

etry Festival in the odd numbered years. Last July the 2019 flyoff was held in Muncie, Indiana. Since the FAI events seldom change we are given the challenge to continually work to perfect a design over a

long period of time. For the S9 Helicopter Duration event the basic rules and motor class has not changed in 15 years. This article is about one such design, which was primarily made to be a simple approach to this complicated event. Its helicopter recovery rotor unit fits in the same 40 mm diameter FAI style bodies used for the S3 parachute and S6 streamer duration events. Building the bodies has been covered in other *Sport Rocketry* articles, and links to detailed building

instructions and a video can be found on the NAR website's Spacemodeling page.

The Model's History

Preparing for the 2007 U.S. team selection flyoff my choice of models to fly in S9 was limited. At that time the state-of-the-art design was George Gassaway's "flop-rotor" which has long thin flat balsa blades that fold in the middle. For me, these were a lot of work to build, prep, and deploy reliably. I knew I needed a simpler design so I tried something I saw the European fliers doing and I managed to put six single rotor blades in a 40mm tube! They had to be thin, curled, and arranged to unfold like the petals of a flower. Using only three blades still proved to be best, but this curled blade's shape improved their structural strength which allowed them to be made from thin balsa which needed no airfoils sanded in them. Wow, a shortcut in building time, better reliability, and a lot of performance from less material! This could

Wanna Fly FAI?

Give this S9 a Whirl!

by Keith "Herby" Vinyard
NAR 24568

Photo 1.
Keith holding an original version
of the S9 Gyrocopter design in 2008.

Photo by George Gassaway.

Photo 2 (Insert). S9 model in flight.

Introduction

The rocketeers that make up the U.S. Spacemodeling team love to fly the FAI events. FAI is the sanctioning body for international rocket competitions and hosts its World Spacemodeling Championships (WSMC) in the summer of the even numbered years. The NAR hosts the U.S. team selection flyoff as part of the Annual Rock-

be a project worth pursuing, so fast forward 11 years to July 2018. At the WSMC held in Poland, the entire U.S. Junior and Senior teams flew models with rotors constructed this way. Our best finish was from former NAR national contest board chairman Steve Humphrey who placed 4th in the flyoff with nine other competitors, just missing being on the medal stand. And at the recent 2019 U.S. team selection flyoff, every S9 entry was made this way.

By the 2010 WSMC, the blade's shape had become very close to what it still is today. The widest portion with the most pitch is near the hub and drives the rotation. The width gradually tapers to the tips, which are level with no pitch. In the early years the rotor unit was pushed out of the body with an ejection plug and the shock cord was mounted internal. The bodies were made with a steep 8-degree tapered tailcone which allowed for 11.25" long blades to fit in a minimum length body, by FAI rules.

At the 2011 U.S. team flyoff, the model's popularity was growing. About half of

Photo 4.
Set of dry S9 formed blades
(with some more soaking in ammonia
solution in background).



Photo 3.
Wet S9 blades taped to
mandrel (top) and wrapped with
cloth strips (bottom).

the entries had curled blades. It was at that meet when Katherine Humphrey (Steve's daughter) flew a model with a long nose cone shoulder that acted as a piston to pull the rotor unit out of the body when ejection gases pressurized the tube. This solved the problem of breaking the fragile blades at ejection, and quickly led to using the normal S3/S6 body having a 5 degree

tapered tailcone with a more aerodynamic shape. Now, longer 13.5" blades that extend down to the motor tube fit in the minimum length body. These changes made for higher boosts and longer descent times.

At the 2012 WSMC, half of the U.S. competitors flew models with these innovations, and another, mounting the shock cord externally. This system came about as a method of deploying the antennae of a Walston tracking transmitter from where it was coiled up in the body during boost.

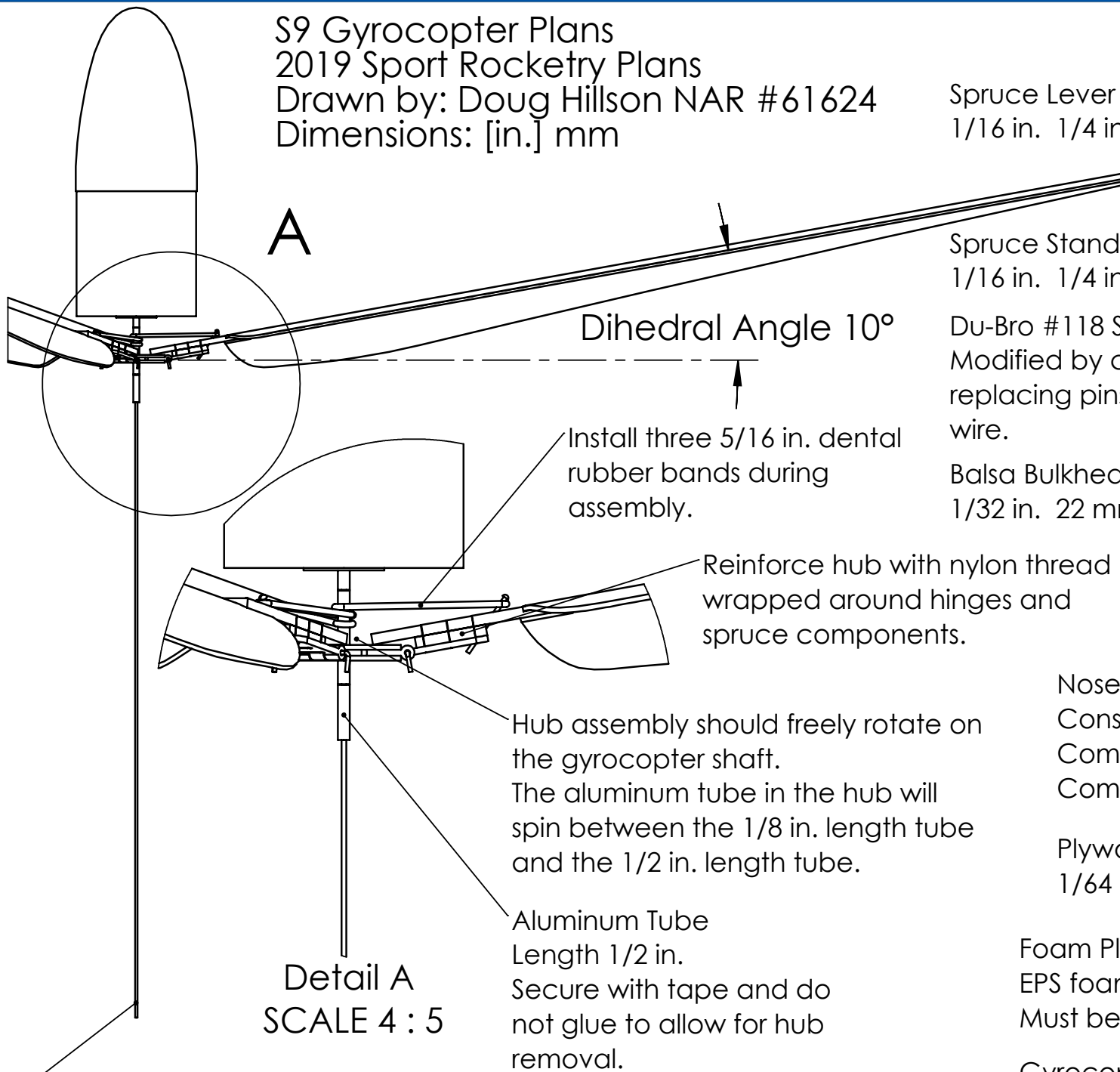
Tim VanMilligan of Apogee Components published some very good articles in his *Peak of Flight* newsletter about making the curled blades, and on developing a hub with laser cut parts that are easier for young modelers to assemble. That hub is used in his Rotary Revolution FAI S9 competition kit. Tim and his daughters continued to experiment with blade design for the basis of several NARAM Research and Development competition projects.

Numerous other R&D projects about the design have been made, and it was even scaled up and successfully flown by Alan Stokker in the G Helicopter Duration event at NARAM-59.

Undoubtedly, the design's highest honor was taken at the 2014 WSMC in Bulgaria when Senior S9 team member Trip Barber took home an individual bronze medal. Doug Hillson has done a wonderful job drafting Trip's model. Those plans can

S9 Gyrocopter Plans
 2019 Sport Rocketry Plans
 Drawn by: Doug Hillson NAR #61624
 Dimensions: [in.] mm

Spruce Lever
 1/16 in. 1/4 in.



Spruce Stand
 1/16 in. 1/4 in.

Du-Bro #118 S
 Modified by a
 replacing pin
 wire.

Balsa Bulkhead
 1/32 in. 22 mm

Nose
 Cons
 Com
 Com

Plywa
 1/64

Foam PL
 EPS foar
 Must be

Gyrocopter
 nose ass
 and bot
 cone or

Aluminu
 Length 1

Gyrocopter Shaft

0.06 in. nominal diameter carbon fiber, length is 12 in.

Some fliers use 0.04 in. nominal diameter.

Wrap shock cord around carbon fiber and glue with cyanoacrylate.

Some fliers will extend length to past blade tip and install shock cord mount.

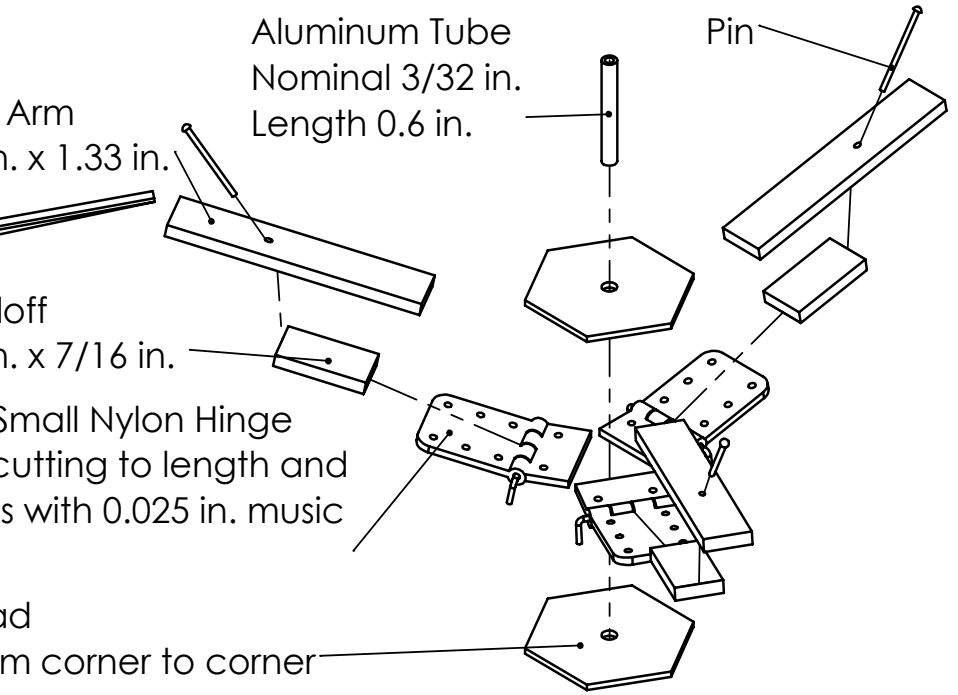
Detail A
 SCALE 4 : 5

Aluminum Tube

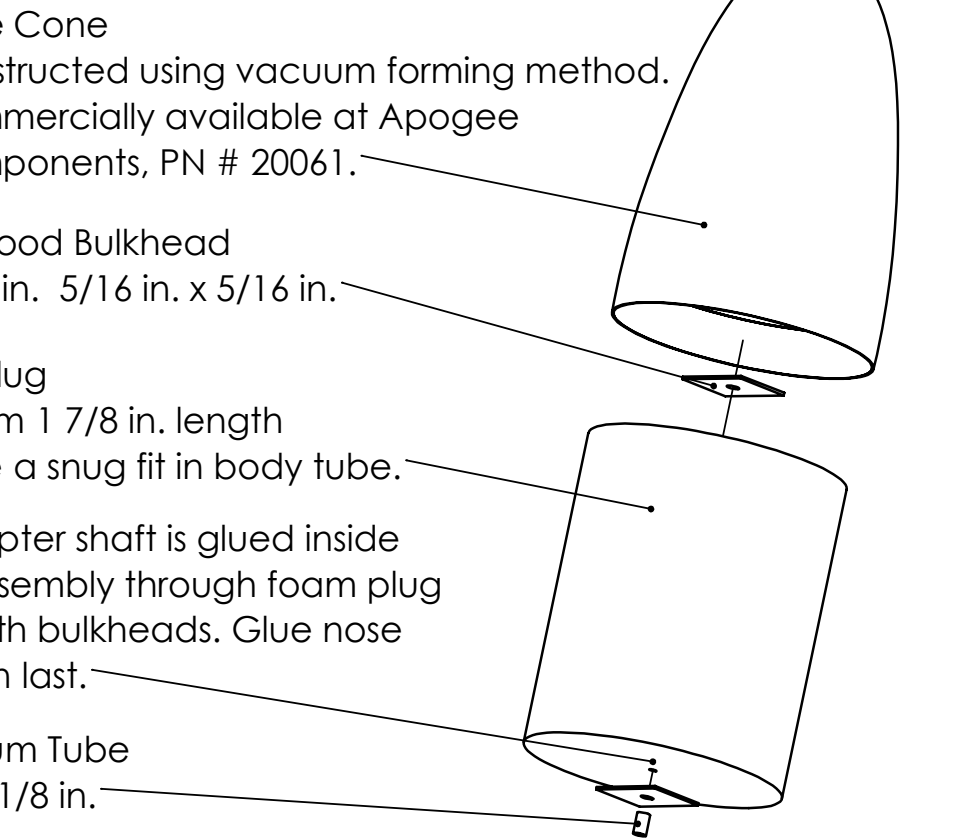
Length 1/2 in.

Secure with tape and do not glue to allow for hub removal.

View of Complete Gyrocopter
 SCALE 2 : 5



Hub Assembly Exploded View
SCALE 4 : 5



Nose Cone Assembly Exploded View
SCALE 2 : 3

be found at the NAR/FAI website.

It has been a true pleasure watching this un-named design evolve from its beginning. Without the interest from many of my NAR friends and U.S. teammates who like to experiment and think outside the box it would not have developed into what it is today. I eagerly wait seeing future innovations and improvements!

Making the Blades

The trademark of this design is the cambered blade shape and high speed at which they spin. The blades are made from 1/32" C grain balsa with the straight trailing edge parallel with the grain. Soak them in a 20% ammonia to water solution until soft enough to form without cracking. Ammonia is used to solubilize plant lignin in many bio-chemical extracting processes, and has been used for many years to assist in shaping wood. My original blades were shaped on a 40mm FAI mandrel but now I use similar sized PVC and galvanized metal pipe since the blades are now longer than my original mandrel. I can also make more blades at one time. Another nice thing about using hollow pipe is that you can place a rope through its center and suspend it at a comfortable working height, which makes the wrapping process easier.

Mark the mandrel or pipe's centerline in two or three places around it with a marker to have a guide for positioning the blades. Use masking tape to secure the ends of the wetted blades in place. I use strips of bedsheet about 3" wide to wrap the blades tightly to the mandrel. Tape one end of the cloth strip near one end of the mandrel and start the wrap on a 45° angle (see Photo 3). Secure the other end of the wrap with tape and allow sufficient time for the blades to completely dry before removing. Marks in the outer surface of the balsa will be left from the wraps but will sand out with fine grit sandpaper. For sanding the upper side of the blades, support the blade on a piece of PVC pipe. Also, round all the edges. My blades are 13.5" long and 1.75" wide. At 2.125" from the root end they steadily taper to the tip where they are 3/4" wide. See the dry blades in Photo 4.

Making the Hub

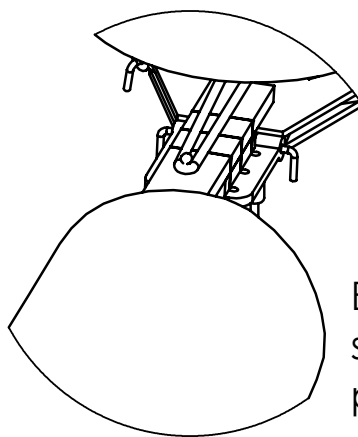
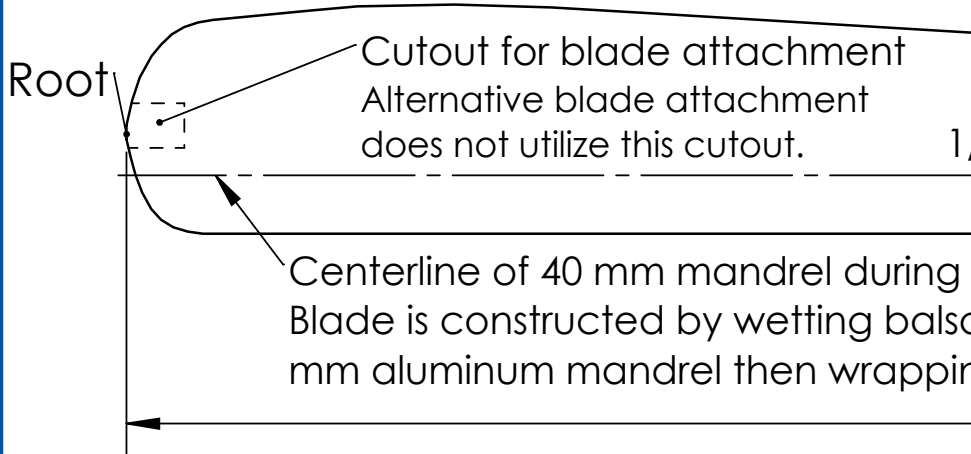
The "Herby Hub," as Steve Humphrey coined it, uses spruce or basswood lever

arms (blade arms) as extensions of the balsa blades, which also act as the dihedral stop when deployed. Commercially purchased #118 DU-BRO small nylon model airplane hinges are used to link the blade arms to the hub core. 0.625" dental rubber bands put around the hub's aluminum tube spindle are stretched out and attached around pins on the top of the blade arms to deploy the blades. A spacer between the lever arm and the hinge creates the correct dihedral when the blades are deployed into position.

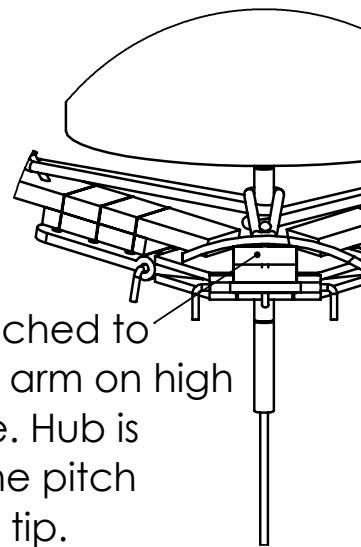
Sort the hinges so the knuckles are all arranged the same way. This way the blades (also all made in the same direction) are interchangeable. Trim the hinge half that will be mounted in the hub core, cutting the corners off so the three hinges will fit together on a balsa hub plate and have space in the center of the plate for mounting the aluminum tube spindle. Use a drop of medium or thick CA to glue the hinges on the hub plate. Glue the top plate on with the grain running in a different direction as the bottom plate. Carefully add thin cyanoacrylate glue (CA) to the top and bottom surfaces of the hub plates as reinforcement, but don't let the thin CA get into the moving part of the hinge or you will have some extra work to free them up!

Photo 5 shows the hub jig that makes alignment easy. This jig uses one half of the hinge to align the other (trimmed) half of the hinge onto a hub plate. The photo shows a black tube underneath for placing the aluminum tube into for its perpendicular alignment in the hub's center. Photo 6 shows a hub being built on the jig. After the hub is complete, I use a Dremel cut-off wheel to grind off the flattened end of the hinge pins so they can be removed. Save them, these will be used as the pins in the blade arms that the rubber bands will be hooked on.

Consistency in building rotor units is a must. I strongly recommend using a jig for attaching the blade arms to the blades. The blade arm attachment jig in the full-page drawing is used in two steps. The first is to mark the cutout slot in the root end of the blades. The other end of the jig will align the blade arm in the cutout slot for gluing. This method attaches the blade arms close to the center of the blades' root ends, and when the unit is folded and placed in the 40mm body it easily fits without touching the tube walls except at the blade tips in the tailcone.



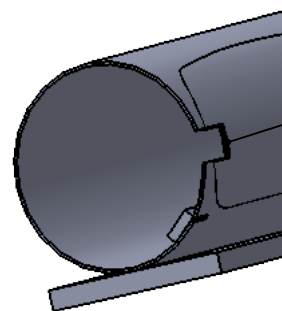
Blade is attached to spruce lever arm on high pressure side. Hub is parallel to the pitch angle of the tip.



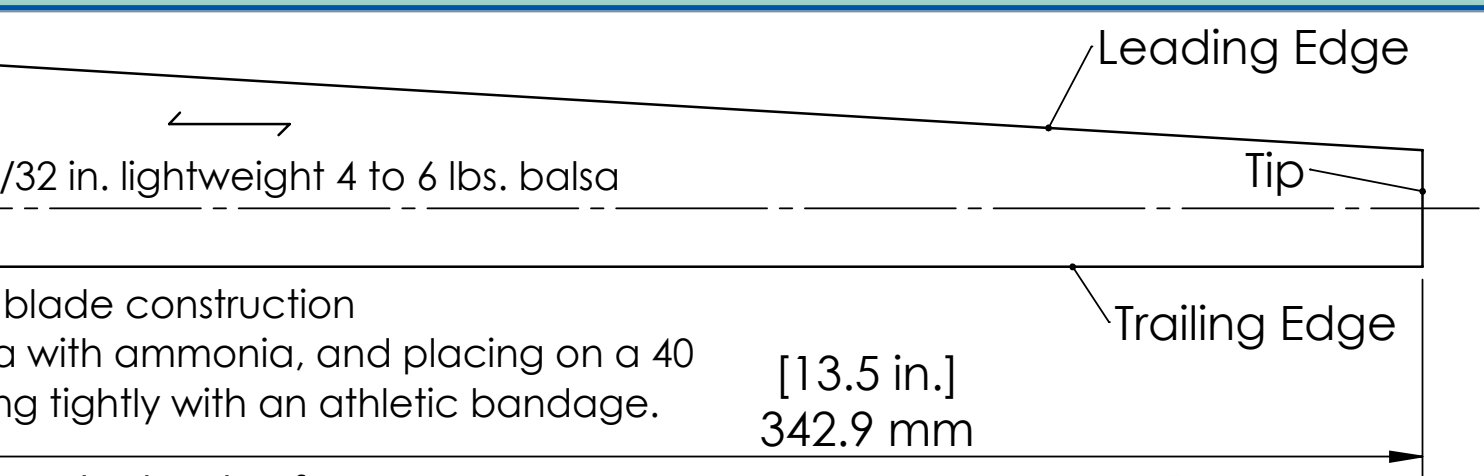
Alternative Blade Attachment View SCALE 1 : 1

The alternative blade attachment method is likely easier to construct, but will likely result in poorer airflow near the blade root. A jig is still recommended for this method.

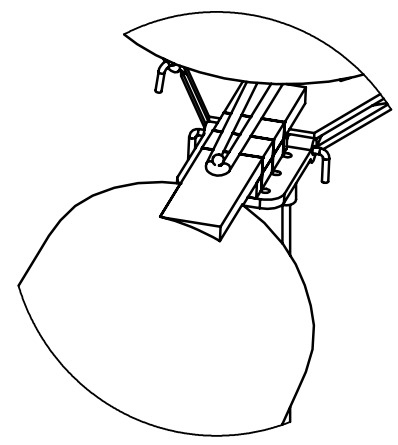
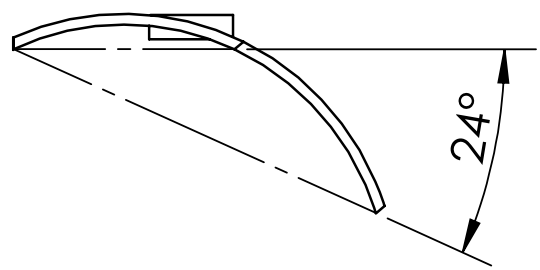
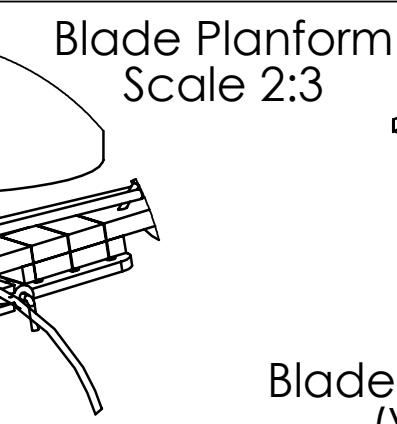
To use this attachment method, attach the blade at the blade tip's centerline.



Example Blade SCALE

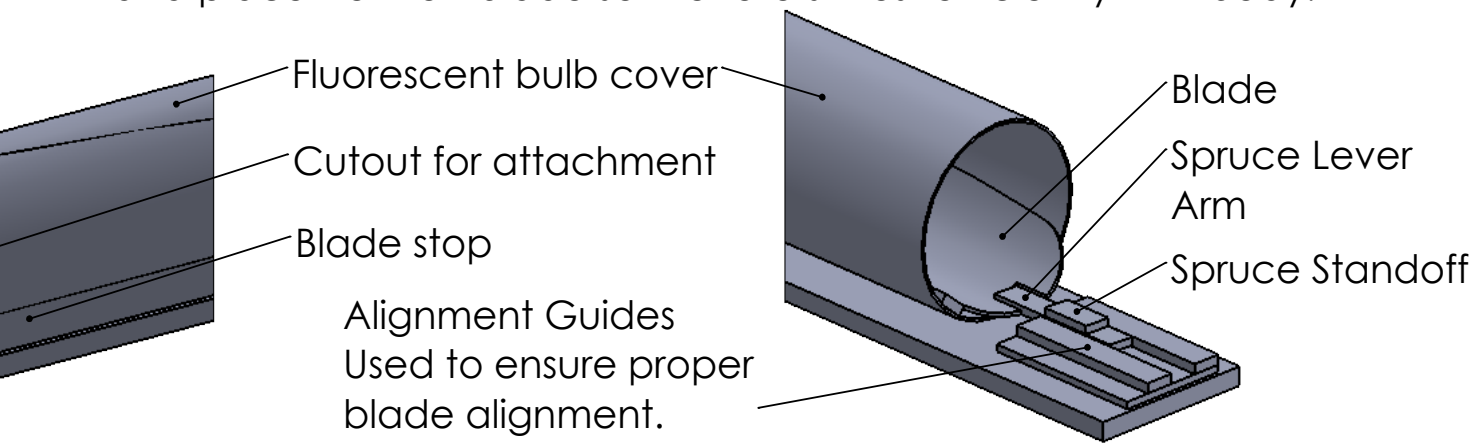


blade construction
 a with ammonia, and placing on a 40
 ng tightly with an athletic bandage.



Pitch angle at tip is 0° and at root is 24°. This pitch angle results from the geometry and construction of blade. The blade should be attached to the hub so that the hub is parallel to the pitch angle of the blade tip.

A jig is strongly recommended to achieve the correct attachment angle and placement on blade so the rotors most efficiently fit in body.



Jig for Cutout
SCALE 1:2

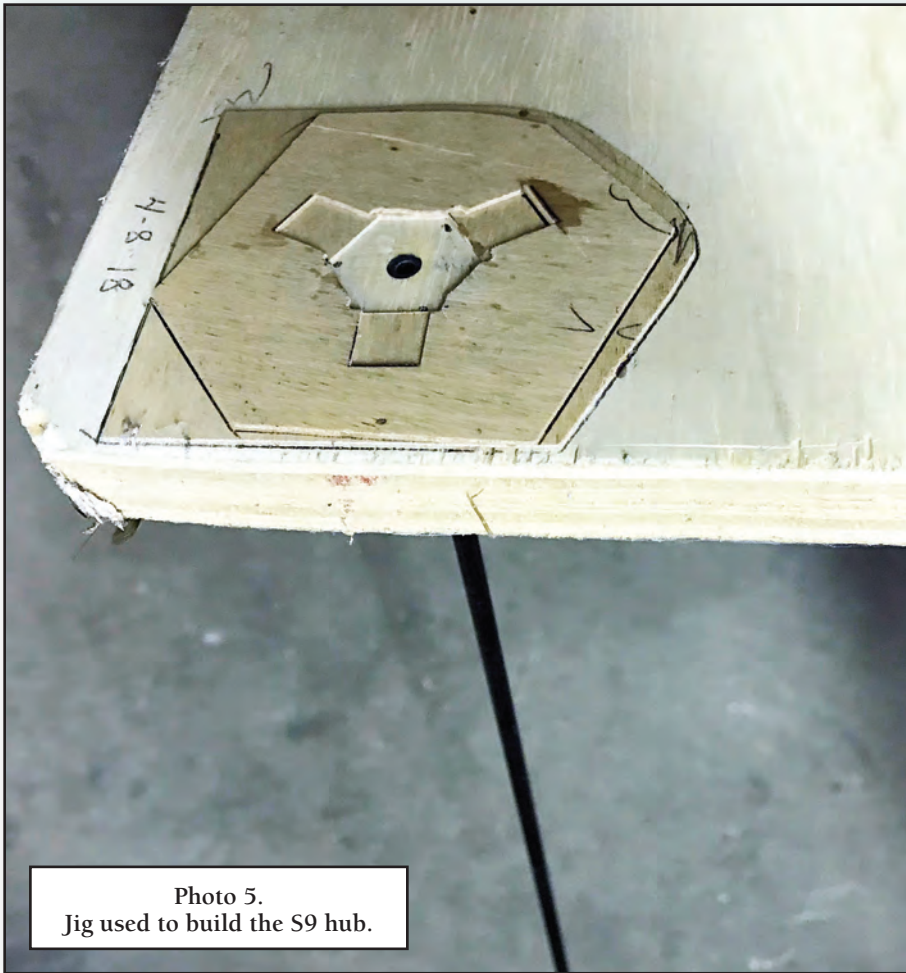


Photo 5.
Jig used to build the S9 hub.

the blade arm. Before attaching, make sure the hinge knuckles are oriented correctly to join the hinge halves on the hub. Use thin CA to reinforce the hinge/blade arm joint and thread.

Drill a small hole on a 15 degree angle through the top side of the blade arms and put the original hinge pins in the holes, leaving enough pin exposed to hook the rubber band on. Cut off any excess on the bottom side and use thin CA to secure in place. Join the hinges back together using .025 music wires as the replacements for the original pins, and bend the wire ends 90 degrees to secure them in place. Hook up the rubber bands and adjust the dihedral by sanding/filing off the ends of the blade arms where they meet the upper hub plate. If too much is removed, thick CA can be used to build it back up.

Making the Central Shaft Assembly

The backbone of the rotor unit is a 12" long x .06" (1.5mm) diameter carbon rod.

You can use the alternative blade attachment method as shown in the drawing where the blade arms are attached on the bottom of the blades and are centered in line with the center of the 3/4" wide blade tips. However, this method moves the blade arm attachment location toward the blade's trailing edge, and will require more room when the folded unit is placed in the body. Note that aligning the blade arm with the centerline of the 3/4" width of the blade's tip gives the tip zero pitch. If the arm is positioned closer to the trailing edge, the blade will have more negative incidence overall and will spin up fast, but lose lifting efficiency at the outer region of the rotor. If the arm is positioned further from the trailing edge, positive incidence at the tips will create more lift in the outer region, but will have a harder time initiating rotation after ejection, and if extreme, will stall the tips and not rotate.

With either blade arm attachment method, attach the hinge halves by wrapping thread through the holes in the hinges and around the blade arms. The distance between the holes in the hinges is conveniently very close to the width of the blade arms, which properly aligns the hinge on

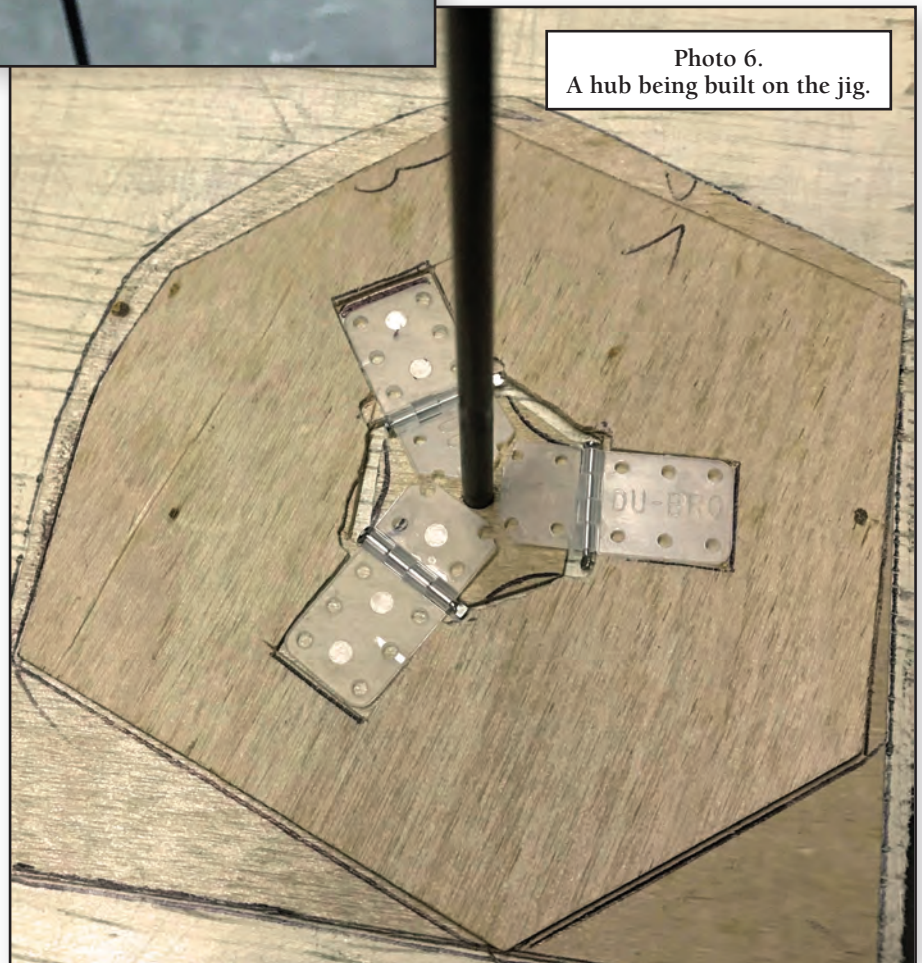


Photo 6.
A hub being built on the jig.

One end is glued into a 1.875" long foam ejection plug that acts as the nose cone shoulder and ejection piston.

The ejection plugs are cut out of sheet foam using a plug "cutting" tool. You will need to make this tool by wrapping heavy, epoxy saturated fiberglass cloth around your 40 mm mandrel, similar to the way you make an FAI body. An article on making plugs may be found on the NAR website's Spacemodeling page.

EPS (expanded polystyrene) foam works perfect for making plugs. It is white, somewhat spongy, bead foam that weighs a mere 1/2 gram. Center the carbon rod through the plug, extending about 1/4" and through a small plywood plate. Wrap

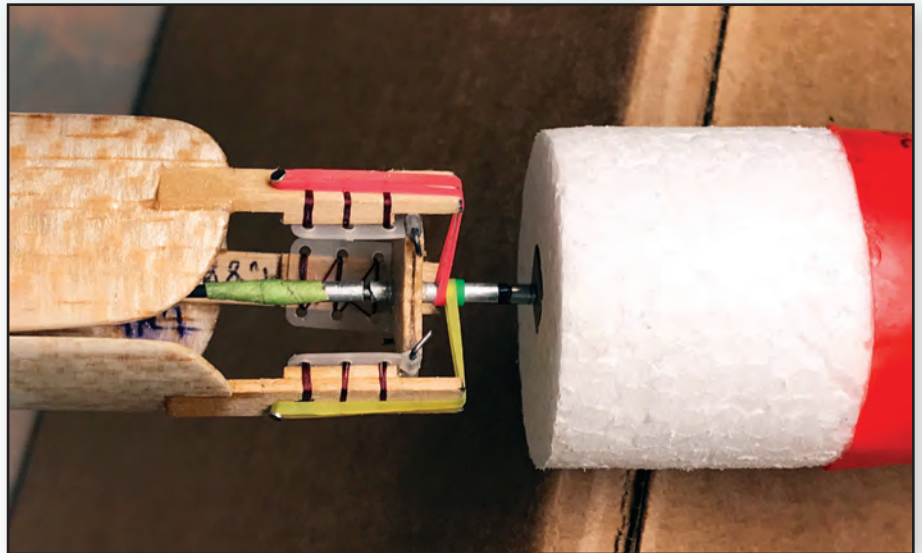


Photo 7.
Completed rotor core.

rubber bands will be wrapped around it and not be placed around the shim. Below the hub's aluminum spindle tube add another 1/2" long piece of aluminum tube and tape it to the carbon rod to hold the free-wheeling hub assembly in position. At the bottom end of the carbon rod attach a piece of 75 lb. braided Kevlar line about 43" long as the shock cord. Photos 7 and 8 show the completed rotor core.

Tuning the Rotor Unit

Once you have assembled the rotor unit and it is on the central shaft assembly with the rubber bands hooked up, you will need to tune the balance, pitch, and dihedral. Dihedral, or the angle that the deployed blades are at in relation to the central shaft, is the least critical of the three.

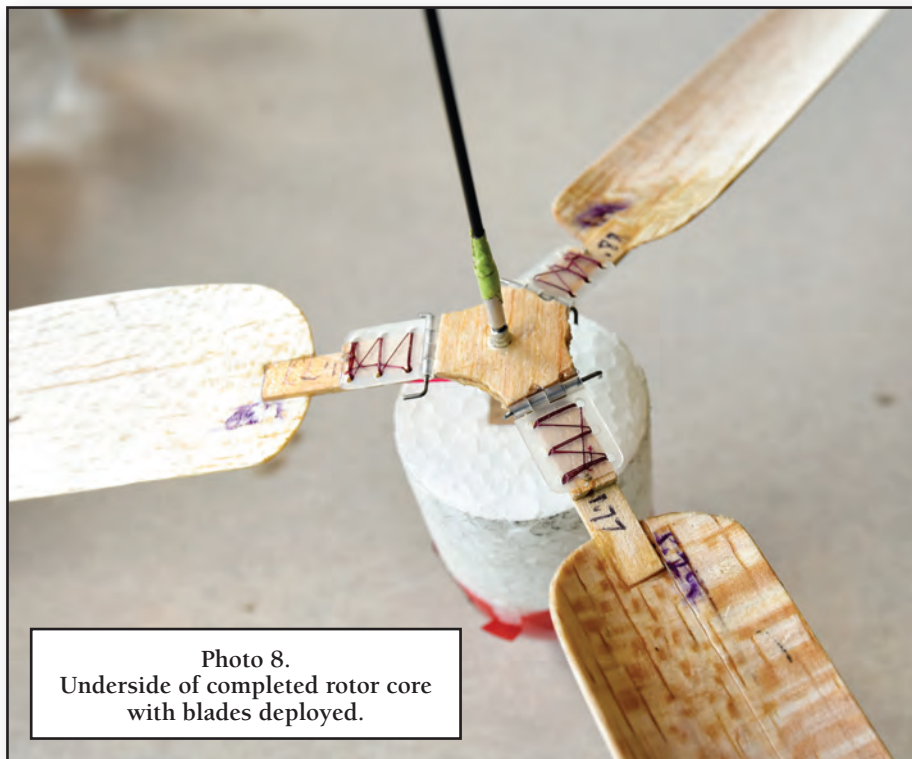


Photo 8.
Underside of completed rotor core
with blades deployed.

this protruding end of the rod with thread and glue to secure the plate on the end of the rod. Glue the nose cone on the top of the plug with foam safe glue. Below the foam plug, friction fit another small plywood plate onto the rod, and push it up against the underneath side of the plug. Slide a 1/8" long piece of 3/32" OD aluminum tube over the carbon rod and up against the plywood plate, then slide the rotor unit on. The 1/8" tube will shim the deployed blades of the rotor unit away from the foam plug when deployed, and act as a bushing for the free-wheeling hub to ride against. Note that the upper portion of the aluminum spindle tube of the hub needs to be long enough so that all three

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Photo 9.
Kevlar shock line needs to be straight with no twisting.

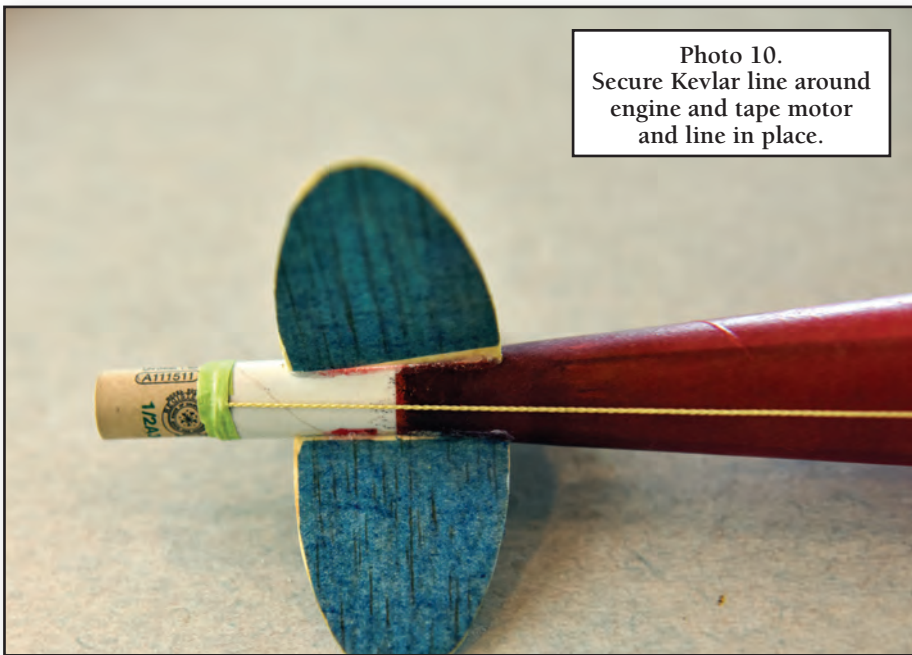


Photo 10.
Secure Kevlar line around engine and tape motor and line in place.

I'm not sure if there is an optimal dihedral angle for sink rate, but the more angle the unit has, the quicker it will transition and start rotation, especially if the unit is heavier than the rocket body. Try to make the three blade angles the same, but if they are a degree or two off, it doesn't seem to cause major problems, unlike balance and pitch differences.

While holding the central shaft sideways, make sure the blades are balanced. Gravity will orient heavier blades down to indicate which blades need to be lightened. You can sand the upper surface of the blades to make fine adjustments, but you may also have to add weight to the lighter ones. This is also a good time to treat the end grain of the blade tips with CA or epoxy to prevent damage from the ejection charge, since this process may unevenly add weight. When the blades are balanced the hub will not rotate on its own, no mat-



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Keith loads his S9 model on into a tower at the 2019 U.S. team tryouts.



ter which blade is positioned up. Out of balance blades will make the unit descend with a revolving motion, instead of staying positioned on its vertical central axis.

The same symptom will occur if the blades have differing pitch. If you built consistently, using jigs, they should have the same pitch, however changing humidity will affect balsa wood and will often need minor adjustments. Holding the central shaft upright, rotate the unit to inspect the pitch of the blades at the tips. If they are slightly off, twist them by hand to give them a temporary set.

Flying the Model

Fold the rotor blades together, pull the Kevlar line taught around the tip of one blade and up the side as you insert the unit straight into the rocket body. The line needs to be straight up the inside of the tube, out the top of the body and straight down to the end of the tube with no twisting (see Photo 9).

Insert a motor, secure the Kevlar line around the motor where it meets the tube and tape the motor, line, and tube together (see Photo 10). Use a motor with an appropriate ejection delay time so the ejection

is close to or short of apogee. Fortunately Estes A3-4T motors work very well, since they are the only lightweight NAR safety certified motors allowed for current contest use in the United States.

At ejection the rotor unit is forced out, the blades deploy, and when the line is fully extended, the body will be pulled around backward. This swinging action of the body absorbs the excess energy of ejection and prevents damaging any part of the model. The Kevlar cord easily handles the heat of the ejection charge from dozens of flights and it is more likely that you will lose the model before you need to change a scorched and weakened cord. As a matter of fact I have lost four models out of my last six contest flights, so my present challenge with this decade old design is to develop a lightweight and reliable de-thermalizer system. Which just goes to show that flying these FAI events year after year never gets boring, only more challenging. So if this sounds interesting to you, start building, flying and experimenting. And good luck in future U.S. team flyoffs!

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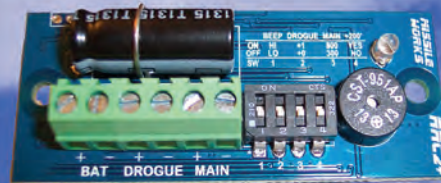
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