The Joy of Flex

by Kevin Paul Wickart

The intent of this article is to help to overcome the aura of mystery and air of uncertainty that seems to surround the construction and trimming of flex-wing gliders. I hope to accomplish this by guiding the reader through the procedures needed to build a basic flexie, while discussing various facts, theories, and observations regarding this class of glider.

The Back Story

The glider popularly known as the "flexie," or flex-wing glider, developed primarily from the work of Francis Rogallo, inventor of the delta-winged kite that bears his name. During his time as a NASA engineer, Rogallo experimented with using the sparless wings in place of standard parachutes for recovery of space capsules. The idea was scrapped, but the Rogallo wing went on to become the standard for hang gliders.

Flexies had been examined for model rocketry use on a number of occasions in the late 1960's and 1970's, but never really caught on until people started flying them in boost-glider competitions. There, the ultra-light gliders dominated standard rigid-wing models until the rules were changed to give flexies their own event.

Let's Go Fly a Kite

Ask most any competitor what he/she dislikes about flexies, and you're likely to hear one or more of the following:

1. Flexies are inconsistent. Build half a dozen using the same techniques, and you'll get six different flight profiles.
2. Flexies are hard to build.
3. Flexies are hard to trim.
4. Flexies are unreliable. Fly the same flexie six times and it may not transition all the time, may not glide the same, may not deploy, etc.
5. Flexies don't do well in breezy conditions.
6. Flexies aren't "real" gliders; they're kites.

I'm sure there are more, and I can't deny that some of this is perhaps deserved, but much of it is not:

1. Flexies are not so much inconsistent as they are sensitive to variations in design and construction.
2. There are two parts of the construction process that are genuinely difficult, neither of which requires any special skills. The first takes some practice, and the second has a very simple solution.
3. Thanks to some research by Pavel Pinkas, trimming is much easier than it used to be. Some design decisions can also help make trimming easier.
4. Some of this is true, but weather conditions and flight profile may have more to do with these problems than the nature of the glider.
5. It's true that they have a generally lower "maximum wind" speed than conventional gliders, but research has shown that a properly designed flexie can glide into winds of 5 to 10 miles per hour.
6. Okay, they do resemble kites. But Rogallo demonstrated that a wing of this design does generate lift. And since flexies exhibit the same flight characteristics as gliders in their response to changes in trim, the only reasonable conclusion is that they are gliders.

Flexie Design

Fear not—I'm not going to go into an in-depth analysis of flex-wing physics, for two reasons: First, that's not what this article is about; and second, I have no idea of why flexies glide like they do. Well…maybe *some* idea.

The basic flexie design is quite simple. Take three spars of equal length and join them at one end so that the outer two form an angle somewhere between 90 and 120 degrees, with the third spar bisecting this angle. The outer spars should have some dihedral, the standard being 1/8 inch of dihedral for each inch of spar length. This forms the frame.

Cover the frame with lightweight material (dry-cleaning bag plastic is great) so that the material is pulled tight at the front of the glider but billows at the rear.

That's all there is to it. The design complication comes from the need to be able to fold the glider up during boost and have it deploy reliably at ejection. Once you've overcome that, the rest is actually pretty easy.

The usual method—but certainly not the *only* method—is to form a spring-hinge out of thin wire. The center of the hinge mounts to the center spar, with the outer spars attached to the spring-loaded arms of the hinge. Creating this hinge takes a bit of practice, but once you get the hang of bending wire the process is fairly easy. Feel free to experiment with other hinge and

A NARCON attendee measures the extra length of plastic need to create the billow of the flexie.

spring mechanisms until you find one that suits you the best.

Building Your Flexie

The flex-wing glider we'll be building is a standard competition style with a wire spring-hinge, as described above. In addition to the parts below, you will need a hobby knife, ruler, cellophane tape, ballpoint pen or fine point marker, and glue (CA is preferred, but you can make do with white or yellow glue).

Parts List: Spruce spars (3); spring hinge; heavy (carpet or blue jean) thread or Kevlar™ thread; plastic or Mylar film.

1. Attach the spring hinge. Use a bit of glue to tack the hinge into place on the center spar. Wrap thread around the spar and hinge mount, and then soak the thread with glue to secure the hinge. *Avoid getting glue into the spring coils!*

2. Attach the wing spars. Tack one of the wing spars to one of the hinge arms with glue. As above, wrap the spar/arm area with thread and soak with glue to secure it, taking care to keep the glue out of the spring coils. Repeat with the other arm.

3. Set the dihedral. Make sure the wing spars form *at least* a 90-degree angle to the center spar. It's okay if they sweep forward, but not if they sweep backward. Gently bend the hinge as needed. Also make sure that the wing spars have dihedral in them. If not, gently bend the hinge arms upward until you have the desired dihedral.

4. Establish the sweep angle. Draw your desired angle (from 90 to 120 degrees) on a large piece of paper or poster board, with a line bisecting the angle, and extend the lines to at least the length of the spars. Tape the glider frame, face up, to the angle guide. The nose should be in the corner and the spars down the indicated lines. Mark each spar one-quarter to one-third of its length from the nose of the glider (mark the same distance on each spar). Tie one end of the thread around a wing spar at the mark and secure it with a tiny bit of glue. Loop the thread around the center spar at its mark, keeping a little tension on the thread (not enough to bend the spar), and secure with glue. Wrap the thread around the other wing spar at the mark and secure with glue. When dry, make sure each thread mounting point is securely glued. Remove the tape holding the frame to the angle guide.

Participants at Kevin's talk built basic flexies.

5. Get ready to cover. Tape the wing covering film to your workbench so that it is taut and even, with no wrinkles. Turn the frame upside-down and tape the nose and spar ends to the film. The wing spars should be at full spread from the center spar, but not so much so that they are bending outward. Tape the entire length of the center spar to the film, up to where the hinge attaches.

6. Mark the billow. Place the ruler along the line formed by the tail ends of the center spar and one of the wing spars, and draw a line extending between 1 and 2 inches outside of the wing spar. Connect the end of this line to the mark on the wing spar you made in Step 4. Repeat for the other wing spar. This establishes the "billow" of the glider.

7. Cut out the covering. Here's another place where you need to take a bit of care. Use a hobby knife to cut the film, using the outside edges of the wing spars as guides, from the marks you made in step 4 to the nose. Then, using the ruler as a straightedge guide, cut the film along the lines you drew in Step 6 and from the tips of the wing spars to the tail end of the center spar. You should now have a roughly flexie-shaped piece of film hanging from the center spar.

8. Cover the taut area. Keeping a bit of tension on the angle thread, tape the free edge of the film to the spar from the nose to the point where the thread attaches. Make sure the film is taut without deforming the spars; it does not need to be drumhead tight, just reasonably taut. Repeat for the other spar.

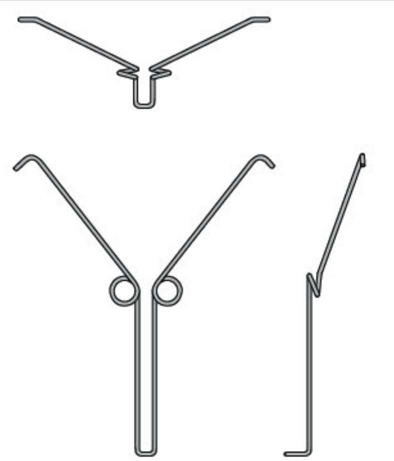
9. Cover the billowy area. Working from the angle thread toward the tail, tape the rest of the edges of the film to the spars. There will be some overhang at the tail ends of the wing spars, which can be cut off (so can the film over the hinge attachment points).

10. Enjoy. Sit back and admire your handiwork—You're done!

Trimming Your Flexie

In 2001, Pavel and Tom Pinkas conducted a research project on flexie trimming for NARAM-43. The main thrust of this project was to find and perfect a means of trimming flex-wing gliders by changing a single physical parameter. The discussion that follows borrows a great deal from this research.

Trimming a flexie can be accomplished the same way most people trim conventional gliders: by adding a bit of nose mass to correct a stall, or a bit of tail mass to correct a dive. Flexies, however, are highly sensitive to changes in trim, for reasons that will be discussed momentarily. In addition, clay is usually not desirable for balance due to the glider being folded up and stored in a body tube; clay tends to gum up the spring hinge or rub off on the inside of the body tube.



Three-view drawing of the standard flexie spring.

Perhaps the easiest method of post-construction trimming is to use a small piece of tape to attach small bits of scrap wood to the spars in the appropriate locations. Once trim is achieved, replace the tape with small amounts of glue. You can trim turns in or out in this manner, but if you are flying competition you may want to try altering the dihedral on one wing to add or eliminate a turn.

For most of the history of flex-wing gliders in NAR competition, the standard rule of thumb was "build several flexies, fly them, and keep the ones that seem to work well." Not only is this a thoroughly unscientific approach, but also suffers from the problem that the flexies that work the best also tend to float away never to return.

The CHEDAR-1 Team set out to find a better method. They examined the various physical attributes of flex-wing gliders with an eye toward finding something that could be changed without too much trouble *after* the glider was built. Many of these—length/weight of spars, weight of covering material, and weight of the spring hinge—are quite difficult to change on the field, and were tantamount to rebuilding the glider from scratch. The others have the capacity to be trim parameters, but were discarded for the following reasons:

Flex therapist Kevin Wickart helps NARCON attendees overcome their fear of flying flexies.

- *Angle between outer spars*—Reducing the angle will help to correct a dive, but also increases the depth of the billow, thus the angle of attack, making accurate trimming quite difficult.
- *Size of the area where the covering is taut*—There has not been a clear correlation determined between this parameter and glider behavior.

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- *Spar dihedral*—This parameter affects glide behavior in a complex manner. Increasing the dihedral improves roll stability and can generate more lift (up to a point) but also increases the tendency of the glider to turn. Establishing a specific dihedral angle is very difficult as the spring hinge is quite flexible, so the angle tends to change readily with wind, wing loading, etc. Furthermore, increasing the dihedral angle alone is not enough to correct a dive due to a heavy nose or insufficient billow.

Wing billow, on the other hand, remains constant. While changing this value on the field can be challenging, as it requires changing the entire wing covering, it is certainly something that can be accomplished as easily as making a parachute.

NOTE: Wing billow is quantified by the length of the covering measured to the outside of each wing spar ("selvage" for those of you versed in sewing jargon) when cutting out the covering.

Perhaps the most compelling reason for trimming by changing the amount of billow instead of trimming with weight is that gliders trimmed with weight, while they may glide fine indoors or in light breezes, are quite often unreliable in flight. On the other hand, gliders trimmed by incorporating a proper amount of billow have proven to be very reliable even in moderate breezes.

A flex-wing glider with zero billow—one in which the entire covering is pulled taut or nearly so—exhibits a strong tendency to dive. A glider with too much billow will stall, indicating that billow acts in much the same manner as adding weight to the tail. However, experiments show that a glider with insufficient billow cannot be properly trimmed with weight; the lack of billow becomes a critical design flaw that must be altered.

As mentioned before, increasing the amount of billow increases the wing angle of attack, which moves the glider's Center of Pressure forward (rather than using weight to move the CG backward). In addition, increased billow tends to lower the overall CG of the glider and increase the area of the "keel," which improves roll and yaw stability.

All of this would indicate that there is an optimal amount of billow for a given size of glider that will result in a perfect glide with no further trimming needed. Experimental data and common sense would indicate that this is indeed the case. For example: a 90-degree flexie with 15" spars needed no further trimming (with weight) with 2" of billow. However, there is one more factor to consider.

A flex-wing glider has a very short glide interval—reflected as the amount of weight needed to go from a dive to a stall—and its optimum glide point is very close to its stall point. This is important because it helps to explain why a flexie that transitions and glides perfectly indoors and under lighter wind conditions will suddenly become highly unreliable in slightly higher winds: the conditions push the glider beyond its glide interval and into a dive or stall from which it may not recover. This is especially likely in a 120-degree flexie, which starts out with a smaller interval to begin with.

The data from Pavel and Tom's experiment show that increasing the amount of billow for a flexie of given size and wing angle does not change the interval between stall and optimum glide appreciably; this value remains relatively constant. It can, however, significantly increase the interval between optimum glide and dive. Furthermore, it appears that for a given flexie configuration there is an optimum amount of billow that maximizes the glide interval (4" for the example above). And this means that the glider is much more likely to pull out of a death-dive caused by wind and/or sloppy deployment, and to glide well in higher winds.

Increasing billow significantly beyond the stall point does not affect glider performance appreciably…or beneficially.

To Sum Up:

The traditionally held opinions that flex-wing gliders are (a) difficult to build, (b) difficult to trim, and (c) squirrelly and unreliable in flight are incorrect.

With a little bit of practice making the spring hinges, flexie construction is relatively quick and easy. Certain design decisions made before and during construction, combined with sufficient billow in the wing material, will result in a glider that is easy to trim. Sufficient billow has been shown experimentally to increase the stability and reliability of flex-wing gliders.