DESIGN AND MANUFACTURE OF HYBRID ROCKET BODY FOR RIT M.E.T.E.O.R. ORBITAL LAUNCH SYSTEMS – FLYING ROCKET

Andrew Scarlata/ RIT Mechanical Engineering Student

Dave Hall/ RIT Mechanical Engineering Student

Geoff Cassell/ RIT Mechanical Engineering Student

Luke Cadin/ RIT Mechanical Engineering Student

Zack Mott/ RIT Mechanical Engineering Student

Brian Whitbeck/ RIT Mechanical Engineering Student

Garett Pickett/ RIT Electrical Engineering Student

ABSTRACT
The ever increasing costs of sending objects into low Earth orbit have given way to university based hybrid rocket programs. Hybrid rockets are superior to solid fuel rockets in terms of environmental cleanliness, safety, controllability, and cost. The Microsystems engineering and technology for the exploration of outer space regions (METEOR) project at Rochester Institute of Technology is currently constructing a launch capable hybrid rocket. The design offered here outlines its basic layout and structure, and preliminary structural and thermal analyses.

INTRODUCTION
The Rochester Institute of Technology METEOR project is in its construction phase for an HTPB/N₂O hybrid rocket. The 2007 Flying Rocket team is working through the multidisciplinary senior design program at Rochester Institute of Technology. The team is composed of 5th year mechanical and electrical engineering students working in the Winter 2006-2 and Spring 2006-3 quarters. It is one of several teams, working in conjunction, committed to the success of the METEOR program.

The primary objective of this project is to build a fully realized hybrid rocket, validated by appropriate structural and thermal analyses.

The goals of this project include: attaining a structure to propellant mass ratio of 1:10, finding and obtaining components necessary for an easy assembly, and arriving at an acceptable factor of safety.

ROCKET OVERVIEW
The body of the rocket is divided into three distinct shells. The top shell holds the nitrous oxide tank, the middle shell contains the nitrous delivery system, and the bottom shell encloses the rocket engine components. The shells are held together through custom machined brackets. The material varies for each shell dependent on the environment and forces the individual shell is subjected to. The total rocket body can be seen in figure 1.

Figure 1: Total Rocket Body
**Top Shell**

The top shell is a simple 6061 aluminum cylinder, and is approximately 1/16” thick with a 9” inner diameter. The top shell protects the composite tank from the environment, as well as adding to the overall mechanical stability of the rocket. The attachment between the top and middle shells is a custom machined 7075 aluminum bracket. The hole pattern on the bracket provides the requisite number of bolts to ensure no structural failures during testing.

**Nitrous Oxide Tank**

To hold the nitrous oxide, the oxidizer for our rocket, a composite overwrapped pressure vessel (COPV) was selected. This pressure vessel is rated with a working pressure of 3295 psi and a factor of safety (FOS) of 3.4. It is 8.7” in diameter, 28.9” long, and weighs 8.48 kilograms. The internal volume is 1200 cubic inches. This will hold the estimated 13.1 kg of nitrous oxide: 12.1 kg for main engine, 1 kg for guidance, which would fill 1016 cubic inches, based upon a density of 786.6 kg/m³ at 20 degrees Celsius [1]. The rest of the space is to allow some liquid N₂O to vaporize, which pressurizes the system. The vessel is aluminum lined with a carbon composite overwrap. A metal liner is important, as one composite pressure vessel manufacturer warned there was a risk of a static charge buildup if a plastic liner was used. This is a safety issue, as nitrous oxide vapor is highly detonable [2]. It has a port on one end, with 1.3125”-12 UNF-2B SAE straight threads.

The current pressure vessel is far heavier than need be, owing to the high pressure rating and FOS. An ideal pressure vessel would have our desired working pressure of 750 psi and a factor of safety of 1.5 to 2. Such a tank is not commercially produced, and will need to be custom built. A number of companies were contacted throughout the project but with little success. The major barriers were the team budget and the lack of interest on the part of companies in producing a custom design for such a small run as we needed only two pressure vessels. The current pressure vessel has a working factor of safety of 14.94 at 750 psi.

**Middle Shell**

The middle shell is similar to the top shell, as it is a 6061 aluminum tube with a thickness of 1/16” but with an inner diameter of 4.875”. The middle shell covers the nitrous oxide delivery system. Aluminum was chosen for its low density and sufficient mechanical properties.

**Nitrous Oxide Delivery System (NODS)**

The NODS, seen in figure 2, is responsible for transferring the nitrous oxide from the composite tank to the injector plate. The flow is controlled by a series of check valves, a high pressure ball valve, and a quick disconnect system.

![Figure 2: NODS](image)

After the initial transition from tank to feed system, the nitrous oxide flows through a tee junction. The composite tank will be filled through this tee junction. The next fixture is a ball valve that is operated by a custom mounted servo, as seen in figure 3. The servo is attached to a pair of threaded rods that screw into collars affixed to the ends of the ball valve. The servo is remotely operated and will open the ball valve when launch is set. The nitrous oxide then flows through another tee junction containing a check valve. This is to ensure that the pressure stays within safe limits and so the nitrous oxide does not travel back up into the nitrous oxide tank. After the check valve, some of the nitrous oxide is teed off for use in the guidance system. The remaining oxidizer is run though a connection to the injector plate.

![Figure 3: Custom Mounted Servo](image)
Injector Plate

The injector plate is made of titanium, grade 2, so it can be easily welded to the bottom shell. The weld ensures that no leakage occurs during ignition. It is a custom machined part and represents the barrier between the middle and bottom shells. It contains a pattern of 9 injector holes which flash the nitrous oxide into a vapor.

Ignition System

The current ignition system is composed of a high resistance nickel chromium (NiChrom) wire running through a mixture of pyrodex, ammonium perchlorate, and lacquer. This mixture dries into a solid part. Pyrodex is a black powder that will ignite at relatively low temperatures. Current is run through the NiChrom wire to ignite the black powder. In order to set off the igniter, it was found that the mixture repeatedly needed 1.5 amps and 3 volts. Since there are two igniters being used in parallel, the total amperage necessary is 3.0 amps. The power source that is able to provide the needed voltage, yet keep weight at a minimum, is a lithium polymer battery pack, specifically a 2 cell Lithium Polymer 700mAh 20C battery pack which has a discharge rate of 14 amps and weighs 50 grams. The actual circuit used in the ignition system can be seen in figure 4.

When the simulations were complete, the circuit was laid out using PCB Express and constructed. (figure 5).

Bottom Shell

The bottom shell of the design contains the pre and post combustion chambers, the nozzle, and the engine core, and the design can be seen in figure 7. The shell thickness is 1/16" and the inner diameter is 4.875". The walls of this shell are subjected to a 3600°F operating temperature and a 50 psi operating pressure. Through extensive testing and finite element analysis,
it was determined that the only practical metal to use would be titanium. Titanium has a high melting point, high strength retention at elevated temperatures, good corrosion resistance, and has a relatively low density, all of the characteristics needed in a rocket body. Though there are many different alloys of titanium, grade 5 titanium is the ideal alloy for this application. Grade 5 titanium is a combination of titanium (90%), aluminum (6%), and vanadium (4%), and is the most widely used alloy in the titanium industry. It is used in many aerospace applications, particularly in airframe design and engine components. The shell will be created by rolling a sheet of titanium and welding into a seamless tube. Unfortunately, on its own, the titanium will not be able to stand up to the intense heat upon ignition. As a consequence, the fuel grain diameter is oversized to take advantage of the inherent insulation properties the solid fuel provides. At the nozzle end, the heat will be the most intense, and as a result, a layer of ceramic insulation has been placed between the nozzle and the shell wall. The pre and post combustion chambers, as well as the nozzle geometry, have been optimized by the Steel Rocket team (07105).

**Insulation**

In order for the titanium shell to stay intact, a layer of insulation is needed to protect against the intense heat of the ignition. The insulation is only needed around the nozzle and the injector plate, the hottest parts of the rocket during flight. Two methods of insulation have been produced. The first method involves a combination of ceramic mat and high density ceramic board, and can be seen in figure 8. This type of ceramic insulation is made from refractory (high temperature) fiber. Both the mat and the board provide low heat conductivity and storage, resistance to thermal shock and oxidizing agents, and provide a layer of mechanical stability. The board is easily machinable, and can be quickly custom shaped. The mat is highly flexible and can be shaped around a variety of contours.

![Figure 8: Insulation, Method 1](image)

The second method of insulation is a formable sheet. The insulation combines refractory fibers with inorganic binders to form a wet felt. The insulation can be formed around a variety of shapes and dries to form a solid shape. The material resists cracking and has excellent thermal shock resistance. A plastic mold has been made, so the insulation can be shaped before the final design has been manufactured. The mold comes in four parts and can be seen in figure 9.

![Figure 9: Ceramic Insulation Mold](image)
All of the insulation methods are rated to 2300°F, with a melting point of 3200°F. Since the burn time on the rocket is a mere 50 seconds, the insulation will provide more than adequate protection from the extreme temperature given off by ignition.

**ANALYSIS**

Structural and thermal analyses were used to verify the design. ANSYS was used for the thermal analysis and COSMOSworks for the structural analysis.

**Thermal Testing**

An ANSYS model of the graphite nozzle and steel test chamber section was created in order to match thermal data recorded during testing of the hybrid engine assembly. Using properties predicted by the NASA chemical equilibrium program, CEA2, a convection coefficient for the propellant gas was derived. With this convection coefficient, the ANSYS model was able to match the temperature data recorded on February 24, 2007 to within 40 Kelvin. This verifies that the process used to estimate a convection coefficient from the CEA2 predictions and test data is accurate. The results can be seen in figure 10.

**Structural Testing**

The bottom shell is the most critical part; therefore most analysis was done on the bottom shell. The shell was tested for its resistance to internal pressures, and for the strength of its bolt hole pattern. The results of these tests can be seen in figures 12 and 13, respectively.

As can be seen in figure 12, the minimum factor of safety was approximately 1.4, and occurred around the bolt holes. The operating pressure for the bottom shell was calculated to be between 300 and 500 psi, so it
was tested at 750 psi to take into account any spikes in pressure that could occur.

![Figure 13: Bolt Hole Test](image)

As can be seen in figure 13, the minimum factor of safety is 3.9, and occurs along the shell body. To calculate the amount of force seen by each bolt, the amount of stress seen by the nozzle was divided among the 12 holes. This test was done to ensure that the bolts did not shear through the titanium shell.

ACKNOWLEDGEMENTS

The 2007 Flying Rocket team would like to thank the RIT College of Engineering for its uncompromising support of the METEOR project. Also, the team would like to acknowledge the efforts of Dr. Dorin Patru and Dr. Jeffrey Kozak. Without their devotion and expertise, the project would not have left the launch pad. Also, the Flying Rocket team would like to thank Dr. Hany Ghoneim, for providing insightful technical direction. In addition, special recognition should be given to the RIT machine shop staff, Dave Hathaway, Steve Kosciol, and Robert Kreynik, whose generous contributions of both time and proficiency were essential to the completion of this project. Lastly, the Flying Rocket team would like to thank Harris Corporation and Excelco for their munificent donations.

REFERENCES


Appendix: Combustion Chamber Assembly
Appendix: Rocket Assembly

<table>
<thead>
<tr>
<th>ITEM NO.</th>
<th>DESCRIPTION</th>
<th>QTY</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Bottom Cylinder Shell</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>Fuel System</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Tank and Shell Junction Bracket</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>Joiner</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>Heater Assembly</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Combustion Assembly</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Nut</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Bolt</td>
<td></td>
</tr>
</tbody>
</table>