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The Effects of Spin Stabilization in Amateur Rocketry

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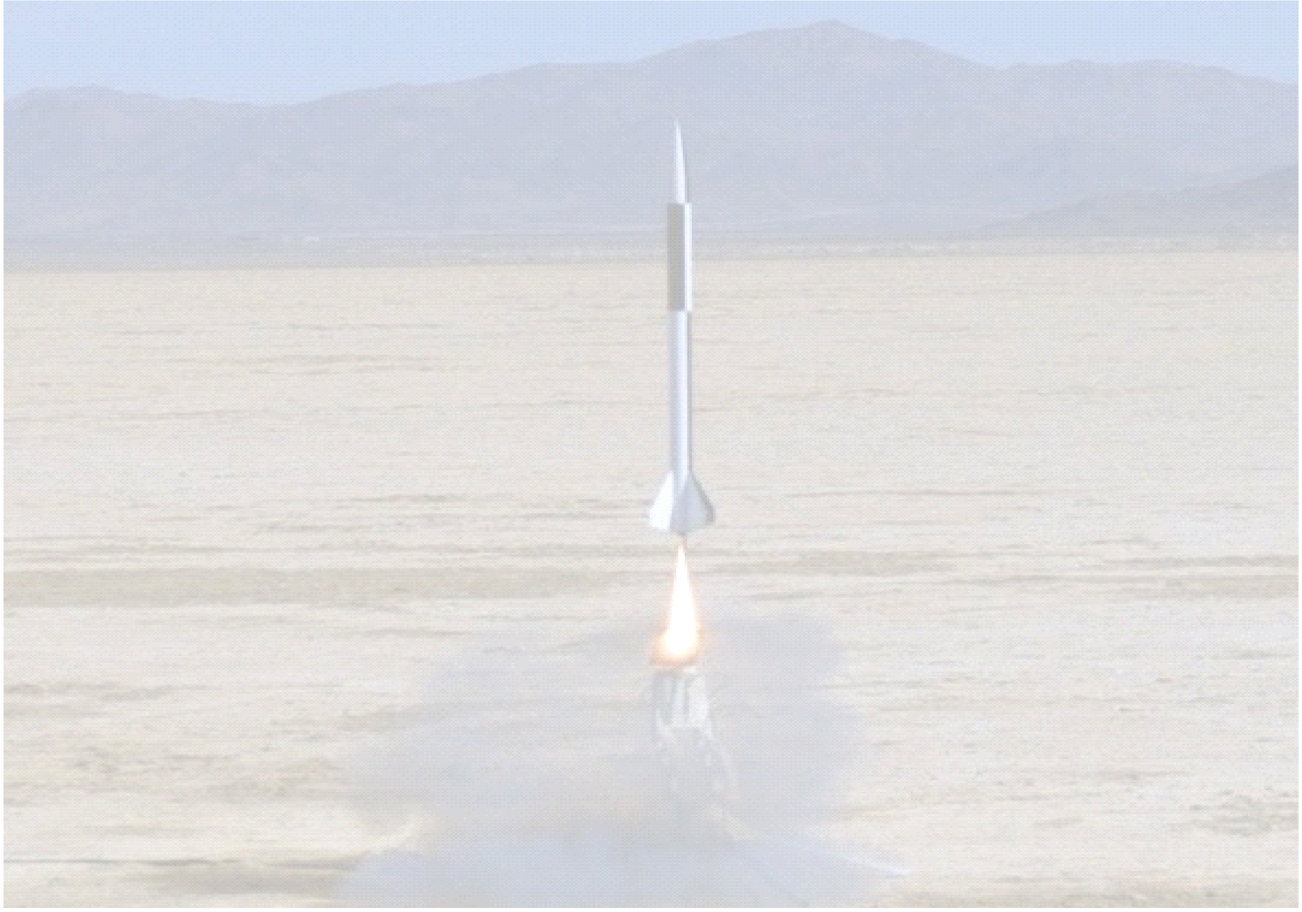


1.0 Abstract

Objective: The purpose of this experiment was to research the effects of spin stabilization on the altitude of an amateur rocket. The hypothesis was that while spin is beneficial for stabilization purposes, excessive spin could result in a decrease in altitude.

Materials and Methods: Six Aerotech Airspike rocket kits were used for this project. Five of the rockets included the addition of fin tabs at different angles to induce various amounts of spin. A payload section was also added to house electronics used to record flight data. For recording flight data, a Rocket Data Acquisition System, or RDAS, unit was used. The RDAS is equipped with an altimeter, accelerometer, and six analog-to-digital channels for recording additional data. A photo cell circuit, wired to the RDAS unit, was used to determine roll rate. Each rocket was flown an average of three times to gather data. All flights used an Aerotech Econojet F20-7 rocket motor.

Results: The data from the flights was recorded on the RDAS unit and then downloaded onto a computer and graphed for analysis. The results proved the hypothesis. The faster a rocket was spinning, the lower the altitude achieved.

Conclusions: The energy taken to spin the rocket decreased the altitude achieved. The final results plotted on a graph as altitude versus roll rate, shows a second order equation. This was found to be caused by the amount of drag produced by the spinning of the fins, with this drag being proportional to the square of the angular velocity.

2.0 Introduction

Amateur hobby rockets are constantly getting wind cocked, flying astray, etc. due to stability problems. This results in a loss in altitude, and can be dangerous to bystanders and flyers alike. A simple economic way to fix this problem is with the use of spin stabilization. The main research of this paper was to find whether spinning can actually decrease the altitude. While spinning a rocket can help correct off center masses and thrust abnormalities, it also adds extra drag. The drag is created by the fins being pushed through the air like paddles. The purpose of this experiment was to find how much this excessive drag affects the altitude of a rocket, and to derive an equation to tell how much altitude a rocket has lost if the roll rate was known.

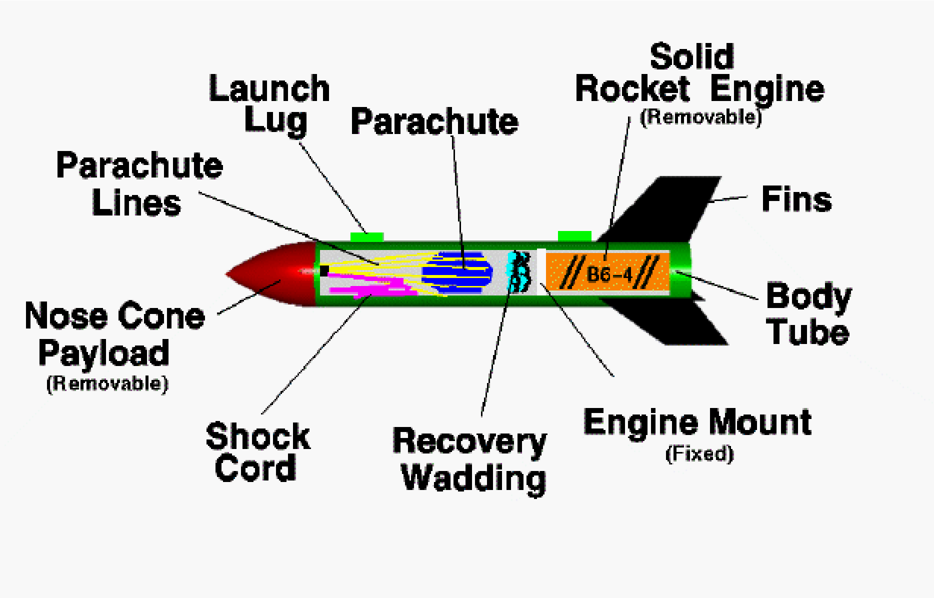
3.0 Literature Review

3.1 Basics of Rocketry

3.1.1 Parts of a Rocket

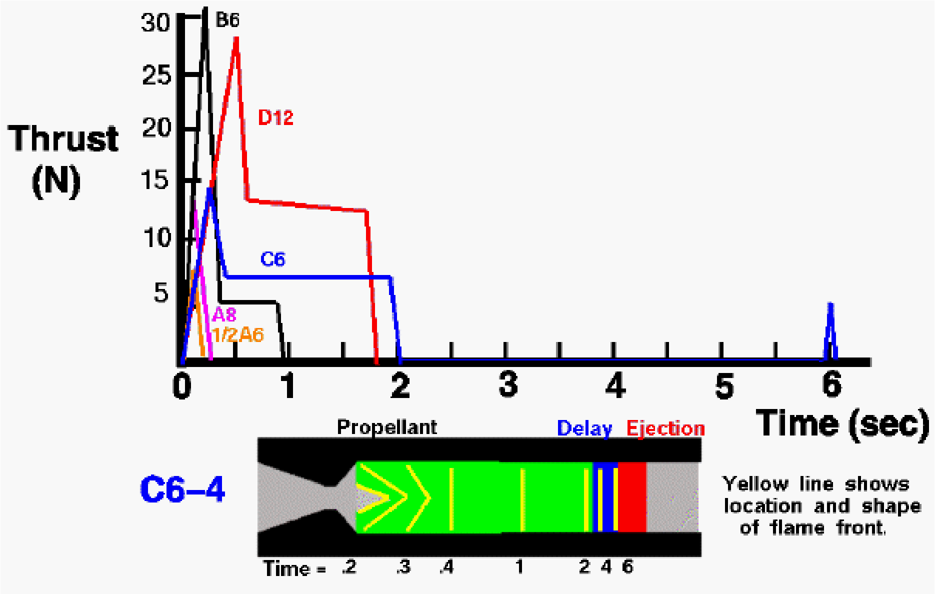
The first thing one should know about rocketry are the parts of a simple single-stage, model rocket. The first and most important parts are the body tube, nose cone, and fins. The body tube can be made from cardboard, fiberglass, or any other of a number of composites. The fins and nose cone can be made of balsa wood, plastic, metal, fiberglass or many other materials.

FIGURE 1. **Parts of a Model Rocket** **(Glenn Research Center, NASA)**



The next most important part is the motor. Inside the rocket is a motor mount, which holds the motor in place. The letter designation on a motor is the total impulse of that motor. An A motor has 2.5 newton seconds total impulse. Total impulse is the integral of thrust in newtons times the number of seconds that the force is applied. If a force of ten newtons is applied for one second, the total impulse is ten newton seconds. If the same force of ten newtons is applied for two seconds, the total impulse is twenty newton seconds. A B motor has twice the total impulse of an A, and a C twice the total impulse of a B, etc. The first number designation on a motor is the average thrust. Thrust is the force applied. The higher the number, the more thrust, and the faster the motor burns. The second number is the delay time in seconds. If you have a C6-7, the motor has ten newton seconds total impulse, six newton seconds average thrust, and a seven second delay element. The delay element burns from when the motor stops burning. When the delay element has burned, it ignites the ejection charge, which blows the nose cone off, and the parachute or streamer out. On larger rockets, delay charges are rarely used. Most of the time, an altimeter is used to set of the ejection charge. (Beginner's Guide to Aeronautics)

FIGURE 2. **Rocket Engine Performance** **(Glenn Research Center, NASA)**



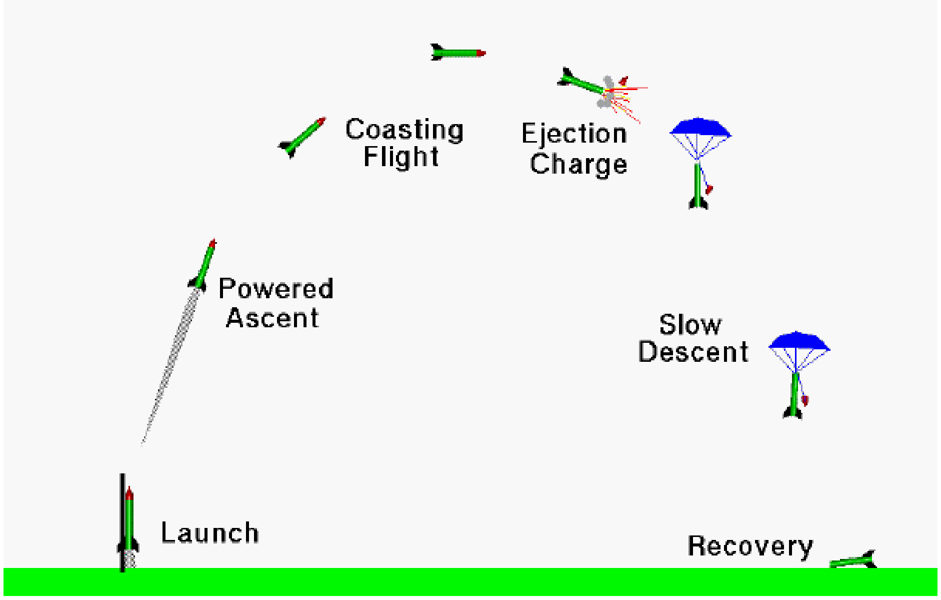
The parachute or streamer is the next most important part of a rocket, without this, a rocket would become a “lawn dart”. On most larger rockets, a parachute is used, giving a lighter landing. For some small rockets, a streamer is enough to prevent damage. The shroud lines are the lines from the parachute to the shock cord. A shock cord is used in smaller rockets. It is an elastic cord that attaches the parachute, nose cone, and body together. In larger rockets, webbing or other static cord is used. To prevent the hot gasses from damaging the parachute, recovery wadding is inserted just below the shock cord every flight to protect the recovery harness. In larger rockets, either a wire mesh is permanently installed, pistons are used to push out the parachute, or deployment bags are used which contain the parachute within them. (Beginner's Guide to Aeronautics)

Launch lugs are small “straws” that are placed on the outside of a rocket to be slipped over a launch rod. The launch rod is used for stability for the first part of flight. Instead of launch lugs and a launch rod, rail guides and a launch rail can be used. Rail guides are basically screws that hang out the side of the rocket, and slip into a notch that runs along a rail. Large sounding rockets usually have no external lugs at all. They are usually shot out of a barrel. A sounding rocket is a rocket designed for high altitude atmospheric research capable of traveling at hyper sonic speeds. (Beginner's Guide to Aeronautics)

3.1.2 A Normal Flight

A normal flight of a single stage model rocket usually consists of five or six distinct phases. The first is liftoff. This happens when the motor is ignited, and the rocket leaves the pad. The second is the powered flight. This is when the rocket is flying under thrust from the motor. The third phase is coasting flight. This happens after motor burnout, but before apogee or deployment. The next two don't always happen in the same order, but hopefully at the same time. Apogee, is when the rocket has reached its peak altitude and starts its gravity turn or tail stand back towards earth. Deployment is when the parachute or streamer is deployed by the ejection charge. Recovery is the last phase. Recovery is the rocket's controlled descent back to earth. (Beginner's Guide to Aeronautics)

FIGURE 3. **Flight of a Model Rocket** **(Glenn Research Center, NASA)**



3.1.3 Simple Stability

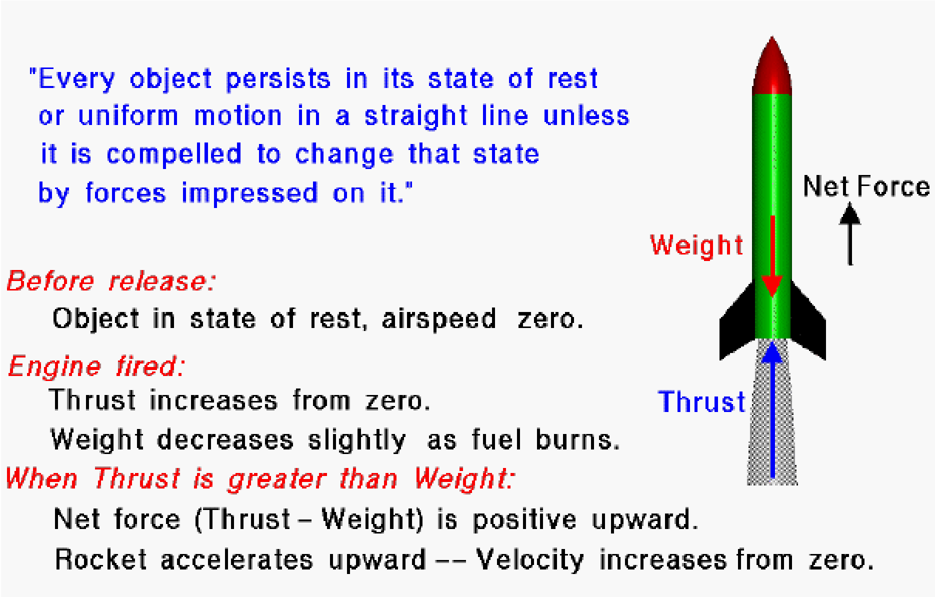
For a rocket to be stable, the center of gravity (CG) must be higher in the rocket than the center of pressure (CP). A simple way of finding the center of gravity, is to balance the rocket on something. The balancing point, is the CG. Finding the CP is more complicated, and will be explained later in the more complex Stability and Thrust section. A simple test of stability for small rockets is to tie a piece of string around the CG and swing it in circles over your head. After a few rotations, if the rocket's nose cone is facing forward, it is stable. If the rocket is wobbling, or facing a wrong direction, the rocket is unstable. Two simple ways to fix this are to move the center of gravity forward or move the center of pressure back. To move the CG forward, you can add weight to the nose cone. To move the CP back, you can make the fins bigger. (Beginner's Guide to Aeronautics)

3.2 Newton’s Laws

3.2.1 Newton’s First Law of Motion

Newton's first law of motion is known as inertia. It basically states that an object will remain at rest or in uniform motion in a straight line until acted upon by an outside force. An object is at rest if it is not moving relative to its immediate surroundings. Another important thing to know about in order to understand this law, is balanced and unbalanced forces. If something is being held and whatever it is being held by is not moving, then the object is at rest. Even though the object is at rest, there are still forces acting upon it. The force of gravity is pulling it towards the earth, and the stand is keeping it up, the forces are balanced. If the stand is moved, the forces are unbalanced, and the object changes from a state of rest to a state of motion. When the forces are balanced, there is no net force. (Beginner's Guide to Aeronautics)

FIGURE 4. **Newton’s First Law** **(Glenn Research Center, NASA)**



"Every object persists in its state of rest or uniform motion in a straight line unless it is compelled to change that state by forces impressed on it."

Before release:
Object in state of rest, airspeed zero.

Engine fired:
Thrust increases from zero.
Weight decreases slightly as fuel burns.

When Thrust is greater than Weight:
Net force (Thrust – Weight) is positive upward.
Rocket accelerates upward -- Velocity increases from zero.

A rocket lifting off is a good example of this law. Before ignition the rocket is sitting on its fins and the weight of the rocket is balanced by the reaction of the earth to the weight as described in Newton's third law. Hence, there is no net force, and the rocket would remain at a state of rest forever. When the motor is lit, the thrust is an opposing force to the weight. As long as the thrust is less than the weight, the combination of the thrust and the re-action force through the fins, balance the weight and there is no net force, and the rocket doesn't move. When the thrust is equal to the weight, there is no longer any reaction force through the fins, but the net force is still zero. As soon as the thrust exceeds the weight, there is now an external net force, and the rocket will takeoff. To continue accelerating, the thrust must be greater than the weight plus the drag. If the thrust is equal to the weight of the rocket plus the drag, the rocket will continue to fly at a fixed rate, but will not accelerate. (Beginner's Guide to Aeronautics)

3.2.2 Newton’s Second Law of Motion

Put in simple terms, Newton's second law of motion is Force is equal to mass times acceleration. The most common way of explaining this law is the cannon example. When a cannon is shot off, the gunpowder inside explodes, propelling the ball out of the cannon. At the same time, the cannon is pushed backwards slightly. This is an example of action reaction, which is Newton's third law. You can determine what happens to the cannon and the ball, by using the following equations.

$$F = \text{mass (cannon)} * \text{acceleration (cannon)} \tag{EQ 1}$$

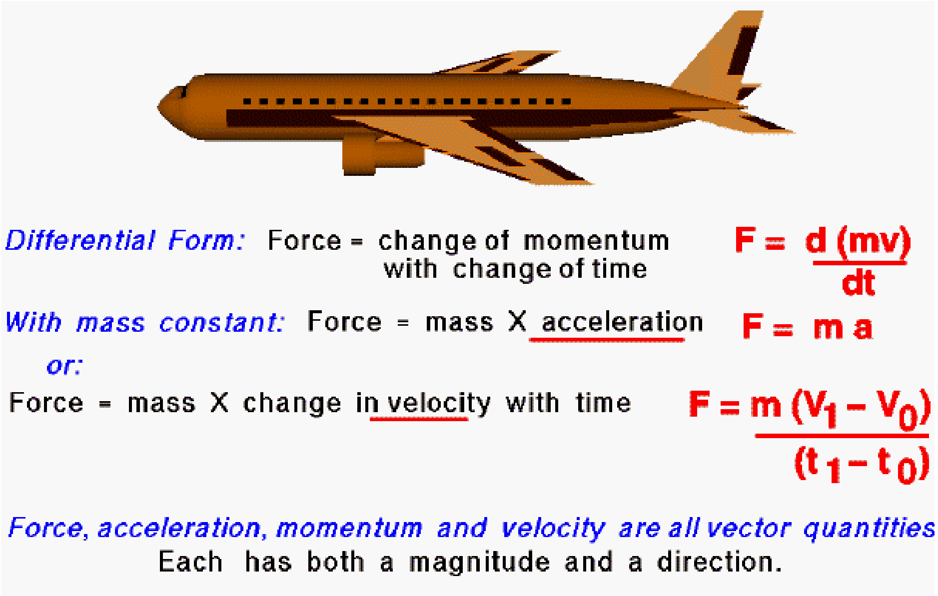
$$F = \text{mass (ball)} * \text{acceleration (ball)} \tag{EQ 2}$$

The first equation is for the cannon itself, and the second one for the cannon ball. Since the force is the same, the equation can be rewritten as shown.

$$\text{mass (cannon)} * \text{acceleration (cannon)} = \text{mass (ball)} * \text{acceleration (ball)} \tag{EQ 3}$$

In order to keep the two sides of the equation equal, the acceleration and mass vary according to each other. The cannon would have a high mass, and a low acceleration. The ball would have the lower mass, and higher acceleration. This same basic principle works with rockets as well. Replace the cannon with the rocket, and the ball with the hot gasses that are coming out of the motor. The gas shoots out in one direction, pushing the rocket in the opposite direction. The one major difference between a rocket and the cannon ball example is that the explosion in the cannon only lasts a split second. The thrust from the motor of a rocket, continues until the motor burns out. Also, the mass of the rocket changes considerably during flight because of the burning propellant. To keep both sides of the equation equal, the acceleration must increase as the mass decreases. (Beginner's Guide to Aeronautics)

FIGURE 5. **Newton's Second Law** **(Glenn Research Center, NASA)**



Differential Form: Force = change of momentum with change of time $F = \frac{d\,(mv)}{dt}$

With mass constant: Force = mass X acceleration $F = m\,a$

or:

Force = mass X change in velocity with time $F = \frac{m\,(V_1 - V_0)}{(t_1 - t_0)}$

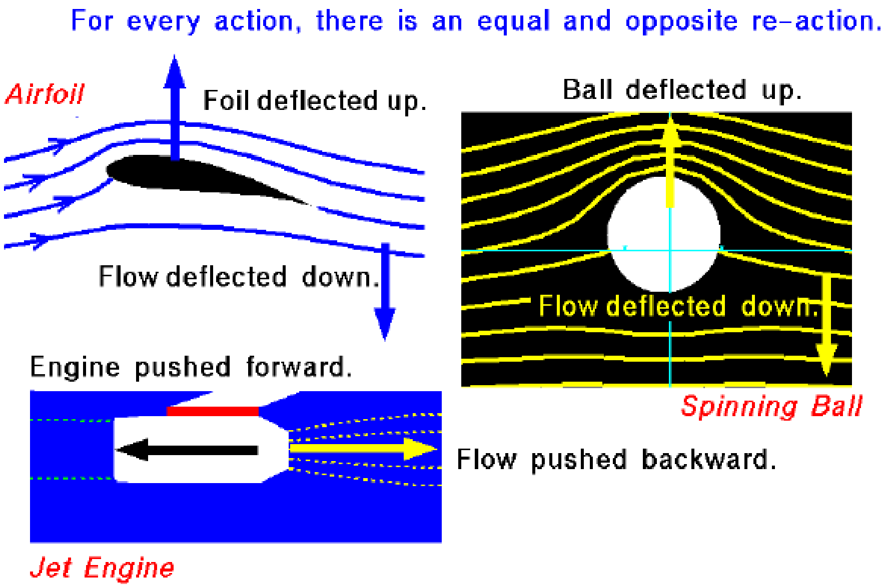
Force, acceleration, momentum and velocity are all vector quantities

Each has both a magnitude and a direction.

3.2.3 Newton's Third Law of Motion

Newton's third law states that for every action there is an equal and opposite reaction. When a rocket's motor ignites, the gases push against the rocket, and the rocket pushes against the gasses. A good example of this law is as follows. A skateboarder is standing on his skateboard, neither are moving, they are in a state of rest. Then the skateboarder jumps off in the direction that he was pointing. The jumping is called the action. In reaction, the board moves in the opposite direction. With rockets, the action is the expelling of gas out of the rocket. The reaction is the rocket moving in the opposite direction. One of the most commonly asked questions about rockets, is how can they work in space without air to push on? Think again of the skateboarder. All the air does is create drag. If the skateboarder were in a vacuum, the board would go further. A rocket works the same way again. The air just creates drag, and makes the rocket slow down and is more inefficient. Also, the gasses must push the surrounding air out of the way, using up some extra energy. In the vacuum of space, the gasses can escape freely. (Beginner's Guide to Aeronautics)

FIGURE 6. **Newton’s Third Law** **(Glenn Research Center, NASA)**

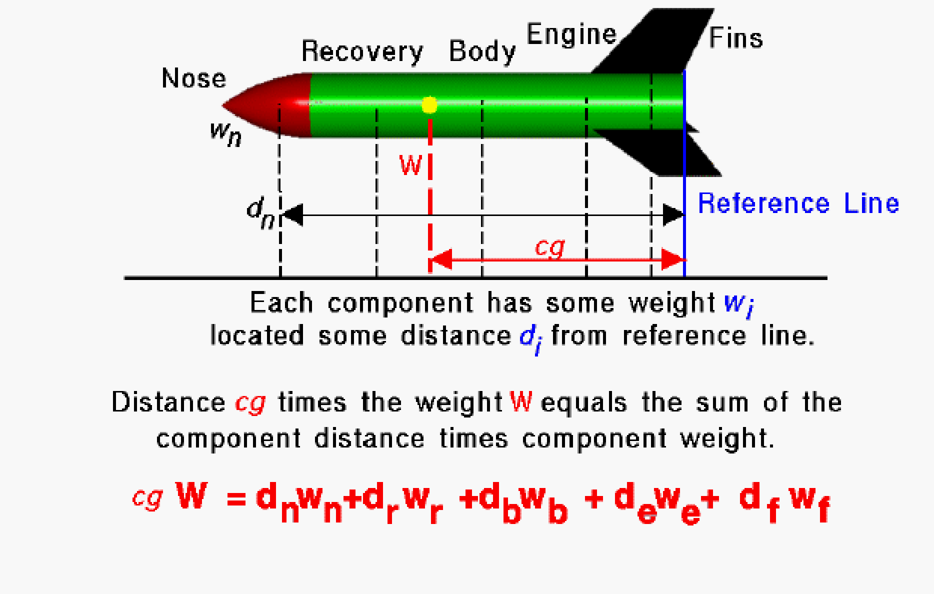


3.3 More Complex Stability and Thrust

3.3.1 Determining Center of Gravity and Center of Pressure

The center of gravity is the average location of the mass of the rocket. To determine the center of gravity of a rocket, you must first find the weight and distance from a reference line, usually the back of the body tube, of every component. The distance of the nose (don), is the distance from the reference line to the center of gravity of the nose cone. In order to find the CG of the rocket, you must first find the CG of every other part of the rocket. A simple way to find the CG is to balance the rocket. Another simple, but slightly more complicated way is to tie a piece of string to a point on the rocket, say the tip of a fin. Hang a weight on the end of a piece of string from the same point. Draw a line on the rocket where the string crosses it. Next, hang the rocket from another point, for instance the nose cone. Hang the weight and draw the line again. Where the two lines cross, is the center of gravity. (Beginner's Guide to Aeronautics)

FIGURE 7. **Determining Center of Gravity (CG)** **(Glenn Research Center, NASA)**



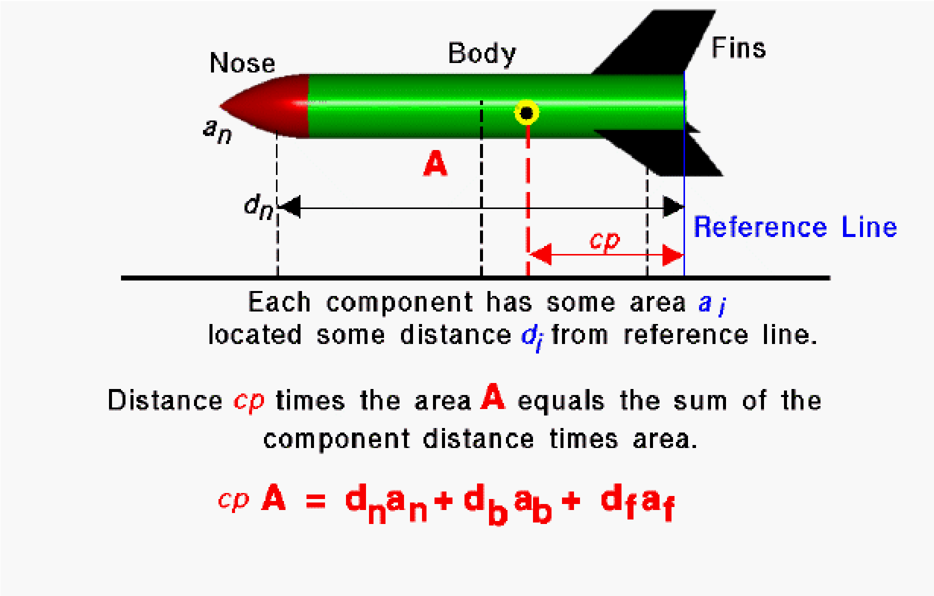
Each component has some weight w_i located some distance d_i from reference line.

Distance cg times the weight W equals the sum of the component distance times component weight.

$$cg\ W = d_n w_n + d_r w_r + d_b w_b + d_e w_e + d_f w_f$$

The CP is the point at which aerodynamic forces act on a rocket. It is possible to calculate the center of pressure, but it is a complicated procedure with the use of calculus. The aerodynamic forces are the result of pressure variations around the surface of the rocket. To find the CP, the integral of the pressure times the unit normal, times the area, times the distance from a reference line would have to be determined. Then divide by the integral of the pressure times the unit normal, times the area. This is what is done for full-scale rockets. There is a simpler way to calculate the CP of a model rocket that is symmetrical about its axis. After reducing the three dimensional problem into only two dimensions, the two dimensional layout can be used to find the CP. For model rockets, the degree of the pressure variation is small. If it is presumed that the pressure is nearly constant, finding the average location of the pressure times the area distribution reduces to finding just the average location of the projected area distribution. A very simplified way to find the CP is as follows. Trace the outline of the rocket onto cardboard, and cut it out. Balance the cutout either by hanging it from a string, or balancing it on an edge. The point at which it balances, the CG of the cut out, is roughly the CP of the rocket. (Beginner's Guide to Aeronautics)

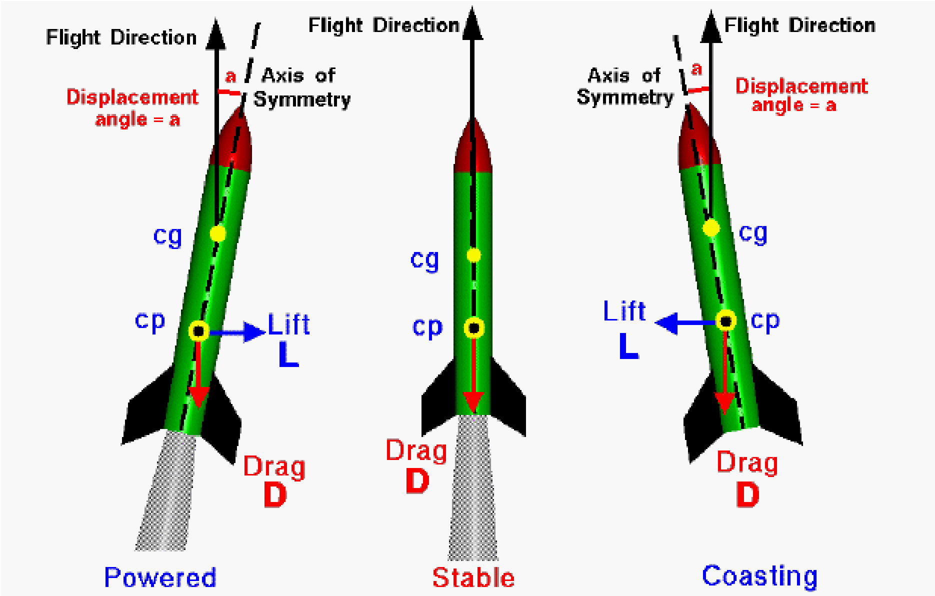
FIGURE 8. **Determining Center of Pressure (CP)** **(Glenn Research Center, NASA)**



3.3.2 Lift and Drag of a Model Rocket

A rocket, just as any other flying object, rotates around its center of gravity. This rotation causes the rocket to incline at an angle “a” to the flight path. When this happens, it causes the body and fins of the rocket to generate a lift force. The aerodynamic drag is almost constant for small inclinations. The lift and drag forces both act through the center of pressure. Figure 9 shows three examples of rockets with straight flight paths despite the inclination.

FIGURE 9. **Stability of a Model Rocket** **(Glenn Research Center, NASA)**



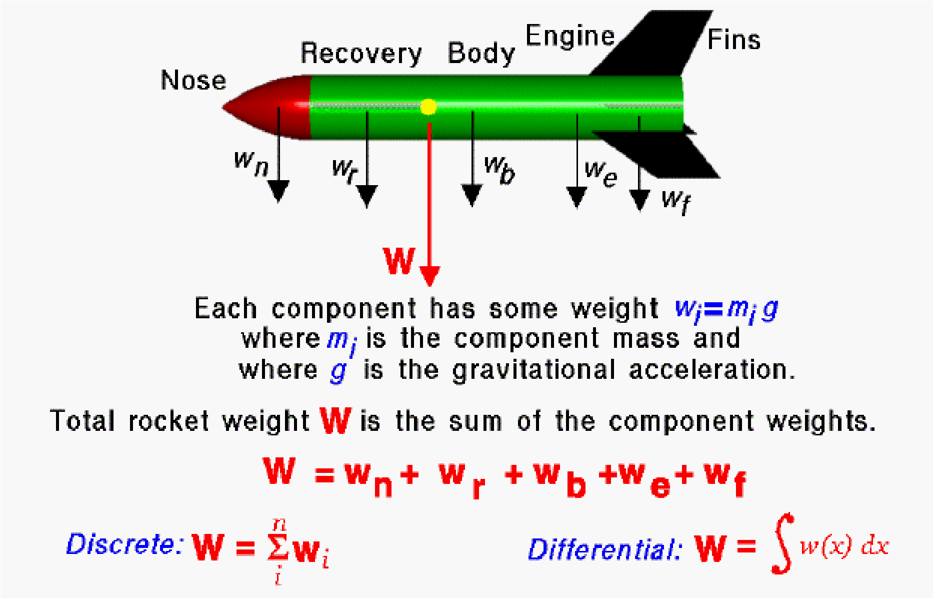
The letter “a” in Figure 9 denotes the inclination. In the example above it can be seen that the lift generated by the rocket is directed to the right, downwind side of the rocket. The lift from the coasting rocket is also directed to the downwind side. In the case of the powered rocket, the lift and drag both torque the rocket around the CG back to a straight flight. The same is will happen with a coasting rocket. These forces are called restoring forces because they restore the rocket back to it's original flight path. The restoring forces work for rockets when the CG is above the CP.

If the CP is higher than the CG, a de-stabilizing force is created. In this case, any small movement of the nose will cause forces making the displacement greater. For an unguided rocket to be stable, the CG must be higher than the CP. (Beginner's Guide to Aeronautics)

3.3.3 Weight of a Model Rocket

Weight is the force generated by the gravitational attraction of the earth on the model rocket. The mass is distributed throughout the rocket and for some problems it is important to know the distribution. But for rocket trajectory and stability, all that is needed to be known is the total weight and the location of the CG. For full-scale rockets, the determining of the weight is a tedious process involving the use of calculus. There is a simpler way to find the weight of a rocket. But first the weight of every component must be known.

FIGURE 10. **Determining Rocket Weight** **(Glenn Research Center, NASA)**



Each component has some weight $w_i = m_i g$ where m_i is the component mass and where g is the gravitational acceleration.

Total rocket weight **W** is the sum of the component weights.

$$W = w_n + w_r + w_b + w_e + w_f$$

Discrete: $W = \sum_i^n w_i$ Differential: $W = \int w(x)\,dx$

The individual component weight is simply the mass of the component times the gravitational constant, g, which is 32.2 ft./square sec. in

English units and 9.8 meters/square sec. in metric units. The total weight of the rocket is the sum of all the individual weights of the components. The sideways M symbol is the Greek letter sigma, which indicates summation. The i below the sigma is an index, and the index goes from 1 to some number n, which is the total number of parts. The equation says that the weight of the rocket is equal to the sum of the weight of n parts. (Beginner's Guide to Aeronautics)

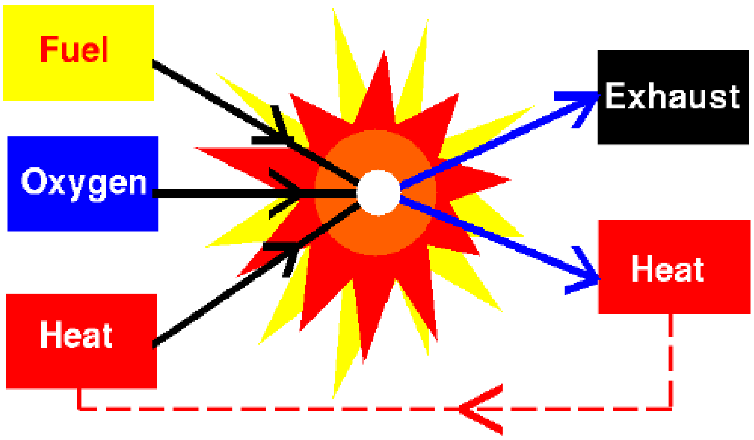
3.3.4 Roll, Pitch and Yaw

In flight, any spinning or tumbling takes place around one or more of three axes. These movements are called roll, pitch, and yaw. The point where all three of these axes intersect is the CG. Roll is not very important on a rocket, and can actually help stabilization. Movement on either of the other axes can be very bad. Unstable action on the pitch and yaw axes will cause the rocket to stray from its planned flight course. The center of pressure exists only when air is flowing past the moving rocket. This flowing air, rubbing and pushing against the outer surface of the rocket, can cause it to begin moving around one of its three axes. Think about a weather vane. A weather vane is an arrow-like stick that is mounted on a rooftop and is used for telling wind direction. The arrow is attached to a vertical rod that acts as a pivot point. The arrow is balanced so that the CG is the pivot point. When the wind blows, the arrow turns, and the head of the arrow points in the direction of the wind. The tail of the arrow points in the downwind direction. The reason that the weather vane arrow points into the wind is that the tail of the arrow has a much larger surface area than the arrowhead. The flowing air imparts a greater force to the tail of the arrow than to the head, and then the tail is pushed away. There is a point on the arrow where the surface area is the same on one side as the other. This spot is the CP. The CP is not in the same place as the CG. If it were, then neither end of the arrow would be favored by the wind and the arrow would not point in any direction. The center of pressure is between the center of mass and the tail end of the arrow. This means that the tail end has more surface area than the head end. It is extremely important that the CP in a rocket is located closer to the tail Than the CG. If they are in the same place or very near each other, then the rocket will be unstable in flight. If the CP is not below the CG, the rocket will begin to rotate about the CG in the pitch and yaw axes, producing a dangerous situation. With the center of pressure located in the right place, the rocket will remain stable. Roll happens about the axis of the rocket, not the CG. The roll, pitch, and yaw are important in rockets with guidance systems, which control the three. (Beginner's Guide to Aeronautics)

3.3.5 Propellant Types

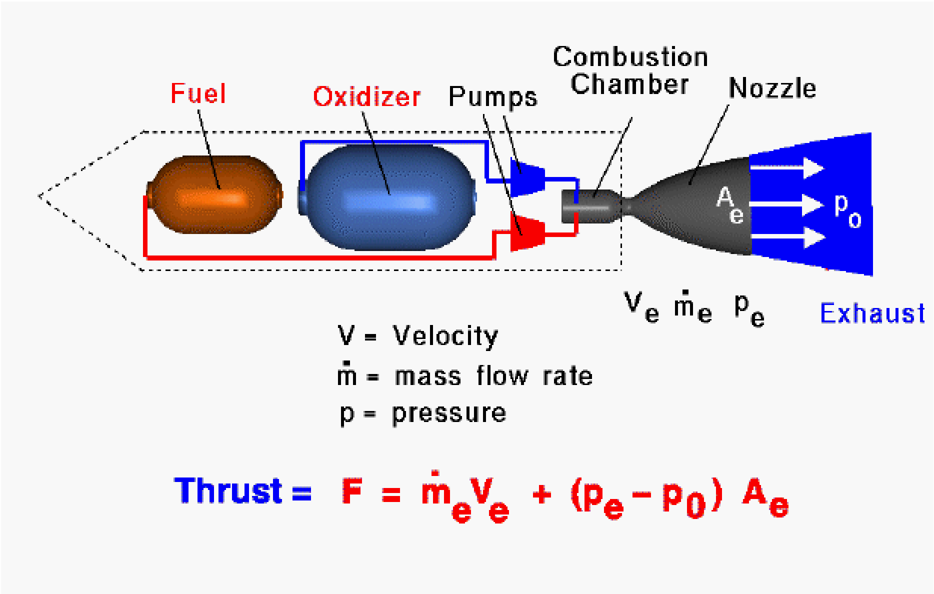
Most rockets have either solid or liquid propellant. Both types consist of the fuel and oxidizer, and create combustion.

FIGURE 11. **Combustion** **(Glenn Research Center, NASA)**



A liquid engine is the more complicated of the two, requiring more equipment, but with higher thrust. A liquid engine usually has two tanks, one for the oxidizer, and one for the fuel. The oxidizer and fuel are usually gasses that have been chilled to the point of a liquid. The liquids are pumped into a combustion chamber. In the chamber, the gasses are ignited, and are sent through the nozzle. Most full-scale rockets use liquid motors for a number of reasons. Liquid motors are capable of delivering more thrust than solid motors. The amount of thrust can be controlled in liquid motors, by changing the amount of propellant being injected into the combustion chamber.

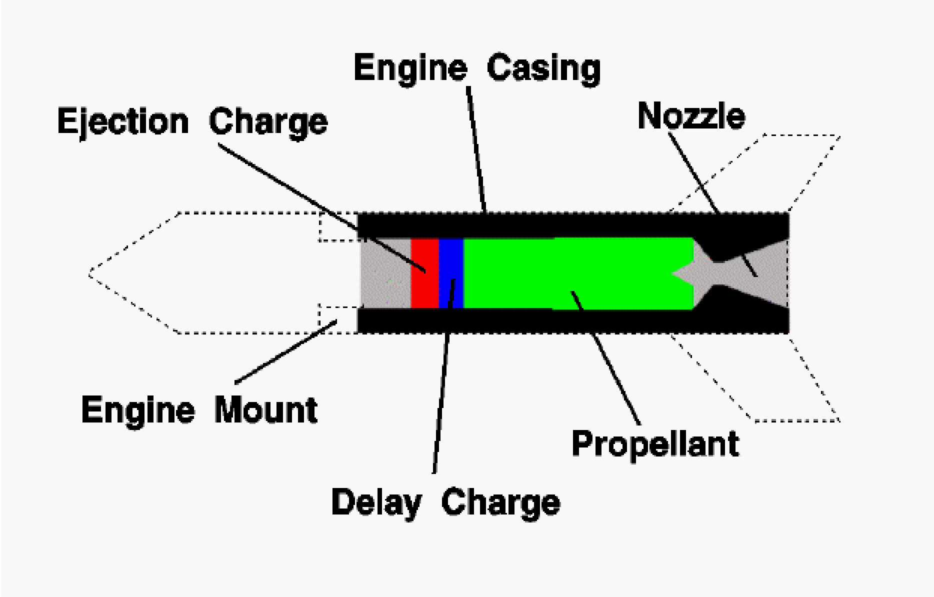
FIGURE 12. **Rocket Thrust** **(Glenn Research Center, NASA)**



A solid rocket motor has both the oxidizer and the fuel mixed together, and is dry. After ignition, solid rocket motors have a fairly stable thrust output, and are hard to change in flight. Solid rocket motors usually have hollow cores to increase thrust. Solid propellant burns surface area. With a hollow or star shaped core, the motors will burn faster. If there is no core, the motor will burn over a longer period of time, but with less thrust.

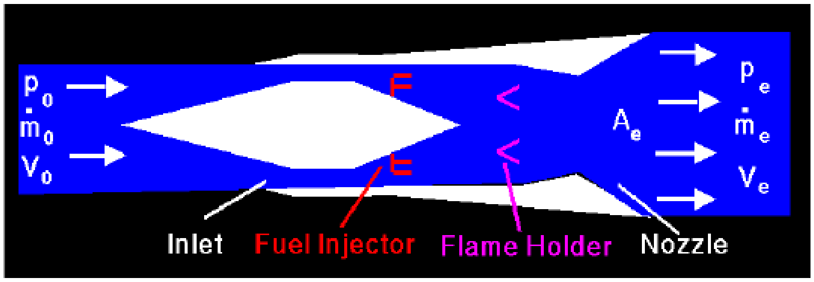
It is very difficult to start and stop solid rocket motors in flight. Some motors have fire extinguishers to stop the motors, but it is still difficult to get it to work. Others have release hatches, so that the motors can drop off of the rocket.

FIGURE 13. **Model Solid Rocket Engine** **(Glenn Research Center, NASA)**



Another type of propulsion that some rockets use is ramjet propulsion. The only downside is that there must be some other sort of engine to get the rocket or plane moving first. Thrust is made when the hot exhaust passes from the combustion of a fuel through a nozzle. The nozzle speeds up the flow, and the reaction to this acceleration is thrust. To keep the flow through the nozzle, the combustion must occur at a higher pressure than the pressure at the nozzle exit. In a ramjet, “ramming” air into the combustor using the speed of the vehicle creates the high pressure. The external air that is brought into the propulsion system becomes the working fluid, like a jet engine. In a jet engine, the high pressure in the combustor is made by a piece of machinery called a compressor. But there are no compressors in a ramjet engine. Because of this, ramjets are lighter and simpler than normal jets. Ramjets produce thrust only when the vehicle is already moving; ramjets cannot produce thrust when the engine is stationary or static. Until aerodynamic losses become a main factor, the higher the speed, the better a ramjet works. (Beginner's Guide to Aeronautics)

FIGURE 14. **Ramjet Thrust** **(Glenn Research Center, NASA)**



$$\text{Thrust} = F = \dot{m}_e V_e - \dot{m}_0 V_0 + (p_e - p_0) A_e$$

3.4 Guidance Systems

3.4.1 Passive Controls

Passive controls are fixed devices that keep rockets stabilized by their very presence on the rocket's exterior. Fins, vanes, sticks, etcetera, are all examples of passive guidance. You already know what fins are. Vanes are plates at the bottom of the nozzle that are tilted in either a clockwise or counterclockwise direction. As the thrust hits the vanes, it is getting diverted. The reaction to it being diverted is the rocket spinning at a high velocity. Sticks are what the Chinese used on the first rockets, they are just tied onto the rocket to move the CP backwards, but they don't always work too well. (Beginner's Guide to Aeronautics)

3.4.2 Active Controls

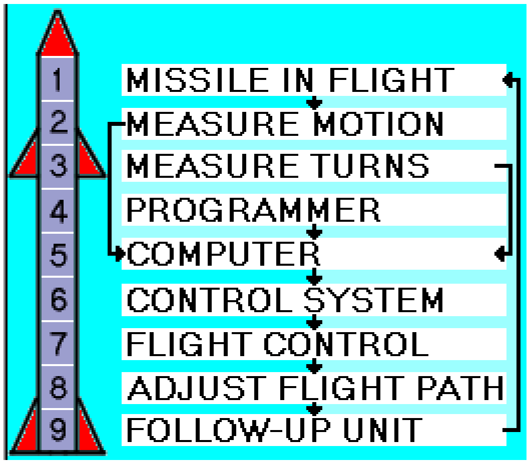
Active controls are parts of a rocket that move to steer or correct the flight of a rocket. There three main types of active controls; gimbaled nozzles, fins, and canards. The fins and canards are the same, except for where they are mounted. The fins are towards the tail of the rocket, while canards are by the nose cone. They both rotate to adjust the flight path on one of the three axes. Gimbaled thrust is slightly more complicated. When using gimbaled thrust, there can be no fins or canards at all, and external nozzle moves, aiming the thrust, to correct the flight path.(Reme Museum of Technology)

3.4.3 Guidance Controls

There are three main types of active guidance systems: inertial, command, and homing. The Inertial Missile Guidance System tests if the missile is on course to the target. It makes adjustments by checking a pre-set flight plan. When in flight the missile's computer takes input from the accelerometers and the gyroscopes. The accelerometers measure the horizontal, vertical and forward motion along with the velocity of the missile. The gyroscopes measure the roll, pitch and yaw of the missile.

The computer compares this data with the pre-set flight path from the program. An error signal is sent to the control, which activates the flight control mechanism to adjust the flight path of the missile. The data is relayed back by the follow up unit, therefore constantly monitoring and adjusting the flight of the missile to the target.(Reme Museum of Technology)

FIGURE 15. **Inertial Guidance System** **(Reme Museum of Technology)**



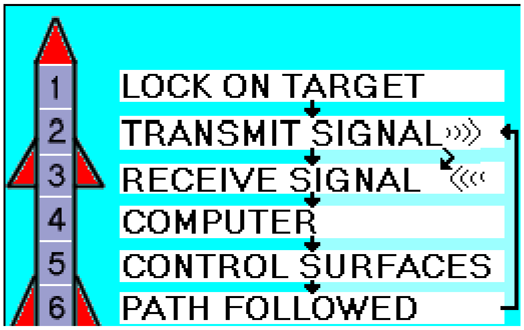
With the second type, Command Missile Guidance System there is no guidance equipment within the missile. The commands are sent to the missile by wire, radar or laser. These commands tell the missile to change course if it is not directed toward the target. The guidance system has a target tracker, a missile tracker, a computer and a transmitter. The computer calculates the change in the missile's flight path using the target tracker and sends a signal using the transmitter to the missile to guide it back to the correct flight path. The receiver receives the signal and the passive controls will put the missile back on course. The missile is constantly monitored until it reaches the target. A wire can be used to guide the missile to the target. A wire is connected to the missile the other end is connected to the guidance system. Signals are sent along the wire to the missile to keep the missile on track. Radar can be used to guide the missile to the target. The range is measured by timing the passage of electromagnetic waves to and from the target. The direction is measured using an antenna to project the waves in a narrow beam. The direction of the antenna indicates the direction of the target. The velocity or target movement is measured by measuring the difference between the transmitted frequency and the frequency of the reflection from the target. (Reme Museum of Technology)

FIGURE 16. **Command Guidance System** **(Reme Museum of Technology)**

A Laser can be used to guide the missile to the target. Laser stands for Light Amplification by Stimulated Emission of Radiation. When atoms are stimulated to a higher level of activity than their normal level, they emit light as they calm down to their usual level. The coherent light beam of a Laser is created if the atoms emit radiation in step with a wave. Using this beam extremely accurate results for range finding and marking a target are given.(Reme Museum of Technology)

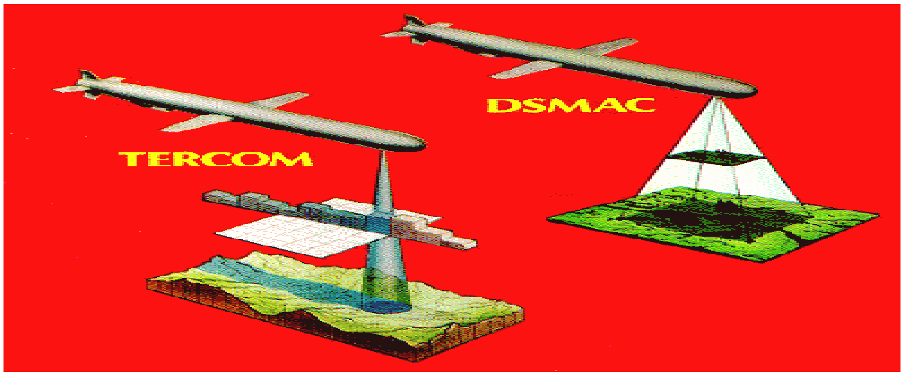
The third main type of missile or rocket guidance system is homing. The Homing missile guidance system is contained inside the missile. The missile 'Homes in' on the electromagnetic waves, which are sent from the target. These waves are transmitted from a transmitter in the missile at the target. The reflected wave feeds the computer with data that calculates the course to the target. The data is processed and the control part missile steers the missile in the correct direction.(Reme Museum of Technology)

FIGURE 17. **Homing Guidance System** **(Reme Museum of Technology)**



Another type of guidance system is TERCOM, terrain contour matching. TERCOM usually has GPS and DSMAC also. GPS stands for Global Positioning System. Using three satellites, a GPS unit can pinpoint its location on the earth. DSMAC stands for Digital Scene Matching Area Correlation. DSMAC compares a digitally stored image of the target with the image that it sees at the time. TERCOM uses radar to check the ground below it and checks it against a stored map reference to compare with the actual terrain to determine the missile's position. If necessary, a change in direction is made to place the missile on course to the target. Terminal guidance in the target area is provided by the optical Digital Scene Matching Area Correlation (DSMAC) system, which compares a stored image of target with the actual target image.

FIGURE 18. **Terrain Contour & Digital Scene Matching Guidance (BGM-109 Tomahawk)**



3.5 History of Rockets

The first examples of mechanical propulsion were around the year 400 BC. There are stories of a Greek man, Archytas, using steam to push a wooden pigeon along guide wires. He was using Newton's third law of motion, which was not realized until the seventeenth century. Approximately 300 years later, Hero of Alexandria, invented the Hero engine. It is a sphere mounted on top of a pot of boiling water. The steam went through two pipes up to the sphere, and escaped out of two angled spouts. As the steam escaped, the sphere would spin. (Beginner's Guide to Aeronautics)

FIGURE 19. **Hero Engine** **(Beginner’s Guide to Aeronautics)**

The first actual rockets were the Chinese fire arrows. It is believed that these were invented by accident. Bamboo tubes were filled with a primitive form of gunpowder meant to explode for use in celebrations. It is possible that instead of exploding, some would fly away. In the year 1232 the Chinese used rockets in the war against the Mongols. While the actual damage inflicted may have been little, the psychological effects would have given the Chinese a great advantage.

FIGURE 20. **Chinese Fire Arrows** **(Beginner’s Guide to Aeronautics)**

Chinese soldier launches fire-arrow

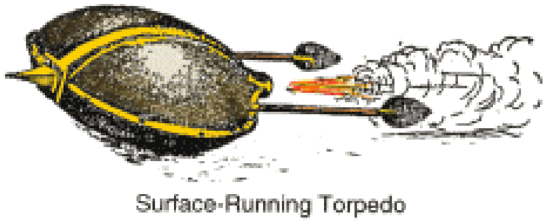
There is a story of a Chinese official, Wan-Hu, who placed two large kites, and forty seven fire arrows to a chair in an attempt to fly. After the rockets were lit, a large smoke cloud formed and when it cleared, Wan-Hu and his chair were nowhere to be found. It is likely that if this did happen, Wan-Hu did not fly, but blew up.

FIGURE 21. **Wan Hu Rocket Chair** **(Beginner’s Guide to Aeronautics)**

Legendary Chinese official Wan Hu braces himself for "liftoff"

Jean Froissart of France discovered the use of a tube as a simple launch mechanism for rockets. This is the same basic design still used today for bazookas. In Italy, Joanes de Fontana invented a surface torpedo. It was in the shape of a disk, and was used to set enemy ships ablaze.

FIGURE 22. **Surface Running Torpedo** **(Beginner's Guide to Aeronautics)**



German fireworks maker Johann Schmidlap invented the use of staging in his "step rocket". A rocket would fly to a certain altitude, at which point, a smaller one would ignite and fly higher before lighting the firework. This is the same basic principle applied today in large rockets used to get to space.

In the late seventeenth century, Sir Isaac Newton developed the three basic laws of motion, still used to this day for rocketry. He explained how and why rockets worked. This greatly impacted the design of rockets at the time.

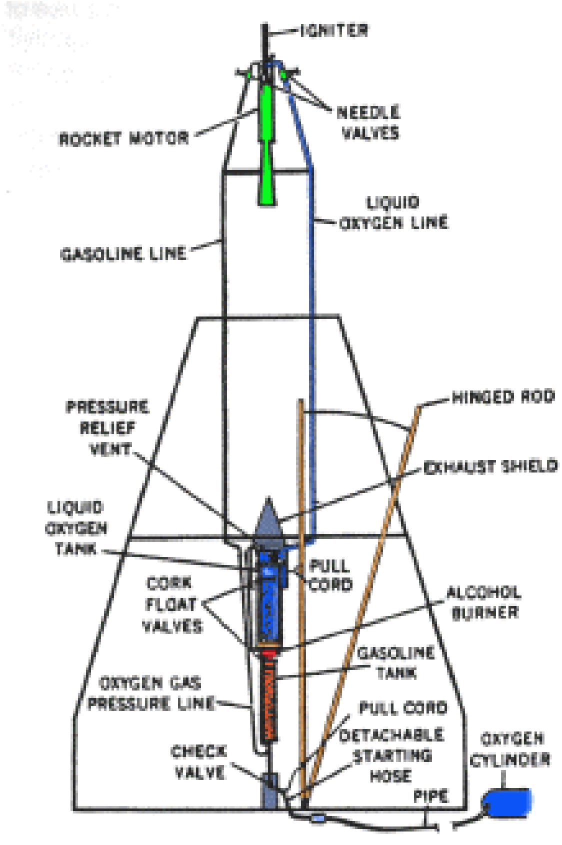
In 1720, a Dutch professor, Willem Gravesande made model cars and used steam to propel them. In Germany and Russia, rockets with a mass of greater than forty five kilograms were being made. These were the most powerful rockets of their time, and left holes in the ground where they had been launched.

In the late eighteenth to early nineteenth century, rockets started being used for war again. The use of rockets by India against the British caught the eye of artillery expert British Colonel William Congreve. In 1799, Congreve started to design rockets for use by the British. His rockets were very successful during the War of 1812. They were used at the battle at Fort McHenry and inspired Francis Scott Key to write “the rockets red glare” in The Star Spangled Banner. Although the rockets worked, they still were not very accurate and proved effective only in large numbers.

The world over, scientists worked to improve rocket technology. Englishman William Hale invented spin stabilization as a form of guidance used to increase the accuracy of the rockets. Small vanes were placed beneath the exhaust nozzle, causing the rocket to spin. Even though rockets were somewhat effective as weapons of war, they went back to peacetime uses as more sophisticated and accurate artillery was developed for use in battle such as rifled cannons with exploding warheads. In 1898 Russian school teacher Konstantin Tsiolkovsky had the idea of using rockets to explore space. He suggested the use of liquid instead of solid propulsion.

In the early twentieth century, Robert H. Goddard had the goal of flying rockets to altitudes higher than weather balloons. He concluded that the use of liquid fuel was needed. Liquid rockets were much more complicated to build, needing fuel tanks, turbines, combustion chambers, and the nozzle. On March 16 1926, Goddard flew his first liquid propelled rocket. Although it only flew for two and a half seconds and to an altitude of twelve and a half meters, it was a large and important step forward in the world of rocketry.

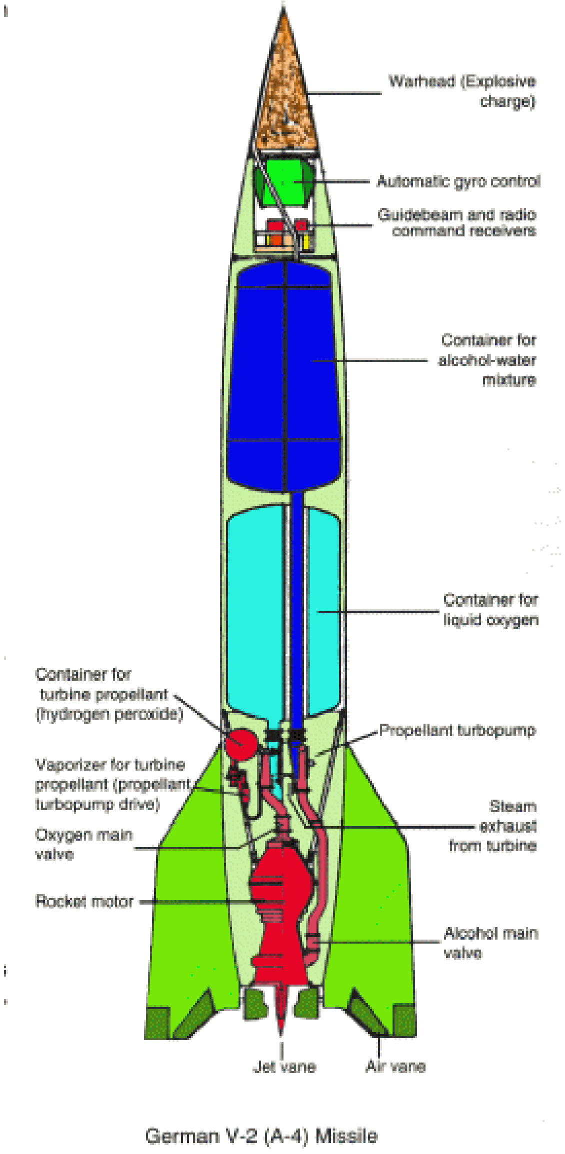
FIGURE 23. **Goddard's Rocket** **(Beginner's Guide to Aeronautics)**



Dr. Goddard's 1926 Rocket

The V2, developed by Wernher Von Braun and his team, known in Germany as the A-4, was used as a ballistic missile in World War Two. It used liquid oxygen and alcohol, burning one ton every seven seconds. The missile was used to blow up whole city blocks. Lucky for the allies, the missile was introduced too late in the war to have much of an effect on the outcome of the war.(Beginner's Guide to Aeronautics)

FIGURE 24. **German V-2 Rocket** **(Beginner's Guide to Aeronautics)**



Plans for trans-Atlantic ballistic missiles were being made by Germany to strike the USA towards the end of the war. They would have a winged upper stage, but wouldn't have much room in the payload section. Fortunately the war ended before these plans could be implemented.

At the end of the Second World War, most of the German rocket scientists went to either the USSR or the US. Both the Russians and the Americans started their own rocket and space programs. The research and rockets went from sounding rockets to intercontinental ballistic missiles. At the start of the space program, the boosters from missiles such as the Titan or the Redstone were used to get into space.

On October 4, 1957 the world was stunned to hear the news of the first artificial satellite in orbit. Sputnik had been launched by the Soviets. Later that year, the Soviets also put up a rocket with a dog named Laika on board. The dog survived for seven days before being put to sleep before the oxygen ran out. Not long after, the US put up its own satellite. On January 31, 1958, Explorer was placed into orbit. And later that year, NASA, the National Aeronautics and Space Administration, was created.

4.0 Materials & Methods

4.1 Materials

4.1.1 Rocket Parts

Tools:
- Ruler
- Cement and 15 minute Epoxy
- Utility or Exacto knife
- Wood Dowel
- Sandpaper

Fin tabs:
- 11/16 inch balsa wood sheet
- 11/16 inch dowel rod
- 11/8 inch dowel rod
- 13/16 inch dowel rod
- 11/4 inch dowel rod
- 15/16 inch dowel rod

Six Aerotech Airspike Kits:
- 6 - Thrust Rings
- 6 - Thrust Ring Flanges
- 6 - Motor Tubes
- 6 - Motor Hooks
- 12 - 4-fin FIN-LOK^{TM} Rings
- 12 - Centering rings
- 24 - Fins
- 6 - Cooling mesh
- 6 - Ejection gas baffles
- 6 - Screw eyes
- 6 - Shock cords
- 6 - Body tubes
- 12 - Launch lugs
- 6 - Nose cones
- 8 - Parachutes
- 6 - “F” spacer tubes

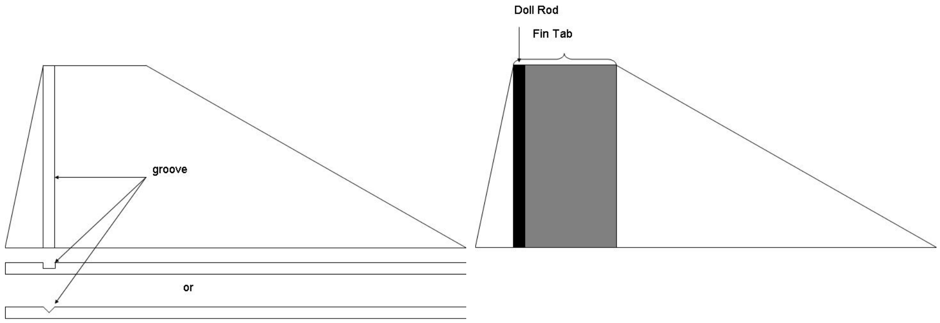
Payload section:
- 2 - Body tubes, 8 in
- 2 - Couplers, 4 in
- 2 - Bulk Plates

Electronics Items:
- 2 - RDAS Flight Computers
- 2 - Vector boards
- 2 - Photo cell variable resistors
- 2 - 270 ohm resistors

4.2 Methods

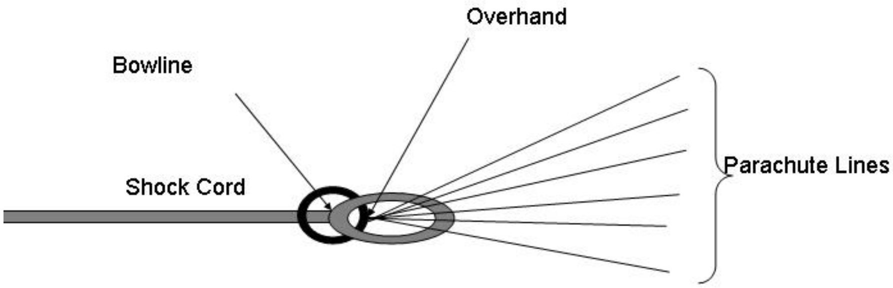
The rockets were made following the instruction sheet included with this paper except steps three and four of body and fin assembly and steps three and four of final assembly and finishing. For the assembly of the fin tabs, 1/16 inch balsa wood sheets, and dowel rods increasing in diameter by a 16th inch from 1/16 inch to 5/16 inch were used. Using either a utility knife or a Dremel handheld tool, an approximately 3/16 inch deep 3/16 inch wide groove was made in the fin ½ inch up from the bottom. The dowel rod was cut into 2 ¼ inch long pieces. The groove was filled with super glue, and a piece of dowel rod was put on it. The sides of the dowel rod were taped to hold it in place until the glue is dry. The 1/16 inch balsa wood sheet was cut into 20 pieces that measure 2 ¼ by 1 ½ inches. Cement was applied along the two longer edges and the balsa wood tab was put in place on top of the dowel rod. Tape was applied to the edges of the tab. After the glue dried, a bead of cement was applied along the upper edge of the fin tab, and allowed to dry. After the fin tabs were assembled, step three of body and fin assembly was completed.

FIGURE 25. **Fin Tab Assembly Detail**



To make the payload section, an eight inch long piece of body tube was needed, as well as a four inch piece of coupler tubing. The coupler tubing was inserted two inches into the body tube so that half was in and half was out, and glued into place. Using an Exacto knife a ½ inch diameter hole was cut into the tube five inches from the bottom. A ¼ inch hole was drilled in the bulk plate for the recovery harness. The shock cord was put through the hole, and the end of it was epoxied to the plywood. To tie the ends of the shock cords of all rockets and payloads to parachutes, first a bowline was tied at the end of the shock cord. An overhand knot was tied with the end of the parachute strings, leaving a hole. The end of the shock cord was fed through the loop in the end of the strings to the parachute, and then the parachute was fed through the loop in the end of the shock cord.

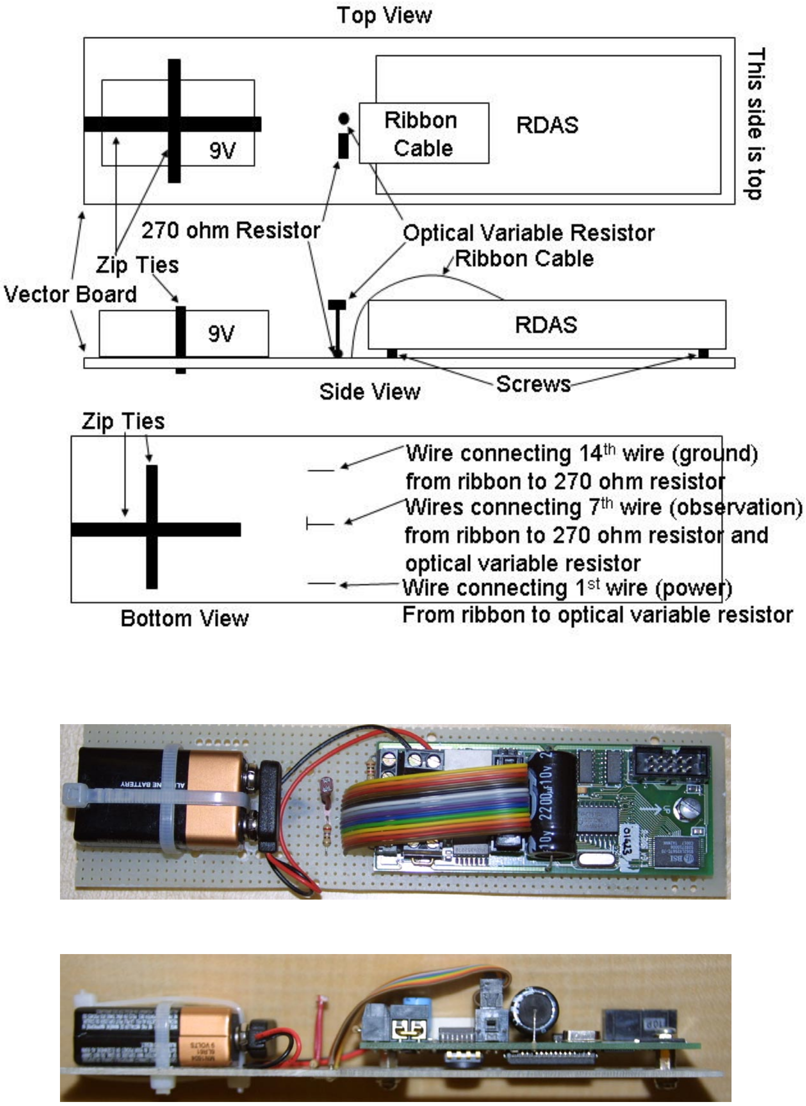
FIGURE 26. **Shock Cord to Parachute Attachment Detail**



For the electronics a piece of vector board measuring 7 by 1 ¾ inches was used. Two 1/32 inch holes were drilled, both centered in width, the first ½ inch from the top, the second 3 ½ inches from the top. These holes were for the number 4 hardware used to screw the RDAS unit in place. Four more 1/32 inch holes were drilled where the zip ties to hold the battery were attached. One was centered at the very bottom of the board, making more of a notch than a hole. The second was also centered, and was 5 1/8 inches down from the top. The last two were ½ inch in from either side, and 5 7/8 inches from the top.The optical variable resistor, as well as the 270 ohm resistor, were placed 4 ¼ inches from the top, with the wires coming through on the bottom side of the board.

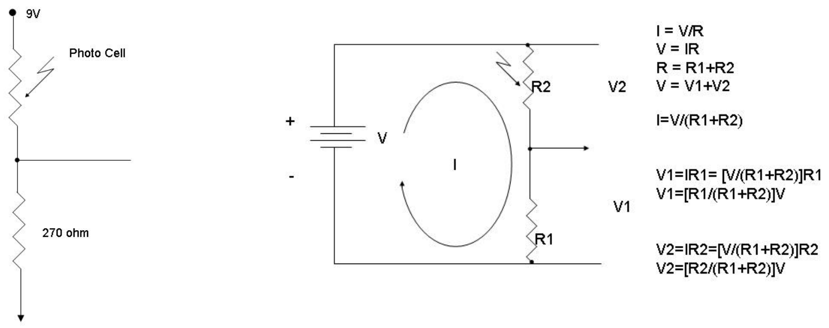
The 1st, 7th, and 14th wires from the ribbon cable went through to the other side. The 1st cable was soldered to one lead from the optical variable resistor. The 7th cable was soldered to both the other side of the optical variable resistor and the 270 ohm resistor. The other side of the 270 ohm resistor was soldered to the 14th wire of the ribbon cable.

FIGURE 27. **RDAS & Roll Rate Sensor Assembly Detail**



Before the actual circuit was made, the needed strength of a resistor was first found. A volt ohm meter (VOM) was used to find the optimal resistor value for the roll rate circuit. First, a ½ inch hole is cut where the photo cell will be. The board was placed inside the payload section with the photo cell placed right beneath the hole. Using the VOM to find the difference in resistance, the tube was taken outside and faced towards the sun as well as away. The schematic to the right shows the circuit used to measure roll rate. Using Ohm's law, it was figured that by using a 270 ohm resistor, the voltage would be between 4.5 and 0 volts. Ohm's law is demonstrated in the schematic below. The voltage being measured is that across R1. The voltage V1 is found knowing that V1=IR1. Knowing that I=V/R and that R=R1+R2, V/(R1+R2) can be substituted for I. In this way, R2 indirectly changes V1 by changing the total current I that flows through the circuit. To make the circuit work for the recording capabilities of the RDAS, the voltage recorded can be no more than five volts. R1 is equal to R2's lowest resistance, in this case, 300 ohms. In making R1 equal to R2's lowest resistance, when R2 is at its lowest resistance, the total resistance R is half of the voltage. When voltage V is nine volts, then the highest voltage across R1, V1, will be 4.5 volts. A 300 ohm resistor could not be found, so a 270 ohm resistor was used instead. Using a 270 ohm resistor, V1's highest voltage would be 4.3 volts.

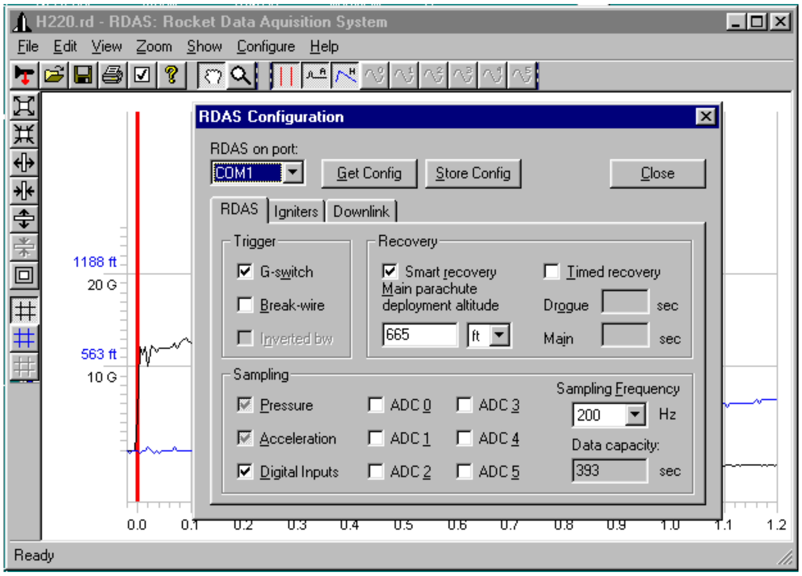
FIGURE 28. **Roll Rate Sensor Schematic & Operating Equations**



4.2.1 Rocket Data Acquisition System & Software

The recording unit chosen for this project was the RDAS. RDAS stands for Rocket Data Acquisition system. The RDAS unit is equipped with a barometric altimeter as well as an accelerometer. It comes with software used to download and plot the data collected. The RDAS also has 6 analog channels capable of recording zero to five volts and 4 digital inputs for expansion. This recording capability made it possible to connect the roll rate sensor by using one of the analog recording channels. The RDAS has 32 KB of RAM for recording preflight data, and 512 KB of flash EEPROM capable of recording over eight minutes of flight data at 200 samples per second. The sampling is started by a G-switch needing at least 2.5 gees for at least 0.25 seconds. The manual for the RDAS can be found at www.iae.nl./users/aed/rdas/download.htm.

FIGURE 29. **RDAS Software Screen Shot**



RDAS on port: COM1

Trigger
☑ G-switch
☐ Break-wire
☐ Inverted bw

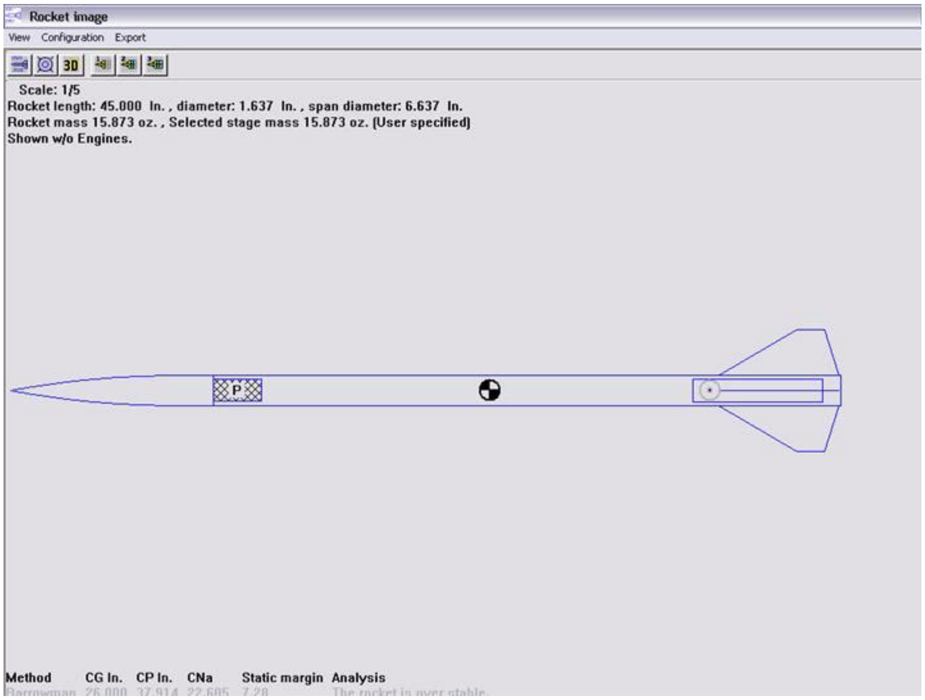
Recovery
☑ Smart recovery
Main parachute deployment altitude: 665 ft
☐ Timed recovery
Drogue: sec
Main: sec

Sampling
☑ Pressure
☑ Acceleration
☑ Digital Inputs
☐ ADC 0
☐ ADC 1
☐ ADC 2
☐ ADC 3
☐ ADC 4
☐ ADC 5
Sampling Frequency: 200 Hz
Data capacity: 393 sec

4.2.2 Rocket Simulation Software

Another program used in the project was RockSim. RockSim is a rocketry simulation program. The rocket being used was entered in the program, and simulated with the desired motor. The program calculates the expected altitude, acceleration, time to apogee, and the optimal delay. The program was used because the rocket was modified. The kit built per the instructions is designed to be stable. Because a payload section and electronics were added on, the stability had to be re-checked. Also, there had to be no doubt that the size rocket motor planned for use would be powerful enough to safely fly the rocket. Even though the spin keeps the rocket on a straighter path, the rocket must first be stable.

FIGURE 30. RockSim Software Screen Shot



Scale: 1/5
Rocket length: 45.000 In. , diameter: 1.637 In. , span diameter: 6.637 In.
Rocket mass 15.873 oz. , Selected stage mass 15.873 oz. (User specified)
Shown w/o Engines.

Method	CG In.	CP In.	CNa	Static margin	Analysis
Barrowman	26.000	37.914	22.605	7.28	The rocket is over stable.

5.0 Results

The following graphs are the results obtained from the experiments. A plotting program called RDAS Plot was used to graph the results. Acceleration, altitude, and roll are all plotted on the Y axis vs. time on the X axis. The green line represents the acceleration in gees, the red line represents the altitude in feet, and the blue line represents the output of the roll rate sensor in volts. Time is measured in seconds.

5.1 Booster 1 (Fin Tab Angle: 0 deg.)

FIGURE 31. **Booster 1, Flight 1, Data thru Apogee**

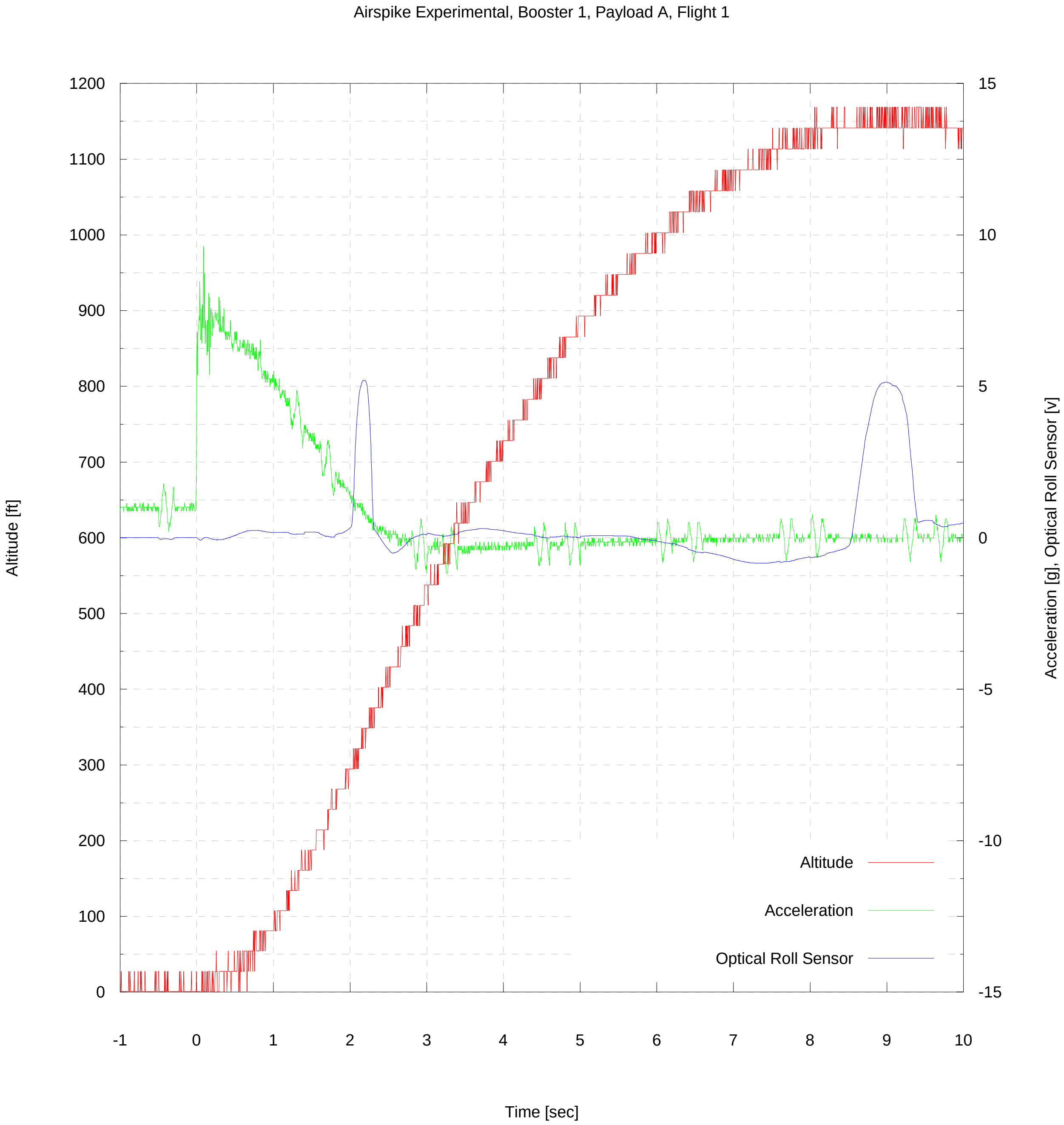


FIGURE 32. **Booster 1, Flight 2, Data thru Apogee**

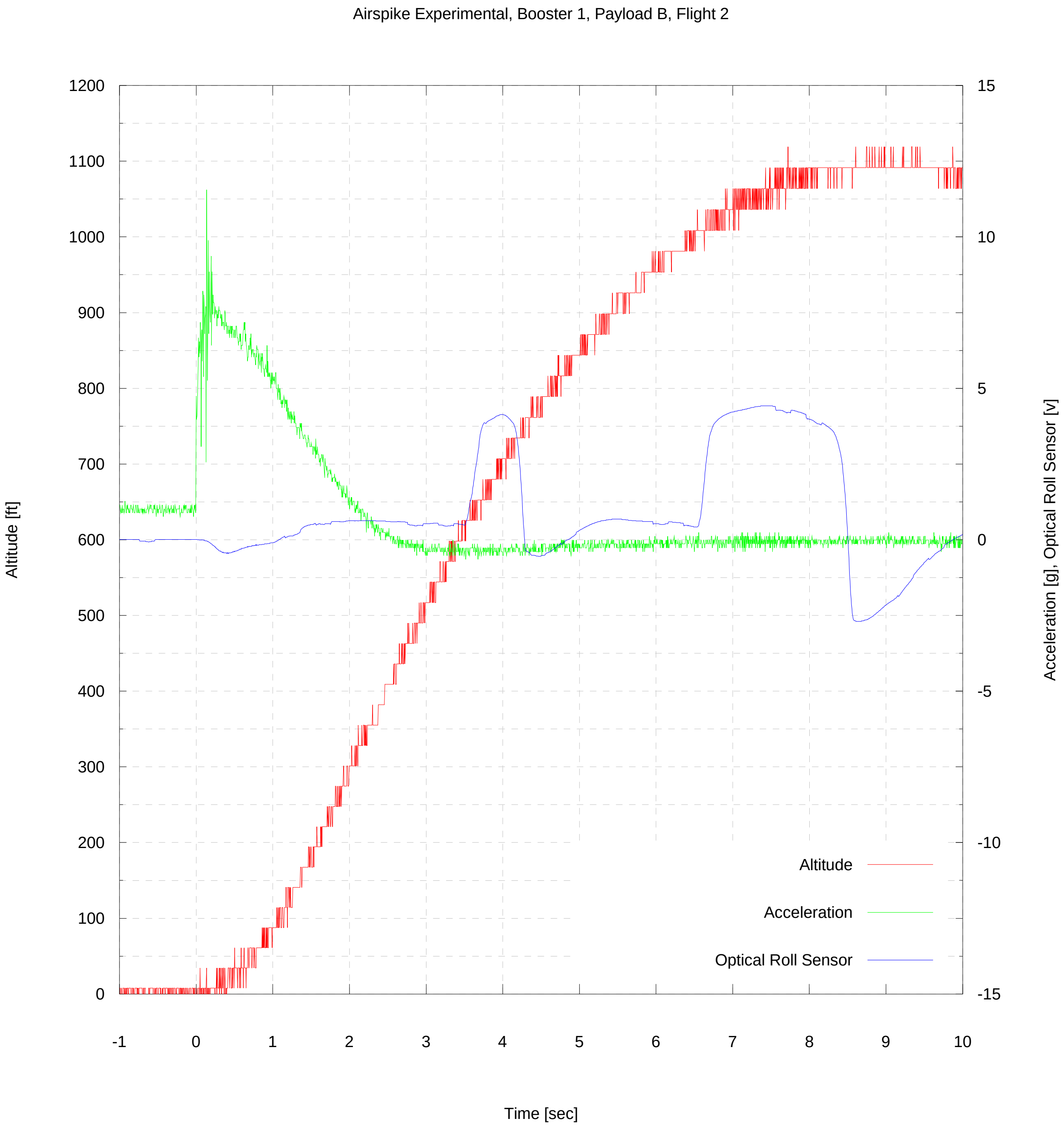


FIGURE 33. **Booster 1, Flight 3, Data thru Apogee**

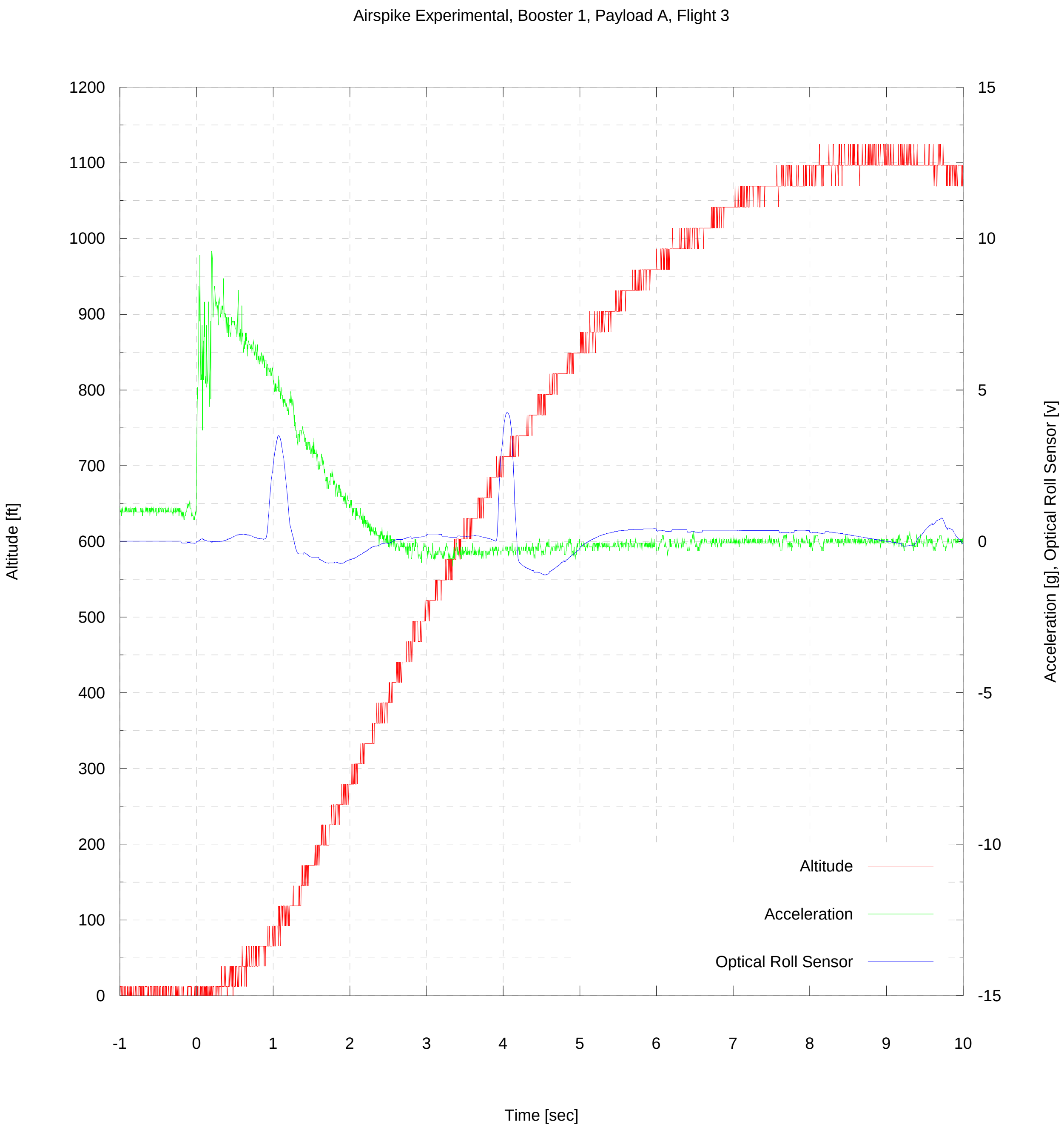
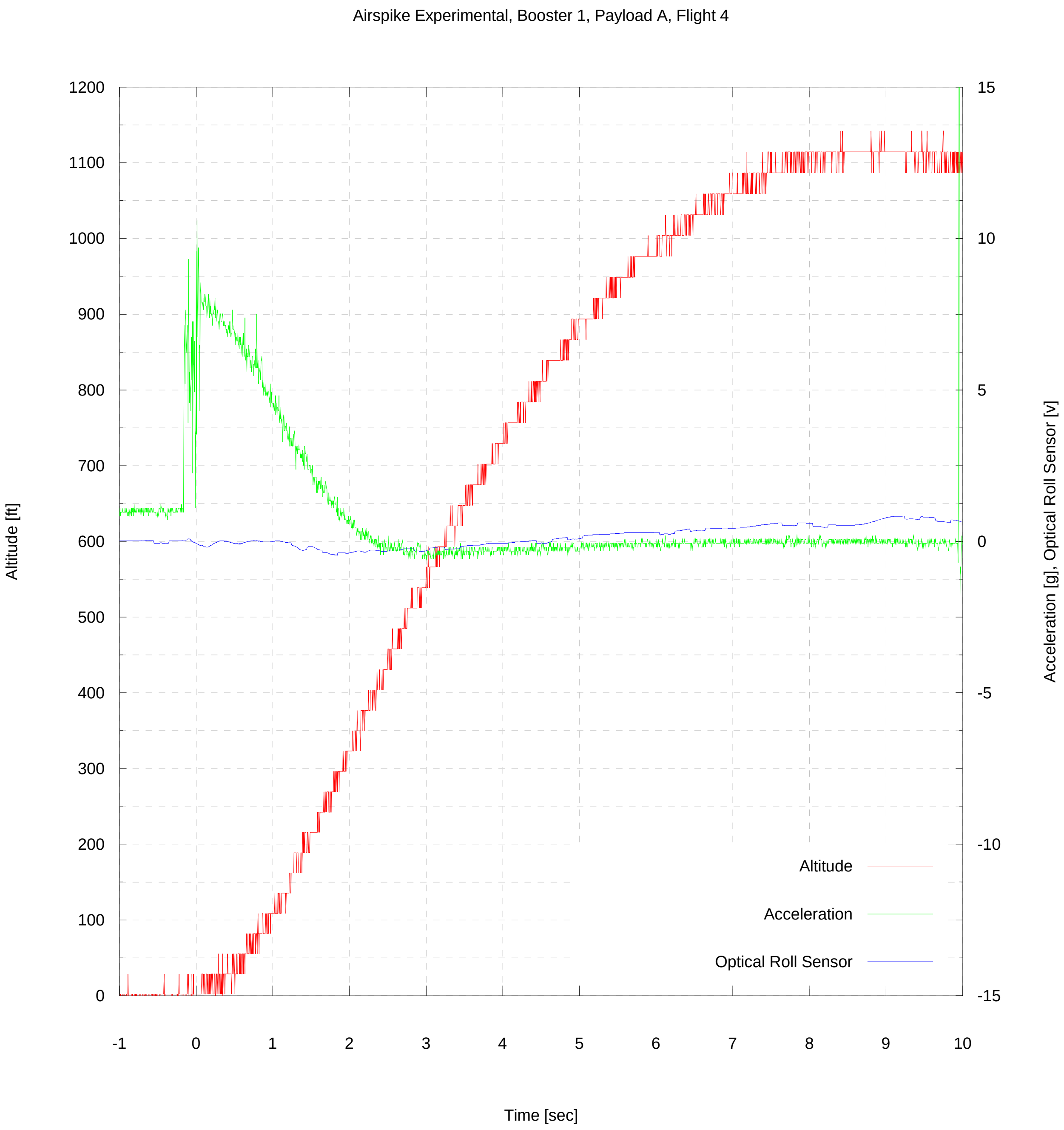


FIGURE 34. Booster 1, Flight 4, Data thru Apogee



5.2 Booster 2 (Fin Tab Angle: 2.4 deg.)

FIGURE 35. **Booster 2, Flight 1, Data thru Apogee**

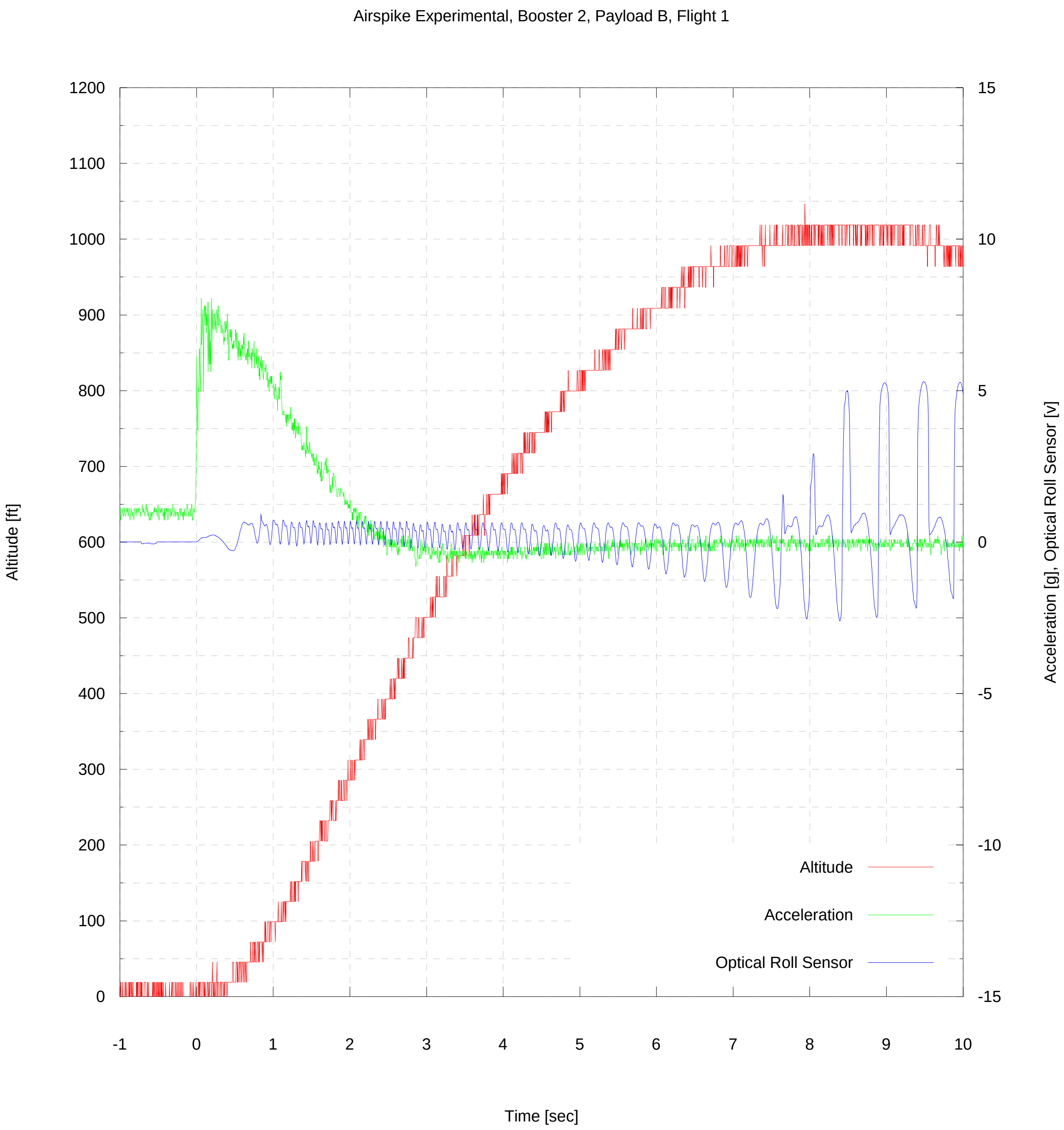
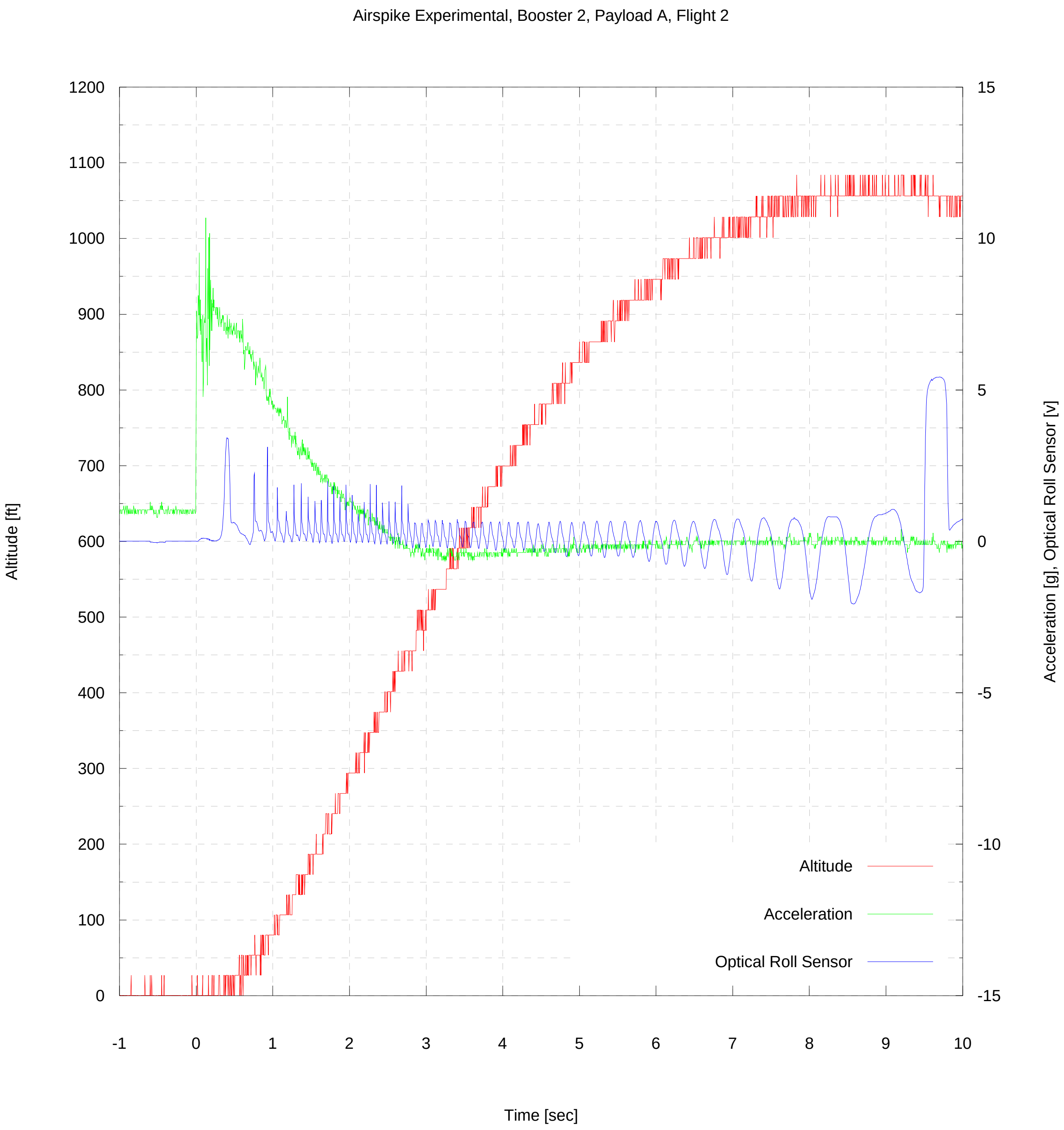


FIGURE 36. Booster 2, Flight 2, Data thru Apogee



5.3 Booster 3 (Fin Tab Angle: 4.8 deg.)

FIGURE 37. **Booster 3, Flight 1, Data thru Apogee**

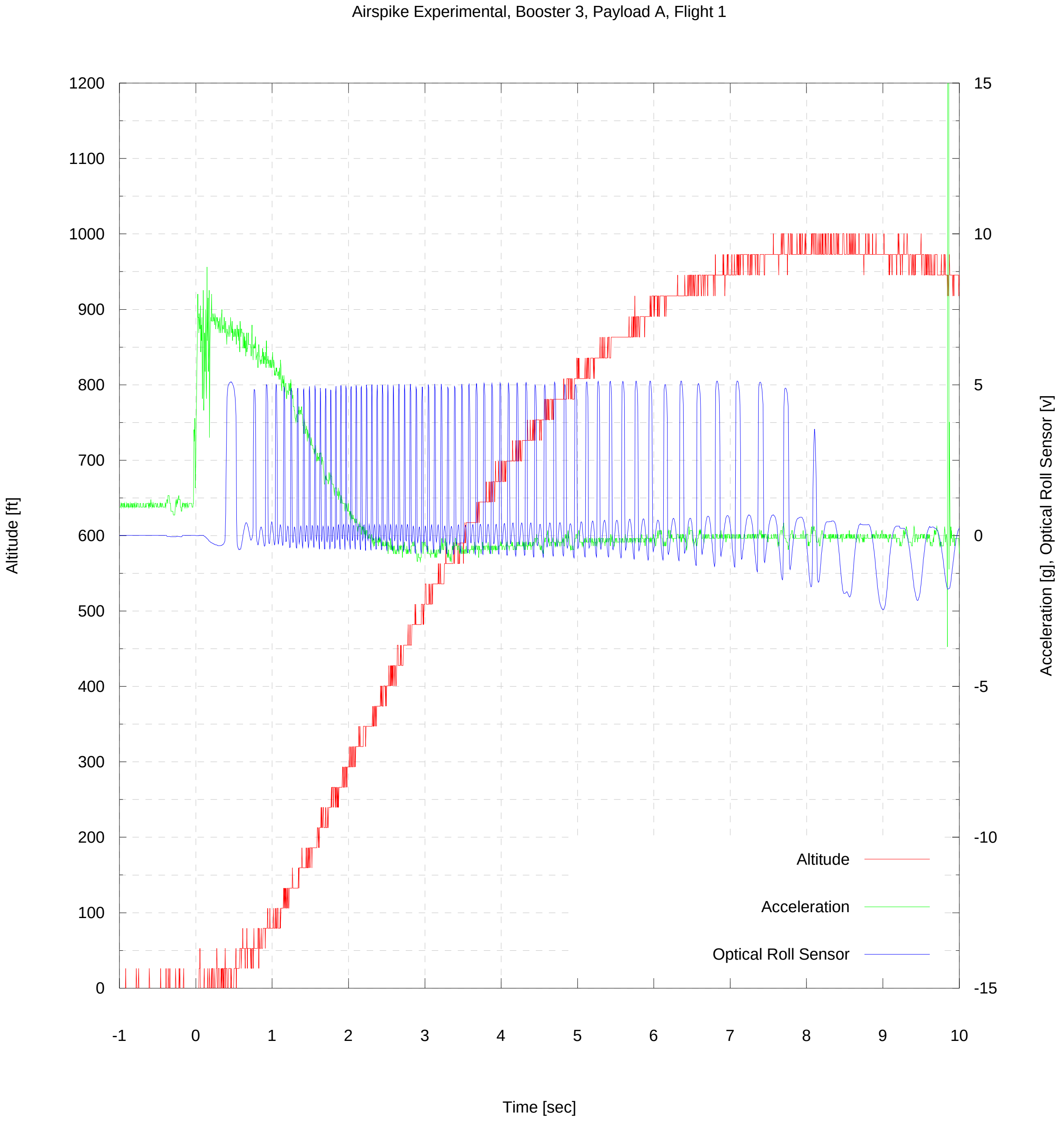


FIGURE 38. **Booster 3, Flight 2, Data thru Apogee**

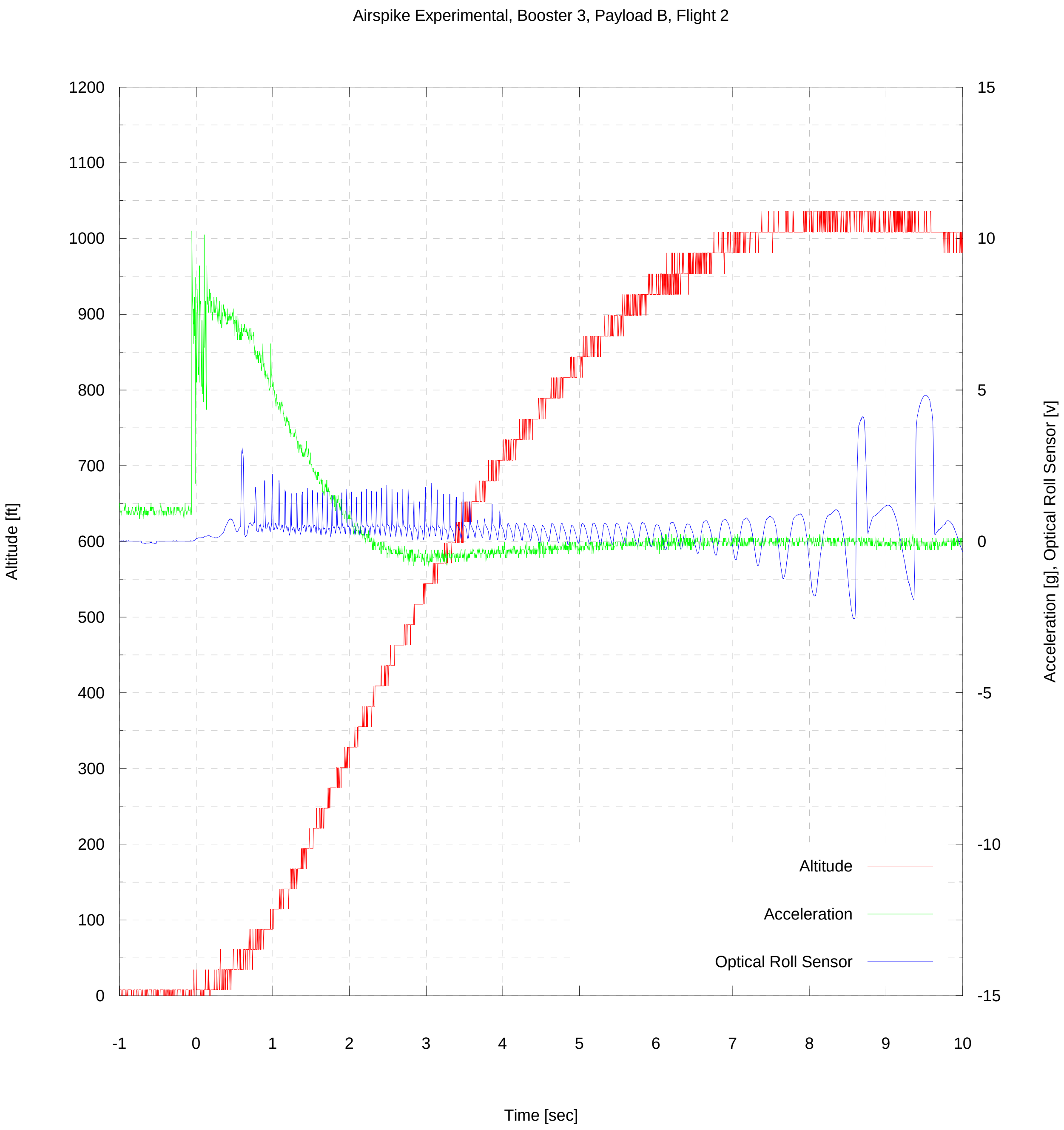


FIGURE 39. **Booster 3, Flight 3, Data thru Apogee**

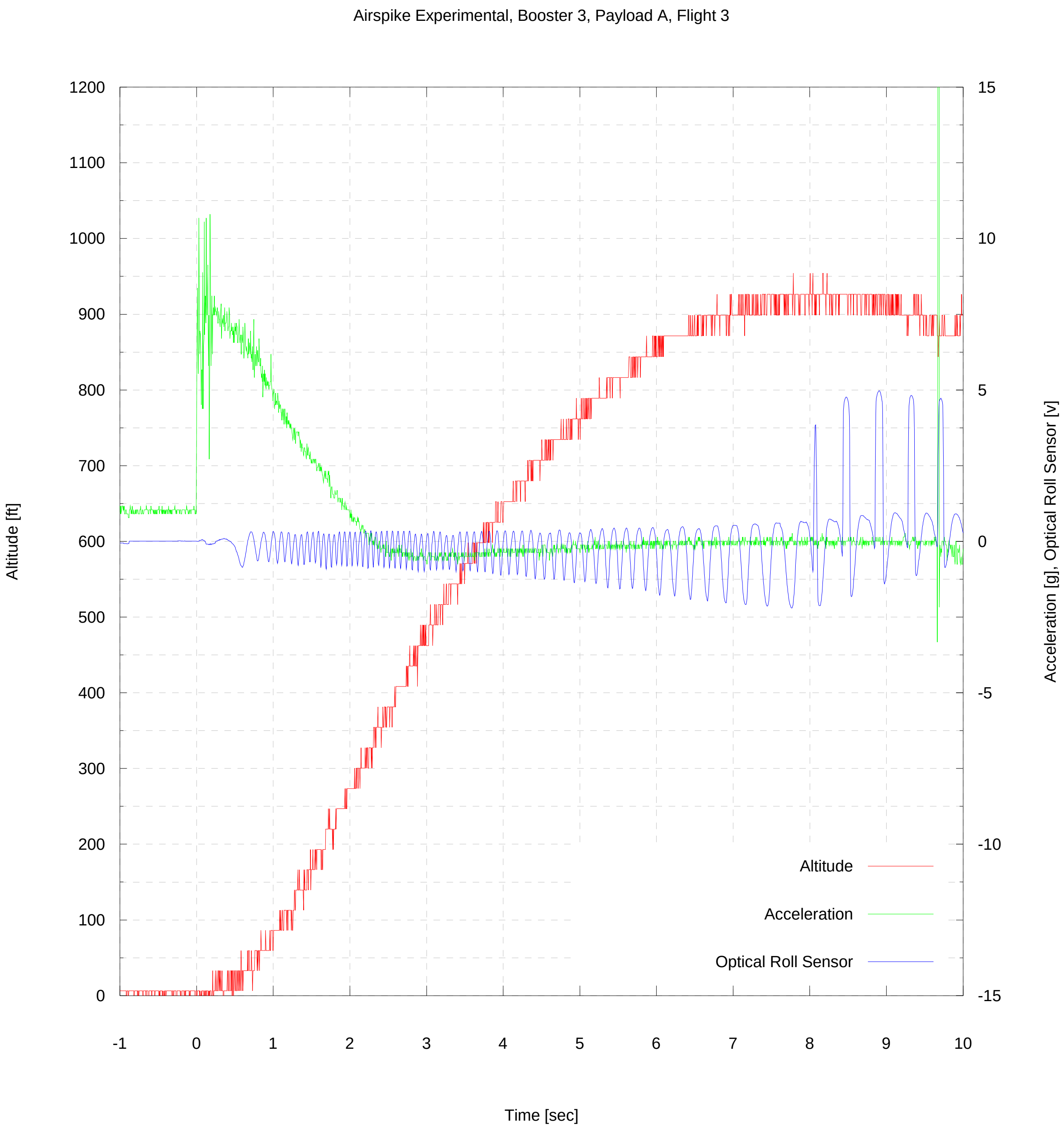
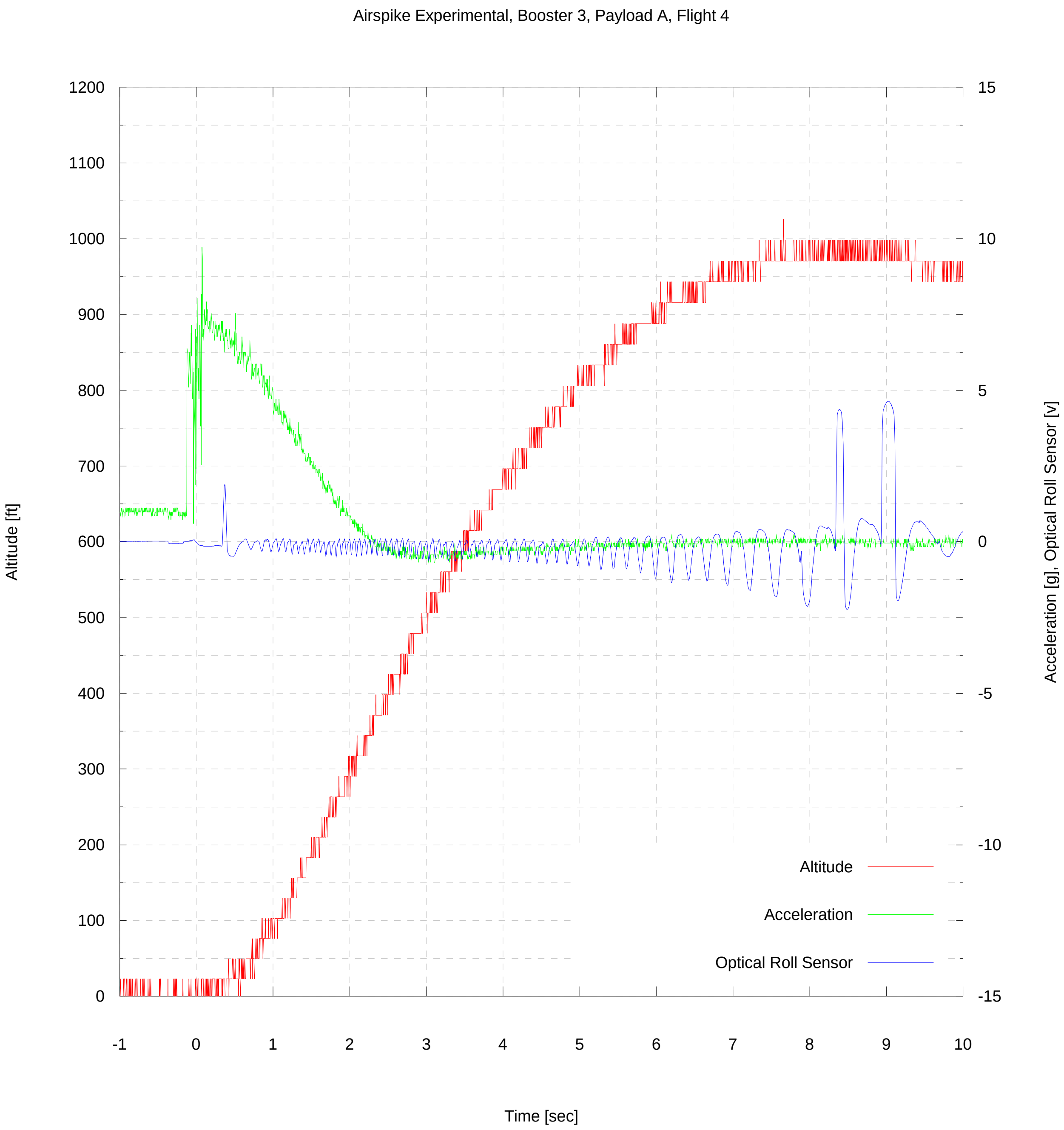


FIGURE 40. **Booster 3, Flight 4, Data thru Apogee**



5.4 Booster 4 (Fin Tab Angle: 7.2 deg.)

FIGURE 41. **Booster 4, Flight 1, Data thru Apogee**

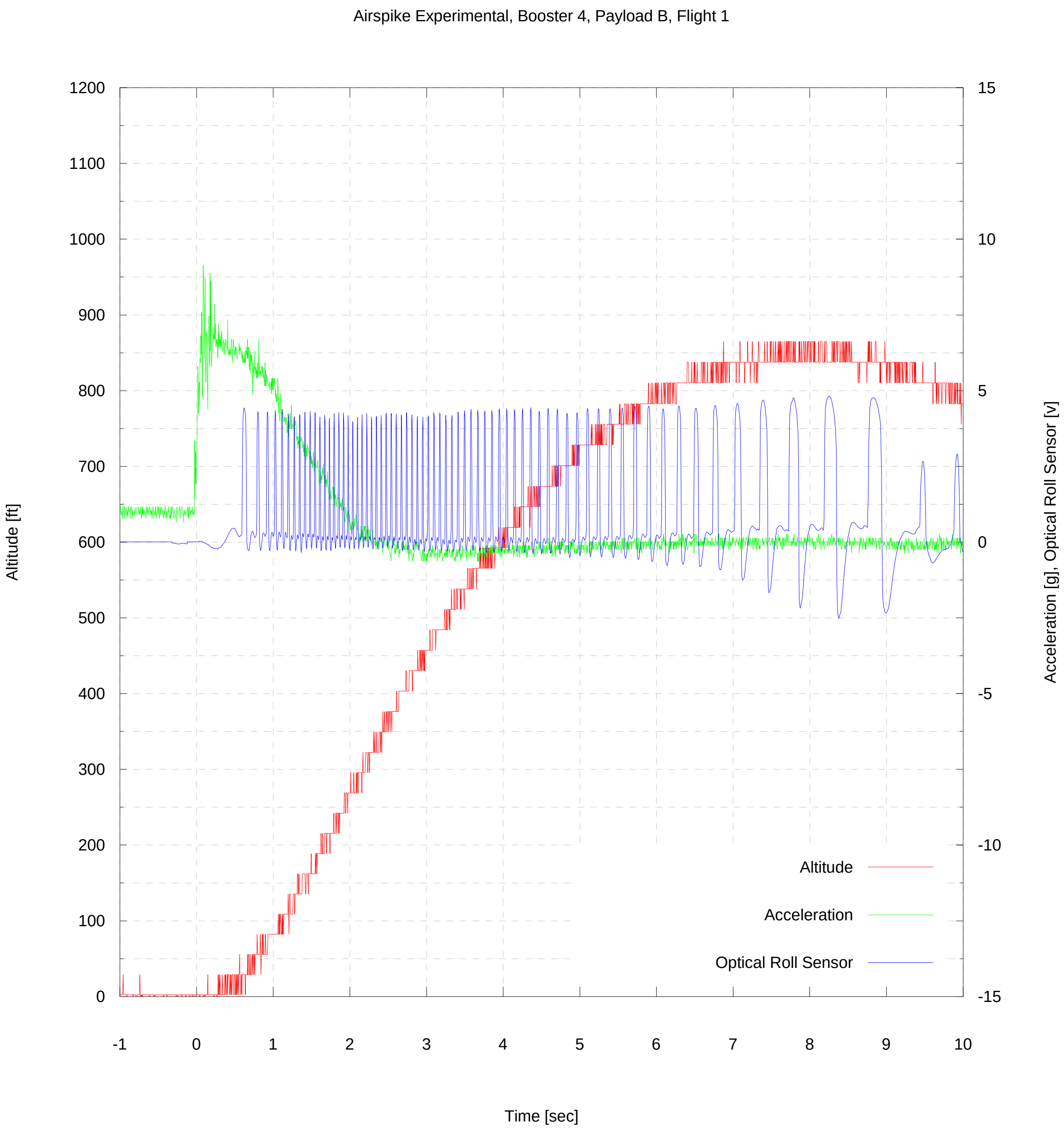


FIGURE 42. **Booster 4, Flight 2, Data thru Apogee**

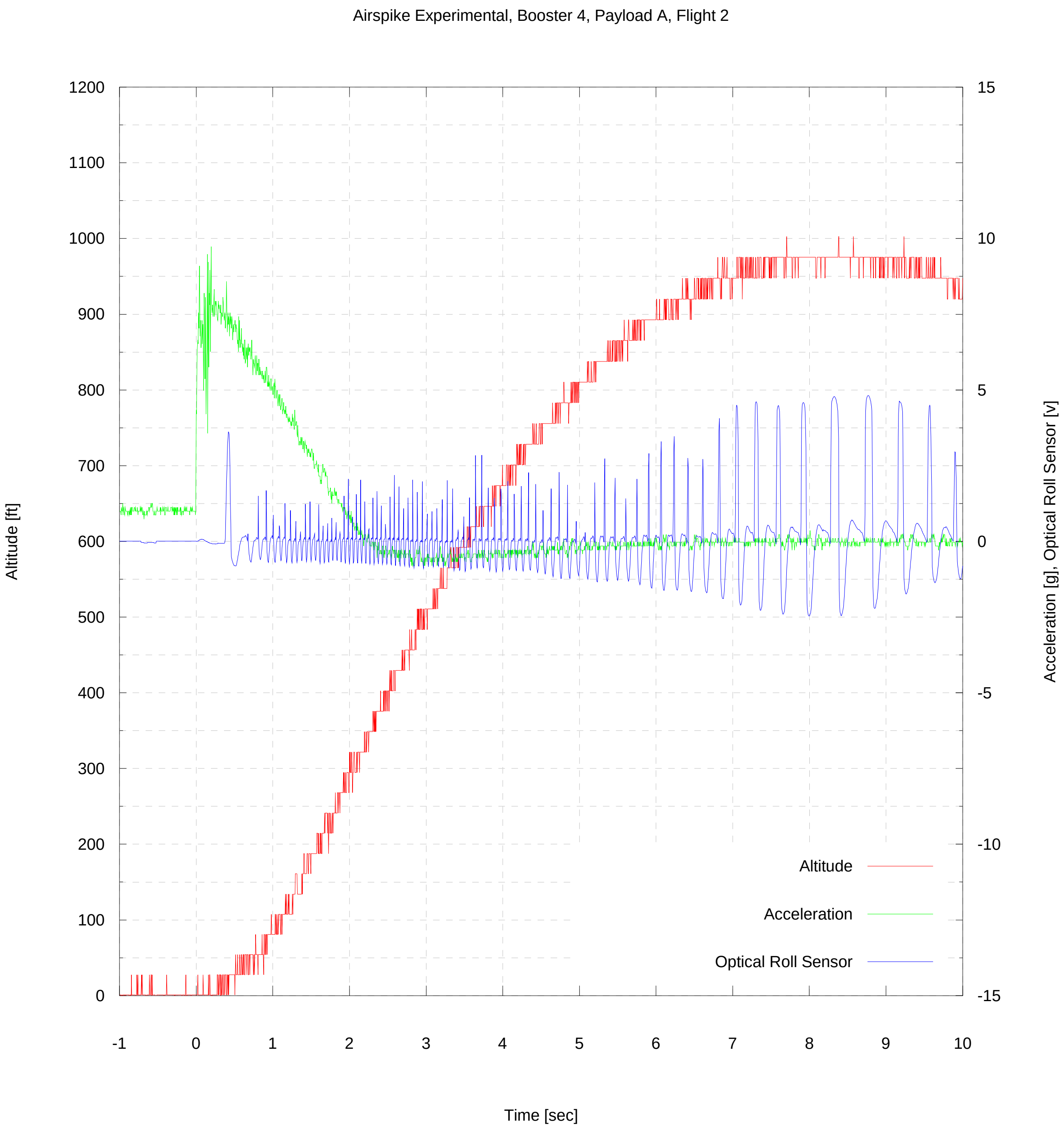


FIGURE 43. Booster 4, Flight 3, Data thru Apogee

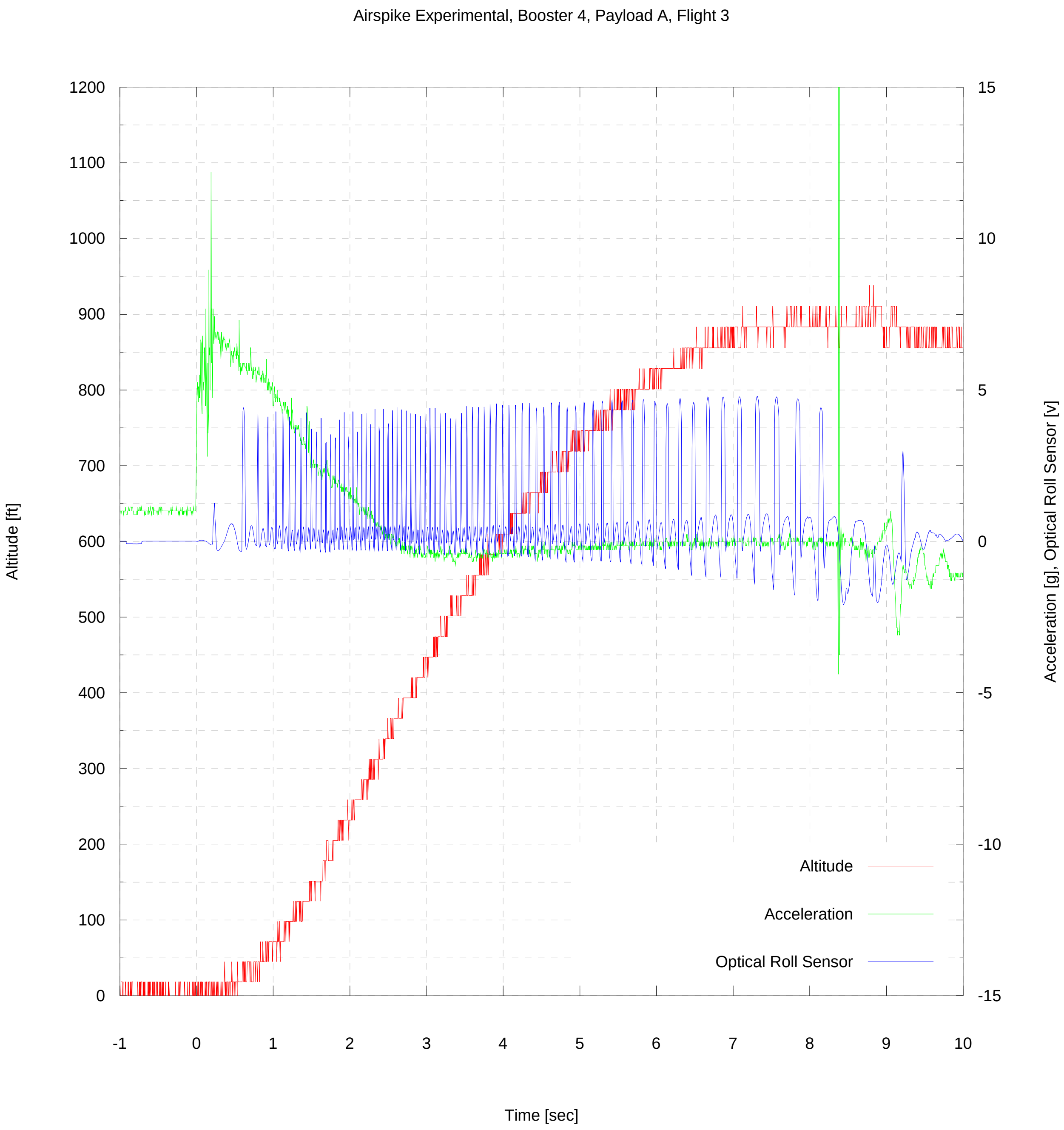
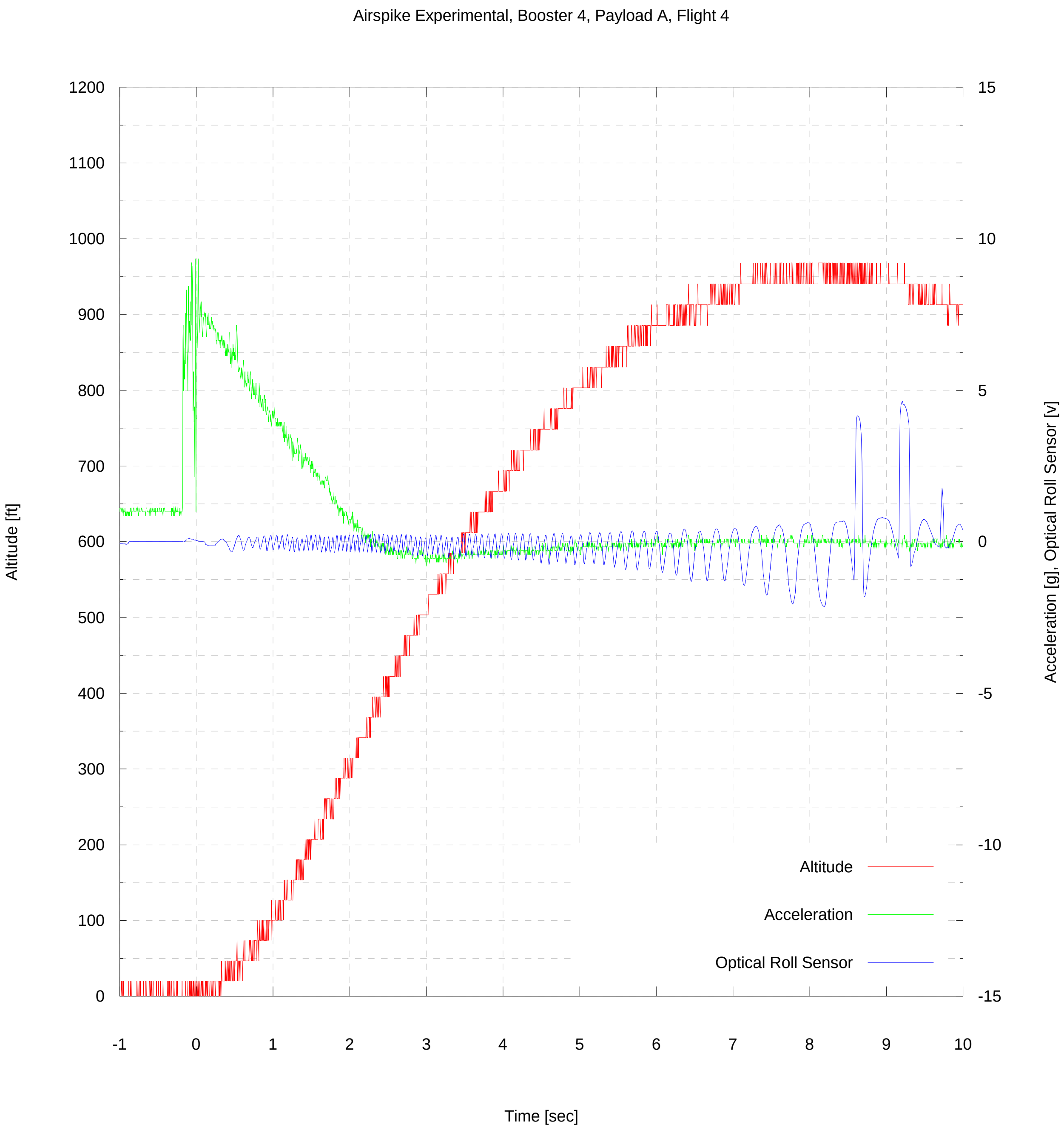


FIGURE 44. Booster 4, Flight 4, Data thru Apogee



5.5 Booster 5 (Fin Tab Angle: 9.6 deg.)

FIGURE 45. **Booster 5, Flight 1, Data thru Apogee**

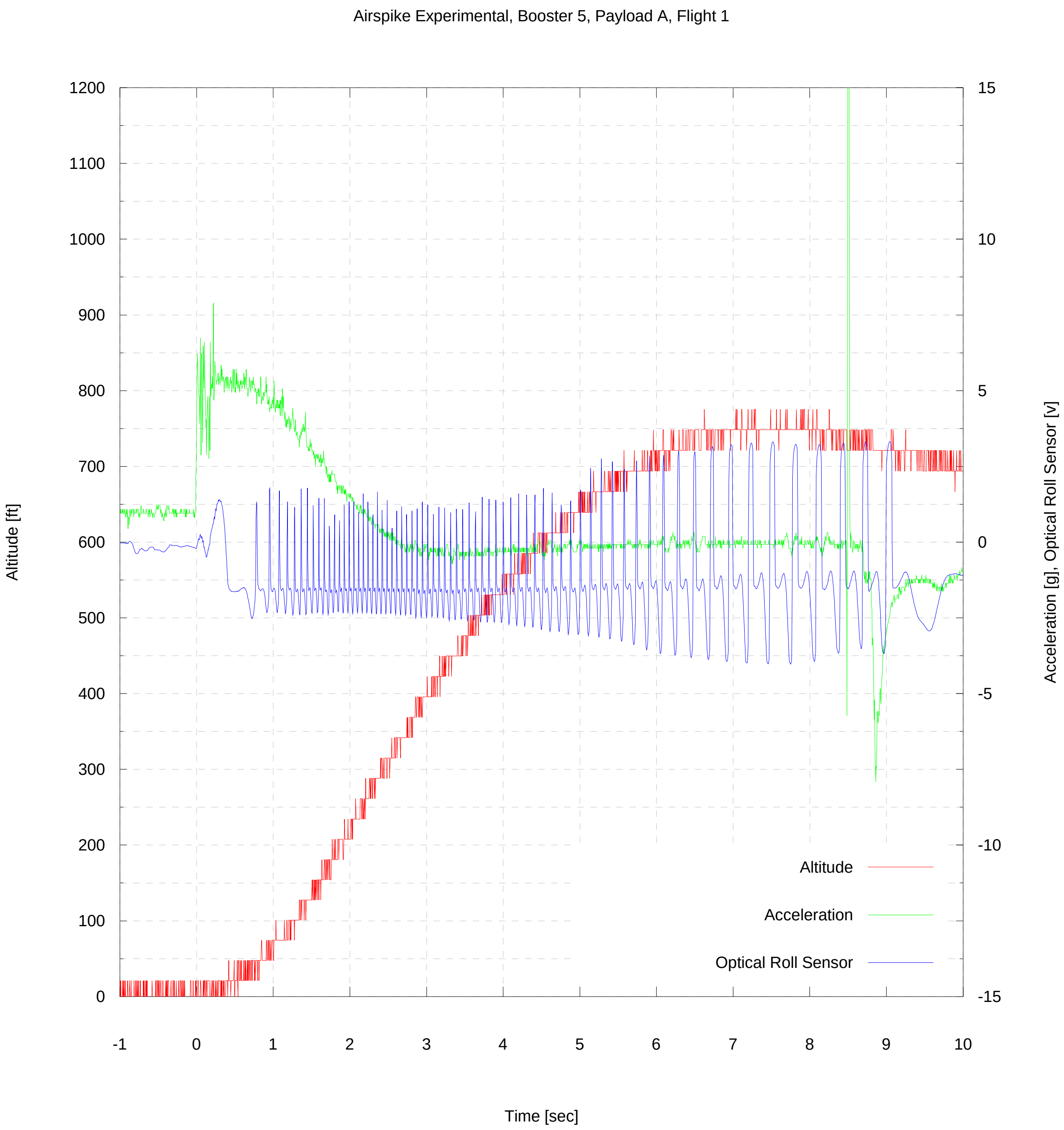
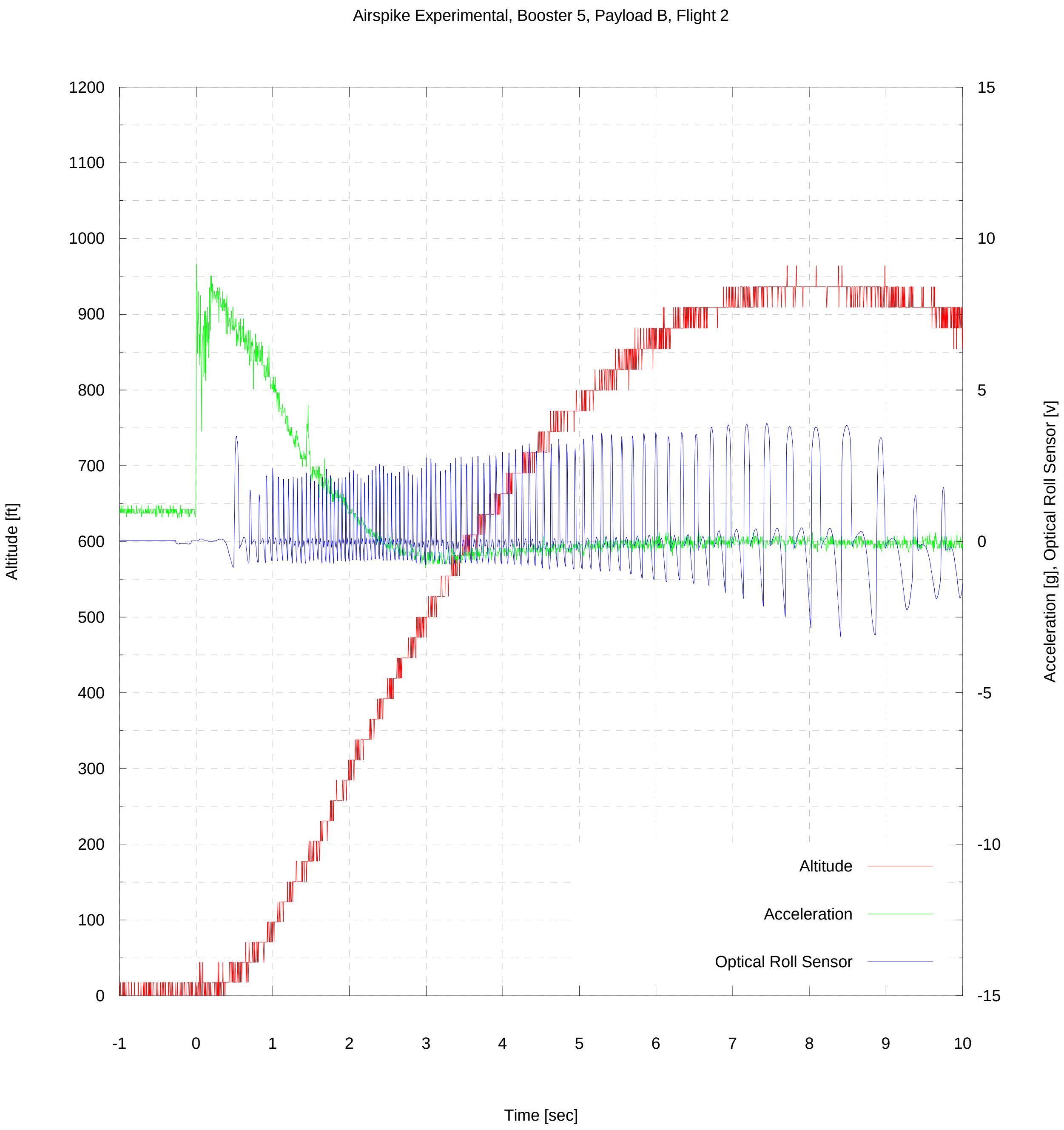


FIGURE 46. Booster 5, Flight 2, Data thru Apogee



5.6 Booster 6 (Fin Tab Angle: 12.0 deg.)

FIGURE 47. **Booster 6, Flight 1, Data thru Apogee**

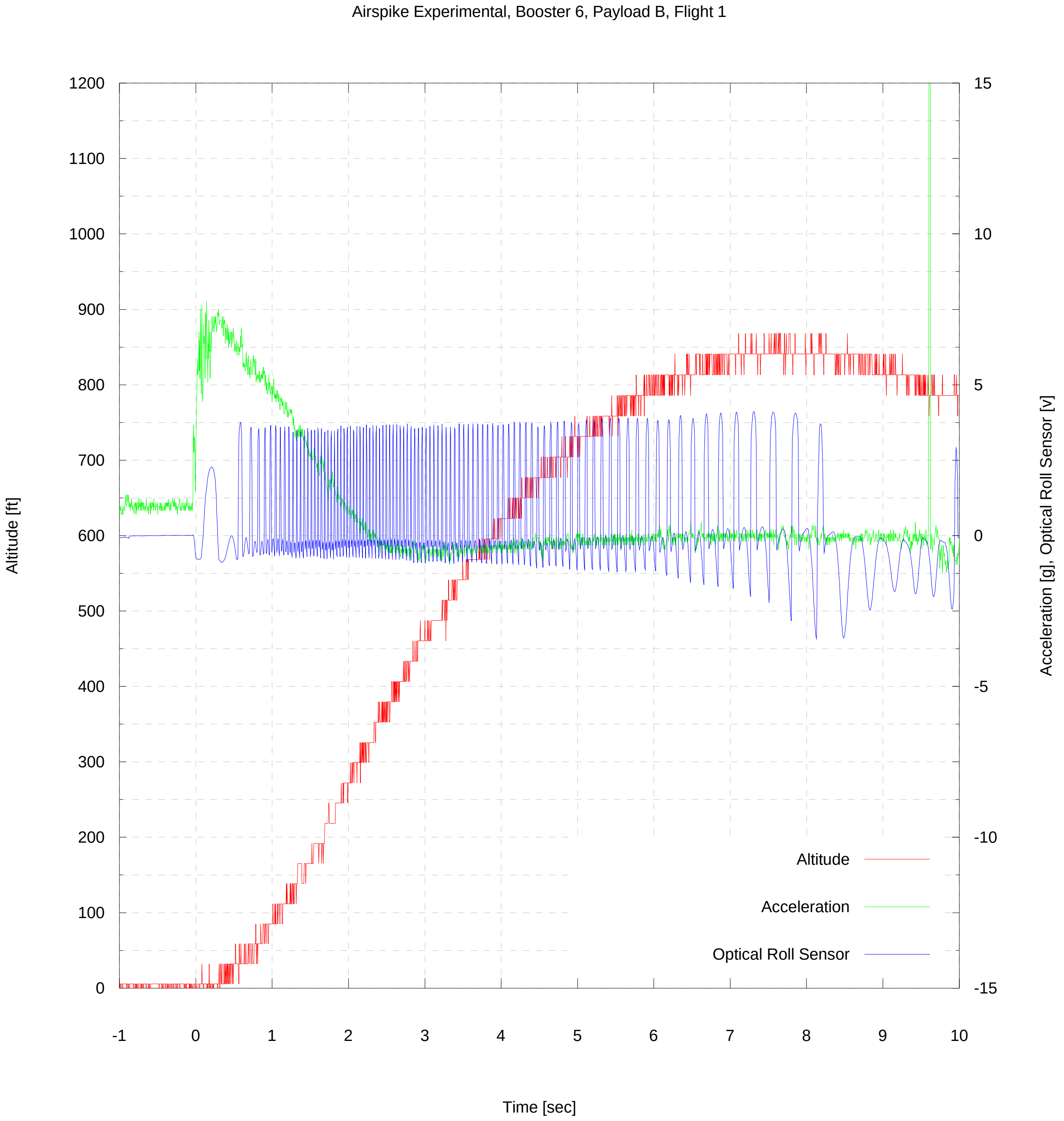


FIGURE 48. **Booster 6, Flight 2, Data thru Apogee**

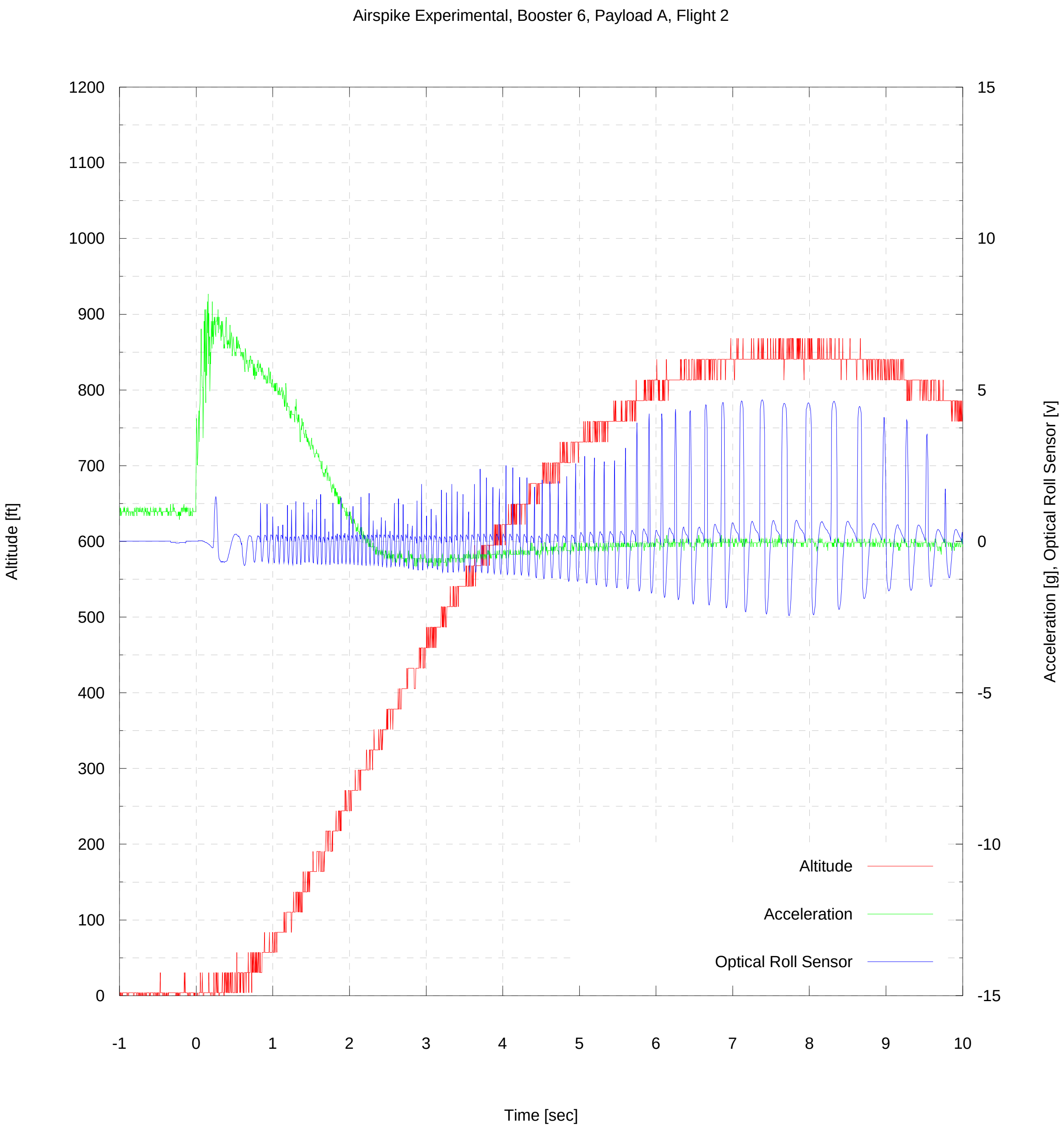


FIGURE 49.

6.0 Conclusions

6.1 Launch Report

The launch was an overall success. Although the goal of launching six rockets four times each was not reached due to a few malfunctions, sufficient data was recorded in a total of 18 flights. One of the two payload sections was lost, two of the six rockets were lost, and a third suffered minor damage to the fin tabs.

FIGURE 50. **Typical Rocket Prep and Launch Photos**

On the third flight of rocket number two, the rocket came in ballistic. The problem was human error. The motor was not fully inserted into the rocket, and when the ejection charge went off, the motor kicked itself out of the rocket. Without an ejection charge, the recovery didn't work. On the second flight of rocket five, the parachute did not deploy correctly. The payload section came down under chute just fine, but the parachute on the booster did not come out. On the first flight of rocket six, one of the fin tabs cracked upon landing. On the second flight of rocket number six, the fin tab fell off during the boost phase.

FIGURE 51. **Photos of damage to Rocket 2, Payload B after recovery failure**

Some minor problems with parachute deployment were encountered in the first few flights, but they were soon solved. A total of eighteen flights were flown in three hours. A rocket would be prepped for flight and flown. After it was put on the launch rod, the next rocket would be prepped. When the rocket was recovered, the data would be downloaded onto a laptop from the RDAS, and the next rocket would be launched. After a round of six rockets, the motors would be replaced and the process was repeated. The results are summarized below.

TABLE 1. **Results Summary Table**

Booster #	Fin Angle (deg)	Payload #	Flight #	Roll Rate (rps)	Altitude (ft)	Std Dev (ft)	Mean (ft)	Degradation (%)
1	0.0	A	1	0.2	1169			
1	0.0	B	2	0.2	1119			
1	0.0	A	3	0.2	1125			
1	0.0	A	4	0.0	1142	22	1139	
2	2.4	B	1	13.0	1019			
2	2.4	A	2	13.0	1084	46	1052	7.7%
3	4.8	A	1	14.0	1000			
3	4.8	B	2	15.0	1036			
3	4.8	A	3	15.0	954			
3	4.8	A	4	15.0	998	34	997	12.4%
4	7.2	B	1	16.0	865			
4	7.2	A	2	16.0	1003			
4	7.2	A	3	17.0	911			
4	7.2	A	4	18.0	968	61	937	17.7%
5	9.6	A	1	17.0	776			
5	9.6	B	2	20.0	964	133	870	23.6%
6	12.0	B	1	22.0	868			
6	12.0	A	2	19.0	868	0	868	23.8%

6.2 Roll Rate Sensor

To collect the necessary roll rate information a sensor to record the spin of the rockets was needed. To achieve this, an optical variable resistor was used. When the resistor is in sunlight, the resistance is lowered, and when it is in shade, the resistance is once again raised. Along with the RDAS and a 270 ohm resistor, a circuit was built to measure the roll rate of the rocket. The design of the optical sensor was validated when the first flight came back with the expected data. The information was analyzed on the graphs with the rest of the information from the RDAS.

One of the problems with the roll rate sensor was with the nine volt battery that powered the unit. When the LED and the beeper in the RDAS would blink and beep, it was apparent that the battery did not have enough power. When the board beeped, the voltage in the recording channel for the optical sensor dropped. This can be seen in the graphs of the data gathered.

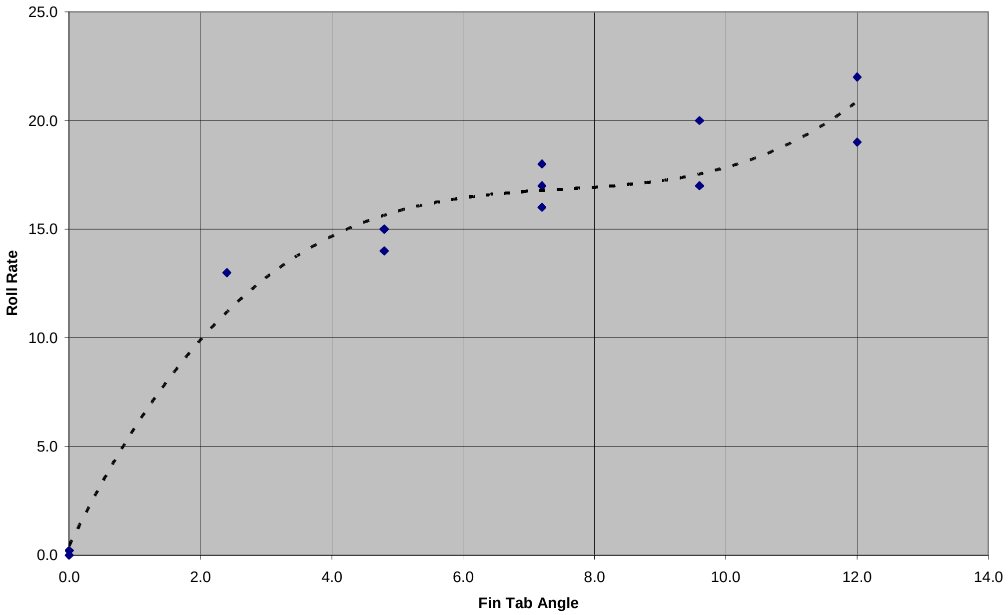
Another problem, that has not yet been solved, is again a recording problem in the graphs. After the voltage rises from the sensor being in the sun, as it comes back down it rises again before continuing to the bottom. This pattern was first thought to be another problem with the battery. After the voltage reaches a high enough point, it drains the battery. As the voltage lowers, the battery has a chance to “recharge” itself, and the voltage rises again. This hypothesis was disproved because in three of the graphs, the pattern is backwards. Another theory about this problem is that the angle of the sensor in comparison with that of the rocket and sun creates the problem. The sensor may have bent down when the rocket launched. If so, the hole in the side of the rocket might have cast a weird shadow on the photo cell. The angle that the rocket took off at, as well as the angle of the sun at the time also might have affected the results.

6.3 Inducing Roll

The hypothesis of inducing roll was proved correct. The fin tabs created increasing roll in accordance to increasing fin tab angles. The data from the optical roll rate sensor was used to analyze the roll rate. The graph of the data moved up and down as the sensor moved in and out of the sun. Each peak is one roll. By counting the peaks in the densest area in one second, the maximum spin is found in revolutions per second (rps).

A problem with inducing roll was the effect on recovery. Because such a high roll rate was being achieved, 12-22 rps, when the booster and payload separated, the parachute was twisting. When the parachute would open, the payload would still be spinning at a high velocity twisting the shroud lines and shock cord until the parachute couldn't open. The solution was to roll the parachute more tightly as well as to wrap more of the shock cord around it. When the parachute was tightly rolled, the inflation of the parachute was slowed. As the parachute inflated, the spinning payload had more time to slow down the spinning.

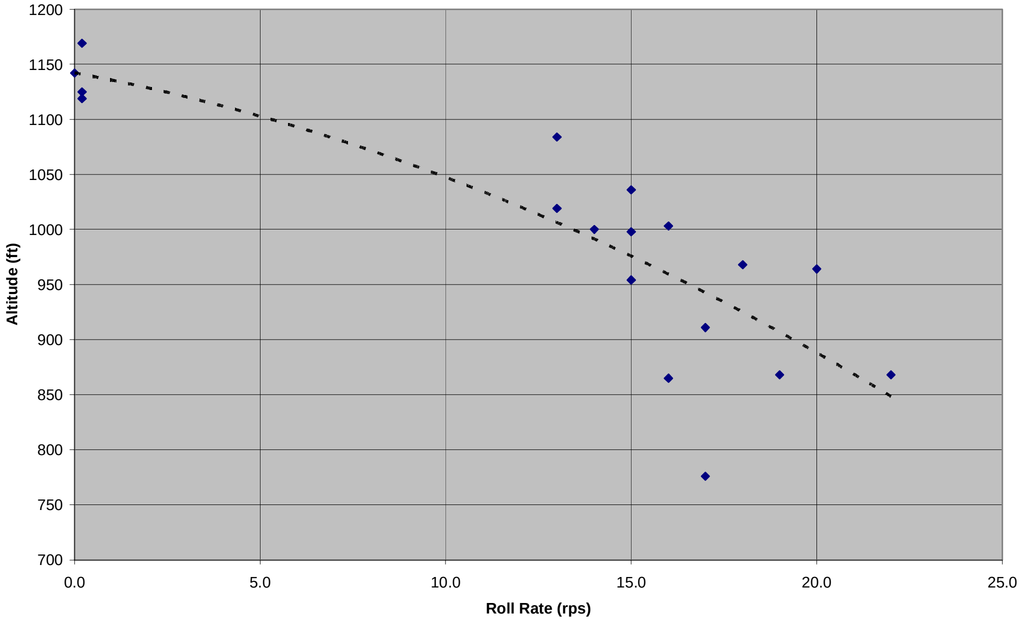
FIGURE 52. **Roll Rate vs. Fin Tab Angle**



6.4 Effect on Altitude

The spin had the predicted effect on the rockets. As soon as the data was downloaded and graphed, it was apparent that the spin had a great effect on the altitude achieved by the rocket. The roll rates achieved varied from 0 - 22 revolutions per second. The hypothesis was proved correct. There was a great degradation of altitude in the flights. Such a dramatic change happened because of the extra force used to push the fins through the air laterally. The fins were like the paddles of a paddle boat, using a lot of force that would normally be used to push the rocket upwards. The results are plotted below. The graph is plotted as altitude versus roll rate. The shape of the graph, second order, agrees with the fact that drag of the spinning fins is proportional to the square of their angular velocity.

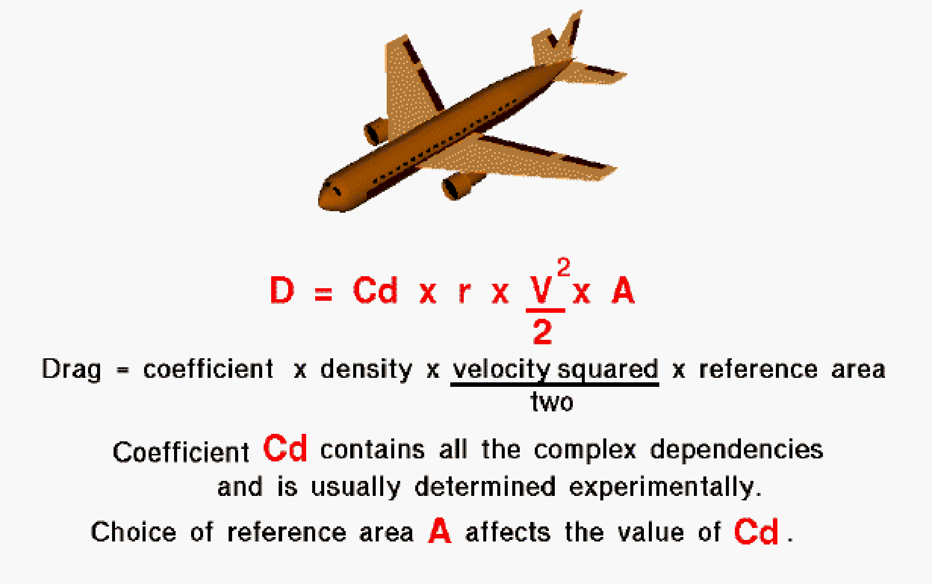
FIGURE 53. **Altitude vs. Roll Rate**



6.5 Mathematical Modeling

After the data had been collected, more research was done to find an equation for the amount of force lost as the fins are being pushed through the air like the paddles of a paddle boat. An equation for drag was first needed to find the drag of the spinning fins. Drag is equal to the Coefficient of Drag (Cd) times the air density (ρ) times the velocity squared over two times the area of the surface.

FIGURE 54. **Drag Equation** **(Glenn Research Center, NASA)**



$$D = Cd \times r \times \frac{V^2}{2} \times A$$

$$\text{Drag} = \text{coefficient} \times \text{density} \times \frac{\text{velocity squared}}{\text{two}} \times \text{reference area}$$

Coefficient Cd contains all the complex dependencies and is usually determined experimentally.

Choice of reference area A affects the value of Cd.

The coefficient of drag for a flat surface is 1.28. The standard air density at sea level is 1.3 Kg/m^3. To find the velocity, the angular velocity of the fins in revolutions per second must be changed to linear velocity in meters per second. To do this, an arbitrary point on a fin was used. This point was 2.5 inches from the center, meaning it has a 2.5 inch radius. The linear velocity is equal to the circumference of the circle times the revolutions per second.

$$V = 2\pi r \ * \ \text{rev/s} \qquad \text{(EQ 4)}$$

$$\text{Drag} = Cd \;*\; \rho \;*\; v^2/2 \;*\; A \tag{EQ 5}$$

$$\text{Drag} = Cd \;*\; \rho \;*\; (2\pi\, r \;*\; \text{rev/s})^2 \;*\; A \tag{EQ 6}$$

Accounting for the fact that there are four fins, the whole equation is multiplied by four.

$$\text{Drag} = 4 * 1.28 * 1.3\ \text{Kg/m}^3 * (2\pi * 0.0635\text{m} * \text{rev/s})^2 /2 * 0.006452\ \text{m}^2 \tag{EQ 7}$$

$$\text{Drag} = 0.003418 \;*\; (\text{rev/s})^2 \quad \text{(Newtons)} \tag{EQ 8}$$

To find the force used over time, the drag multiplied by the time gives the answer of the impulse in Newton seconds. The final equation is the drag, 0.003418, times the revolutions squared, times the time to apogee.

$$\text{Fin Impulse} = 0.003418 \;*\; (\text{rev/s})^2 \;*\; t_a \quad \text{(Newton seconds)} \tag{EQ 9}$$

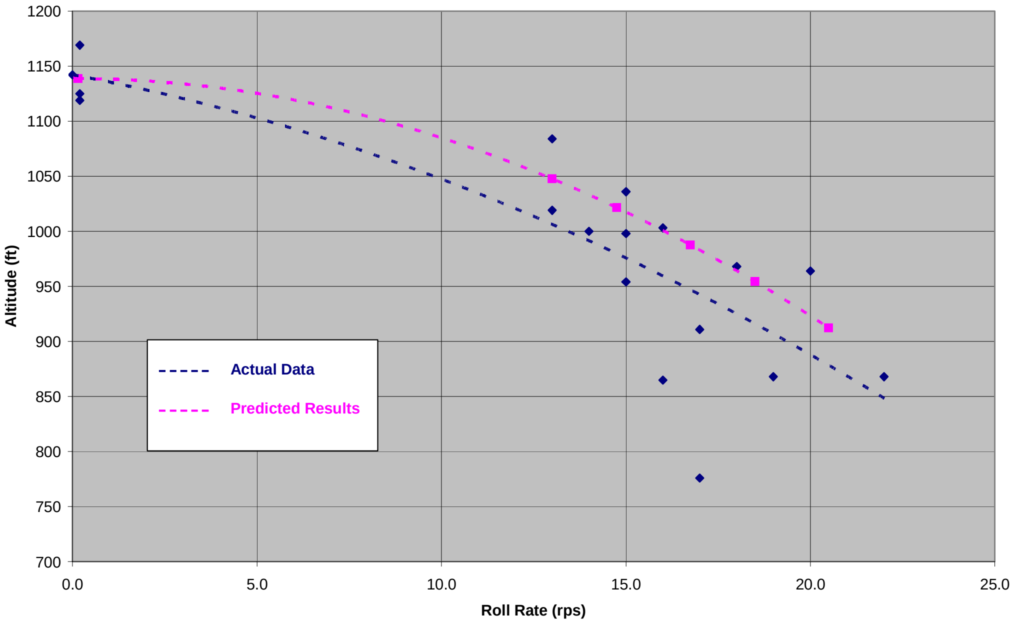
The values predicted using the equation come relatively close to those actually recorded. The force over time consumed by spinning the fins was calculated as a percent of the total impulse of the motor. This percentage was then used to calculate the altitude degradation as a function of roll rate. It was assumed that the altitude would degrade proportionally to the energy consumed by the spinning fins. The table below shows these results.

FIGURE 55. **Predicted Results Summary Table**

		Observed			Prediction		
Booster #	Fin Angle (deg)	Mean Roll Rate (rps)	Mean Altitude (ft)	Mean Degradation (%)	Calculated Fin Impulse (Ns)	Fin Impulse / Motor Impulse (%)	Predicted Altitude (ft)
1	0.0	0.2	1139		0.0	0.0%	1139
2	2.4	13.0	1052	7.7%	5.2	8.0%	1048
3	4.8	14.8	997	12.4%	6.7	10.3%	1021
4	7.2	16.8	937	17.7%	8.6	13.3%	988
5	9.6	18.5	870	23.6%	10.5	16.2%	954
6	12.0	20.5	868	23.8%	12.9	19.9%	912

The altitude predictions were then compared with the actual results from the experiment. The graph below shows the predicted altitudes and the observed altitudes. As can be seen in the graph, the predicted results are a close match to the actual data, with the actual data being slightly lower. This can be explained by other variables in the experiment that impacted altitude but were not completely controlled: wind, temperature, and angle of departure to mention a few.

FIGURE 56. Observed Altitude and Predicted Altitude vs. Roll Rate



6.6 Other Observations

Looking at the accelerometer it is obvious that there were some problems with the igniters. A fraction of a second after launch, the gees would drop back down as the igniters yanked free of the alligator clips.

By observing the roll rate data, it can be determined at what time into the flight the rocket cleared the launch rod. The rocket would try to start spinning as soon as it started moving, but could not until it was off of the rod. When the roll starts on the graph, is the time at which the rocket has cleared the launch rod.

Also shown on the graph, is the point in time when the rocket achieved its maximum roll rate. The top roll rate for the rockets was at approximately motor burn out on all of the rockets. At this time the rocket probably also reached its highest velocity.

7.0 Works Cited

Reme Museum of Technology

<http://www.cs.rdg.ac.uk/cs/ug/projects/ssu96nld/guidance.htm>

BGM-109 Tomahawk

<http://www.fas.org/man/dod-101/sys/smart/bgm-109.htm>

Beginners Guide to Aeronautics

<http://www.grc.nasa.gov/Other_Groups/K-12/airplane/index.html>

7.1 Pictures

Command missile guidance
Homing missile guidance
Reme Museum of Technology

<http://www.cs.rdg.ac.uk/cs/ug/projects/ssu96nld/guidance.htm>

TERCOM and DSMAC
BGM-109 Tomahawk

<http://www.fas.org/man/dod-101/sys/smart/bgm-109.htm>

Rocket parts
Rocket Flight
Newton's first law
Newton's second law
Newton's third law
Determine CG
Determine CP

Determine weight

Stability

Solid rocket motor

Liquid rocket motor

Combustion

Hero Engine

Chinese Fire Arrows

Chinese soldier fire arrow

Surface torpedo

Engine performance

German V2

Goddards 1926 liquid rocket

Ramjet

Wanhu Rocket

Beginners Guide to Aeronautics

<http://www.grc.nasa.gov/Other_Groups/K-12/airplane/index.html>

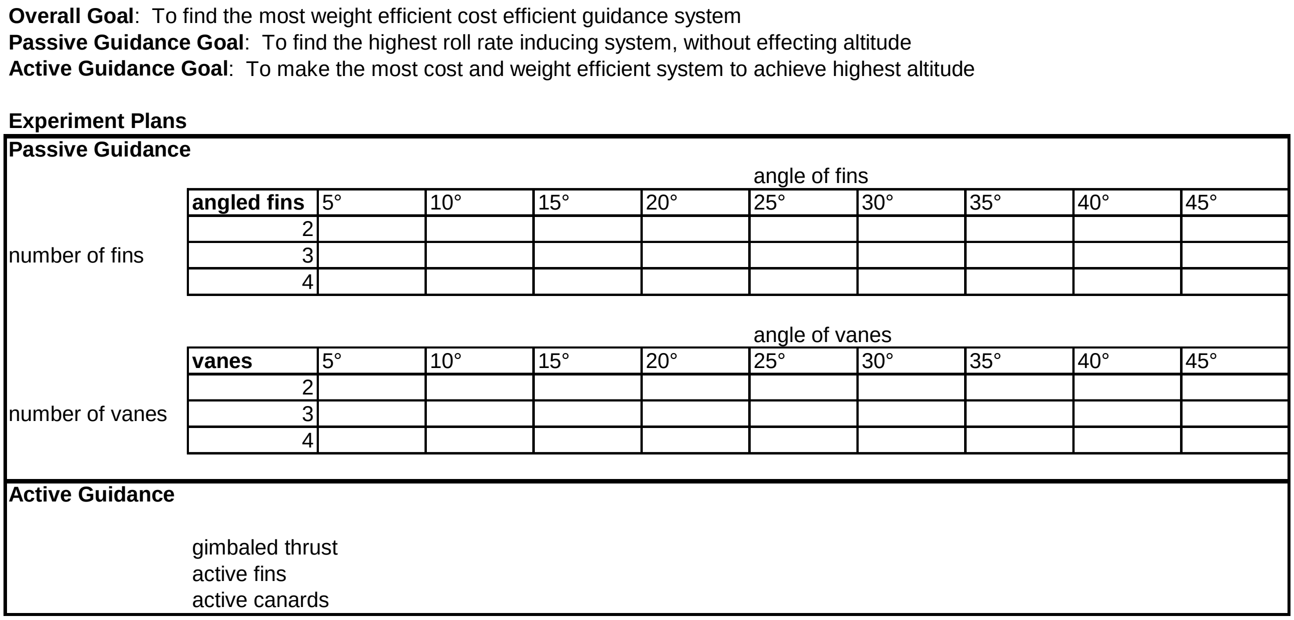
8.0 Appendix A -- Correspondence with Mentor

> > ------- Original Message -------
> > > From: Evan Gates <evan.gates@gbrocketry.com>
> > > To: “scott@blacksky.com” <scott@blacksky.com>
> > > Date: Sat, 12 Jan 2002 11:17:12 -0800
> > >
> > > Dear Scott Bartel,
> > > I am looking for mentors in the field of aeronautical engineering.
> > > I am doing a science project in my class and I am in the
> > > eighth grade. I wanted to know if you would be able to help me if I
> > > came across something I didn't understand or to lend advice. All
> > > correspondence will be via email and will be forwarded/cc to my
> > > science teacher, Louis Garcia.
> > > Please email me if you are interested in being a mentor or know
> > >somebody else who would be.
> > >
> > > Sincerely,
> > > Evan

> > -----Original Message-----
> > From: Scott Bartel [mailto:scott@blacksky.com]
> > Sent: Saturday, January 12, 2002 4:04 PM
> > To: Evan Gates
> > Subject: Re:
> >
> > Evan,
> > Yes I can assist you with questions regarding Aerospace. I might
> > also be able to point you in the right directions should you get
> > stumped.
> Scott

> ------- Original Message -------
> > From: Evan Gates <evan.gates@gbrocketry.com>
> > To: 'Scott Bartel' <scott@blacksky.com>
> > Subject: Project hypothesis and approval
> > Date: Tue, 22 Jan 2002 20:42:46 -0800
> >
> > Hey Scott,
> >
> > I'm not sure that I explained last time that I need you to reply to this
> > telling me whether it is a possible science project. I'm sorry to be
> > bugging you if you have already gotten the email and just haven't
> > had the time to reply. I don't mean to pester, but I need this approval
> > asap. Without the approval, my science teacher won't let me start my
> > project.

FIGURE 57. **Original Experiment Design Summary**



Overall Goal: To find the most weight efficient cost efficient guidance system
Passive Guidance Goal: To find the highest roll rate inducing system, without effecting altitude
Active Guidance Goal: To make the most cost and weight efficient system to achieve highest altitude

Experiment Plans

Passive Guidance

		angle of fins								
	angled fins	5°	10°	15°	20°	25°	30°	35°	40°	45°
	2									
number of fins	3									
	4									

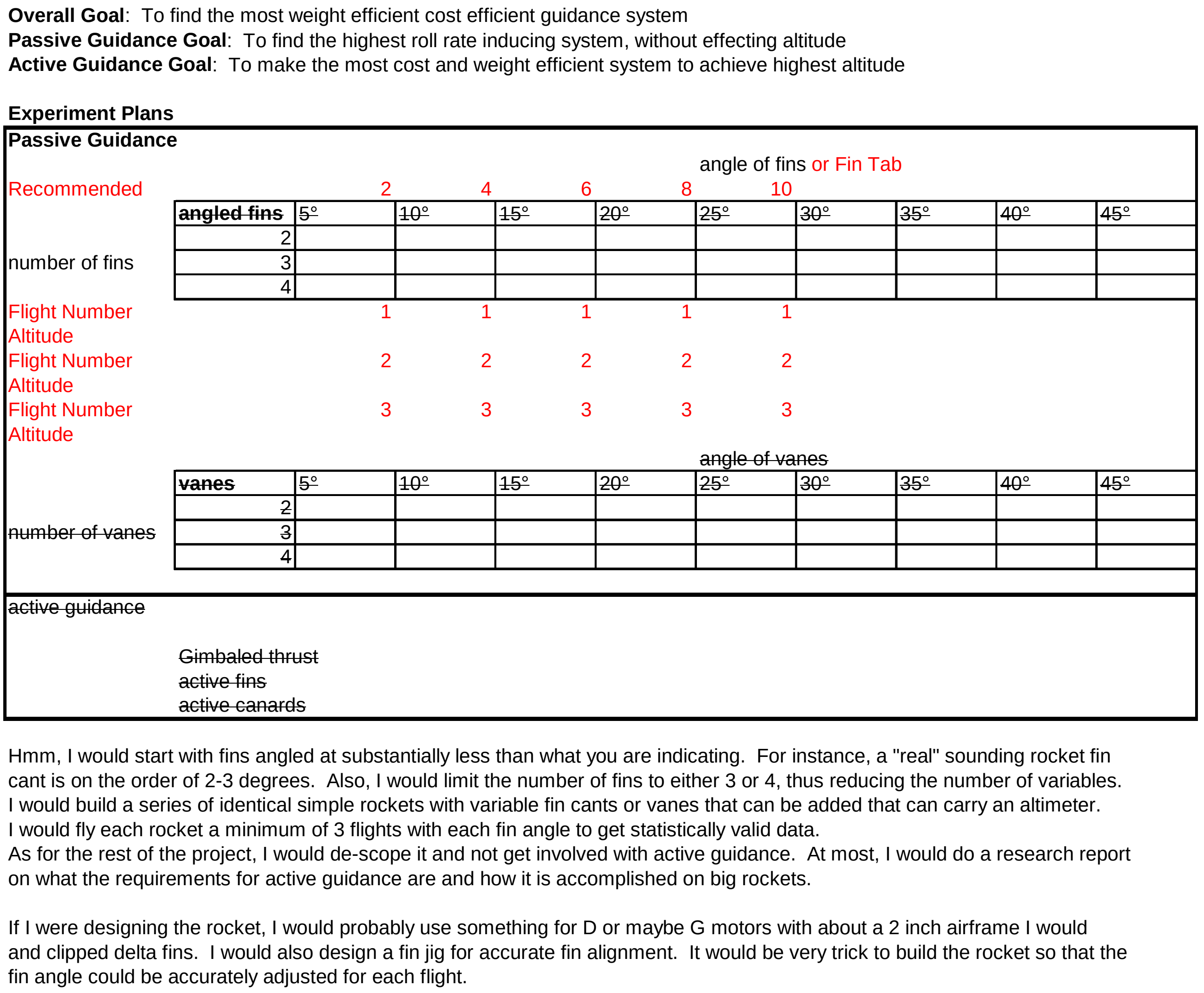
		angle of vanes								
	vanes	5°	10°	15°	20°	25°	30°	35°	40°	45°
	2									
number of vanes	3									
	4									

Active Guidance

gimbaled thrust
active fins
active canards

> -----Original Message-----
> From: Scott Bartel [mailto:scott@blacksky.com]
> Sent: Wednesday, January 23, 2002 9:28 AM
> To: Evan Gates
> Subject: Re: Project hypothesis and approval
>
> Evan, I have attached a commented file. The short version is to reduce
> the experiment complexity, by reducing the number of variables, but
> increasing the number of flights. Give me a call if you have questions,
> 760 730 3701. Scott

FIGURE 58. Commented Experiment Design Summary



Overall Goal: To find the most weight efficient cost efficient guidance system
Passive Guidance Goal: To find the highest roll rate inducing system, without effecting altitude
Active Guidance Goal: To make the most cost and weight efficient system to achieve highest altitude

Experiment Plans

Passive Guidance

angle of fins or Fin Tab

Recommended		2	4	6	8	10				
	~~angled fins~~	~~5°~~	~~10°~~	~~15°~~	~~20°~~	~~25°~~	~~30°~~	~~35°~~	~~40°~~	~~45°~~
	2									
number of fins	3									
	4									
Flight Number		1	1	1	1	1				
Altitude										
Flight Number		2	2	2	2	2				
Altitude										
Flight Number		3	3	3	3	3				
Altitude										

~~angle of vanes~~

	~~vanes~~	~~5°~~	~~10°~~	~~15°~~	~~20°~~	~~25°~~	~~30°~~	~~35°~~	~~40°~~	~~45°~~
	~~2~~									
~~number of vanes~~	~~3~~									
	4									

~~active guidance~~

~~Gimbaled thrust~~
~~active fins~~
~~active canards~~

Hmm, I would start with fins angled at substantially less than what you are indicating. For instance, a "real" sounding rocket fin cant is on the order of 2-3 degrees. Also, I would limit the number of fins to either 3 or 4, thus reducing the number of variables.
I would build a series of identical simple rockets with variable fin cants or vanes that can be added that can carry an altimeter.
I would fly each rocket a minimum of 3 flights with each fin angle to get statistically valid data.
As for the rest of the project, I would de-scope it and not get involved with active guidance. At most, I would do a research report on what the requirements for active guidance are and how it is accomplished on big rockets.

If I were designing the rocket, I would probably use something for D or maybe G motors with about a 2 inch airframe I would and clipped delta fins. I would also design a fin jig for accurate fin alignment. It would be very trick to build the rocket so that the fin angle could be accurately adjusted for each flight.

------- Original Message -------
> From: Evan Gates <evan.gates@gbrocketry.com>
> To: 'Scott Bartel' <scott@blacksky.com>
> Subject: RE: Project hypothesis and approval
> Date: Sun, 27 Jan 2002 14:38:31 -0800
>
> Instead of canting the fins, I was wondering if it was possible to add a
> balsawood triangular prism on the bottom of all the fins at different
> angles. I have included a file to show what I meant.
>
> E

> -----Original Message-----
> From: Scott Bartel [mailto:scott@blacksky.com]
> To: Evan Gates
> Subject: Re: Project hypothesis and approval
>
> A tab should be fine. You might want to consider using a sine bar
> scheme to generate the fin tab angles. Using thin fiberglass (0.031"
> or 0.020") and a piece of wire or perhaps dowel or plastic rod to angle
> the fin. See the attached PPT file for details.