Issue 639 / November 19th, 2024

PEAK OF FLIGHT NEWSLETTER

Apogee Components, Inc. / ApogeeRockets.com / Colorado Springs, CO

Development of the Apogee Nike Hercules

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COVER PHOTO

Apogee Nike Hercules Rocket Kit

The Nike Hercules is our up-and-coming rocket kit that pushes the limits on what a 2-stage scale hercules rocket can do.
It is releasing on November 26th, 2024!.

FEATURED ARTICLES

Development of the Nike Hercules

by Martin Jay McKee

In this Article, Martin Reflects on the development process, from start to finish, of the massive Nike Hercules Rocket Kit Project here at Apogee Components.

Developing the Nike Hercules Rocket Kit

by Tim Van Milligan

In this Article, Tim gives his own take on the extensive development process that the team at Apogee took on with the Nike Hercules Rocket Kit.

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About this Newsletter

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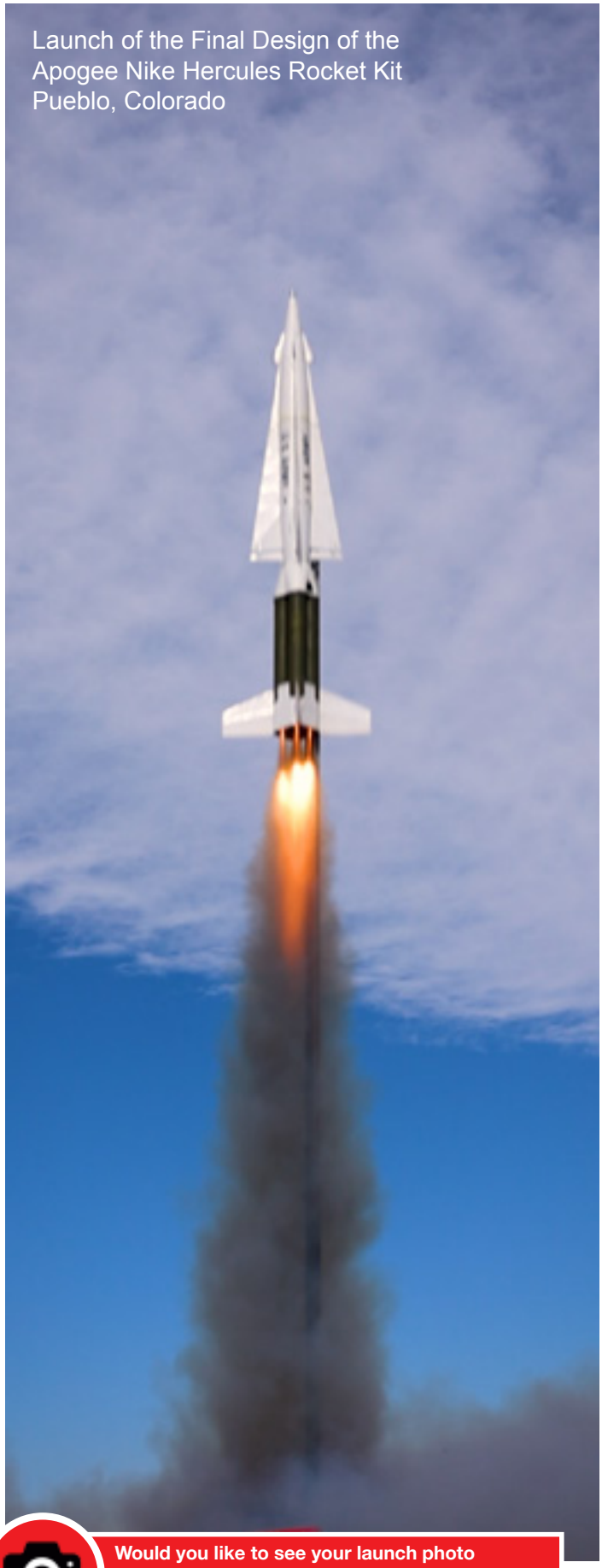

Launch of the Final Design of the Apogee Nike Hercules Rocket Kit
Pueblo, Colorado

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Development of the Nike Hercules

by Martin Jay McKee

Pre-history of the Apogee Nike-Hercules

The Nike-Hercules was a surface-to-air weapon system that was initially put into service in 1958, was deployed in the United States of America until the early 1970s, and in the allied nations until the 1990s. It was created as an anti-bomber ordinance with a nuclear capability that was intended to detonate within a convoy of bombers and knock them all out of the sky with a single missile. While this capability was never used operationally, the missile was successfully tested time and time again against test drones and was even moderately successful against ICBM (Inter-continental Ballistic Missiles) in tests.

Since early in the existence of model rocketry, the Nike-Hercules has been a popular subject. Nevertheless, due to its complexity and marginal stability, kits have been few and far between. It could reasonably be said that a Nike-Hercules kit has been in the works

A Nike Hercules Missile Being Prepped For Launch

at Apogee for decades. Back in 1998, Tim Van Milligan created and released the Nike-Hercules Plan Set for an advanced model rocket building class. Tim has often said that even as a child this was one of his favorite rockets, and it shows. In addition to the plan set, there has been a set of very detailed drawings floating around the Apogee office for two decades. They have been, alternately, stuck in a corner and pulled out to make attempts in the past – but not this time – now, they are being used to build a kit worthy of the Nike-Hercules design and to the Apogee quality standards.

The result of one of those attempts was a prototype built around the PNC-56 nosecone in the popular BT-70 size. This is the same scale that a great many of the Nike-Hercules kits have been produced in and it is popular for a reason. It is a large enough size to be impressive and for a two-stage version to be reasonable while still small enough to be widely approachable. This particular prototype (which I view as Prototype 0) was designed with a full cluster of four 24 mm motors in the booster (sadly destroyed long ago) and a 24 mm motor that was electronically ignited in the sustainer. The prototype flew well and was a crowd-pleaser, but everything was custom-manufactured. The boattail and interstage coupler were 3D printed on the cutting-edge (at the time) resin 3D printer that Tim had acquired shortly before. Also, the boattail provided only barely enough room for staging electronics, and working on the rocket was exceptionally difficult.

While successful as a model rocket, the prototype still wasn't in the form of a kit that Apogee could put its name on. So, the detailed drawings went back into their corner and waited several more years, until I started doing product development in 2022.

Conceptual Design

Even though the Nike-Hercules kit is being released more than two years after I started in my position at Apogee Components, it was one of the first rockets on my list of kits. Shortly after I started in the middle of 2022, Tim tasked me to come up with a list of 12 rockets to develop and release in 2023. Being somewhat naive (and struggling to come up with 12 rocket ideas all at once) I proposed the Nike-Hercules for a late 2023 release. This was accepted, and

Nike Hercules Prototype 0, Designed at Apogee Rockets

Our Custom Scale Allows for Extreme Detail in the Small Parts

since it was clear to be a highly involved kit, the conceptual design of the kit began immediately.

Initially, I had begun planning with the assumption that the kit would continue to be based around the same BT-70 body tube that had been used in the prototype so many years earlier. It's certainly a good size, and there's a reason that it is used for so many kits. However, there was one problem that became apparent when I started doing market research—That's the size of all the other kits! To make the Nike-Hercules a kit worth buying, it was necessary for us to make it stand out from the crowd. We decided that our way to do that is to make it a different size.

For a short time, I toyed with the idea of scaling it up almost two times, up to 4" diameter. As it happens, our PNC-98 nosecone has almost perfect dimensions, and the AT-56 body tube is close to the correct scale on the Nike boosters. It's an idea that I'm still toying with for a personal project, but it was immediately clear that such a rocket (roughly 1:7.5 scale) would be far too big to be commercially viable given all the other custom parts that were going to be required to do the Nike-Hercules justice. As such, I determined that it should be constructed around our thin-wall 3" tubing. There was only one problem: we still didn't have the nosecone. Nonetheless, we decided to continue.

Having decided on a general scale, we needed to decide on the motor lineup. This was a quick decision. While a cluster of 29mm Estes motors would be sufficient for the expected weight

of the rocket, a cluster of 24mm Estes motors would not be. So the booster would have to be 29 mm to give customers flexibility. However, it was less clear what the sustainer motor should be. The Hercules missile is not an inherently stable design so it was clear that the smaller the sustainer motor, the better. Nevertheless, flexibility won out and a 29mm mount was selected. In hindsight, this was an excellent choice because it meant that we had an easy-to-use (and light) selection of motors to do test flights with, such as the Cesaroni F32.

Picture (from left to right) Apogee Catalyst, Apogee HiRoc, Apogee Nike Hercules, and Apogee Kronos

The initial prototype used rear ejection of all four motors and four separate parachutes. Such a complicated system was justified because it provided redundancy. If only one of the tubes had contained the recovery system, a single motor failing to light at liftoff could have resulted in a complete failure of deployment. This was, however, a very time-consuming recovery system to prepare. So, I worked on developing a design that would allow a single parachute to be used for booster recovery and – simultaneously – I intended to make flights on two (diagonally opposed) motors in the booster possible. The final design was several months in the future, but the basic design was determined.

The only decision left to make was if the rocket would fit in the scale or sport-scale camp. It was clear from the beginning that the Nike-Hercules kit would be one of our more expensive rockets. It includes a number of parts that we would need to have manufactured just for the kit and as a small manufacturer we simply cannot take advantage of economies of scale. Rather than have an expensive sport-scale kit, we would target making the most realistic Nike Hercules kit ever manufactured, and I believe that we have met and exceeded our goals along those lines. The final scale of 1:10.25 was chosen so that the body size on the Hercules is just a smidge under scale and the Nike booster tubes are just a hair oversized. The simpler 1:10 scale based on the Hercules missile would have led to a greater than 5% variation from the true scale which was my own (very arbitrary) threshold. During the process of design, there were slight changes to the fin profile to improve stability, but all these changes were made with an eye on remaining under 5% from the scale profile. The result is an exceptionally accurate rocket that still flies well on a plethora of engine combinations.

Creation of Parts

After determining the overall scale of the kit, the first step was to design and order a new nose cone to be used on the Nike Hercules. Getting parts blow molded, however, is an expensive proposition so we worked to make sure the nose cone would be usable in other kits. Luckily, it ends up being – essentially – a 5:1 ogive nosecone. The only “special” features are the slightly more round than typical tip and the careful design to make cutting off the base of the nosecone easy. The rounded tip is prototypical for the Nike-Hercules and as it was already clear that the recovery system would need to be fit inside the nose cone, the base of the shoulder would need to be removed. It might as well be an easy thing to do! The nosecone (the Apogee PNC-74A) arrived over a year ago now, and has since been used in three kits released before the Nike-Hercules: the Kronos, Catalyst, and Hiroc.

The second part that was designed is the boattail. In the end, the boattail is blow molded just like the nose cone. However,

unlike the nose cone, it was difficult to make usable in additional applications. This is a problem for us, as a part that is usable in only one kit is a part that is guaranteed to be more expensive. Much as we are determined for our kits to be of the utmost quality, we are acutely aware that cost is a primary driver for many hobbyists. We want our money to go as far as possible as well. Cheaper kits mean more rockets and/or more motors! All of this led to some debate about how the boattail should be formed. My initial plan was to use a balsa wood frame with a cardstock transition covering it. After some close thought, it became pretty clear that the balsa wouldn't be strong enough so it was never built (even as a test), but a couple of versions of a plywood frame with either cardstock or styrene as a skin were assembled. They worked well but had two problems. The first is that they were a pain to build. There was never a world in which this was going to be an easy kit, but we did try to avoid things that were needlessly challenging. Also, the amount of production work that would need to be done in-house, between laser cutting the frame parts and the skin, the built-up solution was still not going to be cheap.

In the end, we agreed that a custom blow-molded part was the best balance of ease of assembly, weight, and cost. In fact, the finished part comes in at around 30g (1 oz) when trimmed for installation, about 2/3 the weight of the built-up solution while still being stronger and more rigid. To offset the cost of tooling, we planned ahead and designed the boattail with integrated cut lines for AT-56 (BT-70), and AT-66 (BT-80) sizes, so it could potentially be used as transitions in other applications. We don't currently have any kits that do so, but it's nice to know that we could.

The Nike Hercules Features a Custom Blow-Molded Boattail, with Integrated Cut Lines for Use in Future Applications

The most contentious part was, without doubt, the interstage transition. As there was no possibility of it being used on any other kit, we knew from the beginning that whatever we did would have to make economic sense just with the Nike-Hercules kit. With the complexity of the kit and the cost to fly it, we knew that this would never rival our Zephyr in a game of numbers sold (disregarding kits sold in bulk packs for educational use, the Zephyr is currently our best-selling kit). So caution was warranted. Like the boattail, my original plan was to make a built-up interstage. After all, it was made of sheet metal on the full-scale Nike-Hercules so, despite the strange shape, it actually has only minimal compound curves. Similarly to the boattail, it would have been easy to build with a plywood frame and a sheeting of cardstock or thin plywood (e.g. 1/32"). Doing this would have been an interesting design exercise and for the customer, it would have been an intense phase of

The Interstage Connects and Aligns the Four Booster Tubes

building the kit. After substantial back and forth during our product development meetings, I was convinced to instead injection mold the parts for the good of the customers.

Not only would building the interstage have been quite involved, the interstage must be exceptionally accurate, as it connects the four booster tubes and also acts to align and mount the sustainer. Any inaccuracy in assembly would have resulted in either a mess to be fixed or an unflyable rocket, and that's not what we wanted. We want our customers to be successful, so injection molded it was. As it happens, this was the first part I've ever worked on designing for injection molding and it's far from trivial. There are a number of issues that can cause trouble in getting the tooling made as well as in getting clean parts when manufacturing starts. The biggest issue that we ran into with the interstage was the fact that it is covered in difficult overhangs. Rather than a simple two-piece mold, the body of the interstage required a multipart mold complete with small inserts and complicated, staged, assembly and disassembly. In addition to this, it is necessary to design the part in such a way that the wall thickness is consistent in all areas to minimize the effect of differential shrinkage which can lead to surface imperfections or even overall warpage of the part.

Prototype I (intended as a quick mockup)

The first prototype of the Nike-Hercules was created months before either the blow-molded boattail or the injection-molded interstage were ordered. They were both designed, however, so the prototype used 3D-printed parts in place of the final parts. These parts were printed out of PLA and at a thickness that made them very nearly the expected weight of the final, manufactured parts. They were – as a result of their material makeup – much more brittle than the final parts would be, a property that was demonstrated in grand fashion on the prototype's second flight.

As Prototype I was intended as only a quick mockup of the design to test stability and performance with the expected motor configuration, the Hercules sustainer was built with flat 1/8" plywood fins rather than the airfoiled fins which had always been intended. At the time, we were working quite quickly, as we were

still targeting a late 2023 release date for the kit. While the design for an airfoiled booster had been completed, the same was not true for the upper stage. Also missing were many of the small surface details that were later added and, of course, a full set of decals. Nevertheless, the first prototype looked surprisingly accurate from a short distance and the first launch was absolutely beautiful.

The first flight of Prototype I was a full-stack flight that was intended to stage from a cluster of four Estes E16-4 motors to an Aerotech F25-6. Liftoff was a spectacle to behold and validated that the Nike-Hercules was a rocket worth building. The rocket climbed on the four engines straight into the sky and… failed to start the upper stage. Figures… A post-mortem identified the problem as an igniter that was incompatible with the staging electronics. The Aerotech F25 had been a last-minute selection and while smaller, Quest, motors had been lit successfully with the same electronics, the larger FirstFire igniters were shown in later testing to consistently only smolder when triggered by the battery and other electronics we had been using. It was no surprise that the air start had failed. All that said, both the motor ejection on the booster and the apogee charge controlled by the electronics on the upper stage worked perfectly and the rocket was recovered. Sadly, it couldn't be said to have been without damage. The flight did result in a nasty zipper on the Hercules sustainer.

Prototype I was flown again at the following launch. The plan was to fly the upper stage by itself once to check stability and then to fly the full stack to test the complete flight profile. Just as the upper stage left the pad, the Aerotech F67C suffered a CATO severe enough that it blew the (highly brittle!) boattail apart and shattered the motor such that only small parts of the casing were found. Oy. So ended the flight career of Prototype I. Ironically, post-CATO, the upper stage coasted in a very stable manner until, once again, the electronic deployment saved what remained of the rocket except for, once again, a significant zipper. The first booster was in good shape, however, and the two flights did prove the general stability of the design. Also, it was clear that the sustainer was extremely prone to zippering, so I worked to adjust my method of packing the recovery system to deploy in a more controlled way.

Prototype I of the Nike Hercules Rocket Kit

Despite our successes with Prototype I, we were in the middle of releasing a dozen kits in a year and it was clear that we were not going to reach our initial goal of releasing in 2023. With many of the parts already designed, one prototype built, and all the misplaced optimism of a project that hadn't been fully envisioned yet, we felt that pushing it out just one year would be a piece of cake. In this atmosphere, we buckled down to complete the remainder of our twelve rockets for 2023 and officially announced the Nike-Hercules project at the manufacturer's forum at NARCON 2024.

Hiroc: A productive tangent

Before announcing the Nike-Hercules at NARCON 2024, we also started development of the Hiroc kit that acted as a test bed for developing many of the procedures that we knew were likely to be part of the final Hercules kit, but had not yet been tested in other products. This included features such as the laser cutting on the boattail and several construction methods that, while not unique to the Hiroc, were not currently used in our catalog of kits. An added motivation was to provide an advanced/intermediate-level scale kit that would give our customers additional practice in the methods needed to build our most challenging kits: the Saturn V, Saturn IB, and Nike-Hercules (being chief among them).

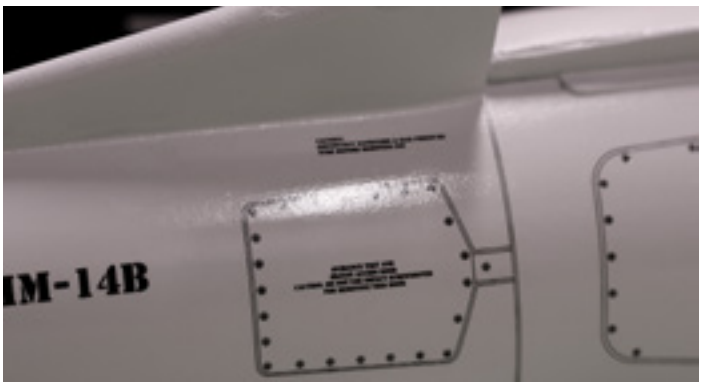
As a relatively standard rocket, the Hiroc was a nice prototype to work with while still providing a suitable test bed. The production procedure that was a primary concern – and thus justified testing – was the laser cutting of our HIPS (high-impact polystyrene), blow-molded, nose cones. While we already do laser trimming of vacuum-formed polystyrene parts, we have never done anything as physically large as the PNC-74A nosecone. The part is almost exactly the maximum size that can be handled by the rotary attachment for our laser cutter. This is not an accident. The nosecone – designed months before – had been designed with this process in mind. The shoulder was sized to ensure that even with the long 5:1 ogive shape, the part from the manufacturer would fit in the machine for cutting. Dialing in the power and cutting speed along with the autofocus settings was an interesting process and took longer than expected. The cutting results were also not as clean as desired, but with proper settings, they were usable and resulted in parts that made through-the-wall (TTW) fins possible. The use of TTW fins on the Nike-Hercules was desired from the very beginning, but not for strength. Rather, the many fins on a fully built Hercules missile posed a prime construction challenge and we wanted to ensure the easiest successful build possible.

Another characteristic feature of the Nike-Hercules that we wanted to replicate is the airfoiled fins. One of my goals with the kit was to ensure that it didn't become a plastic model, so I had no desire to use heavy, injection-molded, fins on the Nike-Hercules.

Photo of an Assembled Apogee HIROC Scale Model Kit

Historical Photo of the HIROC Missile

As such, we worked off the assumption that all the fins would be sanded to shape. However, balsa wood would not be strong enough for a rocket the magnitude of a 1/10 scale Nike-Hercules, especially when considering the fact that the fins would be sanded to a knife edge. In order to ensure sufficient strength without making shaping overly difficult, the decision was made to use a multi-part fin with a strong core (basswood on the Hiroc and plywood on the Nike-Hercules), with a balsa wood facing. While this more than doubles the number of parts that must be laser cut, the results were better than expected. The final fins are aesthetically pleasing, the construction was quite simple, and the final weight was surprisingly low.



Custom Decals Show Various Hatches and Surface Details

Other construction processes that were used on the Hiroc with the intention to later use them on the Nike-Hercules include printed cardstock to produce surface details and decals to provide otherwise difficult-to-recreate visual surface detail. Very simple surface details on the Hiroc, such as the tank joining band, were created by layers of cardstock where the details were simply printed and cut out by hand. This idea had been used earlier – in an even simpler form – on the Black Brant VC to good effect. For the simple examples on the Black Brant and Hiroc, the use of cardstock was a no-brainer. Even with successful examples, the survivability and aesthetic nature of the much more extensive cardstock planned for the Nike-Hercules was still an open question.

On the other hand, the decals created for the Hiroc, which represent the assembly screws between rocket sections, were wildly successful in creating the desired overall surface texture. While it was already apparent that due to the need for an opaque white backing layer, we would have to get decals manufactured externally for the Nike-Hercules rather than producing them internally (as we do for many of our kits), there was no doubt that the many hatches and other surface details that appear on the Nike-Hercules would be beautifully rendered with just the simple use of, appropriately designed, decals.

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Prototype II (intended as a potential prototype)

In addition to the Hiroc, which was still in process, there were several other kit ideas that were floated as part of the NARCON 2024 presentation, where the Nike-Hercules was first announced. None of them have been dropped and we put varying amounts of work into each of them. But, when little work had been done on the Nike-Hercules, short of design in the computer as NSL West was approaching, it became clear that I would need to resurrect the booster I already had and build a new upper stage to test what might be considered a releasable design for a 2024 release date.

Prototype II was the first Hercules built – as intended – with airfoiled fins. The fins were constructed with 1/16" plywood cores and 3/16" balsa wood facings that were then sanded down. While it was certainly possible, building this one prototype demonstrated to me conclusively that I needed to do a major redesign. The fins on the Hercules are long and thin, and sanding so much of the unwieldy fins off was a nightmare. The fins were also relatively heavy. Even before its first flight, it was clear that Prototype II was not the final kit design. Still, it was worth getting some flights in, and it was worth showing off the partially complete set of decals!

There were a couple of generally successful flights of Prototype II at SCORE (Southern Colorado Rocketeers). The first of these was entirely nominal. The boost – again – was beautiful and the upper stage lit for a successful flight which resulted in just a small zipper in the sustainer (again!). The second was less successful, but much more interesting. The liftoff began cleanly but then the second CATO of the Nike-Hercules program occurred. One of the four booster motors suffered a CATO which ripped the side of the booster tube wide open while the booster motor exited the motor mount from the bottom. As it happens, the original booster design did not yet have the final motor retention solution, the motors were merely taped in. Despite the destruction wrought by the disintegrating motor, the Nike-Hercules continued to climb as if nothing had happened to a nominal upper-stage ignition and recovery of both stages. It wasn't until the rocket was recovered that I was even aware that something had happened, as I completely missed the destruction while I was focused on tracking the rocket with my camera.

Prototype II of the Apogee Nike Hercules Rocket

One of the Four Booster Motors Suffered a CATO at Liftoff

At the time of the CATO, NSL West (2024) was fast approaching and we still wanted to be able to fly a Nike-Hercules at the launch, so the booster was simply repaired with a new tube spliced in and the booster repainted. The now somewhat less attractive booster achieved another fully successful flight at NLS West where the booster was recovered with no additional damage and the sustainer had only a small zipper. Modifying the packing method of the sustainer had certainly been helpful for mitigating some of the loads that we had been seeing on earlier flights. We wanted a more robust solution, however, and while we discussed the possibility of a shroud for the thin Kevlar, or a leader of kevlar tape; we were uncertain as to the best solution. It wasn't long, however, before Tim came up with the perfect solution, which we rapidly developed and have already released as its own product. The shock cord weaves through the Zipper Shield, which then straddles the open tube end to provide a wider contact surface. This one small addition to the kit ensured that none of the remaining flights resulted in any zipper at all.

Just prior to NSL West, we also finalized the design of the detail parts and the decals. The detail parts on the Nike-Hercules kit are injection molded and, of course, following the design work, the files had to be sent to our vendor, the tooling made, and the parts manufactured, so it would be some time before the final parts arrived. Instead, we simply 3D printed the parts to allow a fully detailed Nike-Hercules to fly at NSL. To be honest, while our use of 3D printing in parts that our customers receive has been fairly minor at this point, the process itself has proven to be exceptionally useful during the prototyping phase and to produce in-house production fixtures and jigs. It was one of the smaller wins of the Nike-Hercules project that we found so many ways to speed up development with the help of 3D printing that can be carried forward into future projects.

Nike Hercules Prototype II Rocket at NSL West

In addition to the detail parts, the design of scale-accurate decals was also completed before NSL, so we were able to fly a model that was very similar to what the final kit would look like.

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Prototype III of the Nike Hercules—The Upper Stage

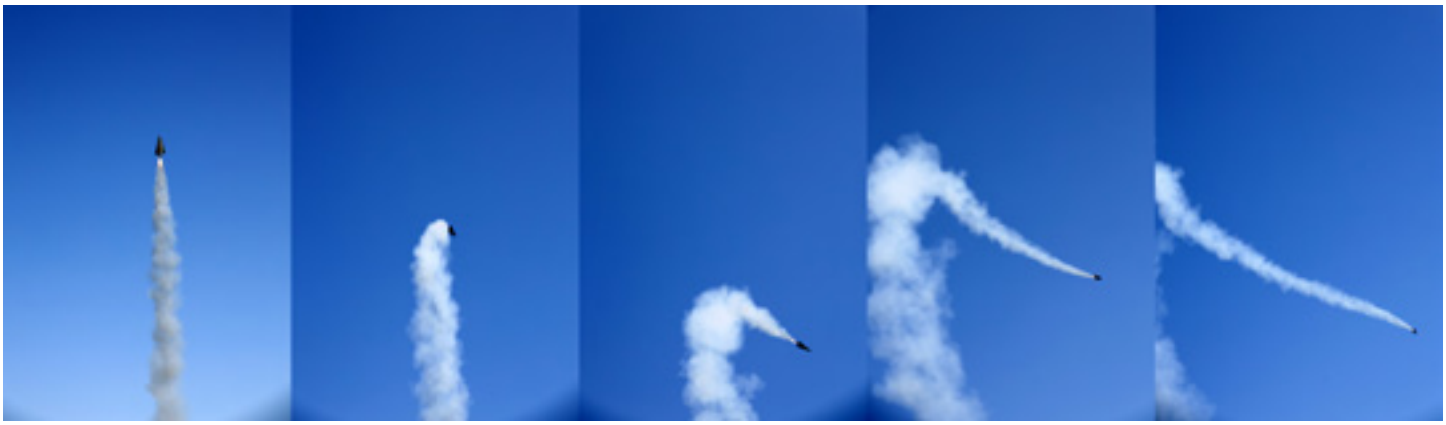
Building a Nike Hercules Rocket Plywood Fin Core

While the completed rocket was visually very close to what we envisioned for the final kit, some building procedures were simply more difficult than necessary and needed to be changed. Perhaps the most obvious of these is the structure of the fins. While the first two prototypes were made with solid wood fins (flat on prototype I and sanded to an airfoil on prototype II), shaping the fins was quite difficult, so it needed more engineering. Rather than sanding them to shape, the fins were redesigned to be built up in a style that was reminiscent of a model airplane. The plywood core remained as a way to strengthen the edge of the fins, and simultaneously align the basswood ribs. Lastly, rather than sanded balsa wood, the surface of the fins were changed to cardstock sheeting.

Other small changes in the design were made after the testing of prototype II, but none had as large an impact on the final form of the kit as the built-up structure on the booster and sustainer main fins. The booster retention system was designed, and more surface details were added. Moreover, engraved alignment marks were added to make construction easier and more accurate.

Prototype III (test article)

Having successfully built and tested a sustainer, we desired to understand a bit better how much inherent stability the Hercules actually had. As it stood, it flew well, but we did hope to be able to decrease the nose weight to make flights on less expensive motors possible. At the same time, we had the goal to fly at the upcoming NARAM launch and there were a number of changes that we decided were worth making, so we'd need a new prototype. I began building two new Hercules stages and a new Nike-Booster



Nike Hercules Upper Stage Photo Sequence of Flight Path

stage. The first to be completed would fly as just the Hercules sustainer, with half the nose weight of the previous prototypes. It was expected to fly only once. The second Hercules was being built in parallel as we wished our example rocket to be as scale as possible and, as such, did not wish to have launch guides on the upper stage but they were necessary for the test. Also, if the test was unsuccessful, it would be much easier to add additional nose weight to an uncompleted rocket than to one already fully built and painted. Prototype III was completed and flown with one week remaining before NARAM. The flight proved to be one of the few times in the development process that inspired… adult language.

Prototype III was flown on an Aerotech F67W, as we had previously noticed that the Hercules could be a bit squirrely when under heavy acceleration. The combination of reduced nose weight and high thrust was intended to be a “worst-case” test. Perhaps we hit that goal a bit too well. Upon ignition, the rocket boosted straight up about 50’, turned 90 degrees to be almost exactly parallel to the ground, and flew (thankfully away from the crowd) several hundred feet until the nose dropped enough that the electronic recovery deployed the parachute. Given only a week before a major launch, the “failure” of the flight was crushing, and the stress of the project was starting to get to me. Things didn’t seem quite so bleak to others around the office, so I pressed forward in attempting to get things sorted out for NARAM the week following. The primary concern, of course, was to ensure that the Nike-Hercules could reliably be flown safely. Any time a rocket that is supposed to be stable reacts in an odd manner, I want to know the reason.

Luckily, I got a good sequence of photos of the flight at 40 frames per second. Because I was able to capture the images at roughly the speed of video, but at the full resolution of my camera, I was able to see exactly what path the rocket had taken during the flight. One thing was clear. The rocket was not unstable. The initial boost was beautifully vertical until quite some way after the launch rod and then, after the flight deviation, the flight was extremely straight (despite being horizontal). On the day of the flight, we were having gusty winds. While it wasn’t getting much above 12-15 mph, the gusts would come out of the blue and die down just as quickly. As it happened, there had been a gust during the boost and the Hercules had weather cocked directly into it. So, the first concern, instability, was not the issue. Nevertheless, a rocket that was so prone to weather cocking was not good either. So the next test was to measure the rocket’s moment of inertia and compare it to other rockets in the same size range.

To test the moment of inertia, I set up a hacked-together bifilar pendulum rig and collected data for the Hercules along with several of the other short-and-stubby kits that we sell (the Catalyst, LOC V2, LOC Patriot, etc.). I had gone into the tests certain that the Hercules would have a much lower moment of inertia than the others, given its large response to the wind gust. As it happens, the overall moment of inertia was not particularly low. That confused me for about an hour until I realized the blatantly obvious about the Hercules missile: the fins are huge. While the moment of inertia was not particularly small when compared directly, when compared after normalizing based on fin volume, it absolutely was. Fin volume, in this context, is equal to the area of the fins multiplied by the stability margin, that is, the distance of the CP (center of pressure) behind the CG (center of gravity). And while it's not a direct measurement, the fin volume does give us a good proxy for how much force righting torque the fins can apply. Having identified the issue as one of sensitivity rather than instability, it became much easier to evaluate solutions.

With an actual measured moment of inertia, it was simple enough to calculate how the addition of point weights would modify it. Given that the fin force was overriding the moderating effect of the moment of inertia, the question became, “how does adding more nose weight affect the sensitivity to gusts.” Of course, adding nose weight would move the CG forward, which also increases the effectiveness of the fins by increasing the fin volume – increasing sensitivity. Simultaneously, the added weight at a distance from the CG will increase the moment of inertia – decreasing sensitivity. So, which has a greater effect? Of course, flight testing isn’t the way to find a solution to this problem. Flight testing, fun as it may be, is time-consuming and expensive. Our position was ideal for simply calculating the effect of added weight, however. Fin volume is a geometric property of the rocket and is easy to calculate given a known center of gravity. Meanwhile, the change in both the moment of inertia and the center of gravity are easy to calculate if the clay is assumed to be a point mass. While that’s not entirely accurate, it’s very close to it in this situation. So, I estimated the sensitivity with different nose weights and the effects of the moment of inertia were steadily more powerful than fin volume.

Perhaps it was a long detour to go out of our way to decide to go back to the amount of nose weight we had been using before, but the reason to do so was to understand not just that it worked, but why. Having run the tests and calculations, I could be confident that we were making a choice that not only would work in some conditions, but that we were making a choice that was the safest and most reliable in as many conditions as possible. However, that alone was not enough. While the nose weight was an improvement, I wanted just a bit more. Enter spin stabilization.

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I'm not personally a huge fan of spin stabilization, but I would not deny that it has its uses. The final change that we made as a result of the flight of prototype III was to add about 3 degrees of cant to the elevons at the aft of the Hercules. This is not enough spinning force to create a rapid spin, but it does result in a fair rate of spin once the Hercules is flying on its own. The result of this spin is a greatly increased resistance to the sort of flight deviation that was experienced by Prototype III. Combined with the nose weight, the remaining prototypes have tracked significantly straighter than the initial two prototypes.

Prototype IV (final prototype)

The final prototype had to be completed rapidly as it remained unassembled and unpainted the Monday before NARAM started. The analysis of the flight of Prototype III and the decisions made as a result had taken much of the day, so it wasn't until late on that Monday before I was able to make progress toward completing Prototype IV. The full complement of clay nose weight was inserted, and the forward bulkhead was glued in. The elevons were cut off and reglued to include the desired cant, and the sustainer primed.

Prototype IV, the Final Prototype Design for the Rocket Kit

Luckily, the booster, which is significantly more difficult to paint than the sustainer, had already been completed the previous week (and resulted in the laser-cut stencil article found in PoF #633). The week before NARAM was, like NSL West before it, a whirlwind of activity getting our final Nike-Hercules design ready. In addition to painting the sustainer and applying decals, both the upper stage and booster were weathered. All of this was happening while I was feverishly trying to complete my Black Brant XI build that was to be entered in the Giant Sport Scale competition. Somehow, amazingly,

all of the rockets that we had targeted having complete for NARAM were done come 5pm on Friday night, and we prepared for a long week of being on the field.

NARAM saw three flights of the Nike-Hercules, Prototype IV. The first flight (on Saturday) was nice except that the deployment charge got placed under the ebay sled in such a way that when it fired it blew off the ebay door and crumpled the sled itself. This led to a couple more notes for the final design, the main one being to reinforce the sled and hatch mount Despite that, the flight was precisely what we had hoped for as NARAM was a major chance to show the community what we had been working on. Even better, the manufacturer's forum was on Sunday evening, and we wanted to show the Herc off then. It was quite a relief for it to come back in one piece and be available for the forum. But, we weren't planning on only one flight during the week. We had intended at least two.

The second flight was on Wednesday and resulted in a failure to stage. This was, of course, frustrating, but it was actually an example of everything working as it should. Throughout the week, there had been fairly significant wind, so the rocket was placed on the pad angled into the wind (to minimize drifting onto the contest range), and the initial launch angle combined with some weather cocking meant that when the rocket was at altitude and ready to stage, it was already outside the safety cone, and the off-axis lock-out of the Blue Raven it was flying with, suppressed staging. Both the booster and sustainer deployed the recovery systems correctly, but the high winds did, unfortunately, lead to a crack in one of the booster fins when the wind forced it sideways against some brush. The fix was to build a new fin and reattach it, so Wednesday evening saw the building of the fin, and Thursday its painting. This flight did highlight a potential weakness in the fin design though, so it resulted in a slight tweak to the design of the fin core.

The final Herc flight at NARAM was again almost (but not quite) perfect. The boost was beautiful. Staging was excellent, the recovery systems came out as desired… and the nose cone separated; the shock cord had broken. The booster and aft section of the sustainer came down under parachute with no damage. The nose cone did not fare as well. It came in ballistic from apogee

Nike Hercules Booster and Sustainer Under the Parachute

(around 1700' on that flight) and lodged itself nearly six inches into the ground. In doing so, it blew out the sides of the nose cone as the bulkhead continued forward at impact. Amazingly, however, it was repairable. Prototype IV is not as pretty as it once was, but it has flown many times since.

The final note that we took from the NARAM flights was to lengthen and increase the strength of the Kevlar in the sustainer.

The addition of these several strengthening measures required us to source some new shock cord to sit between our 300# and 1500#. This 750# kevlar still worked with the Zipper Shields as designed and does not take nearly the space nor add nearly the weight that a 1500# shock cord would while providing some nice "belt and braces" protection above and beyond the 300# shock cord that was originally used. It could be argued that lengthening the shock cord would have been sufficient. That is likely true, however, given the large amount of nose weight required in this rocket, it made sense to err on the side of ruggedness.

Following NARAM, the Nike-Hercules made a trip to AIRfest with Tim. Once again the booster sustained fin damage on landing, but the flight was otherwise excellent. That resulted in yet another fin core redesign, and also the addition of some 3D printed guides for the couplers between the boosters and the interstage. Before the AIRfest flight, I had prepared the rocket for all the test flights. Coming at the rocket fresh, Tim was able to identify the alignment of the four coupler tubes on the booster as one of the more difficult parts of preparation. When that was identified, it was an easy thing to come up with a solution. Just before AIRfest, Tim had started preparing to record the video instructions but had not yet gotten into the studio, so I had just a bit of time to make changes before we had to lock the design down entirely.

Nike Hercules Single Motor Launch

The recording of the videos did not mean the end of testing, however. Prototype IV has flown several more times. One flight was to test it on a two-motor cluster (of Aerotech F67-4W) motors in the booster. This was an interesting flight for several reasons. In addition to flying on two rather than four motors, this flight was going to test the possibility of using two parachutes to recover the booster section rather than one larger parachute. Of course, the flight was even more interesting than expected because one of the motors did not light (an issue with the igniter, as it turned out), so we got to see how the Nike-Hercules handled an asymmetric thrust condition. And, as it happens, it handled it extremely well. The boost was surprisingly straight given it was flying on only a single off-axis motor. There was only a very slight curve. Once again, ignition of the upper stage was correctly suppressed due to insufficient altitude, and both recovery systems deployed properly. The tested two-parachute solution proved to be less than optimal as it tangled, so we stuck with the single parachute for production.

More recently, we wanted to get flight footage of the Nike-Hercules taking off with four composite motors. And it's quite a sight. The interesting thing that we discovered about the Nike-Hercules is that it was actually very easy to fly it under Class I rules, as long as the motors are all composites. The lower specific impulse of black powder means that most suitable combinations of Estes motors end up Class II due to propellant mass. Although, it is entirely possible to fly with four Quest D22 motors in the booster and something like an Aerotech E20 in the sustainer as a mid-power (class I) flight that will still reach over 1200' with lots of flame and smoke.

Working Toward Release

Having completed the design and development of the kit, and having tested it to the point that we were sure it was a reliable performer, the final three tasks left to us were creating the written instructions, designing the packaging, and final production. By far the most in-depth of these was in creating the instructions.

I was adamant that we needed to include written instructions in the kit in addition to the video instructions we had already begun to record. Of course, I already wrote the text for the instructions. That was what Tim was working off of when recording the video instructions. All told, the written instructions are over 16,000 words. In terms of fiction writing, that blows right past a short story and lands nicely within the range of a novella. It's a book. Then again, there are 220 construction steps and 24 preflight steps that are described, so it's not unreasonable. But, it takes time to create illustrations. We finally had a chance to dig in on the illustrations in late September, and we intended to release the kit in late fall. So we decided to go outside our typical procedure and hire outside illustrators. Working from the recorded video instructions, the illustrators created the individual step illustrations while I worked on the more detailed images that came between major assemblies and Tim worked on building up the web page (and herding the cats that were the illustrators).

In the end, the instruction book contains 262 illustrations and spreads over 72 pages. By itself, it is a project that we could be proud of, but the surprising thing, perhaps, is that it was just the cherry on top of the project. In addition to a beautiful physical instruction book, we will be releasing over four hours of edited construction videos along with the Nike-Hercules kit (edited down

The Final Kit Design for the Nike Hercules

The Final Box Design for the Nike Hercules

from nearly 10 hours of raw footage!). These forms of instructions, along with several newsletter articles already released and more still in the pipeline, should make the Nike-Hercules a project that is attainable by anyone with the time and patience to undertake it. Honestly, I found building the Nike-Hercules to be one of the more restful of my recent rocket builds due to the repetition inherent in all the fins, all the tubes, and all the details.

Once we had a good bead on the Nike-Hercules instructions and knew that we were likely to reach our scheduled release target, we went to work creating the packaging for the kit. Many of our kits, of course, are sold in polybags. We do that for a number of reasons. Polybags allow us to keep our kit costs lower. They also lead to lower shipping costs. Since the Nike-Hercules was already going to be a more expensive kit, however, we wanted to ensure that the kit arrived in the best condition possible so, like the Saturn V and Saturn IB kits, we decided to package the Nike-Hercules in a box. We have also enjoyed how the addition of a well-designed face card transforms the look of a kit, so our new graphic designer was given free rein to design some beautiful packaging and he came through. In the end, I think the Nike-Hercules ended up as possibly our most handsome kit ever, and from the standpoint of practicality, the box makes it much easier for our production team to build it the same every time as we do not need to allow for parts sliding all over the place like we do in a polybag.

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Of course, there are hundreds of tiny steps to take care of for a product release the magnitude of the Nike-Hercules Kit. There are all the inventory challenges, marketing materials, website content, as well as related articles and videos. But the last major hurdle was to get the first run of kits built. Even with the parts manufactured, building the Nike-Hercules kit is not a negligible process. As a final quality assurance step, we produced an official build order and ran a training so that all of us would be able to build it in the same way and absolutely minimize the possibility of missing parts (despite the complexity of the kit).

We are not inexperienced with building up complicated kits, of course. Both the Saturn V and Saturn IB kits are quite complex, as are some of our more recent releases such as the Draco BG and Hermes HLV. But the Nike-Hercules kit is complicated on a whole different level than most and given the years of development effort and investment in tooling, we wanted to make extra sure that our customers ended up with the best experience possible.

The Apogee Team Building the Nike Hercules Kits

Every Prototype of the Nike Hercules Created at Apogee

Conclusion

Every project, even when overall triumphant, ends with some regrets; the Nike-Hercules is no exception to this rule. There are many things I wish I could have done through the course of the project that either due to budget or time constraints (or both!) proved to not be possible. As far as the kit itself is concerned, I am happy with the results. That said, I would have liked to provide even more detail and I would have liked to have acquired more reference material. When it comes to production though, there are processes I would have much preferred to change. Such as transitioning some of the laser cutting to CNC machining.

As it stands, the kit has a high degree of scale detail but things such as surface rivets are left up to the builder (though we did provide significant information regarding placement as part of the kit). The interstage is an absolutely beautiful part and the mold for it was already a complicated affair, but in an ideal world, rivets could have been molded into the part directly. To do so, however, would have led to tooling that was less reliable and more prone to failure. In addition, molded in rivets makes surface finishing significantly more difficult. Similarly, additional sets of decals made with puff ink would have allowed us to provide a simple solution for the application of rivets in the kit. In this case, the cost would absolutely have been prohibitive.

From the standpoint of reference, I would have been able to create significantly more detail if I had had the opportunity to travel and collect photos of real Nike-Hercules rockets. That, also, was not something that was feasible either from the standpoint of time or of cost. We did have a large cache of photographs that Tim had collected several years ago when NARCON toured the SF-88 Nike-Hercules site and, of course, we had a collection of drawings. Added to that, I found a handful of books on Nike-Hercules history as well as several primary documents such as training manuals and collections of technical data. The amount of reference that we had was excellent and allowed us to end up with a kit that is a very accurate representation of the full-scale prototype, but more is always better.

The biggest thing I would change if I could is the way that we are conducting manufacturing on the nose cone and boat tail. Each part is blow-molded but we add engraving and slots in-house. Currently, those operations are completed on our laser cutter which, though certainly functional, is not as clean as I would like. Building a custom CNC rotary mill was an idea floated several months ago and which got to the point that we identified the basic parts required. Between NSL West, NARAM, AIRfest, and all the development, however, it was clear that there would be no time to design, build, and configure such a piece of equipment. Still, that is one area that I do feel we could improve our production process that would be better for both our own efficiency and for the quality of the final product. It is an idea that we may revisit in the future.

The Nike-Hercules is a rocket that provided a wide variety of challenges to us as a company and to me as a designer. From the mechanical and aerodynamic design of the rocket to the production processes, marketing, packaging, and instructions, we all made an effort to push past the limits of with previous kits and make the Nike-Hercules something unique and special. It is certainly my hope that the result is something that gives the community as much chance for growth and discovery as it has us.

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Developing the Nike Hercules Rocket Kit

by Tim Van Milligan

Now that you've read Martin's article on the development of the Nike Hercules, I thought I'd give you mine.

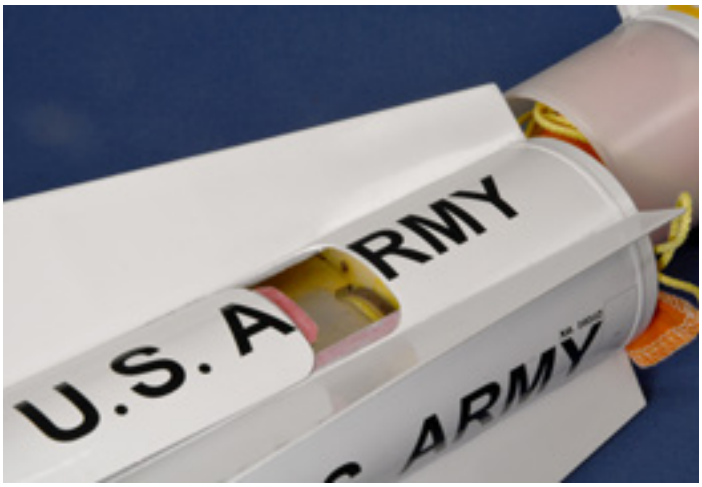
The Nike-Hercules kit is probably the biggest rocket kit project that we've ever taken on here at Apogee Components. And we've done some very big things in the past, like the 1/70th scale Saturn V, Saturn 1B, X-15, the Star Lift Mega Lander, Draco, and the TTV to name a few. They all had a number of challenges to them, and we're really proud to offer them to our customers.

With the Nike-Hercules, it was even more intense, but it was something that we knew we could handle.

Last year, we had a goal to produce 12 new kits, which we were able to achieve. By doing so many, we were able to really hone our process of developing and producing a kit. That served us well, because we used all of the skills we learned during that process. And there were some significant projects in that mix of rockets, including the Draco swing-wing boost glider, the Hermes 4-engine cluster rocket with strap-on booster pods, and the TTV, a two stage rocket featuring electronic ignition of the upper stage..

This year, instead of creating a lot of kits, we decided to do a big project that we knew would take a long time. The project that I tasked the team, was to produce the Nike Hercules missile. It has been a favorite of mine since I was a kid. I remember first seeing it as a sketch in a Centuri publication, and it really caught my attention. I just liked the masculine look of the rocket, and the raw power it exudes. It is so complex, that there have been very few kits released of this famous rocket, and in my opinion, none of them does the rocket the homage it deserves.

I've been planning on eventually kitting up the Nike Hercules. That was the reason that in the early 2000's that I invested in the 5-to-1 Ogive-shaped nose cone that is used on so many of the



The Larger Scale of the Apogee Nike Hercules Allows for More Room for Electronics and Details

DynaStar kits. I had planned on making the kit based on that nose cone, which would put it's diameter at a BT-70 size (2.2 inches).

During the initial planning phase for our 2033 kit line-up, we talked about doing a 3" diameter rocket. So we budgeted for a new 3" nose cone, and I left it up to Martin Jay McKee to choose the shape. He also liked the 5-to-1 ogive shape nose cone, because we talked about maybe upscaling or downscaling some of our other kits in the future. We made the purchase of the mold, and I'm happy to report that the new 3-inch diameter nose cone did get used in a bunch of kits last year: the Kronos, Catalyst, and Hiroc.

I don't recall that Martin mentioned to me that he was thinking about doing a larger version of the Nike Hercules. I was totally happy with a 2.2" size kit, so I wasn't even contemplating doing a larger version at first.

As we rolled into 2024, we knew it was time to start working on its development. Martin presented me with the idea of going with a larger version, and had several good reasons to go "bigger." A first reason was that the booster stage could use standard BT-60 size tubes for the four motor cluster. So instead of having to source a custom sized body tube, we could use our existing stock.

The second reason was that the larger version based on a 3" diameter nose could use 29mm rocket motors. The smaller 2.2" diameter rocket would be really tough to get all the electronics and wiring into it. With the larger diameter model, there was just a lot more room in the rocket, and it opened up a lot more options.

Those were the compelling reasons for me to decide to make the upper stage based on a 3-inch tube rather than the BT-70. And in hindsight, it was an excellent choice, and I'm really happy that we made the decision to do that.

At this point, we started the process of making a kit, and it followed the traditional path that we always use. I talked about this process in **Peak-of-Flight Newsletter #638 (https://www.apogeerockets.com/education/downloads/Newsletter638.pdf).** However, this one required a few more special parts that we didn't have in house. I knew that eventually, we'd have to order an injection mold tool to make the transition in the middle of the rocket that holds the two stages together. So that would put the timeline for release towards the second half of the year.

Completed Apogee Nike Hercules Photographed Outdoors

Some differences from the basic kit design process included:
- The kit not only needed the plastic transition, but also new blow-molded boattail for the upper stage.

- The Nike Hercules also had a number of surface details that required an additional injection mold tool. So we purchased a mold with 29 individual parts on it.

- This year we invested in a new 3D printer (SLA style) to replace my old prototyping machine that I had gotten in 2014. The 3D print technology has come a long way, and we're on the cusp of where the technology can be used for small runs of "production" parts. For the Nike Hercules, I actually didn't want to use any 3D printed parts. That's why I purchased the injection molded tool to make the small detailed parts that are glued to the outside of the rocket. But we discovered during flight testing that we needed some plastic end-caps to make it easier to put the transition onto the booster stage. Since the other injection mold parts were already finalized and that tool was being made, I had no other good alternative. So there are four 3D-printed rings in the kit. Had we discovered we needed them earlier, they would have been in the parts sets with the other small parts.

- I had originally planned that we would only release a set of video instructions for the kit, and not printed instructions like our other kits. This was due to the model's complexity and really odd-shape which would make drawing it a chore. I envisioned that it would be like the Saturn V and the Saturn 1B kits, which don't have printed instructions. Those models do well with customers - at least they can build and fly them successfully. But there is a trend in the rocketry industry to skimp on printed instructions - which causes a lot more work for our customer service team. We get a lot of complaints about other rocket companies because they don't provide printed instructions. So we decided to invest in the production of the instructions.

-I also wanted video instructions, because those have a different function; they teach "technique," which is just as important as the sequence. How you hold your hands when sanding, for example, is a technique that can make the process go faster and easier. The assembly videos took about a month and a half to record. This was a little bit of a hold up that prevented our instruction illustrations from being started.

- Since the number of steps in the instruction sheet was in the "hundreds", I decided to hire extra artists to help illustrate all the steps. They would use the written text, and the video instructions

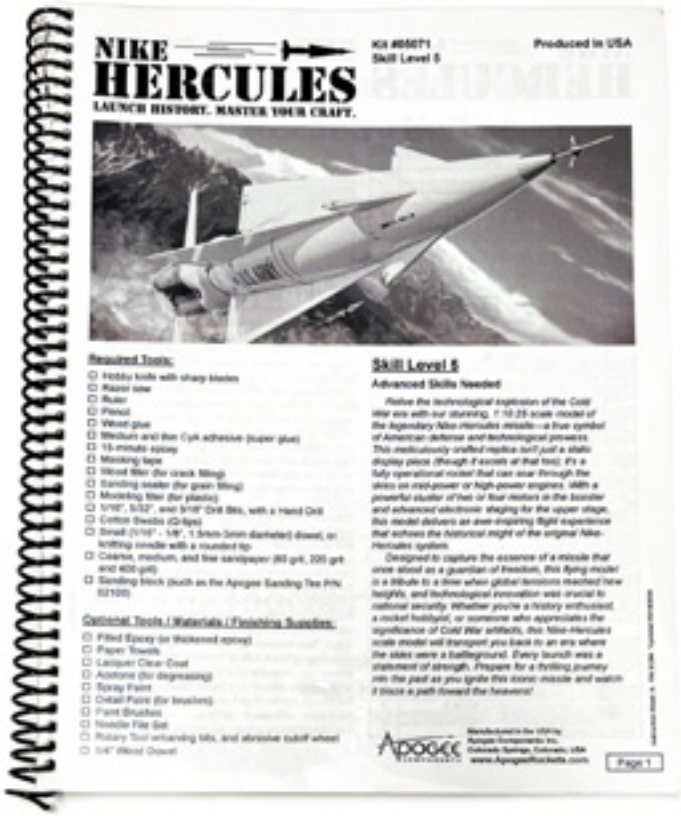
Front Packaging of the Nike Hercules Boxes—We Revamped our Packaging Design With This Kit for a More Premium Feel

that I made to draw the images. All told, we had a total of seven artists (including Martin and myself) that worked on the images.

- In one day, an artist can draw about 5 or 6 individual steps in the instructions. With so many steps, and seven artists working on them, we were able to get the first round of illustrations done in a little over a month. Since none of the outside artists had ever seen a model rocket before, they did make a lot of mistakes that needed to be corrected. Hopefully we caught them all in the final editing of the book.

- The instructions turned out to be a literal "book." There are 72 pages in the book, and we're quite pleased at the way it turned out. They are much like the other instructions that we're known for here at Apogee Componentes. With all the illustrations, and the video assembly sequence too, we believe that our customers will be successful in building this very involved rocket.

- Also this year, we also hired a new graphic artist (Ogden) during the summer, and this kit was his baptism by fire (blow torch, you might say). I'm really proud of the work that he did, without knowing anything of how we operate. He worked on every aspect of the project, from editing videos, making the package artwork,


NIKE HERCULES
LAUNCH HISTORY. MASTER YOUR CRAFT.
Kit #05071
Skill Level 5
Produced in USA
Required Tools:
Optional Tools / Materials / Finishing Supplies:
Skill Level 5
Advanced Skills Needed
Page 1

The 72-Page Spiral-Bound Nike Hercules Instruction Booklet

producing the instruction book using the illustrations we made, and working on all the marketing materials. His involvement was critical to the completion.

- The rest of the team really stepped up too. This really became a group project where everyone contributed. I could see the excitement they had, and everyone wanted it to succeed.

As I write this, we're heavily in production on all the components of the kit, and it is just about ready to go out the door. I have to say that I'm really pleased at how it came out, as it is better in every way than I had expected at the beginning of the project. My only fear is that customers will put the kit into their "build pile" of models that they'll eventually get around to starting. I would hate to see it collect dust. This is a model that is so exciting, that it should never be in the build pile; it should be built and flown.

So I hope you enjoyed reading my recollections on this model. And I'm interested in hearing your Nike Hercules stories too. Please send them to us.

About The Author:

Tim Van Milligan (a.k.a. "Mr. Rocket") is a real rocket scientist who likes helping out other rocketeers. He is an avid rocketry competitor and is Level 3 high power certified. He has a B.S. in Aeronautical Engineering from Embry-Riddle Aeronautical University in Daytona Beach, Florida, and has worked toward an M.S. in Space Technology from the Florida Institute of Technology in Melbourne, Florida. Currently, he is the owner of Apogee Components (http://www.apogeerockets.com) and also the author of the books: Model Rocket Design and Construction, 69 Simple Science Fair Projects with Model Rockets: Aeronautics and publisher of the "Peak-of-Flight" newsletter, a FREE ezine newsletter about model rockets. You can email him by using the contact form at https://www.apogeerockets.com/Contact.

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SUBMITTING ARTICLES TO APOGEE

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.

When you have an idea for an article you'd like to submit, please use our contact form at **https://www.apogeerockets.com/Contact**. After review, we will be able to tell you if your article idea will be appropriate for our publication.

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

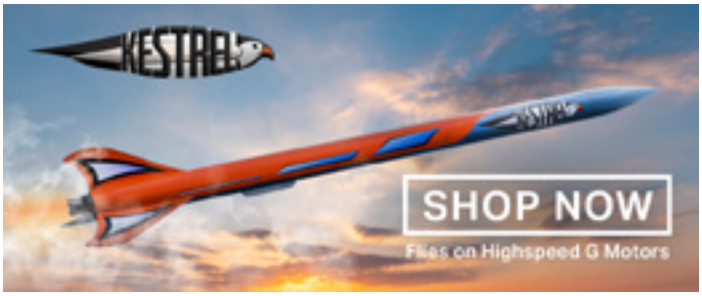
All articles submitted to Peak-of-Flight must not run in another publication before inclusion in the *POF* newsletter, but it may be based on another work such as a prior article, R&D report, etc. After we have published and paid for an article, you are free to submit them to other publications.

RATES

Apogee Components offers **$300** for a quality-written article over 2,000 words in length. Payment is pro-rated for shorter articles.

WHERE WILL IT APPEAR?

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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