ORBITAL CLASS NANOSATELLITE LAUNCH VEHICLE
SPIN-STABILIZATION SYSTEM

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ABSTRACT

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Cost-effective small launch vehicles are highly desired by organizations that wish to place CUBESATS into low Earth orbits (LEO) without piggy backing off larger payloads. Spyder, a four stage small launch vehicle, is under development. In order to keep costs down, Spyder will avoid complex and expensive avionic systems by implementing a robust spin-stabilization system. This project focuses on the design and development of Spyders 3-4 stage spin-up mechanism using standard hobby solid rocket motors (SRMs). Motor sizing analysis shows that a total impulse of 170-220 Ns is required to achieve the desired spin rate of 4 Hz. Due to inherent layout concerns, simultaneous ignition of the SRMs is crucial to prevent mission failure precession and nutation angles. MATLAB simulations show that a motor firing delay no greater than 20 ms ensures that maximum nutation angles remain less than 10 degrees. Development of a scaled Space Shuttle-derived ignition circuit is underway.
Testing procedures will involve use of a passive hemispherical air bearing with mass moments of inertia about the roll axis matching those of Spyder. A myRIO unit will control the ignition circuit and collect motion data from various instruments. The results of the test are expected to match closely with those derived from the MATLAB simulation. Manufacturing options for the final design are also under consideration to ensure the product remains light and cost effective.
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Chapter 1

Nomenclature

CUBESAT = small satellite intended for space research

LEO = low earth orbit

Spyder = nano launch vehicle

SRMs = standard hobby solid rocket motors

Python = computer programming language, Enthought Canopy 2.7

Creo = Creo Parametric 3.0

LabView = Laboratory Virtual Instrument Engineering Workbench, 2016

MATLAB = Matrix Laboratory, version R2017a

Ns = Newton seconds, measure of impulse

Hz = hertz, unit of frequency, equal to the reciprocal of the period

ms = milliseconds, measurement of time

km = kilometer

MEOP = maximum expected operating pressure
Chapter 2

Introduction

Spin stabilization is a technique where a projectiles rotational motion is implemented in a manner that ensures flight stability. The small rocket designed for nano vehicle launch, Spyder, will use spin stabilization to reduce launch cost. This makes the elimination of a large, heavy, expensive avionic system commonly used in large launch vehicles to maintain flight stability and course correct as needed possible. With the equipment and system weight lower, more Cubesats, small satellites intended for space and atmospheric research, may be launched into Low Earth Orbit (LEO).

Being a four-stage rocket, Spyders spin stabilization system requires multiple spin-up and de-spin systems. Spin up at launch will be obtained by means of tail wings and the atmosphere. De-spin is required in order to accurately course correct while the rocket is in motion. Various de-spin methods exist, but the one incorporated in Spyders design is yo-yo de-spin. As the yo-yo travels away from the rocket, the rocket’s moment of inertia increases resulting in greater energy requirements to continue spinning at the initial velocity. Since no additional energy is added to the system, the rockets spin slows to a gradual stop. The vessel must undergo spin-up before the next motor fires. The 3-4 spin-up stage consists of small solid rocket motors. When
fired in precise directions determined through optimization processes, the resulting thrust induces a spin on the vehicle.

While designing the spin-up system between the third and fourth stage, analyzing the rockets resulting precession and nutation from the axis of rotation will prove critical to the overall mission. Large precession or nutation directly correlate to flight instability. Possible causes of large precession and nutation are as follows: mismatched rocket motor impulse, time differences between spin-up motor ignition, motor distance from the center of gravity, overall center of gravity position relative to the rocket, etc. Any variable or situation compromising flight stability results in mission failure and must be identified, accounted for with testing, and resolved before flight. Computer modeling provides a way to predict the rockets behavior after manipulating the parameters. Developing a test article that matches Spyders actual configuration and environment will either confirm or negate the accuracy of the computer model. Further analysis of the data gathered from accelerometers and gyroscopes will provide the information needed to move forward in the overall rocket design.
Chapter 3

Background

CUBESATs are miniaturized satellites, typically weighing less than three pounds, designed for space research. Because launch costs a minimum of 50 million dollars, sending a CUBESAT into LEO is challenging. Unlike larger satellites, CUBESATs only launch if room exists in the launch vehicle after mission equipment is secured. If flight is procured, placing a CUBESAT directly into its intended orbit is unlikely. Multiple advances in technology have been developed in order to maneuver the CUBESAT into the target orbit. However, direct launch into the intended orbit is still desirable.

Spyder, a four stage small launch vehicle, is currently being designed specifically for launching CUBESATS. The goal is to achieve launch for no more than 3 million dollars. The four stages allow excess mass to be discarded reducing the load size carried by the following stage. In order to decrease cost further, mass is not the only factor being reduced. Spyder will not require a complex avionic system. Instead, it will rely on rotational motion for stabilization. Spin-up stages will be placed along the vehicle to generate the 4 Hz rotation needed for stabilization. A typical flight trajectory begins with ignition and aerodynamically induced spin-stabilization. Before the first stage separates, the rocket must undergo de-spin. After stage separation
occurs, cold gas thrusters fire to angle the vehicle to the correct trajectory before then next engine fires. The second stage engine then fires and aerodynamics provide the needed spin for stabilization. The second stage separation process is almost identical to first. At the third stage, the rocket will undergo yoyo de-spin to stop rotation prior to stage separation. The cold gas thrusters again correct trajectory. At an altitude of 90 km, aerodynamics can no longer be utilized to spin up the rocket. Instead, solid rocket motors firing in opposing directions spin up the rocket before the final engine ignites.

The overall goal of this project is the design of the 3-4 stage spin-up system. Simulating rocket behavior with a computer simulation, developing a physical passive hemispherical air bearing test article, and determining the motor size required to achieve stable flight will aid in accomplishing this goal. Each task involves multiple components, which shall be expounded upon hereafter.
Chapter 4

Research and Design

4.1 SRM Component Design

Before a test article can be built and testing conducted, designing must come first. Standing as the main component of the spin-up stage, the design of the spin-up SRMs takes first priority. Accounting for efficiency, reliability, and safety, the design process was broken into smaller tasks. These are as followed: creating computer simulations, matching moments of inertia, developing a test article, and designing a robust ignition circuit. Subsections 1-5 contain greater detailed.

4.1.1 Selecting a Motor

Rockets operate under the conditions identified in Newtons Second Law of Motion: For every action, there is an opposite and equal reaction. In the case of rockets, the force produced from the gases exiting the nozzle equals the change in momentum divided by a calculated time step:

\[
F = \frac{m_1v_1 - m_0v_0}{t_1 - t_o} 
\] (4.1)
Figure 4.1 An example of a thrust profile found from thrustcurve.org. The x-axis represents the duration of motor burn while the y-axis identifies the thrust measured at a given section of the burn. The horizontal blue line identifies the average thrust. The vertical line indicates the burn time. Integrating this curve yields the total impulse.

Thrust changes with time due to the mass and velocity changing with time. Plotting the thrust against time is known as a thrust curve. From the graph, the rocket's maximum thrust, average thrust, and burn time can be identified. Integrating the area under the curve provides a value called the impulse (J). The mathematical derivation begins with the rocket's angular momentum (L), which equals the moment of inertia (I) about a selected axis (z-axis rotation or roll for this situation) times the angular velocity (ω). Momentum changes with mass. Since mass changes with time, so does the angular velocity. Since the system has three separate axes of rotation, the angular momentum is equal to the sum of all moments (M) of the system. Integrating over the moments as a function of time with respect to time is equal to the force applied at a given radius over time. The total force applied over time is simply the total impulse.
4.1 SRM Component Design

\[ L = I_{\text{roll}} \omega \]  \hspace{1cm} (4.2)

\[ \sum M = I_{\text{roll}} \Delta \omega \]  \hspace{1cm} (4.3)

\[ \int M(t) dt = I_{\text{roll}} \Delta \omega \]  \hspace{1cm} (4.4)

\[ F * r dt = I_{\text{roll}} \Delta \omega \]  \hspace{1cm} (4.5)

\[ J * r = I_{\text{roll}} \Delta \omega \]  \hspace{1cm} (4.6)

\[ J = \frac{I_{\text{roll}} \Delta \omega}{r} \]  \hspace{1cm} (4.7)

In order to obtain rotation of 4 Hz, a motor with enough energy must be used. Knowing the total impulse of a rocket motor allows for an appropriate selection.

Since Spyders values for roll moment of inertia and angular acceleration had previously been calculated, the impulse requirements only vary with moment arm length. An Excel spreadsheet was enlisted to generate the thrust requirements at varied moment arm length. Data from thrustcurve.org was used for comparison of impulses. After some discussion the AeroTech G339 was selected. With space-grade propellant, this motor was an appropriate candidate required to generate a 4 Hz rotation of the Spyder rocket at 90 km. However, since the D21 and I200 motors were already in possession, testing would be conducted with these motors instead. The D21 motors will provide a proof of concept system test to determine the functionality of the test
article. To match the impulse of a more powerful motor, two of the I200s six propellant grains will be encased and used as a rocket motor. This test will determine the accuracy of the computer simulation in describing real world motion.

4.1.2 Nozzle Performance in Space

Nozzle functionality and efficiency is based on Bernoullis principle: fluid flows from a region of high pressure to low pressure; thus, a low-velocity fluid has a high pressure and a high-velocity fluid has low pressure. Fuel burning in the motor increases the pressure contained within the motor causing the burning fuel to flow toward the nozzle. Standard rocket motors have converging-diverging nozzles. Due to physical properties of fluids, a converging section accelerated the fluid particles to the speed of sound and the diverging section then accelerates the particles beyond the speed of sound. The throat is the section of the nozzle with the smallest cross-sectional area, and the nozzles exit plane is the widest cross-sectional area. An expansion ratio \( \epsilon \), which can be a factor in a rockets performance efficiency, is the relationship of the exit plane area divided by the area of the throat. According to Bernoulli, as \( \epsilon \) increases the pressure of the fuel particles exiting the motor decreases accelerating the particles.

Limits of the expansion ratio do exist. Atmospheric conditions can limit the rockets performance. Optimal nozzle performance occurs when the nozzles exit pressure matches the atmospheric pressure. Hobby rocket motor manufactures traditionally use nozzles with \( \epsilon \) approximately equal to five because the exit pressure this produces matches that of the atmospheric pressure at sea level. Seeing as the test will be conducted at an elevation close to sea level, commercially available nozzles will be implemented in the test article. Figure 4.2 is a 3D-printed model as a reference.

Increasing \( \epsilon \) results in exit pressure decreasing below atmospheric pressure causing
4.1 SRM Component Design

Figure 4.2 Additive manufactured model of sea-level nozzle.

Shockwaves to form in the exiting flow; thus, decreasing flow velocity. However, when a nozzle is operating in near vacuum conditions, exit pressure approaches zero. This causes $\epsilon$ to approach infinity. The increase in nozzle performance is limited by the mass of the nozzle, which occurs when $\epsilon$ approaches 70.

With 70 as the upper limit for $\epsilon$, a spreadsheet in Microsoft Excel was created for the intent to analytically estimate the nozzle performance for Aerotech G339 motor in a near vacuum environment. Figure 4.3 shows the CAD representation of the nozzle predicted to increase the motors specific impulse 26 percent. Note, this model does not account for anomalies in fuel composition, varying motor mass, nozzle ablation, or other inefficiencies. Also, the geometric constraints of the Spyder launch vehicle were not taken into consideration. A canted and/or scarfed nozzle may be necessary to incorporate nozzles into the system. An analysis of these modifications will provide further information on the value of $\epsilon$ and increase of the final performance estimated for the system. Thus, the spreadsheet created gives an upper limit to be modified in the future.
In testing the spin-up system design, the standard aluminum hobby rocket motor case is sufficient. However, to accommodate the larger nozzle required for space flight, new spin-up motor cases must be incorporated into the design. As a pressure vessel, rocket motor cases experience two different types of stresses: hoop stress experienced in the radial direction and longitudinal stress along the vessel. Since longitudinal stress is significantly smaller than hoop stress, most casing calculations focus on accounting for hoop stress. Hoop stress is calculated by multiplying the pressure by the mean diameter (diameter minus one wall thickness) and dividing that value by twice the thickness.

\[
\sigma_H = \frac{PD_m}{2t}
\]  

(4.8)

Studying hoop stress was only a fundamental step in the case designing process.
Moving on to calculating required case thickness, a Python code was created. To calculate the required spin-up rocket motor case thickness, the program utilized the standard rocket safety equations.

\[
MEOP = 1.03 \times P_{max} \tag{4.9}
\]

\[
P_b = SafetyFactor \times MEOP \tag{4.10}
\]

\[
T_{cs} = \frac{P_br_{cs}}{F_{tu}} \tag{4.11}
\]

In rocketry, the maximum expected operating pressure (MEOP) is simply the maximum pressure (P\text{max}) a vessel is expected to experience multiplied by the industrial standard of 1.03. This is one of the many safety factors taken into consideration during calculating. To calculate the base pressure (P\text{b}) of the calculations that will follow, the MEOP is multiplied by an additional safety factor. The case thickness is then calculated by multiplying the base pressure by the case radius (r_{cs}) and then dividing that value by the ultimate tensile strength (F_{tu}) (the capacity of a material to withstand a elongating load).

Given the nature of hobby rocket motors, manufacturing options for the case are numerous. The traditional metal cases would work. Metal-coated printed cases may also work and reduce mass. To analyze the possible options, a Python script was written. The program utilizes a set of materials with their associated properties, such as density and ultimate tensile strength. After prompting the user for dimensions and material, the program runs through a unit converter to put everything into SI units. Then the code uses the listed equations to calculate case thickness of that given material. Going one step further, the code then uses the associated case material density to
Figure 4.4 An example segment of the Python script and the program’s outputting feature. Random values were implemented in generating this output and have no significance to the project. This was done to illustrate the code’s functionality.
calculate case mass. An optimization function was then incorporated. This function
determines the lightest case by calculating the mass of a given case constructed with
every material within the programs database and returns the calculated case mass,
thickness, and material. Given limitations in material data, further material testing
is required before replacement of the metal rocket motor cases can be implemented
in design.

4.1.4 A Robust Initiation System

Spyders requirements for the ignition system include reliability, robust safety features,
scalability between system testing and actual mission flight, and small mass. Several
options were considered for the spin-up solid rocket motors initiation. The hobby
rocket industry has several types of igniters; however, guaranteed performance in
space is critical to the mission.

Electric matched, the go to igniter for hobby rocket launchers, would satisfy the
weigh restriction for Spyder. Yet, the reliability of these igniters is far from ideal.
Certain conditions must be met in order to achieve ignition and those conditions do
not exist at high altitudes. Through-bulkhear initiators proved to be more space
consuming than ideal. Scaled BKNO3 pyrotechnic initiators demonstrated less safety
that the previous. All were considered, but were ultimately ruled out due to these
issues. Orbital ATKs semi-conductor bridge (SCB) initiator was discovered upon
further research. Figure 4.5 shows the size and basic design of the SCB.

The SCB’s specifications matched all requirements for our ignition device. The
device is made with titanium subhydride potassium perchlorate acting as the py-
rotechnical material. Weighing only 0.588 grams, it is lightweight and will not replace
research instrumentation. The pressure output is 729 psi in 10cc. The rocket motor
casing will be able to withstand the igniter’s pressure. Safety is built into the circuit
through a bridgewire resistance of 1.0 ohm. Also, it has a maximum no-fire current of 1 amp for 5 minutes. The igniter will not fire by accident. Plus the SBC has demonstrated reliability of 95 percent. This increases the safety of future test setup and installation.

4.2 Computer Simulation Components

Before conducting any physical tests of the spin-up system, a MATLAB simulation was developed to model the flight dynamics of the Spyder launch vehicle. The simulation uses MATLABs built-in ode45 differential equation tool to numerically solve the following system of differential equations of motion of a body rotating about its center of mass.

\[
\dot{\omega}_x = M_x - \frac{(I_{zz} - I_{yy})\omega_y\omega_z}{I_{xx}}
\]  

(4.12)

\[
\dot{\omega}_y = M_y - \frac{(I_{xx} - I_{zz})\omega_x\omega_z}{I_{yy}}
\]  

(4.13)

\[
\dot{\omega}_z = M_z - \frac{(I_{yy} - I_{xx})\omega_x\omega_y}{I_{zz}}
\]  

(4.14)
4.2 Computer Simulation Components

\[ \dot{\psi} = (\omega_y \sin \phi + \omega_z \cos \phi) \sec \theta \]  

(4.15)

\[ \dot{\theta} = \omega_y \cos \phi - \omega_z \sin \phi \]  

(4.16)

\[ \dot{\phi} = \omega_x + (\omega_y \sin \phi + \omega_z \cos \phi) \tan \theta \]  

(4.17)

Note that \( \vec{\omega} \) is the angular rotation rate of the body in the inertial frame, \( \vec{M} \) is the resultant moment, \( \vec{I} \) is the inertia tensor for the body, and \( \psi, \theta, \) and \( \phi \) are the Euler angles. These equations model a \( \psi-\theta-\phi \) rotation also known as a 3-2-1 or z-y-x rotation. \( \vec{M} \) is directly affected by several physical factors that the MATLAB simulation addresses. Important simulation variables include radial and vertical lever arms for the solid rocket motor (SRM) thrust vectors, mismatched impulses due to thrust uncertainty, and motor ignition mismatch.

Ideally, the SRMs should be placed on the plane of the center of mass of the vehicle. However, due to geometric constraints, the SRMs must be vertically offset from the center of mass plane. For Spyders layout, the most extreme vertical lever arm is approximately 25 inches. For the following simulations, this value was modeled to ensure that any flight perturbations experienced by the launch vehicle would not be as severe in less extreme layout options. Out of all factors that could hinder mission success, a mismatch between the spin-up motors igniting resulted in the greatest instability in flight. Two example simulations, Figure 4.6 and Figure 4.7 are the I200 test motors results.

In the two figures, the top three graphs display the Euler angle time profiles. The bottom left graph presents the maximum nutation angle of the launch vehicle, the angle between the longitudinal axis of the rocket and the vertical axis of the inertial
frame. The bottom middle graph shows the path of the longitudinal axis of the rocket. The bottom right plot displays an animation of the launch vehicle. Based on previous work, Spyder can tolerate a maximum nutation angle of 10 degrees and still obtain an appropriate LEO orbit. The spin-up motors fire for approximately 1.7 seconds and the final stage motor is expected to fire for approximately 30 seconds. In the figures, the maximum nutation angle is reached during the final stage motor burn and thus is an important parameter to ensure mission success. Notice in Figure 4.6 that a motor firing mismatch of 20 ms produces a maximum nutation angle under 5 degrees. However, Figure 4.7 shows that a motor firing mismatch of 80 ms produces a maximum nutation angle over 20 degrees resulting in an unstable flight path.

The chart, Figure 4.8, displays a plot of the maximum nutation angle versus the motor firing mismatch of the same Spyder layout. To produce a nutation angle of
10 degrees, the motor firing mismatch would have to be approximately 38 ms. To account for future design modifications, a target motor firing mismatch of 20 ms is appropriate for Spyders spin-up system. A firing mismatch longer than 20 ms would likely result in an unstable flight.

4.3 Matching Spyders Moment of Inertia

Ideally, the test article would match the previously calculated pitch, yaw, and roll moment of inertia values thereby providing a real world test. Matching Spyders moment of inertia proved to be a challenging task. To accomplish this, the parallel axis theorem must be utilized.
Figure 4.8 Determination of tolerable motor ignition mismatch for a maximum nutation angle of 10 degrees.
\[ I_{total} = I_{CM} + d^2 M \] (4.18)

This is because the test article components and data acquisition instruments will not be placed directly on the rotational axes.

### 4.3.1 The Functionality of the Python Program

The first attempt of matching the moments involved writing a Python code, which would calculate the three moments of inertia tensor for the test article. Programming this model seemed optimal because it would tie physics principles into the design of on object. The goal was to accurately predict the physical behavior of the rotating test article before construction of the test article began. Each instrument, having its own unique moment of inertia, placed on the test article would effect the overall moment of inertia. The parallel axis theorem became a major part of the code.

The writing process was slow. Often, the white board was implemented to check and double check moment of inertia equations. After prompting the user for the number of objects incorporated in the test article design, the program enters a for loop. The program then requests further parameters (dimensions, mass, material, location from a specified origin, etc.) from the user. Once provided, the program calculates each objects volume, mass if unknown, and moment of inertia tenser for the object about its center of mass. The program then applies the parallel axis theorem to each component before running through the loop for the next object. Summation of all pitch, yaw, and roll values takes place throughout each loop iteration.

Debugging the program occurred during the entire writing process, but peaked upon completion. For proof of program applicability and dependability, simple hand calculations were made. Multiple systems were invented to test a specific situation. For example, a multi-sphere systems centered on the same plane equally distanced...
from the rotational axis was invented to test the accuracy in adding the moments for the respective axis. These shapes were then modified ranging from cuboids to hemispheres with random dimensions, masses, and locations assigned to provided another comparison. If the solutions did not match, both hand calculations and computer code were double checked to identify which generated the error. Once the source of error was discovered, corrections were made, calculations were reworked, and comparison was again made. This process continued until both solutions matched.

4.3.2 Abandoning Python

The task of coding in Python undertook in the beginning of the design process not only seemed probable, but ideal. The code would run all the calculations as the test article took form. The dimensions would need to be inputed every time the design was modified. Optimizing the moments would assign the instruments their placement on the test article. The test article would be built matching the program requirements.
4.3 Matching Spyders Moment of Inertia

Problems arose while implementing the Python program to design the test article. The code required the exact test article design and selected instrumentation layouts in order to decompose the article into individual pieces whose moments could be added together. Without a physical test article, implementing the Python code proved rather difficult. While the code worked as it was written, it could not be used to design the test article.

Creo was being implemented along the Python program for referencing between the possible design. With its integrated calculations of the moments during the actual design process, Creo soon became the better choice for not only design, but for calculation as well. The recently created Python program was abandoned at this stage in the design process.

4.3.3 Using Creo to Match Spyders Moment of Inertia

Overcoming this challenge involved using Creo technology to design the test article. Creo has a built-in function specifically for calculating moments of inertia. Relying on this built-in feature, the test article model was digitally constructed with the mass and dimensional requirements needed to match Spyders moments. With this program, matching Spyders moments no longer proved difficult and success was achieved.

However, constructing and using the test article according to the design would not be realistic. Figure 4.10 shows the output design Creo calculated would match all three moments. The required dimensions would limit accuracy in precession and nutation angle measurements only allowing for one degree of movement in the pitch and yaw axes. The data collected from this design would be unpractical for analyzing. It would provide no information about Spyder’s flight stability. Also, the article would be too tall to use on the purchased hemispherical air bearing in the test cell designated for experimentation.
Figure 4.10 Picture of the test article designed in Creo. Standing around 2 meters tall, building and using this design is unrealistic.

Deciding to develop a testable system required sacrificing perfect moment matches, but the data gained from an operational test system was worth the sacrifice. Addition test article design was required. Matching all the moments was no longer the focus; matching the roll moment became the goal. The roll axis was chosen because the stability along that axis would be most effected by the spin-up system.

4.4 A Practical Test Article

The initial designs for the test article involved matching Spyders moments of inertia about all three axes. However, due to the physical limitations of our test equipment, it was deemed unfeasible to continue with that design. The maximum nutation angles for the test article were less than one degree about the pitch and roll axes due to the counter-ballast bellow the hemispherical air bearing impacting the pedestal because
of test article overall length. Because of this limitation, the test criteria was changed
to match Spyders moment of inertia about only one, the roll axis. With this new cri-
terion, the test articles design was significantly reduced which resulted in a maximum
perturbation angle of about seven degrees.

The test article was fully designed within Creo, and all hardware was then selected
via McMaster-Carr. The majority of all material, except for some fasteners from
Home Depot, was scavenged from the NASA scrap yard. Recycling the metal not only
saved 1500 dollars, but reduced some of the required welding labor. The machinery
lab provided everything needed for cutting and test article construction.

The test article, figure 4.11, features a custom-fabricated aluminum pedestal,
which features an 80 mm t-slot and water jet-cut aluminum gussets. These were
all welded together into a single component. The main baseplate was also composed
of aluminum and was cut using the water jet. One and a half-inch t-slots were fas-
tened to the baseplate, and various support structures, masses, and rocket motors
were then fastened to the t-slots. The test article also features a micro-adjustment
assembly which utilizes masses along an acme rod to fine-tune the center of mass
about all three axes.

4.5 Developing a Robust Ignition Circuit

An ignition circuit was developed using concepts found in Space Shuttle, SLS, and
Atlas V booster ignition circuits. These circuits were used as references because
they demonstrated reliability and inherent safety features, both characteristics being
derived largely from the redundancy found in these circuits. The igniters, wired in
parallel, are fired by the discharge of a 1,000 F capacitor charged by a 22 V battery.
The circuit has power available when the terminals of the battery are connected,
Figure 4.11 Early test article partial assembly.
4.5 Developing a Robust Ignition Circuit

but the capacitor does not begin charging until a 3.3 V ARM signal is sent to the circuit by the user. The capacitor takes less than three seconds to be fully charged. The capacitor is not discharged through the load until two 3.3 V signals are sent in the form of FIRE 1 and FIRE 2 from the user. The complete circuit is shown in Figure 4.12.

Research, construction, and testing the circuit required patience and diligence. Multimeters were employed to analyze the voltage being supplied to the circuit and the drop between resistors. In order to test the functionality of the circuit, LEDs were strategically placed. One light indicated the “Fire 1” command had been received while the other one acknowledged that the “Fire 2” command was given powering the full circuit. This triggered the igniters firing the solid hobby rocket motors, thus spinning up the rocket.

This circuit is designed to fire two SCB initiators produced by Orbital ATK, but these were not available for testing by the students. Because these require significantly less energy for firing than standard hobby rocket motor initiators, electric matches, the
circuit was modified slightly. The ARM component was bypassed and the capacitor was not used. The firing charge was therefore supplied by the battery. This still supplied two degrees of redundancy was deemed acceptable by the test students and personnel.
Chapter 5

Results and Conclusion

The first test was conducted on the ignition circuit to ensure two solid rocket motors fired simultaneously. Two standard hobby rockets were chosen and electric matches were used for initiation of the solid propellant. No quantitative data was collected for this proof of concept test. The two solid rocket motors were successfully ignited simultaneously Figure 5.1.

Even though the test article did not experience testing at that time, several conclusions can be drawn from research. Standard hobby rocket motors present feasibility for implementation into the spin-up design. Producing enough impulse, they are capable of generating the required 4 Hz stabilizing angular velocity. When considering cost, hobby rocket motors are not expensive. As for accessibility, ordering hobby rocket motors does not demand a great amount of time or stress. According to the computer simulation, a motor ignition time mismatch of 20 ms or less is sufficient to negate the likelihood of producing mission critical nutation angles. Given the ignition circuit designed, igniting two solid hobby rocket motors with this time constraint can be achieved.

Testing of the test article was conducted in December of 2017. The data was not
Figure 5.1 Two hobby solid rocket motors (ignited with the ignition circuit) display near simultaneous firing.
forwarded on the the team members; however, a video showing a spinning test article was provided. UP Aerospace is still working toward Spyder’s test flight in White Sands New Mexico.
Chapter 6

Future Work

Considering ways to reduce stage mass, the spin-up rocket motor case material may be a topic of research. In order to make an educated decision regarding what material to use in constructing the casing, additional material testing should be completed. Analyzing the advantages and disadvantages in instating printed material rather than traditional metal should involve processing data gather on ultimate tensile strength, erosion rates, other thermal properties and cost of material and processing. Also, the implementation of metal coated plastics may also be an option for consideration.

Prior work has predicted that a larger nozzle expansion ratio will increase performance in a near-vacuum environment, further design needs to be conducted. With the given rocket system, determining the geometric constraints stands as a key factor. Also, determining when the mass limitations outweigh the performance improvement of the motors for the designs.

In an attempt to accommodate for the geometric constraints facing Spyder, the idea of canting and scarfing the nozzle was born. The idea is that the motor improvements associated with a larger expansion ratio can be achieved in a small space if the nozzle is inserted higher into the propellant grain (scarfed) or curved rather
than being strait (canted). Testing hobby rocket motors with canted, scarfed, or both nozzles must be completed before the idea can be ruled out.

Utilizing available space and determining placement of the components must be completed before Spyder flies. How to separate the stage without influencing the final stage and payload must be determined. If the stage does not hold together properly, the forces experienced during flight may damage the system rendering it unable to stabilize the rocket effectively. If stage separation has a great influence of spyder, it may cause the rockets trajectory to change or create instability in flight. Developing a way to simulate and test stage separation before flight proves beneficial.

Test firing a statistical number of motors allows the confirmation of thruster performance. Gathering the data would allow thrust and impulse variations in motors to be identified. The model can then account for these variations more accurately simulating rocket flight.
Chapter 7

Bibliography


