compliant
The test sequence shall span a 30 minute interval	Compliant
The test sequence shall occur every 3 hours.	Compliant
The test sequence shall occur 5 times per day.	Compliant
There shall be a 9 hour recovery time utilized for charging after the 5 rounds of testing are completed.	Compliant
The mass margin for all hardware shall be no less than 15%.	
The power margin for the project shall be no less than 16 W.	Compliant
the power margin for the project shall be no greater than 22 W.	Compliant

Figure 10: Compliance Matrices

References

Shea, Garrett. “Appendix J: Semp Content Outline.” *NASA*, NASA, 16 Oct. 2019, https://www.nasa.gov/seh/appendix-jsemp-content-outline.

Shea, Garrett. “2.1 The Common Technical Processes and the SE Engine.” *NASA*, NASA, 27 Feb. 2019, https://www.nasa.gov/seh/2-1_technical-processes.