University of Colorado
Department of Aerospace Engineering Sciences
ASEN 4018
Project Definition Document
HICKAM (Hybrid-rocket Information-Collection, Knowledgebase and Analysis Module)
Monday 2nd October, 2017

Approvals

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<th>Date</th>
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1. Problem Statement

Successful engineering requires measuring the reliability, performance and quality of a product. This is a necessary aspect of the design process and is implemented through testing and evaluation. However, testing often requires extensive setup and safety measures at the expense of time, financial cost, and material and personnel resources. In the case of such a substantial piece of equipment as a rocket engine, testing takes considerable effort and brings forth the need for a safe and efficient testing platform to ensure the maximum return of investment of these resources required in a testing environment.

The goal of project HICKAM (Hybrid-rocket Information-Collection, Knowledgebase and Analysis Module) is to address this problem through the design and fabrication of a modular, compact testing platform for hybrid rocket engines. This test stand will be designed to test class O hybrid rocket engines, characterized by a total impulse range of 4,600-9,210 lbf*s. The team will also manufacture two hybrid engines of the same design to characterize the platform’s performance in order to ensure consistency. The platform will be designed to allow for ease of transportation and maintenance. In addition, the platform will allow for safe yet efficient testing in order to shorten the time required to conduct the tests from start to finish.

Success at the completion of the project will be the construction and verification of a hybrid rocket test platform that measures quantities that are utilized in characterization of engine performance as well as the assembly of two operational hybrid rocket engines. The engines are expected to be tested on the test stand. The quantities to be measured include the engine thrust over time, thrust duration and delay, maximum thrust, specific impulse, and nozzle temperature for the minimum level of success.

2. Previous Work

From 2001 to 2008, the University of Colorado supported the MaCH-SR1 project. The MaCH-SR1 project aimed to develop and test a hybrid rocket engine. The MaCH-SR1 project designed hybrid rocket engines that could provide a maximum of 5,000 pounds of thrust. In order to measure the maximum amount of thrust generated by the designed hybrid rocket engines, the MaCH-SR1 teams designed static test stands. Throughout the course of the MaCH-SR1, both horizontal and vertical test stands were designed and constructed. For the MaCH-SR1 project Matt Rhode was mentioned in the acknowledgements and he will be a valuable resource for information on the HICKAM. HICKAM aims to design a test stand to characterize N20-HTPB hybrid rocket motors. In order to successfully characterize a hybrid rocket motor, HICKAM must collect more data than just the maximum thrust. The test bed will use design elements from the MaCH-SR1 projects and knowledge gained to apply to the HICKAM system.

Another goal of HICKAM is to manufacture two hybrid rocket motors to collect and analyze data using the HICKAM test bed. The MaCH-SR1 projects from 2001 to 2008 provided designs of successful hybrid rocket motors. These hybrid rocket motor designs can provide anywhere from 100 to 5,000 pounds of thrust. Analyzing the designs of previous MaCH-SR1 projects will allow for team to select and adapt a design which best suites HICKAM’s purpose.

The University of Colorado has also sponsored HYSOR, a graduate project that aimed to build a sounding rocket with a hybrid rocket motor. The HYSOR provides insight on the development and fabrication of hybrid rocket motors. HYSOR gives insight into the shape and design of the fuel grain to be used in the rocket. HYSOR also gave insight into how the different fuel grains give different thrust curves for the different fuel grain designs. HYSOR also helps provides background on the important characteristics of hybrid rocket motors and how to measure some difficult measurements such as combustion chamber pressure.

Projects from other universities have conducted similar projects involving hybrid rockets. A hybrid rocket test stand was built by a team at Texas A&M. The Texas A&M project built a hybrid rocket test stand but only tested thrust values on the scale of a few pounds of force. Although on a much smaller scale than the current project the project from Texas A&M gave insight into a fuel pump system, structural system and data acquisition system. The work from Texas A&M will be used to help develop the pressure feed system as well as the ignition system used for their rocket.

With hybrid rockets one of the trade offs for safety is that the fuel oxidizer combination is more difficult to ignite versus liquid or solid rockets. A graduate research team from Utah State University conducted a study of a direct electrical arc ignition system. The direct arc system was shown to use as little as 10 watts to initiate combustion in a hybrid rocket motor. This system has advantages over a steel wool ignition system because it requires less mass which is one of the main concerns in rocketry. One advantage with this system is that only the main propellants are required to ignite the engine which saves on mass and simplicity. Another advantage to this system is that it allows for the possibility of multiple restarts which was previously a very difficult challenge when developing hybrid rockets. This Utah State University research will help guide the development of the ignition system in the HICKAM system.
3. Specific Objectives

The HICKAM and the hybrid rocket motor designs will be validated through software modeling, inspection, and testing to ensure system performance. Two rocket motor test articles will be manufactured using the same design, along with the design and development of the HICKAM stand. This motor design will be inherited from a hybrid rocket built in a previous TBD project, that generated up to 300 lbf of thrust. HICKAM will support at least a safety factor of 1.7. Before hot firing on HICKAM, the test articles will be put under a cold flow test on the HICKAM stand. The motors will then be set up and statically hot fired at a testing facility on their test platform to prove the HICKAM’s capabilities. The test stand shall not take heavy industrial loading equipment (ie. cranes, semi-trucks) for setup and transportation.

Table 1 examines three tiers of difficulty in the completion of this project. Each increasing tier involves more challenging software validation obstacles. Level 1 provides the basic mission goals and design requirements for HICKAM, this includes the analysis of basic rocket motor characteristics. The next level adds more complexity to the mission and the system’s development. The level 2 analysis items will require special equipment to analyze, driving up the cost of this project. Level 3 has the final mission goal of the entire year, it presents difficult software validation topics and user convenience aspects. The cost of the equipment to analyze these rocket motor characteristics also poses a challenge.

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Mission Goals</th>
<th>Analysis Items</th>
<th>Software</th>
<th>Storage</th>
<th>Camera</th>
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<tbody>
<tr>
<td>Level 1</td>
<td>Design and development of HICKAM and test articles, support up to 600 lbf of thrust</td>
<td>Measure thrust (delay, duration, and maximum), specific impulse, total impulse, mass of the rocket engine, nozzle temperature</td>
<td>Collect discrete data and analyze system performance, output to a file</td>
<td>Ability to be transported in a single, durable container, set-up and test within 72 hours</td>
<td>Visual recording of test fire</td>
</tr>
<tr>
<td>Level 2</td>
<td>Successful static cold flow test, data collection and analysis of the two test articles</td>
<td>Measure of combustion chamber pressure, regression rate of fuel</td>
<td>GUI for user to explore and graph specific data and values</td>
<td>Step-by-step instruction setup that can be done by any qualified technician/engineer</td>
<td>Remote observation and thermal recording of test fire</td>
</tr>
<tr>
<td>Level 3</td>
<td>Successful static hot fire test, data collection and analysis of the two test articles</td>
<td>Measure oxidizer flow rate, vibration behavior, source ignition shock, exhaust temperature</td>
<td>–</td>
<td>Ability to use battery power for instruments, not on-site power</td>
<td>Recording with a high frame rate (TBD) camera</td>
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4. Functional Requirements

4.1. Functional Block Diagram (FBD)

Figure 1 shows the Functional Block Diagram for the HICKAM module. The module will be physically split into two primary systems: the test stand and the computer system. The computer shall be a command center, as well as data ingestion and analysis module. It shall be able to control the ignition and throttle valve of the test stand, as seen from the control lines connecting the computer with cable interface on the test stand. It shall also acquire direct sensor data from the test stand and analyze it to find the required rocket motor parameters, given in the “Data Analysis” block within the computer. The test stand shall have a Static Fire Subsystem, consisting of an on-board power management system, which would take power inputs from external power source, ignitor and oxidizer throttle valve actuator. The test stand shall also contain an Oxidizer Storage and Feed Subsystem, incorporating an on-board oxidizer tank with
the throttle valve and oxidizer feed lines, leading to the test article. The test article itself shall have ignition interface with the Static Fire Subsystem, as well as oxidizer input lines and mechanical sensor interface. The latter shall consist of various mechanical adapters or modifications to attach strain, acceleration, pressure, and temperature sensors. The sensors shall be incorporated inside the Sensor Package Subsystem, with the Data Acquisition lines leading to the computer.

Figure 1. Functional Block Diagram

4.2. Concept of Operations (CONOPS)

To better understand the mission of the project, a concept of operations was made and can be seen in Figure 2. This figure describes the elements of the mission as seen from an outside perspective. As can be seen from elements 1-3, the mission starts with the transportation of the HICKAM and test articles to a predetermined test facility, unboxing of the test stand, and setup. The set up entails securing the test stand to the ground to prevent it from moving. The next element of the mission is securing the test article, hybrid rocket engine, to the HICKAM. The following elements are really important to ensure a successful and safe mission. After these checks, signal will be sent to start collecting
data and ignite the rocket engine. The DAQ acquisition system will collect data pertinent to the characterization of a hybrid rocket for the approximate 20 seconds burn time. Data collected includes: the total force provide, the duration of thrust, pressure of combustion chamber, and regression of both the solid and liquid fuels. Once the data is collected and the engine goes out a 30 minute wait period is implemented for safety assurance. After these 30 minutes the following three mission elements are to remove the test article from the HICKAM, box it, and transport it back to HQ. Within 72 hours of initializing the mission, a spec sheet for the rocket engine will be compiled based on the data collected during the test.

Figure 2. Concept of Operations for engineered system
5. Critical Project Elements

5.1. Budget Management and Scheduling

Project HICKAM requires the manufacturing of a test stand and two hybrid rocket engines. After research into past CU senior projects, it is highly anticipated that the project will cost more than $5,000 just in materials and sensor packages. Due to the large scope of the project, additional funding will be necessary outside of the allotted $5,000. Therefore, the team must apply for additional grant funding. Manufacturing two rocket engines on top of the test stand increases the risk of this project failing due to financial and time constraints. Exceeding the budget will place the project at high risk of not being completed. Managing the budget and schedule will not cost monetary value, but will require creative and organized processes to accomplish the project with strict time and budget constraints.

5.2. Data Acquisition and Analysis System

Data collection and analysis is critical because it is the driving motive for using a static test stand to characterize a hybrid rocket engine. The data acquisition and analysis system will allow for the characterization of the rocket engine through the measurement and calculation of various parameters, such as thrust, ISP, vibration profile, etc. The test stand must not only secure the engine, but also secure the sensor package in a way that ensures accurate measurement and data integrity.

5.3. Securing Test Facility and Meeting Facility Requirements

Legal static hot fires of rocket engines require the use of a specialized facility. Research into past projects and discussions with members of the PAB have made it clear that securing a test facility is an absolutely crucial element of this project: without a test facility, HICKAM cannot be operationally tested. Test sites are few in number, often have strict testing and safety requirements, and sometimes charge for testing time (depending on location). As such, the test site can heavily influence elements of the design, ranging from project budget to test stand structure.

5.4. System Validation using Computational Modeling

Computational modeling is a critical validation method to confirm the accuracy of the measurements obtained from the test stand and without it, the project will be unsuccessful. Data from temperature, pressure, and thrust measurements needs to be compared to an analytical model to ensure the HICKAM module is capturing data accurately. Computational models will also be necessary to validate the design of the test stand and test articles. Specifically, heat transfer, structural, and fluid models will be required in order to adequately capture system loads and behavior and ensure that the system can accomplish its objectives safely. CAD models of the test stand are also required for manufacturing. Although there is no financial cost in developing these models, they will require large amounts of time to develop.

5.5. Proper Manufacturing of the Test Stand and the Rocket Engines

A major difficulty of this project is the manufacturing of both the test stand and the two hybrid rocket engines in strict accordance with our CAD models. Precision in the manufacturing of the test stand and the rocket engines is critical to ensure the effectiveness and safety of the system. Due to the amount of manufacturing that needs to be done, manufacturing must take place much sooner than originally planned: manufacturing will need begin in the fall semester to finish the system in time for testing in the spring. The manufacturing process will not be a significant financial cost, but will require a considerable amount of time.

5.6. Safety Protocols and Methods

The HICKAM project will require the handling of explosive fuels, liquid oxidizer, high currents and voltages, and high pressure chambers; therefore, the development of safety protocols and methods is absolutely critical. These safety concerns will influence the design of the mechanical components and software, as well as necessitate a proper barrier at the test site to protect personnel in the event of a catastrophic failure during hot-fire.
6. Team Skills and Interests

<table>
<thead>
<tr>
<th>Critical Project Elements</th>
<th>Team Members and Associated Skills/Interests</th>
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| Budget and Scheduling     | Olagappan Chidambaram: Experience managing budgets for various engineering projects, and currently studying project management.  
                           | Haleigh Flaherty: Two years experience as a project manager for high altitude balloon payloads.  
                           | Kirill Kravchuk: Strong technical communication and leadership skills through participation in NASA SBIR funded “TentGuild”, “Oneweb”, and Space Grant.  
                           | Savant Suykerbuyk: Extensive leadership and management experience in military, and currently studying project management. |
| System Validation Using Computational Modeling | Nate O’Neill: Interested in computational design, multi-physics modeling and analysis, and design optimization.  
                                      | Angel Ortega: Interested in structure of the project. Propulsion background with COBRA.  
                                      | Gerardo Pulido: Thruster Heat transfer and fluid analysis.  
                                      | Dylan Reed: Interested in learning more about propulsion.  
                                      | Olagappan Chidambaram: Solidworks experience.  
                                      | Angel Ortega: Solidworks experience.  
                                      | Nate O’Neill: Solidwords experience.  
                                      | Tommy Pestolesi: Solidworks and rocket motor design. |
| Manufacturing of the Rocket Engine and Test Stand | Savant Suykerbuyk: Experience in machining, airframes, and powerplants maintenance in aviation.  
                                                     | Angel Ortega: Some machining experience with interests in developing skills.  
                                                     | Nate O’Neill: 150+ hours of manufacturing experience; designed and manufactured Sodium DEMOF filter for Doppler-free lidar spectroscopy.  
                                                     | Gerardo Pulido: Propulsion component machining and tubing. |
| Data Acquisition and Analysis System | Olagappan Chidambaram: 7 years of electronics and programming experience, and currently taking microavionics course.  
                                          | Kirill Kravchuk: Interested in electronics and software, experienced in mission analytics and testing.  
                                          | Brian Ortiz: Interested in expanding my electronics knowledge.  
                                          | Dylan Reed: 6 years of programming experience, and interested in improving on these skills.  
                                          | Jaquelyn Romano: Electronics, software and microavionics. |
| Securing Test Facility and Meeting Facility Requirements | Haleigh Flaherty: Experience writing test procedures and reports, as well as experience directing tests.  
                                                              | Brian Ortiz: R and D with AFRL with several testing procedures.  
                                                              | Sage Sherman: Performed ~200 human subject tests for artificial gravity research with self-written procedures. |
                          | Haleigh Flaherty: Experience with safety in writing and leading safety protocols. |

7. Resources

The scope of project HICKAM requires many resources to fulfill requirements and fund the project. The table at the end of Section 7 provides a summary of the resources and sources detailed in this section.

7.1. Budget and Scheduling

To assist with the limited budget, project HICKAM will apply for additional funding and borrowing as much equipment as possible. For additional funding the financial lead is currently applying for a $3,000 Engineering Excellence Fund (EEF) grant and researching more possible grants.

The team has already confirmed with the customer that components do not need to be purchased, but instead can be rented or borrowed. This will assist with the limited budget as the team has already discussed borrowing load cells and a data acquisition system (DAQ) from the ITLL. The customer has also offered possible equipment donations from Orbital ATK.
Since the team is not required to design the hybrid rocket engines, they plan to select an engine and begin manufacturing in the Fall 2017 semester. This will allow the second semester to be spent on manufacturing the test stand and give adequate time for testing.

7.2. Data Acquisition and Analysis System

As stated in Section 7.1, the team plans to borrow a DAQ from Dan Godrick with the ITLL. Trudy Schwartz, will also be a resource to help implement a Data Acquisition and Analysis System.

7.3. Secure Test Facility and Meeting Facility Requirements

One of the major resources is a test facility. The team has already started this process and is currently working with two primary locations, Front Range Airport and Platteville Airport, with guidance from Matt Rhode. The team has already contacted Front Range airport and is currently discussing provided facility resources and location rental fees. Matt Rhode has contacted Platteville Airport and is working with them to receive approval for a hot fire test. The two locations have different provided resources and on-site requirements. The team will ensure compliance to these requirements once the site final selection is made.

7.4. System Validation using Computational Modeling

For assistance with computational modeling, the team will receive guidance from Professor John Evans, Professor Kurt Maute, Professor Lakshmi Kantha, and Professor Peter Hamlington. For assistance with the structural integrity of the system we will use our group’s advisor Francisco Lopez Jimenez. The group will also be in close contact with Matt Rhode to get insight on the structural integrity of the test stand. The group will also use past projects as resources to guide the design of the structural integrity of the test stand. The HySOR project from CU had developed a test stand that secured a hybrid rocket motor for static testing, information from this project will be used to help guide the design of the HICKAM system. The MaCH SR1 project had also developed a test stand for a hybrid rocket that was statically test fired and gathered data about thrust and burn duration. Both of these projects provide insight in the development and construction of the test stand.

7.5. Manufacturing of the Rocket Engine and Test Stand

Trudy Schwartz and Matt Rhode have offered their guidance in manufacturing the test stand. The team plans to use the aerospace machine shop and team member Savant Suykerbuyk’s experience in manufacturing for the project.

7.6. Safety Protocols and Methods

Work with Matt Rhode and Bobby Hodgkinson to determine proper mechanical safeties and placement. Their mechanical experience with similar applications will be key to properly augmenting the system with mechanical fail safes to ensure the system performs safe operations by default. Consult other faculty, such as Professor Torin Clark and Professor Allie Anderson, with testing experience for safety protocols, like proper checklist writing and possible training procedures. Consult Trudy Schwartz for guidelines on safety oriented software methods, so that the electronic control method will automatically abort dangerous behavior without requiring human input.
Critical Project Element | Resource/Source
------------------------|----------------------------------
Budget and Scheduling  | Apply to grants for additional funding. Rent and borrow components when possible. Begin manufacturing of the rocket motors this semester.

Data Acquisition and Processing System | Borrow DAQ system from ITLL. Support from Trudy Schwartz.

Secure Test Facility and Meeting Facility Requirements | Work with Matt Rhode on selecting a test site. Currently pursuing Front Range Airport and Platteville Airport.


Manufacturing of the Rocket Engine and Test Stand | Support from Trudy Schwartz and Matt Rhodes. Experience with aerospace engineering machine shop via Savant Suykerbuyk.

Safety Protocol and Methods | Work with Matt Rhode and Bobby Hodgkinson to determine proper mechanical safeties and placement, Professor Torin Clark and Professor Allie Anderson for safety protocols, and Trudy Schwartz for guidelines on software methods.

References


