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Developing Hybrid Near-Space Technologies For Affordable Access To Suborbital Space

Brian David Badders

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DEVELOPING HYBRID NEAR-SPACE TECHNOLOGIES FOR AFFORDABLE ACCESS TO SUBORBITAL SPACE

by

Brian David Badders
Bachelor of Science, Case Western Reserve University, 2012
Master of Science, University of North Dakota, 2013

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Submitted to the Graduate Faculty

of the

University of North Dakota

in partial fulfillment of the requirements

for the degree of

Master of Science

Grand Forks, North Dakota
December
2013

This thesis, submitted by Brian David Badders in partial fulfillment of the requirements for the Degree of Master of Science from the University of North Dakota, has been read by the Faculty Advisory Committee under whom the work has been done and is hereby approved.

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Dean, School of Graduate Studies

December 10, 2013

Date

PERMISSION

Title	Developing Hybrid Near-Space Technologies for Affordable Access to Suborbital Space
Department	Space Studies
Degree	Master of Science

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ABSTRACT

High power rockets and high altitude balloons are two near-space technologies that could be combined in order to provide access to the mesosphere and, eventually, suborbital space. This "rockoon" technology has been used by several large budget space programs before being abandoned in favor of even more expensive, albeit more accurate, ground launch systems. With the increased development of nano-satellites and atmospheric sensors, combined with rising interest in global atmospheric data, there is an increase in desire for affordable access to extreme altitudes that does not necessarily require the precision of ground launches.

Development of hybrid near-space technologies for access to over 200k ft. on a small budget brings many challenges within engineering, systems integration, cost analysis, market analysis, and business planning. This research includes the design and simulation testing of all the systems needed for a safe and reusable launch system, the cost analysis for initial production, the development of a business plan, and the development of a marketing plan. This project has both engineering and scientific significance in that it can prove the space readiness of new technologies, raise their technology readiness levels (TRLs), expedite the development process, and also provide new data to the scientific community. It also has the ability to stimulate university involvement in the aerospace industry and help to inspire the next generation of workers in the space sector.

Previous development of high altitude balloon/high power rocket hybrid systems have been undertaken by government funded military programs or large aerospace corporations with varying degrees of success. However, there has yet to be a successful flight with this type of system which provides access to the upper mesosphere in a university setting. This project will aim to design and analyze a viable system while testing the engineering process under challenging budgetary constraints.

The technical, engineering, and systems integration challenges that will be investigated are rocket design, launch platform design, communications, ignition systems, recovery systems, and stabilization methods. This will be done using rocket performance simulation software, computer-aided design software, and computational fluid dynamic analysis software.

The business planning is also an important part of this research. Through detailed market analysis, the needs for the proposed product/services being developed will be assessed. Through the combination of detailed cost analysis and the market needs, the economic viability of this launch system will be determined.

CHAPTER I

INTRODUCTION

High-Altitude Ballooning

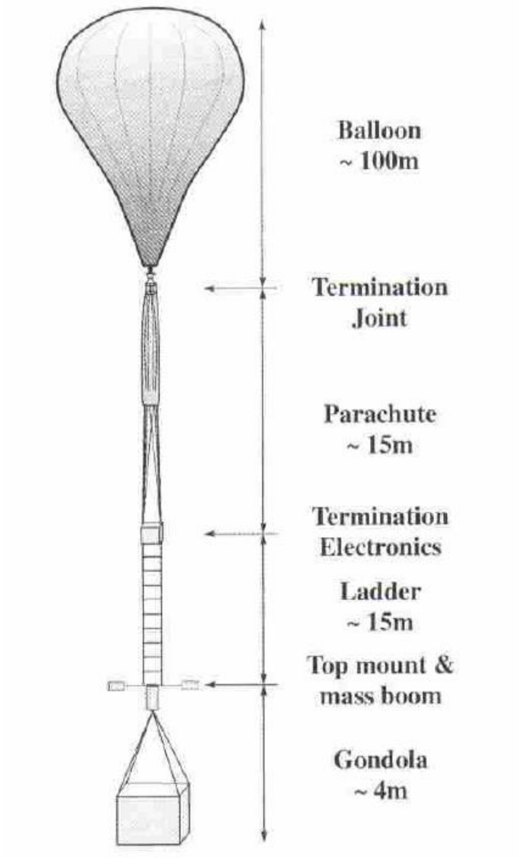
History and Utilization

Balloon-Based Technology

High-altitude balloons have had a wide variety of uses for many years. These uses range from simple winds aloft soundings to complex observations of the Earth and space. Utilizing stratospheric balloons as platforms for scientific research has introduced an increasingly wider community to space research (Feiter, 1972, p. 198). In recent years, balloon-borne "instruments have proved to be an important tool for probing the composition and state of the atmosphere" (Quine, 2002, p. 618).

A typical high-altitude ballooning payload train consists of a gondola rotational mount, suspension cables, a parachute that is rigged to deploy when the payload is separated from the balloon, and the balloon. See figure below for graphic representation of a typical payload train (Quine, 2002, p.620). Depending on the payload train design, there may be one or more termination joints equipped with a timed or remotely controlled cut-down mechanism. More complex designs may include drive motors and mass booms for added inertial stability.

Figure 1: Typical Flight Train



Balloons made of either latex or lightweight plastic are filled with a lifting gas, such as helium or hydrogen. The heavier the payload is, the more lift-gas is needed. A sufficiently massive payload may also require larger balloons and heavier suspension cables and mechanisms.

The systems present in the flight train must be capable of operating in a wide range of environmental conditions. These conditions can include variations in wind speeds, radiation, humidity, and temperature.

Balloon systems must operate under a range of harsh environments.

> During ascent, systems cool rapidly as they pass through the tropopause and, if unprotected, may cool as low as -40 degrees Celsius. At float altitude during the day the Sun provides a large heat input, and systems can reach 55 degrees Celsius. At night, systems cool again as they radiate energy to space. Since at float altitude the ambient pressure is less than 1000 Pa, there is little convective cooling, and thermal designs must use conductive or radiative solutions (Quine, 2002, p.620).

Regulatory Environment

Unmanned balloon flights in the United States are governed by the Federal Aviation Administration under Federal Aviation Regulations (FAR) Part 101. See Appendix A for FAR Part 101. These regulations serve to protect the safety of people and property both on the ground and in the air. The regulations cover many important topics for planning a high altitude balloon launch.

In order to comply with regulations, the balloon shall not fly less than 1000 feet over a congested area of a city, town, or settlement. The flight shall occur “in such a manner that impact of the balloon, or part thereof including its payload, with the surface creates a hazard to persons or property not associated with the operation” (FAR Part 101, 2013). In order to avoid potentially dangerous scenarios, the balloon must be equipped with at least two payload cut-down mechanisms that operate independently of each other in order to terminate the balloon flight. The balloon should also be equipped with a "radar reflective device(s) or material that will present an echo to surface radar operating in the 200 MHz to 2700 MHz frequency range" (FAR Part 101, 2013).

Prior to launch, FAR Part 101 §101.37 indicates the information that must be provided to the nearest FAA ATC facility.

> (1) The balloon identification. (2) The estimated date and time of launching, amended as necessary to remain within plus or minus 30 minutes. (3) The location of the launching site. (4) The cruising altitude. (5) The forecast trajectory and estimated time to cruising altitude or 60,000 feet standard pressure altitude, whichever is lower. (6) The length and diameter of the balloon, length of the suspension device, weight of the payload, and length of the trailing antenna. (7) The duration of flight. (8) The forecast time and location of impact with the surface of the earth (FAR Part 101, 2013).

During ascent and flight, the balloon operator must "(1) Unless ATC requires otherwise, monitor the course of the balloon and record its position at least every two hours; and (2) Forward any balloon position reports requested by ATC" (FAR Part 101, 2013). "One hour before beginning descent, each person operating an unmanned free balloon shall forward to the nearest FAA ATC facility the following information regarding the balloon: (1) The current geographical position. (2) The altitude. (3) The forecast time of penetration of 60,000 feet standard pressure altitude (if applicable). (4) The forecast trajectory for the balance of the flight. (5) The forecast time and location of impact with the surface of the earth" (FAR Part 101, 2013).

Scientific Value

High-altitude balloons have long been the lowest cost option for atmospheric and space research, outside of ground-based equipment. However, the technology is still evolving. Recent developments have brought about "new balloon-borne pointing systems, capable of pointing a suite of instruments with respect to an inertial reference frame from a pendulating platform… with typical pointing accuracies quoted between +/- 0.017 degrees and +/_ 0.3 degrees" (Quine et al., 2002, p. 618). While the range of these values depend on environmental effects, new systems have opened up new research areas for ballooning in the form of high resolution Earth, solar, and space observations.

Long duration missions have also lead to important proof of concept missions for planetary analogs (White, 2005, p. 625). "This successful effort constituted a proof-of-concept demonstration that a large Venus balloon was feasible for carrying a 45 kg payload for multiple days at this altitude. As such, it represented the next step beyond the two Soviet VEGA balloons (Kremnev et al., 1986, p. 1408) that flew at Venus in 1985, but with a much smaller 7 kg payload each" (Hall et al., 2008, p. 93). Making advances in ballooning technology in general leads to scientific discoveries and engineering design options. Scientific ballooning efforts on Earth even support proposals for scientific investigation of the Venusian atmosphere using a “gas chromatograph, mass spectrometer and other instruments on a multi-day flight around the planet” (Hall et al., 2008, p. 93).

In addition to scientific research, high-altitude balloon flights also provide access to a unique environment for advancing the development of space technologies. The near-space environment is the closest natural analog environment that can be used for testing new space components in order to provide a certain level of confidence in a technology before spaceflight.

Existing Markets

Atmospheric and space science departments tend to utilize university programs and student employees in order to conduct balloon launches. The relatively simple technologies combined with low associated operating costs make these ballooning programs attractive. Balloon flights are used for both complex science experiments and middle school level education and public outreach events. High-altitude ballooning has proven to be an engaging, hands-on, learning tool for K-12 students, as well as a platform for serious science and engineering payloads at the university level.

While many university programs or research facilities conduct their own launches, many researchers opt to have their flight operations “provided by a launch contractor, who typically provides launch facilities, ground-to-balloon communications, gondola power, and flight services, including termination and recovery” (Quine, 2002, p.619). Contracting launch services allows for scientists and engineers to focus all their efforts on payload development. Many companies, such as Sky-Probe, High Altitude Science, StratoStar, and JP Aerospace profit on the need for reliable launch, tracking, and recovery services combined with the opportunity to capitalize on the growing science, technology, engineering, and mathematics (STEM) education market.

High-Power Rocketry

History and Utilization

High-power rocketry is similar to model rocketry except that high-power rockets utilize a class of motors with higher impulse ranges that are purchased from certified manufacturers. This is where high-power rocketry differs from experimental or amateur rocketry where rocket motors are custom built using a wide variety of solid, liquid, and hybrid propellant fuel mixtures and materials.

> High-power rockets are about as close as a civilian can get to the stuff the government uses to launch Sidewinder missiles…high-power rockets use a much more powerful mix of ammonium perchlorate to supply oxygen, aluminum and hydroxyl-terminated polybutadiene as the fuel (Fisher, 2000, p. 395).

In the late 1980s, “high-power rockets were relatively primitive, the selection of rocket motors was limited, and onboard electronics or virtually non-existent” (Canepa, 2005, p. 2). Modern high-power rockets range from simple and affordable kits to complex custom builds that are “electronics equipped works of art loaded with multiple motors developing thousands of pounds of thrust” (Canepa, 2005, p. 2).

In order to ensure safe and reliable operations for high-power rockets, several organizations have formed. The oldest and largest organization for high-power rocketry in the U.S. is the National Association of Rocketry (NAR). “This non-profit organization represents the hobby to public safety officials and federal agencies, and plays a key role in maintaining the safety of the hobby through rocket engine certification testing and safety code development” (Sport Rocketry, 2013). The NAR is a “recognized national authority for safety certification of consumer rocket motors and user certification of high-power rocket fliers in the U.S.” (Organizational Statement, 2013). Another national organization, Tripoli Rocketry Association, serves to “perpetuate the safety, advancement, and future of non-professional rocketry, above that described by the National Association of Rocketry” (Tripoli, 2013). These organizations function as customer liaisons with

> …manufacturers, national media, local public safety officials, and government regulatory agencies such as the Department of Transportation, Federal Aviation Administration, Bureau of Alcohol Tobacco Firearms and Explosives, and Consumer Product Safety Commission (Organizational Statement, 2013).

Regulatory Environment

High-power rocket flights in the United States are governed by the Federal Aviation Administration under Federal Aviation Regulations (FAR) Part 101 as well as the National Fire Protection Association NFPA 1127. See Appendix A for FAR Part 101 and NFPA 1127. These regulations serve to eliminate hazards to persons, property, and other aircraft. The regulations cover many important topics that are essential for planning a high-power rocket launch.

The general operating limitations state that a rocket must be unmanned, launched on a suborbital trajectory, and not cross into the territory of a foreign country without prior authorization from both countries. For high-power rockets, the launch must occur at least 5 nautical miles from any airport boundary without prior authorization from the FAA and outside of controlled airspace without prior authorization from the FAA (FAR Part 101, 2013).

Prior to launch, FAR Part 101 indicates the information that must be provided to the nearest FAA ATC facility.

> (a) The name and address of the operator; except when there are multiple participants at a single event, the name and address of the person so designated as the event launch coordinator, whose duties include coordination of the required launch data estimates and coordinating the launch event; (b) Date and time the activity will begin; (c) Radius of the affected area on the ground in nautical

> miles; (d) Location of the center of the affected area in latitude and longitude coordinates; (e) Highest affected altitude; (f) Duration of the activity; (g) Any other pertinent information requested by the ATC facility (FAR Part 101, 2013).

Since high-power rocketry involves explosives, the National Fire Protection Association, Department of Transportation, Bureau of Alcohol Tobacco Firearms and Explosives, and Consumer Product Safety Commission look to address additional safety concerns. These organizations look to ensure the safe transportation and storage of high power rocket motors and look to set guidelines for fire safety at the launch site.

Scientific Value

High-power rocketry can provide unique insight into several scientific and engineering problems. Payloads onboard a high-power rocket can experience gravitational loading, supersonic velocities, and gather atmospheric data. The use of rocketry has been endorsed by NASA and aerospace industry partners in an effort to support development of the Space Launch System (SLS). "Payloads developed by teams will address research needs of different subsystems on the SLS" (Student Launch – NASA, 2013).

Existing Markets

"High-power rocketry is one of the fastest growing hobbies in the United States and is rapidly spreading to many parts of the globe, including Canada, Europe, and

Australia” (Canepa, 2005, p. 2). While high-power rocketry normally attracts a few hundred participants throughout the country at local launches almost every weekend, national launches and competitions can attract thousands at a single event.

In order to support the growing interest in high-power rocketry, several companies have been formed in order to provide rocket motors and components to this market. Some of the earliest companies that are still present today were Aerotech, LOC/Precision, and Public Missiles Systems (Canepa, 2005, p. 2).

> It [High-power rocketry] has grown since then [1957] to a worldwide hobby with over 12 million flights per year and used in 25,000 schools around the U.S. Its safety record is extraordinarily good, especially compared to most other outdoor activities. It is recognized and permitted under Federal and all 50 states’ laws and regulations, and its safe and inexpensive products are available in toy and hobby stores nationwide (Sport Rocketry, 2013).

Hybrid System

History and Utilization

Previous rockoon projects, or hybrid systems composed of high altitude balloons and rockets, have been undertaken by government funded military programs or large aerospace corporations with varying degrees of success. However, there has yet to be a successful rockoon flight into the upper stratosphere in a university setting. This project will test the engineering process under very stringent budget constraints.

Many countries, such as the United States, Japan, and Romania, have been involved in rockoon development as part of their national space programs, militaries, or large commercial space efforts. The United States developed rockoon technology through their Deacon Rocket Project and Project Farside before they were abandoned in favor of more accurate rockets.

> “In 1950 James Van Allen was seeking solutions for the economic study of the upper atmosphere, sun, and cosmic rays at high altitudes. Sounding rockets launched from sea level required heavy and expensive booster stages to get the upper stage and payload through the high drag ascent through the lower atmosphere. He conceived the idea of taking a small rocket above most of the earth's atmosphere by balloon, before igniting the single stage that would take it to space” (Deacon Rockoon, 2013).

The Deacon Rocket was launched from 9km to 27km altitude to an apogee around 50km to 100km at a cost that was one tenth that of a sounding rocket that could reach the same altitude (Deacon Rockoon, 2013). Project Farside was an even larger demonstration which attempted to “reach extreme altitudes with the rockoon concept. Using a four-stage solid-propellant rocket hung below a 106,188m^3 (3,750,000-ft^3) balloon, altitudes approaching 6,437 km (4,000 mi) were reached during the fall of 1957” (Farside, 2013). The technology also has the potential for expansion. “A secondary goal of Farside was to test concepts for a larger five-stage follow-on vehicle, which was to reach the vicinity of the moon. However, this project never materialized" (Ordway, 1960).

Other countries also turned to rockoon technology in the infancy of their space programs. In 1956, with Japan searching for a way to reach higher and higher altitudes, the Japanese Rocket Society developed rockoon technology by the orders of the Science Council of Japan (Harvey, 2010, p. 8). Even today, companies are turning back to early rockoon technology for affordable access to space. "The non-profit Aeronautics and Cosmonautics Romanian Association (ARCA) is one of 22 registered teams competing for the Google Lunar X Prize and is using rockoon technology for the initial phases of the mission" (Courtland, 2010).

Regulatory environment

While there are currently no regulations specifically for launching a high-power rocket from an unmanned balloon at altitude, there are several important guidelines that must be followed in order to adhere to the regulations of each technology separately. The entire flight must be precisely planned beforehand and all necessary information should be presented to the nearest FAA ATC facility. This information includes estimated ground location of the launch site, duration of flight, and forecast time and location of the landing site.

It is reasonable to assume that the following information for the rocket must be provided to the FAA at least 45 days before the proposed operation.

> (2) Type of propulsion (liquid or solid), fuel(s) and oxidizer(s), (3) Description of the launcher(s) planned to be used, including any airborne platform(s), (4) Description of recovery system, (5) Highest altitude, above ground level, expected to be reached, (6) Launch site latitude, longitude, and elevation, and (7) Any additional safety procedures that will be followed (FAR Part 101, 2013).

Because of the nature of the launch platform, and not necessarily because of the complexity of the rocket, the rocket may be considered to be a Class 3 – Advanced High-power rocket. This "requires a certificate of waiver or authorization the person planning the operation must provide the information below for each type of rocket to the FAA at least 45 days before the proposed operation" (FAR Part 101, 2013). While waivers have been awarded for rockoon launches to entities such as JP Aerospace, each new technology demonstration must prove a certain level of safety and reliability. While there are no specific precedents to follow, additional information that would be expected comes from FAR Part 101 §101.29.

> (1) The information requirements of paragraph (a) of this section, (2) Maximum possible range, (3) The dynamic stability characteristics for the entire flight profile, (4) A description of all major rocket systems, including structural, pneumatic, propellant, propulsion, ignition, electrical, avionics, recovery, wind-weighting, flight

> control, and tracking, (5) A description of other support equipment necessary for a safe operation, (6) The planned flight profile and sequence of events, (7) All nominal impact areas, including those for any spent motors and other discarded hardware, within three standard deviations of the mean impact point, (8) Launch commit criteria, (9) Countdown procedures, and (10) Mishap procedures (FAR Part 101, 2013).

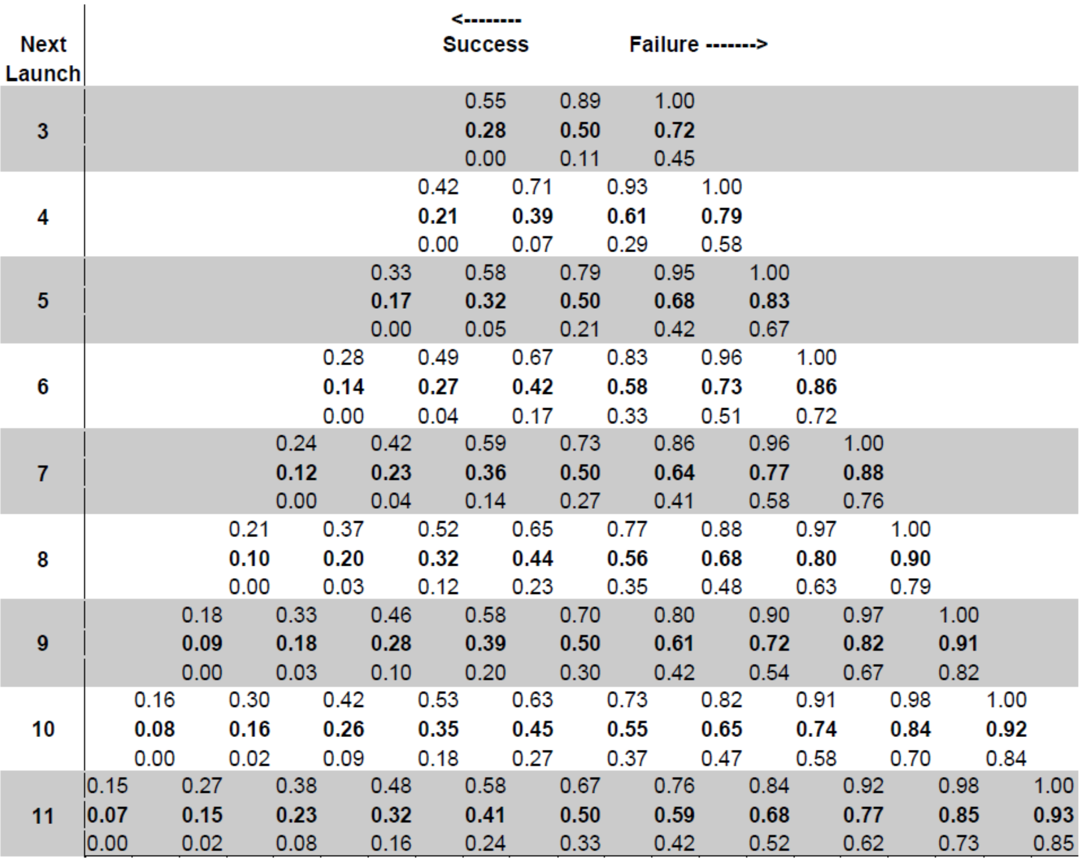
The FAA's Guide to Probability of Failure Analysis for New Expendable Launch Vehicles outlines expectations necessary to prove the safe operation of new launch vehicles. While it states that definitions of significant flight events may be made "on a case-by-case basis…such as when a balloon launching craft is airborne" (Commercial Space Transportation, 2005, p. 3), there are certain guidelines in place for gauging the safety of flight operations. The following list from pages 3-4 of the FAA's Guide to Probability of Failure Analysis for New Expendable Launch Vehicles outlines necessary information to consider for new launch vehicles.

- Account for launch vehicle failure probability in a consistent manner
- Incorporate accurate data, scientific principles, and valid methodologies
- Account for the outcomes of all previous flights

- Account for changes to the vehicle configuration and other factors
- Design characteristics of the vehicle.
- Development and integration processes of the vehicle, including especially the extent of integrated system testing.
- Related work experience of the launch and development team members
- Outcomes of all previous flights of similar vehicles developed and launched by the launch operator.
- Country where the vehicle was developed and launched.

Through the Common Standards Working Group (CSWG), a guide has been developed for conducting valid probability of failure analyses for new expendable launch vehicles. Launch vehicle developers are expected to have “produced at least one launch vehicle with a demonstrated probability of failure less than or equal to 33 percent” (Commercial Space Transportation, 2005, p. 5). The following figure shows the failure probability reference vales and confidence limits for a launch vehicle that has completed at least two flights. This indicates that at least two test launches will be necessary during the test and evaluation stages of development.

Figure 2: Failure Probability Reference Values



Next Launch	<-------- Success										Failure ------->
3	0.55	0.89	1.00								
	0.28	**0.50**	**0.72**								
	0.00	0.11	0.45								
4	0.42	0.71	0.93	1.00							
	0.21	**0.39**	**0.61**	**0.79**							
	0.00	0.07	0.29	0.58							
5	0.33	0.58	0.79	0.95	1.00						
	0.17	**0.32**	**0.50**	**0.68**	**0.83**						
	0.00	0.05	0.21	0.42	0.67						
6	0.28	0.49	0.67	0.83	0.96	1.00					
	0.14	**0.27**	**0.42**	**0.58**	**0.73**	**0.86**					
	0.00	0.04	0.17	0.33	0.51	0.72					
7	0.24	0.42	0.59	0.73	0.86	0.96	1.00				
	0.12	**0.23**	**0.36**	**0.50**	**0.64**	**0.77**	**0.88**				
	0.00	0.04	0.14	0.27	0.41	0.58	0.76				
8	0.21	0.37	0.52	0.65	0.77	0.88	0.97	1.00			
	0.10	**0.20**	**0.32**	**0.44**	**0.56**	**0.68**	**0.80**	**0.90**			
	0.00	0.03	0.12	0.23	0.35	0.48	0.63	0.79			
9	0.18	0.33	0.46	0.58	0.70	0.80	0.90	0.97	1.00		
	0.09	**0.18**	**0.28**	**0.39**	**0.50**	**0.61**	**0.72**	**0.82**	**0.91**		
	0.00	0.03	0.10	0.20	0.30	0.42	0.54	0.67	0.82		
10	0.16	0.30	0.42	0.53	0.63	0.73	0.82	0.91	0.98	1.00	
	0.08	**0.16**	**0.26**	**0.35**	**0.45**	**0.55**	**0.65**	**0.74**	**0.84**	**0.92**	
	0.00	0.02	0.09	0.18	0.27	0.37	0.47	0.58	0.70	0.84	
11	0.15	0.27	0.38	0.48	0.58	0.67	0.76	0.84	0.92	0.98	1.00
	0.07	**0.15**	**0.23**	**0.32**	**0.41**	**0.50**	**0.59**	**0.68**	**0.77**	**0.85**	**0.93**
	0.00	0.02	0.08	0.16	0.24	0.33	0.42	0.52	0.62	0.73	0.85

The process for using this figure is described below.

> Reference values are shown in bold. The reference values are the midpoints between 60-percent, two-sided confidence limits of the binomial distribution. For the special cases of zero failures or all failures, the reference values are equal to the midpoints between the 80-percent, one-sided confidence limit of the binomial distribution and zero or one, respectively. Values listed on the far left of [Figure 2] apply when no launch failures were experienced. Values

> on the far right apply when only launch failures are experienced. Values in between apply to flight histories that include both failures and successes. Upper and lower confidence bounds in table A are shown directly above and below each reference value. These confidence bounds are based on 60-percent, two-sided confidence limits of the binomial distribution. For the special cases of zero failures or all failures, the upper and lower confidence bounds are equal to the 80-percent, one-sided confidence limit and zero or one, respectively. The midpoint between the 60-percent, two-sided confidence limits and, for zero failures, the midpoint between the 80-percent, one-sided confidence limit provide answers that are reasonable and consistent with current practice (Commercial Space Transportation, 2005, p. 7).

Scientific Value

Near space is an area that lies between 20km and 100km above the surface of the Earth. High altitude balloons (HAB) and sounding rockets are able to access these altitudes, but each has limitations. While high altitude balloons can be simple and inexpensive, they are limited to altitudes ranging from 18km to 38km. Sounding rockets can reach altitudes ranging from 50km to 1,500km, but can be very expensive and complex. An inexpensive and simpler rocket is a high-power rocket, which utilizes a Reloadable Motor System (RMS), but these high-power rockets are usually not capable of reaching near-space altitudes. However, when launched from a high-altitude balloon, high-power rockets can reach altitudes that neither technology could reach on its own all for a fraction of the cost of a sounding rocket.

There are several reasons to pursue rockoon technology development. Although national space programs have abandoned this technology in favor of larger sounding rockets, the affordability of rockoon technology is very attractive to smaller businesses or research universities. There are also scientific benefits as well. Delicate sensors that cannot withstand the stresses experienced on a powerful rocket flying though the dense lower atmosphere can ascend slowly through this region in order to perform their measurements once in the mesosphere. These experiments may include any number of ozone, UV radiation, X-ray astronomy, or aeronomy experiments at much higher altitudes than can be reach by high altitude balloons. “In the 1950s, the NRL used a balloon-rocket combination called Rockoon in experiments to investigate solar radiation and cosmic rays” (Federal Aviation Administration, 2005, p. 35). The goals of weather balloons, such as air pollution monitoring, temperature, remote sensing, or military research may also be complemented by data from higher altitudes. Measurements from higher altitudes can show how trends relate to data obtained from lower altitudes.

The mesosphere is of particular interest to scientists because it is an area that is too high to be reached by high altitude balloons and too low to be reached by orbiting spacecraft (Jarvis, 2001, p. 2218). This lack of access has led to this region being very poorly studied. Some phenomena that are not fully understood, such as polar mesospheric clouds, noctilucent clouds, electrical discharges (Neubert, 2013, p.2373), breaking of gravity waves, density shears, and meteor interactions (Friedrich, 2012, p. 1495). There is a growing realization that this region is an "important link in the vertical transfer of energy and material in the atmosphere, that mesospheric phenomena may be the most sensitive indicator of global temperature change, and that this region is becoming increasingly relevant to aerospace technology" (Jarvis, 2001, p. 2218).

New space technology can also be tested in this near-space environment aboard high-altitude balloons and rockoons. Since this is above 99% of the atmosphere, it provides access to an equivalent analog space environment in which new technologies can be tested and new data can be obtained. This may also be a cornerstone for an alternative form of space launch vehicles. There is a large amount of interest in delivering suborbital/orbital payloads to space for reduced costs compared to ground launches. Any developments in this technology would add to the body of knowledge and help make access to space more affordable.

Potential Markets

Through surveying the interests and financial ability of several educational institutions, the existence of a definitive market has been verified. This market is not likely to decrease over time because educational institutions would rely on this technology year after year. Through providing successful launch services, the year-over-year profit margins and market share are projected to increase.

The majority of initial interest has been from CubeSat developers and university level atmospheric science programs. There have been no geographical limitations imposed on this market as several entities, mostly university CubeSat programs, from countries around the world have indicated interest.

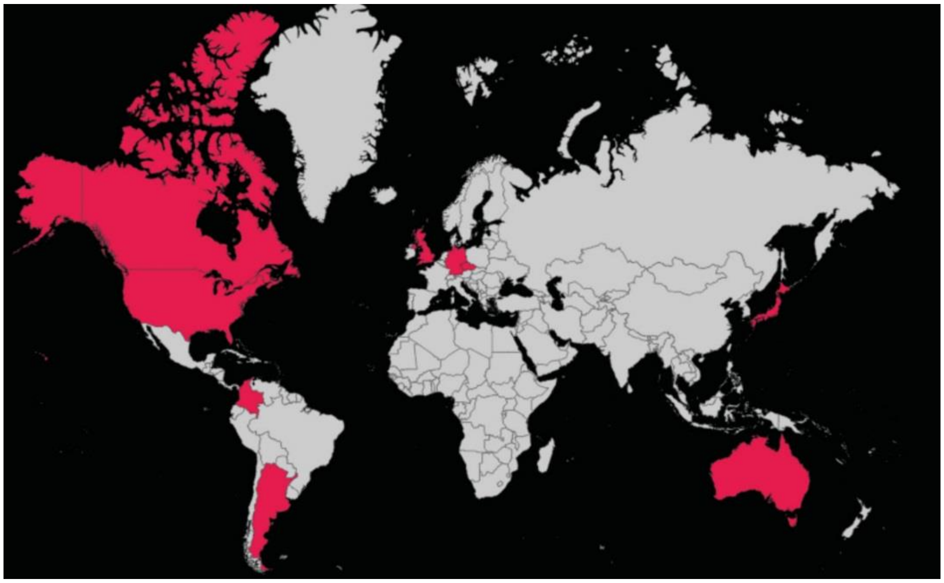


Figure 3: Represented Countries with Declared Interests.

Experimental Hypothesis

The development of hybrid near-space technologies has the ability to provide access to extreme altitudes that cannot be reach by high altitude balloons and at an attractive price compared to sounding rockets. The initial cost analysis, market analysis, and business planning will provide insight into potential future developments of hybrid near-space technologies that can support both space scientific and space engineering endeavors.

Statement of Problem

With the recent trends in scientific interest in global warming, it is important to gather data from higher altitudes in order to complement the data received at lower altitudes by standard weather balloons. While expensive sounding rockets are able to enter this region, the high price dictates that growth of scientific knowledge has been incredibly slow or has ceased to exist in some cases. For atmospheric studies of extreme altitudes, there is a distinct lack of data especially in the mesospheric regions. This is mainly due to the inability of current affordable technologies to reach these altitudes.

Growing interest in orbital space technologies among small companies and universities has led to the increased development of small satellites for commercial and academic use. While small scale spacecraft have been developed for fractions of the cost of their large scale counterparts, this price may still be out of budgetary reach for some. In order to cut costs even further, organizations with small budgets have begun substituting high quality space-rated components for inexpensive off the shelf electronics. Before risking the success of an entire mission on these inexpensive components, it is viable to test them in a natural analog space environment such as near-space.

The problem is that there is a lack of affordable technological solutions for delivering payloads to over 200,000 feet in altitude. This thesis attempts to outline a potential solution in the form of a high-power rocket launched from a high-altitude balloon platform at an affordable price of $10,000 to the customer.

CHAPTER II

METHODOLOGY

In an attempt to answer the problem posed, this study utilized various methods in order to address the two major components of the problem statement. The first component is to develop a technology that can provide access to over 200,000 feet in altitude and the second is constrain the budget so that this launch service could be made available to customers for around $10,000. The first step in this methodology was to limit and define the scope of the research in order to rapidly move to conceptual design phases for the technology. In order to do this, decision matrices were employed in order to make quick, but educated, design decisions. Once a conceptual design was created, the details of this design were used to estimate the costs associated with each of the subsystems.

The next step after initial cost analysis was to move into more detailed engineering design and analysis for the chosen design option. This involved further definitions of the mission statement and measures of success. Initial design success was then verified through running flight simulations in Rocksim 9 and tweaking the design in order to optimize performance. The basic design was finalized and a more detailed model was constructed using Autodesk Inventor Professional 2014. This model was then subjected to computational fluid dynamic analysis using Autodesk Simulation CFD 2014. This provided a visual depiction of the stresses associated with supersonic flight at a variety of altitudes. The flight values obtained from flight and computational fluid dynamics simulations allowed for deriving the initial requirements for the design of the launch platform.

Using the rocket and launch platform designs, further insight into the associated costs and marketability of the technology could be explored. The life-cycle costs for a company built around developing and selling this type of launch services were estimated. The potential markets for this service were defined and business planning exercises were used in order to identify specific variables of interest throughout the life of the business. Finally, a business plan was then developed in order to summarize and convey the important aspects of the business to potential investors or customers.

Scope of Research

Decision Matrices

The decision matrix is an appropriate method to use because it is an effective way of prioritizing a list of options by assessing the relative significance of design options. Decision matrices are useful because they narrow the options down to one choice when there are several decision factors and criteria involved (Tague, 2004, p. 219). The initial decision process could easily take many months and a large amount of resources if each design option was carried out to final conceptual design stages before a decision was made. Decision matrices allow for decisions to be made much faster with less resources while still being accurate.

Since each design option is multi-dimensional, it is important to employ a quantitative technique in order to rank those options. This is beneficial for this research as it allows for making educated decisions that narrow the scope and allow for more in-depth analysis. The following decision matrices consist of established criteria that are weighted relative to their importance and then scored with a -1, 0, or 1 based on their comparative performance with higher scores being associated with better performance for the specified criteria. The overall scores were then compared to determine rank.

The weighting of each criteria is as follows:

1=Lower Importance, 2=Important, 3=Very Important.

Research and Development Time -1: Research and development time is of lower importance because the initial design work of the system can be utilized and built upon throughout the complete product life cycle, which is significantly longer.

Research and Development Cost -1: Research and development costs are of lower importance since it is a nonrecurring cost.

Production and Construction Time -2: The ease of which the final product can be constructed is important as this also allows for increased product/service availability as well as quicker repairs.

Production and Construction Cost -2: It is important to limit the amount of costly production methods and materials. The ease with which the final product can be constructed is important as this limits costs associated with wages.

Materials Needed -2: The amount and type of materials needed will determine, in part, how easy the structure will be to assemble, and contribute to its overall weight and strength.

Materials Cost -2: This is important because varying costs of different materials and quantities of raw materials or commercial off-the-shelf components needs to be carefully considered.

Tools Needed -1: The amount and types of tools needed is of lower importance, but it can have a significant impact on the overall tooling costs, repair costs, and mobility of the entire system. It can also carry with it storage or membership fees.

Tooling Cost -1: The cost of tooling is of lower importance, but as the complexity of the design increases, more specialized tools may be needed. This increases the overall production and construction costs, as well as repair costs.

Repair Costs -2: Repair costs are important because these semi-recurring costs due to failures or general maintenance needs will span the lifetime of the product.

Design Complexity -3: It is very important to have a design that can be developed, tested, and repaired within a short timeframe in order to limit the associated costs. Varying some small features may be very complex, costly, and time consuming, while only yielding small gains in performance.

Engineering Payload Benefits -2: The engineering payload benefits are important because more capabilities that are offered to engineering based customers would lead to more bookings and more revenues.

Scientific Payload Benefits -2: The scientific payload benefits are important because more capabilities that are offered to science based customers would lead to more bookings and more revenues.

Ground Path -1: The ground path associated with the design option is of lower importance. However, the more area the potential ground path covers as well as the number of paths affects the cost, safety, and clearance necessary for a given design option. The ability to track multiple components increases the complexity of the operations.

Flight Clearance -2: Flight clearance is important because it is necessary in order to conduct a launch legally within FAA and FCC policies. The ability to obtain flight clearance is directly related to the safety of the operations and the lack of interference with any other unrelated systems.

Mean lifetime -2: The mean lifetime is important because a short lifetime is associated with incurring more frequent production and construction costs. It also may mean more repair costs and the potential to be prone to a higher failure rate.

Failure Rate -3: The failure rate of a design option is very important because a system failure could result in an overall mission failure as well as damages to the system and any customer payloads. A higher failure rate means more repair costs can be expected as well as the need for a higher number of spares.

Stability -2: Stability is important since this will control how predictably the rocket will fly and be able to handle the forces that will be acting on the structure. It also mean a safer flight and lower failure rates.

System Mass -3: The system mass is very important as it is a driving factor for the amount of recurring material purchases needed to be made. The heavier the system is, the more lifting gas and balloons are needed for every launch. This also adds difficulty for obtaining flight clearance and for transporting the system.

Size/Mobility -2: The size and mobility of the design option are important because as the size increases the costs required to transport the system increase. As the system become larger, the production and construction times and costs may also increase as larger systems can often be more difficult to work with.

Additional Systems Required -3: The requirement for additional systems in some design options is very important. Some design solutions may require additional recovery systems, tracking systems, and the development of more complex subsystems. This drives up costs and difficulty for performing operations.

For the rocket design, there are eight different design options that are considered. Option 1 is a single stage rocket that relies on the passive geometric stabilization of the fins. Option 2 is a single stage rocket that relies on passive spin stabilization from initial rotational inertia. Option 3 is a single stage rocket that relies on active stabilization from cold gas thrusters. Option 4 is a single stage rocket that relies on active stabilization from mechanical gyroscopes. Option 5 is a two stage rocket that relies on the passive geometric stabilization of the fins. Option 6 is a two stage rocket that relies on passive spin stabilization from initial rotational inertia. Option 7 is a two stage rocket that relies on active stabilization from cold gas thrusters. Option 8 is a two stage rocket that relies on active stabilization from mechanical gyroscopes. The following table shows the decision matrix for rocket design options.

Table 1: Rocket Design Weighted Decision Matrix

Criteria	Weight	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6	Option 7	Option 8
R&D Time	1	1	0	-1	-1	0	0	-1	-1
R&D Cost	1	1	0	-1	-1	0	0	-1	-1
Production and Construction Time	2	1	1	-1	-1	0	-1	-1	-1
Production and Construction Cost	2	1	0	-1	-1	-1	-1	-1	-1
Materials Needed	2	1	1	-1	0	0	-1	-1	-1
Materials Cost	2	1	1	-1	-1	0	-1	-1	-1
Tools Needed	1	0	0	-1	0	0	0	-1	-1
Tooling Cost	1	0	0	-1	-1	0	-1	-1	-1
Repair Costs	2	1	1	-1	-1	0	0	-1	-1
Design Complexity	3	1	1	-1	0	0	-1	-1	-1
Engineering Payload Benefits	2	0	0	0	0	1	1	1	1
Scientific Payload Benefits	2	-1	0	0	0	1	1	1	1
Ground Path	1	1	1	1	1	-1	-1	-1	-1
Flight Clearance	2	-1	1	1	1	-1	0	0	0
Mean lifetime	2	1	1	0	0	0	-1	-1	-1
Failure Rate	3	-1	0	-1	0	-1	-1	-1	-1
Stability	2	-1	0	1	1	1	0	1	1
System Mass	3	1	1	0	0	0	0	-1	-1
Size/Mobility	2	1	1	0	0	0	-1	-1	-1
Additional systems required	3	1	0	-1	-1	0	-1	-1	-1
Total Plus		13	10	3	3	3	2	3	3
Total Minus		4	0	12	8	4	11	16	16
Weighted Total		**17**	**21**	**-18**	**-9**	**-2**	**-19**	**-25**	**-25**

The decision matrix indicated that the most appropriate design option is Option 2, the single stage rocket that relies on passive spin stabilization from initial rotational inertia. The relatively low design complexity, failure rates, and number of additional systems required were some of the most important factors connected to the high score this design option received.

For the launch platform design, there are four different basic design options that are considered. Option 1 is a platform that is actively stabilized by cold gas thrusters and is lifted by several small balloons. Option 2 is a platform that is passively stabilized by mechanical gyroscopes and is lifted by several small balloons. Option 3 is a platform that is actively stabilized by cold gas thrusters and is lifted by few large balloons. Option 4 is a platform that is passively stabilized by mechanical gyroscopes and is lifted by few large balloons. The following table shows the decision matrix for launch platform design options.

Table 2: Launch Platform Design Weighted Decision Matrix

Criteria	**Weight**	**Option 1**	**Option 2**	**Option 3**	**Option 4**
R&D Time	1	-1	0	-1	0
R&D Cost	1	-1	0	-1	0
Production and Construction Time	2	-1	0	-1	0
Production and Construction Cost	2	-1	1	-1	0
Materials Needed	2	1	-1	1	0
Materials Cost	2	-1	1	-1	0
Tools Needed	1	-1	0	-1	-1
Tooling Cost	1	-1	0	-1	-1
Repair Costs	2	-1	0	-1	0
Design Complexity	3	-1	0	-1	1
Ground Path	1	0	0	0	0
Failure Rate	3	0	1	-1	0
Stability	2	1	0	1	0
System Mass	3	-1	0	-1	0
Size/Mobility	2	-1	0	-1	0
Additional systems required	3	-1	1	-1	1
Total Plus		2	4	2	2
Total Minus		12	1	13	2
Weighted Total		**-19**	**8**	**-22**	**4**

The decision matrix indicated that the most appropriate design option is Option 2, the platform that is passively stabilized by mechanical gyroscopes and is lifted by several small balloons. The relatively low failure rates, material needs, and material costs were some of the most important factors connected to the high score this design option received.

Cost Analysis

Since cost is a driving factor for the design of this hybrid system, it is important to estimate the costs associated with each subsystem. In doing so, weaknesses and alternative approaches can easily be seen in the onset of the design process. The following tables have been used in order to estimate costs and inform the aforementioned decision matrices. This allows for educated decisions regarding system characteristics and alternatives to be made based on initial cost estimates for the most notable components. The following tables show the material costs and masses associated with the launch platform, rocket, lifting equipment, construction materials, and a summary of the recurring costs. See Appendix B for Component Vendors of key components.

Table 3: Launch Platform Associated Materials Cost

Item	**Nonrecurring Cost ($)**	**Recurring Cost ($/Quantity)**	**Quantity**	**Total Cost ($)**	**Mass (lbs.)**	**Flight Mass (lbs)**
Mechanical gyroscopes	150	-	1	150	15	15
Stock Metal (aluminum)	200	-	1	200	15	15
Power supply	20	-	1	20	0.5	0.5
Microcontroller	40	-	1	40	0.1	0.1
Micro-trak GPS-HAM transmitter	335	-	1	335	0.5	0.5
Programming Cable	20	-	1	20	0	0
Serial to USB adapter	20	-	1	20	0	0
Kenwood TM-D710A APRS transceiver	505	-	1	505	0	0
Spot 3 Tracker	150	-	1	150	0.25	0.25
Spot 3 Tracker Subscription	-	100	1	100	0	0
Open Source APRS Software	0	-	1	0	0	0
IMU	20	-	1	20	0	0
Data Logger	20	-	1	20	0	0
Parachutes	100	-	2	200	0.125	0.25
Ignition Charges	-	12.5	2	25	0	0
Ground Computer	600	-	1	600	0	0
Balloons (600g)	-	60	8	480	1.35	10.8
String	10	-	1	10	0.1	0.1
Totals:	**2190**	**172.5**		**2895**	**32.93**	**42.5**

Table 4: Rocket Associated Materials Cost

Item	**Nonrecurring Cost ($)**	**Recurring Cost ($/Quantity)**	**Quantity**	**Total Cost ($)**	**Mass (lbs)**	**Flight Mass (lbs)**
Carbon Fiber Body Tube	400	-	2	800	3	6
Motor Retention System	50	-	1	50	0.25	0.25
RMS Motor Casing	180	-	1	180	2	2
Motor Reloads	-	485	1	485	32.6	32.6
Nosecone (aluminum tip)	80	-	1	80	0.1	0.1
Tubular Polycarbonate	40	-	1	40	1	1
Nylon webbing	20	-	1	20	1	1
Eyebolts and Quick-links	15	-	1	15	1	1
Black Powder	-	5	1	5	0.1	0.1
Parachutes	50	-	2	100	0.25	0.5
Igniter	10	-	2	20	0.1	0.2
Microcontroller	40	-	1	40	0.1	0.1
GPS Chip	20	-	1	20	0	0
IMU	20	-	1	20	0	0
Data Logger	20	-	1	20	0	0
Miscellaneous (nuts, bolts, sheer pins)	50	-	1	50	1	1
Micro-trak GPS-HAM transmitter	335	-	1	335	0.5	0.5
Altimeters	80	-	2	160	0.1	0.2
Totals:	**1410**	**490**	**22**	**2440**	**43.1**	**46.55**

Table 5: Lifting Equipment Associated Materials Cost

Item	Nonrecurring Cost ($)	Recurring Cost ($/Quantity)	Quantity	Total Cost ($)
Helium Tank	-	162	9	1458
Regulator	160	-	1	160
APRS Tracking Software	-	-	-	-
Miscellaneous: Filling hoses, couplers, tape, batteries, etc.	25	-	1	25
Totals:	**185**	**162**	**10**	**1643**

Table 6: Construction Materials Associated Costs

Item	Nonrecurring Cost ($)	Recurring Cost ($/Quantity)	Quantity	Total Cost ($)
Epoxy	120	-	1	120
Bulkhead wood	20	-	1	20
Machine Shop Access	-	100	1	0
Dremmel tool	50	-	1	50
Plastic sheeting	10	-	1	10
Clear-coat spray paint	20	-	1	20
Standard tool set	100	-	1	100
Sandpaper	25	-	1	25
Plastic gloves	10	-	1	10
Respirator	40	-	1	40
Sleeved gloves	15	-	1	15
Mixing sticks and buckets	20	-	1	20
Totals:	**430**	**100**	**12**	**430**

Table 7: Recurring Materials/Other Costs

Cost Items	**Cost Per Launch ($)**	**Annual Costs ($)**	**Monthly Total Cost ($) (for 22 Launches)**
Rocket	490	-	898.33
Helium	1296	-	2376
Balloons	540	-	940
Machine Shop Access		1200	100
Subscription Services	-	100	8.33
Ignition Charges	25	-	45.83
Totals:	**2291**	**1300**	**4313.5**

Engineering Design

Rocket Design

The subsystems that are required to accomplish the mission include the launch vehicle and launch platform and their respective recovery systems, ignition systems, communication systems, and power systems.

Mission statement

The primary objective of this effort is to design and construct a safe, and stable rocket that will reach approximately 200,000 feet in altitude and be fully recoverable and reusable.

Rocket Launch Success Criteria

A successful rocket launch will consist of reaching an altitude at apogee no less than 5.00% below the target altitude.

Rocket Recovery Success Criteria

A successful recovery of the rocket will consist of the recovery system ejecting at the appropriate time and altitude and recovering the rocket on the ground such that it is deemed reusable for future launches.

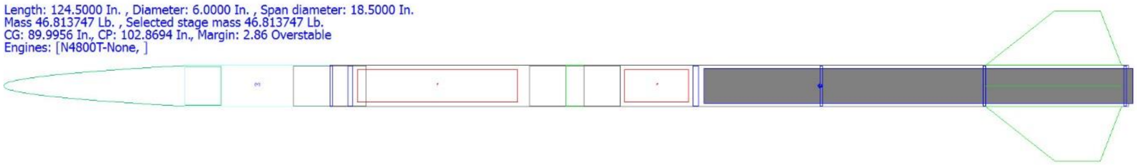
Payload Success Criteria

A successful payload system will consist of an appropriately massed payload that is fully integrated onboard the rocket. The system should operate successfully during and after the launch and be capable of storing and/or transmitting any recorded values.

Design Software

The initial design was completed using the flight simulation software, Rocksim 9. After the airframe was constructed, a more detailed design was created using Autodesk Inventor Professional 2014, a computer-aided design software package. See Appendix C for Launch Vehicle Summary and Appendix D for CAD Drawings. The following figures show the rocket design overview from Rocksim 9 and Autodesk Inventor.

Figure 4. Rocksim 9 Rocket Design.



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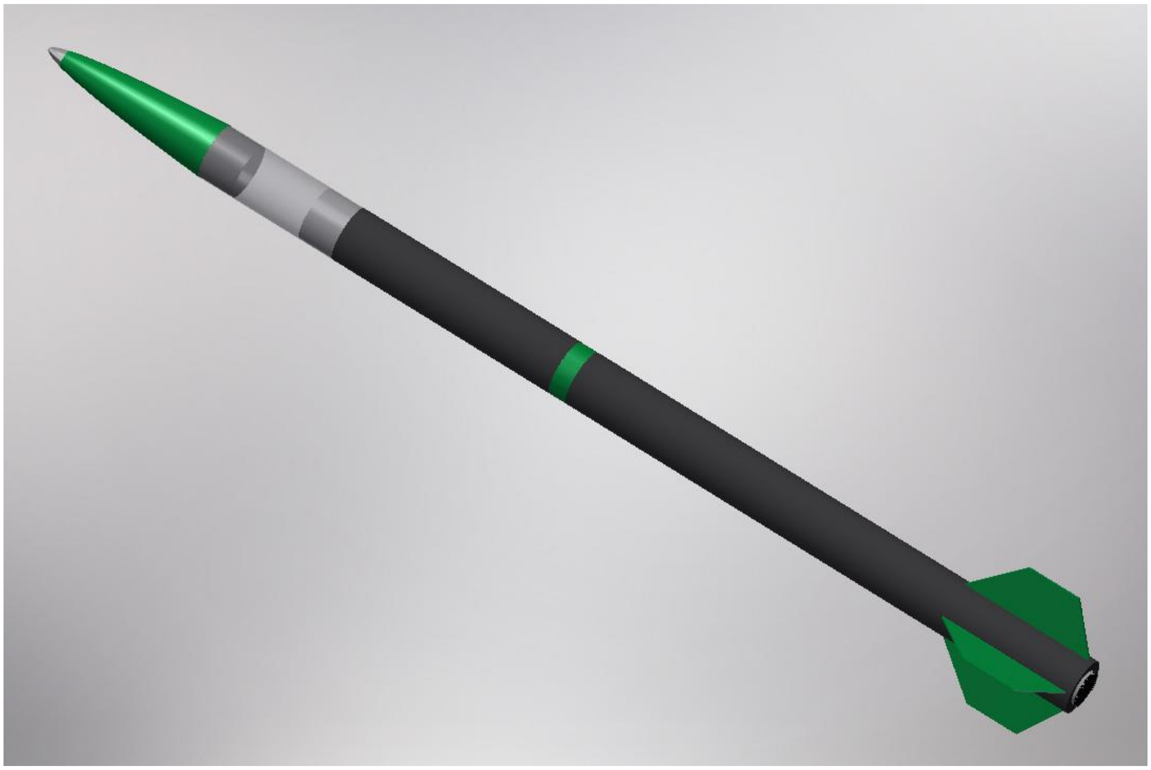
Length: 124.5000 In. , Diameter: 6.0000 In. , Span diameter: 18.5000 In.
Mass 46.813747 Lb. , Selected stage mass 46.813747 Lb.
CG: 89.9956 In., CP: 102.8694 In., Margin: 2.86 Overstable
Engines: [N4800T-None, ]
```

Figure 5: Autodesk Inventor 2014 Rocket Design



Each component of the rocket was designed to maximize efficiency and performance. The 6in. diameter was chosen so that it would accept the larger 98mm motor diameters as well as full 2U cubesat payloads. The design of the fin can is such that the fin geometry provides enough stabilizing force as the CP is sufficiently far enough behind the CG. The swept trailing edge ensures that the fin damage due to landing is minimized and the angled edges provide less friction. The length of the airframe ensures that the motor, recovery system, and payload fit comfortably. The nose cone was designed from a ½-power series formula for efficiency at supersonic speeds using the following formula.

$$y = R\left(\frac{x}{L}\right)^{n} \qquad (1$$

Where,

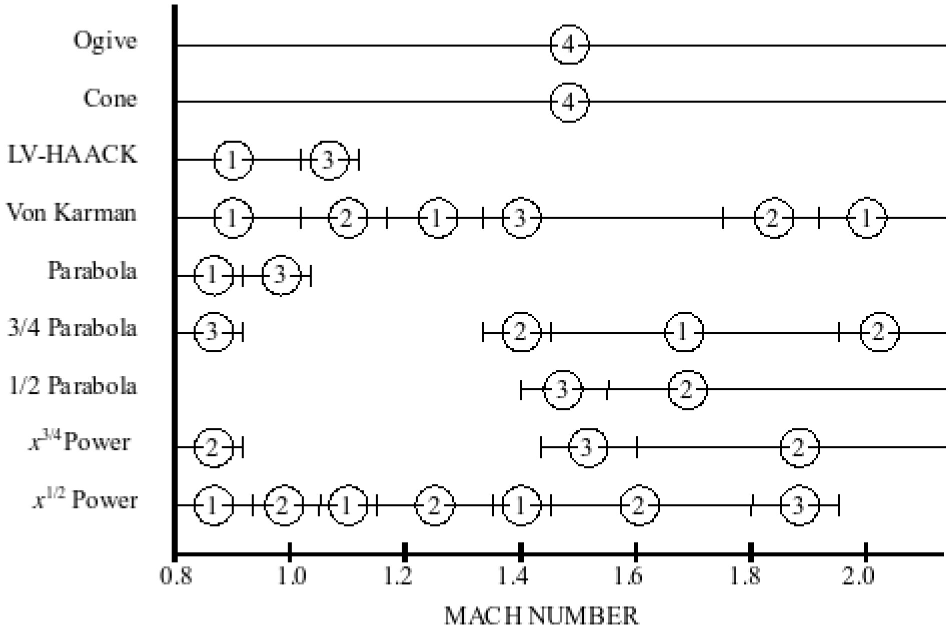
n = 0.5

R = nose cone radius at the base

L = length of the nose cone from tip to base

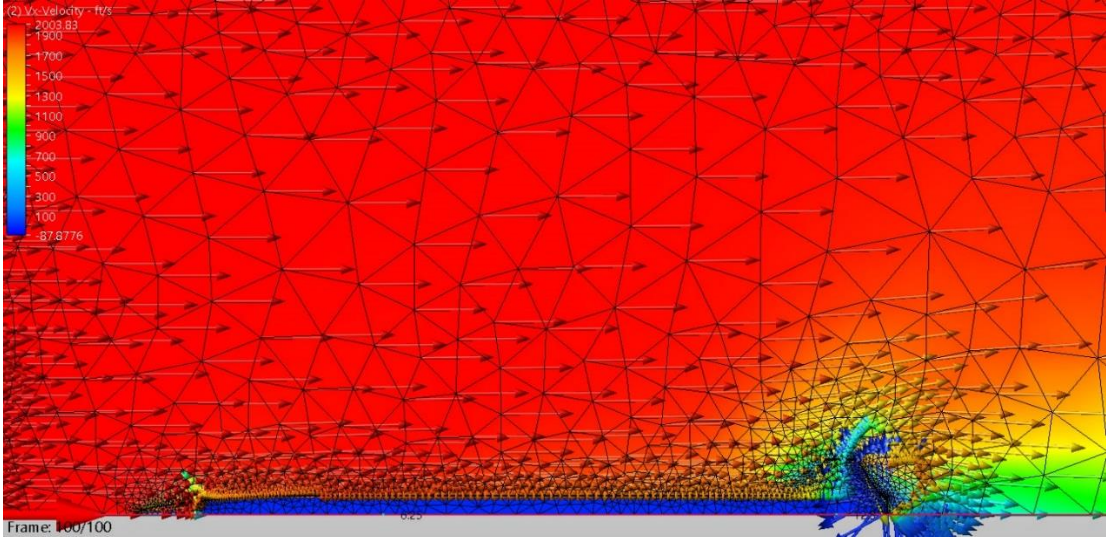
The ½-power series formula was selected based on the following comparison in the figure below of drag characteristics of various nose cone shapes in the transonic to low-Mach regions. Rankings are: superior (1), good (2), fair (3), inferior (4) (Crowell, 1996, p. 9).

Figure 6. Nose Cone Performance



Computational fluid dynamic (CFD) analysis was then performed using Autodesk Simulation CFD 2014. This software provides insight into the temperature, pressure, and kinetic energy influences on the rocket as it travels at subsonic, transonic, and supersonic speeds. This is done by using a computer to perform numerical methods and algorithms to solve fluid dynamics problems. The following figure is an example of the CFD analysis with the associated region vectors.

Figure 7: Velocity Vector Global Vector Example



“Simulation CFD software provides fast, accurate, and flexible fluid flow and thermal simulation tools to help predict product performance, optimize designs, and validate product behavior before manufacturing” (Simulation CFD, 2013). This is important as it can help to minimize reliance on physical prototypes which cuts costs in research and development and speeds up the production process. Making the best design decisions as early in the product development process as possible can help eliminate problems from mechanical stress, vibration, and motion, and multiphysics that could arise downstream. The following table shows the benefits of the Autodesk Simulation CFD software (Simulation CFD, 2013).

Table 8: Autodesk Simulation CFD Benefits

Predict performance	Gain valuable insight and reduce the risk of failure by accurately predicting how designs will respond to ordinary and extreme use.
Optimize designs	Reduce costs and get innovative designs to market faster without compromising safety or performance. Prevent over-engineering and control material usage.
Validate design decisions	Create quality products, improve building and infrastructure designs, meet safety requirements, and avoid costly mistakes by validating critical design decisions and material choices before manufacturing or construction begins

This study modeled the flow over the rocket geometry moving at Mach 2.2 to Mach 3.4, through air, at sea level to 60,000 ft. Using techniques recommended for high-speed external flow, the rocket geometry was immersed in a large air volume. The geometry is axisymmetric about the x-axis. The mesh was resized to be very fine near the body to capture the strong gradients and much coarser near the far field boundary to speed up the calculations. The model was also cut in half and symmetry was used in order to reduce the overall analysis size.

The external compressible flow was classified as an aerodynamic application that was in open air (at sea-level and altitude), as opposed to basic wind tunnel testing. This is typically useful for designing for flow over a wing, missile, or aircraft nacelle. For open air applications, the solution domain is not defined as part of the model (unlike a wind-tunnel).

To set up the simulation, the velocity of the object and static pressure are set for the inlet boundary condition. The outlet is specified as an unknown boundary condition neither the outlet pressure nor the velocity are known for supersonic flow. A free-stream velocity that matches the rocket velocity is assigned as a far-field boundary in order to develop the flow quicker. The Automatic Mesh Sizing tool was utilized for initial mesh assignments. This mesh was automatically concentrated long the regions of the rocket that contained high curvatures and large size variation. In order to focus the aerodynamic study on areas of interest, the mesh was redefined to be finer for regions around the rocket body and in the wake region. This allows for accurate representation of the flow physics in these typical high-velocity and high-gradient regions.

Recovery System

The launch platform will utilize a drogue parachute deployment at apogee, and a main parachute deployment at a lower altitude. The parachute sizes, descent rates, and kinetic energy calculations have been completed. The parachutes will be connected to a rip-stop nylon webbing. They will have quick links attached at each end for ease of assembly and removal. The quick links will also be attached to eye bolts which are epoxied into place on the altimeter bay’s bulk head. The shock cord’s length is long enough to ensure that none of the rocket’s structural components will collide during decent. Sheer pins will be used in conjunction with precision friction fitting at the separation points. The following table shows the desired rocket capability requirements and the solutions for the requirements.

Table 9: Rocket Capabilities and Solutions

Performance Characteristics for Systems and Subsystems the launch vehicle shall…	**How the requirement will be satisfied**
carry payload	Customer dependent payload.
deliver the science payload to upper stratosphere	Simulations. This will be verified with onboard altimeter readings and GPS data.
have recovery system electronics	The launch platform and rocket will be equipped with two altimeters that will be activated by a keyed switch on the exterior of the rocket.
recoverable and reusable	All components of the rocket and launch platform will be recovered after flight. This will be verified by inspection of each component after flight.
have a drogue and main parachute	The rocket and launch platform design will have a drogue that will deploy at apogee and a main that will deploy at a lower altitude.
be assembled within 2 hours	Launch procedures defined to ensure efficient assembly of all components within the time allotted.
be able to function for over two hours	The payload will be programmed to be able to take data for over two hours and the entire system will have enough power for the duration of the flight. The system will be tested to perform this requirement before flight.
have data that can be collected and analyzed	Data will be collected on board, and will be transferred to a computer via USB after landing. Some data will be transmitted through HAM radio.
have a tracking device	HAM radio integrated GPS and Spot Tracker
use a commercially available solid-fuel RMS motor	Design using RMS motors.
have a successful test launch	Ground launch of rocket or tethered balloon launch.
have a safety checklist	Compiled a list of safety precautions that will be used at all launch events.
not exceed initial projected budget	Detailed budget analysis.

The rocket is a critical component which is designed around various requirements and performance characteristics. This rocket must be able to meet the mission objectives and include all the necessary design elements which will allowed it to be safe, reliable, and reusable.

Launch Platform Design

The requirements of the overall system drive the design of a uniquely functioning launch platform. Typical high altitude balloon payloads are simply tied to the balloon using string and simple knots. However, when the orientation and stability of the payload are high priorities, the development of a sophisticated launch platform is necessary. The platform must keep the rocket upright and stable during the entire launch sequence to ensure safety, mission success, and optimal performance.

Mission statement

The primary objective of this effort is to design and construct a safe, and stable launch platform that will launch the rocket from a predetermined altitude and launch angle above a predetermined geographic location in a stable manner and be fully recoverable and reusable.

Launch Platform Success Criteria

A successful launch platform performance will consist a successful remote ignition at a predetermined altitude and location and descend in a controlled manner under parachute recovery system and land in a desirable location.

Rocket Recovery Success Criteria

A successful recovery of the launch platform will consist of the recovery system ejecting at the appropriate time and altitude and recovering the launch platform on the ground such that it is deemed reusable for future launches.

Equivalent Airspeed Analysis

In order to plan a successful mission, the launch altitude must be predetermined and factored into launch site selection criteria. As the density of the atmosphere decays with increasing altitude, rockets must fly faster in order to achieve the same stabilizing force as the altitude increases. The most critical part of the flight of the rocket is immediately after separation from the launch rail. The function of the rail is to provide stability to the rocket until it reaches a certain velocity at which it will be self-stabilizing due to the moment force relationship between the CG and CP. In the following equations, the basic lift equation is manipulated to draw a relationship between equivalent air-speed, true air-speed, and the relative air density. Equivalent air-speed is then solved for in order to discover the length of launch rail needed at various altitudes.

$$\frac{1}{2}\rho_{sl}V_{eas}^2SC_L = \frac{1}{2}\rho_a V_{tas}^2SC_L \qquad (2$$

$$\sigma = \frac{\rho_a}{\rho_{sl}} \qquad (3$$

$$V_{eas} = V_{tas}\sqrt{\sigma} \qquad (4$$

$$L_{ra} = \frac{V_{eas}^2}{2a} \qquad (5$$

Where,

a = acceleration

C_L = Coefficient of Lift

Lra = length of launch rail

ρ_a = pressure at altitude

ρ_{sl} = pressure at sea-level

S = fin semi span

V_{eas} = velocity at equivalent airspeed

V_{tas} = velocity at true airspeed

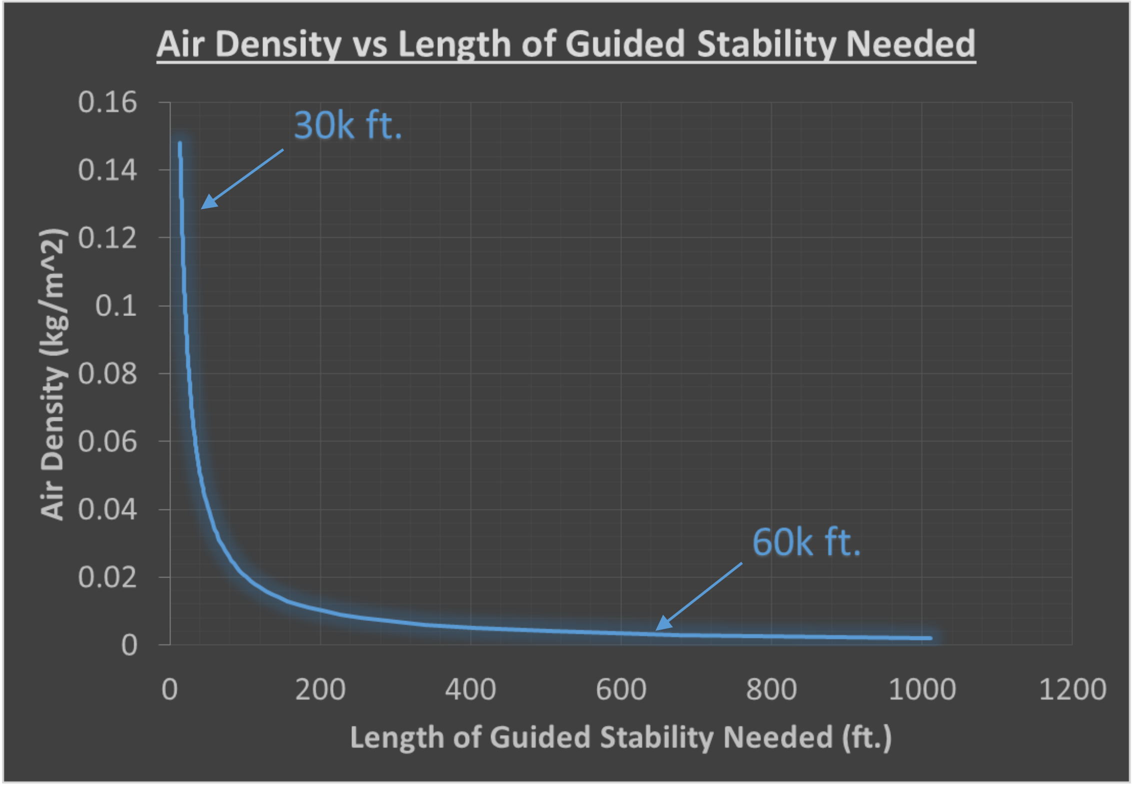
σ = relative density

See Appendix E Equivalent Airspeed Analysis for python code which calculates the L_{ra} equivalent spin stabilization needed as a function of relative density and Appendix F for Air Properties at Altitude.

For the N1000W motor, the acceleration constant at approximately 340f/s/s throughout the launch phase of the flight. The minimum L_{rsl} needed to reach a stable velocity of 44.6ft/s is 36.7in. For this V_{eas} to be reached at altitude, with a realistic L_{ra} of less than 200in., the maximum altitude for a stable flight would be at approximately 28,500ft at an air density of 0.2300 kg/m^2. If launched from this altitude, the simulated apogee of the rocket will be at only 116,200 ft. This motor does not meet the criteria for a successful mission.

For the N4800T motor, the acceleration constant at approximately 915f/s/s throughout the launch phase of the flight. The minimum L_{rsl} needed to reach a stable velocity of 45.6ft/s is 20in. For this V_{eas} to be reached at altitude, with a realistic L_{ra} of less than 200in., the maximum altitude for a stable flight would be at approximately 32,000ft at an air density of 0.1300 kg/m^2. If launched from this altitude, the simulated apogee of the rocket will be at approximately 205,100 ft. This meets the criteria for a successful mission. The following figure shows the relationship between air density and the length of guided needed at launch for a safe and stable flight.

Figure 8: Air Density vs Length of Guided Stability Needed



Spin Stabilization

The self-stabilization of a rocket can be accomplished through its geometric interaction with the atmosphere alone, or through its rotational inertia. Spin stabilization is immune to most altitude affects and could allow for the rocket to have a more stable flight. A self-spinning rocket or a rotating platform would be too large and heavy for this application. However, it may be possible to impart an initial spin on the rocket to boost its stability during the initial launch rail departure while not encroaching on the mass and cost budgets. A helical launch rail that is of a realistic length, less than 200in., can be designed to impart spin of over 10 rotations per second. The following figure shows an example of a helical launch rail used for a Super Loki rocket (Sokol et. al, 2003, p. 14).

Figure 9: Super Loki Helical Launch Rail

As this spinning slows throughout the flight, the appropriate airspeed will be reach so that fin stabilization can occur. Spin stabilization can take the place of hundreds of feet of launch rail guidance at altitudes exceeding 60,000ft. This allows for the maximum altitude of the N1000W motor to be increased to 154,800ft. and the maximum altitude of the N4800T motor to be increased to 225,300ft.

Active 2-Axis Platform Stabilization

The launch platform relies on the mechanical gyroscopic motion of two active stabilizers. The gyroscopic motion acts as a restoring force on the launch platform as it is influenced by wind and velocity differentials. These stabilizers are offset by 90 degrees in order to provide stabilizations along two axis. For the maximum correcting force, these stabilizers will be positioned at the center of gravity of the entire launch platform and rocket assembly.

Communication and Ignition System

The communications system is required for safe operations and procedures. This system is designed around the Arduino Mega 2560 prototyping platform. An inertial measurement unit, data logger, GPS chip, and an amateur radio transceiver will be integrated into this platform. Through this design, the system will be able to relay its current position as well as the orientation of the platform. Once an appropriate launch location has been reached, a command will be sent from the ground to initiate the ignition of the rocket motor.

Recovery System

The launch platform will utilize a drogue parachute that is pre-deployed. At apogee, the launch platform will fall under drogue at a high rate of descent to minimize wind drift. The main parachute will be deployed at a lower altitude in order to slow the rate of descent in order to minimize the kinetic energy on landing. The parachutes will be connected to a rip-stop nylon webbing. They will have quick links attached at each end for ease of assembly and removal. The quick links will also be attached to eye bolts which are epoxied into place on the altimeter bay's bulk head. The shock cord's length is long enough to ensure that none of the rocket's structural components will collide during decent. Sheer pins will be used in conjunction with precision friction fitting at the separation points.

Balloons and Lifting Gas

The overall mass of the launch platform and rocket determine the amount of lifting gas that is needed to lift the system. Helium has a lifting force of about 1gram per liter. In a typical 200 cubic foot Helium cylinder there is about 5,650 liters of gas. This provides a lifting force of about 12.45 lbs. A 600g meteorological balloon can accept over 200 cubic feet of Helium and can, therefore, lift about 12.5 lbs. The initial design has a mass of approximately 90lbs. and requires eight 200cf Helium tanks and eight 600g balloons. While these balloons are not rated to withstand the stresses of lifting this weight to their maximum altitudes, the desired altitude is much lower. The performance of these balloons will be verified during the test and evaluation phase of development.

It is important to import local winds aloft data from the most recent wind sounding measurements into mapping software. Doing so will allow for calculations of desired ascent and decent rates to provide some level of control over the launch site, burst altitude location, and predicted landing site. In the event that the local winds aloft data are not available or accurate, a sounding balloon shall be launched prior to the mission in order to obtain important wind speed and directional information so that predictions can be made.

Marketability

Cost Analysis

“The first step is to develop preliminary cost analysis requirements descriptions which identify the technical and operational parameters (*cost drivers*)” (Wertz et. al, 1999, p. 784). These will serve as the basic inputs for cost models. In order to establish a foundation for understanding and comparing costs, the following assumptions will be included:

- Costs are listed in constant-year dollars
- Inflation rate forecasts are implemented
- Learning curve percentage is implemented

The goal of this analysis is to identify the costs associated with the selected approach and to provide a potential source for recommending a more cost effective deign. The major cost drivers will be identified and life-cycle costs will be estimated. The life-cycle costs are broken down into Research, Development, Test and Evaluation (RDT&E), Production, and Operations and Maintenance. Since this hybrid technology is significantly different from any other technology with similar capabilities, an analogy-based cost estimating method would not yield appropriate results. This analysis will utilize a detailed bottom-up cost estimating method (Bearden, 1990). This includes specifying the low level elements that make up the system and estimating the cost of materials and labor to develop and produce each element. In doing so, the cost estimation can be tailored to this specific program (Apgar, 1996).

For this study, the life cycle cost is expressed by the following equations from Dhillon, 1989, Blanchard, 1978, and Monteith, 1979, p. 262.

$$LCC = C_{rd} + C_{pc} + C_{os} + C_f \qquad (6$$

Where

LCC is the system life cycle cost.

C_{rd} is research and development cost.

C_{pc} is production and construction cost.

C_{os} is operation and support cost.

C_f is failure cost.

The nonrecurring research and development cost, C_{rd}, is expressed by:

$$C_{rd} = \sum_{j=1}^{7} C_{rdj} \tag{7}$$

Where C_{rdj} is the *j*th cost element of the research and development cost for

j = 1 (means product planning);

j = 2 (means engineering design);

j = 3 (means system life cycle management);

j = 4 (means system test and evaluation);

j = 5 (means system research);

j = 6 (means system software); and

j = 7 (means design documentation).

The following table shows the research and development costs associated with each cost element.

Table 10: Research and Development Costs

Cost Element	**Associated Components**	**Associated Cost ($)**	**Total Cost ($)**
j = 1 (product planning)	1 Week Engineering Wages	750	750
j = 2 (engineering design);	1 Week Engineering Wages	750	750
j = 3 (system life cycle management)	3 Week Management Wages	3000	3000
j = 4 (system test and evaluation)*	Construction Materials Filling Equipment Rocket Materials Launch Platform Materials 1 Week Engineering Wages Travel	430 2962 2925 2895 750 600	10562
j = 5 (system research)	1 Week Engineering Wages	750	750
j = 6 (system software)	Software Trails 1 Week Engineering Wages	0 750	750
j = 7 (design documentation)	1 Week General Wages	750	750
C_{rd}			17312

Multiple system test and evaluation launches are necessary to ensure a certain level of confidence for safety and regulations, as well as for determining spin and vibration operating requirements for customer payloads. The customer will be responsible for ensuring the payload can withstand the launch and flight environment. The following costs for production and construction represent the development of two active systems and one spare system.

The semi-recurring production and construction cost, C_{pc}, is expressed by:

$$C_{pc} = \sum_{j=1}^{5} C_{pcj} \quad (8$$

Where C_{pcj} is the *j*th cost element of the production and construction cost for

j = 1 (means manufacturing);

j = 2 (means construction);

j = 3 (means quality control);

j = 4 (means initial logistics support); and

j = 5 (means industrial engineering and operations analysis).

The following table shows the production and construction costs associated with each cost element.

Table 11: Production and Construction Costs

Cost Element	**Associated Components**	**Associated Cost ($)**	**Total Cost ($)**
j = 1 (manufacturing)	1 Week Engineering Wages 1 Month Machine Shop Access	750 100	850
j = 2 (construction)	Construction Materials Rocket Materials Launch Platform Materials 1 Week Engineering Wages	430 3660 4342.5 750	9182.5
j = 3 (quality control)	1 Week Engineering Wages	750	750
j = 4 (initial logistics support)	1 Week Engineering Wages	750	750
j = 5 (industrial engineering and operations analysis)	1 Week Management Wages	1000	1000
$\mathbf{C_{pc}}$			12532.5

The annual operation and support cost, C_{os}, is expressed by:

$$C_{os} = \sum_{j=1}^{3} C_{osj} \quad (9$$

Where Cos_j is the *j*th cost element of the operation and support cost for

j = 1 (means system or product operations);

j = 2 (means product or system distribution); and

j = 3 (means sustaining logistic support).

The following table shows the annual operating costs associated with each cost element.

Table 12: Annual Operation Costs

Cost Element	**Associated Components**	**Associated Monthly Cost ($)**	**Total Annual Cost ($)**
j = 1 (system operations)	Engineering Wages Materials/Other	1500-3500 4309	75708
j = 2 (system distribution)	Marketing Wages Events/Conferences Travel	1000-2000 500 600	28200
j = 3 (sustaining logistic support)	Management Wages Rent/Office Legal/Accounting Travel	1000 1000 500 600	37200
C_{os}			141108

There are several modes of failure that could result in damage to the rocket or launch platform systems. Damage to the launch platform is unlikely due to its recovery system being pre-deployed and its design being relatively more robust than the rocket. It is also less expensive to repair than the rocket. Therefore, the failure costs are estimated using failure rates and life expectancy of the rocket alone. The failure costs of the rocket are the most important to estimate as they are the most likely costs to be incurred and the large difference in associated costs allow for this to be the most conservative and accurate estimate.

The recurring failure cost, C_f, is expressed by

$$C_f = \lambda(n)(C_r + C_s) \quad (10$$

where

λ is unit constant failure rate. The unit constant failure rate is estimated to be 0.2.

n is expected life of the product/unit. The expected life of the unit is 0.5 years.

C_r is repair cost.

C_s is cost of spares.

The cost of spares, C_s, is expressed by

$$C_s = C_u(K) \quad (11$$

where

C_u is unit spare cost.

K is fractional number of spare units for each active unit. For this scenario, there will be one spare unit for every two active units.

The following table shows the failure costs associated with each cost element.

Table 13: Failure Costs

Cost Element	**Associated Components**	**Associated Cost ($)**	**Total Cost ($)**
C_r	Carbon Fiber Epoxy Resin 1 Week Engineering Wages Body Tube Replacement	100 120 750 400	1370
C_u	Construction Materials Rocket Materials Launch Platform Materials 1 Week Engineering Wages	430 2440 2895 750	6515

Therefore,

$$C_s = (\$6515)\left(\frac{1}{2}\right) \qquad (12$$

$$C_s = \$3257.5 \qquad (13$$

$$C_f = (0.2)(0.5)(\$1370 + \$3257.5) \qquad (14$$

$$C_f = \$462.75 \qquad (15$$

The overall system life cycle cost is:

$$LCC = \$17312 + \$12532.5 + \$141108 + \$462.75 \qquad (16$$

$$LCC = \$171415.25 \qquad (17$$

The system unit life cycle cost for is:

$$LCC_{unit} = \frac{LCC}{\#\ units} \qquad (18$$

$$LCC_{unit} = \frac{\$171415.25}{3\ units} \tag*{(19}$$

$$LCC_{unit} = \$57138.42 \tag*{(20}$$

Market Analysis

Market Summary

This business is set to grow from graduate level studies and experience with students and educators in both high power rocketry and high altitude ballooning programs. This provides the business with good information about the market and a great deal of knowledge about the customers. Leveraging this information will allow for a better understanding of who is served, what the specific needs are, and the most effective ways to communicate with them (Kotler).

Target Markets

The primary target markets are colleges and universities, cubesat developers, and aerospace component developers. Customers in these markets are interested in developing space capabilities in support of cubesat programs or the development of various space-rated components. Customers focused on space or atmospheric sciences in these markets are also interested in recording data and making scientific discoveries in a poorly understood region of the atmosphere.

Market Demographics

The profile for the typical customer consist of the following demographics:

This business has no set geographic target area. By leveraging the expansive reach of the internet and transportation of goods and services, this business can serve customers all across the United States, and even in other countries. The total target population in the United States includes the portion of approximately 4,400 degree granting institutions of higher education that offer aerospace engineering and atmospheric science based degrees.

This business targets the gender neutral, age 18 to 30, college educated demographic. While age is not necessarily an important factor, the majority of college level students involved in aerospace engineering or atmospheric science programs are within this age range. Important customers outside of this age range include the faculty advisors and principle investigators for aerospace related programs. The target market is identified regardless of gender, ethnicity, socio-economic standing, religion, or marital status.

Market Needs

The market needs are based off of atmospheric science research needs in this region of the atmosphere and the needs of cubesat developers. Atmospheric science research customers are in need of a launch system that can delivery scientific experiments to the mesosphere, a poorly research region of the atmosphere.

Most atmospheric sensors are small in size and mass and will fit very comfortably within a 6 inch diameter rocket payload bay. The altitude range that must be reached is from approximately 160,000 feet to 328,000 feet. These scientific payloads may require vent holes for direct interaction with the atmosphere and access to an unobstructed optical section of the payload bay.

Cubesat or space hardware developers are in need of a launch service that can deliver engineering prototypes to the highest altitude possible. Altitudes above 200,000 feet are in a range that is acceptably higher than the reach of high altitude balloons to provide a more relevant space-like environment.

The payload bay must be able to accept payloads with standard cubesat dimensions of approximately 10cm cube. The 6 inch diameter payload bay and up to 8 inches of unobstructed optical viewing allows for acceptance of the standard 2U cubesat form factor. In order for the benefits of this technology to be apparent, the advantages over high altitude balloons and sounding rockets must be commensurate with the associated costs. The customers need to be given an attractive price point in order to select this technology.

Market Trends and Growth

The market trends and growth rates are functions of cubesat development trends, global atmospheric research interest trends, and growth rates in aerospace industry. Cubesat development has seen exponential growth over the past decade due to the ability to endorse low-cost commercial off-the-shelf based systems and non-traditional space approaches (Puig-Suari, 2012). University funding of cubesat programs has led to pathways for increasing performance while limiting mass and volume to standard form factors. While the current standards are still evolving, the growth in the industry is linked to commercial electronics development and advancement trends, aerospace industry growth forecasts, and the growing popularity of university cubesat programs. Over the past decade, there has been a growing interest in global change in an endeavor to understand the changing climate and how humans are affecting these changes. In order to understand these global trends, the atmospheric science research and funding has increased. Global change is still very poorly understood, and the market for making discoveries in this area is forecasted to grow over the next decade.

Strengths, Weaknesses, Opportunities, and Threats Analysis

SWOT analysis is an important planning method for evaluating a business venture. "The models provide a framework for identifying strengths and weaknesses, environmental opportunities and threats" (Bernoider, 2002, p. 564). This exercise can help to determine the attainability of an objective and to inform the future business planning. SWOT analysis has been ranked among the highest techniques used by firms for strategic analysis (Glaister and Falshaw, 1999, p.107). Many companies are now conducting SWOT analysis as to identify factors for the business planning process before proceeding to formulating their strategy (Houben *et al*., 1999, p. 125; Roth and Washburn, 1999, p. 50). "Having identified these factors, strategies are developed which may build on the strengths, eliminate the weaknesses, exploit the opportunities or counter the threats" (Dyson, 2004, p. 632). While all factors considered are not of equal value or priority, this exercise is important for making strategic plans for successful business operating plans both initially and in the long term.

Strengths

- Provides access to mesosphere which high altitude balloons cannot provide
- Lower cost when compared to sounding rockets
- Ability to accept cubesat payloads
- Ability to expand scientific knowledge
- Can potentially be launched from a wider variety of locations than sounding rockets

Weaknesses

- Cannot provide access to suborbital space
- Obtaining initial customers for a relatively unproven technology
- More geographically limited than high altitude balloon launches
- Increased complexity for prediction and tracking capabilities

Opportunities

- Technology can be rapidly improved to reach suborbital space
- Develop strategic partnerships with universities or aerospace component developers
- In-house development of rocket engines can cut costs
- Implementing Hydrogen lifting gas solutions could cut costs
- Services are align with growing trends in current and forecasted interest in global climate change and cubesat development
- Discoveries of scientific importance can lead to increased customers

Threats

- Regulations may hinder launch opportunities
- Initial failures may severely damage customer interest
- Interest may decrease as available launch sites decrease
- Service is susceptible to unpredictable weather

Sensitivity of Alternatives

The decision matrices provided the initial rationale for pursuing a specific design choice to satisfy the objectives. After estimating the life cycle costs, it is important to take an in-depth look into the sensitivity of some of the key qualitative assumptions within the decision matrices.

The rocket design option that was ranked second was Option 1, a single stage rocket that relies on the passive geometric stabilization of the fins. This option was scored based on the assumption that the rocket would require some sort of stabilization in addition to geometric fin stabilization. However, if tests concluded that a rocket could be launched in a safe and stable manner above 60,000 feet without implementation of additional stabilization methods, then this option would be scored differently in several highly sensitive criteria.

In this scenario, the stability, failure rate, and flight clearance criteria would receive more favorable scores. The changes based on this one assumption would give this option a higher weighted total of 26 than the selected option at a score of 21. By testing this one assumption and affecting only three of the criteria the score of Option 1 could change from 17 to 26. This shows that the decisions to pursue Option 1 or Option

2 is highly sensitive. This could lead to decreasing many of the life cycle costs as well as improving the annual operating plan. The other design options lack this level of sensitivity as they all received negative overall scores. In order for any of these options to be selected, there would need to exist rationale for changing multiple assumptions and a large number of criteria weights.

The launch platform design option that was ranked second was Option 4, a platform that is passively stabilized by mechanical gyroscopes and is lifted by few large balloons. This option was scored based on the assumption that the material costs for a few large balloons were more than the costs for several small balloons. However, partnerships with vendors and buying in bulk could allow for this option to decrease in overall cost and allow for a more favorable score. The failure rate was assumed to be higher as one malfunctioning balloon in a system of few balloons would be more likely to cause a mission failure than one malfunctioning balloon in a system of many. However, through prolonged testing of larger balloons, it may be determined that their reliability is on par with the selected system. If the scores for both material costs and failure rates were altered, the weighted total for Option 4 would change from 4 to 9 and Option two would decrease from a score of 8 to a score of 5. This shows a high level of sensitivity between design options 2 and 4. Design options 1 and 3 both rely on cold gas thruster technology and additional complex systems. The scoring for the criteria are not likely to change. The scores are very low at -19 and -22 which indicates that these options are not sensitive to the basic assumptions or changes in the criteria.

In the initial phases of research and development, in particular the system test and evaluation element, are important for verifying or disproving these assumptions. In doing so, a more accurate model for the operating plan and life cycle costs can be developed and could lead to a more successful business venture.

Business Plan

Problem/Opportunity

There are several problems that could be solved using a hybrid high altitude balloon and high power rocket system. These problems include those in both scientific and engineering activities. For atmospheric studies of the extreme altitudes, there is a distinct lack of data especially in the mesospheric regions. This is mainly due to the inability of current affordable technologies to reach these altitudes. While expensive sounding rockets are able to enter this region, the high price dictates that growth of scientific knowledge has been incredibly slow or has ceased to exist in some cases. With the recent trends in scientific interest in global warming, it is important to gather data from higher altitudes in order to complement the data received at lower altitudes by standard weather balloons. Various public, private, and government grants are awarded for global weather and atmospheric science experiments which could benefit from hybrid near-space technologies.

Growing interest in orbital space technologies among small companies and universities has led to the increased development of small satellites for commercial and academic use. While small scale spacecraft have been developed for fractions of the cost of their large scale counterparts, these price may still be out of budgetary reach for some. In order to cut costs even further, organizations with small budgets have begun substituting high quality space-rated components for inexpensive off the shelf electronics.

Before risking the success of an entire mission on these inexpensive components, it is important to test them in the best analog space environment possible: near-space. There is an opportunities for hybrid near-space technologies to fill this market need and provide spacecraft mission designers and engineers with the evidence they need to make risk avert decisions.

Unfair Advantage

While it has been shown that this hybrid technology is not new and has been used in the past, the ability to downscale the technology and apply it to new markets has not been attempted. This technology has been used by several large budget national space programs. However, through downsizing the technology and operating costs, this technology could be applied to new markets within the small business sector and in university settings. Previous attempts have been made though university projects that often relied on undergraduate engineering students making use of very small budgets. The attempts for extreme altitude flights have been met with varying levels of success and have often been postponed as the students involved graduate or move on to different projects.

By creating a dedicated organization with the ability to raise its own capital through selling products and services, higher levels of research and development funds can be expected. This research and development would be based off of graduate level research which is connected to decades of rocketry and high altitude ballooning experience in both academia and industry. Several potential customers have already been identified and have submitted letters of intent.

Sales and Marketing

When taking the hybrid-technology product to market, particularly during the introduction phase, a direct sales model would be followed. While channel sales could boost the overall amount of product sales, the product is very closely linked with the service provided. Even if the technology was acquired, it would be useless without the proper training and expertise that would be required to use it effectively and safely. In the future, this training could be provided through recorded or written training manuals and the sales model could show characteristics of both direct and channel sales.

Through direct sales, all of the profit is will be unbroken and available for company use. The cost of acquisition of a customer is measured in salaries and overheads needed to contact and support a growing number of customers. In order to minimize these costs, the marketing of the product and services will include retaining customers for multiple sales. Outlining contracts for multiple flights will minimize the customer acquisition efforts and promote our marketing efforts as long standing displays of the product and services exist.

Initial target customers in academia exist in space science, atmospheric science, and aerospace engineering departments all over the United States. These customers often engage in multi-year science and engineering programs that could benefit from one or more extreme altitude flights. Commercial spacecraft developers would also be targeted as customers as their needs to prove the ability of new components to operate in space-like environments must be satisfied. Advanced technology developers such as these are constantly modifying and making improvements to their technologies to stay relevant in the fast paced computer world. Hybrid near-space technologies could become an integral part of the development process of space-rated components.

Competition

One major competitor that this company faces is from scientific balloons. New developments in scientific ballooning technologies have allowed for flights to reach altitudes of over 170,000 feet. It also has the ability to remain at higher altitudes much longer than a rocket flying through at very high velocities. While ballooning technology has more heritage, scientific balloons that fly to these extreme heights rely on development methods that are currently only available to national space programs. The maximum altitude reached is also far less than the 200,000+ feet altitude that is attainable with hybrid technologies.

There are several companies that have utilized high-altitude ballooning technologies for both educational development and for advertising. Companies such as Sky-Probe, High Altitude Science, and StratoStar offer launch services starting at $2,500 or offer kits at around $1,000. JP Aerospace has supplemented its educational services with commercial ad space being sold from $400 for a 2” by 2” picture to $20,000 for video of a full 4” by 8” panel. Many universities also conduct their own launches for their students or members of the local community. These program incur much of the same start-up costs and often hire student employees to conduct the launch services.

These programs typically cost around $5,000 per year plus an additional $3,000 to $6,000 for student wages.

The other major competitor is sounding rockets. This rockets have the ability to reach much higher altitudes than a hybrid high altitude balloon and high power rocket system. However, this technology has several downfalls that this company could capitalized on. This cost is the most important factor as prices start in the $20,000 range. This cost to the customer also includes a large deposit. As military technology is often in use, there are several protocols and operating costs that need to be factored in as well. Expensive transportation costs, payment for range safety officials, and fees for obtaining the appropriate permissions for a launch into space. This company provides a technology and service that is far less costly and more accessible to a wider range of customers.

For the most part, the use of sounding rockets has been limited to government programs with flight being awarded to universities on very competitive proposal or lottery based selection processes. Sounding rockets available at price points from $3,000 to $5,000, such as the Sighter or Zuni launch vehicles utilized by the Australian Space Research Institute, reach maximum altitudes of around only 20,000 ft. For larger military sounding rockets in the U.S., launch sites may be restricted to certain locations. This can be very limiting for scientific and discoveries and actually add costs. The "Air Force requires a $25,000 nonrefundable deposit for launching from Cape Canaveral. And that's just the deposit!" (Sokol et. al, 2003, p. 20). A university sounding rocket program, such as JAMSTAR at the Florida Institute of Technology, can cost up to $8,000 on material purchases alone, not including over $25,000 in financial and material donations (Sokol et. al, 2003, p. 72).

The final competitor comes in the form of environment simulators, such as a thermal vacuum chamber. When developing technologies that operate in extreme environments that are difficult to get to, the use of a simulated environment is often used. Most thermal vacuum chambers are able to simulate altitudes of up to 90,000 feet and a full range of temperatures that may be experienced in space. However, most of these champers are not capable of running both thermal cycling and altitude cycling concurrently. This provides a less realistic environment and less assurance that the operation of the equipment is actually being validated. Use of thermal vacuum chambers can vary in availability and cost to a number of customers. With hybrid technology, customers will be assured that there equipment can operate in the most relevant environment to space for the development of space components. Thermal vacuum chambers are also completely useless for any customer interested in taking scientific measurements in a real environment.

Business Model and Operational Scenario

The business model will consist of a partner network of scientists and engineers that provide key activities and resources to customers. Hybrid near-space technologies enable this company to offer scientific and engineering flights to extreme altitudes that in support of multiple research and development goals. By establishing direct client relationships, the customers will be a fee for the service of launching and retrieving their payload. Through partnering with various educational institutions and aerospace component manufacturers, a value proposition for supplying our capabilities can be made directly to the customer segment. The success of business model is based on potential revenues outweighing estimated costs.

The typical operational scenario would be initiated by signing a contract for an upcoming launch opportunity. Based on flight clearance time frames, the earliest launch date would likely be 30 to 45 days in the future. This time window provides ample time for determining launch site location, safety protocols, and recovery options for safe and reliable flights. Depending on flight clearance allowances, the first choice for launch location would be decided on by the customer. In the event that the location selected is not available for use due to the regulatory environment surrounding this technology, a back-up site would be utilized. These back-up sites would likely be in a location with unrestricted airspace, such as the Black Rock Desert in Nevada or from the east coast of the United States with flight operations occurring over the Atlantic Ocean. International launch sites would also be considered based on ease of exporting/importing the technology and the regulations in the foreign country.

After the launch cite and preliminary launch approval is granted, detailed analysis of the launch site, recovery sites, and winds aloft data will be performed. It is important to obtain a range of available altitudes and GPS coordinates that are acceptable to initiate the launch sequence from. The results of this analysis will be used to obtain final flight approval from the FAA. Meanwhile, the customer payload will be integrated with the rocket prior to launch.

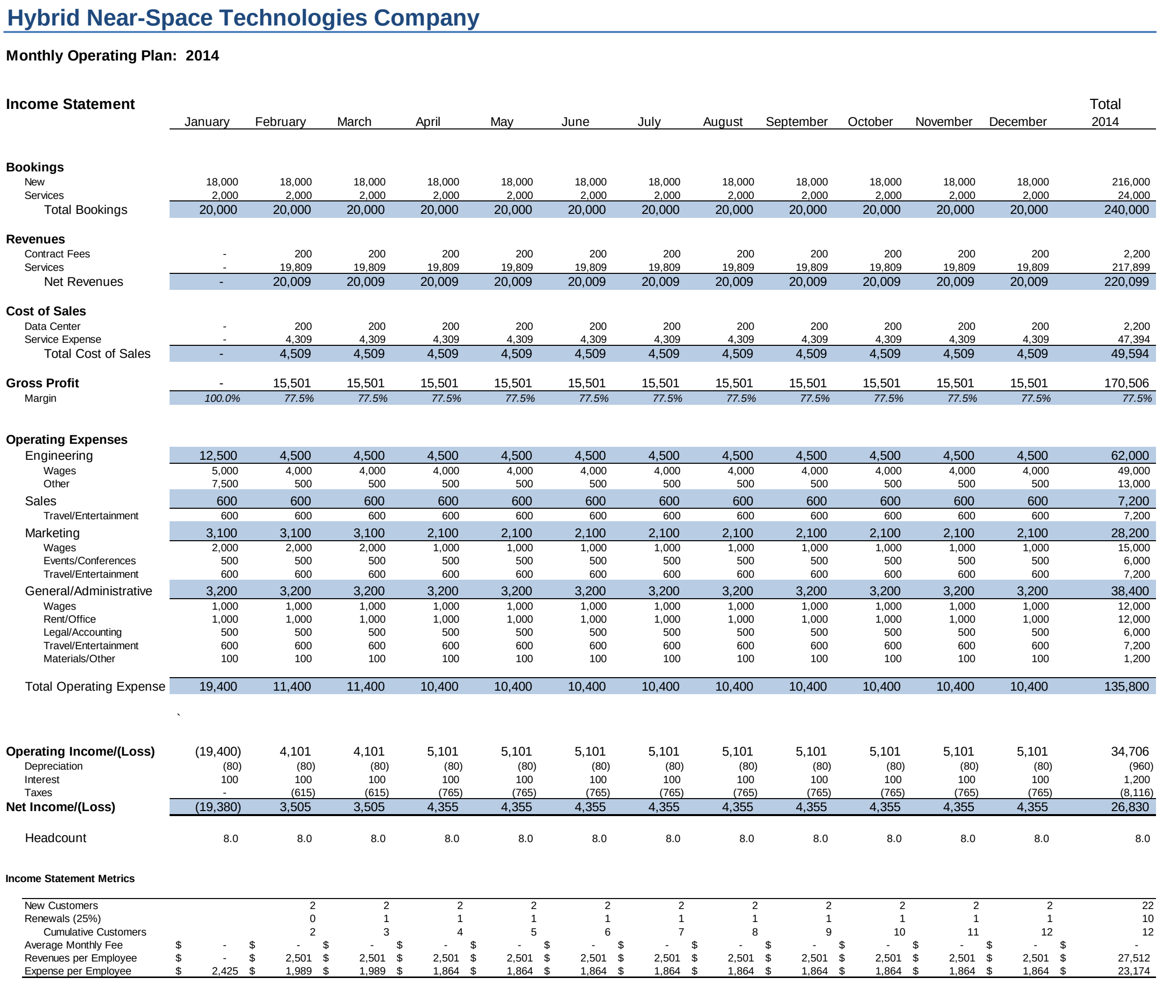
The launch operations consist of filling the balloons with lifting gas and arming all of the rocket and launch platform systems. After the hybrid system begins its ascent, the tracking system will relay the coordinates and altitude to the ground. When the system reaches a predetermined acceptable launch position, a signal from the ground will be sent to initiate the rocket motor ignition. The rocket and launch platform will then be tracked as two separate systems.

During the recovery phase, the balloon will descend under a pre-deployed drogue parachute until it reaches a lower altitude. At this predetermined altitude, the main parachute recovery system will be deployed automatically to slow the descent and the platform will be tracked on the ground and recovered via a company vehicle. When the rocket reaches apogee, a gravity switch will activate the drogue parachute recovery system and it will descend until it reaches a lower altitude. At this predetermined altitude, the main parachute will be automatically deployed and lower the descent rate to a safe landing velocity. The rocket will be tracked on the ground and recovered via a company vehicle. The customer payload will be removed from the rocket payload bay and returned to the customer along with all the data recorded from the on-board flight data recorders. This would conclude the customer related phase of operations and the hybrid system would then be subject to a post flight examination and undergo any repairs necessary.

Forecast

The following tables show income statements from a monthly operating plan for a company in its first and second year of revenues. The intent is to show a certain level of detail that an investor would expect in an operating plan income statement for an emerging aerospace company. In this operating plan, the revenue numbers reflect the growth in customers shown in the metrics at the bottom, and all the other numbers scale appropriately with that growth. The key assumptions driving revenue growth and expenses are that two units will be sold per month at $10,000 and that the company will be in the 15% tax bracket in 2014 and the 25% bracket in 2015.   The following tables show the income statement plans for 2014 and 2015.

Table 14: Income Statement Plan 2014



Hybrid Near-Space Technologies Company

Monthly Operating Plan: 2014

Income Statement	January	February	March	April	May	June	July	August	September	October	November	December	Total 2014
Bookings													
New	18,000	18,000	18,000	18,000	18,000	18,000	18,000	18,000	18,000	18,000	18,000	18,000	216,000
Services	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	24,000
Total Bookings	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	240,000
Revenues													
Contract Fees	-	200	200	200	200	200	200	200	200	200	200	200	2,200
Services	-	19,809	19,809	19,809	19,809	19,809	19,809	19,809	19,809	19,809	19,809	19,809	217,899
Net Revenues	-	20,009	20,009	20,009	20,009	20,009	20,009	20,009	20,009	20,009	20,009	20,009	220,099
Cost of Sales													
Data Center	-	200	200	200	200	200	200	200	200	200	200	200	2,200
Service Expense	-	4,309	4,309	4,309	4,309	4,309	4,309	4,309	4,309	4,309	4,309	4,309	47,394
Total Cost of Sales	-	4,509	4,509	4,509	4,509	4,509	4,509	4,509	4,509	4,509	4,509	4,509	49,594
Gross Profit	-	15,501	15,501	15,501	15,501	15,501	15,501	15,501	15,501	15,501	15,501	15,501	170,506
Margin	*100.0%*	*77.5%*	*77.5%*	*77.5%*	*77.5%*	*77.5%*	*77.5%*	*77.5%*	*77.5%*	*77.5%*	*77.5%*	*77.5%*	*77.5%*
Operating Expenses													
Engineering	12,500	4,500	4,500	4,500	4,500	4,500	4,500	4,500	4,500	4,500	4,500	4,500	62,000
Wages	5,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	49,000
Other	7,500	500	500	500	500	500	500	500	500	500	500	500	13,000
Sales	600	600	600	600	600	600	600	600	600	600	600	600	7,200
Travel/Entertainment	600	600	600	600	600	600	600	600	600	600	600	600	7,200
Marketing	3,100	3,100	3,100	2,100	2,100	2,100	2,100	2,100	2,100	2,100	2,100	2,100	28,200
Wages	2,000	2,000	2,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	15,000
Events/Conferences	500	500	500	500	500	500	500	500	500	500	500	500	6,000
Travel/Entertainment	600	600	600	600	600	600	600	600	600	600	600	600	7,200
General/Administrative	3,200	3,200	3,200	3,200	3,200	3,200	3,200	3,200	3,200	3,200	3,200	3,200	38,400
Wages	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	12,000
Rent/Office	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	12,000
Legal/Accounting	500	500	500	500	500	500	500	500	500	500	500	500	6,000
Travel/Entertainment	600	600	600	600	600	600	600	600	600	600	600	600	7,200
Materials/Other	100	100	100	100	100	100	100	100	100	100	100	100	1,200
Total Operating Expense	19,400	11,400	11,400	10,400	10,400	10,400	10,400	10,400	10,400	10,400	10,400	10,400	135,800
`													
Operating Income/(Loss)	(19,400)	4,101	4,101	5,101	5,101	5,101	5,101	5,101	5,101	5,101	5,101	5,101	34,706
Depreciation	(80)	(80)	(80)	(80)	(80)	(80)	(80)	(80)	(80)	(80)	(80)	(80)	(960)
Interest	100	100	100	100	100	100	100	100	100	100	100	100	1,200
Taxes	-	(615)	(615)	(765)	(765)	(765)	(765)	(765)	(765)	(765)	(765)	(765)	(8,116)
Net Income/(Loss)	(19,380)	3,505	3,505	4,355	4,355	4,355	4,355	4,355	4,355	4,355	4,355	4,355	26,830
Headcount	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0

Income Statement Metrics

New Customers		2	2	2	2	2	2	2	2	2	2	2	22
Renewals (25%)		0	1	1	1	1	1	1	1	1	1	1	10
Cumulative Customers		2	3	4	5	6	7	8	9	10	11	12	12
Average Monthly Fee	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Revenues per Employee	$ -	$ 2,501	$ 2,501	$ 2,501	$ 2,501	$ 2,501	$ 2,501	$ 2,501	$ 2,501	$ 2,501	$ 2,501	$ 2,501	$ 27,512
Expense per Employee	$ 2,425	$ 1,989	$ 1,989	$ 1,864	$ 1,864	$ 1,864	$ 1,864	$ 1,864	$ 1,864	$ 1,864	$ 1,864	$ 1,864	$ 23,174

Table 15: Income Statement Plan 2015

Hybrid Near-Space Technologies Company

Monthly Operating Plan: 2015

Income Statement	January	February	March	April	May	June	July	August	September	October	November	December	Total 2015
Bookings													
New	18,000	18,000	18,000	18,000	18,000	18,000	18,000	18,000	18,000	18,000	18,000	18,000	216,000
Services	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	24,000
Total Bookings	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	240,000
Revenues													
Contract Fees	200	200	200	200	200	200	200	200	200	200	200	200	2,400
Services	19,809	19,809	19,809	19,809	19,809	19,809	19,809	19,809	19,809	19,809	19,809	19,809	237,708
Net Revenues	20,009	20,009	20,009	20,009	20,009	20,009	20,009	20,009	20,009	20,009	20,009	20,009	240,108
Cost of Sales													
Data Center	200	200	200	200	200	200	200	200	200	200	200	200	2,400
Service Expense	4,309	4,309	4,309	4,309	4,309	4,309	4,309	4,309	4,309	4,309	4,309	4,309	51,702
Total Cost of Sales	4,509	4,509	4,509	4,509	4,509	4,509	4,509	4,509	4,509	4,509	4,509	4,509	54,102
Gross Profit	15,501	15,501	15,501	15,501	15,501	15,501	15,501	15,501	15,501	15,501	15,501	15,501	186,006
Margin	*77.5%*	*77.5%*	*77.5%*	*77.5%*	*77.5%*	*77.5%*	*77.5%*	*77.5%*	*77.5%*	*77.5%*	*77.5%*	*77.5%*	*77.5%*
Operating Expenses													
Engineering	4,500	4,500	4,500	4,500	4,500	4,500	4,500	4,500	4,500	4,500	4,500	4,500	54,000
Wages	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	48,000
Other	500	500	500	500	500	500	500	500	500	500	500	500	6,000
Sales	600	600	600	600	600	600	600	600	600	600	600	600	7,200
Travel/Entertainment	600	600	600	600	600	600	600	600	600	600	600	600	7,200
Marketing	2,100	2,100	2,100	2,100	2,100	2,100	2,100	2,100	2,100	2,100	2,100	2,100	25,200
Wages	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	12,000
Events/Conferences	500	500	500	500	500	500	500	500	500	500	500	500	6,000
Travel/Entertainment	600	600	600	600	600	600	600	600	600	600	600	600	7,200
General/Administrative	3,200	3,200	3,200	3,200	3,200	3,200	3,200	3,200	3,200	3,200	3,200	3,200	38,400
Wages	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	12,000
Rent/Office	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	12,000
Legal/Accounting	500	500	500	500	500	500	500	500	500	500	500	500	6,000
Travel/Entertainment	600	600	600	600	600	600	600	600	600	600	600	600	7,200
Materials/Other	100	100	100	100	100	100	100	100	100	100	100	100	1,200
Total Operating Expense	10,400	10,400	10,400	10,400	10,400	10,400	10,400	10,400	10,400	10,400	10,400	10,400	124,800
Operating Income/(Loss)	5,101	5,101	5,101	5,101	5,101	5,101	5,101	5,101	5,101	5,101	5,101	5,101	61,206
Depreciation	(80)	(80)	(80)	(80)	(80)	(80)	(80)	(80)	(80)	(80)	(80)	(80)	(960)
Interest	100	100	100	100	100	100	100	100	100	100	100	100	1,200
Taxes	(1,275)	(1,275)	(1,275)	(1,275)	(1,275)	(1,275)	(1,275)	(1,275)	(1,275)	(1,275)	(1,275)	(1,275)	(15,302)
Net Income/(Loss)	3,845	3,845	3,845	3,845	3,845	3,845	3,845	3,845	3,845	3,845	3,845	3,845	46,145
Headcount	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0

Income Statement Metrics

New Customers	2	2	2	2	2	2	2	2	2	2	2	2	24
Renewals (25%)	0	1	1	1	1	1	1	1	1	1	1	1	11
Cumulative Customers	2	3	4	5	6	7	8	9	10	11	12	13	13
Revenues per Employee	$ 2,501	$ 2,501	$ 2,501	$ 2,501	$ 2,501	$ 2,501	$ 2,501	$ 2,501	$ 2,501	$ 2,501	$ 2,501	$ 2,501	$ 30,014
Expense per Employee	$ 1,864	$ 1,864	$ 1,864	$ 1,864	$ 1,864	$ 1,864	$ 1,864	$ 1,864	$ 1,864	$ 1,864	$ 1,864	$ 1,864	$ 22,363

Team

This company has a core team with several years of experience building and flying high power rockets and high altitude balloons with a variety of scientific payloads and are ready to work towards providing a new type of launch service. Previous professional experience in a wide variety of engineering and science research and development projects at leading advanced technology corporations has left this team poised to offer this new and sophisticated launch service.

This company has access to exclusive intellectual property developed alongside graduate level research and has close connections within the National Aeronautic and Space Administration and several private and commercial aerospace companies. Throughout the growth process of the company, the ability to add corporate partners and an advisory committee consisting of distinguished scientists and engineers is promising.

Status and Milestones

Without any outside funding, this company has completed design and simulation testing for a hybrid near-space technology based launch system. The current design shows promise for reaching altitudes over 280,000 feet, providing access to a new region of the atmosphere important for scientific and engineering progress. The initial market analysis and financial estimates provide the rationale that there are many stakeholders that should be interested in investing. The technology has reach a critical design milestone and is soon moving into initial construction and subsystem testing. This company will soon be ready to move into the final research and development phases and begin offering launch services to a variety of customers.

CHAPTER III

RESULTS

Design Verification

Simulation Results

The following figures show the simulation data from a launch at sea level, 40,000ft., 50,000ft., and 60,000ft. The figures show the simulated values for altitude (above launch altitude), Mach number, velocity in the y-direction, and acceleration in the y-direction throughout the flight. The current version of Rocksim simulation software does not allow for both the launch altitude and landing altitude to be set by the user. In order to estimate the landing conditions, the same simulation was run with a sea-level launch and landing altitude. See Appendix G for Simulation Results Summary Data.

Figure 10: Rocksim 9 Simulation at Sea Level

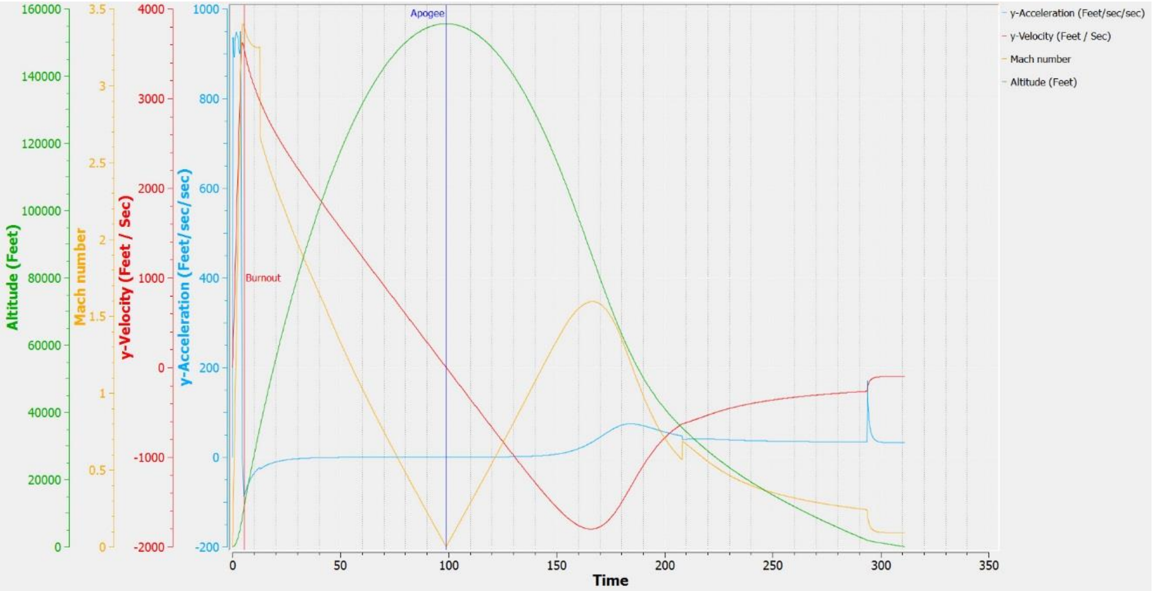


Figure 11: Rocksim 9 Simulation Data at 40,000 Feet.

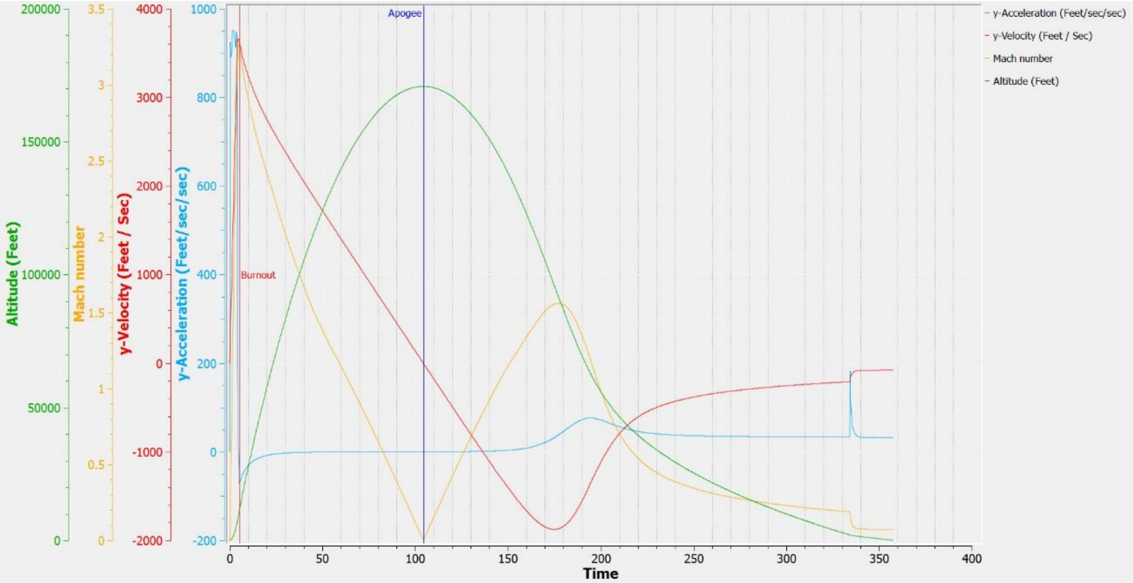


Figure 12: Rocksim 9 Simulation Data at 50,000 Feet.

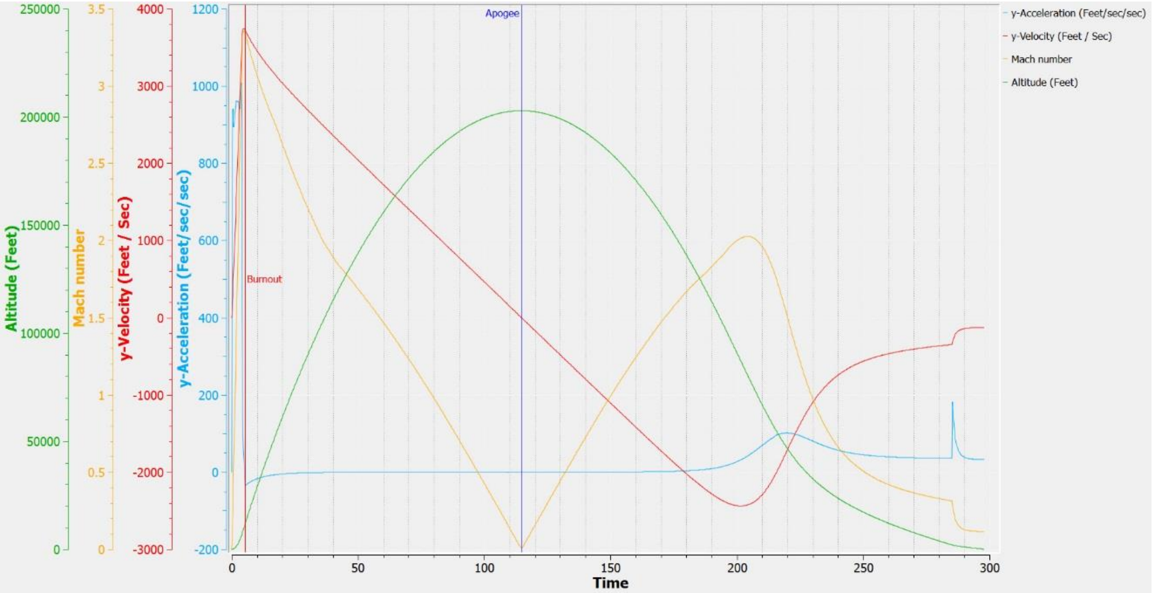
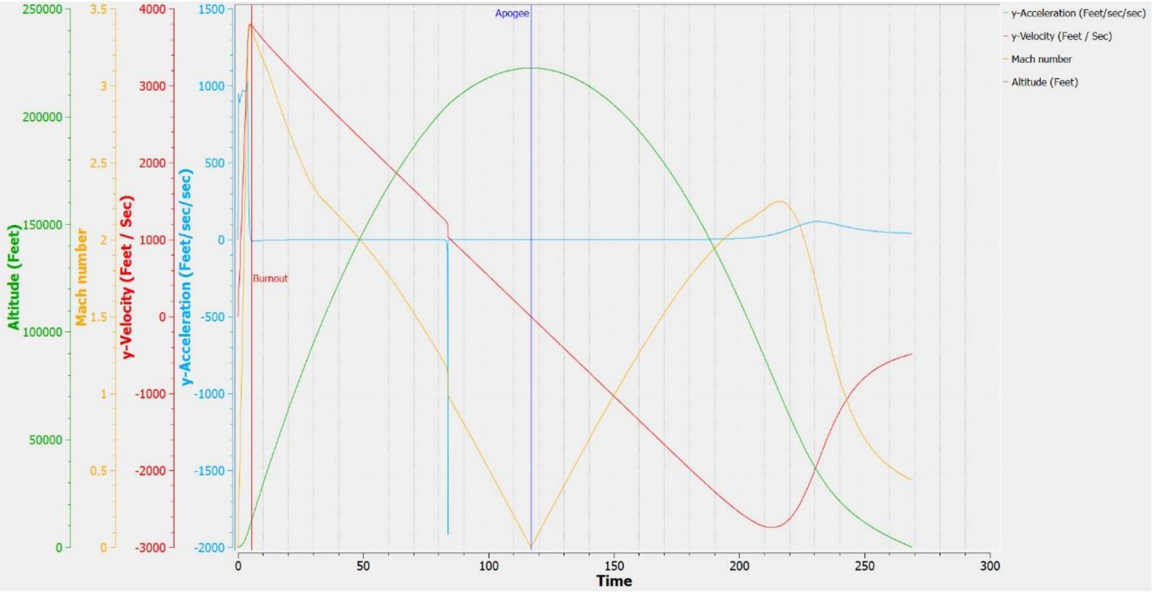


Figure 13: Rocksim 9 Simulation Data at 60,000 Feet.



Maximum Values

Table 16: Rocksim 9 Simulation Data.

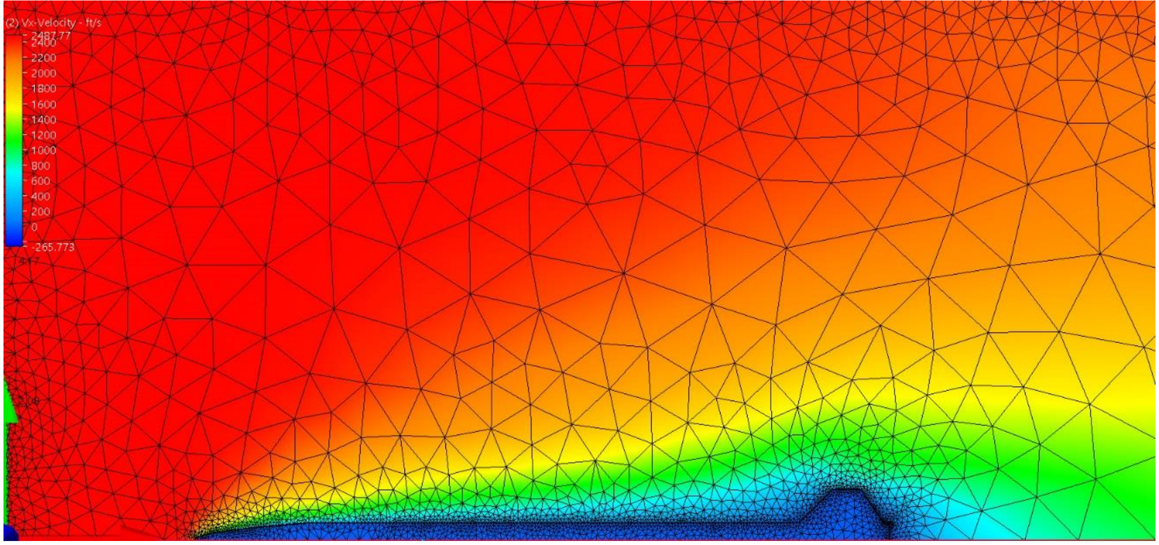
	Sea Level Launch	40,000 ft. Launch	50,000 ft. Launch	60,000 ft. Launch
Altitude (ft. above Sea Level	23,474	210,778	252,406	280,142
Mach Number	2.217	3.278	3.353	3.388
Acceleration (ft./s^2)	942.35	939.57	977.81	993.92
Velocity (y) (ft./s)	2476.01	3659.67	3743.09	3782.14

The table above shows the maximum values for the simulations.

Computational Fluid Dynamics Analysis Results

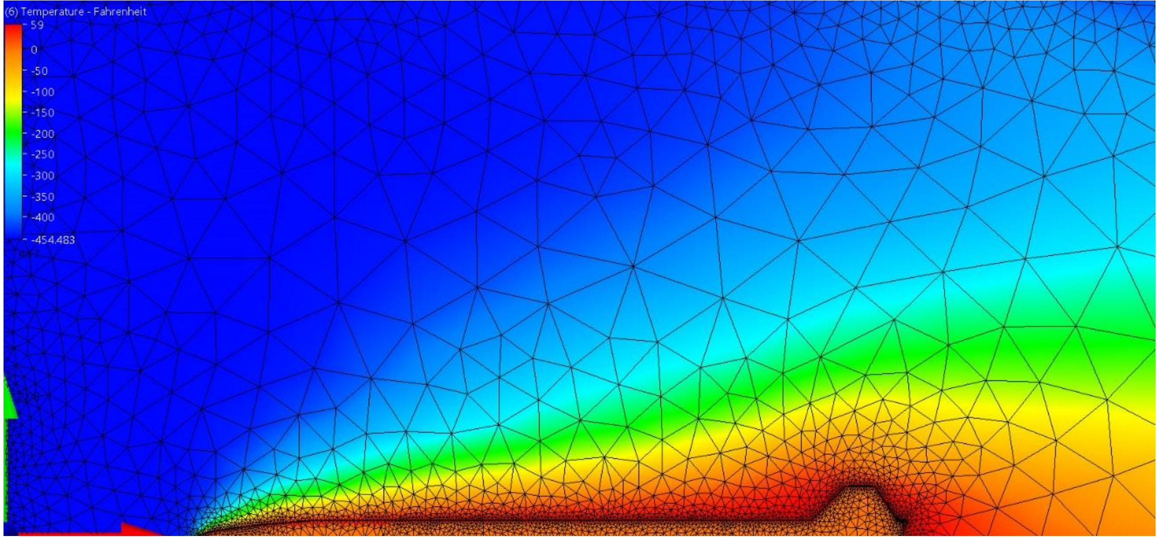
The inlet velocity boundary condition is compressible air flow at 2476ft./s to 3782ft./s., inlet pressure boundary condition is 0Pa, the outlet boundary condition is unknown, and the free-stream velocity boundary condition is 2476ft./s to 3782ft./s. The following figures show the interaction with the shock upstream of the rocket nosecone, the leading edges of the fins, as well as the wake downstream. The following figures show the results for velocity in the direction parallel to the motion of the rocket, temperature, and static pressure on the nose cone.

Figure 14: Velocity Vx Global Result.



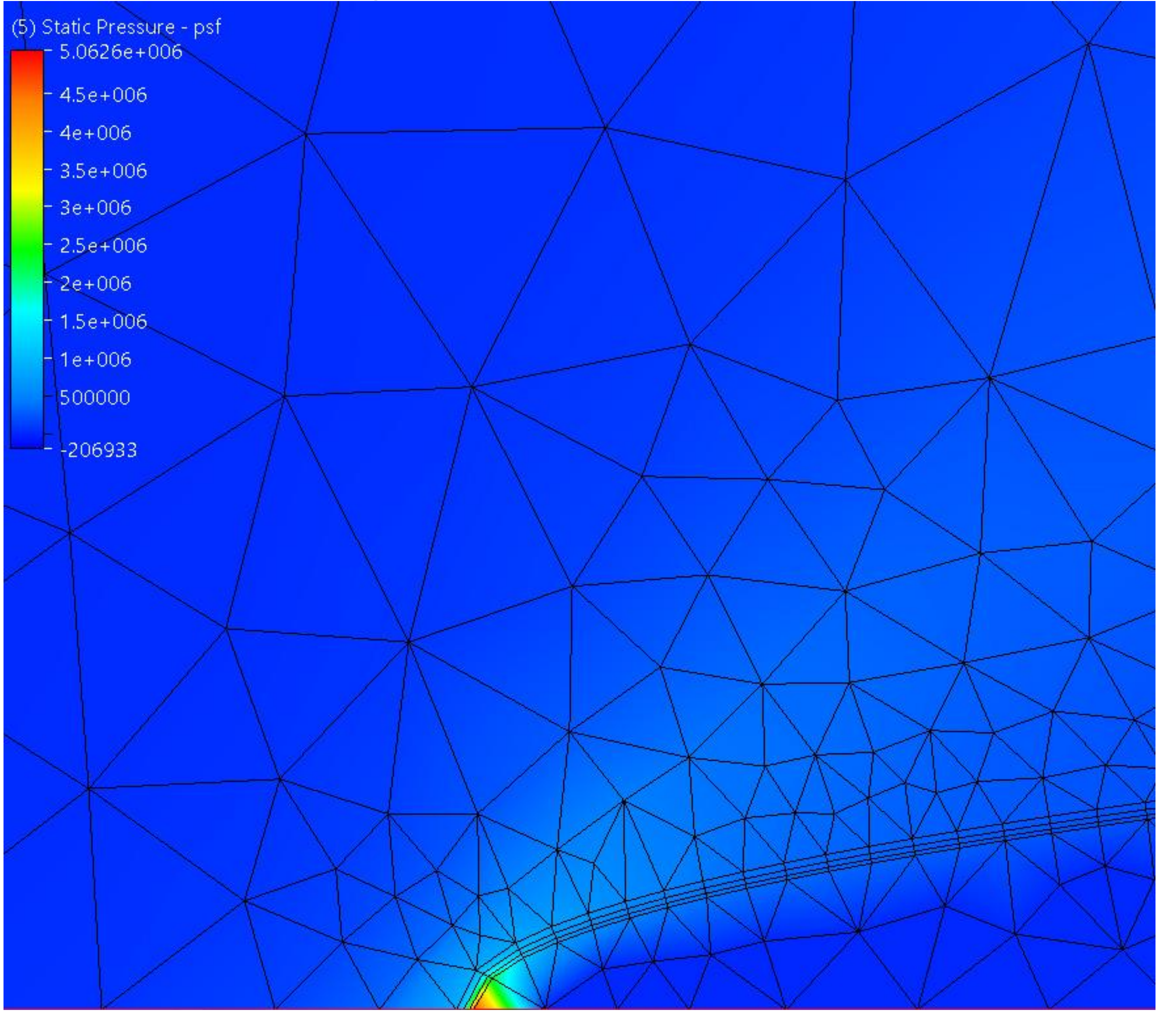
The velocity result, shown above in Figure 14, indicates that the geometry of the rocket acts to slow the movement of the air the most around the fins and aft of the rocket in the wake. This indicates that at the maximum velocity the fins are interacting appropriately with the air to benefit from passive geometric fin stabilization without any anomalous flow patterns.

Figure 15: Temperature Global Result



The temperature result, shown above in Figure 15, indicates that the most significant thermal interaction with the atmosphere occurs at the nose cone. This is to be expected as much of the drag force is concentrated on the tip of the nose cone. This justifies utilizing an aluminum nose cone for limiting thermal damage to the rocket.

Figure 16: Static Pressure Global Result



The static pressure result, shown above in Figure 16, indicates that the nose cone is subjected to very high instantaneous pressure. This result was obtained during a transonic region of flight where maximum pressure is expected. This result was not seen throughout the majority of the flight and verifies the efficiency of the ½-power series nose cone shape for the simulated velocities.

Costs and Marketability

Overview Financial Summary

The following table is a high-level summary of financial projections that would be suitable for use in an executive summary or first pitch to investors. The intention is to illustrate the financial merit to the more detailed annual income statement plans. Dollar values have been adjusted to reflect inflation factors relative to the year 2014. The inflation factor for years 2014-2016 are 3.0% and for years 2017-2018 are 0.31% based on projections by the Office of the Secretary of Defense (SMAD). Dollar values have also been adjusted to reflect projected annual growth rates. To estimate this projected growth over the next five years, the US growth rates from the FAA Aerospace Forecast Fiscal Years 2013-2033 were used as an industry standard. The growth rates used were 3.4% for 2015, 3.0% for 2016, and 2.5% for 2017-2018 (FAA). The following table shows the overview financial summary based off of the income statement plans for years 2014 and 2015.

Table 17: Overview Financial Summary

Summary of Projections ($Thousands)

	2014	2015	2016	2017	2018
Revenues	$ 220.10	$ 241.03	$ 241.03	$ 239.86	$ 238.47
Expenses	$ 134.80	$ 125.28	$ 125.28	$ 124.56	$ 123.83
Profit	$ 85.30	$ 115.75	$ 115.75	$ 115.31	$ 114.64
Investment Received	$ -	$ -	$ -	$ -	$ -

Driving Metrics:

New Users	22.0	24.8	25.6	26.2	26.9
Renewals	10.0	12.0	13.0	13.0	14.0
Head Count	12	12	13	13	14

Break-Even Analysis

In the Break-even analysis, all costs of operations are considered variable and all other costs are considered fixed as the costs would be incurred regardless of sales. Each unit is considered a new or renewal customer. The assumed values are taken from the Income Statement Plan 2014 and 2015 Tables from Chapter II. The analysis indicates that 25 units or $175,299 in annual sales revenue and 24 units or $165,616 in 2015 in annual sales revenue is required to reach the break-even point in 2014 and 2015, respectively, as shown in the following table.

Table 18: Break-Even Analysis

Hybrid Near-Space Technologies Company

Break-Even Analysis

	2014		2015	
Annual Units Break-Even	25		24	
Annual Sales Break-Even	$ 175,299		$ 165,616	
Assumptions:				
Average Per Unit Revenue	$ 6,878	*	$ 6,860	**
Average Per Unit Variable Cost	$ 1,550	*	$ 1,691	**
Estimated Annual Fixed Cost	$ 135,800		$ 124,800	

* assuming 1 unit sold to each new customer (22) and each renewal customer (10)

* *assuming 1 unit sold to each new customer (24) and each renewal customer (11)

Executive Summary

This business provides hybrid near-space technologies for affordable access to the mesosphere and is improving capabilities for accessing suborbital space. This business provides students, educators, and aerospace industries with scientific and engineering development opportunities. The current focus is to provide a high altitude balloon based launch platform for launching payloads to extreme altitudes onboard a high power rocket. This provides customers with new access to a region of the atmosphere that is of interest to a variety of scientific and engineering endeavors. The exploration process is streamlined as this company takes care of payload integration, launch, tracking, and recovery. The customer’s only concern is the science that they are interested in! Colleges and industry are given access to science and engineering capabilities that are typically reserved for high cost sounding rockets.

This technology has been developed under the guidance of NASA scientists and engineers as well as space science and engineering professions in academia. Through developing this intellectual property alongside graduate level research, the contacts in industry and academia provide a competitive advantage over other efforts of this nature. The identification of various potential markets and the receipt of letters of interest also places this effort ahead of any competitors. The core team behind this research has several years of expertise in high altitude ballooning, high power rocketry, and working within FAA and FCC regulations.

The current status of this effort is the completion of research and development phases that have provided successful simulation results. The life cycle costing and operating costs have been estimated, which shows growth and profit over the next five years. The next milestone is to transition into the development and testing phases after sufficient funding has been identified.

CHAPTER IV

DISCUSSION

Science and Engineering Supported

The initial analysis, design, and simulation testing of hybrid near-space technologies supports the efforts of using a HAB/HPR system for providing access to the mesosphere and eventually suborbital space. While it is less accurate than a ground launch system, the current market shows a need for affordable access to extreme altitudes which does not require such precision. A preliminary system has been designed and analyzed which can deliver small payloads to approximately 280,000 ft. in altitude at a low cost to customers of $10,000. There has already been a large amount of interest in this technology and the university involvement, education outreach, and public outreach can help to inspire new generations to get involved in aerospace ventures.

Costs and Marketability

The estimated life cycle costs total approximately $171,000 with the majority of these costs, over $85,000, coming in the form of wages. The target markets consisting of university programs, cubesat developers, and aerospace component developers has been growing in recent years. This growth, combined with the ability to deliver launch services which provide unique scientific and engineering value regardless of geographic area, outlines some of the strengths of this business model. When ignoring operating costs, the annual service expenses are around only $54,000 for 24 launches, or about

$2,250 per launch with start-up costs of about $15,000. This is a very attractive price point for a university program. A university based effort could take advantage of low labor costs, access to materials and tools, and additional funding options that are only available to educational institutions such as privately and governmental grants as well as tax-exempt donations and purchases.

The cost to the customer for hybrid near-space technologies are on par with high-altitude ballooning based companies and sounding rocket organizations. The unique ability to provide access to the upper mesosphere at an attractive price point is a strength that should drive further investigation into this effort. While there are some weaknesses in the reliability of the technology and potential threats from the regulatory environment at this point, the ability to provide affordable access to suborbital space and align with growing trends in the aerospace industry is a great opportunity.

The lack of comparable alternative technologies made it necessary to utilize a different approach to market analysis. Instead of being able to defining operating parameters by assessing analogous technologies and markets, the market size for this hybrid technology was based on its extremely affordable price point. At $10,000, this technology caters to scientific and engineering needs at a fraction of the price of typical university science and engineering endeavors. It is difficult to quantify the engineering value to a CubeSat program that can cost over $200,000 or the scientific value to making new discoveries in a relatively unexplored region. This effort focused on creating an extremely attractive price point and developing a viable business case.

Business Success

Through detailed cost estimation, operational planning, and business planning, a viable business scenario was created. A hybrid “rockoon” system could be utilized to provide affordable access to the upper mesosphere at a cost of $10,000 to the customer. However, the success of the business is dependent on the amount of customers each year. Analysis shows that just 24 customers per year are needed to break-even in an average year. This number of customers is somewhat optimistic, but could definitely be possible based on the proposed operational scenario and number of employees. This business could handle two launches per month by current estimates which, therefore, verifies the experimental hypothesis. However, it is relatively uncertain how many customers would actually commit to a $10,000 contract.

The scientific and engineering value of this launch service can vary greatly from one customer to another. Further analysis into determining a definitive market and price point is required before being able to responsibly proceed with further business development. The likely next step would be to verify the size of the market and approval of a price point. This would be done through a long term market survey and analysis effort. Surveying the interest and financial abilities of dozens of educational institutions and aerospace companies would be able to determine the likelihood of a successful business venture and an appropriate price point for sustained operations

Another method for addressing some of the uncertainties associated with this business would be to support prototype development under a university sponsored program or a special projects branch of an existing company. This would limit many of the research and development, and production and construction costs associated with wages, rent, and seed funding. This technology could then be slowly introduced into the market with limited associated risk.

APPENDICES

Appendix A
Regulations

(FAR Part 101)

Subpart A—General

§101.1 Applicability.

(a) This part prescribes rules governing the operation in the United States, of the following:

(1) Except as provided for in §101.7, any balloon that is moored to the surface of the earth or an object thereon and that has a diameter of more than 6 feet or a gas capacity of more than 115 cubic feet.

(2) Except as provided for in §101.7, any kite that weighs more than 5 pounds and is intended to be flown at the end of a rope or cable.

(3) Any amateur rocket except aerial firework displays.

(4) Except as provided for in §101.7, any unmanned free balloon that—

(i) Carries a payload package that weighs more than four pounds and has a weight/size ratio of more than three ounces per square inch on any surface of the package, determined by dividing the total weight in ounces of the payload package by the area in square inches of its smallest surface;

(ii) Carries a payload package that weighs more than six pounds;

(iii) Carries a payload, of two or more packages, that weighs more than 12 pounds; or

(iv) Uses a rope or other device for suspension of the payload that requires an impact force of more than 50 pounds to separate the suspended payload from the balloon.

(b) For the purposes of this part, a *gyroglider* attached to a vehicle on the surface of the earth is considered to be a kite.

[Doc. No. 1580, 28 FR 6721, June 29, 1963, as amended by Amdt. 101-1, 29 FR 46, Jan. 3, 1964; Amdt. 101-3, 35 FR 8213, May 26, 1970; Amdt. 101-8, 73 FR 73781, Dec. 4, 2008; 74 FR 38092, July 31, 2009]

§101.3 Waivers.

No person may conduct operations that require a deviation from this part except under a certificate of waiver issued by the Administrator.

[Doc. No. 1580, 28 FR 6721, June 29, 1963]

§101.5 Operations in prohibited or restricted areas.

No person may operate a moored balloon, kite, amateur rocket, or unmanned free balloon in a prohibited or restricted area unless he has permission from the using or controlling agency, as appropriate.

[Doc. No. 1457, 29 FR 46, Jan. 3, 1964, as amended at 74 FR 38092, July 31, 2009]

§101.7 Hazardous operations.

(a) No person may operate any moored balloon, kite, amateur rocket, or unmanned free balloon in a manner that creates a hazard to other persons, or their property.

(b) No person operating any moored balloon, kite, amateur rocket, or unmanned free balloon may allow an object to be dropped therefrom, if such action creates a hazard to other persons or their property.

(Sec. 6(c), Department of Transportation Act (49 U.S.C. 1655(c)))

[Doc. No. 12800, 39 FR 22252, June 21, 1974, as amended at 74 FR 38092, July 31, 2009]

Subpart C— Amateur Rockets

§101.21 Applicability.

(a) This subpart applies to operating unmanned rockets. However, a person operating an unmanned rocket within a restricted area must comply with §101.25(b)(7)(ii) and with any additional limitations imposed by the using or controlling agency.

(b) A person operating an unmanned rocket other than an amateur rocket as defined in §1.1 of this chapter must comply with 14 CFR Chapter III.

[Doc. No. FAA-2007-27390, 73 FR 73781, Dec. 4, 2008]

§101.22 Definitions.

The following definitions apply to this subpart:

(a) *Class 1—Model Rocket* means an amateur rocket that:

(1) Uses no more than 125 grams (4.4 ounces) of propellant;

(2) Uses a slow-burning propellant;

(3) Is made of paper, wood, or breakable plastic;

(4) Contains no substantial metal parts; and

(5) Weighs no more than 1,500 grams (53 ounces), including the propellant.

(b) *Class 2—High-Power Rocket* means an amateur rocket other than a model rocket that is propelled by a motor or motors having a combined total impulse of 40,960 Newton-seconds (9,208 pound-seconds) or less.

(c) *Class 3—Advanced High-Power Rocket* means an amateur rocket other than a model rocket or high-power rocket.

[Doc. No. FAA-2007-27390, 73 FR 73781, Dec. 4, 2008]

§101.23 General operating limitations.

(a) You must operate an amateur rocket in such a manner that it:

(1) Is launched on a suborbital trajectory;

(2) When launched, must not cross into the territory of a foreign country unless an agreement is in place between the United States and the country of concern;

(3) Is unmanned; and

(4) Does not create a hazard to persons, property, or other aircraft.

(b) The FAA may specify additional operating limitations necessary to ensure that air traffic is not adversely affected, and public safety is not jeopardized.

[Doc. No. FAA-2007-27390, 73 FR 73781, Dec. 4, 2008]

§101.25 Operating limitations for Class 2-High Power Rockets and Class 3-Advanced High Power Rockets.

When operating *Class 2-High Power Rockets* or *Class 3-Advanced High Power* Rockets, you must comply with the General Operating Limitations of §101.23. In addition, you must not operate *Class 2-High Power Rockets* or *Class 3-Advanced High Power* Rockets—

(a) At any altitude where clouds or obscuring phenomena of more than five-tenths coverage prevails;

(b) At any altitude where the horizontal visibility is less than five miles;

(c) Into any cloud;

(d) Between sunset and sunrise without prior authorization from the FAA;

(e) Within 9.26 kilometers (5 nautical miles) of any airport boundary without prior authorization from the FAA;

(f) In controlled airspace without prior authorization from the FAA;

(g) Unless you observe the greater of the following separation distances from any person or property that is not associated with the operations:

(1) Not less than one-quarter the maximum expected altitude;

(2) 457 meters (1,500 ft.);

(h) Unless a person at least eighteen years old is present, is charged with ensuring the safety of the operation, and has final approval authority for initiating high-power rocket flight; and

(i) Unless reasonable precautions are provided to report and control a fire caused by rocket activities.

[74 FR 38092, July 31, 2009, as amended by Amdt. 101-8, 74 FR 47435, Sept. 16, 2009]

§101.27 ATC notification for all launches.

No person may operate an unmanned rocket other than a Class 1—Model Rocket unless that person gives the following information to the FAA ATC facility nearest to the place of intended operation no less than 24 hours before and no more than three days before beginning the operation:

(a) The name and address of the operator; except when there are multiple participants at a single event, the name and address of the person so designated as the event launch coordinator, whose duties include coordination of the required launch data estimates and coordinating the launch event;

(b) Date and time the activity will begin;

(c) Radius of the affected area on the ground in nautical miles;

(d) Location of the center of the affected area in latitude and longitude coordinates;

(e) Highest affected altitude;

(f) Duration of the activity;

(g) Any other pertinent information requested by the ATC facility.

[Doc. No. FAA-2007-27390, 73 FR 73781, Dec. 4, 2008, as amended at Doc. No. FAA-2007-27390, 74 FR 31843, July 6, 2009]

§101.29 Information requirements.

(a) *Class 2—High-Power Rockets*. When a Class 2—High-Power Rocket requires a certificate of waiver or authorization, the person planning the operation must provide the information below on each type of rocket to the FAA at least 45 days before the proposed operation. The FAA may request additional information if necessary to ensure the proposed operations can be safely conducted. The information shall include for each type of Class 2 rocket expected to be flown:

(1) Estimated number of rockets,

(2) Type of propulsion (liquid or solid), fuel(s) and oxidizer(s),

(3) Description of the launcher(s) planned to be used, including any airborne platform(s),

(4) Description of recovery system,

(5) Highest altitude, above ground level, expected to be reached,

(6) Launch site latitude, longitude, and elevation, and

(7) Any additional safety procedures that will be followed.

(b) *Class 3—Advanced High-Power Rockets*. When a Class 3—Advanced High-Power Rocket requires a certificate of waiver or authorization the person planning the operation must provide the information below for each type of rocket to the FAA at least 45 days before the proposed operation. The FAA may request additional information if necessary to ensure the proposed operations can be safely conducted. The information shall include for each type of Class 3 rocket expected to be flown:

(1) The information requirements of paragraph (a) of this section,

(2) Maximum possible range,

(3) The dynamic stability characteristics for the entire flight profile,

(4) A description of all major rocket systems, including structural, pneumatic, propellant, propulsion, ignition, electrical, avionics, recovery, wind-weighting, flight control, and tracking,

(5) A description of other support equipment necessary for a safe operation,

(6) The planned flight profile and sequence of events,

(7) All nominal impact areas, including those for any spent motors and other discarded hardware, within three standard deviations of the mean impact point,

(8) Launch commit criteria,

(9) Countdown procedures, and

(10) Mishap procedures.

[Doc. No. FAA-2007-27390, 73 FR 73781, Dec. 4, 2008, as amended at Doc. No. FAA-2007-27390, 74 FR 31843, July 6, 2009]

Subpart D—Unmanned Free Balloons

SOURCE: Docket No. 1457, 29 FR 47, Jan. 3, 1964, unless otherwise noted.

§101.31 Applicability.

This subpart applies to the operation of unmanned free balloons. However, a person operating an unmanned free balloon within a restricted area must comply only with §101.33 (d) and (e) and with any additional limitations that are imposed by the using or controlling agency, as appropriate.

§101.33 Operating limitations.

No person may operate an unmanned free balloon—

(a) Unless otherwise authorized by ATC, below 2,000 feet above the surface within the lateral boundaries of the surface areas of Class B, Class C, Class D, or Class E airspace designated for an airport;

(b) At any altitude where there are clouds or obscuring phenomena of more than five-tenths coverage;

(c) At any altitude below 60,000 feet standard pressure altitude where the horizontal visibility is less than five miles;

(d) During the first 1,000 feet of ascent, over a congested area of a city, town, or settlement or an open-air assembly of persons not associated with the operation; or

(e) In such a manner that impact of the balloon, or part thereof including its payload, with the surface creates a hazard to persons or property not associated with the operation.

[Doc. No. 1457, 29 FR 47, Jan. 3, 1964, as amended by Amdt. 101-5, 56 FR 65662, Dec. 17, 1991]

§101.35 Equipment and marking requirements.

(a) No person may operate an unmanned free balloon unless—

(1) It is equipped with at least two payload cut-down systems or devices that operate independently of each other;

(2) At least two methods, systems, devices, or combinations thereof, that function independently of each other, are employed for terminating the flight of the balloon envelope; and

(3) The balloon envelope is equipped with a radar reflective device(s) or material that will present an echo to surface radar operating in the 200 MHz to 2700 MHz frequency range.

The operator shall activate the appropriate devices required by paragraphs (a) (1) and (2) of this section when weather conditions are less than those prescribed for operation under this subpart, or if a malfunction or any other reason makes the further operation hazardous to other air traffic or to persons and property on the surface.

(b) No person may operate an unmanned free balloon below 60,000 feet standard pressure altitude between sunset and sunrise (as corrected to the altitude of operation) unless the balloon and its attachments and payload, whether or not they become separated during the operation, are equipped with lights that are visible for at least 5 miles and have a flash frequency of at least 40, and not more than 100, cycles per minute.

(c) No person may operate an unmanned free balloon that is equipped with a trailing antenna that requires an impact force of more than 50 pounds to break it at any point, unless the antenna has colored pennants or streamers that are attached at not more than 50 foot intervals and that are visible for at least one mile.

(d) No person may operate between sunrise and sunset an unmanned free balloon that is equipped with a suspension device (other than a highly conspicuously colored open parachute) more than 50 feet along, unless the suspension device is colored in alternate bands of high conspicuity colors or has colored pennants or streamers attached which are visible for at least one mile.

(Sec. 6(c), Department of Transportation Act (49 U.S.C. 1655(c)))

[Doc. No. 1457, 29 FR 47, Jan. 3, 1964, as amended by Amdt. 101-2, 32 FR 5254, Mar. 29, 1967; Amdt. 101-4, 39 FR 22252, June 21, 1974]

§101.37 Notice requirements.

(a) *Prelaunch notice:* Except as provided in paragraph (b) of this section, no person may operate an unmanned free balloon unless, within 6 to 24 hours before beginning the operation, he gives the following information to the FAA ATC facility that is nearest to the place of intended operation:

(1) The balloon identification.

(2) The estimated date and time of launching, amended as necessary to remain within plus or minus 30 minutes.

(3) The location of the launching site.

(4) The cruising altitude.

(5) The forecast trajectory and estimated time to cruising altitude or 60,000 feet standard pressure altitude, whichever is lower.

(6) The length and diameter of the balloon, length of the suspension device, weight of the payload, and length of the trailing antenna.

(7) The duration of flight.

(8) The forecast time and location of impact with the surface of the earth.

(b) For solar or cosmic disturbance investigations involving a critical time element, the information in paragraph (a) of this section shall be given within 30 minutes to 24 hours before beginning the operation.

(c) *Cancellation notice:* If the operation is canceled, the person who intended to conduct the operation shall immediately notify the nearest FAA ATC facility.

(d) *Launch notice:* Each person operating an unmanned free balloon shall notify the nearest FAA or military ATC facility of the launch time immediately after the balloon is launched.

§101.39 Balloon position reports.

(a) Each person operating an unmanned free balloon shall:

(1) Unless ATC requires otherwise, monitor the course of the balloon and record its position at least every two hours; and

(2) Forward any balloon position reports requested by ATC.

(b) One hour before beginning descent, each person operating an unmanned free balloon shall forward to the nearest FAA ATC facility the following information regarding the balloon:

(1) The current geographical position.

(2) The altitude.

(3) The forecast time of penetration of 60,000 feet standard pressure altitude (if applicable).

(4) The forecast trajectory for the balance of the flight.

(5) The forecast time and location of impact with the surface of the earth.

(c) If a balloon position report is not recorded for any two-hour period of flight, the person operating an unmanned free balloon shall immediately notify the nearest FAA ATC facility. The notice shall include the last recorded position and any revision of the forecast trajectory. The nearest FAA ATC facility shall be notified immediately when tracking of the balloon is re-established.

(d) Each person operating an unmanned free balloon shall notify the nearest FAA ATC facility when the operation is ended.

Filing for FAA Launch Authorization

Class 2 High Power Rockets

The new Class 2 rocket category covers high power rockets with up to 40,960 N-s total impulse. While the old rules prohibited flying unmanned rockets into controlled airspace the new rules do not. The new rules do however require prior authorization before launching. This is part of the operating limitations at 14 CFR 101.25.

Operating limitations for Class 2 High Power Rockets.

a. You must comply with the General Operating Limitations of § 101.23.
b. In addition, you must not operate a Class 2 High Power Rocket
    1. At any altitude where clouds or obscuring phenomena of more than five tenths coverage prevails;

2. At any altitude where the horizontal visibility is less than five miles;
3. Into any cloud;
4. Between sunset and sunrise without prior authorization from the FAA;
5. Within 8 kilometers (5 statute miles) of any airport boundary without prior authorization from the FAA;
6. In controlled airspace without prior authorization from the FAA;
7. Unless you observe the greater of the following separation distances from any person or property that is not associated with the operations applies:
    1. Not less than one quarter the maximum expected altitude;
    2. 457 meters (1,500 ft.);
8. Unless a person at least eighteen years old is present, is charged with ensuring the safety of the operation, and has final approval authority for initiating highpower rocket flight; and
9. Unless reasonable precautions are provided to report and control a fire caused by rocket activities.

Application and Forms

To apply for authorization, you need to obtain an Application for Waiver or Authorization, FAA Form 7711-2. You will have to file your application with one of the

FAA's regional offices and their contacts. Applications must be filed not later than 45 days prior to the date of proposed operations. You should plan on applying for authorization as far in advance as possible. I suggest 60 or more days just to add extra time to your launch project management time line. Launch participants will want to know the altitude limits and other special provisions when they make their plans.

Filling out the form is complicated by it being designed for airshows so the information it requests is not the same as the information required by 14 CFR 101.29:

When a Class 2 High Power Rocket requires a certificate of waiver or authorization, the person planning the operation must provide the information below on each type of rocket to the FAA at least 45 days before the proposed operation. The FAA may request additional information if necessary to ensure the proposed operations can be safely conducted. The information shall include for each type of Class 2 rocket expected to be flown:

1. Estimated number of rockets,
2. Type of propulsion (liquid or solid), fuel(s) and oxidizer(s),
3. Description of the launcher(s) planned to be used, including any airborne platform(s),
4. Description of recovery system,
5. Highest altitude, above ground level, expected to be reached,
6. Launch site latitude, longitude, and elevation, and

7. Any additional safety procedures that will be followed.

While items 5 and 6 are a good match for item 8 on the application the others match nothing. Include that information on a separate sheet(s).

Please note that a new 7711-2 form was issued in August 2008. Applications must be filed in triplicate, signed, and be accompanied by 7.5 series topographic quadrangle map(s) published by the USGS of the proposed operating areas. These need to be printed out and marked up with depictions of your flight line, launch control point, safety dispatch, and fire control equipment (fire extinguisher normally). We will show you how to make this map easy later in this document.

Airspace Review

The FAA is charged with ensuring the safe use of a public resource: the airspace above all our heads. The primary way they do their job is by making sure that airplanes work as they were designed and have adequate operational limits, ensuring that pilots and other airspace professionals (like controllers) have been adequately trained and receive recurrent training, and by separating airspace users in operation by adequate distances. It is the latter which will have the most bearing on your application.

Appendix B
Component Vendors

Vendor	Item
AirGas Inc.	
	200cf Helium Tank
	Helium Regulator
	Hoses, couplers, tape, etc.
Public Missiles Ltd.	
	Carbon Fiber Body Tube
	Motor Retension System
	RMS Motor Casing
	Nylon Webbing
	Parachutes
	Altimeters
Rocketry Warehouse	
	Nose cone
AeroTech	
	Motor Reloads
Byonics	
	Micro-Trak GPS-HAM transmitter
West Systems	
	Epoxy Resin
HamCity	
	Kenwood TM-D710A APRS transceiver
Spot LLC.	
	Spot 3 Tracker
High Altitude Science/Kaymont Consolidated Industries	
	600-3000g Balloons

Appendix C
Launch Vehicle Summary

Vehicle Dimensions

Length: 124.5

Diameter: 6

Span: 18.5

Unloaded mass: 25.282

Loaded Mass: 46.813 lbs.

CP: 102.87

CG: 90

Margin: 2.86

Fin Dimensions

Root: 15

Tip: 5

Sweep length: 7.625

Semi Span: 6

Motor Choice

Reloadable Motor System, N-Class Motor

Designation: Aerotech N4800T

Diameter: 98mm

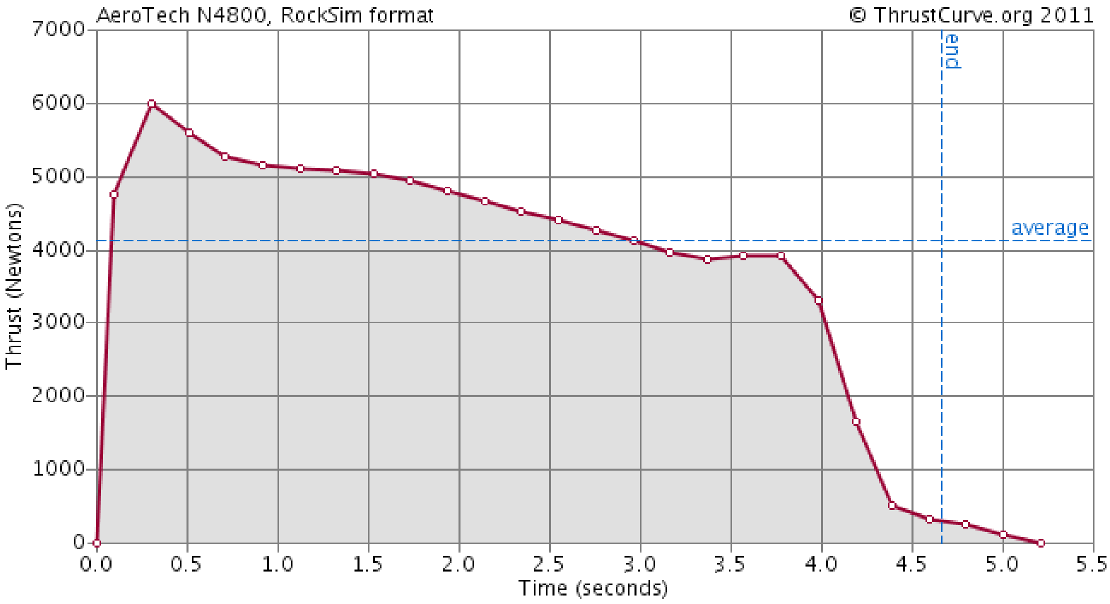
Length: 47.2835

Burn: 5.21s

Thrust: 3702.24 (average)

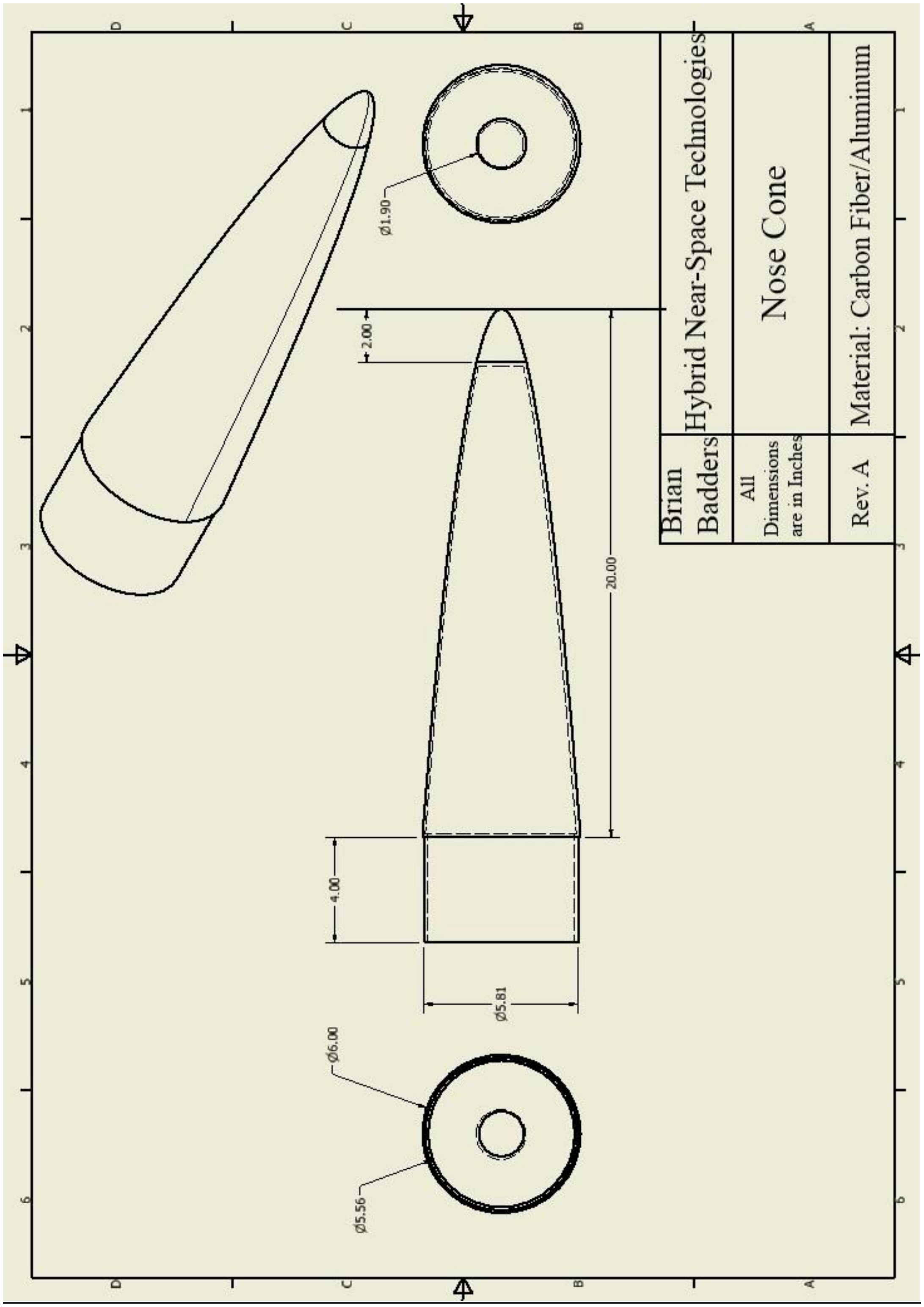
Impulse: 19273.861 N-s (total)

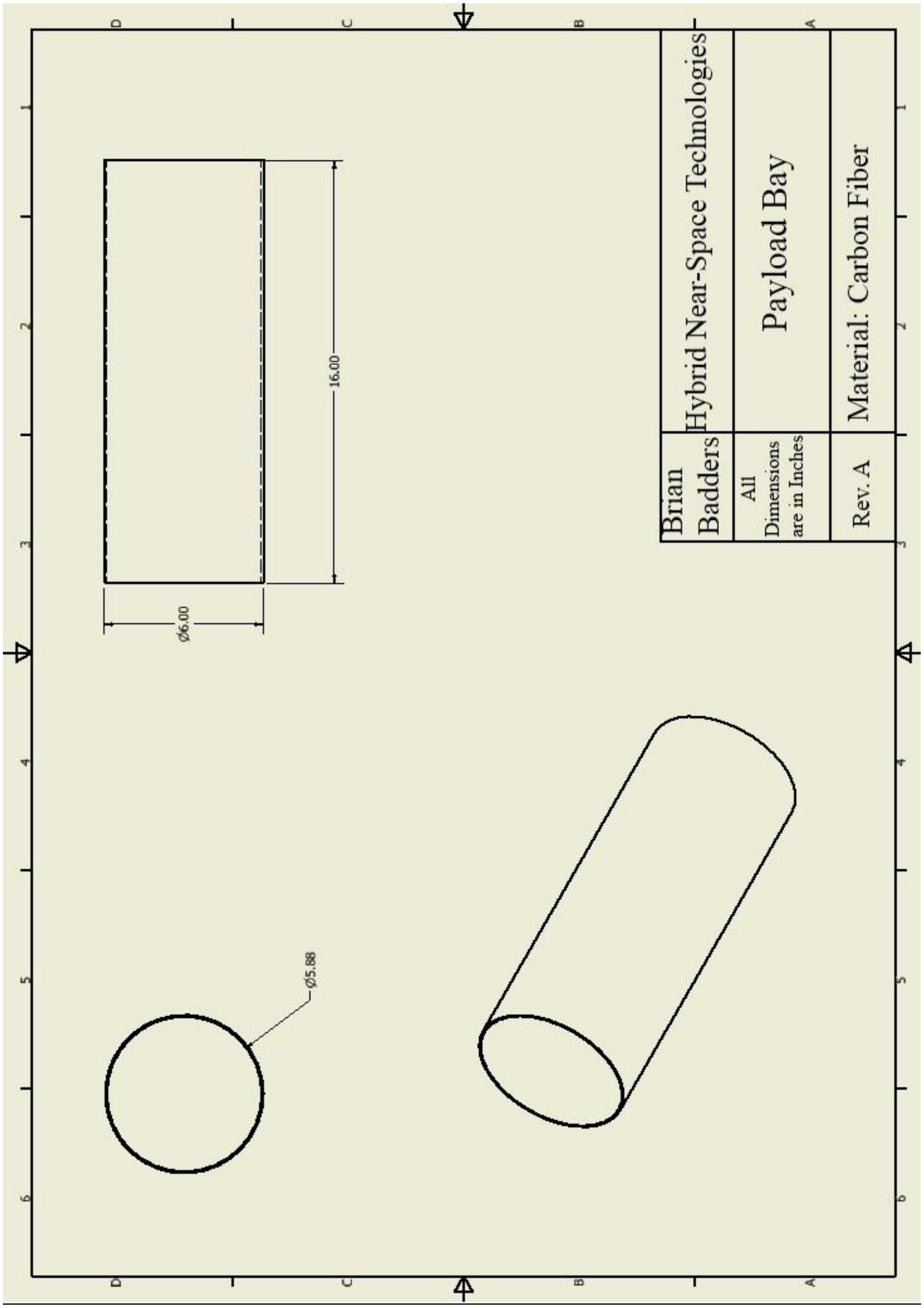
Thrust Curve



N4800T Thrust Curve. (Coker, 2008)

Appendix D
CAD Drawings

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Hybrid Near-Space Technologies
All Dimensions are in Inches
Payload Bay
Rev. A
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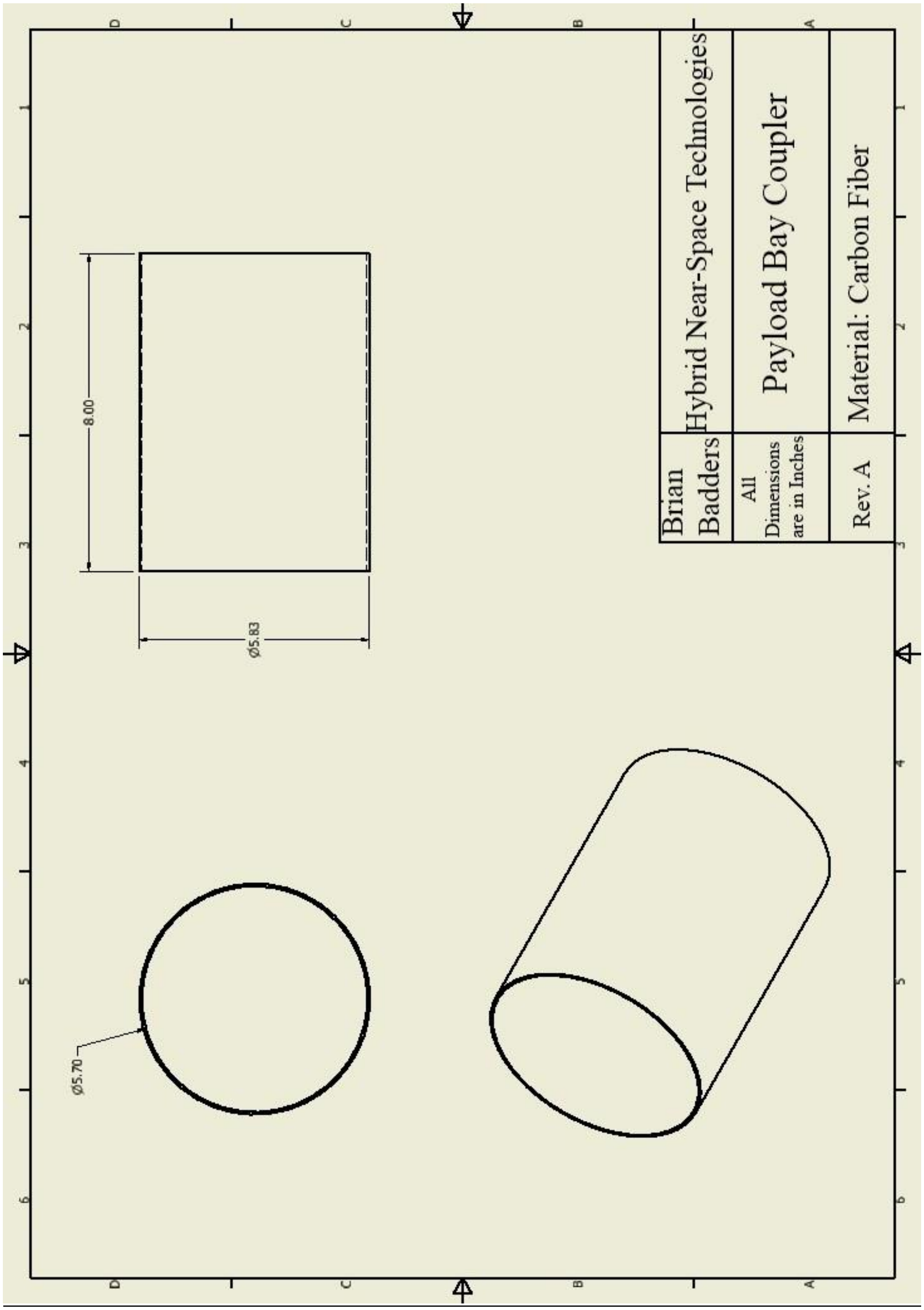
Ø5.88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Brian Badders
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Rev. A
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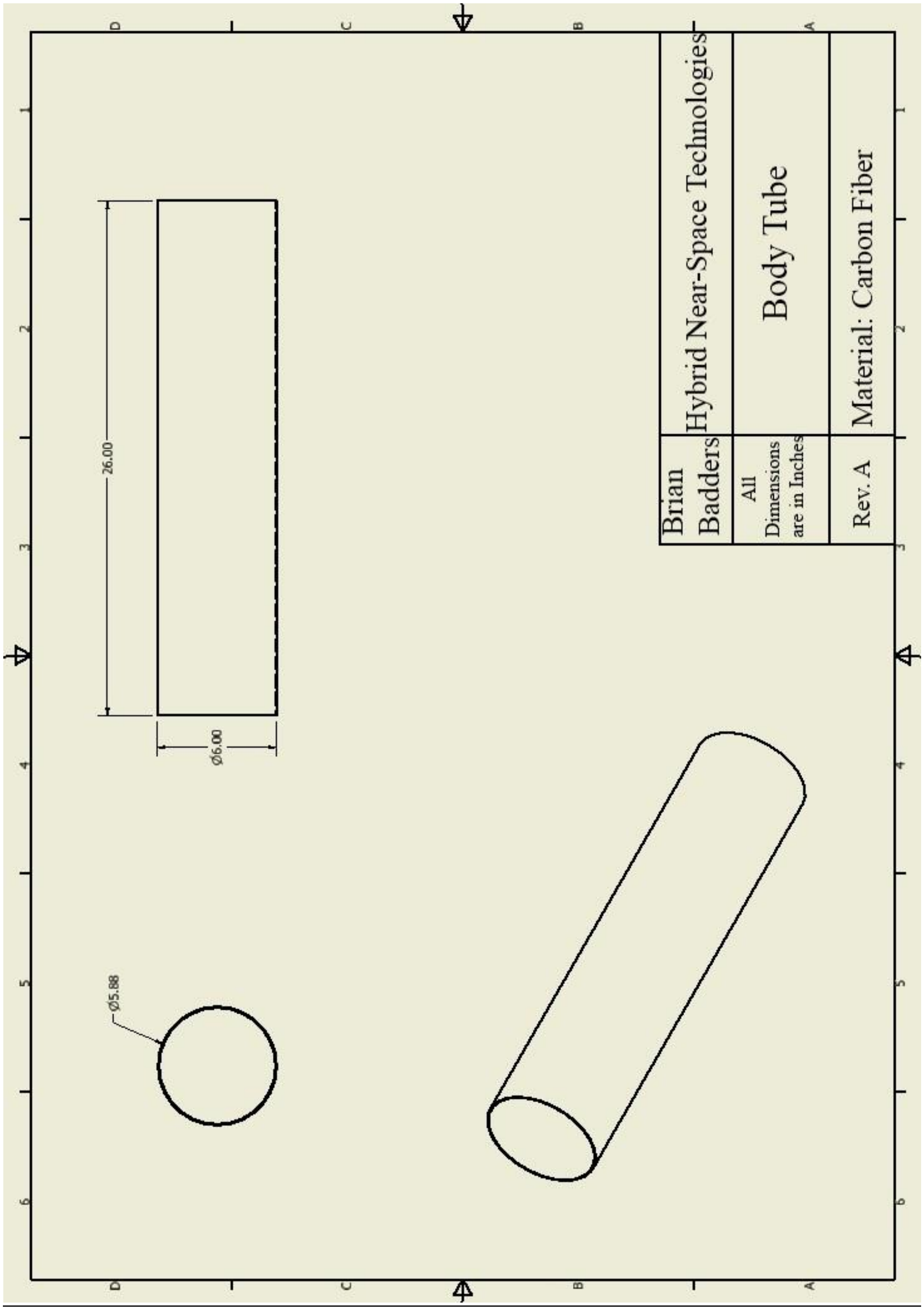
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Body Tube
Rev. A
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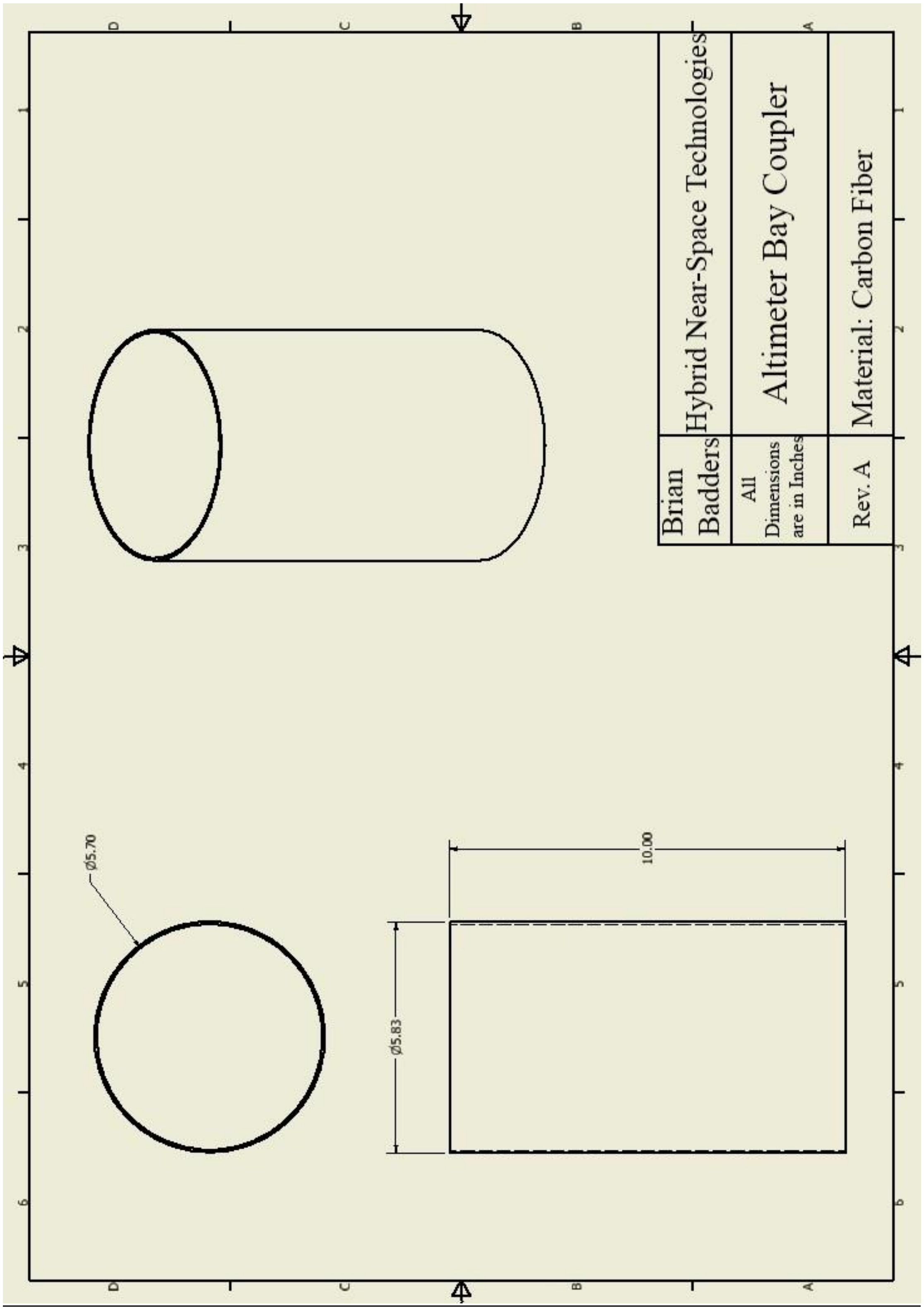
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Brian Badders
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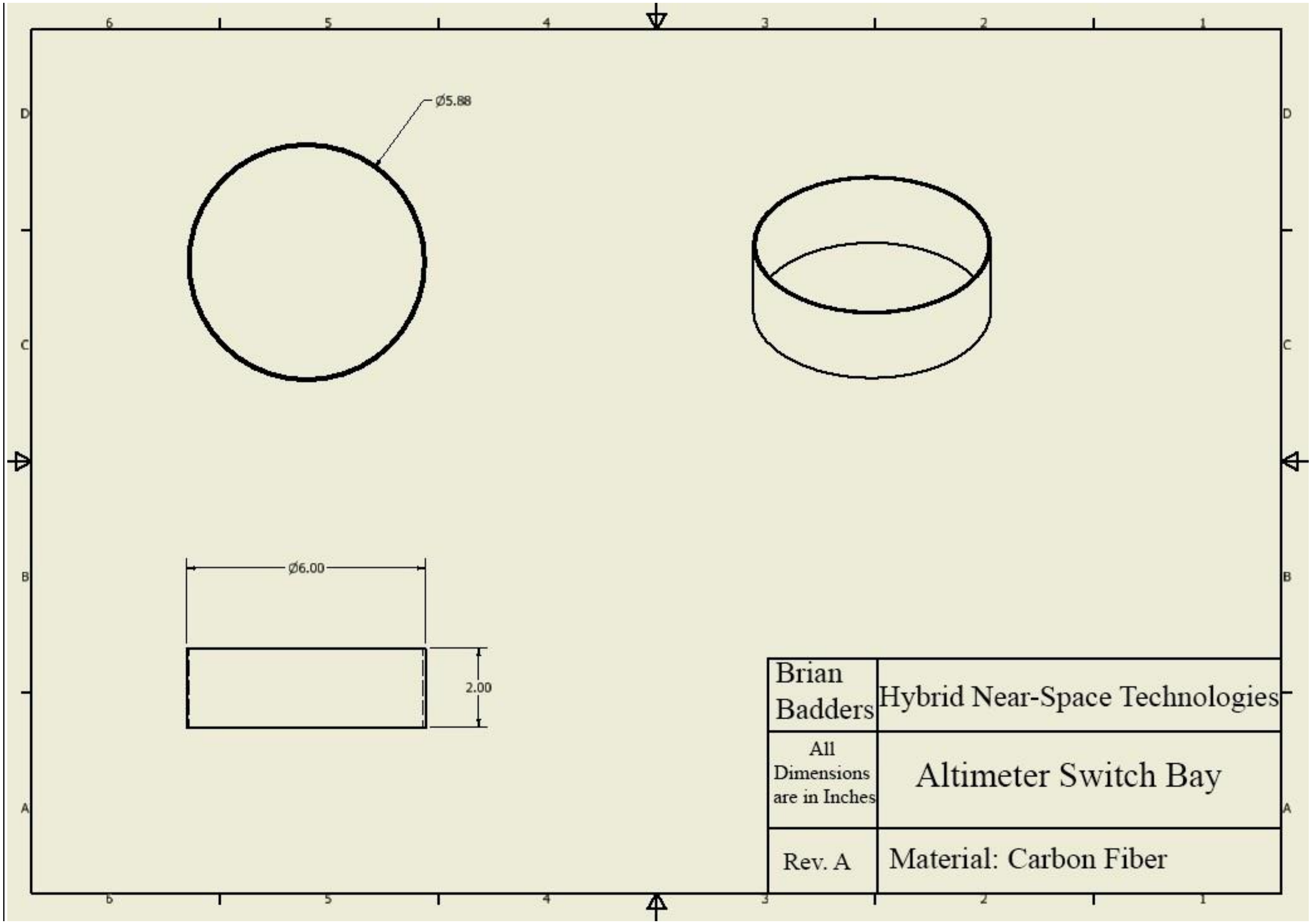
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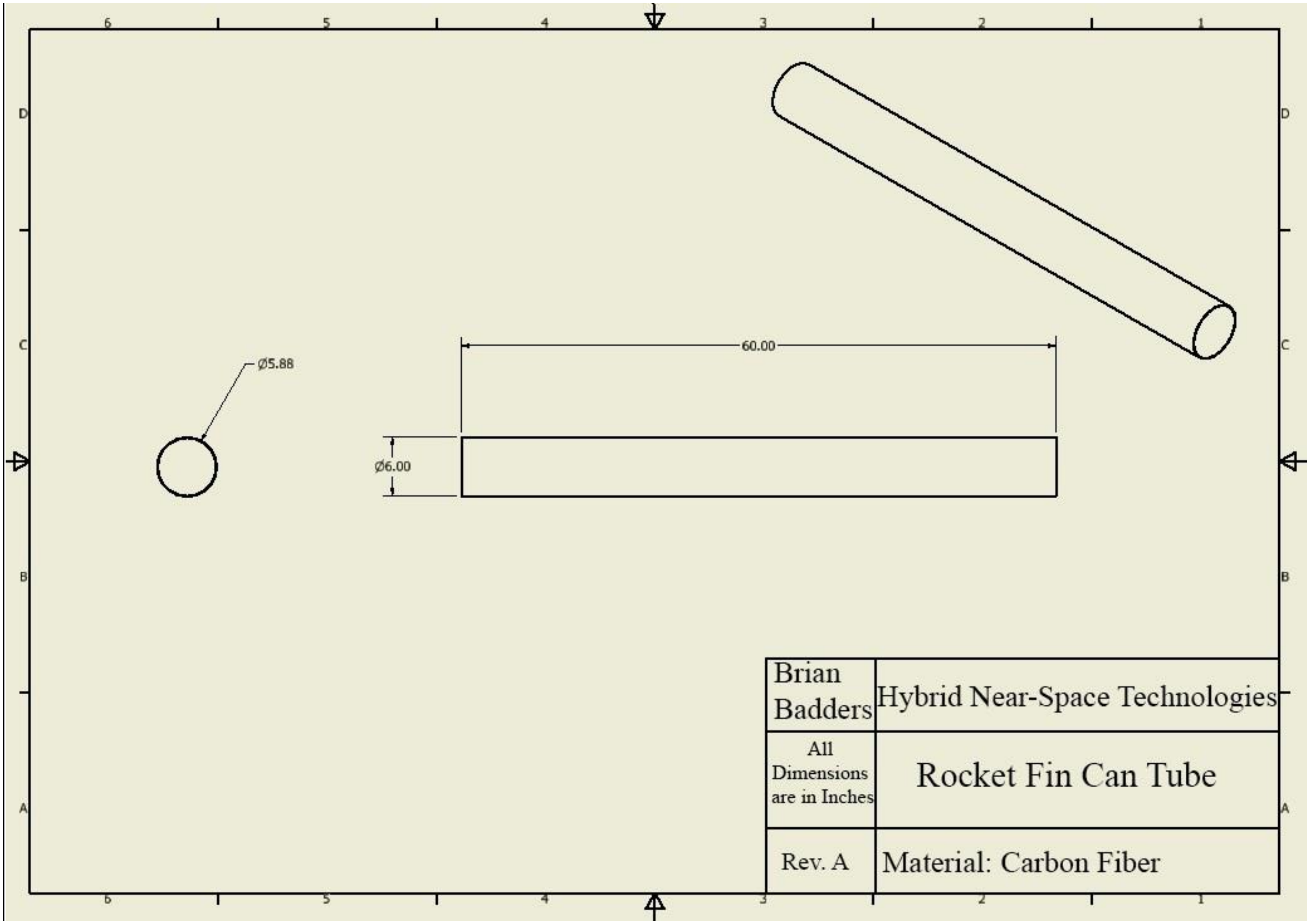
A



Brian Badders

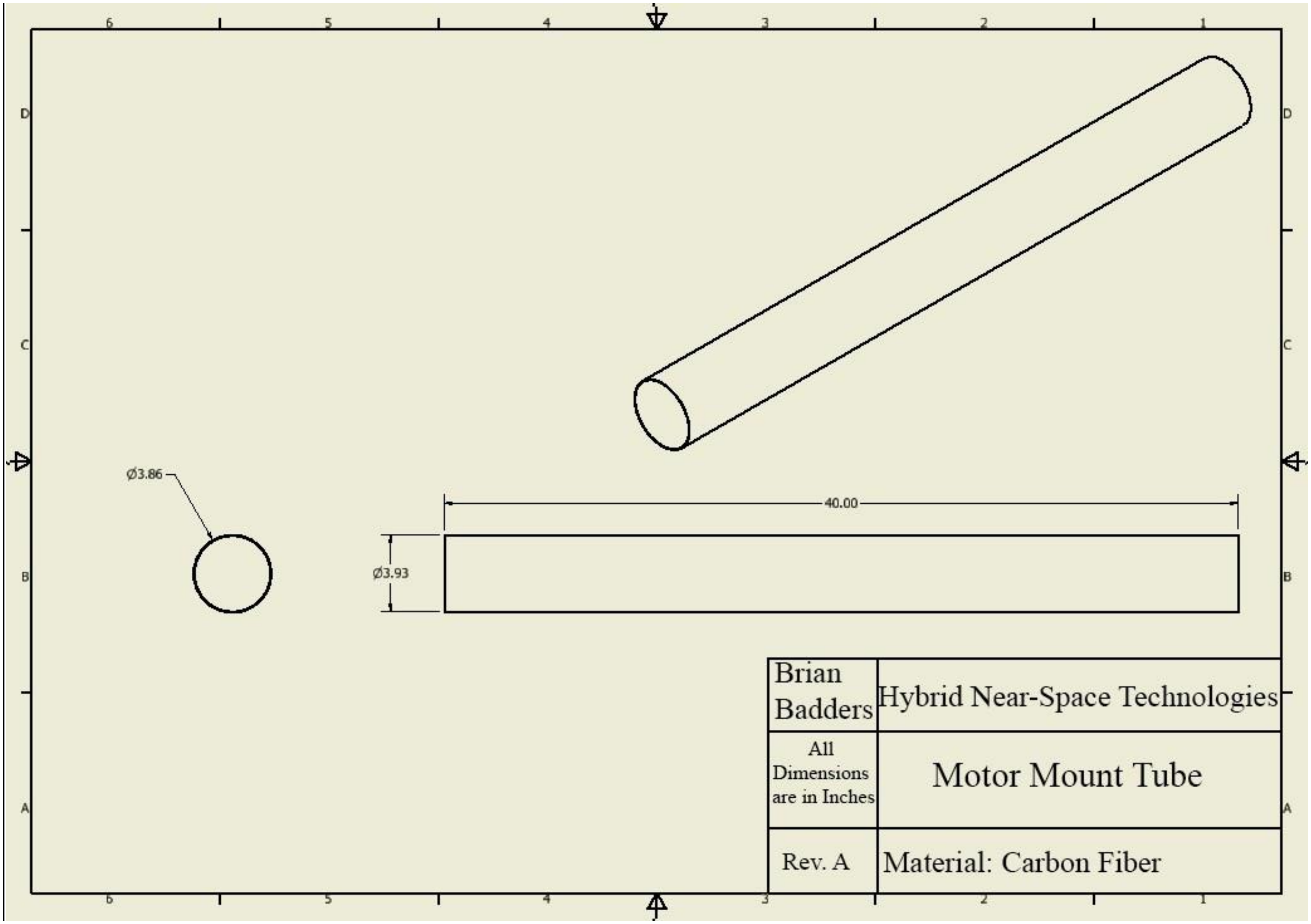
Hybrid Near-Space Technologies

All Dimensions are in Inches

Rocket Fin Can Tube

Rev. A

Material: Carbon Fiber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Brian Badders
Hybrid Near-Space Technologies
All Dimensions are in Inches
Motor Mount Tube
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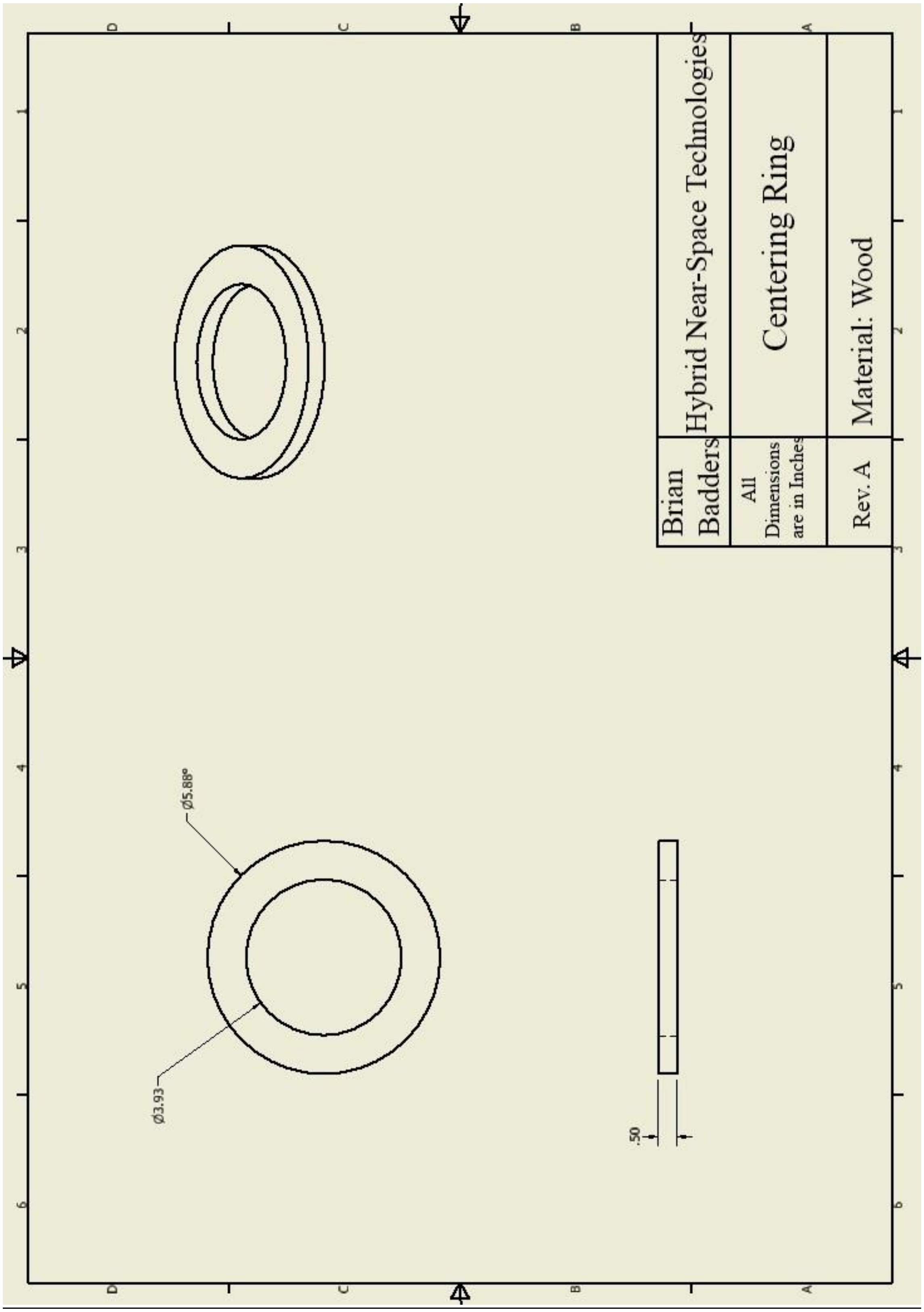
2
1
D
C
B
A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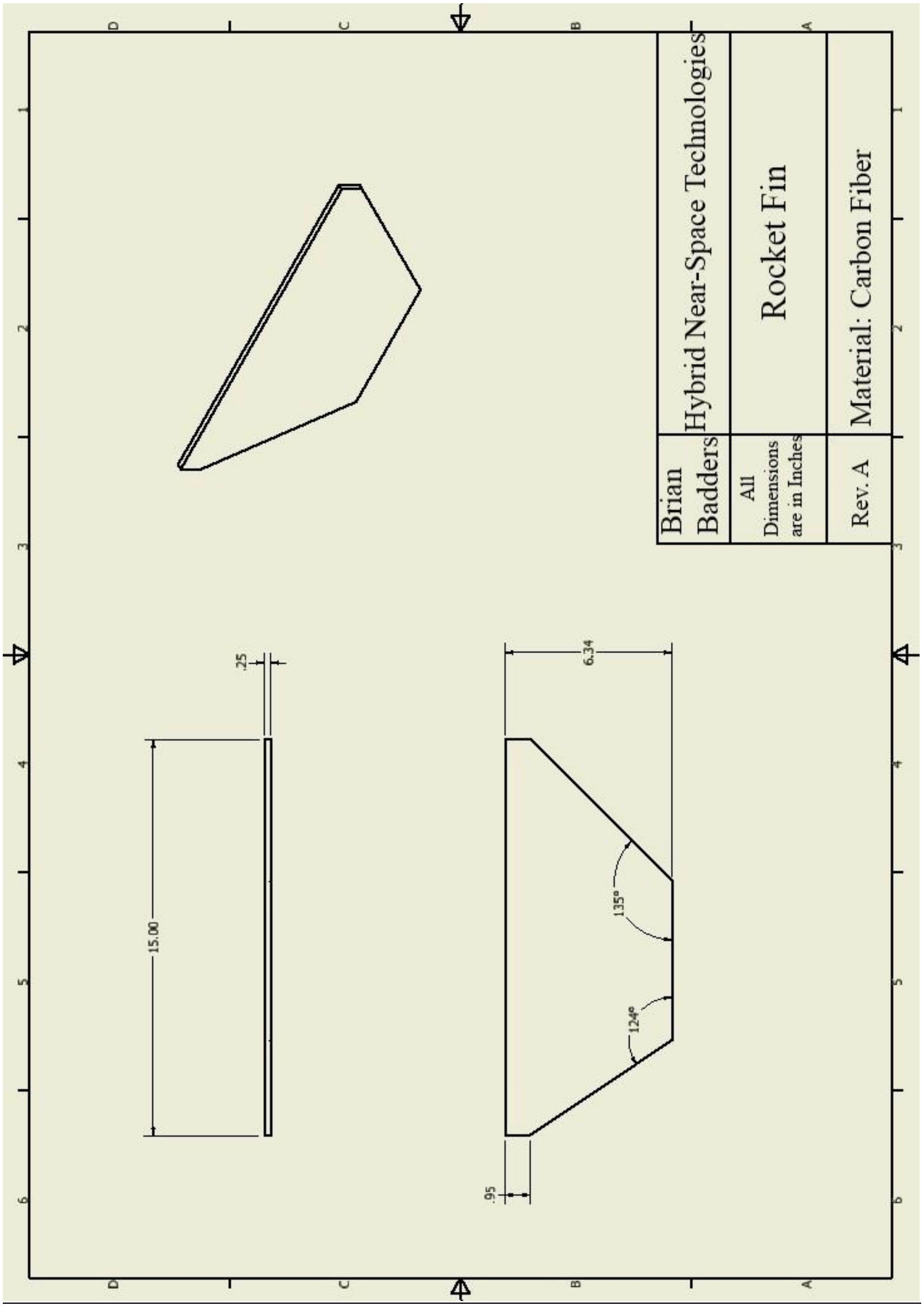
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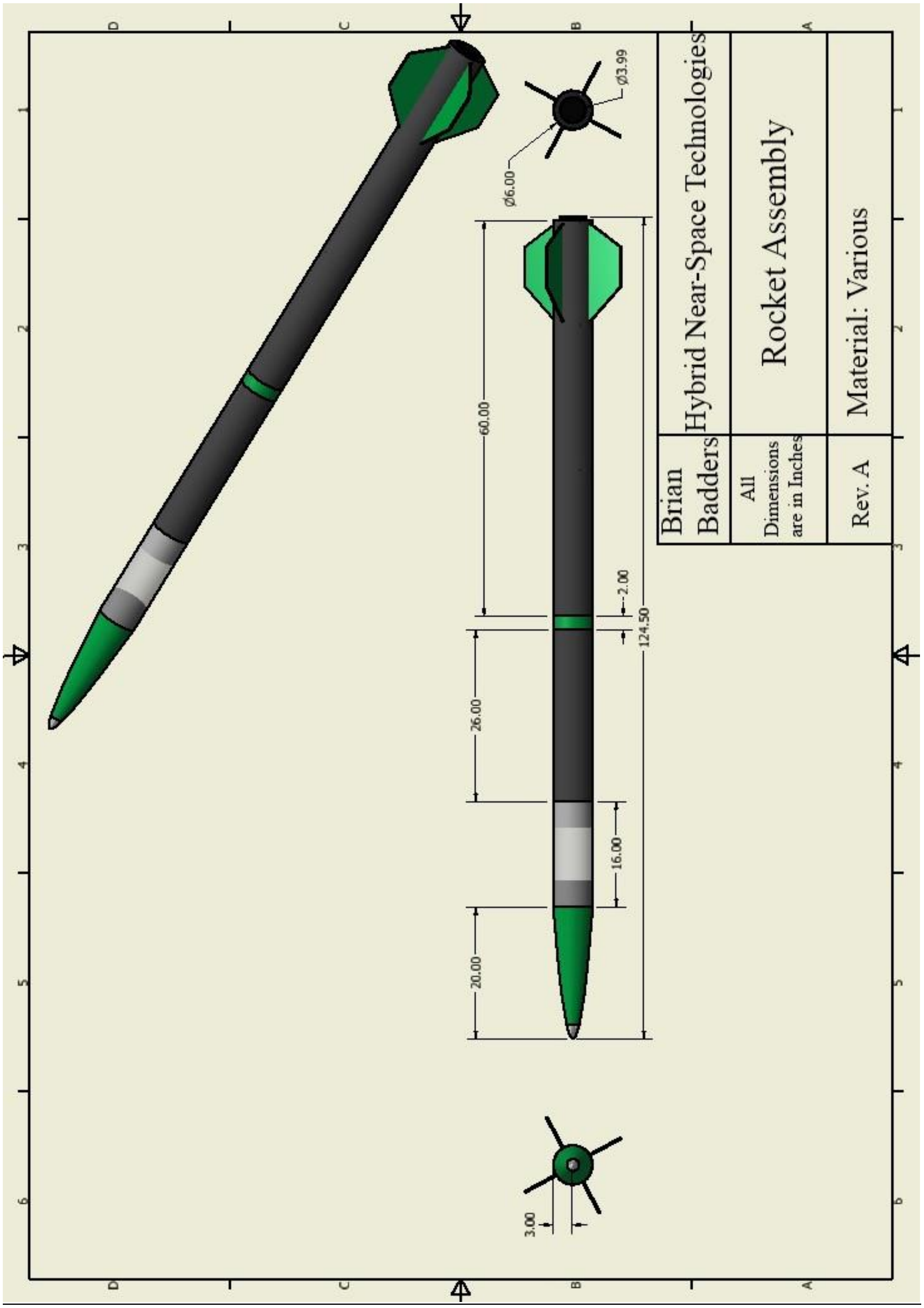
Brian Badders
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Rev. A
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26.00
16.00
20.00
3.00
A
B
C
D
1
2
3
4
5
6

Appendix E
Equivalent Airspeed Analysis

```
import math


def stability(A,Vtas,Lrsl):

    Psl=1.225

    Pa=0.00001846

    step=.01

    while Pa <= 1.225:

        sigma=Pa/Psl

        Veas=Vtas*math.sqrt(sigma)

        Lra=((Veas**2)/(2*A))

        ratio=(20)*(8.166790237704923/Lra)

        if ratio>=20 and ratio<=200:

            print(ratio, Pa)

        Pa+=step


>>> stability(915,45.6,20)

188.43478072267587 0.13001845999999997
```

```
import math
```

```
def stability(A,Vtas,Lrsl):
    Psl=1.225
    Pa=0.00001846
    step=.01
    while Pa <= 1.225:
        sigma=Pa/Psl
        Veas=Vtas*math.sqrt(sigma)
        Lra=((Veas**2)/(2*A))
        ratio=(20)*(8.166790237704923/Lra)
        if ratio>=20 and ratio<=200:
            print(ratio, Pa)
        Pa+=step


>>> stability(340,44.6,36.7)
191.7237425204916 0.23001846000000006



import math


def stability(A,Vtas,Lrsl):
    Psl=1.225
    Pa=0.00001846
    step=.001
```

```
    while Pa <= 1.225:
        sigma=Pa/Psl
        Veas=Vtas*math.sqrt(sigma)
        Lra=((Veas**2)/(2*A))
        ratio=(20)*(1.1362622950819672131147540983607/Lra)
        if ratio>=20 and ratio<=20000:
            print(ratio, Pa)
        Pa+=step
>>> stability (915,45.6,20)
12137.96656857208 0.00201846
8116.721772029445 0.00301846
```

Appendix F
Air Properties at Altitude

Barometric Pressure vs. Altitude Table									
Altitude Above Sea Level			Temperature		Barometer		Atmospheric Pressure		
Feet	Miles	Meters	F	C	In. Hg. Abs.	mm Hg. Abs.	PSI	Kg / sq. cm	kPa
0		0	59	15	29.92	760	14.696	1.0333	101.33
500		153	57	14	29.38	746.3	14.43	1.015	99.49
1000		305	55	13	28.86	733	14.16	0.996	97.63
1500		458	54	12	28.33	719.6	13.91	0.978	95.91
2000		610	52	11	27.82	706.6	13.66	0.96	94.19
2500		763	50	10	27.32	693.9	13.41	0.943	92.46
3000		915	48	9	26.82	681.2	13.17	0.926	90.81
3500		1068	47	8	26.33	668.8	12.93	0.909	89.15
4000		1220	45	7	25.84	656.3	12.69	0.892	87.49
4500		1373	43	6	25.37	644.4	12.46	0.876	85.91
5000	0.95	1526	41	5	24.9	632.5	12.23	0.86	84.33
6000	1.1	1831	38	3	23.99	609.3	11.78	0.828	81.22
7000	1.3	2136	34	1	23.1	586.7	11.34	0.797	78.19
8000	1.5	2441	31	-1	22.23	564.6	10.91	0.767	75.22
9000	1.7	2746	27	-3	21.39	543.3	10.5	0.738	72.4
10,000	1.9	3050	23	-5	20.58	522.7	10.1	0.71	69.64
15,000	2.8	4577	6	-14	16.89	429	8.29	0.583	57.16
20,000	3.8	6102	-12	-24	13.76	349.5	6.76	0.475	46.61
25,000	4.7	7628	-30	-34	11.12	282.4	5.46	0.384	37.65
30,000	5.7	9153	-48	-44	8.903	226.1	4.37	0.307	30.13
35,000	6.6	10,679	-66	-54	7.06	179.3	3.47	0.244	23.93
40,000	7.6	12,204	-70	-57	5.558	141.2	2.73	0.192	18.82
45,000	8.5	13,730	-70	-57	4.375	111.1	2.15	0.151	14.82
50,000	9.5	15,255	-70	-57	3.444	87.5	1.69	0.119	11.65
55,000	10.4	16,781	-70	-57	2.712	68.9	1.33	0.0935	9.17
60,000	11.4	18,306	-70	-57	2.135	54.2	1.05	0.0738	7.24
70,000	13.3	21,357	-67	-55	1.325	33.7	0.651	0.651	4.49
80,000	15.2	24,408	-62	-52	0.8273	21	0.406	0.406	2.8
90,000	17.1	27,459	-57	-59	0.52	13.2	0.255	0.255	1.76
100,000	18.9	30,510	-51	-46	0.329	8.36	0.162	0.162	1.12
200,000	37.9	60,960	-20	-29	0.006	0.155	0.003	0	0.021
250,000	47	76,200	-89	-67	0	0	0	0	0

Appendix G
Simulation Results

- Sea-Level Launch Simulation results

Engine selection

[N4800T-None]

Simulation control parameters

- Flight resolution: 800.000000 samples/second
- Descent resolution: 1.000000 samples/second
- Method: 4th Order runge-kuta.
- End the simulation when the rocket reaches the ground.

Launch conditions

- **Altitude: 0.00000 Ft.**
- Relative humidity: 50.000 %
- Temperature: 67.420 Deg. F
- Pressure: 29.9213 In.

Wind speed model: Calm (0-2 MPH)

- Low wind speed: 0.0000 MPH
- High wind speed: 2.0000 MPH

Wind turbulence: Fairly constant speed (0.01)

- Frequency: 0.010000 rad/second

- Wind starts at altitude: 0.00000 Ft.
- Launch guide angle: 0.000 Deg.
- Latitude: 40.910 Degrees

Launch guide data:

- Launch guide length: 200.5000 In.
- Velocity at launch guide departure: 164.1632 ft/s
- The launch guide was cleared at : 0.262 Seconds
- User specified minimum velocity for stable flight: 43.9993 ft/s
- Minimum velocity for stable flight reached at: 20.0080 In.

Max data values:

- Maximum acceleration:Vertical (y): 924.335 Ft./s/sHorizontal (x): 0.804 Ft./s/sMagnitude: 924.335 Ft./s/s
- Maximum velocity:Vertical (y): 2476.0104 ft/s, Horizontal (x): 2.9333 ft/s, Magnitude: 2476.0134 ft/s
- Maximum range from launch site: 806.70349 Ft.
- Maximum altitude: 23474.77345 Ft.

Recovery system data

- P: Main Parachute Deployed at : 450.483 Seconds
- Velocity at deployment: 43.9912 ft/s
- Altitude at deployment: 1999.94644 Ft.
- Range at deployment: 566.39214 Ft.

- P: Parachute Deployed at : 31.844 Seconds
- Velocity at deployment: 1.1318 ft/s
- Altitude at deployment: 23474.77344 Ft.
- Range at deployment: -50.62191 Ft.

Time data

- Time to burnout: 5.206 Sec.
- Time to apogee: 31.844 Sec.
- Optimal ejection delay: 26.637 Sec.

Landing data

- Successful landing
- Time to landing: 565.946 Sec.
- Range at landing: 806.70349

Velocity at landing: Vertical: -17.0301 ft/s , Horizontal: 1.2939 ft/s , Magnitude: 17.0792 ft/s

- 40,000 ft. Launch Simulation results

Engine selection

[N4800T-None]

Simulation control parameters

- Flight resolution: 800.000000 samples/second
- Descent resolution: 1.000000 samples/second
- Method: 4th Order runge-kuta.
- End the simulation when the rocket reaches the ground.

Launch conditions

- Altitude: 40000.000 Ft.
- Relative humidity: 50.000 %
- Temperature: -67.420 Deg. F
- Pressure: 5.5517 In.

Wind speed model: Calm (0-2 MPH)

- Low wind speed: 0.0000 MPH
- High wind speed: 2.0000 MPH

Wind turbulence: Fairly constant speed (0.01)

- Frequency: 0.010000 rad/second
- Wind starts at altitude: 0.00000 Ft.
- Launch guide angle: 0.000 Deg.
- Latitude: 40.910 Degrees

Launch guide data:

- Launch guide length: 200.5000 In.
- Velocity at launch guide departure: 163.1759 ft/s

- The launch guide was cleared at : 0.261 Seconds
- User specified minimum velocity for stable flight: 43.9993 ft/s
- Minimum velocity for stable flight reached at: 20.0175 In.

Max data values:

- Maximum acceleration:Vertical (y): 939.577 Ft./s/sHorizontal (x): 0.327 Ft./s/sMagnitude: 939.590 Ft./s/s
- Maximum velocity:Vertical (y): 3659.6678 ft/s, Horizontal (x): 1.9260 ft/s, Magnitude: 3659.7042 ft/s
- Maximum range from launch site: 1445.39478 Ft.
- Maximum altitude: 170778.67548 Ft.

Recovery system data

- P: Main Parachute Deployed at : 334.625 Seconds
- Velocity at deployment: 202.6610 ft/s
- Altitude at deployment: 1999.97690 Ft.
- Range at deployment: -1305.86737 Ft.
- P: Parachute Deployed at : 104.392 Seconds
- Velocity at deployment: 13.8920 ft/s
- Altitude at deployment: 170778.67548 Ft.
- Range at deployment: -1445.39478 Ft.

Time data

- Time to burnout: 5.206 Sec.

- Time to apogee: 104.392 Sec.
- Optimal ejection delay: 99.186 Sec.

Landing data

- Successful landing
- Time to landing: 361.879 Sec.
- Range at landing: -1299.88323

Velocity at landing: Vertical: -64.9261 ft/s , Horizontal: 0.3313 ft/s , Magnitude: 64.9270 ft/s

- 50,000 ft. Launch Simulation results

Engine selection

[N4800T-None]

Simulation control parameters

- Flight resolution: 800.000000 samples/second
- Descent resolution: 1.000000 samples/second
- Method: 4th Order runge-kuta.
- End the simulation when the rocket reaches the ground.

Launch conditions

- Altitude: 50000.000 Ft.
- Relative humidity: 50.000 %
- Temperature: -69.000 Deg. F
- Pressure: 3.4449 In.

Wind speed model: Calm (0-2 MPH)

- Low wind speed: 0.0000 MPH
- High wind speed: 2.0000 MPH

Wind turbulence: Fairly constant speed (0.01)

- Frequency: 0.010000 rad/second
- Wind starts at altitude: 0.00000 Ft.
- Launch guide angle: 0.000 Deg.
- Latitude: 40.910 Degrees

Launch guide data:

- Launch guide length: 200.5000 In.
- Velocity at launch guide departure: 163.1873 ft/s
- The launch guide was cleared at : 0.261 Seconds
- User specified minimum velocity for stable flight: 43.9993 ft/s
- Minimum velocity for stable flight reached at: 20.0197 In.

Max data values:

- Maximum acceleration:Vertical (y): 977.810 Ft./s/sHorizontal (x): 4656.795 Ft./s/sMagnitude: 703476.134 Ft./s/s
- Maximum velocity:Vertical (y): 3743.0915 ft/s, Horizontal (x): 4.7104 ft/s, Magnitude: 3743.0917 ft/s
- Maximum range from launch site: 120.75472 Ft.
- Maximum altitude: 202406.37458 Ft.

Recovery system data

- P: Main Parachute Deployed at : 259.326 Seconds
- Velocity at deployment: 348.3235 ft/s
- Altitude at deployment: 1999.67795 Ft.
- Range at deployment: 28.76891 Ft.
- P: Parachute Deployed at : 109.395 Seconds
- Velocity at deployment: 711.5578 ft/s
- Altitude at deployment: 202406.02620 Ft.
- Range at deployment: -120.75242 Ft.

Time data

- Time to burnout: 5.206 Sec.
- Time to apogee: 109.395 Sec.
- Optimal ejection delay: 104.189 Sec.

Landing data

- Successful landing

- Time to landing: 272.243 Sec.
- Range at landing: 56.02205
- Velocity at landing: Vertical: -127.3970 ft/s , Horizontal: 2.1941 ft/s , Magnitude: 127.4159 ft/s

- 60,000 ft. Launch Simulation results

Engine selection

[N4800T-None]

Simulation control parameters

- Flight resolution: 800.000000 samples/second
- Descent resolution: 1.000000 samples/second
- Method: 4th Order runge-kuta.
- End the simulation when the rocket reaches the ground.

Launch conditions

- Altitude: 60000.000 Ft.
- Relative humidity: 50.000 %
- Temperature: -69.000 Deg. F
- Pressure: 2.1339 In.

Wind speed model: Calm (0-2 MPH)

- Low wind speed: 0.0000 MPH
- High wind speed: 2.0000 MPH

Wind turbulence: Fairly constant speed (0.01)

- Frequency: 0.010000 rad/second

- Wind starts at altitude: 0.00000 Ft.
- Launch guide angle: 0.000 Deg.
- Latitude: 40.910 Degrees

Launch guide data:

- Launch guide length: 200.5000 In.
- Velocity at launch guide departure: 163.1971 ft/s
- The launch guide was cleared at : 0.261 Seconds
- User specified minimum velocity for stable flight: 43.9993 ft/s
- Minimum velocity for stable flight reached at: 20.0220 In.

Max data values:

- Maximum acceleration:Vertical (y): 993.921 Ft./s/sHorizontal (x): 52.631 Ft./s/sMagnitude: 3853.462 Ft./s/s
- Maximum velocity:Vertical (y): 3782.1415 ft/s, Horizontal (x): 2.4406 ft/s, Magnitude: 3782.1543 ft/s
- Maximum range from launch site: 1099.11785 Ft.
- Maximum altitude: 220142.89793 Ft.

Recovery system data

- P: Main Parachute Deployed at : 256.887 Seconds
- Velocity at deployment: 706.6373 ft/s
- Altitude at deployment: 1999.59904 Ft.
- Range at deployment: -890.40216 Ft.
- P: Parachute Deployed at : 119.672 Seconds
- Velocity at deployment: 9.1681 ft/s
- Altitude at deployment: 220142.89793 Ft.
- Range at deployment: -1099.11785 Ft.

Time data

- Time to burnout: 5.206 Sec.
- Time to apogee: 119.672 Sec.
- Optimal ejection delay: 114.466 Sec.

Landing data

- Successful landing
- Time to landing: 262.076 Sec.
- Range at landing: -887.52815
- Velocity at landing: Vertical: -257.9897 ft/s , Horizontal: 0.5243 ft/s , Magnitude: 257.9903 ft/s

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