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Development of a New and Simplified Helicopter Rotor Hub

By Tim Van Milligan

This article comes from my NARAM 56 R&D report. It details my design philosophy when creating the new helicopter hub that I used in the GyroChaser (www.ApogeeRockets.com/Rocket_Kits/Skill_Level_4_Kits/Gyro_Chaser), and also in the new Rotary Revolution kit (www.ApogeeRockets.com/Rocket_Kits/Skill_Level_4_Kits/Rotary_Revolution)

Background

The project's goal originally started when I tried to create an easy-to-assemble helicopter hub that my girls could assemble and use to be competitive at the FAI fly-offs in the summer of 2013. Even though they were seasoned competitors, I felt they were at a disadvantage in this case because they had never competed in FAI helicopter style competition. I consider FAI style to be vastly different from NAR style helicopter duration because the configuration of the models is quite different.

To be competitive, the modeler needs a low drag design for boost, which points to the strategy of using internally carried rotor blades. In NAR competition, they are usually carried externally, because there is no limitation on the diameter of the rocket in the Pink Book rules. In FAI events, there is a minimum diameter for the rocket, and the internal space is going to be present in the design, whether you use it to hold the blades or not. Therefore, a competitor might as well use the internal space.

The big problem, because my children were young and lacking building skills, was that I felt it took too much fine muscle skills to put together a complex hub that required precision assembly. I foresaw that they would be frustrated by the process, and end up with a helicopter that was out of balance and wouldn't perform very well.

Therefore, I set out to simplify the hub, to make it easy for them to assemble and yet one that was both lightweight and would fly sufficiently well.

Approach Taken

This project followed the standard incremental process

that one might use when developing any new type of invention:

- A: Background research. Find out what is the current standard.
- B: Build what other people built
- C: Weigh the pros and cons of the "industry standard"
- D: Try to eliminate the cons with a revised design
- E: Test the new design
- F: Repeat the process until the original goal is sufficiently achieved

I followed that approach. The hardest part was doing the research of past helicopter hub designs. The reason is that the information is scattered in so many locations.

References to previous work done on the subject, found in research preparatory to this report

My previous experience working on FAI style helicopters was in 1993. Prior to that time, the Gyrocopter event within the FAI was not flown in competition. It was sort of a provisional event. George Gassaway and I, working independently, came up with two different designs for the proposed event. I published them in the *Journal of the International Space Modeling Society* (J.I.S.S. Volume 1, Number 4; July 1993 (see Figures 1 and 2).

Both of us based our hubs on the small plastic hinges that are common in the model aircraft industry. The pros of these hinges were they were readily available, cheap, and reliable.

One minor disadvantage of these hinges is that they require



Figure 1: Tim Van Milligan's Octopus design used 8 blades to form a tube when folded down. It didn't fly very well, unfortunately.

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Development of a New Rotor Hub

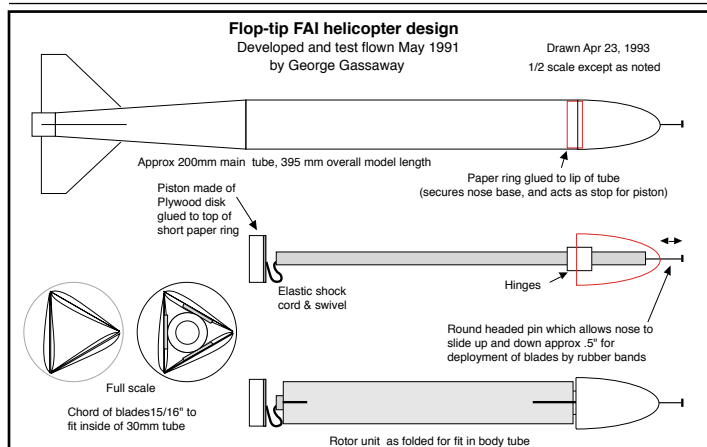


Figure 2: George Gassaway's original Flop Tip helicopter for the FAI S9 gyrocopter duration event.

flat plane surfaces in order to mount them. But the biggest issue that I had with them is that they are hard to glue to, because they are made from Nylon® plastic. When gluing them down to wood using super glue (the only glue that sticks to that type of plastic), you had to be very careful not to get any into the hinge pin cavity. If you do, the hinge immediately seizes up and has to be replaced. I foresaw that this issue would be a great challenge to my girls building their rockets and therefore to be avoided if at all possible. It is very tricky to keep the glue away from the hinge pin (been there... done that).

Another type of hinge that I've seen used is the music-wire variety, which was common in the Rose-a-roc style helicopters. Flis Kits currently sells a Rose-a-Roc kit at: www.fliskits.com/products/rocketkits/kit_detail/rosearoc.htm.

In Apogee Components' *Peak-of-Flight newsletter* is a plan for a 40mm diameter FAI style helicopter using bent music wire (see Figure 3). It was submitted by British flyer, Stuart Lodge (Peak-of-Flight Newsletters #83 and #84 –

June 14, 2002 and June 28, 2002 which can be downloaded at: www.ApogeeRockets.com/Education/Downloads/Newsletter83.pdf and www.ApogeeRockets.com/Education/Downloads/Newsletter84.pdf

The pros of hinges made from music-wire are that you can find music-wire in any hobby shop, and they are cheaper than the nylon hinges. It can also be formed to fit any shape rocket.

The con of music-wire hinges is they are very hard to bend accurately. And if you figure there are multiple hinges on each model, it is likely that the rocket will be unbalanced when flown.

They are also hard to attach to the rocket because they have to be anchored into the wood with staple-like fasteners (also made from music wire). With all the disadvantages of music-wire hinges, I felt that this style of pivot was even harder to deal with than nylon hinges, and would be too complex for children in A-division to assemble.

The final style of hub that I was familiar with was the molded resin hubs that I created in the mid 1990's for Apogee Components. The company used to sell a kit called the *Micro Whirl-A-Tron* that was a similar to the Rose-A-Roc, but the hub was molded from Urethane resin (see Figure 4). The advantage of these hubs was that all the critical

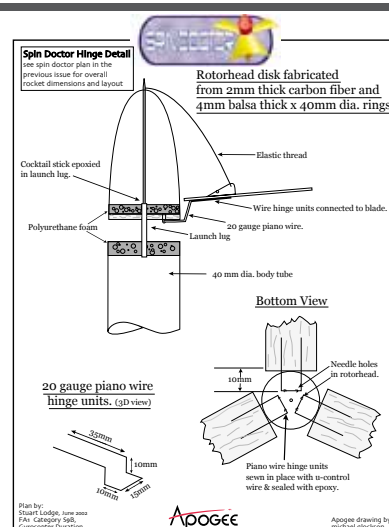


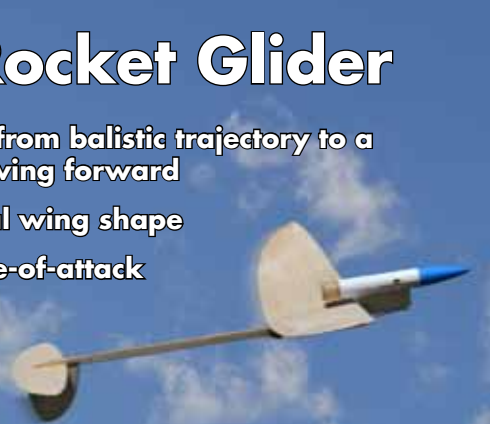
Figure 3: The Spin Doctor by Stuart Lodge.

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Development of a New Rotor Hub



Figure 4: The Micro Whirl-A-Tron kit used a urethane hub that was molded using silicone rubber molds.

angles needed to insure rotation were built into the hubs.

However, the hubs were brittle and not very strong. They usually broke when the model landed on the ground. They also suffered from the same situation as the nylon hinges, in that if you got glue on the hinge pin, they would seize up and become non-functional. They were also very difficult to mold and took a lot of post-production processing of trimming off excess resin before they were ready to go out to customers. I recall the reject rate was approximately 50 percent, so they were very expensive to produce. It was around the year 2000 that I stopped producing the hubs for Apogee Components.

Since I wasn't too involved in FAI flying, for the next



Figure 5 & 6: Photos of hubs used at the Internats fly-offs in the summer of 2011.

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Development of a New Rotor Hub

10 years, I didn't keep up with the development of hubs for internally carried rotor blades. In 2011, at NARAM-53 in Cincinnati, Ohio, I was able to watch some of the fly-offs for the 2012 US SpaceModeling team. I happened to watch some of the S9A (A-engine Gyrocopter) flights. I was amazed at how lightweight the models were, and how well they flew. So when possible, I took pictures of the models, and in particular, the hubs (see Figures 5 and 6).

What I found that had changed significantly since my last foray into hub design, was that the blades were no longer flat planks of wood, but were curved. The advantage of this was that a bigger, yet lighter weight blade could be carried inside the rocket, and that the spin was created as a byproduct of the planform shape of the rotor.

It was really an ingenious way to make an efficient helicopter model, and while I don't know who the inventor was, I think that most people attribute the development to Keith Vinyard.

I wrote an article on how to make these styles of curved blades in July 2, 2013 issue of the *Peak-of-Flight Newsletter* (www.ApogeeRockets.com/Education/Downloads/Newsletter342.pdf).

While the blades were radically different, the hubs had changed only a little. They were still generally a flat disk to which the hinges were attached. Basically, there were two changes. One was that they were made from thinner layers of wood so that they weighed less. Second, the nylon hinge flap was sandwiched between the layers (see Figure 7). This secures the flap of the plastic hinge better, and it can't accidentally debond and come off the hub. This can be a significant issue with the nylon plastic flaps, because they are slick and the glue doesn't stick well.

Since the blade's surface was curved, and the nylon

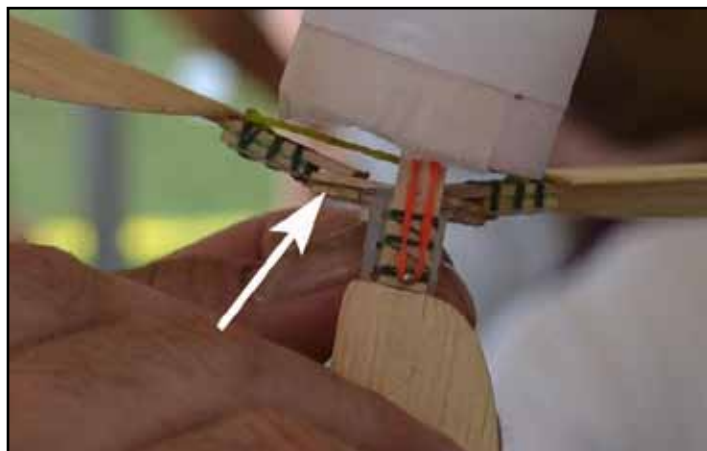


Figure 7: Here the nylon hinge flap is sandwiched between two pieces of balsa wood to make the hub.

hinges require a flat surface for attachment, what the modelers did was to first bond the blades to a square post, and then bond that post to the nylon hinge.

This was effective, because the post could extend across both flaps of the nylon hinge, even though it was only glued to one flap. The extra projection could be used to create a dihedral stop as the blade was deployed. I really liked this adaptation, because it did solve the dihedral problem without having to resort to limit-strings that were attached between the central shaft of the rocket and the bottom of the blades as shown in Figure 8.

Additional images for the current state-of-the-art helicopter hubs are available at:

<https://sites.google.com/site/xfaispacemodeling/wsmc-events/s9---gyrocopter-duration>

But there was one problem with using the post; the surface area that contacted with the nylon flap was significantly reduced. This would make it easier for the post to

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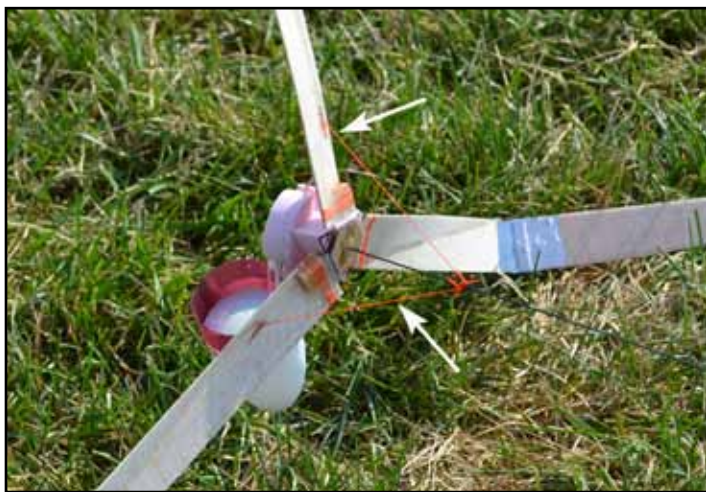


Figure 8: Limit strings that are attached to the undersides of the blades prevent the blades from rotating too far. In effect, this sets the dihedral angle of the blades when in the deployed position.

debond and the whole blade would come off the model. The solution, as can be seen in the photo on the previous page, was to use string to tie the post to the flap. The hinge flap contains holes, so these became convenient for tying on the wooden posts.

Pros and Cons of the Previous State-of-the-Art Helicopter Hubs

What I liked best about the designs described previ-

ously, is that the square post that is used to attach the blade to the hinge flap works well. It is the key mechanism that is required when using a blade that has a curved underside. And the post allows the blades to stop at the right dihedral angle.

I took to building a hub just like the ones I saw in the pictures. And almost immediately, I discovered how complex they really were. There are a lot of parts that go into a hub, each that had to be carefully shaped prior to assembly.

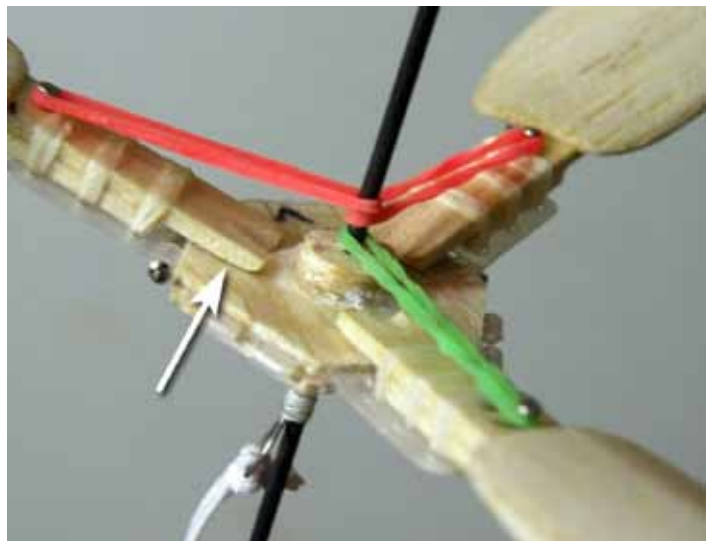


Figure 9: The post sets the dihedral angle of the rotor blade. But the hub has many parts, lots of glue joints, and a complex assembly sequence.

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Development of a New Rotor Hub

Because of the abundance of parts, there were a lot of glue joints that had to be made. In the end, there were a lot of chances for construction errors to creep into the system. That means that they would not be very precise, and they would be unbalanced.

Incrementally Improving the Rotor Hub

In June 2013, Dan Kafun, a business acquaintance of mine, was looking for some extra income for his machine shop (Rocket Industries). He suggested that I lease time on the laser cutter that he owned. I took him up on the offer, and soon was cutting centering rings for the kits at Apogee Components. This was about the same time I was trying to tackle the redesign of the rotor hub, so it wasn't very long before I was cutting out parts specifically for the hub.

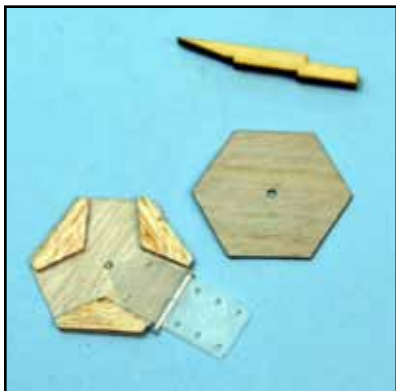


Figure 10: The central disk was composed of a sandwich of 1/64" thick plywood. Triangular corner pieces cut from balsa aligned the hinges perfectly. The post (top right) was cut in a lightning-bolt shape to fit over the plastic hinge flap better.

At first, I was just using the laser to cut parts for the existing design that other people were building. It saved a lot of time, and sped up the construction for my daughters. The parts were more precise and needed less shaping to fit together properly.

One thing I did right away was to put cut-outs for the hinge flap into the central disk. (where the hinge flap

was attached to the body of the rocket). This was important, because it ensured the hinges were perfectly perpendicular to the central shaft, so the blades would stick straight out, and be exactly 120 degrees around the central shaft. This was done by cutting little triangular pieces out of balsa wood that created the cut-out for the hinge to drop into (see Figure 10).

The disk, being a combination of balsa wood and 1/64 inch thick plywood, was really lightweight and also strong.

The other change I made was to cut out the wooden post from 1/4" thick plywood instead of using a solid piece of spruce wood that previous designs had used. The reason was that I wanted to cut the dihedral angle precisely into the part, instead of shaping it later with a sanding block. It is the little lightning-bolt shaped piece in Figure 10 and also shown in operation in Figure 11.

Using the laser cutter, I also cut a small pocket into the underside of the post for the hinge flap to sit into. This little pocket allowed more surface area of the post to contact the central disk when the blades rotated upwards during deployment. This reduced the amount of lateral (side-to-side) wobble that the blade would experience, because there was more surface friction, since more of the post was in contact with the disk. This wobble is inherent in plastic

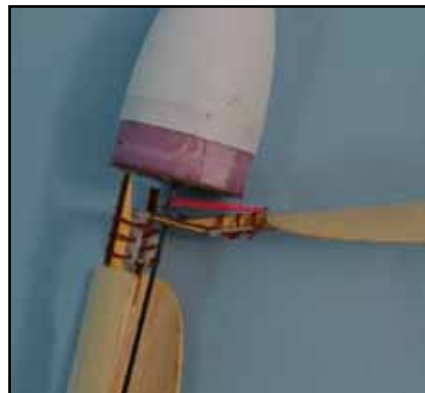


Figure 11: The laser-cut post set the dihedral angle much better, and was more consistent from blade to blade.

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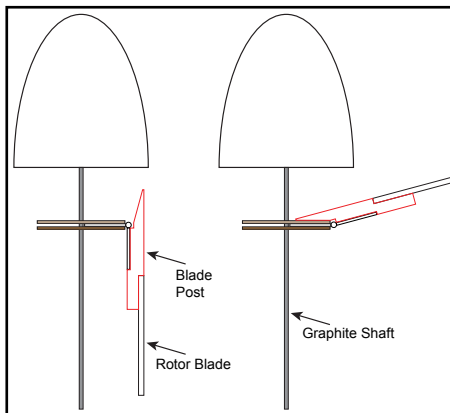


Figure 12: The original drawing used to figure out how big and what shape to make the blade post.

hinges, because there is a little bit of slop in the hinge pin as it passes through the hinge flaps. So I felt I solved the problem of keeping the blades deployed perpendicular to the central shaft.

The first hub I assembled with these small changes was a big improvement over the industry

standard design. They assembled easier because the parts were precision-cut using the laser cutter. And that precision translated into a more balanced part that worked well when we flew the completed helicopter model. My daughters were able to assemble it with the only help being the attachment of the posts to the nylon hinge (and wrapping the thread to hold them down securely).

It dawned on me that I could shave a little weight on the plywood posts that were mounted to the blades by reducing the thickness from 1/4" to 1/8". The 1/4" thick was overkill from a strength standpoint. Even the 1/8" thick plywood posts were practically indestructible, and they actually fit better to the underside of the curved rotor blades.

This new laser-cut design worked really well, and this is what my daughters used when they competed for a slot on the US team at the tryouts held in Aurora, Ohio in the summer of 2013. My older daughter, Allison Van Milligan, made the team with this model. I was quite pleased, because we had only two months to prepare for the contest.

Further Improvements to the Hub

After we returned from the fly-offs, and conferring with other team members, I described some of the problems we still had building the hub. The most significant was aligning the rotor blades to the wooden posts on the hub.

Keith Vinyard sent me some photographs of the elaborate jig that he made for this purpose. It consisted of a fiberglass trough that the blade sat on while the wooden post was glued on.

I was worried that this would be too complex a procedure for my girls to do, so I looked for a different solution

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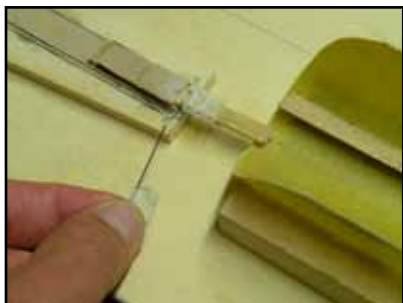
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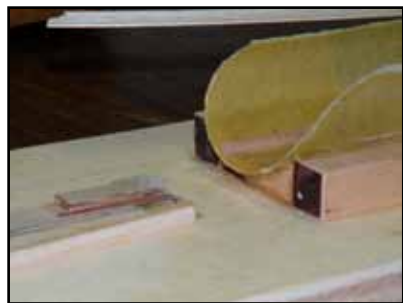
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Development of a New Rotor Hub



Figures 13, 14 & 15: A fixture for aligning the blade post (also called blade arm) to the rotor blades. The trough holds the blades aligned with the hinge while the post is glued on. This assures that everything is straight.



to the blade alignment issue.

Then I remembered the slots that I had cut into the blades of the Estes Skywinder kit that I designed in the early 1990's. The purpose of the slots were to align the blades to the posts. It would only require reshaping the post to provide a tab on the top so that it could pass through the slot in the blade.



Since that Skywinder idea was in my mind at the time, I remembered that the back edge of the tab could be used as the hook to hold the rubber band. This meant that I didn't even need to put music-wire hooks into the posts that were required on previous designs.

Getting Rid of the Nylon Hinge



Figures 16 & 17: Cutting a couple of slots into the rotor blade and putting a tab on the wooden post allows the blade to align perfectly with the post without using an assembly fixture. Notice that I also cut some "lightening holes" into the plywood post to remove some extra mass.

While I felt the hub as a great improvement over existing designs, I still felt it had some drawbacks. The big one was the nylon hinge. I was talking with Dan Kafun about this issue, and he showed me a helicopter he used in a previous Regional NAR contest. It was a Rota-Roc style helicopter with externally mounted blades, but he used his laser cutter to make custom hinges for the model. He wanted to pre-set the angle-of-attack into the flat blades, so he needed the hinge line at an angle to the tube. So that it wasn't perpendicular to the length of the rocket, like a normal hinge might be applied.

To accomplish this, he made the hinge from plywood with a hinge-pin made from 1/16" diameter brass tube. The



Figure 18: Blade attachment for the Estes Skywinder kit from the 1990's. The projecting tab through the clear plastic blade was used as a rubber band hook to pull open the blade.

Continued on page 10

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Development of a New Rotor Hub



Figure 19: A hub design by John Boren that used a metal post for the pivot point of the rotor blade.

use of the 1/16" diameter tube as the hinge pin gave me the idea that the nylon hinge could be removed.

The big breakthrough was realizing that the pivot point could pass through the wooden post.

At this point, I had to design the post so that it had a hole in it for the 1/16" diameter tube. And at the same time, I had to figure out how to hold the tube to the central hub disk.

I really liked my lightning bolt shaped blade posts (Figures 10 - 12), so I started with that design and begun modifying it to put the pivot point in the middle of the post.

After working through the mechanics of how the pivot would operate, and how it had to engage into the slot on the balsa wood blade, the actual shape of the wood post changed significantly. Figure 20 shows the newest shape for the blade post.

The pivot point was a challenging issue though. My thinking was: I could put the aluminum tube through the blade post, but how would it be secured to the hub disk?

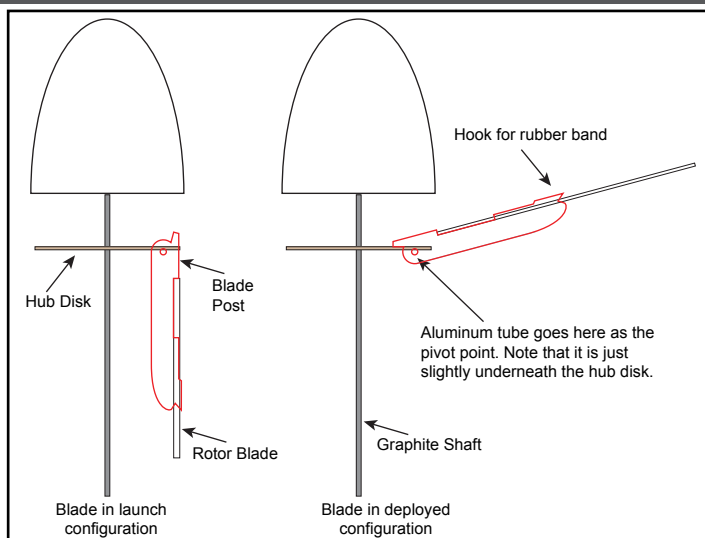


Figure 20: The shape of the blade post changed once the hinge pin passed through its middle.

Since the tube was cylindrical, it would roll right off the hub disk, and wouldn't hold its position accurately.

It came to me that I could cut some rectangles in the disk that were slightly smaller than the diameter of the tube, so that the tube wouldn't roll out of position while it was being glued down. These slots could be positioned accurately so that the blades would be exactly 120° apart.

I also realized that a slot as wide as the post would need to radiate out from the center of the disk. This was needed because the blade post had to pass through the middle of the disk as it swung upward. While this slot would decrease the strength of the disk, it had the advantage of keeping the post from wobbling from side to side. In effect, it allows the post to be made from thinner material. So I reduced the post from 1/8" wide plywood to just 1/32" thick.

Things sure seemed to be coming together very nicely.

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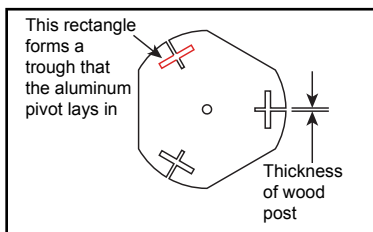


Figure 21: The central hub disk. It is made from a single piece of thin plywood.

Everything just felt like it was falling together in a very fortuitous way. I know I'm not a genius, so I think that when you borrow good ideas from other people and apply them in a new way, sometimes things work out really well.

The final design is shown in Figure 22.

Building the new design was a breeze. It was so easy to do, that I only had to show my girls just once how to assemble the hub, and they were off on their own – pushing me out of the way. That is the greatest feeling a father can have: when his child can demonstrate competence while they seek independence.

There were a few minor tweaks to the dimensions of the slots and the location of the pivot point after the first design. I was designing for a 40mm diameter rocket, so I moved the rectangle for the pivot pin to optimize for the fit of the blades into the tube. Initially, they were too far away from the central shaft of the hub, and that caused the blades to touch the sides of the tube. But moving them inward was a simple adjustment.

The original design was a fixed hub that was glued directly to the central graphite shaft. Because of this, the

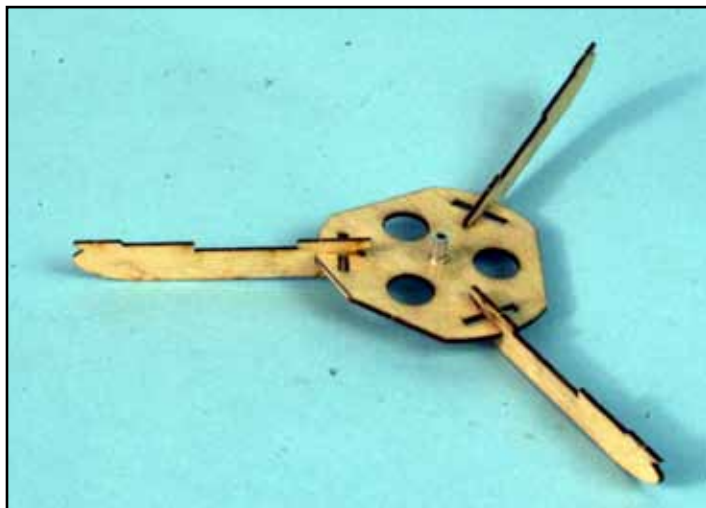


Figure 22: The finished 40mm diameter hub consists of just eight parts and weighs 1.5 grams. Note that extra holes were cut in the disk to remove more weight.

entire model spun during descent. The bad result was that the shock cord that held the hub to the body tube twisted up significantly. The blades still spun fine, but it was a chore to prep for the next flight because the shock cord had to be untwisted.

Making a free-spinning hub was a very simple modification. The size of the central hole in the disk was increased. This allowed it to be glued to an aluminum tube that fit over the central graphite shaft (see Figure 22). The tube and the entire hub could then spin independently of

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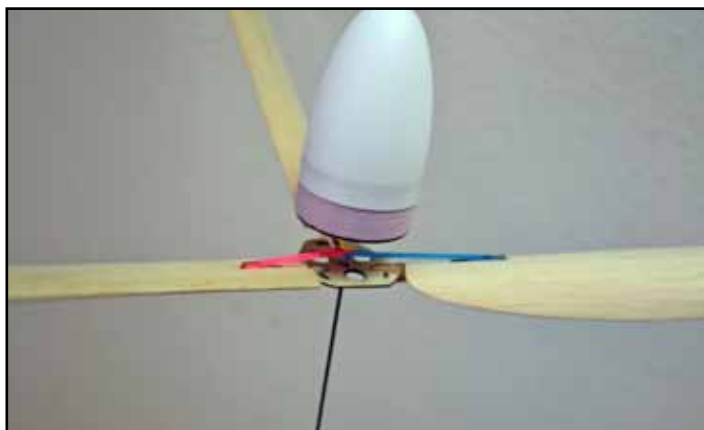


Figure 23: The completed model (Rotary Revolution kit). This is the top side of the central hub disk.

the graphite shaft and the rest of the model.

To be honest, the shock cord still gets twisted during the flight, because there is still a little friction in the system. That friction means the graphite shaft spins with the hub, although not at the same high-rotation rate. But the twisting is not as severe, and it is quicker to reprep the rocket for its next flight.

The only other tweak I've since made to the new hub is to put some lightening holes in the posts and the central disk. The only purpose of this was to decrease weight, which has been minimized to only 1.5 grams. The hub and the blades are so lightweight, that I finally reduced the length of the shock cord that connects the graphite shaft to

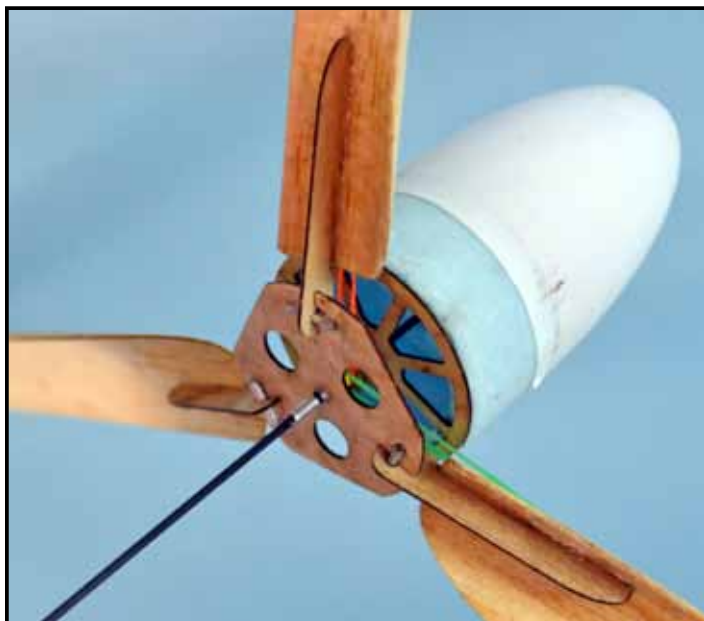


Figure 24: The underside view of the central hub disk.

the tube. Typically the shock cord needs to be long enough to allow the nose section to slow down before the line becomes taut. But because the hub and blades have such a low inertia, they slow down quickly after being ejected from the model. You could think of it as ejecting lightweight feathers from the tube.

Shortening the shock cord is a good thing in this case. It reduces the chances of the blades being fouled in the shock cord as the rocket tumbles at ejection. Again, the de-

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Development of a New Rotor Hub



Figure 25: Examples of the laser-cut parts for an ungraded helicopter hub. The wheel-looking disks hold the nose cone to the graphite shaft.

The next size I attempted was for a 24mm diameter rocket. The reason was that the events list for NARAM-56 had been released, and I wanted to get a jump on a competitive model for C-engine Helicopter Duration.

Since I now knew the steps to create this design, the hub was reduced in size fairly easily. There was still plenty of room inside the rocket for the hub. The blades, however, were a tighter squeeze. The rotor blade shape couldn't simply be scaled down. The reason is the thickness of the wood prevented it from sliding into the body tube. It finally had to have a new rotor blade shape for it to fit. The rotor blades had to be made skinnier (higher aspect ratio).

But this new hub worked fantastic. The first time the hub was used in competition, my daughter Ashley set a new C-engine helicopter duration record of 310 seconds (over 5 minutes of hang time).

Next, I tried to design a hub that would allow an 18mm diameter rocket to carry internal helicopter rotor blades. This was a harder challenge, because there is so little room

sign of the hub affects the entire model and makes it more reliable.

Other Helicopter Sizes Using This New Hub

Once I had the 40mm helicopter design completed, I asked myself if this design could be translated to other size rockets. And the answer was "yes," it could.

in the rocket. I was able to get the hub in the rocket, but during the first flight test, the blades broke right at ejection. It probably is possible to make a internal rotor helicopter that small, but I haven't had time to work the problem further.

The final project was to go back to the 40mm hub, and to sell it in kit form for people that want something competitive for the FAI style gyrocopter event. The result is the *Rotary Revolution* kit. I believe that this hub will instantly level the playing field for the novice because it is easy to assemble, and is as light weight as anything a seasoned veteran might make.

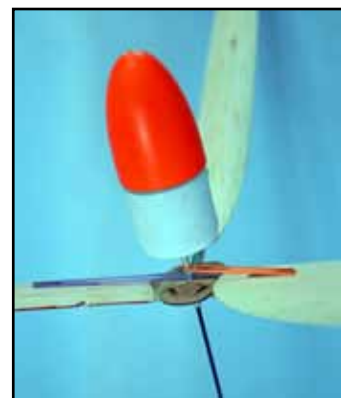


Figure 26: The hub from Apogee's Gyro Chaser kit. It set one record of over 5 minutes in C-engine Helicopter Duration.

About The Author:

Tim Van Milligan (a.k.a. "Mr. Rocket") is a real rocket scientist who likes helping out other rocketeers. Before he started writing articles and books about rocketry, he worked on the Delta II rocket that launched satellites into orbit. He has a B.S. in Aeronautical Engineering from Embry-Riddle Aeronautical University in Daytona Beach, Florida, and has worked toward a 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 the curator of the rocketry education web site: <http://www.apogeerockets.com/education/>. He is also the author of the books: "Model Rocket Design and Construction," "69 Simple Science Fair Projects with Model Rockets: Aeronautics" and publisher of a FREE e-zine newsletter about model rockets.

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