

Project Definition Document

*Aerospace Senior Projects (ASEN 4018 & 4028)
Fall 2004 and Spring 2005*

1.0 Project Information

1.1 Project Title

MaCH-SR1: Multi-disciplinary University of Colorado High altitude Student Rocket

1.2 Project Customers

none

2.0 Background and Context

MaCH-SR1 is an ongoing project theme, now entering it's fourth year of study. There are 4 phases to the project, summarized in **Table 1** below. The project is currently in Phase II.

Table 1: MaCH-SR1 History

Phase	Description	Dates
Phase 0	Logistics- build up the team, get funding, set up accounts, lay down the infrastructure, learn rocket science, do initial designs	Sept 2000 - Jul 2001
Phase I	Design, build, and test 1000-lb thrust class hybrid rocket engines. Data and experience gathered from these tests will be used to design the Phase II engines	Jul 2001 – May 2003
Phase II	Design, build, and test 5000-lb thrust class hybrid engines. These will be optimized for thrust, weight and Isp, built for flight, and then flight-tested to gather data on static vs. dynamic performance	May 2003 – Current
<i>Phase III</i>	<i>Design, build and test 13,000-lb thrust class hybrid engine based off of experience and data from the prior engines, and prepare it for the first space shot.</i>	
<i>Phase IV</i>	<i>Optimize the designs from flight data and build the MaCH-SR2. This rocket will be in active University service for use with research payloads that need high-altitude delivery</i>	

The MaCH-SR1 will be built around hybrid rocket technology. The decision to use hybrid rocket technology for this project is based on three main points:

- Hybrid Rocketry is a relatively undeveloped science, thus leaving room for research.

- Hybrids are inherently safe since they use an inert solid fuel that is only brought into contact with the oxidizer at the time of ignition.
- This inherent safety implies decreased costs over other types of propulsion.
- Hybrid motors are essentially solid rockets which allow for intermittent operation.

3.0 Objectives

3.1 Overall Objective

The overall objective of this year's MaCH-SR1 project is to conceive, design, fabricate, integrate and verify an improved design for the MaCH-SR1 combustion chamber. The combustion chamber of a hybrid rocket is still highly un-documented, and thus allows for the greatest experimentation. A detailed design of this vital component can greatly affect the overall structural weight, and thus the T/W ratio of the rocket. The improvements made will be a reduced structural mass by 20% and a better casting process to reduce imperfections in the solid fuel. The reduction in imperfections will improve the thrust consistency, and our planned approach will reduce fuel cast time by 20%. The combination of reduced mass and better thrust consistency will improve the T/W ratio by an amount determined through firing tests.. Studies will be conducted in the areas of structural design and fuel manufacturing processes:

- Structural Design Areas
 - Injector Interface
 - Combustion Chamber Tube
 - Nozzle Interface
- Structural Design Methods
 - Mechanical/Parts
 - Materials
- Fuel Design
 - Fuel Quality
 - Casting Methods
 - Mandrel Removal Procedure/Mandrel Design

The fuel design of hybrid rockets is also relatively un-documented. While last year's fuel design proved effective, many surface imperfections were present which caused significant problems. Many resources were also wasted in the casting process. This year, the fuel design objective is to engineer methods by which surface flaws can be eliminated, and waste can be avoided.

In order to test the T/W ratio of the final chamber design, it must also be integrated into a Lockheed Martin-build oxidizer/feed system that was proposed by LM at the end of last year's project.

3.1.1 Baseline Evaluation

3.1.1.1 Structural Baseline

Objective

In order to evaluate the effectiveness of alternative structural design, a baseline will be established.

Discussion

The baseline design will be that of the previous year's 300 lb lab-scale combustion chambers, as shown in **Figure 1**. The historical design specs are summarized in **Table 2**.

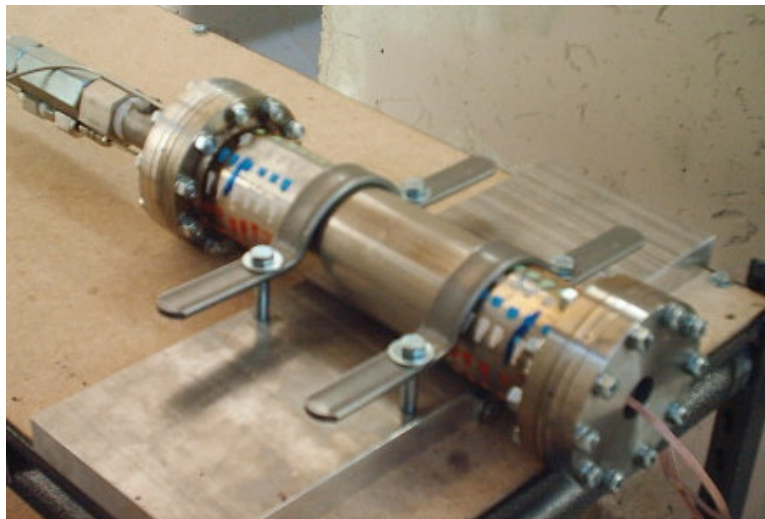


Figure 1: Lab-Scale Chamber

Table 2: Historical Baseline Specifications

Specification	Value
Inner Diameter	3.75"
Length	17.8"
Weight	TBD
Design Pressure	TBD
Pressure FOS	TBD
Design Temperature	TBD

This year's team will re-construct this historical design, and use it as the baseline design. The resource usage in the following areas will be documented for comparison with alternate designs:

- Overall Time

- Material Costs

After the construction process is complete, the produced chamber's physical characteristics will be tested for compliance with the above performance specifications, and to establish baseline values:

- Static Pressure Testing (compare to design)
- Thermal Testing
- Mass Properties

3.1.1.2 Fuel Mix/Cast Baseline

Objective

In order to evaluate the effectiveness of an alternative casting process, a baseline will be established.

Discussion

The baseline design will be that of the previous year's 4-point lab-scale "star" configuration used on the 2003-2004 year's design, as shown in **Figure 2**, and summarized in **Table 3**.

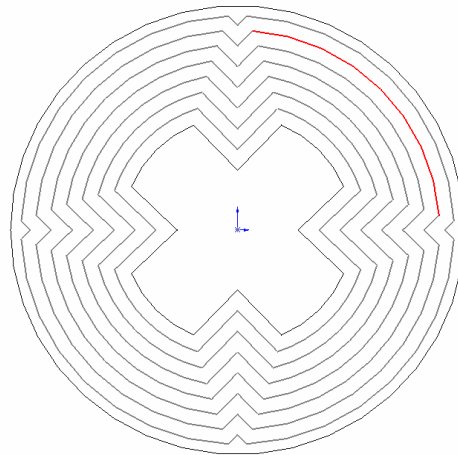


Figure 2: Lab-Scale Fuel Configuration

Table 3: Fuel Baseline Specifications

Specification	Value
Outer Diameter	3.75"
Outer Star Diameter	1.897"
Inner Star Diameter	1"
Fuel Surface Area	TBD
Burn Time	15 s
Port Length	17.8"
Safety Margin	7.5 s

An engineering model will be constructed based on this design, and the utilized resources will be measured. These resources are:

- Mandrel Machining Time
- Casting Time
- Mandrel Removal Time
- Material Costs

After the baseline fuel model is constructed, the produced fuel will be tested for:

- Number of surface flaws over **TBD**¹ mm
- Fuel Quality²

3.1.2 Structural Optimization

3.1.2.1 Computer-aided Design Engineering Model Studies

Objective

Studies will be conducted on the combustion chamber's structural design, in order to down-select to the designs that best perform as specified below. The number of initial studies will be driven by the outcomes of first studies, until a desirable set of designs have been created, or which a maximum of 3 will be selected for further analysis. The designs will be based on the lab-scale dimensions, for ease of comparison. Objective specifications are summarized in **Table 4** below:

Table 4: Computer Design Specifications

Specification	Value
Inner Diameter	3.75"
Length	17.8"
Weight	< 20% of Baseline
Design Pressure	>-5% from Baseline
Design Temperature	>-5% from Baseline
Manufacturing Time	>-5% from Baseline

The latter 3 specifications are noted in the minimal form for continued evaluation. They are by no means the desired results, as the minimum time and maximum pressure/temperature results are desired.

¹ Surface flaw length will be established after research of fuel de-bonding incident last year, and examination of baseline fuel model.

² The fuel quality verification methods are still being researched

Discussion

The designs used in the trade studies will be input into an FEM analysis software suite, such as ANSYS™ or Solidworks™. After the designs are input into the program, the performance tests, weight, and manufacturing time will be calculated, and the results recorded. Manufacturing time will be estimated using CAM software and its included manufacturing time estimation method. Cost will be estimated based on market price material and components required. From this data, the 3 designs that produce the best combination of performance results and manufacturing time will be selected. The selection criteria are based on the minimization of weight, without losing critical design specifications or time. Any design which does not show a weight decrease of at least 20% and a maximum decrease in pressure/temperature qualifications of 5% will be eliminated. A matrix similar to the one shown in **Table 5** could be utilized to compare the remaining designs, from which the top three will be selected.

Table 5: Trade Study Evaluation Matrix

Performance Specification	Measured Values	Weighted Values
Weight		(Measured / Target)
Cost		(Measured / Target)
Time		(Measured / Target)
Total Score		$(-weight*C1+cost*C2+Time*C3)^3$

3.1.2.2 Design Practical Analyses

Objective

The objective of building the lab-scale models is to test and verify the three designs selected from the computer-aided design. In order to compare the results of these test chambers to those of the baseline, **Table 4** will again dictate the requirements.

Discussion

Scale models have been successfully used in previous years for verifying models and for use in trade studies. This year, the primary focus will be on creating 2 prototypes of each of the selected 3 designs, resulting in 6 total prototypes. Some criteria upon which each chamber could be evaluated are shown in the example matrix, **Table 6**:

Table 6: Manufacturing Evaluation Matrix

	Performance Specification	Measured Performance	% Improvement from Baseline
Maximize	Design Pressure		

³ Where: $c1 + c2 + c3 = 1$ values are chosen based on priorities of project. These values are $c1=0.15$ $c2=0.35$ and $c3=0.50$ or the appropriate **TBD** weightings.

(+) % desired	Design Temperature		$\frac{Design - Baseline}{Baseline} \times 100$
Minimize (-) % desired	Weight		$\frac{Design - Baseline}{Baseline} \times 100$
	Manufacturing Time		
	Material Costs		
	Assembly Time		
		Total % Improvement	

3.1.3 Fuel Mix/Cast Process Optimization

3.1.3.1 Mandrel Design Optimization

Objective

The objective of optimizing the mandrel design is to achieve the lowest possible amount of time and materials wasted. The mandrel design also affects the surface uniformity, as discussed in 3.1.3.2 below. The minimum improvement objective is a 20% resource decrease from the baseline method used in last year's project in:

- Material Costs
- Mandrel Removal Time
- Total Mandrel Manufacturing Time

Discussion

Last year, a mandrel required TBD hours of fabrication time, but was destroyed in the removal process. This year, a new mandrel design will be produced that allows easy construction and removal, and minimizes the wasted resources mentioned above. In the event that the 20% improvement objective cannot be achieved, the best % improvement will be utilized.

3.1.3.2 Surface Optimization

Objective

The objective of the fuel cast optimization is to achieve a more stable method of casting the fuel. This, in conjunction with a new mandrel design, will produce more uniform fuel surfaces, with an objective of minimizing the number of surface cracks greater than TBD⁴ mm to less than 20% of those found on the baseline.

⁴ See footnote # 1 on page number 2

Discussion

In order to achieve a more constant thrust output, the fuel must be as uniform as possible. The burn surface continuity is an important parameter for ignition, so the number of surface flaws on the internal ignition surface should be minimized. After mandrel removal, the inner surface would have to be visually inspected, and any observed cracks measured with calipers. One of this year’s team members, Nicole Ortmann, spent the past summer interning at ATK Thiokol in the mixing/casting department, learning the technical methods of achieving a homogeneous fuel mixture, and has a technical advisory contact at that company.

3.1.3.3 Fuel Casting Process Budget Minimization

Objective

The objective of the budget minimization is to decrease the time and material resources wasted, while still maximizing the fuel surface uniformity, and fuel quality⁵.

Discussion

As mentioned above, the results of the casting success are measured in the number of significant imperfections (>**TBD**⁶ mm) shown on the fuel surface after mandrel removal. The resource usage is considered in time and material cost. A matrix that could be used for fuel process evaluation is shown as **Table 7**:

Table 7: Casting Evaluation Matrix

	Performance Specification	Measured Performance	% Improvement from Baseline
Maximize Results (+) % desired	Mandrel Manufacturing Time		$\frac{Baseline - Design}{Baseline} \times 100$
	Mandrel Removal Time		
	Mix Time		
	Large Surface Flaw Presence		
		Total % Improvement	

⁵ See footnote #2 on page 2

⁶ See footnote #1 on page 2

Any method with a total improvement of more than 20% would be considered for final integration into the rocket process. The method with the highest overall score would be the most efficient process, and considered the most desirable.

3.1.3.4 Fuel Mix/Cast Facilities Protection

Objective

The objective of the mix/cast facilities protection is to minimize the impact of these procedures on the casting facilities. The team must do no damage to the facilities, and must leave no residuals behind.

Discussion

The availability of casting facilities has been jeopardized by the previous years' lack of facilities protection. MaCH-SR1 was able to retain these facilities this year by insuring zero impact to them. This will be possible by following a strict set of setup, operation, and clean-up procedures. This process currently undergoing development, and will be approved by ITLL staff before casting begins.

3.2 System Interface Compatibility

3.2.1 Objective

The objective of system interface compatibility is to insure that the designed rocket will easily "connect" with the oxidizer/feed system and the data acquisition systems at Lockheed Martin.

3.2.2 Discussion

In order to test that the designs discussed in previous sections will perform during a real firing, the combustion chamber and fuel need to be integrated into an oxidizer/feed system. Lockheed Martin proposed to build a dedicated and adaptable test stand for the MaCH-SR1 team's use. The specifics of the required interfaces have yet TBD by Lockheed Martin. MaCH-SR1 team member, Josh Stamps is acting as the primary contact for the group with Lockheed Martin.

3.3 Safety

3.3.1 Facilities Safety

3.3.1.1 Objective

This project will be conducted with safety in mind. As such, the project shall meet the safety specifications of the University of Colorado, the Aerospace Engineering Department, Lockheed Martin and any other facilities used at all times.

3.3.1.2 Discussion

The Aerospace Engineering Department, Lockheed Martin, and the University of Colorado all have safety requirements that must be met in order to conduct a project at or with the sponsorship of these facility/institutions. In addition, because of the

elements involved in this project, accidents have a high risk of causing death or injury. An accident would jeopardize the continuation of the project in further years. Therefore, a safety engineer will be assigned to document these requirements, and make sure that are followed during the project.

3.3.2 Project Factor of Safety for pressurized and thermal systems

3.3.2.1 Objective

To prevent accidents with pressurized/thermal systems a factor of 2.5 or **TBD**⁷ will be used on all systems falling under this category. In order to verify non-destructively that components are safe, they will be proof-tested to 1.5 maximum operating pressures. In order to verify ultimate pressure and thermal design, a chamber will be for the tested to the ultimate design pressure and thermal limits.

3.3.2.2 Discussion

In the 2003-2004 project the factors of safety shown in **Table 8** were used:

Table 8: Previous FOS

Component	Factor of Safety	Justification
Test Stand	1.5	Previous experience
Combustion Chamber - Pressure	2.5	NASA documentation
Fuel Grain Thickness	2	Burn time to 45 Seconds
Combustion Chamber - Temperature	4	1 minute at 3000°C
Plumbing/Valves	2.5	NASA documentation
Oxidizer/Presurant Tanks	2.5	NASA documentation

10/7/03

2003-2004

Extra 51

The project team shall use the same safety factors for this year project, because no destructive thermal tests are possible at the engine operating temperature. Therefore verification will be limited to product design.

4.0 Required Engineering Expertise

Table 9: Required Technical Expertise

Technical Expertise	How Applied
Structural Design/Analysis	Re-design of the combustion chamber
Composite Material Science	Composite Design/Fabrication/Testing
Fuel Mixing/Casting	Fuel casting optimization process

⁷ ASME Pressure Vessel Codes are to be researched

FEM	theoretical testing of structure
Machining	shop work for all custom parts
Design for Manufacturability Engineering	to expedite & insure safety of machining processes
Welding	fabrication/integration of structures
Project Management	Project organization, budgeting, resource allocation, scheduling, etc.
CAD/CAM	CAD/CAM designs of all new components & system integration
System Engineering	System optimization/integration, design trade-off analysis
Instrumentation / Data Acquisition	To sense and record data
Integration & Test	integration & test planning/operations for the Lockheed Martin facilities' standards
Environmental & Health Operation / Safety Engineering	training/education/coherence to CU's environmental & health dept. standards, operations, etc.
Budget/Funds Procurement	budget collection, distribution, and management throughout the project life

5.0 Resources

5.1 Facilities

5.1.1 Lockheed Martin Launch Testing Facilities

These facilities have been utilized in previous years of MaCH-SR1, and the contact information has been passed along to the current team. Preliminary contact has already been made with Charles Box of LM. LM has expressed interest in building and providing a universal test stand that provides oxidizer.

5.1.2 Metal Fabrication Shop

The ASEN machine shop will be utilized for all major component constructions, under the supervision of Matt Rhode.

5.1.3 Electronics/Instrumentation Shop

Both the ASEN and the ITLL electronics shops will be utilized.

5.1.4 Welding Machinery

The use of CU's welding capabilities will be performed by Matt Rhode of CU's aerospace department.

5.1.5 Structural Testing Equipment

The thermal testing equipment is available through the ITLL module equipment checkout. Pressure testing facilities are being pursued.

5.1.6 Casting Facilities

In previous years, the ITLL "clean room" has been available after hours to the MaCH-SR1 team for fuel casting procedures. After consultation with Mike Elliot of the ITLL Staff, this location will continue to be available for this purpose. See section 3.1.3.4.

5.2 Additional Advisors

5.2.1 Previous MaCH-SR1 Team Members

Previous MaCH-SR1 team members Ervin Krauss and Kevin McWilliams have offered their services to the current team. As previous team members, their insights are highly valued.

5.2.2 Process Verification Advisors

David Clough, Associate Chair of CU's Chemical and Biological Engineering, and Mike Elliot, ITLL Staff, have offered their expertise in the fields of chemical and manufacturing process verification, respectively. Their recommendations have been used in the creation of all evaluation matrices.

5.2.3 Fuel Casting/Mixing

David Schmidt of ATK Thiokol's mixing/casting department is on the contact list of MaCH-SR1's team, and has been extremely helpful in the past with both general and technical information.

5.2.4 Rocket Systems Integration/Construction

Mick Cermack of Ball Aerospace & Technologies Corp. is a long-time rocket hobbyist, with many years of experience in large amateur rocket construction and launch capabilities with *Missile Works* of Westminster, CO. He has offered his services in technical advising on rocket integration/construction issues.

5.3 Funds

In addition to the \$4000 allocated ASEN budget, funding opportunities will be pursued as they arise. Two team members have been assigned preliminarily to funds procurement, in order to follow up on potential industry sponsorship opportunities, as well as University grant applications. One of these team members will be assigned to budget analysis & management for the duration of the project. The application information for various University technical grants has already been obtained, and

the application process will be underway in the coming week(s). Industry support in the form of monetary donations and support is also being pursued with both historical contributors to MaCH-SR1 and new companies.

The budget shall have a built in 25% contingency based on the total funds allocated. This contingency can be put towards unforeseen costs in the manufacturing phase.

5.4 Human Resources

The project shall be limited to a total of 6,000 man-hours of labor not including advisor time or outside labor. A 35% contingency must be built into all labor estimates.