Department of Aerospace Engineering Sciences
Senior Projects – ASEN 4018

MaCH-SR1
Project Definition Document (PDD)

Document History

Release	Date	Description	Name
Initial			

Approval

Title	Name	Signature	Date
Customer			
Advisor #1			
Advisor #2			
CC			

Project Definition Document

Aerospace Senior Projects (ASEN 4018 & 4028)

1.0 Information

1.1 Project Title

Multi-disciplinary University of **C**olorado **H**ybrid **S**tudent **R**ocket Project or MaCH-SR1

1.2 Project Customers

NAME: Professor Lakshmi Kantha
ADDRESS: University of Colorado
Phone: 303-492-3014
Email: kantha@colorado.edu

1.3 Group Members

Include name, e-mail and any other pertinent contact information

Stacey Bagg stacey.bagg@colorado.edu	Richard Bell bellr@colorado.edu
Bradley Crittenden crittenb@colorado.edu	Wesley Haigh wesley.haigh@colorado.edu
Jared Santistevan santistj@colorado.edu	Leon Slavkin slavkin@colorado.edu
Robert Wuest wuest@colorado.edu	

1.4 Other Interested Students

Include name, e-mail and any other pertinent information including major and academic year (sophomore, junior, etc), expected contribution to the project and weekly time commitment. Involvement of other students on the project requires the approval of the course coordinator.

None yet

2.0 Background and Context

The CU undergraduate hybrid rocket project, MaCH-SR1, was selected by this year's senior project team on the basis that high altitude hybrid rocket technology is a relatively new and unproven science that will provide a rich learning experience for future careers in rocket design. The major components of the CU hybrid rocket include a rubber-like solid rocket fuel called Hydroxyl-terminated polybutadiene (HTPB) which produces an exothermic reaction when a liquid oxidizer fuel, Nitrous Oxide, is injected through it and ignited. This type of rocket offers a safer launch, test, and transport capability in comparison with liquid or solid rockets since both fuels must be present in the combustion chamber along with an ignition source for large-scale combustion, and thrust, to occur. Other advantages of this type of rocket are throttling and restart ability.

MaCH-SR1 is a multi-year undergraduate project that has been geared towards building a flight-ready hybrid rocket for CU that can achieve a low earth orbit altitude. The successful completion of such a rocket would aid both future CU research efforts and student satellite missions at a fraction of the cost required for existing launch methods while offering safer propellants than liquid or solid rockets. In addition, it should be noted that a rocket with these specifications has not been built and flown by any university within the United States at this point, making this multi-year project a novel and highly ambitious concept in itself. Unfortunately, reaching the milestone for 2007-2008 set out by the first MaCH-SR1 team in 2001 is impossible with the current status of the project.

This year's team will be the sixth team to contribute to the project. All previous teams have focused on the propulsion system with feasibility tests starting with lab-scale prototype engines. These started with a 5,000 lb_f thrust engine, a 300 lb_f engine, a carbon fiber and aluminum end cap oxidizer tank, and vertical as well as horizontal static test fire configurations. It has been verified that the combustion chamber and nozzle have performed effectively for the 300lb_f rocket engine. However, the 300lb_f rocket injection, feed, ignition, and oxidizer tank system have not been thoroughly proven. The injection and feed system design are understood to contain flaws and remain untested in a static test fire configuration. The steel wool and lox ignition system is reliable but has resulted in some nozzle damage upon ejection from the combustion chamber. Finally the oxidizer tank designed and built in the 2005-2006 academic year resulted in catastrophic failure during test. Novel components of this year's project will involve the design, test, and verification of a new ignition, feed, and injection subsystem. Successful completion of this year's project will provide a strong propulsion system foundation for future teams to build upon and a greater possibility of the multi-year project's success.

3.0 Goal

This year's Mach-SR1 team shall build on the work of previous projects by working towards a self sufficient hybrid rocket that can deliver a payload to a TBD altitude.

4.0 Objectives

This year's Mach-SR1 project will work towards the goal of eventually launching a 300 lb hybrid rocket for the University. This is the second year for this specific project, and thus we will build on the work of the previous team by redesigning several key rocket components that are necessary for flight readiness. Specifically this includes the ignition system and the feed and injection systems for the oxidizer. In addition several parts such as the nozzle and combustion chamber will need to be fabricated based on the previous year's design for the full-system hot-fire test at Lockheed Martin. Previously built oxidizer tanks have failed, and thus this team shall purchase a prefabricated tank to reduce risk and allow the group to focus on new components. Finally, a new test stand will need to be designed and developed to allow for the hot-fire test that will verify system functionality and performance.

For us to have a successful project the feed system needs to be designed, built and tested to successfully and safely transport the oxidizer to the combustion chamber. This will be a gravity-feed system that can be tested with water and other liquids to ensure that there are no leaks. In addition the mass flow rate will be measured to ensure that the appropriate amount of oxidizer is being fed into the combustion chamber during firing. The minimum for this system to succeed is to feed oxidizer to the combustion chamber with no leaks.

The injection system is pressure based and works in series with the feed system to properly inject oxidizer into the combustion chamber. This system can also be water tested to ensure no-leakage and proper functionality. At a minimum this component must be leak free and must feed oxidizer into the combustion chamber at a pressure of TBD.

The ignition system will be a completely different design and functionality from all previous groups. In the past this component was designed to ignite the propellant using steel wool with a current running through it. Although this design was occasionally functional for a test project, it is unpractical for use on a real rocket because the steel wool is jettisoned through the nozzle and often caused damage to the nozzle itself. This year's project will focus on developing a simple and reliable system that can be ignited remotely. This system will be tested independently and must ignite to an appropriate temperature at a bare minimum.

The test stand will be designed to support the rocket for a vertical test. This will need to be strain tested with appropriate factors of safety to ensure the rocket will not move during testing or damage the test stand. This stand will also incorporate sensors and will be appropriate for use in the Lockheed Martin facility. At a bare minimum, the test stand will be sized to accommodate the rocket, and will be rated to the thrust levels expected from the engine.
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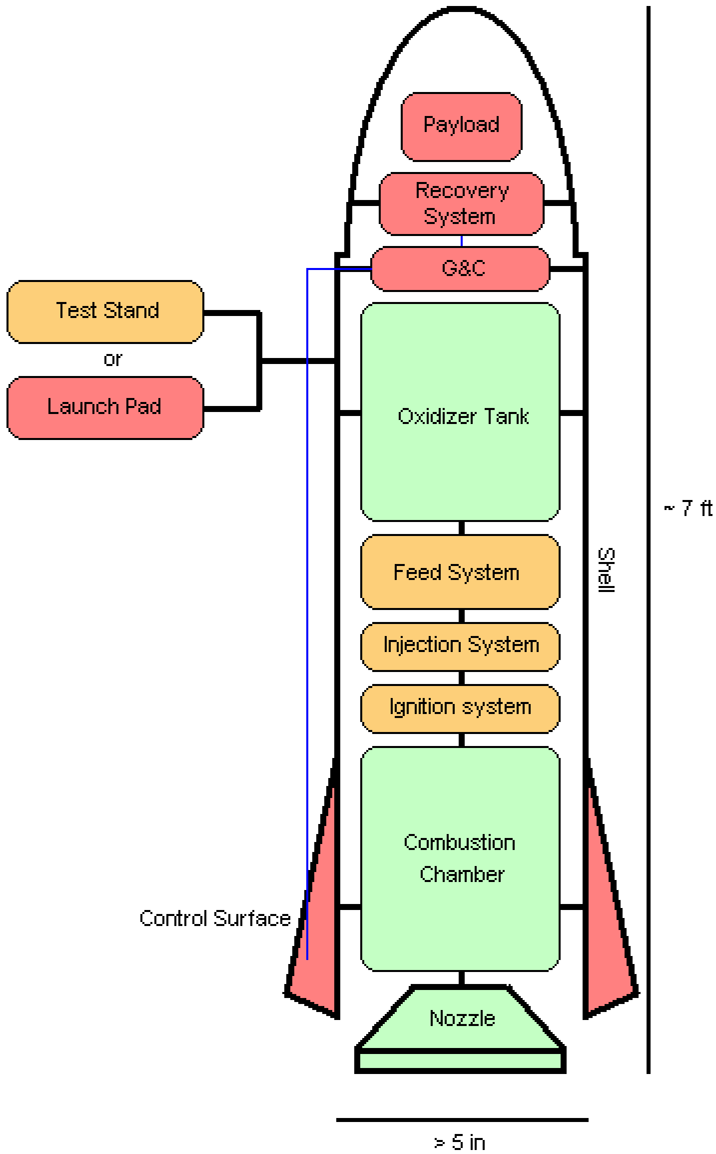
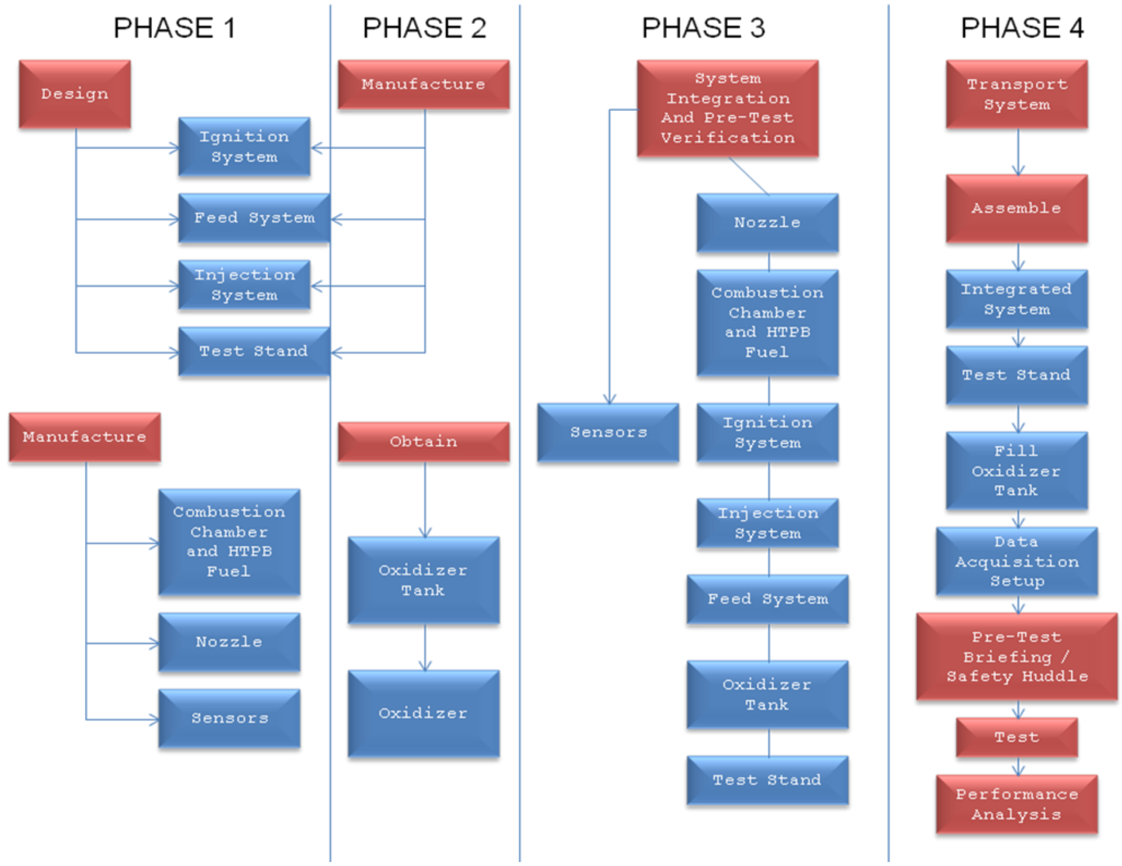
5.0 Functional Block Diagram



In the figure above: the green represents subsystems that need to be remade or bought but not redesigned; the yellow represents subsystems that need to be redesigned and manufactured; and the red are subsystems that need to be designed by future groups.

6.0 System Operational Timeline (Concept of Operations)



7.0 Project Requirements (0.PRJ)

7.1 Level 0 project requirement #1 (0.PRJ.1)

7.1.1 The hybrid rocket engine shall produce 250 lb of thrust for a duration of at least 15 seconds

7.1.2 A hybrid rocket engine shall provide enough thrust to lift the payload and vehicle to the appropriate altitude

7.1.3 From the objective of launching a 1 lb payload to an altitude of 5000 m

7.1.4 Hot fire test at Lockheed Martin using a manufactured test stand

7.2 Level 0 project requirement #2 (0.PRJ.2)

7.2.1 The hybrid rocket engine shall not exceed 100 lbs for the entire wet system, excluding the outer shell and future navigation and control systems

7.2.2 A hybrid rocket engine needs to light enough to reach the desired altitude at the given thrust level

7.2.3 From the objective of launching a 1 lb payload to an altitude of 5000 m

7.2.4 Mass will be verified using measurement tools

8.0 Top Level System Requirements (0.SYS)

8.1 Level 0 system requirement #1 (0.SYS.1)

8.1.1 The system shall only begin producing thrust through an ignition process

8.1.2 The ignition process is necessary because it begins the reaction between the oxidizer and the propellant

8.1.3 Section 7.1

8.1.4 The ignition system will be tested independently to ensure proper functionality and reliability

8.2 Level 0 system requirement #2 (0.SYS.2)

8.2.1 The system shall expel all combustibles through the nozzle during combustion

8.2.2 Thrust is produced by expelling propellant through a nozzle.

8.2.3 Section 7.1

8.2.4 This is a functionality requirement verifiable through inspection

8.3 Level 0 system requirement #3 (0.SYS.3)

8.3.1 An oxidizer shall be stored separately from the propellant

8.3.2 These two components cannot be combined until the combustion process is to begin

8.3.3 Section 7.1

8.3.4 This is a functionality requirement verifiable by inspection

8.4 Level 0 system requirement #4 (0.SYS.4)

8.4.1 The oxidizer shall feed into the propellant area during the ignition process

8.4.2 The fuel needs to mix so it can ignite and produce thrust

8.4.3 Section 7.1

8.4.4 This is a functionality requirement verifiable by inspection

8.5 Level 0 system requirement #5 (0.SYS.5)

8.5.1 The combustion process shall only occur in an isolated section of the rocket

8.5.2 This is necessary to prevent complete system failure

8.5.3 Section 7.1

8.5.4 This is a functionality requirement verifiable by inspection

9.0 Minimum Requirements for Success

This team must produce a successful hot-fire test of a hybrid rocket engine for the project to be considered a success.

10.0 Deliverables

10.1 Deliverable #1 (0.DEL.1)

10.1.1 Complete engine and associated fuel feed/ignition systems. All components necessary to successfully ignite, fuel, and fire the 300 lbf engine developed last year shall be delivered in a form that can be re-used by future teams for testing purposes and successfully integrated into a future rocket shell without significant redesign.

10.2 Deliverable #2 (0.DEL.2)

10.2.1 Test Data. Along with the completed engine, sufficient test data must be provided to demonstrate successful system integration, remote ignition, and thrust capabilities within stated project requirements as per sections 7 and 8.

10.3 Deliverable #3 (0.DEL.3)

10.3.1 Roadmap for future development towards launch vehicle. The development roadmap has changed substantially since it was first created in 2001. At this point, it needs to be completely redesigned to provide a comprehensive design document that details the steps future teams need to take to finalize the project.

11.0 Technical Risk

11.1 Risk #1 (0.RSK.1)

11.1.1 Limited access to necessary test facilities. Lockheed Martin maintains rigorous standards and restrictions for testing. Lockheed Martin also requires a rigid timeline agreement to accommodate testing.

11.1.2 To Mitigate: Communicate clearly and often. Determine timeline early in the project and present to Lockheed Martin as soon as possible. Correspond with Lockheed Martin representative Nicholas Patzer at least once every two weeks to keep project on target and on time. Use Lockheed Martin employees as a resource so project is correctly scoped and timeline is logical.

11.2 Risk #2 (0.RSK.2)

11.2.1 Financial limitations. Previous years had around $8000 to spend not including non-cash donations. This year the fundraising looks to be more difficult with less support from EEF and UROP. We also have a rigorous manufacturing scope, which will require a lot of expensive materials and components. Very few components and materials were saved from previous years.

11.2.2 To Mitigate: Plan frugally--do not buy anything we do not need or can manufacture ourselves. Use professors as a resource in gaining interuniversity funding as well as corporate sponsorship. Request and accept donations of parts or materials.

11.3 Risk #3 (0.RSK.3)

11.3.1 Safety. We are working with chemicals, pressure vessels, high gas temperatures and velocities, and many manufacturing methods. All of these present safety hazards. Safety of the group and anyone around or involved with the project should be the primary concern of the group.

11.3.2 To Mitigate: Strictly follow all safety guidelines provided in past procedures and by mentors, professors, or industry professionals. Do not attempt anything that could be considered unsafe without first consulting a knowledgeable person.

11.4 Risk #4 (0.RSK.4)

11.4.1 Access to oxidizer tank. With limited funding and manufacturing capabilities, providing an oxidizer tank may be difficult.

11.4.2 To Mitigate: If a COTS tank cannot be procured, we will either manufacture our own or use oxidizer provided by a separate system or facility.

11.5 Risk #5 (0.RSK.5)

11.5.1 Limited manufacturing capabilities. The manufacturing of a part could be difficult, even impossible, for our group.

11.5.2 To Mitigate: Most parts have been previously manufactured and proven possible. If the group cannot manufacture a component, then we will find someone with prior experience as a resource or buy the component COTS.

11.6 Risk #6 (0.RSK.6)

11.6.1 Legacy. This project is a multiyear project and often knowledge and materials are lost in the transition between project groups.

11.6.2 This is a class and it’s the education, not the end product that matters. However by leaving behind proper documentation and establishing some milestones that can be done by future classes, the project will grow instead of stagnate. Our group needs to establish these milestones and ensure proper storage of property and knowledge.

12.0 Anticipated Engineering Expertise

Technical Area	**How Applied / Indicate Team Member Responsible**
Precision Mechanical Design	Develop conceptual and detailed solid 3D models of the device components
Propulsion Design	Analyze the requirements of the engine to provide adequate thrust and weight requirements
Material Design	Based on constraints, find the optimal material to be used in the oxidizer tank
Chemical Expert	How the fuel works and how to distribute it correctly and ignite it
Thermal Design	Establish thermal constraints for engine to ensure safe, reliable operation
Data Acquisition Software	Real-time measurement subsystem
Mechanical Fabrication	Part machining
Mechanical and Dynamic Test	Verification of the project
Feed System Design	Reliably inject gas at constant pressure
Structural Expert	Securely attach subsystems of rocket to each other and the test stand

13.0 Resources

13.1 Facilities

The testing of the hot-fire engine will require special facilities able to protect the testers in case of an explosion. Lockheed Martin has such facilities and has been willing in the past to help test previous teams' rockets.

13.2 Additional Advisors

Professor Koster has already been very helpful with providing information about past groups. His knowledge of the overall project and material selection will be instrumental in getting this engine to work.

13.3 Funds

Previous years on the MaCH-SR1 project spent almost $8,000. Since this team intends to build another engine with redesigned subsystems, we will require additional funding. We intend to apply for both UROP and EEF, which have assisted the project in the past. Although the team will attempt to be more frugal than past teams, it is highly unlikely this project will succeed without additional funds.

14.0 Acknowledgements

You need to acknowledge all persons from whom you sought and received advice regarding your project during the development of the PDD. Acknowledgements may include the topic of your discussions and contributions of the person. Acknowledgements include also people who grant you access to their facilities to do the research or manufacturing, or who donate equipment and material needed for your project.

14.1 Customer contacts

Professor Kantha was very helpful in helping define how this team can significantly contribute to the overall goal of constructing a hybrid rocket.

14.2 Faculty members

Professor Koster helped scope the project and provide ideas on a novel component. Professor Palo helped the team with his expertise on scoping, PDD's, and the course objectives. Professor Hussein talked with us about the structural elements and insight on what needs to be tested before being flight ready.

14.3 Graduate Students

We have yet to seek the advice of graduate students. The team is in contact with several past team members and intends to seek advice from several more.

14.4 Undergraduate Students

We have yet to seek the help of undergraduate students. The team may search for undergraduate students interested in working on MaCH-SR1 now and in the future. Recruitment depends on the need and availability.

14.5 Others

Several companies have consistently helped out this project. Lockheed Martin has provided the most assistance. They have provided trained help and their facilities. The team is already in contact with Lockheed Martin and they are interested in helping the project out again.