Team Falcon

Flight Readiness Report

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Executive Summary

Team Falcon

Team Falcon is comprised of four students from the University of Wisconsin-River Falls (UWRF). The team leader, sophomore Timothy Dirks, is a dual-degree major studying physics and electrical engineering. The other members of the team are Brendan Reed (physics), Zac Rintoul (physics and mechanical engineering), and Tyler Capek (mathematics and physics). Timothy and Zac have experience competing in the Wisconsin Space Grant Consortium (WSGC) Collegiate Rocket Competition. This is the second straight year that Team Falcon is competing in the engineering division, and the third year it has competed overall.

Figure 1. Team Falcon after launching their model rocket. From left to right, the members are Zac Rintoul, Tyler Capek, Brendan Reed, and Timothy Dirks.

Competition Parameters

Teams are required to design a one-stage, high-powered rocket that will achieve an apogee, or maximum altitude, of 3000 feet for this year's Wisconsin Space Grant Consortium (WSGC) Collegiate Rocket Competition. The rocket must be recovered safely and in flyable condition. The rocket must be no bigger than seventy-two inches in length and four inches in diameter, and it must weigh no more than seven and one-half pounds. The parachute recovery system must be deployed electronically, and an engine-based back-up deployment system is required. The team whose rocket completes a successful flight and achieves an apogee nearest to 3000 feet will be the winner of the flight portion of the competition. A successful flight, as defined by the WSGC, is a rocket whose apogee is within 500 feet of the target apogee, recovery system that is electronically deployed, and the rocket is recovered intact and in flyable condition.[1]

Rocket Design

Team Falcon built a one-stage rocket that is three inches in diameter and is seventy-one and three-quarter inches in length. The rocket features a ballast system that allows Team Falcon to adjust the rocket's weight between five pounds and seven and one-half pounds. The center of gravity was measured to be forty-four and seven tenths inches from the nosecone. The center of pressure was measured to be forty-seven and eight tenths inches from the nosecone. The rocket will be powered using a Cesaroni I540 rocket motor. The rocket features two sets of fins which provide extra drag, making an apogee of 3000 feet much more easily attained. The rocket's deployment system will feature two parachutes. A drogue parachute is designed to be released at apogee to provide stability during descent. The main parachute, which is much larger, was designed to be released later during the descent to ensure the rocket is safely recovered as well as to minimize drifting. The electronics bay will house two Raven III altimeters. One of these altimeters, supplied by the WSGC, will be used for scoring purposes, while the other altimeter will work in conjunction with the recovery system.

WSGC Collegiate Rocket Competition

Team Falcon's rocket had a very successful showing at the WSGC Collegiate Rocket Competition. The drogue parachute was released at apogee to provide stability during the rocket's descent. The main parachute was supposed to be released at an altitude of 700 feet during the rocket's descent, however the altimeter lost power and the main parachute was never released. This ended up being a blessing in disguise, as the rocket drifted over a mile down wind with just the drogue parachute. The rocket attained an apogee of 2920 feet, had a maximum acceleration of 831 feet per second squared, and achieved a maximum velocity of 526 feet per second. Aside from the maximum acceleration, these numbers agreed statistically with the simulation's results. Team Falcon qualified for the regional competition, and plans to compete.

Budget

The WSGC supplied Team Falcon with a $1000 for use by the team towards rocket parts and competition related travel. Team Falcon also received two travel grants from UWRF's Society for Undergraduate Research, Scholarly and Creative Activity. These grants, which totaled $1468, were awarded for travel to the safety review meeting and the competition. The budget is outlined in the appendix.

Design Features of the Rocket

The challenge presented by this year's rocket competition is to reach an apogee of 3000 feet as precisely as possible. This is to be achieved using a rocket motor that is normally too powerful rocket's small size constraints. As an added challenge, the team had to build a rocket that provided enough air resistance to keep the rocket's maximum altitude around 3000 feet without sacrificing the rocket's stability. All of the major components of the rocket are diagramed in Figure 2.

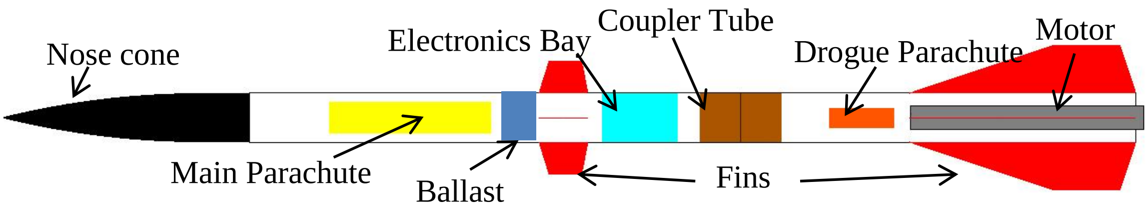

Figure 2. Diagram of Team Falcon's rocket which depicts the rocket's various components.

Internal Framework and Fins

The internal framework and the fins of the rocket are comprised of three-quarter inch plywood. Each piece was designed in AutoCad 2012 and sent to Mathias Die to be laser cut.[2,3] The framework was designed to strengthen the rocket as well as anchor the fins to the rocket. The two-fin design increases drag and makes an apogee of 3000 feet more easily attained. This could have been accomplished with one set of fins; however, they would have had an awkward shape that was not aesthetically pleasing. The extra set of fins also brings the center of pressure closer to the nose cone, effectively increasing stability.

Airframe

The airframe is comprised of two MagnaFrame body tubes, a material sold by Giant Leap Rocketry, which are held together by a phenolic coupler tube.[4] MagnaFrame is interlaced with layers of gray vulcanized cellulose and phenolic. MagnaFrame is strong, light, and inexpensive. It also resists warping caused by moisture, a quality most body tubes do not possess. The airframe houses the internal structure and payload of the rocket. The airframe is fifty-five inches long, three inches in diameter, and it comfortably houses the internal structure of the rocket.

Drogue Parachute

Team Falcon will be using a drogue parachute that is twenty-four inches across. The drogue parachute is made from one-half inch low-porosity nylon.[4] The parachute weighs nine and three-tenths ounces, making it lightweight and durable. The parachute also comprises of only four 1500 pound test barrel swivel suspension lines to connect to the rocket. This makes the parachute less likely to get tangled.

The descent rate of this drogue parachute is rated at seventeen feet per second for a one pound rocket. However, the rocket that Team Falcon has built weighs six and six tenths pounds. Drogue parachutes are generally released at apogee to slow the rocket’s descent just enough so that the much larger main parachute can be released at a lower altitude. By releasing the main parachute at a lower altitude, the rocket is less likely to drift on a windy day.

When the rocket reaches apogee, the drogue parachute will be released. At this point, the airframe’s two pieces will be separated at the coupler tube by a black powder charge. This will effectively release the drogue parachute, and create more surface area for the air to push against. The rocket will be slowed considerably, making an apogee of 3000 feet much more easily attained. The drogue parachute will also help stabilize the rocket during descent, slowing the rocket enough for the main parachute to be released safely.

Main Parachute

Team Falcon purchased a sixty inch parachute comprised of the same material as the drogue parachute.[4] This parachute, along with the suspension cords, weighs fourteen and three-tenths ounces. Generally, the main parachute should have a descent rating between fifteen and twenty-five feet per second. For a ten pound rocket, the descent rate of this parachute is seventeen feet per second. Along with the drogue parachute, the rocket is likely to have a descent rate less than fifteen feet per second.

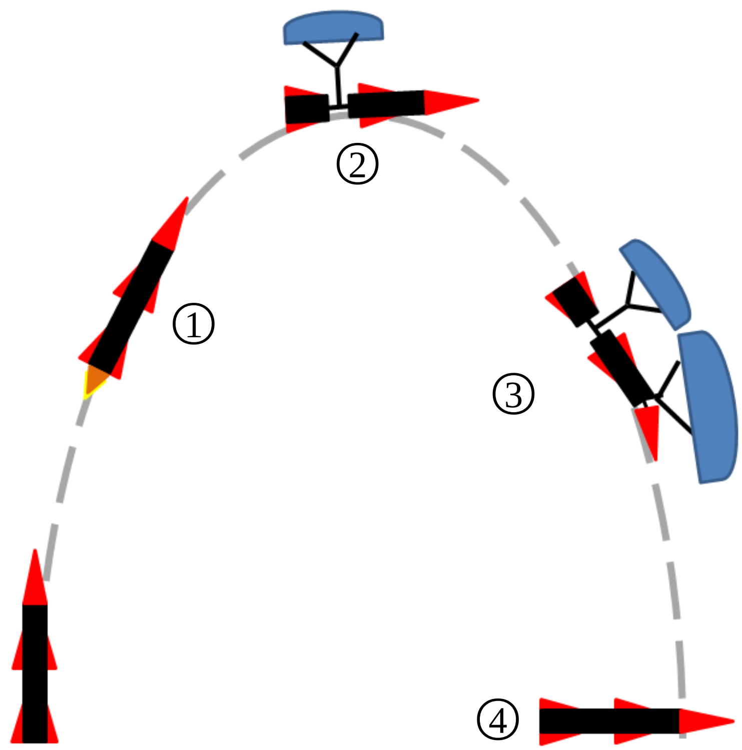

Figure 3. 1) After ignition, the rocket quickly accelerates toward apogee. 2) The drogue parachute is released at apogee. 3) The main parachute is released during the rockets descent. 4) The rocket lands intact and in flyable condition.

Even though such a low descent rate would ensure the rocket is safely recovered, it also makes the rocket more prone to drifting due to atmospheric winds. However, if the main parachute is released at 700 feet, drifting can be significantly reduced. At this altitude, the nose cone will be separated from the upper body tube with a black powder charge, effectively releasing the main parachute. The drogue parachute should slow the rocket's descent enough for the main parachute to be ejected at this altitude. Furthermore, if the rocket is launched at an angle into the wind, any drifting that does occur may bring the rocket to a position that is relatively close to the launch pad. However, this will also lower the predicted apogee as compared to a vertical launch.

Electronics Bay

All of the electronics inside of the rocket are housed inside an electronics bay. The electronics bay consists of a seven inch long phenolic tube that fits snuggly inside of a three inch diameter airframe.[4] The airframe is designed to protect the rocket's electronic systems from shock and isolate them from potentially corrosive gases. The electronics bay is large enough to fit both altimeters, as well as the two nine volt batteries needed to power them.

The electronics bay also acts as an anchor for both of the parachutes, with an eyebolt mounted on both sides. Both of the parachutes are attached to the electronics bay with kevlar shock cords. The main parachute is also attached to the nosecone of the rocket with kevlar cords, while the drogue parachute is attached to an eyebolt inside the lower half of the rocket's internal structure. A fireball is attachted to the kevlar cord between the main parachute and the electronics bay to prevent zippering. This ensures that the rocket stays intact during its descent.

Team Falcon will be flying two Raven III altimeters, one of which is supplied by the WSGC for scoring purposes.[4] Team Falcon will be using the other altimeter to control its recovery systems. The altimeter will be used to output a current to the black powder charges when a chosen set of conditions are fulfilled. For example, the drogue parachute will be released when the barametric pressure begins to increase, which would suggest that the rocket has just started to descend. This prevents the altimeter from sending out a charge to early, but still allows for a deployment as close to apogee as possible. An electronic backup for the drogue parachute is also set to send a charge 2.00 seconds after the rocket reaches apogee. The main parachute will be released when the velocity of the rocket is less than zero (moving in the downward direction) and its altitude reaches an altitude of 672 feet above the launch pad. An electronic backup was setup to release the main parachute at 480 feet above the pad if the main parachute does not eject. The altimeters will be powered by two nine volt batteries.

Computer Simulations

Rocket Properties

Aside from aerodynamics and weight, there are two important elements that must be considered when designing a rocket. The first, center of pressure, is the point at which the aerodynamic lift of a rocket is centered. Its location is most commonly influenced by the length of the airframe and the number of fins on the rocket.[5] By adding a second set of fins, Team Falcon was able bring the center of pressure closer to the nose cone. The center of gravity is the other element of a rocket. It is the point at which the rocket balances when it is completely prepared for flight, including the motor. The center of gravity is influenced most by the weight of the motor, the number and weight of the fins, weight of the nosecone, and the length of the rocket.[5]

RockSim v9.0 provided a means to design Team Falcon's rocket. The software was used to calculate the position of the rocket's center of gravity and the center of pressure from its nosecone for design purposes.[6] These positions are diagramed in Figure 4. Two centers of gravity were calculated: the center of gravity with the rocket motor installed before its ignition and the center of gravity with rocket's post-burn mass.

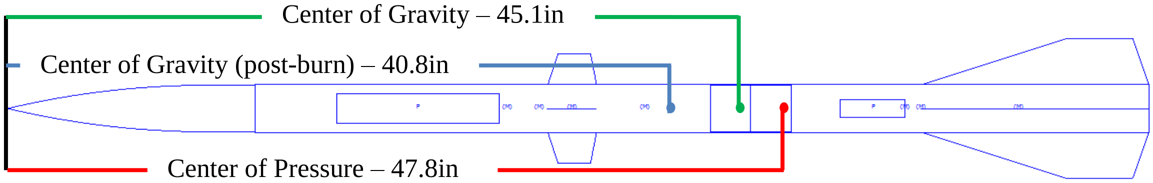

Figure 4. The calculated positions rocket's center of gravity (before and after the rocket's ignition) and its center of pressure from the nosecone are depicted in this diagram.[6]

In order to have a stable flight (a vertical trajectory from the center of pressure) the center of gravity should be at least one body-tube diameter forward of the center of pressure.[5] The positions of the center of gravity and the center of pressure from the nosecone were calculated to be forty-five and one-tenth and forty-seven and four-fifths respectively. The corresponding difference between these two values is two and seven-tenths inches (three-tenths of an inch less than the rocket's diameter).[6] Since the difference was not quite large enough, Team Falcon designed the rocket with an adjustable ballast in between the upper fin section and the main parachute.

Flight Simulation

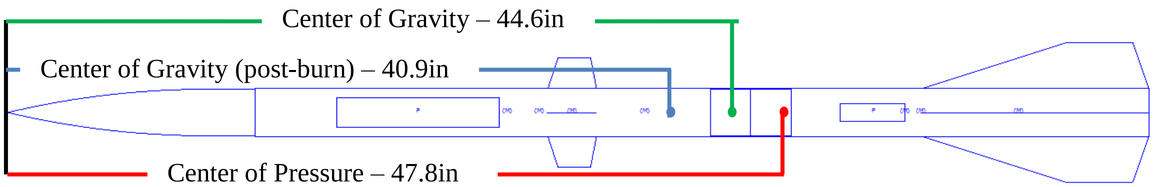

Figure 5. The measured positions rocket's center of gravity (before and after the rocket's ignition) and its center of pressure from the nosecone are depicted in this diagram.[6]

RockSim was also used to simulate the flight of the rocket. It is able to estimate the accuracy of the rocket's flight within five percent error. However, the program assumes the rocket is perfectly constructed, and its estimations overshoot the actual flight path of the rocket. The rocket's actual center of gravity was measured to ensure an accurate simulation. The center of gravity with the rocket motor installed was calculated using this measurement and RockSim. These values, diagramed in Figure 5, are forty and nine-tenths inches and forty-four and six tenths inches respectively. The corresponding difference is three and two tenths inches.

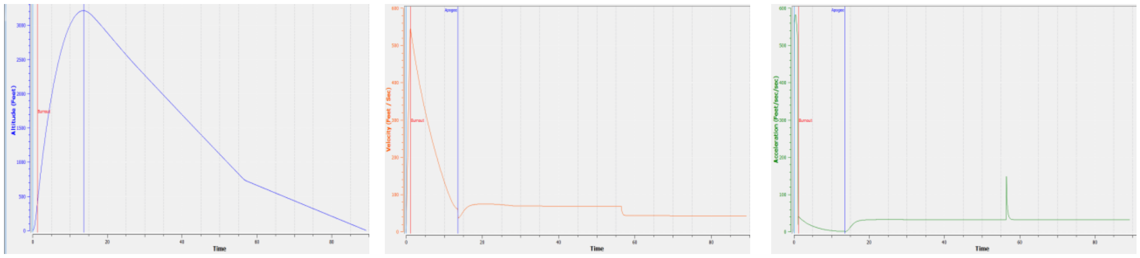

Figure 6. RockSim provided graphs (from left to right) that simulated rocket's altitude, velocity, and acceleration as a function of time.[5]

The rocket's drag coefficient was calculated to be seven-tenths. Weather conditions were chosen to be partly cloudy, fifty degrees Fahrenheit, and slightly breezy (fifteen to twenty-five mile-per-hour winds) to simulate the expected weather conditions for launch day.[7] Since the Richard Bong Recreation Area is at an altitude of 831 feet, this was chosen as the launch altitude.[5] The simulation predicted the following results:

- Apogee: 3213 feet.
- Maximum velocity: 545 feet per second.
- Maximum acceleration: 551 feet per second squared.

Rockets tend to reach an apogee of approximately ten percent less than RockSim's simulations suggest, according to data collected from UWRF's previous rocket teams. This is likely because the program's calculations are assuming that the rocket is perfectly constructed. However, considering RockSim's accuracy is rated within 5%, Team Falcon's rocket should not exceed 3126 feet. In the event that the rocket overshoots 3000 feet, Team Falcon plans to re-launch the rocket at an angle. At a five degree angle, the maximum altitude achieved by the rocket during simulations was 3096 feet.

Construction

Internal Framework and Fins

The internal framework is comprised of laser cut plywood centering rings and fins. The centering rings and fins consist of rectangular slots that fit snuggly together. The internal frame is comprised of the centering rings which are held together by the fins. Each of the joints, where the rectangular slots fit together, was reinforced with epoxy. The inside and outside edges of the centering rings were sanded to make sure that the airframe fits around the frame and motor mount tube fit inside of it. Figure 7 shows that epoxy was used to secure the internal structure, airframe, and motor mount tubes together.

Figure 7. The internal structure and the fins of the rocket at the base of the rocket.

As construction of the rocket was nearing completion, Team Falcon discovered that the rocket's center of gravity was dangerously close to the predicted value for the center of pressure. It was also determined that the rocket weighed only five pounds. So even though the rocket was dangerously unstable, Team Falcon still had room to work in terms of weight. As a result, Team Falcon designed an adjustable ballast system that would move the rocket's center of mass toward the nose cone by approximately three inches. The ballast, depicted in Figure 8, is comprised of epoxied bulkheads which fit snuggly inside of the rockets airframe. It is located between the main parachute and the upper fin structure. Various sizes of brass weights were used to adjust the weight of the ballast.

Figure 8. Team Falcon had to design a ballast system to bring the rocket's center of gravity closer to the nosecone.

Nosecone

The rocket's nose cone is thirteen inches long and is made of high-impact plastic.[4] A four and one-half inch shoulder fits inside of the top of the rocket's airframe. A tab with two holes is connected to the rockets parachute by way of kevlar cords. All of the rough edges on the nosecone were sanded and any grooves filled in with aeropoxy to make the nosecone smooth.

Airframe

The outer surface of the rocket's airframe was sanded so that it would more willingly absorb epoxy and paint. Aeropoxy was used to fill in the grooves that encircled the tube. Both of the tubes are slotted, as depicted by Figure 9, so that the internal structure, with fins attached, could be slid inside the airframe. Aeropoxy was used to fill in the open areas of the slots, and secure the internal framework to the airframe. The airframe consists of two tubes, both of which are held together with a phenolic coupling tube. Paint and primer was also applied to the outside of the tube.

Figure 9. Slots were cut into the airframe so that the internal structure, including fins, can be slid inside.

Electronics Bay

The electronics bay fits inside of the airframe in-between the upper fin structure and the coupler tube. Epoxy was used to anchor the electronics bay in place. The two ends of the electronics bay are held together by two metal rods, which is where the altimeters and batteries will sit.

Conclusion

Team Falcon's goal was to build a rocket that reaches an apogee of exactly 3000 feet. Team Falcon built a rocket whose apogee was 2920 feet at the WSGC collegiate rocket competition. In essence, Team Falcon was successful as they qualified for the regional rocket competition. This was the result of building a rocket that employs two sets of fins to increase the amount of drag experienced by the rocket. The rocket also blew the drogue parachute at apogee to provide stability during the rocket's descent. The rocket's recovery system employs two parachutes, both of which are electronically deployed. RockSim and AutoCAD software has allowed Team Rocket to design a sleek and reliable rocket that will fulfill the team's goal: win this year's competition!

Acknowledgements

Team Falcon wishes to acknowledge Dr. Glenn Spiczak for his advisement throughout the entire process of this competition. The team would also like to thank Dr. Earl Blodgett and the Society of Physics students for their support during the completion. The team wishes to thank Dillon Miller for using AutoCAD to design the internal structure and fins of the rocket. Team Falcon thanks the Society for Undergraduate Research, Creative and Scholarly Activity. The team wishes to thank Andy Hamm for providing team falcon with an outreach opportunity in his class room. Finally, the team would like to thank Lindsay O'Brian for her lending a hand in editing this paper.

Appendix: Budget

Team Falcon 2012-13 Budget				
Item	Description	Cost/Unit	Quantity	Total
Nose Cone	Giant Leap Rocketry nosecone for 3” Diameter tubes.	$19.49	1	$19.49
Body Tube	Giant Leap Rocketry custom pre-cut 3” Magnaframe.	$68	1	$68
Coupler Tube	Giant Leap Rocketry 5” long phenolic coupler tube.	$3	1	$3
Electronics Bay	Giant Leap Rocketry 7” long phenolic avionics bay	$27.49	1	$27.49
Fins, centering rings, bulkheads	3/16” custom laser cut plywood, by Mathias Die.	$175	1	$175
Rail buttons	Giant Leap Rocketry 1.5”x1.5” airfoil shaped rail buttons.	$10	1	$10
Main parachute	Giant Leap Rocketry 60” TAC-1 rip stop nylon parachute	$105	1	$105
Drogue parachute	Giant Leap Rocketry TAC-Drogue rip stop nylon parachute	$29.91	1	$29.91
Parachute protector	Giant Leap Rocketry Kevlar parachute protector	$10.49	2	$20.98
Deployment Bag	Giant Leap Rocketry TAC-1 Bag for 60” parachute	$26.24	1	$26.24
Shock Cord	Giant Leap Rocketry 15ft Kevlar tubular shock cord w/ loop.	$16.58	1	$16.58
Fireball	Giant Leap Rocketry anti-zipper small Kevlar fireball	$15.21	1	$15.21
Altimeter	Featherweight Altimeters, LLC Raven III Altimeter	$155	1	$155
Motor Mount Tube	Giant Leap Rocketry MMT-1.525 18” phenolic motor mount tube	$6.20	1	$6.20
Motor Retainer	Giant Leap Rocketry 38mm Qwik-Lok motor retainer system	$32.95	1	$32.95
Motor Casing	Giant Leap Rocketry Pro38 5 grain casing for Cesaroni I540 motor	$51.65	1	$51.65
Epoxy	Aeropoxy structural adhesive	$45	1	$45
Epoxy Clay	Aeropoxy light filler	$30	1	$30
JB Weld	Heat resistant epoxy for motor mount	$6	3	$18
Paint/Primer	Makes rocket aesthetically pleasing	$50	1	$50
Model Rocket	Competition Requirement	$30	1	$30
Rocket Stand	To prop rocket onto for presentation.	$50	1	$50
Miscellaneous	Gloves, cups, swivels, nuts, bolts, etc.	$38	1	$38
Travel	Safety meeting	$0.36/mi	522 mi	$187.92
Travel	Competition	$0.36/mi	675 mi	$243
			Total	$1454.62

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