Issue 655 / July 1st, 2025

PEAK OF FLIGHT NEWSLETTER

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From Paris to Apogee: A Tale of Two (Three?) Eiffel Towers

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COVER PHOTO



Closeup of the Apogee Eiffel Tower Model Rocket

FEATURED ARTICLES



From Paris to Apogee: A Tale of Two (3?) Eiffel Towers

by Martin Jay McKee

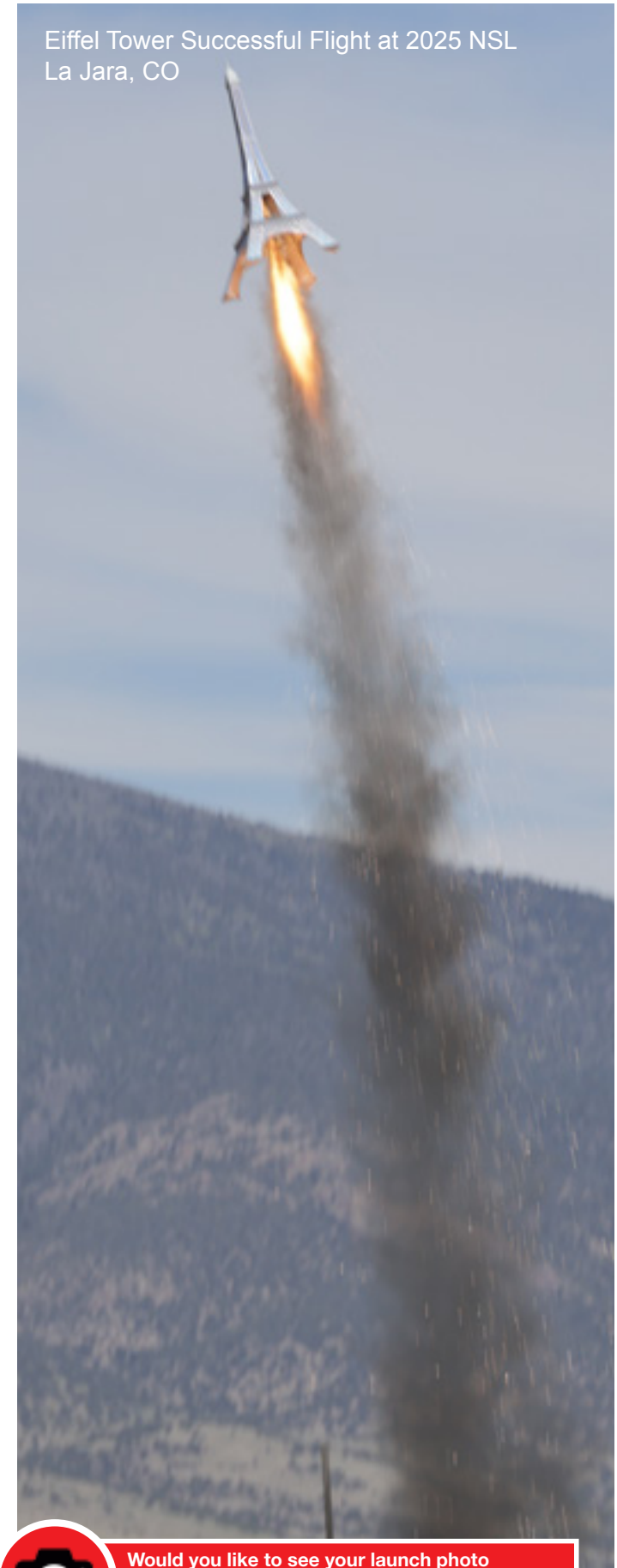
Part 1 of 2 articles examining the path to a successful flight for the custom Apogee Components Eiffel Tower Model Rocket.

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Eiffel Tower Successful Flight at 2025 NSL
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From Paris to Apogee: A Tale of Two (or Three?) Eiffel Towers

by Martin Jay McKee

Back in Peak-of-Flight #599, we published the plans for an Eiffel Tower rocket design. I mentioned that while the original design itself popped into my head very early on in my tenure at Apogee Components, it was not until the idea of flying it higher than the height of the Eiffel Tower came up that I was really motivated to build and fly the design. This is typical for me. I like rockets, but I love the challenges more. And this was a challenge I could get behind. I'm a scientist at heart, so the idea of forcing an architectural abomination of a rocket to a substantial altitude was in and of itself an attractive challenge. Since that plan went out, the Eiffel Tower has — for better or worse — become something of my calling card. Depending on who you ask, I'm either 'that guy from Apogee' or 'the guy with the tower.' Honestly? I'll take either. Regardless, there's one simple question that this (two-part) article seeks to answer: "How do you fly a model of the Eiffel Tower to the height of the real Eiffel Tower?"

The answer is surprisingly simple, of course. You put enough power in it. With a big enough motor, anything can fly to any height. That's not an interesting answer, though, nor satisfying, and it ignores all practicality. If the required motor is too large to actually fit, or the rocket would end up unstable, or the entire



Figure 1: This original Eiffel Tower model as presented in Peak-Of-Flight #599 was flown a total of seven times to collect data. This data was used to estimate the coefficient of drag of the model to make more accurate simulation of the rocket's flights possible.

endeavor is financially impractical, any hypothetical solution is of little or no value. As such, a slightly modified question is much more interesting: “What is the smallest motor that can be used to fly a given Eiffel Tower rocket up to or above the height of the Eiffel Tower?” While extremely similar to the first question, this version allows significantly more nuance and leads to more interesting solutions. It also justifies the sort of deep investigation that I find particularly captivating. Rather than simply packing the largest motor possible into the mount and “sending it,” this refined question leads to the need for greater understanding.

This article follows the model of the other “development of” articles I have written in the past (“Development of the Draco BG” #609 and “Development of the Nike-Hercules” #639) with a bit more of a deep dive into the data collection and analysis that I completed to determine what was required to hit my targeted altitude of 1086’ (331m) or greater. While the current version of RockSim is able to calculate the aerodynamic characteristics of many rockets to a reasonable accuracy, that would never be true of something like the Eiffel Tower. The simplifications which are baked into standard rocket simulation/design software are crucial to making them run quickly and remain easy to use, but for something as unlike a standard rocket as the Eiffel Tower, only direct measurement of a physical model or a fairly comprehensive CFD (computational fluid dynamics) analysis are likely to provide useful data. I used both throughout the course of this project.

This first part of the article discusses the flight program and data analysis that was completed on the first version of the Eiffel Tower and how that analysis informed the construction of the second version. In the second part of this article (Peak-Of-Flight #656), we will explore the process of data collection and analysis for the second version, review the flight that successfully reached the goal, and consider some other methods that could've been used to improve the accuracy of the estimated altitudes generated.

Flights: Back Calculation from Peak Altitude

While I was motivated to build the Eiffel Tower due to a silly altitude challenge, my motivation was certainly chilled somewhat when on the first flight, of the first version (as seen in PoF #599), the rocket hit all of 81’ flying on an Estes E16-4. Only about 1000’ short of the goal… that is, the rocket made it 7.64% of the desired altitude. This was not going to be easy. It was a good flight otherwise, though. The rocket flew very straight and resisted the side wind that was present well. This proved that the rocket flew as expected. The only problem was that it appeared to have a higher drag coefficient than had initially been estimated based upon the naive CFD study that had been conducted prior to construction. The stability estimate provided by the CFD, however, was well validated.

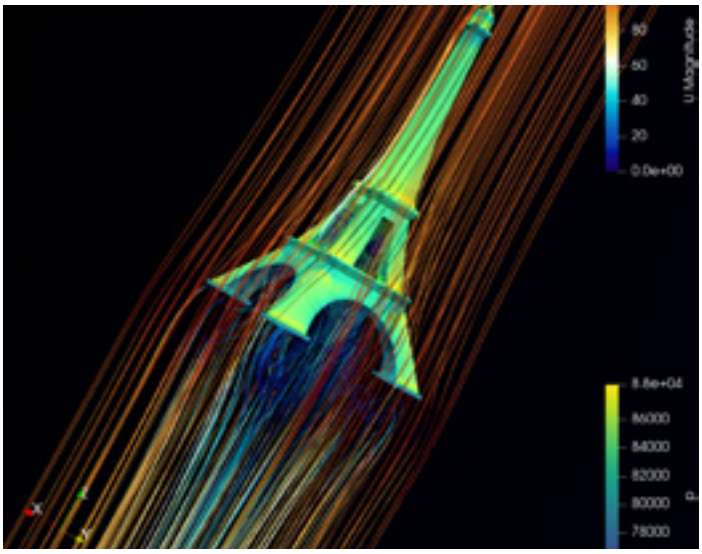


Figure 2: CFD was run on a model of the Eiffel Tower before the first model was even built to ensure stability and estimate the coefficient of drag. This flow simulation shows the rapid slowing (blue streamlines) and turbulence at the base of the rocket. By summing the pressure over all parts of the rocket, the center of pressure was calculated and the expectation was that the rocket would be extremely stable. A similar process was completed to estimate the coefficient of drag.

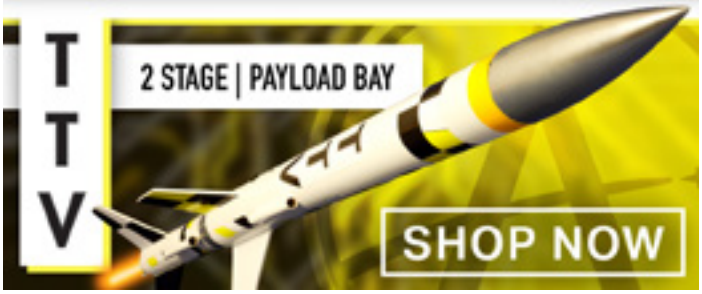


Motor	Total Impulse (N-s)	Base Altitude (m)	Peak Altitude (m)
Estes E16	33.4	1663	24.7
Aerotech F67W	61.1	1663	44.5
Aerotech G74W	82.8	2336	106.1
Aerotech G74W	82.8	1663	86.9
Aerotech G75J	135.6	1663	103
Aerotech H128W	172.9	2336	Not Recorded
Aerotech H165R	165.0	1663	Not Recorded

Table 1: This table contains the data that were recorded during the flight testing of the version 1 Eiffel Tower. When working to estimate the coefficient of drag vs Reynolds Number curve, this was the only measured data available. As might be expected, results were mixed.

Of course, an accurate estimate of the coefficient of drag (Cd) would be absolutely required if an accurate estimate of altitude was desired. Since the entire purpose of the project was to hit a specified altitude with the rocket, a much more accurate estimate of the Cd would be needed. But it's not quite as simple as determining a single number either. The coefficient of drag of a body in a fluid changes depending upon how fast the fluid is flowing over the surface. As such, what was needed was not simply a single Cd number, but a curve which related the Cd to the flow rate. Rather than use velocity directly, many Cd curves use Reynolds Number.

Although there were a total of seven flights made with the initial version of the Eiffel Tower, due to trouble with the electronics, the peak altitudes of the final two test flights were not recorded and, therefore, were not available for backing out the Cd curve. The data from the flight program can be seen in Table 1. My intention was to use a genetic algorithm (which I have used successfully before in similar situations) to evolve a Cd vs Re (coefficient of drag versus Reynolds Number) curve that resulted in the best match to the collected data. Keep in mind, this process was attempting to determine a smooth curve from just five altitudes, in combination with the reference thrust curves and an empty weight.



Velocity, Reynolds Number, and Mach Number

There are multiple ways to construct the coefficient of drag curves. For much of this project, I decided to calculate Cd relative to the axial velocity. Other options are to calculate Cd relative to Reynolds Number (which I used for the version one data) or Mach Number. As outlined on the Wikipedia page (reference 4) Reynolds Number (Re) represents the ratio of forces within a fluid. Specifically, it is the ratio between the inertial (mass-related) forces and the viscous forces. Reynolds Number determines the "flow regime" of an aerodynamic system: laminar or turbulent, and it can be especially useful when low-to-medium velocity flows are being analyzed. Similarly, Mach number (M), as outlined on its own Wikipedia page (reference 2), is the ratio of an object's velocity to the speed of sound in the surrounding medium. While Reynolds Number provides information relevant to flows at lower velocities, Mach Number is most effective in describing high-speed flows. The flows in the Eiffel Tower project were fast enough to be fully turbulent but were too slow to demonstrate transonic or super-sonic effects. As such, calculating Cd against velocity directly worked well.



Life Doesn't Have to be a Drag, But the Air Is

Genetic algorithms were used to optimize a candidate Cd vs V curve inside a very simple one-dimensional flight simulation that took into account the motor thrust, mass of the rocket, and the assumed Cd curve. The thrust was taken directly from the published engine thrust curve (as found on thrustcurve.org), while the drag was modeled as:

$$D = \frac{1}{2}\rho V^2 S C_{d_v} \quad (1)$$

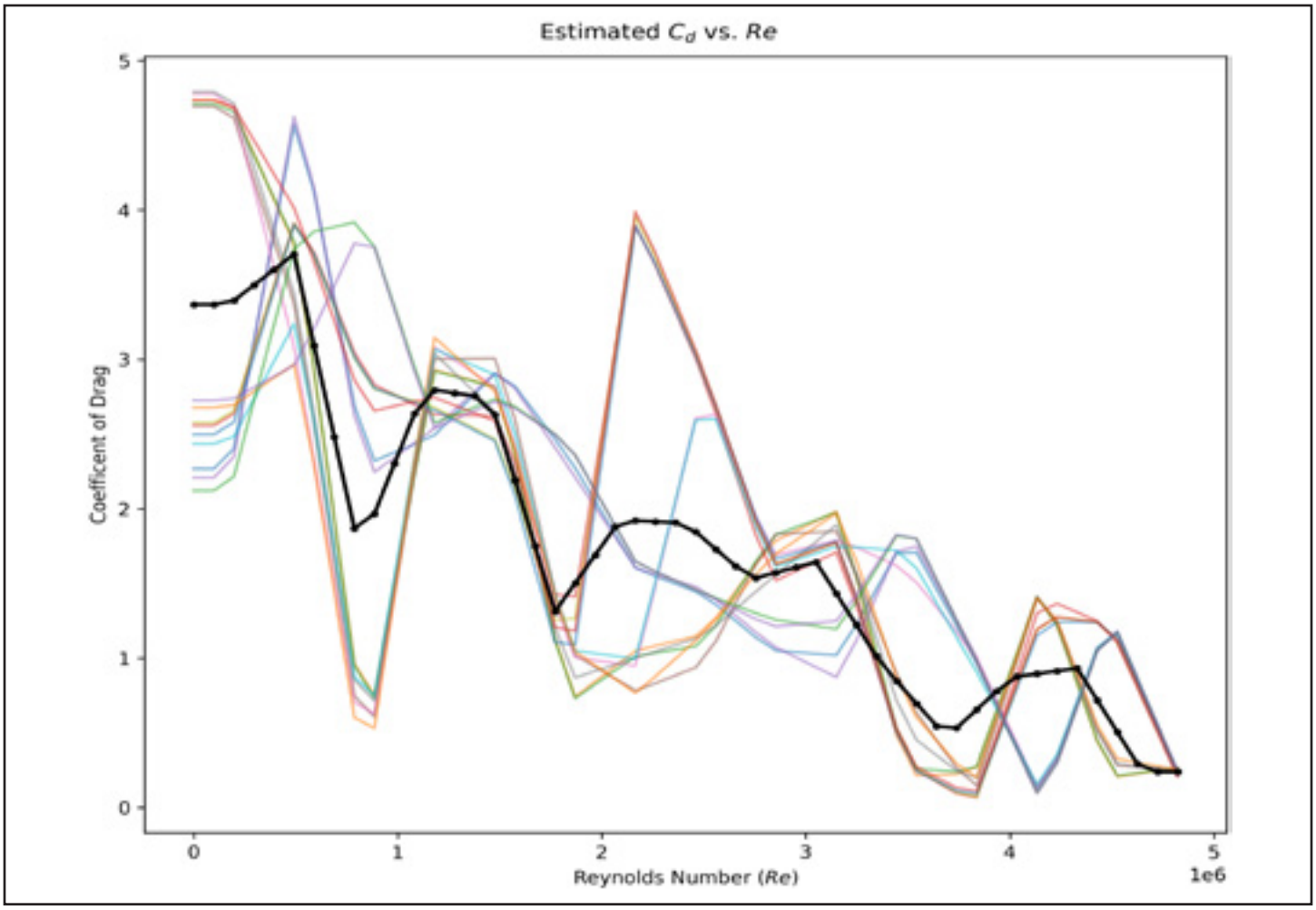
Here rho is the density of air (based on the current rocket altitude above sea level), V is the velocity of the rocket, S is the reference frontal area that is used to calculate the drag, and Cdv is the coefficient of drag of the rocket at velocity V. The mass of the rocket was calculated as:

$$m = m_0 + m_e \quad (2)$$

$$m_e = m_{e_0} + m_p \left(1 - \frac{\int_0^t T(t)\,dt}{I_{tot}}\right) \quad (3)$$

Where the total mass, m, is the sum of the rocket's empty mass, m0, and the estimated mass of the engine at the current time (me). The mass of the engine is calculated as the sum of the engine's empty mass and an estimate of the remaining propellant mass based on the ratio between the impulse burned compared to the motor's total impulse. Due to the dynamics within the engine, this is not a perfect estimate as the specific impulse of the fuel changes with the pressure and temperature within the engine, but it is a reasonable estimate to a first approximation.

Equations 1-3 were used together with some basic 1 degree of freedom Newtonian kinematic equations (for acceleration, velocity, and position, see reference 3) and the motor thrust curve data to simulate flights based on a population of randomly generated coefficient of drag curves. Now is not the time to discuss how genetic algorithms work in any sort of depth. Rather we shall quickly examine an overview of the process. For now, it is enough to say that genetic algorithms are an optimization method inspired by biological evolution that does not need to know anything about the form a solution will take. Rather than depending upon the form (like the model-based optimization in rocket simulation



programs like RockSim), genetic algorithms take advantage of a fitness function. The algorithm runs through some number of "generations" and there are a number of "individuals" in each generation which are candidate solutions. The better solutions are more likely to "reproduce" and are combined together using something like genetic crossover and mutation to mix and modify the available solutions. By preferring the better solutions in this process, the algorithm searches through the space of possible solutions. Basically, to find the best Cd curve, each "individual" was used to do a simulation and the better the simulation matched the measured altitude, the more likely the candidate Cd curve would be to continue to the next generation. Between generations, the curves were "combined," and the process is repeated. In theory, after many generations, the process tends to identify not only the overall shape of the curve, but specific deviations as well.

Figure 3: This graph shows the 15 best Cd curves estimated by the genetic algorithm, and the average (black). This curve shows a decrease in Cd from low to high Reynolds Number conditions

There is some complexity involved in using genetic algorithms (let us know if you're interested in an article about their use in the design of rockets!). For an introduction to the whole method take a look at reference 1. In this case, I was trying to shrink the distance between the apogee of the simulated flights & the measured flights. More fit "individuals" (Candidate Cd curves) resulted in lower altitude errors. Each Cd curve was used to simulate flights with each of the tested motors, and the altitude errors were combined to form a fitness value. The fitness function was designed this way so the data from each flight had an equal effect.

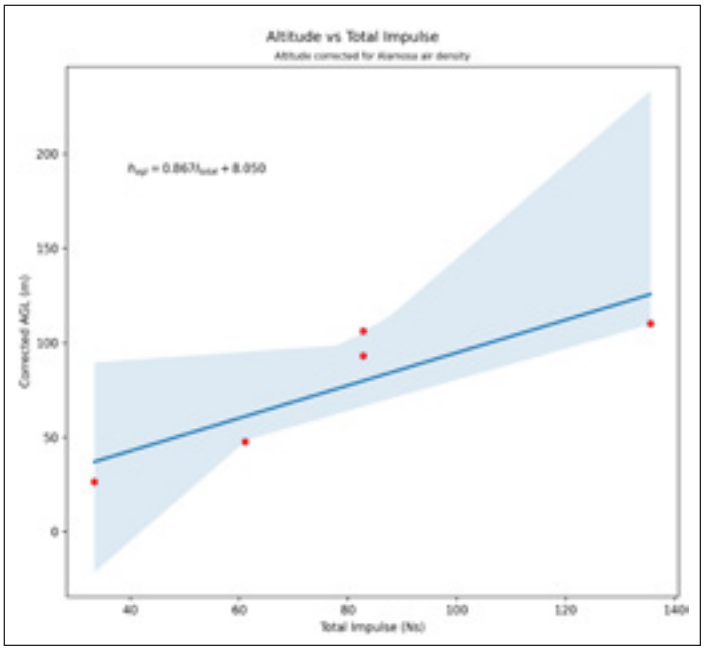


Figure 4: This graph shows the approximate linear fit (dark blue line) between a motor's total impulse and the altitude achieved by a flight of the first Eiffel Tower model. The large deviation of the expected error (light blue) shows that this is not expected to be a very accurate estimate. It would've been much better if the final two flights (which would have sat to the right of the current data) had been correctly recorded.

Truth be told, these attempts to determine a Cd curve using just the peak altitude were not particularly successful, as can be seen from the plot in Figure 3. This plot shows the final results of my genetic algorithm-based approximation attempts. Unlike my later attempts using the version 2 Eiffel Tower, this curve shows the coefficient of drag relative to the Reynolds Number. When I was doing this work, I was expecting much lower velocities overall than were reached on later flights and, as such, I was more concerned that there would be some effect of laminar and turbulent flow throughout the flight. Nevertheless, the estimated curves have an obvious slope to lower values of Cd toward higher Re (velocity). Despite this clear trend, the curves also demonstrate a weird (and clearly unrealistic) undulation across their width. At the largest scales, the curve was showing the expected character, but it was entirely unreasonable to trust the estimated altitudes to any accuracy, given how obviously wrong the details were. In the end, there were simply not enough data points to reliably determine the coefficient of drag relationship.

Having collected the peak altitudes from the flights, however, it was clear that doubling the total impulse of a motor would result in an altitude nearly double, so long as the average velocity (or Reynolds Number) was roughly equivalent. This was further confirmation of expected behavior and allowed for very gross estimations of the required total impulse to reach the target altitude. The first surprise was that very low-thrust (long-burn) motors were somewhat underperforming even when the rocket was flying quite close to vertical. As had been seen in the initial Cd curve estimation attempts, there appeared to be a higher value of Cd when the rocket was going slowly than when it achieved higher speeds. Figure 4 demonstrates the nearly linear relationship between apogee height and total impulse.

In addition to identifying the basic profile of the Cd curve (strongly decreasing with velocity) and approximating what the best motor would be to reach the altitude (a long-burn J-class motor). The flight program of version one allowed me to identify three crucial issues that would need to be fixed. The most obvious of these issues was that the motor mount was simply too small. The 29mm mount would not be capable of containing a large enough engine to reach the desired height. Secondly, during the test flights I repeatedly had trouble correctly deploying the parachute from the small tube at the top of the rocket. Thanks to the high inherent drag of the rocket, these "uncontrolled" recoveries never resulted in the rocket being destroyed but it did cause minor damage on





a majority of the flights: dinged and/or crumpled nose, minor zippers, etc. A number of small repairs were required through the flight test program. Finally, all of the available motors had delays far too long to deploy the parachute near apogee and so even when the parachute was deployed properly, it did so a significant way into the descent.

Construction of Eiffel Tower V2

In order to reach higher altitudes and solve some of the issues I had identified in the first version of the Eiffel Tower, there were several changes that needed to be made. First, the rocket needed a much larger motor mount than the 29mm that the first version had been built with. I decided on 54mm as I had a hunch (based on the flights of the first version) that an Aerotech J99 would be the ideal motor to hit my target altitude. The mount was designed to hold 2-grain, 54mm, motors (e.g. the Aerotech 54/852 case). Additionally, the hacked-on solution that I had come up with for installing electronics in the first version (added somewhere around the third flight to account for the overly long motor delays) needed to go, and be replaced with easier access in a new version. Finally, I wanted more reliable parachute deployment. This last requirement, combined with the larger motor mount requirement, led me to build a rocket that was scaled up by 20% from the original plan. This perfectly fit the 2-grain 54mm motor into the rocket in a way that it was completely hidden and also allowed for a 38mm tube to be used at the top to house the parachute (rather than the 29mm tube on the original plan, or the 33mm tube that was installed later). Larger size, of course, led to an increased overall weight as well as a larger frontal area (a roughly 44% increase). In the end, the additional weight seems to have been almost entirely unimportant; however, the increased frontal area had a massive effect on the achievable altitude.

The construction of the second version was very similar to the first, just a bit bigger. Due to the greater expected forces, some internal stiffeners were added to the legs, but in hindsight, I'm fairly certain that these stiffeners were unnecessary for handling the flight loads. They have proven very nice for absorbing the landing loads of heavy motors, however. The parts were cut out, the inner paper stripped, the edges beveled, the motor mount core assembled, and the foam faces glued into place. Honestly, the construction is so similar to the original plan that it is of little value for us to dig into the basic design here. The changes, however, are probably worth outlining.

Perhaps the most obvious modification that was made to the original design is to add an ebay on the side of the rocket to house a Featherweight Blue Raven and a Lithium Polymer battery. The Blue Raven is a small altimeter, despite the fact that it has quite

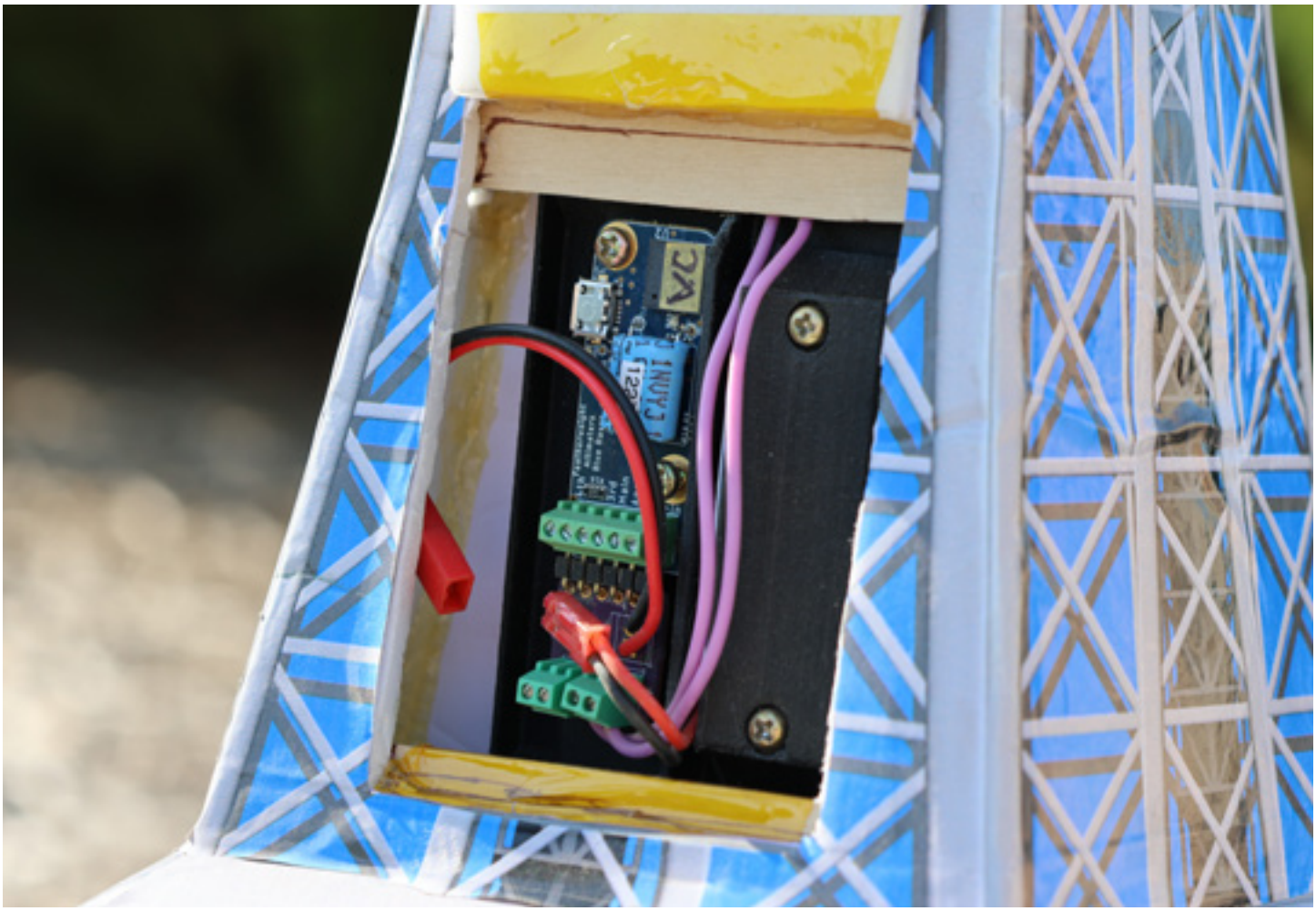


Figure 5: The ebay in the second Eiffel Tower model is accessible through a hatch in the side and contains mounting frames that were 3D printed. The result is an exceptionally sturdy mounting that keeps the electronics well protected while ensuring that the electronics fit well even in the tight constraints between the model skin and the 54mm motor mount tube.

advanced functionality, so it fits easily between the large motor mount tube and the foam-core sides. 3D printed frames were designed and printed so that the electronics would be firmly mounted despite the soft outer structure and rather constrained mounting location.

Like in version 1, the ejection charge wires were routed up the core tube from the electronics, but in version two, they were passed through the side of the core tube and sealed in place. Even from the beginning, I didn't like this solution, but I didn't have any better ideas when I was working on initial construction. The upper section was slightly crumpled on the second flight (on an Aerotech J180) due to an improperly packed parachute (again!). While I could have easily straightened out the body of the rocket, I decided to simply replace the upper section. On the one hand, the crumpled surface would still have been visible and on the other, replacement provided two distinct advantages. Because I had a better idea of how to pack the recovery system after the two flights, I was able to slightly redesign the forward end to increase the available parachute volume and also provide much more direct access to the igniter using a screw-in-place port on the side of the rocket. These changes made preparing the rocket for flight much simpler and quicker.

A Tangent on the Value of "Silly" Projects

Before we end the article for the day, let's meditate for just a moment on the value of a project that, like an Eiffel Tower, is far from normal. There are a variety of ways that we can be driven to learn more things. One of those is if we are presented with a specific need. Ironically, standard projects rarely provide a new "need". In fact, projects might even qualify as standard precisely because they do not impose new problems or questions on us.

Figure 6: For all of the flights on the first Eiffel Tower and the first two flights on the second version, the ejection charge was connected to long wires that passed all the way through the central tube and out the top. This was inconvenient and led to trouble fitting the recovery system into the small tube. The addition of a "through-the-wall" port was a massive improvement to the system overall and only require the design of a few small 3D printed parts.

Weird (for lack of a better term) projects almost always provide challenges that we did not expect and for which we are not prepared. That is the value of "silly" projects. By their very nature, they cause us to explore unique and sometimes innovative features of our interests that we might otherwise ignore or simply miss. They can lead to unique solutions, and in rare cases, entirely new courses of study.







Conclusion

In this installment of working toward flying an Eiffel Tower rocket higher than 1086' (331 m), we examined the flight program and analysis of the first version of the Eiffel Tower and then looked at the modifications that were made in construction of the second version to improve both the reliability of the rocket as well as its altitude capabilities. Coming up in part II, we'll explore the improved data analysis made possible by the collection of significantly more data and then look at possibilities for even greater improvement.

Figure 7: The second version of the Eiffel tower was externally all but identical to the first version except for being 20% larger and stepping up from a 29mm to a 54mm motor mount.



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References

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Mechanics: 1-Dimensional Kinematics *https://www.physicsclassroom.com/calcpad/1dkin/Equation-Overview*

Reynolds Number *https://en.wikipedia.org/wiki/Reynolds_number*

About the Author:

Martin has been designing and building rockets for as long as he can remember. After originally toying with the idea of pursuing a career in Aerospace Engineering, he decided to double major in Computer Science and Fine Arts, spending a decade working in K-12 math & science education. He joined Apogee Components as the Product Designer in 2022.



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We are always looking for quality articles to publish in the *Peak-of-Flight* newsletter. Please submit the "idea" first before you write your article. It will need to be approved first.

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Always include your name, address, and contact information with all submissions. Including best contact information allows us to conduct correspondence faster. If you have questions about the current disposition of a submission, contact the editor via email or phone.

CONTENT WE ARE LOOKING FOR

We prefer articles that have at least one photo or diagram for every 500 words of text. Total article length should be between 2000-4000 words and no shorter than 1750 words. Articles of a "how-to" nature are preferred (though other types of articles will be considered) and can be on any rocketry topic: design, construction, manufacture, decoration, contest organization, etc. Both model rocket and high-power rocket articles are accepted.

CONTENT WE ARE NOT LOOKING FOR

We don't publish articles like "launch reports." They are nice to read, but if you don't learn anything new from them, then they can get boring pretty quick... Example: "Bob flew a blue rocket on a H120 motor for his certification flight." As mentioned above, we're looking for articles that have an educational component to them, which is why we like "how-to" articles.

You can see what articles and topics we've published before at: **https://www.apogeerockets.com/Peak-of-Flight?pof_list=archives&m=education**. You might use this list to give you an idea or two for your topic.

Here are some of the common articles that we reject all the time, because we've published on these topics before:

- How to get a L1, L2, or L3 Cert
- Building cheap rockets and equipment (pads & controllers)
- How to 3D print parts, or a Rocket Kit
- How to Build a cheap Rocket Kit
- Getting Back Into Rocketry After a Long Hiatus

ARTICLE & IMAGES SUBMISSION

Articles may be submitted by emailing them to the editor. Article text can be provided in any standard word processor format, or as plain-text. Graphics should be sent in either a vector format (Adobe Illustrator, SVG, etc.) or a raster format (such as jpg or png) with a width of at least 600 pixels for single column images or 1200 pixels for two-column images. It is preferable for images to be simple enough to be readable in a two-column layout, but special layouts can be used.

Send the images separately via email as well as show where they go by placing them in the word processor document.

ACCEPTANCE

Submitted articles will be evaluated against a rubric (available here on our website). All articles will be evaluated and the results will be sent to the author. In the evaluation process, our goal is to ensure the quality of the content in *Peak-of-Flight*, but we want to publish your article! Resubmission of articles that do not meet the required standard are heavily encouraged.

ORIGINALITY

All articles submitted to Peak-of-Flight must not run in another publication before inclusion in the *POF* newsletter, but it may be based on another work such as a prior article, R&D report, etc. After we have published and paid for an article, you are free to submit them to other publications.

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These articles will mainly be published in our free newsletter, *Peak-of-Flight*. Occasionally some of the higher-quality articles could potentially appear in one of Tim Van Milligan's books that he publishes from time to time.



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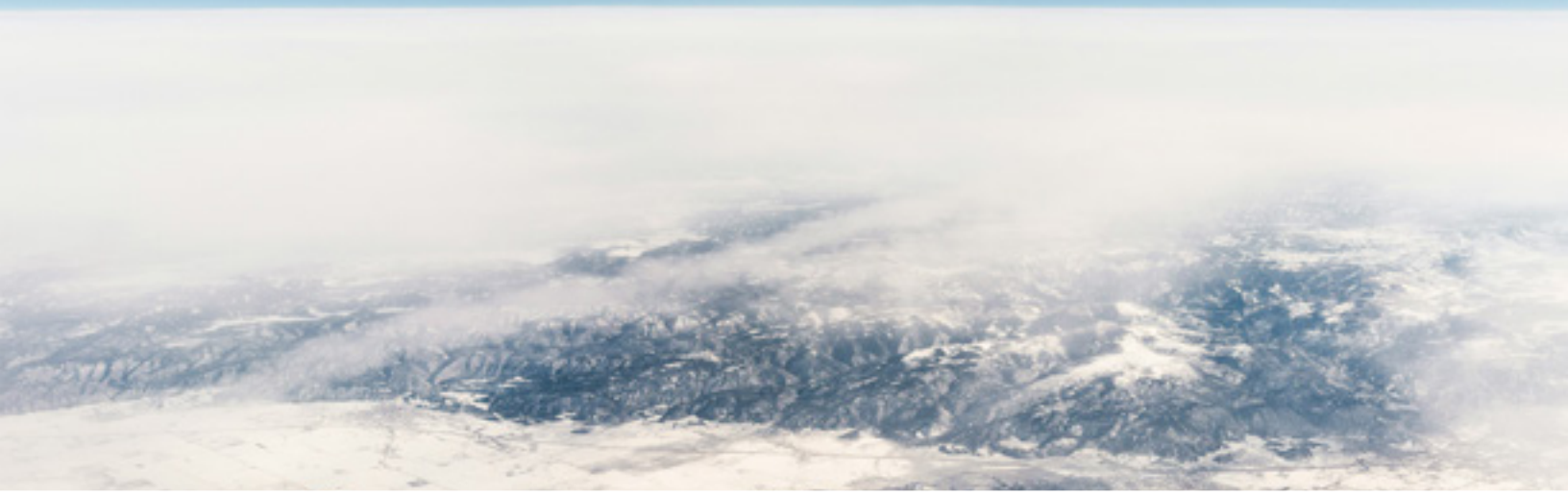
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