Building models for

International Rocket Competition

The skills to fly on an international level are within the grasp of any good competition modeler!

by the U.S. Spacemodeling Team

Trip Barber loading an S6A model onto a tower-piston launcher at the 2006 WSMC.

Model rocket competition is expanding in participation and increasing in sophistication. The best modelers are flocking to it, and winning is a matter of national pride and prestige requiring great modeling and flying skill. This is what is going on in international model rocket competition under the rules of the FAI (Federation Aeronautique Internationale), the international aerosport organization that governs competition and record-setting in all forms of aeronautics around the world. Under its auspices, model rocket competition has steadily grown in popularity and participation globally since its founding in the U.S. in 1959. The first World Spacemodeling Championships (WSMC) in 1972 in Yugoslavia had a handful of modelers flying from 7 countries including the U.S., whose team was led by G. Harry Stine. The 16th World Championships, held in 2006 in Baikonur, Russia, drew over 350 modelers from 23 countries. In between these biennial World Championships, there is now a sustained high level of international competition activity in Europe and Asia. This article, written by a cooperative effort among many members of past U.S. Teams, is about the technology and designs used in international competition. It is intended to pass along the basics of FAI competition design and construction so that more U.S. rocketeers can have a chance to become part of the team that competes for the USA on the world stage.

Model rocket competition is like Olympic basketball competition: the rest of the world uses different rules than the U.S., and being good at playing under our rules does not automatically translate to winning under theirs. While FAI competition started out with the same rules as the U.S. Pink Book in 1972, over the years the two have diverged significantly. U.S. rules promote design diversity and include 30 different events with 134 event-impulse class combinations; FAI rules have only 10 different events and 40 event-impulse class combinations. The U.S. national championships (NARAM) and local meets feature different events and/or impulse classes every year; the World Championships always pick their program from among the same list of 8 events and the same impulse classes of each of these events, although with some different impulse classes for Junior-division competitors (age 18 and under) and Seniors. Because of the repetition of many flights in the same event, foreign world-class modelers have become very skilled at these 8 specific events, and U.S. fliers who go overseas once every two years have a learning curve to climb (or leap over with breakthrough technology) in order to be competitive. That's why we have written this article.

FAI Rules

The primary difference between FAI competition rules and U.S. rules is that in many events the FAI rules specify precisely the minimum allowed dimensions of the rocket, and these minimum dimensions are much larger than what would normally be flown for the equivalent event in the U.S. This leads to very different-looking flight vehicles, requiring a different set of craftsmanship skills to make. FAI modeling emphasizes designs for minimum weight and drag within these large minimum dimensions, and the optimum designs and flight techniques are not immediately obvious to fliers accustomed to U.S. events. The FAI rules evolved to this point over the years as international model rocket motors got smaller and lighter, leading to virtually all the flight vehicles boosting beyond the ability of human eyes to follow and then taking forever to recover, so the airframes were steadily increased in size to improve visibility and make it more challenging to achieve the high durations needed to win.

The rewards can be not only an opportunity to participate in the Olympics of our hobby as a representative of the United States, but also the ability to apply some of these advanced techniques to U.S. competition designs.

The other key difference between FAI flying and U.S. is the rocket motors. European motor manufacturers are small companies that primarily serve competitive hobbyists, not mass-market beginner consumers. Their motors in the B and below impulse classes of most FAI competition events are smaller in both diameter (10.5 millimeters) and length, lighter, more reliable, and higher in total impulse than anything currently made in the U.S. U.S. fliers at a WSMC universally purchase and fly with European motors in the A and B impulse class events. Unfortunately, these European motors are not currently certified for consumer sale in the U.S., so the ability of our fliers to practice with them has been limited in recent years. Team pre-selection practice and selection flying is typically done with Estes A3-4T motors, and then the NAR Board makes special provisions for post-selection team practices using European motors.

FAI rocketry rules are found in Section 4 (Aeromodeling), Volume SM (Space Models) of the overall FAI Sporting Code that governs all aerosports. The Space Models Code can be downloaded from www.fai.org/aeromodelling/documents/sc4. Each FAI Spacemodeling event is known by its "S" code number; for example S6A is FAI-speak for "Streamer Duration (S6), A impulse class." One important aspect of FAI flying and scoring is that all duration events are flown in rounds, with a maximum flight time for a flight in each round similar to multiround U.S. rules. Durations in excess of the "max" do not count, and this scoring system places an absolute premium on reliable, repeatable high performance. A single glitch in one of the three flights by any of the three fliers in a nation's team flying an event generally removes that flier (and the team) from medal contention. FAI timers may use binoculars, which is important for achieving an observed max in the windy weather often found at a WSMC. A flier may enter two models in an event and events have three rounds of flying that are about 90 minutes apart, so at least one of the models must be recovered rapidly to be flown a second time. At a WSMC, the flier does not recover his (or her) own models; teammates do—using binoculars, radios, GPS, tracking beacons, dirt bikes, whatever it takes. Flying FAI truly becomes a team athletic event where organization and teamwork among every member of the team is key to the success of any member of the team. At U.S. team-selection flyoffs, where each flier competes alone and has no recovery assistance, fliers are permitted a different model for each round.

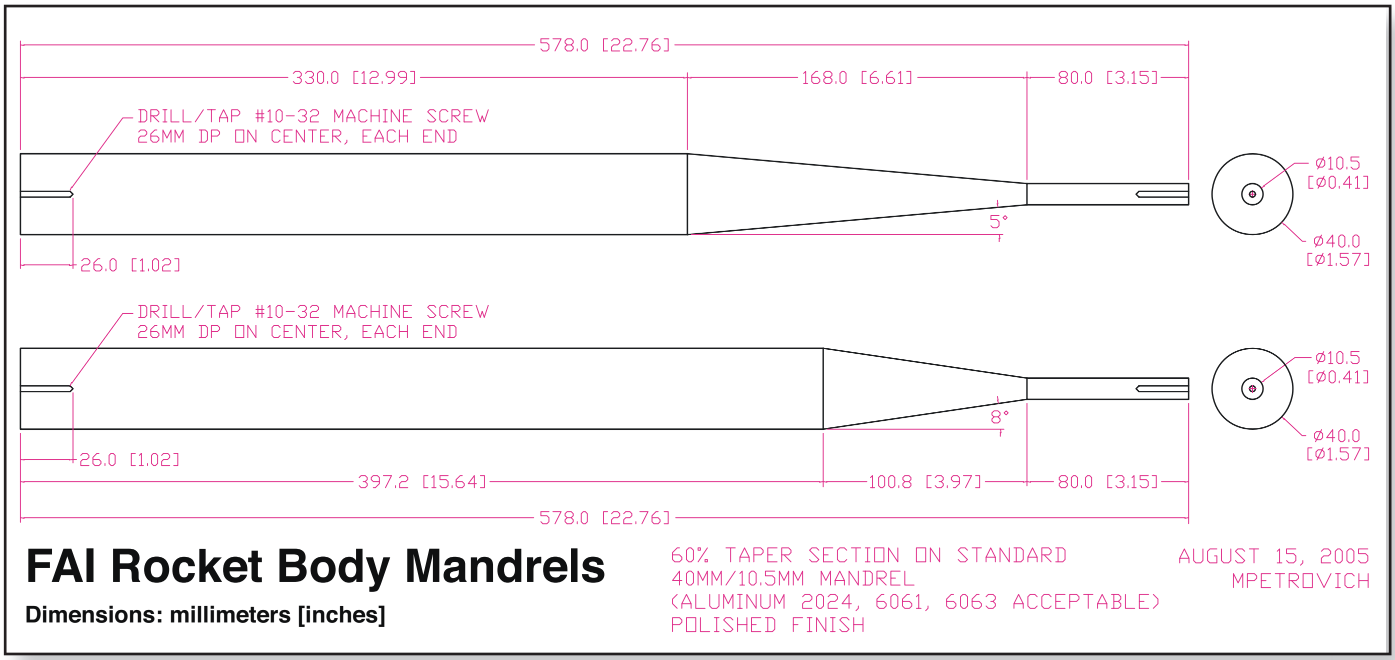
FAI rules specify a minimum body size for certain events, including 4 of the 8 WSMC events (the so-called "tube" events): Altitude (S1A for Juniors, S1B for Seniors); A Parachute Duration (S3A); A Streamer Duration (S6A); and A Gyrocopter Duration (S9A). This minimum size is 500 millimeters (19.7 inches) length, and 40 millimeters body diameter (1.575 inches, roughly a BT-60 size) for at least 50 percent of the total liftoff length. In the case of S1 Altitude, if the model has two stages (and all the winners do), the upper stage must in addition be no smaller in diameter than 18 millimeters (0.709 inches) and must be this diameter for at least 75 percent of its length. The effect of these dimension rules is that all competitive models for these FAI events use extremely lightweight fiberglass bodies, particularly for the 40mm body sections. Much of this article will talk about making these fiberglass bodies and the recovery devices for the three duration events. Altitude (S1) is reportedly not likely to be flown in the next WSMC and its staging technologies are very intricate; it will not be discussed further in this article.

The other 4 of the 8 official WSMC events are Scale (S7), Scale Altitude (S5B for Juniors, S5C for Seniors), A Boost-Glide Duration (S4A), and Radio-Control Rocket-Glider (S8D for Juniors, S8E for Seniors). Of these, Scale Altitude has strange and unique body-size requirements, but it is probably going to be dropped from future WSMC and will not be discussed here. Scale and Rocket-Glider have some unusual flying rules but no odd dimension requirements, and the models flown in this event would look familiar to U.S. competitors. As in the U.S., these two events are for advanced modelers; they will not be discussed further here as they need their own separate detailed treatment. The Boost-Glider rules are fully compatible with U.S. designs, although the designs that win differ from standard U.S. practice; this event will also be discussed in this article.

Making Fiberglass Bodies

The first key to success in the FAI "tube" duration events (S3, S6, and S9) is building the basic 40-millimeter diameter tube fuselage in a way that leads to adequate structural strength, a smooth low-drag non-porous surface finish, and (most importantly) minimum weight. This means using extremely lightweight fiberglass cloth and the right epoxy, laid up over a smooth-surface metal mandrel machined in the shape of the body you're planning to make. There are lots of variations and tricks, but this article will cover the basics. There is more detail (including photos) in a good article by Dave O'Bryan on the NAR website's international competition section. Thin (tracing vellum) paper tubes and tail cones are also a workable option for beginners, at least to compete in the U.S. team-selection flyoffs. There is an article and set of drawings for the paper-body approach by George Gassaway on the NAR website.

Making fiberglass bodies starts with obtaining a mandrel. These are not currently commercially available, and this is an impediment to beginners' entry into FAI flying. Each would-be FAI flier that wants to make fiberglass bodies must make an arrangement to either borrow one or more of these mandrels or have one machined to order, typically from aluminum bar stock. They cost anywhere from $100 to $150 apiece, about the cost of a machined reload casing. Local machine shops should be able to do this, or you can try www.emachineshop.com. Drawings for getting this done are included in this article. Ensure that the machinist puts the smoothest possible surface finish on the mandrel, to make it easy to slide the fiberglass body off after its epoxy sets. The boat tail used on the mandrel



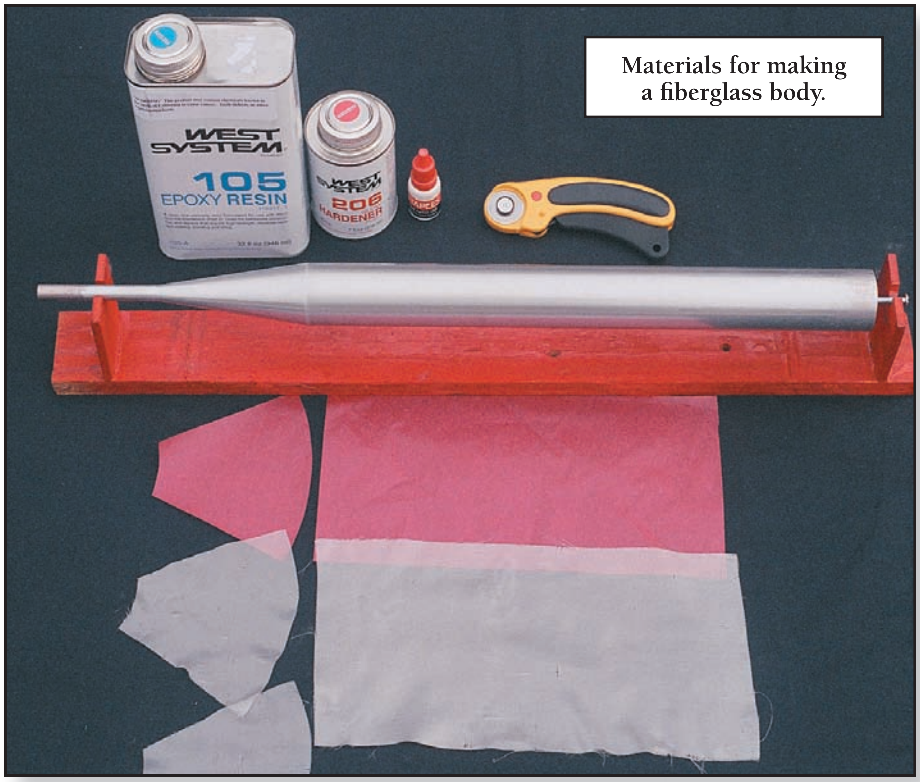
depends on the event the body will be used for: for events where the recovery device is of moderate volume (parachute or streamer), use a shallow (4-5 degree angle) boat tail to reduce body weight and drag; for events with a high-volume recovery device (helicopter blades) or for altitude model lower stages, use a steeper (8-10 degree angle) boat tail. Because the total length of the fiberglass body plus nosecone must be at least 500 millimeters the steeper-angle boat tail body, which has a shorter boat tail length, must use a longer cylindrical section. In all cases the 40 millimeter cylindrical section must end up being at least 50 percent of the overall length of the finished model.

Before laying the fiberglass over the smooth mandrel, it is necessary to put a protective coating of mold-release on the mandrel so the fiberglass can slide off once its epoxy cures. There are many available mold-release agents but the best is Crown 3470, available from Aervoe Industries (www.aervoe.com). This spray-on agent is sold only in case lots (12 cans) at about $50 per case; 12 cans is a near-lifetime supply, so it is good to pool an order with a couple of other fliers. To use, simply spray on two good coats of the agent after cleaning the mandrel surface with a solvent such as acetone. Once the fiberglass body is laid up and its epoxy has cured, heat the mandrel and body in an oven to around 230 degrees, grasp the body at the top and bottom using a thick cloth on your hands while holding the mandrel in a vice by a bolt threaded into its flat end, and the body will slide easily off the mandrel.

All FAI fliers use lightweight fiberglass bodies; Kapton plastic has been used but can crimp under motor thrust and is not recommended in S3 or S6. There is a wide range of personal preferences as to whether the body should be two layers of fiberglass, or one layer of fiberglass plus a layer of something else such as Japanese tissue (as a bottom layer) or 1/2 -mil aluminized Mylar (as a top layer, but only on the cylindrical section). A single layer of light fiberglass does not have enough strength and is so porous that it allows too much leakage of ejection gases. In addition it generally does not have enough durability to survive more than one flight. The tail cone is made with layers of material in the shape of conical sections that, when wrapped around the tail cone, exactly cover it with an overlap of about 1/8 inch and extend about 1/8 inch up the cylindrical section. The cylindrical section is made from a rectangular piece of material that is 5.25 inches wide and 11 to 13.5 inches long, with the longer size being used with shallower boat tail angles.

The fiberglass used for the body should be ultra-light, in the range of 0.5 to 0.75 ounces per square yard. This type of fiberglass is sold by Sig Manufacturing (www.sigmfg.com), Aerospace Composite Products (www.acp-composites.com), The Composites Store (www.cstsales.com) and other vendors. It is applied with a finishing or laminating epoxy with a 30-minute pot life such as West Systems Type 105 (with Type 206 hardener) or MGS Epoxy, both available from Aircraft Spruce & Specialty (www.aircraftspruce.com). These are mixed in precisely-measured proportions in a disposable plastic epoxy-mixing cup, with a couple of drops of a coloring agent such as stamp pad ink or a powder epoxy pigment to enhance model visibility. If the body is going to be made with fiberglass as the bottom layer, the fiberglass is laid out on very thick aluminum foil and coated with epoxy, then carefully peeled off the foil onto the mandrel. If an outer layer of Mylar is going to be used on the cylindrical section, wrap it next around the epoxy-wetted fiberglass. If the lower layer of the body is going to be superlight Japanese tissue (available from Sig, from FAI Model Supply at www.faimodelsupply.com, or from Peck Polymers at www.peck-polymers.com), spread the tissue out on wax paper or aluminum foil and coat the dull side of it with the epoxy, lay it over the mandrel (epoxied side out) and flatten out any wrinkles, then lay the fiberglass over it, being careful to not let the tissue wrinkle as the fiberglass is applied.

The tail cone section needs to be a bit



Materials for making a fiberglass body.

heavier and more durable than the rest of the body due to its closer exposure to ejection gases. Two layers of 0.5- to 0.6-ounce fiberglass and a layer of tissue, or two layers of 0.75-ounce fiberglass with no tissue, work well for the tail. The cylindrical body can be two layers of 0.5-ounce with no tissue, or one layer of 0.75-ounce with an under layer of tissue or a top layer of Mylar. Any time two layers of fiberglass are used, the weaves of the cloth should be at a 45-degree angle from each other for improved stiffness. If the cloth has different weight threads in each direction, align the thinner threads with the long axis of the body. Cut the fiberglass with an extra-sharp razor blade or with an Olfa rotary fabric cutter. The most efficient way to do this is to stack several layers of fiberglass and paper, with the top paper layer having a printout of the template used for cutting the part. Be careful to drape the cut fiberglass onto the mandrel without letting it stretch and get distorted in shape and ensure that the fiberglass cloth is well wetted at all points with the epoxy so it does not permit the ejection charge gases to leak out.

Once the fiberglass body is laid up, keep the mandrel in its cradle, holding it by bolts threaded into each end, until the epoxy fully cures. If the epoxy is thick on the fiberglass, you can lighten the final body by blotting the wet tube with a paper towel. If the outer layer is not Mylar, then it will be necessary to put a smooth finish on the exterior to minimize skin friction drag. Do the initial part of this while the body is still on the mandrel after it has cured, using 400 grit sandpaper briefly then very fine steel wool. Be careful not to sand or polish very much, as the body is quite thin. Once sanded, remove the body from the mandrel as previously described and check it for smoothness and for places with incorrect thickness. It may be necessary to put it back on the mandrel for additional finishing; if so, clean the mandrel and then coat it with talc first. Trim the finished body to final size by first cutting off the tail cone at the right diameter to match the motor mount, and then trim the 40-millimeter cylindrical section to achieve the desired total body length (19.7 inches minus the nose cone length). When you are done, weigh the trimmed and sanded body; if it weighs more than 6 grams, it's too heavy to win in FAI competition.

The Rest of the Model

Once the basic fiberglass rocket body is made, it needs four more things to become an FAI contest model: a motor mount; a nose cone; a recovery system; and fins. Each of these has to be made with close attention to light weight and installed with precise alignment to get the most performance out of the design.

The motor mount should be a short (1.5 inch) piece of body the diameter of the motor type that the model will fly with. If this mount is a body tube section inside the tail cone, put a centering ring near its forward end that is the right diameter to make firm contact with the inside of the fiberglass body when the motor mount is in final position. When making mounts for 10.5 millimeter diameter European motors, these rings will need to be special-made, preferably out of fiber due to fragility of thin balsa, by Balsa Machining Service (www.balsamachining.com). The body tube-style mount is inserted into the tail cone from the nose end, using some form of jig that ensures the mount's body tube is exactly aligned with the centerline of the fiberglass body, and glued into place with cyanoacrylate with a small amount (no more than 1/8 inch) protruding out the back of the tail cone. Some fliers instead use a sharper-angle (and therefore shorter) tail cone, and make the motor-mount "tube" by extending this tail cone with a short cylindrical section of fiberglass that holds the motor. Either way, the motor is

USA SPACEMODELING TEAM SELECTION FLYOFFS

Compete for a spot on the team that will represent the USA at the August 2008 FAI World Spacemodeling Championships in Liepada, Spain.

Selection flyoffs for both Junior (born Sept. 1990 or later) and Senior teams will be held July 28-29 at NARAM-49 in Delton, Michigan. All NAR members are eligible.

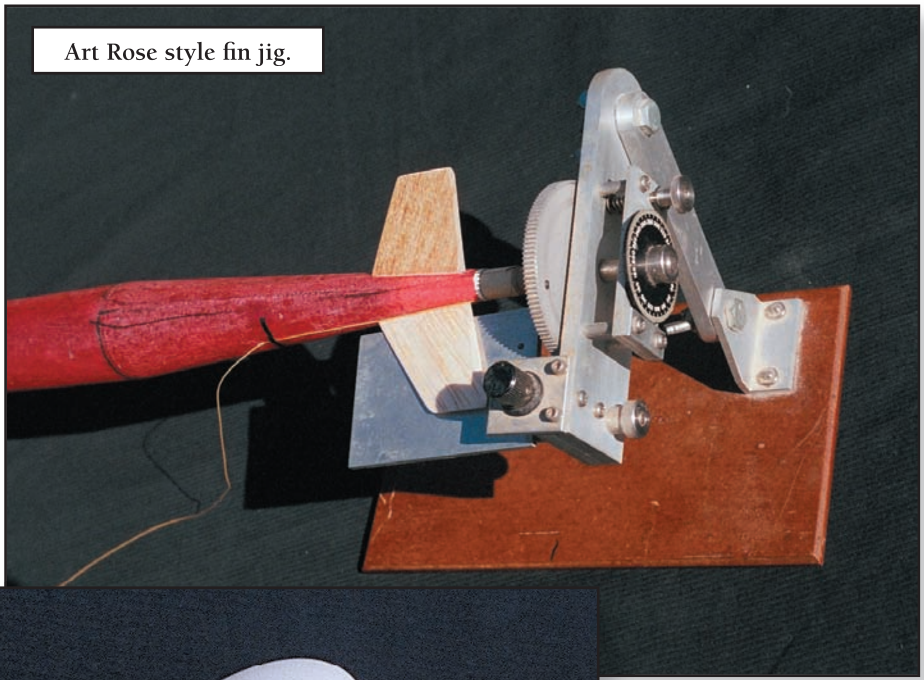
For more details, contact Team Manager John Langford, jsl@aurora.aero.

See the NAR FAI Yahoo Group for information on FAI international competition: http://groups.yahoo.com/group/NAR_FAI_Spacemodeling/

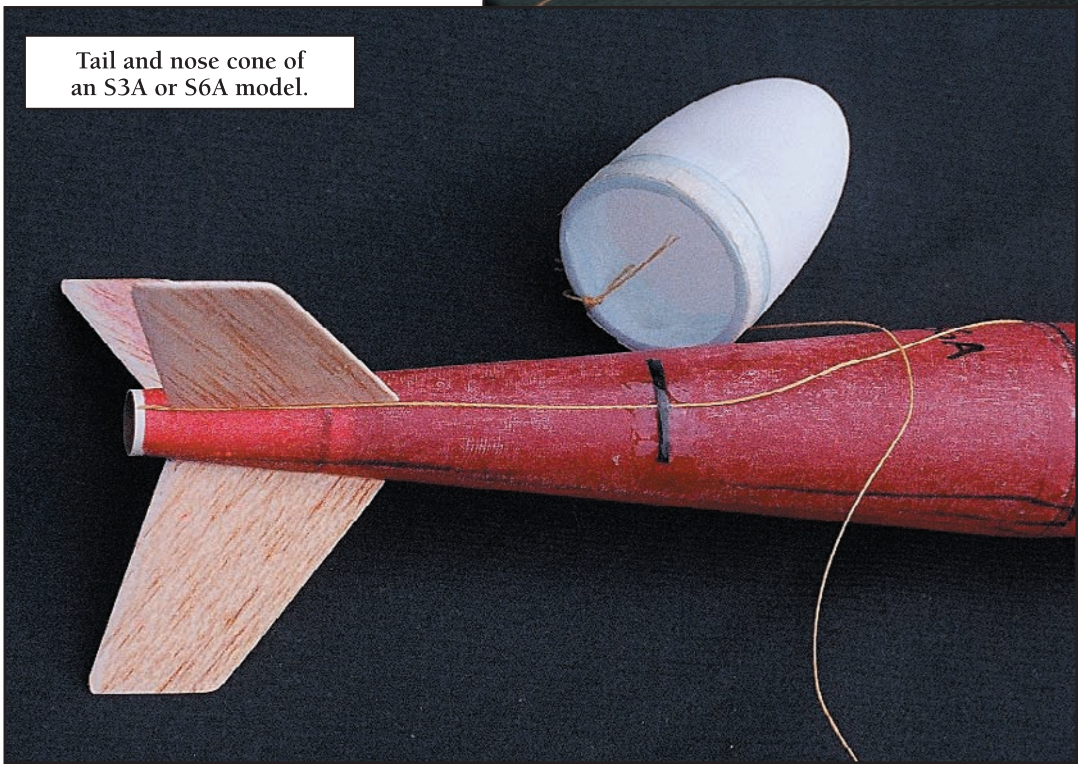
secured in the model with a single wrap of Mylar tape around its protruding casing end and the exposed end of the motor mount tube; there is no engine block.

The nose cone should be a 2.5 to 3 inch long parabolic or rounded ogive shape. Some fliers prefer to make these out of fiberglass, laying gore-shaped strips of cloth on a mold that they fabricate. Others simply use the thin vacu-formed 40 mm FAI plastic cones sold by Apogee Components (www.apogeerockets.com). Either way, the cone is typically mounted on the body with an epoxied-in hollow foam ring shoulder or a short section of fiberglass body that slip-fits inside the main body. The shoulder has a Kevlar line wrapped around and epoxied to it, for attaching the nose cone to the rest of the rocket. The foam shoulder is made from a thin slice of one of the ejection plugs discussed below, from which the center is trimmed out for weight reduction. Balsa nose cones, even hollowed, are non-competitive in weight for FAI flying.

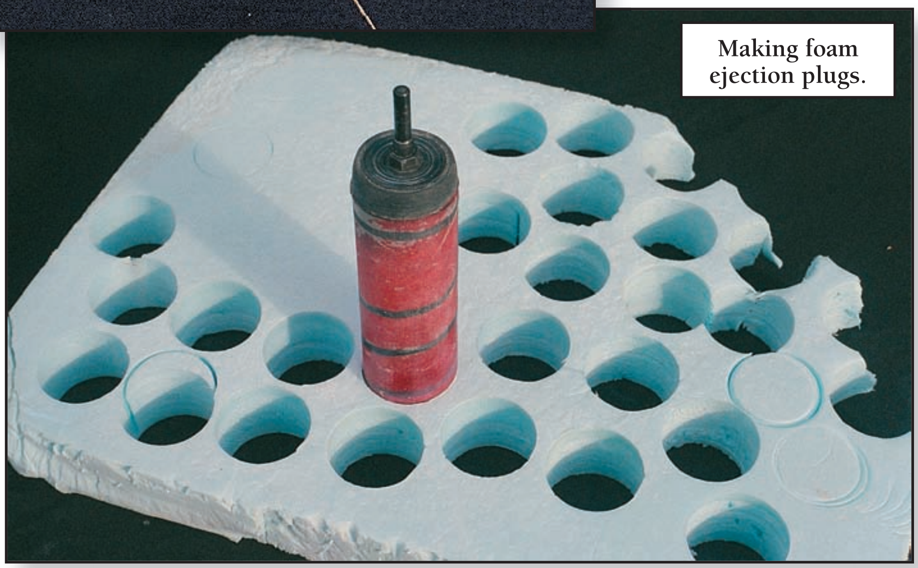
The recovery system is more than the parachute, streamer, or blades, which are discussed in the section on each event. It also includes the anchoring system. For S6 and S3, this is an external line of 50-pound Kevlar secured to the root of one fin, then secured again with carbon fiber or other material to the point on the outside of the tail cone where the body with fins and burned-out motor casing balances, then run up the side of the body and through the nose-body joint to the recovery system. For S6 this external anchor causes the body to fall sideways during recovery, providing drag from its side area. For S3, the external anchor line then may be tacked down to the top edge of the body tube with Mylar tape, so the full weight of the body pulls on the parachute to open it and hold it open. For S9, the anchor line is a heavier Kevlar that also starts at the fin root but then goes inside the body just above the fins. This line connects to a barrel swivel



Art Rose style fin jig.



Tail and nose cone of an S3A or S6A model.



Making foam ejection plugs.

on the bottom of a piston that drives the blades out of the body at ejection.

The other key part of the recovery system is the foam ejection plug that is used instead of recovery wadding. This plug is drilled out of a sheet of 1.5-inch-thick wall-insulation foam sold by building supply stores (the Dow-Corning brand, which is blue in color, works best), using a piece of 40 mm fiberglass body tube that has been heavily reinforced with extra wraps of fiberglass and epoxy and then mounted on a tool that fits into a drill press. There is a good description of how to do this by Andy Tomasch on the NAR website. If the plug fits properly (a bit loosely) it only gets an instantaneous exposure to the ejection charge. A plug that is to be used multiple times, like the one used as a piston in S9 models, needs a coat of epoxy on the exposed side; single-use plugs do not.

The fins need to be lightweight, thin but completely free of warps, and well-finished with a good airfoil. Due to the shape of the body, tapered fins of about 1.5 inches root chord and 1.5 inches span are needed to ensure stability. Balsawood is the normal material used, either light C grain 1/16 inch with a conventional surface finishing system, or 1/32 inch with a rubbed-on epoxy finish or a vacuum-bagged finish of light fiberglass with epoxy. Both epoxy finishes are sandwiched between two sheets of thick Mylar or two mirrors while curing to ensure surface smoothness. See the article on vacuum-bagging by Chris Fouquet on the NAR website; Aerospace Composite Products has vacuum-bagging systems. Sanding-sealer or wood-filler finishing causes 1/32 balsa to warp and should not be used on fins that large and thin. Good, light balsa is available from Sig and from Lone Star Models (www.lonestar-models.com). The fins need to be attached to the farthest-back section of the body (leaving the last 1/8 inch of body clear for the tape that holds in the motor) and aligned using a jig of some type. Tack them on with cyanoacrylate after roughening the attachment area with sandpaper and cleaning off mold-release residue with alcohol. Then reinforce the roots with a thin fillet of epoxy, an adhesive that is flexible enough to remain attached to the fiberglass body as it flexes in flight. The centering ring that holds a motor-mount body tube in place also stiffens the tapering fiberglass body in the area where the fins attach.

Parachute Duration (S3)

FAI parachute duration is all about reliability of parachute performance and the ability of the flier to pick thermals, or updrafts of warm air, when flying. Every good flier of the S3A event gets a max, or a flight of over 5 minutes in duration, on every competition flight unless the weather is bad. At the 2006 World Championships, 15 fliers achieved three maxes each in the initial rounds of competition, and had to go into a flyoff. Anyone who had a parachute fail to fully deploy on any flight due to folding issues or burns from ejection gases was not even in the running for a medal. A properly fitting foam plug should prevent burning, although one sheet of recovery wadding can be placed on top of it for insurance.

S3A models use a basic tube body, and a circular parachute of 30 to 36 inches diameter with 12 to 20 evenly spaced shroud lines that are 1.2 to 1.5 times the parachute diameter. While a larger parachute would certainly fit in one of these 40 millimeter-diameter bodies, the weight of the material would limit rocket altitude and, more importantly, the lightweight body might not provide enough pull weight on the parachute to fully open it. The material used for parachutes is generally some form of colored 1/4-mil polyethylene plastic, or 1/4-mil aluminized Mylar or polyester (available from Aerospace Specialty Products, www.asp-rocketry.com) dusted with baby powder that is rubbed into the material to make it slick.

The shroud lines should be a lightweight multi-stand nylon thread material like the lightest type of the "rod building" thread used by fishermen to attach parts to a fly-fishing pole (such as the Gudebrod brand available from www.merricktackle.com), attached to the chute prior to dusting it with talc using a tape that does not become sticky in heat such as the Mylar tape sold by Aerospace Specialty Products. Fold the tape over the edge of the chute, punch a hole through the middle of the Mylar tape/chute material/Mylar tape sandwich, then pass the shroud line through the hole several times and tie it off.

Folding the parachute is a critical step, and there are several successful techniques; none involve compressing the folded parachute into a tight cylinder or wrapping the shroud lines around it the way fliers often do in the small body tubes used in NAR competition. These would delay what needs to be a near-instantaneous full opening of the parachute at ejection. One folding technique starts with the parachute spread flat on a smooth table, and then doubled over onto itself so that it is a semicircle. From that point techniques vary, but one good technique involves making a series of two or three sets of “Z” folds, each set using thirds of the parachute with the left third being folded lengthwise on top of the center third and the right third being folded underneath the center. At the end of these folds, the shroud lines are laid on top of the long flat strip that the folded parachute has become and the strip is rolled up from the apex end toward the shroud line end in a loose roll, with much of the shroud line length inside this roll.

A simpler technique is to pinch the parachute at its apex and form it into a “spike” which is then folded over twice with the shroud lines run neatly back and forth inside the fold.

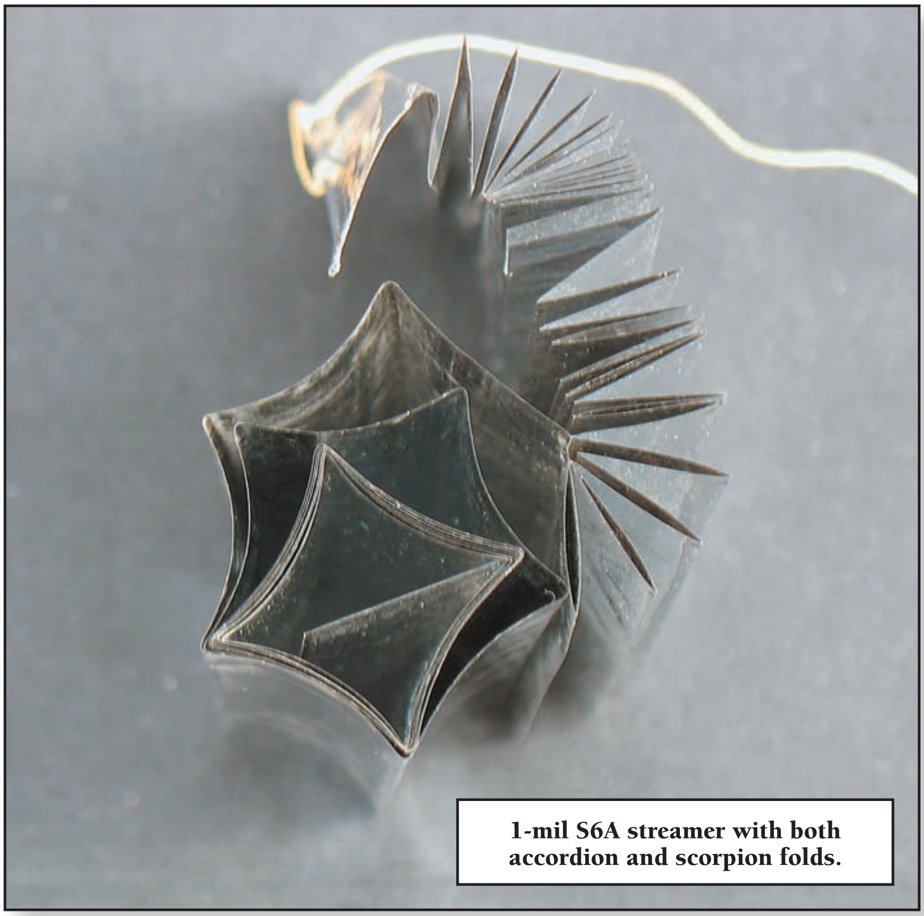
The winning fliers in all FAI duration events are great at picking thermals. Sensing the approach of a thermal is aided by such tools as long telescoping fiberglass poles (available from Into the Wind kite supply, www.intothewind.com) with 20-foot narrow Mylar thermal streamers (available from FAI Model Supply); battery powered machines that blow out a stream of soap bubbles (available from www.funbabytoys.com); or more expensive recording weather devices such as the Kestrel 4000 (available from www.ambientweather.com).

A good article by George Gassaway and Ken Mizoi on how to recognize thermals is posted on the Apogee Rockets website (www.apogeerockets.com/education/detecting_thermals.asp). See also the video “Secrets of Thermal Soaring” by Radio/Carbon Art (www.radiocarbonart.com).

Streamer Duration (S6)

Streamer Duration is all about flight altitude, thermal-picking, and the streamer material plus the folding technique used to put pleats in it. Very few fliers can consistently hit the three-minute max for S6A unless there are thermals present and they are skilled at picking them, and unless their model gets a great flight altitude from a piston launching device. Light weight for the fiberglass body and its nose cone is much more important here than in parachute duration, and it is critical that the body be suspended from an external anchor that is carefully placed to make it fall exactly sideways during recovery, so that drag on it supports it, minimizing the dead weight load on the streamer. It is also important to use a spacer inside the model to hold the ejection plug and streamer as far toward the nose as possible for boost stability. Ensure that the streamer is centered inside the tube so that it does not present an off-center weight on boost that makes the rocket cone and lose altitude. This is usually done by leaving the streamer very loosely furled so it fills the tube and deploys immediately at ejection.

The streamer material preferred by U.S. fliers is one-mil-thick aluminized Mylar/polyester film; standard half-mil parachute material is too limp, and 2-mil Mylar is too heavy. This is a difficult material to find; past U.S. fliers have referred to it as “unobtanium.” It is used in hydroponics, and one source is American Agriculture (www.americanag.com). It is important that whatever material is used for the streamer be light so the streamer does not weigh more than the body of the rocket, yet still stiff enough to hold the dozens of



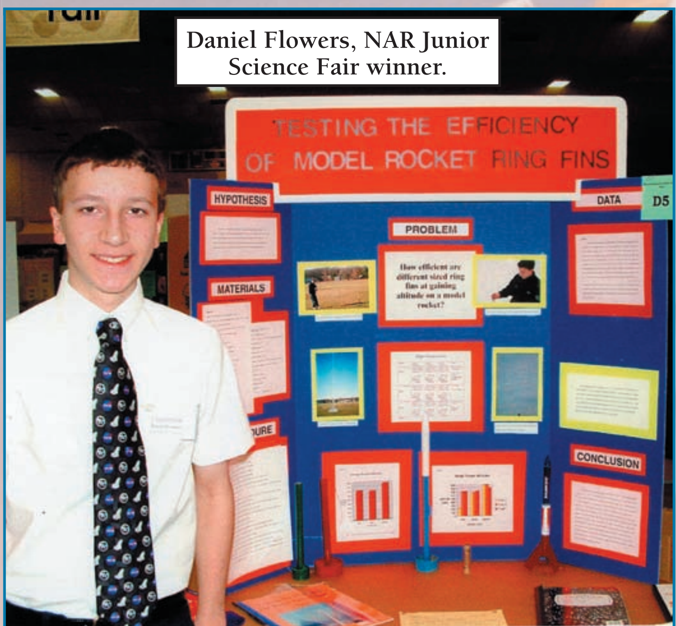
1-mil S6A streamer with both accordion and scorpion folds.

tight creases that competitive FAI streamers have that make them whip and flap vigorously during recovery. This unstable aerodynamic action dramatically increases the drag and performance of the streamer.

FAI rules require that streamers be at least 10 times as long as they are wide. In practice, all competitors use streamers that are exactly 10:1. Average streamer sizes for S6A are in the 4 x 40 inch to 5 x 50 inch range. FAI rules also allow a strip of stiffening material no more than 2 x 2 millimeters to be placed at the end of the streamer where the shroud line attaches, and most competitors use something; 0.020-inch music wire held down with ASP Mylar tape provides all the stiffness needed. FAI rules also allow a "yoke" attachment to both sides of the bottom end of the streamer, which then connects to a single-line attachment to the body that is usually 50-pound Kevlar. This yoke, if used, should have uneven lengths of line, or the streamer should be attached with a single line 1/4 of the way from one side of the end, so that the streamer is loaded off-center; like creases, this promotes the unstable flapping and whipping that enhances performance.

Every nation in an FAI competition has

NAR Junior Member Science Fair Contest



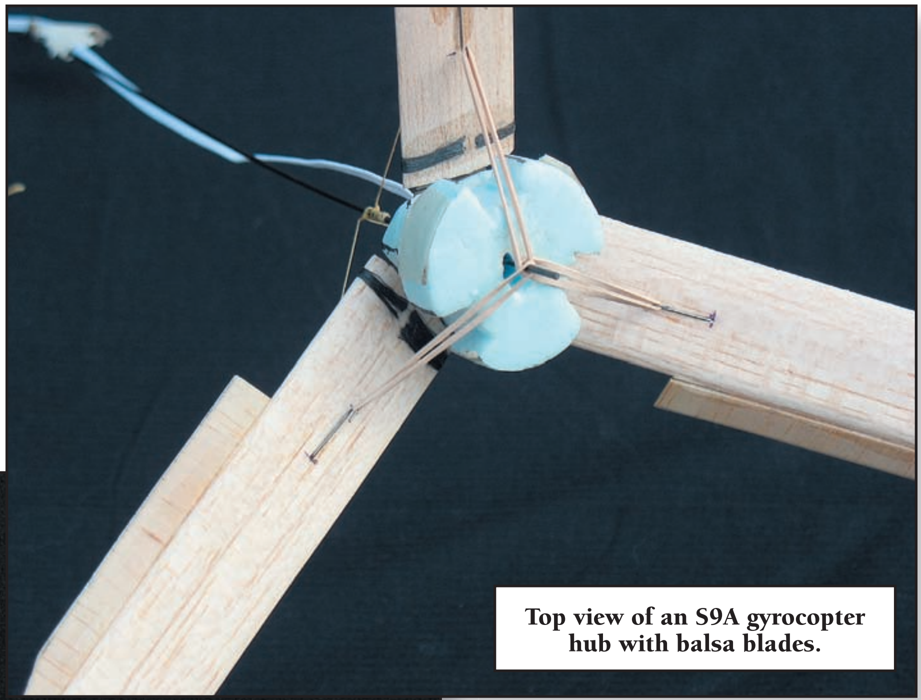
Daniel Flowers, NAR Junior Science Fair winner.

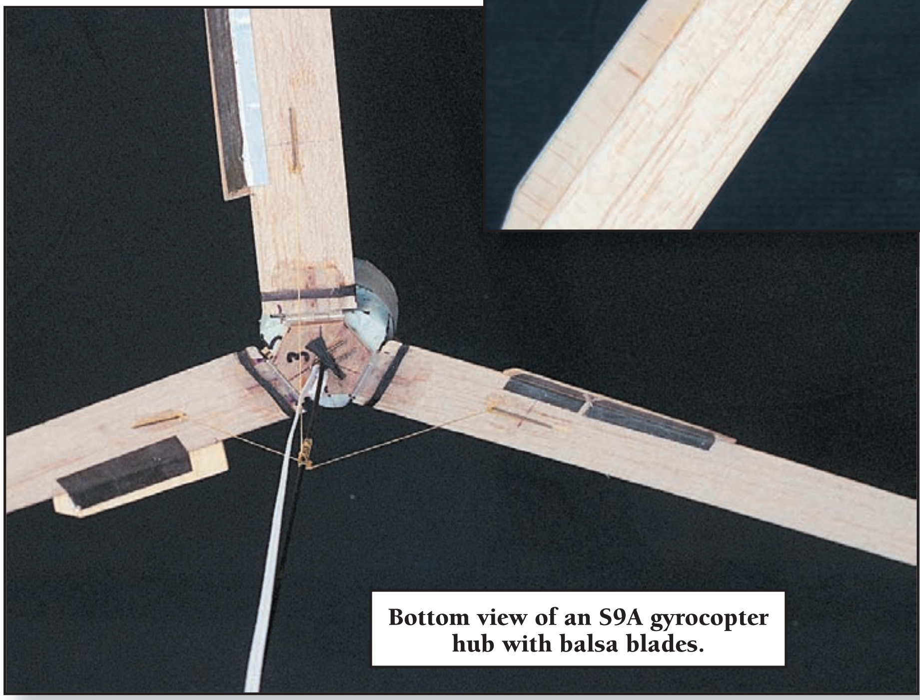
NAR Junior members: Have you done a science fair project that involves model rocketry? If so, you can enter your project into the NAR Junior Member Science Fair Contest. Up to six winners will receive free NAR membership renewals including First Class delivery of Sport Rocketry magazine! If you don't have a science fair project involving model rocketry, start thinking ahead to next year, because the NAR will run this same contest next year.

CONTEST RULES:

1. The contest is open to NAR Junior members.
2. Any science fair project involving model rocketry or high power rocketry is eligible to enter. The project can be a study of some aspect of rocketry, or it can be a project that utilizes rockets as a testing or data collection tool. Projects entered in a previous year's contest are not eligible for entry in this year's contest.
3. Submissions should include photocopies and/or photographs of your science fair report and display graphics. Include whatever material you feel will help the judges to better evaluate your project. You may also submit files on 3.5" diskette, Zip disk, or CD-ROM. A photograph of your self by your science fair display or conducting your rocketry project would be appreciated, but is not required.
4. Entries will be judged on Research Value and Originality, Scientific Thought and Engineering Goals, Organization and Thoroughness, Effort, and Clarity.
5. Membership renewals won in the contest are not transferable to other persons.
6. All Junior members who enter the contest will be listed in *Sport Rocketry* magazine.
7. You retain any copyright and commercial rights to your projects. You grant the NAR the right to publish your project in any of its publications. The entry materials become the property of the NAR and cannot be returned.
8. Deadline for entry (by postmark) is June 30, 2007. (We will run the contest again next year, so start thinking ahead!)
9. Send submissions to: Thomas Beach, Science Fair Contest, 432 Pruitt Avenue, Los Alamos, NM 87544. Be sure to include your name, NAR number, address, phone number, and email address (if applicable).

its own closely guarded secrets of streamer folding. The most common technique used by the U.S. team is competitive, but may not be the state of the art, if we knew what that was. The U.S. method, developed by Ross Hironaka, starts by rolling the flat streamer around a small body tube. The roll is slipped off the tube and compressed flat between two clamped-together pieces of wood. The flattened roll is then heated for several hours in a warm oven at no more than 170 degrees. This heat bakes-in very strong, permanent creases. When the rolled streamer comes out of this process, it wants to stay curled up in a "scorpion's tail" shape which creates a strong whipping motion during descent. The streamer has to be uncurled a bit after this, and is placed in the body tube as an open roll slightly smaller than 40 millimeters in diameter, not in the tight roll with wrapped shroud line usually used in U.S. competition. Some fliers use back-and-forth accordion-style 1/2-inch wide creased-in pleats for the first 50-60 percent of the length of the streamer, with the accordion-folded portion being slipped between the wood plates used in the baking-in process beside the roll and crushed flat with it (not on top of it) during heating.


Top view of an S9A gyrocopter hub with balsa blades.


Bottom view of an S9A gyrocopter hub with balsa blades.

Gyrocopter Duration (S9)

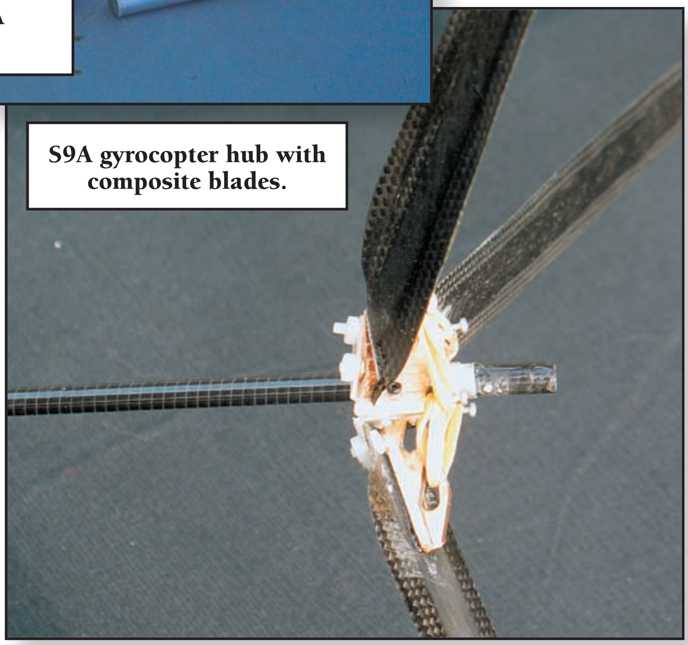
The FAI calls what we know as "helicopter duration" by the accurate title of "gyrocopter duration;" technically, helos have powered blades, gyrocopters do not. This event is all about blade design and construction. The blades are folded down inside the 40-millimeter tubular body during boost and deploy at ejection to rotate around a hub that is built into the nose cone. The best U.S. designs used in recent years, which were perfected by George Gassaway and have been very competitive, used very long balsa blades which first folded in half lengthwise then were folded down to go into the body. The state of the art internationally seems to be moving to shorter, non-folded blades made of materials that can hold a very precise twist along the blade length outward from the hub, to maintain the proper angle for maximum lift-generation. These rotate at higher speeds than the longer blades used by the U.S., generating more lift in a shorter length. Typically, good FAI fliers are now able to achieve the 3-minute max routinely with little thermal lift using these models.

Gyrocopter models also use 40-millimeter tubes, but typically with a sharper boat-tail angle than parachute or streamer, so that more than 50 percent of the body length is cylindrical and therefore wide enough to hold the folded blades, which are generally about 12 inches long. The blades attach to the hub with the same nylon model airplane hinges that U.S. helicopter designs commonly use, and there is a rod (0.040 solid carbon rod of the type used for model airplane pushrods works well) coming out of the bottom of the hub that is slightly longer than the folded blades. The bottom of this rod is where a heavy-duty (150-pound) Kevlar line connects the hub assembly to the booster through an epoxy-coated ejectable foam plug that protects the blades from ejection gases. An elastic shock cord runs along the length of the carbon rod and connects to the Kevlar line at the bottom of the rod to absorb blade-deployment shock. For stability during recovery, the blades operate with a 15-20 degree dihedral angle. This angle is maintained either by hard stops in the hub above the blade root, or by Kevlar limit lines attached to the underside of the blades.

Helicopter blades travel through the air horizontally with a much higher velocity at the tip than they do at the root. If the blade is flat and has the same pitch angle all along its length, then the blades have a different angle of attack with respect to the net airflow (the vector sum of horizontal velocity due to rotation and downward falling velocity) along the length as well. This produces uneven lift loading, and may cause the outer parts of the blade to lose all lift due to negative angle of attack as they reach higher rotation speeds, if their pitch angle down is too sharp. The center two-thirds of the blade typically produce nearly all of its lift, and this part needs to be at an optimum angle for lift, which is a shallower angle than the hub. The inner portion of the blade near the hub needs to be at a high downward angle (or have small downward flaps on the leading edge instead, if the whole blade is at a single shallow angle), so that it can start up the blade system's rotation quickly upon blade deployment. Varying the angle along blade length is very difficult with balsa blades, so the trend is toward thin composite blades with an optimum (different) angle at every point along the blade. For other more complex aerodynamic reasons, it is also desirable to have thinner blade chord at the tip than at the root, so the optimum blade width also varies (tapers) along the span.

S9 is a complex event to design for, but it is an event where the competitive designs are not yet fully optimized, and therefore there is great opportunity for U.S. success through the application of aerodynamics and composite structures technology.

Mark Petrovich prepping an S9A model at the 2006 WSMC.


S9A gyrocopter hub with composite blades.

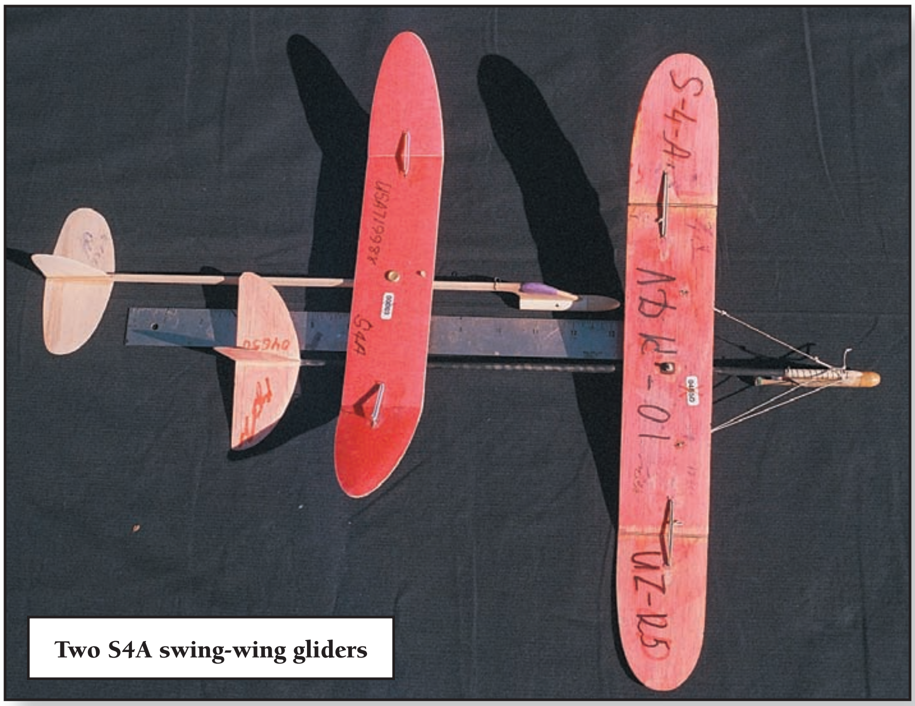
Boost Glider Duration (S4)

Boost Glider is one FAI event where standard U.S. competition designs are generally fully compliant with FAI rules, although simple U.S. designs are not very competitive for a place in an FAI meet. The only unusual aspects of FAI rules are their specification of a minimum boost lift-off weight (glider plus pod) of 18 grams for S4A and their requirement that all portions of the boost trajectory be within a 30-degree cone angle of vertical. Most U.S. "A" boost gliders easily meet the FAI weight requirement and boost straight up, but have a hard time hitting the 3-minute duration in dead air that good FAI designs achieve. Of course, in FAI competition fliers have the advantage of a very low-thrust (A2) motor with a full 2.5 N-sec of total impulse, which gives an outstanding boost altitude compared to a higher-thrust U.S. A3 motor with only 2 N-sec.

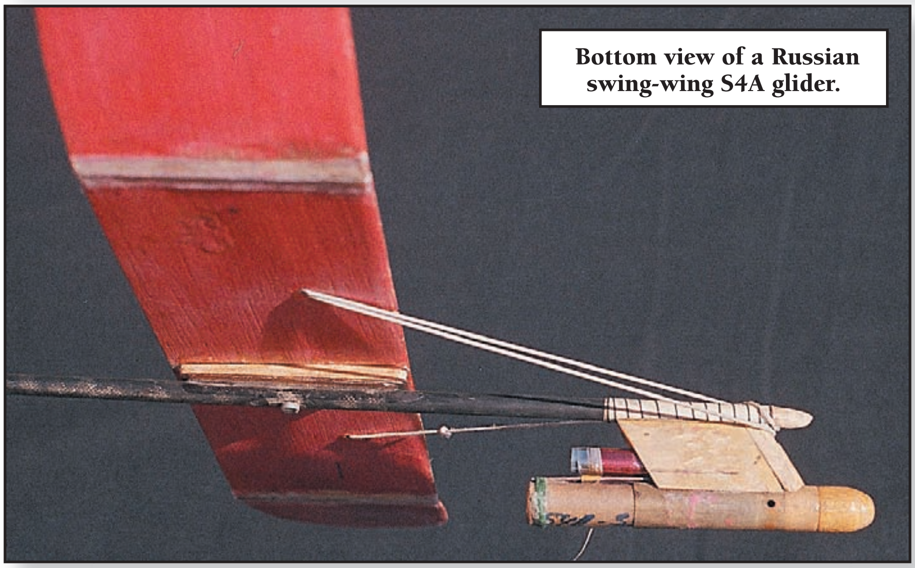
British S4A swing-wing glider.

Uzbek S4A swing-wing in boost configuration.

World Championships seem to always have windy weather, and most U.S. boost



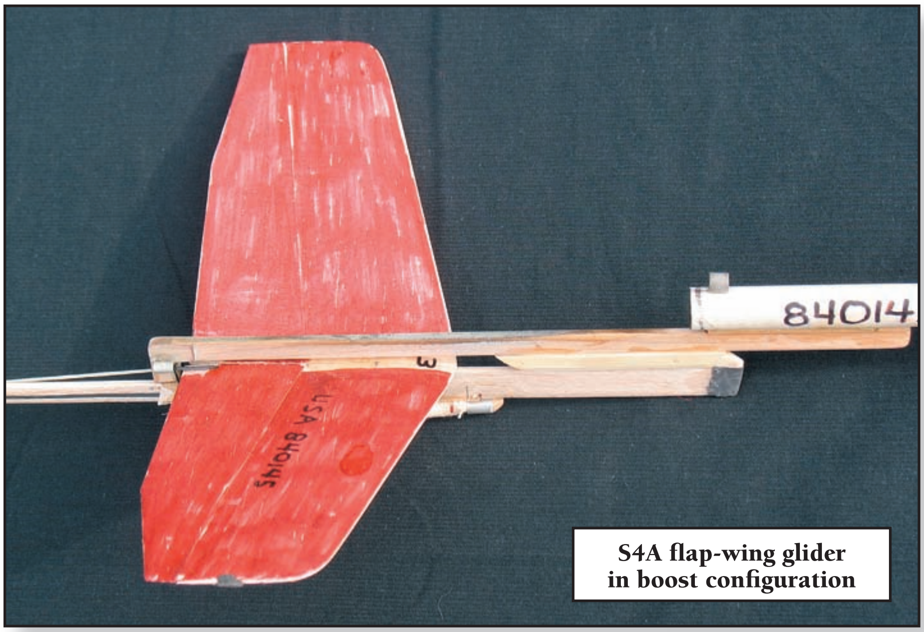
Two S4A swing-wing gliders



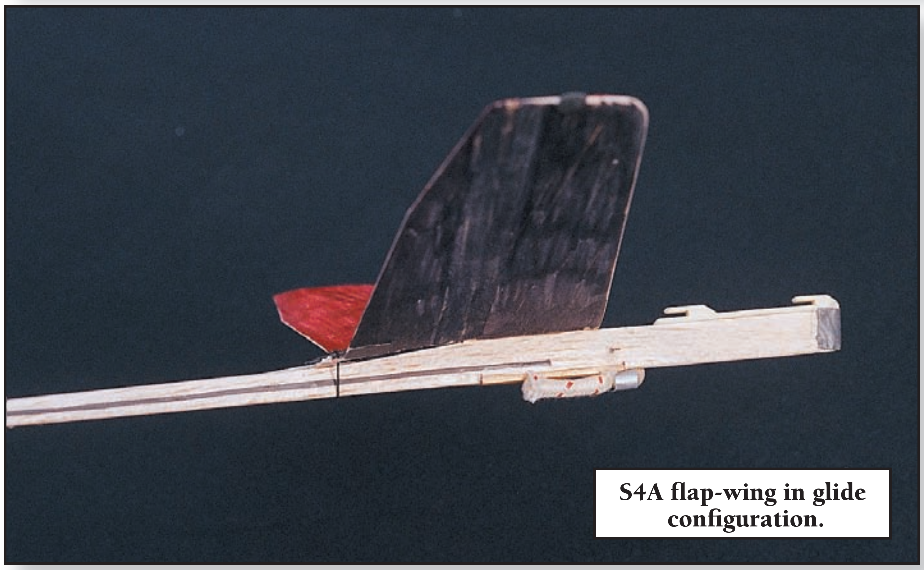
Bottom view of a Russian swing-wing S4A glider.

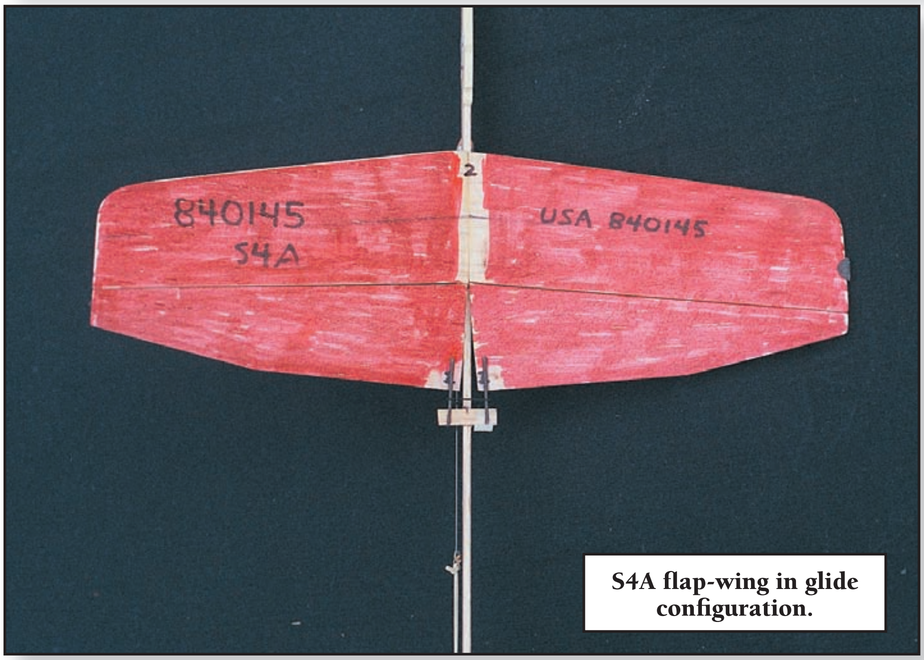
glider pod systems do not handle this well. It is important to have a positive retention system on the pod that can handle wind gusts, both on the pad and in flight. George Gassaway has developed one such retention system that is fairly simple, using two L-shaped hooks on the pod boom that engage in matching receptacles on the glider. Another more complex retention system is the "sling pod" developed some years ago by Art Rose, which uses a rubber band to sling the pod off the glider and a burn thread system to hold the pod on until ejection. Drawings for both the L-hooks and the sling pod are posted in the files section of the NAR_FAI_Spacemodeling Yahoo group. Many foreign FAI fliers solve the pod problem by using designs with a small motor-holder permanently affixed to the glider, and eject the motor with an attached streamer (minimum required size 1 x 12 inches) at apogee. Nearly everyone uses a special launching device for S4 gliders, some with rails instead of a launch lug to eliminate the significant boost drag of the lugs. Others use a launch rod and lugs, but with a stabilizing set of "fingers" at the bottom of the rod to hold the glider against rotation around the rod due to wind gusts on the pad. Some use piston launchers in addition to or in place of the rails or rod.

There are two schools of thought on the optimum design for the gliding portion of an S4A boost-glider. The most common European approach is to use a glider with a fairly large (30 to 40 square inch), high aspect-ratio flop-wing that is flat (zero dihedral) in the center, where it has a pivot at wing mid-point that lets the wing be rotated so that its span is parallel to the fuselage for boost. At burnout, the wing pivots 90 degrees to the normal glide position and the outer half of each side of the wing flops open, with the outer panels being at an angle that provides dihedral. In the U.S., Mark Petrovich's Venus Model Rocketry (www.venusrocketry.com) Giblet kit uses this design approach. A recent Belorussian innovation on this swing-wing that won the 2006 World Championships used a "flying wing" with no fuselage or tail that folds inside a standard 40-millimeter fiberglass tube for boost. Another approach to S4A is to use a smaller (25 to 30 square inch) low aspect-ratio wing with wing flaps that are held up at a slight negative angle of attack during boost (to minimize wing lift and drag) then drop down to a positive 5-7 degrees of angle of attack at pod ejection to maximize wing lift in glide. Bob Parks's Hummingbird design that was published in the July 1993 *High Power Rocketry*



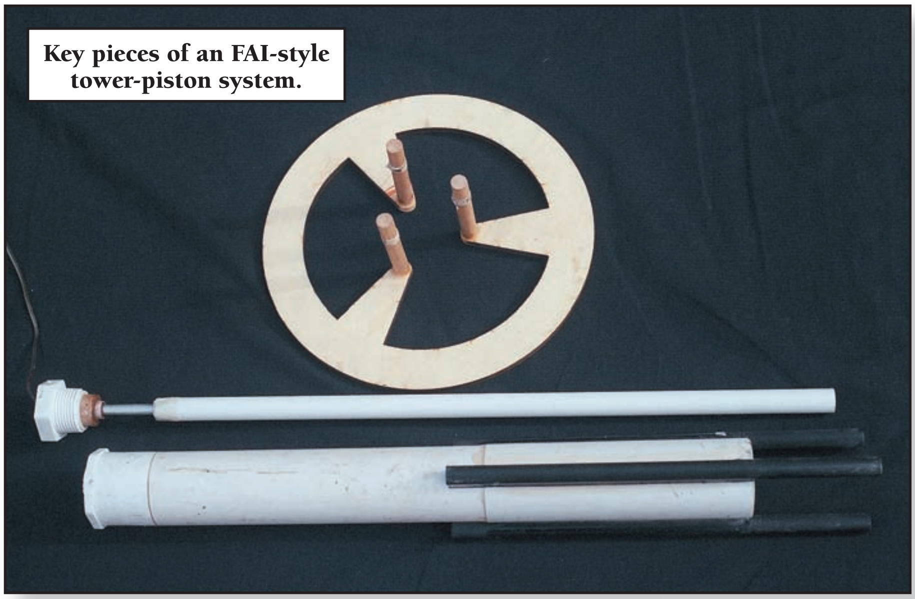
S4A flap-wing glider in boost configuration


S4A flap-wing in glide configuration.



S4A flap-wing in glide configuration.

Model in a tower-piston system.



Key pieces of an FAI-style tower-piston system.

magazine (and is posted in the NAR_FAI group) is a good example of this approach. While a simple fixed-wing glider of the kind commonly used in U.S. competition is not very competitive at a WSMC, it may be good enough to use in the U.S Team-selection flyoffs.

Because fliers aim to put their models into good thermals, and yet have to return and re-use at least one of their models quickly in FAI competition, some use dethermalizers (DTs) in S4A (and some even for parachute duration, S3A) to limit flight duration to just over the max. These DT in S4A generally cause the stabilizer, or a flap on the stabilizer, to pop up sharply. DT design is an article in its own right, but the common DT systems use: slow-burning, small-diameter cotton fuse (sold by Sig) to burn through a thread; a viscous-type thread-release timer such as the 1-gram Czech-made Ikara sold by FAI Model Supply; or a micro-electronic system that fires a small igniter which burns through a thread.

Launching Devices

The tube type models flown in FAI competition for S3, S6, and S9 are generally flown from tower launchers, never from rods that require draggy lugs on the model. Nearly all competitors also use a piston-launcher system to augment motor power at liftoff, some of these with no tower at all. Because most modelers travel by air to get to World Championships, fixed-construction towers are not very practical so the towers are designed to break down for packing and shipment. These designs are fairly simple; all the models flown in FAI competition have exactly the same 40-millimeter body diameter, so the complexity of the adjustable-diameter towers used in U.S. competition is not required. Incorporating the piston launcher in the tower does add back a bit of complexity, however.

Every U.S. flier seems to have his own design for a collapsible tower, but they all have one feature in common: they use removable tubes whose bottom end fits onto a base that sets the 40 millimeter diameter. They also all use a spacer ring at the top that is external to the tubes but has fingers that reach inward from this external ring to mount pegs that fit into the tops of the tubes to stabilize them at 40 millimeter diameter at the top, leaving the space between tubes clear for the rocket's fins to pass through. The tubes can either be lightweight aluminum or other metal (such as electrical conduit), or they can be thin-wall fiberglass tubing such as the 0.5-inch kite spars sold by Into the Wind kite supply. The base of the tower needs to have a means of screwing in or otherwise securely attaching the base of a piston-launcher system exactly in the center of the tower tubes. The tower-piston system should be designed to provide 3 feet or so of guidance to the rocket after the end of the piston stroke, and the base of the tower needs to provide stability to the whole system so it does not blow over in the wind, plus some ability to provide a small angle to the launching direction so the rocket can be aimed slightly downwind in such a way that it weathercocks to the straight-up direction for flights made in windy weather.

U.S. fliers are accustomed to using piston launchers in competition, but U.S. designs typically use paper body tubes for the piston tube and use a standard single-use electrical igniter fitted in the top of the piston head to start the motor. European designs use lightweight, smooth 12-18 inch long fiberglass (or carbon-fiber) piston tubes precision-fitted to a machined piston head for the best possible gas seal and performance. And they use a "spider" system for ignition. This is a tiny tube with fine black powder in it whose top fits up the nozzle of the motor, with the black powder being ignited at the bottom of this tube by a multi-use nichrome wire. These are far more reliable and quicker to prep than U.S piston ignition systems. Unlike the U.S., Europeans appear to have no regulations on the use of loose black powder for model rocketry. While FAI rules require that the launching device impart no extra momentum to the model, and the spider system may in fact do so a little bit as a result of the black powder, this has not been an issue in FAI competition.

Summary

Building for FAI Spacemodeling competition requires learning design and construction techniques that are new to most U.S. model rocket competitors. This learning process takes an investment of time, effort, and money, but the skills are well within the reach of a good competition modeler. There is a community of experienced U.S. FAI fliers standing by on the NAR_FAI_Spacemodeling Yahoo Group to welcome and advise those who want to join this activity. The rewards can be not only an opportunity to participate in the Olympics of our hobby as a representative of the United States, but also the ability to apply some of these advanced techniques to U.S. competition designs.