PROGRESS REPORT FOR HY-V PROJECT

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Abstract

The Hy-V Sounding Rocket Project aims to launch a Terrier-Improved Orion from the NASA flight facility on Wallops Island and test a scramjet engine at an altitude of 80,000 ft at a speed over Mach 5. Much of the progress made during the past year stems from greater cooperation between Virginia Tech and the University of Virginia, greater involvement of faculty, and increased funding. The design of the four components of the scramjet flowpath, the inlet, isolator, combustion chamber, and nozzle, is reaching completion. Several concepts of what will go into the payload and how the payload will be configured have been developed. The target trajectory for the rocket is also being finalized. The progress in these areas will be assessed.

1 Introduction

The Hy-V Project is a joint venture between VSGC Universities, and government and corporate sponsors dedicated to designing, building, and testing a scramjet engine at Mach 5. The design includes two flow paths allowing for two simultaneous scramjet experiments. One flow path will be designed by Virginia Tech and will have only supersonic combustion. The other flow path will be designed by The University of Virginia and will have dual-mode, or super and subsonic combustion. Most of the work is carried out by students while professors from both universities take up an administrative role. The students are broken up into three groups, two from Tech and one from UVA. The Mechanical Engineering Design Team (ME team), headed by Dr. Walter O’Brien and Kathleen Tran, is in charge of designing the combustion chamber, ignition systems, and the nozzle for one of the flow paths. The Aerospace Engineering Design Team (AE team), headed by Dr. Shinpaugh and myself, is in charge of trajectory analysis, external CFD analysis, telemetry, and the overall payload configuration. The UVA Design Team, headed by the project’s PI, Dr. Goyne, is in charge of designing the dual-mode scramjet flow path and the recovery system. It is my job, as Chief Engineer, to collaborate with the team leaders to make sure all work is done by the scheduled deadlines.

2 Progress of the ME Team

The ME team is divided into three subsets: the combustor team, power systems team, and nozzle team. The progress of each of these subsets will be summarized in the following sections.
2.1 The Combustion Chamber

Last year, the 2006-2007 ME Team successfully built and tested a scramjet isolator and combustion chamber at the UVA Dual-Mode Hypersonic Wind Tunnel. The plasma torch used to hold the flame was very large, and the power was supplied by an arc welding power supply. The chamber itself was also heavy and large and was in need of repair due to multiple rounds of testing. However, the data they obtained formed the foundation for more sophisticated designs.

This year’s team expanded upon last year’s work by conceptualizing a flight-weight version of the hardware. The inlet to the chamber measures roughly 1” high and 1.5” wide, and the exit is about 1.413” high and 1.5” wide. The chamber diverges so that the rising stagnation temperature due to the combustion does not create a back pressure in the isolator and the inlet. An adverse back pressure would “unstart” the inlet and stop the combustion process. The exact measurements will be refined after extensive CFD analysis is completed later this year. Due to mechanical conflicts with the UVA tunnel, however, the ME team will not be able to verify the results of the CFD analysis with a physical test. This setback will not greatly affect the course of the project.

Figure 1 also shows the layered materials forming the wall of the combustor. Zirconia is a sprayed-on layer of zirconium oxide and yttrium oxide that is capable of tolerating a temperature of 3000K. It was used in the previous combustion chamber, and the material performed well in multiple tests. Inconnel 600 is a casted alloy that makes up the main body of the chamber. The copper heat sink outside of the Inconnel has the option to be cooled by a fluid. This depends on heat transfer calculations which have not been completed. Lastly, the “Super Insulation” is a silica material similar to that used on the hull of the Space Shuttle. Heat transfer analysis is required to determine the thicknesses of each of the layers. To accomplish this, the team divided the combustion chamber up into 10 sections, as seen in Figure 2. This method of analysis is called nodal analysis. They assume 10% of the fuel is burned in each section of the combustion chamber and the use STANJAN, an adiabatic chemical equilibrium solver, to determine the state of the flow at each node. STANJAN then calculates the conditions at the next node by using the end conditions of the previous section as the initial conditions for the current section. The results of this analysis are in Figure 3. The team assumes a thickness for each of the layers in order to obtain a temperature value at each node for each material. The results show that with the assumption of equilibrium combustion, the worst case scenario for extreme temperatures, the temperatures are well below the melting points of the materials. Future work in this area includes optimizing the thicknesses of the materials to minimize weight and cost and to determine the appropriate outside wall temperature required to protect the payload electronics.

2.2 The Power System

Reducing the ignition circuit from a series of luggage-sized machines to something that can fit inside of a sounding rocket payload is no easy task. The torch requires a current of at least 30A at a voltage of 350V to start. The battery pack required to create a potential this high would be far too heavy so the team decided to use a circuit similar to those used for the flash bulb in a disposable camera. This circuit charges up with a low-voltage battery and discharges by way of a 650V spark (i.e. the flash). Once the torch has started, a normal battery pile is able to maintain the spark at a much lower
The batteries being used will be either lithium-ion or lithium-polymer. These are lightweight, reliable, and have a high energy density. The total weight of the pile is not expected to exceed two pounds.

### 2.3 The Nozzle

The nozzle connects to the exit of the combustion chamber and expands the flow to or above atmospheric pressure at a velocity around the flight velocity. One constraint for the nozzle design is that it must turn the flow outward toward the side of the payload section instead of straight back. This is because the second stage and recovery modules will still be attached to the rear of the payload section and would block a straight flow path. The current design of the nozzle is shown in Figure 4 and Table 2.3.

The numbers in Table 2.3 were derived using the isentropic relations for compressible flow. The real flow, however, will not be isentropic because the viscous effects are important. Because of the sudden turn near the inlet of the nozzle, it is possible that the boundary layer will separate at that point. CFD analysis will be able to determine the effect of viscosity on the rectangular section and whether the flow separates. The CFD results will be verified during the summer when a prototype of the nozzle is tested in the Virginia Tech Supersonic Wind Tunnel.

Calculating the heat transfer in the nozzle is just as important as calculating it for the combustor, but no analysis has been completed. The nozzle team plans to use the same layering as seen in Figure 1. The exact thicknesses of each layer are yet to be determined.

### 2.4 Progress Evaluation

The ME team is on track and is meeting most of its goals. The combustion chamber is close to completion, but tests at UVA have been pushed back to the summer. Development of the starter circuit for the torch has been slow but is progressing. This should also be completed during the summer. The
nozzle team has to finish its CFD analysis of the flow, but they are on schedule and will finish their prototype by the end of the semester. Overall I am pleased with the progress of the ME Team. They have done good work and have significantly contributed to the project.

3 Progress of the AE Team

The 2006-2007 AE team completed several important tasks last spring. First, they chose an 11° straight-edged, clamshell nosecone for the rocket. The nosecone has been used on many sounding rocket missions, has been proved to work consistently, and will be provided to the Hy-V project by one of its sponsors. The payload protection subset of last year’s AE team discussed several recovery options including parachutes and flotation systems. They recommended the use of a high speed and low speed parachute to slow the payload down for a safe ocean landing. Once in the water, they recommended using GPS trackers and dye to act as a visual aid along with NASA’s standard water recovery package. The 2006-2007 AE team also started a trajectory program and some Computational Fluid Dynamics (CFD) analysis to provide preliminary drag data for the simulation. The trajectory program, coded in MATLAB, uses the actual thrust curves for the rocket and models the rocket as a point mass. It also uses a detailed atmosphere model that takes into account the latitude of the launch site and the month of the launch. All of these completed tasks were essential for the completion of the project, and gave this year’s AE team a good place to step up from.

3.1 Trajectory Analysis

This year’s AE team will greatly improve upon the trajectory simulation program. They have implemented a rigid body model of the rocket into the trajectory program while improving the subroutines simulating the launch conditions. The model takes into account the movement of the center of gravity due to mass loss from propellant exiting the rocket and the first stage separation. The team has yet to resolve the issue of the external torques on the rocket due to the fins. They know approximately how much lift the fins can generate but are unclear on how to translate the lift forces into axial rotations and pitching moments. Recently, I compared the results from the AE team’s trajectory analysis to the block data generated by the NASA GEM trajectory software and discovered a large discrepancy in the flight angle. The two trajectories match fairly well until the second stage of the rocket fires. The NASA code shows the rocket launching out of the atmosphere because the flight angle is still relatively vertical. The AE team’s flight angle was almost horizontal at the second stage ignition. Once

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the pitching and rolling moments are actually represented in the simulation, this problem should disappear. The target trajectory will have the rocket flying horizontal into a dynamic pressure of about 1500 psf. This corresponds to about Mach 5.5 at 75000 ft.

3.2 Payload Configuration

This year’s AE team is also designing the overall payload configuration for the payload section of the rocket. The payload configuration team must account for all systems outside of the scramjet flow path including avionics, communications, and data handling. To help with the design, they are using the modeling program NX-4 to accurately manage space and connect components.

The AE team has chosen several parts to be placed in the payload. These include a rate gyro, an accelerometer, PCM encoder, a radar transponder, a S-band transmitter, several pressure transducers, thermocouples, and batteries, and a military-grade GPS unit. Some of these components are pre-packaged and available through the NASA Wallops Flight Facility. Once the parts were chosen, the team proposed two concepts on how to arrange them. Figures 5 and 6 show the top and side views of Concept 1. The diameter of the payload section is 14 inches. The wedges on either side of Figure 5 represent the space taken up by the scramjet flowpath, more specifically the nozzles. The decking shown in Figure 6 is placed between the flowpaths along the payload wall. The remaining space will be taken up by the equipment required to run the experiment.

One advantage of this configuration is that the center of gravity is close to the front of the rocket. This increases its stability. Another advantage is that the design keeps the payload section compact and therefore reduces the required payload length. This saves weight and cost. A disadvantage of Concept 1 is that more insulation will be required to protect the electronics from the heat of the flowpath. Also the tightly packed configuration makes the payload hard to work with if adjustments are needed.

Concept 2, as seen in Figure 7 places the instrument decks well aft of the flowpath. This would leave more room for the experiment while protecting the electronics from heat and electrical and magnetic interference from the plasma torch. The payload will also be more accessible if the electronics are placed further apart. An obvious disadvantage is that the payload section will have to be longer and the center of gravity will be moved back. Both payload configurations will be considered by myself and the faculty. A hybrid of both designs will most likely be used.

3.3 Progress Evaluation

The AE team has done well with what they have been given. Because they are in a mostly supportive role, they must wait for other teams to develop their designs before the AE team is able to continue with its own designs. The trajectory team did not complete all of the goals I set out for them. They fixed major bugs in the program they inherited, but did not complete the simulation of the external torques in the rigid body model. Some work has been done in refining the drag model from last year using CFD analysis, but not enough to be mentioned here. The payload configuration concepts will be useful for next year’s team and their CAD models will help visualize and design the payload.

4 Progress of the UVA Team

The work of the UVA team is well documented through the VSGC. Their main
area of activity is in designing and evaluating different recovery options. The options considered to slow down the rocket include retro rockets, a hypersonic parachute, an air breaking system, and a tumbling maneuver.

After some analysis by Joseph Goings, retro rockets would only give a $\Delta V = 211$ m/s. This is less than one Mach and would not be enough to slow the payload by itself. The rockets also weight about 150 pounds, which is too heavy for our payload.

Todd Harrison has been working on a parachute system. He concluded that the use of a conical ribbon drogue chute (Figure 8) in conjunction with a Hemisflo main parachute (Figure 9) will be enough to slow the rocket to 50 fps for an ocean splash-down. The 18.3 ft diameter main parachute will sustain opening loads up to 185,000 lbs.

Jesse Quinlan is working on an air breaking recovery system. He proposes to deploy large rectangular plates (Figure 10) into the flow to create drag, and estimates the total weight of the system to be about 50 lbs. Jesse will be presenting a poster at the VSGC conference and will be available to give more information.

James Thompson has completed analysis on the effects of a tumbling payload as a means for deceleration. He performed CFD analysis on the payload with a 0° angle-of-attack and with a 90° angle of attack. At a 0° AoA, the rocket would experience a 0.6 g deceleration, and at a 90° AoA, the rocket would experience a 69 g deceleration. Taking a Monte Carlo average of these values there is no estimate for the size and weight of these devices.

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yields a deceleration of 45 g. He is unsure, as am I, on whether this may be too much acceleration for the payload to handle. The highest acceleration experienced during the boost phase of the mission is about 20-25 g. This is above the loading tolerances of many of the electronics. Also extra structural support would be required.

Other areas of activity at UVA include researching the heat transfer between the payload section and the atmosphere during flight. Knowing what thermal properties are required is helpful in choosing the materials for the payload walls and decking. Amanda Smith is also conducting trajectory analysis using the GEM software. She is able to obtain a trajectory by giving the launch angle, payload weight, and coast time between stages as inputs. Amanda has found several solution examples, and we are currently reviewing them to see if they meet our flight conditions.

The coordination of activities between UVA and Virginia Tech has improved. Both Universities have weekly teleconferences they can present their work. I am in regular contact with the representatives at UVA and the flow of information is be-
ginning to move freely. The success of this project rests on this collaboration.

5 Conclusion

The ME team is on target to complete the design of a new combustion chamber and ignition system. The nozzle will also be designed this semester, but both the combustor and the nozzle can only be numerically tested through CFD analysis before the semester is out. The AE team continued the work of last year’s team by fixing the bugs in the trajectory model they inherited. They attempted to make a more accurate trajectory model but have yet to resolve how to represent the external torques imposed on the rocket. They have also designed two payload configuration concepts and selected a list of electronics to be included. The UVA team is progressing well in the area of recovery and presented several options to consider. The Hy-V project is progressing well, but it is unclear if we can meet the May 2009 launch date due to funding and other setbacks.

References


