team

SYSTEMATIC APPROACH TO TRIMMING OF FLEX WING GLIDERS

by CHEDAR-1/T#087: Pavel Pinkas and Thomas Hanzlík-Pinkas

Summary

Flex wing gliders are one of the most difficult designs in rocketry. They are highly sensitive to small changes of their basic dimensions and flying conditions.

The construction of a flex-wing glider is well described in number of articles. Also, a number of successful designs is known and flown. However, the trimming process is usually overlooked and the usual approach is to build number of gliders and then select the better ones for competition.

In our research we strive to remove the uncertainty of the outcome by developing and examining a systematic method for trimming flex wing gliders. The very first step is identifying important dimensions of a flex wing glider and then finding a parameter which can affect the behavior of a flex wing glider. Second requirement is a reasonable sensitivity of the flex wing glider behavior to the changes of chosen parameter (ie. the parameter selected should affect the flex wing glider behavior in a clear and controllable way).

Out of all parameters considered, the amount of billowness at the rear part of a flex wing glider appears to be an easily controllable parameter which has a clear effect on the overall flex wing glider behavior. When gradually increasing the amount of billowness, the flex wing glider changes it's behavior from a dive *(nose first, no glide) to a* stall *(tail heavy, poor glide with swings). In the middle between these two extremes is the range of the amount of billowness that is necessary for smooth glide.*

Also, having a good description of all flex wing glider parameters and their values will allow us to easily create a copy of a successful glider without having to build a number of them and only hope that some of them will work well.

1 Introduction

Flex wing gliders are well known both for their unmatched glide performance and difficulty of trimming. The construction of a flex wing glider is well described in number of articles but the trimming process is often reduced to *"build several of them and take the one which works best (if any)"*. This approach can easily lead to higher level of frustration and may not converge to the goal of having a reliable and well gliding flex wing glider at all.

In our research we attempt to take a more systematic approach to building and trimming flex wing gliders. We present a systematic description of a flex wing glider and the method for its trimming which converges in a finite number of steps.

2 Objectives

In our research we pursue three objectives:

Define a set of parameters which describes a flex wing glider. In order to systematically explore the behavior of a flex wing glider, we need to mark and measure its typical dimensions. This will also allow us to clone a succesfull design without "inventing" it again.

Find a trimming method, which would converge in a finite number of steps. We start from an flex wing glider which is untrimmed and conduct number of well defined steps to determine and correct its particular problem (dive, stall). The whole process is repeated until well the flex wing glider is well trimmed.

Learn more about trimming parameter. We perform a simple single parametric study to explore the effect of trimming parameter over its full possible range.

3 Basic dimensions of a flex wing glider

For the purpose of our research we describe a flex wing glider by following set of parameters (see Table 1):

S	length of spars
w	weight of springs
v	weight of spars
A	angle between the outside spars
T	length of tightly covered area
B	amount of billowness
D	spars dihedral
M	covering material

Table 1: The parameters of a flex wing glider

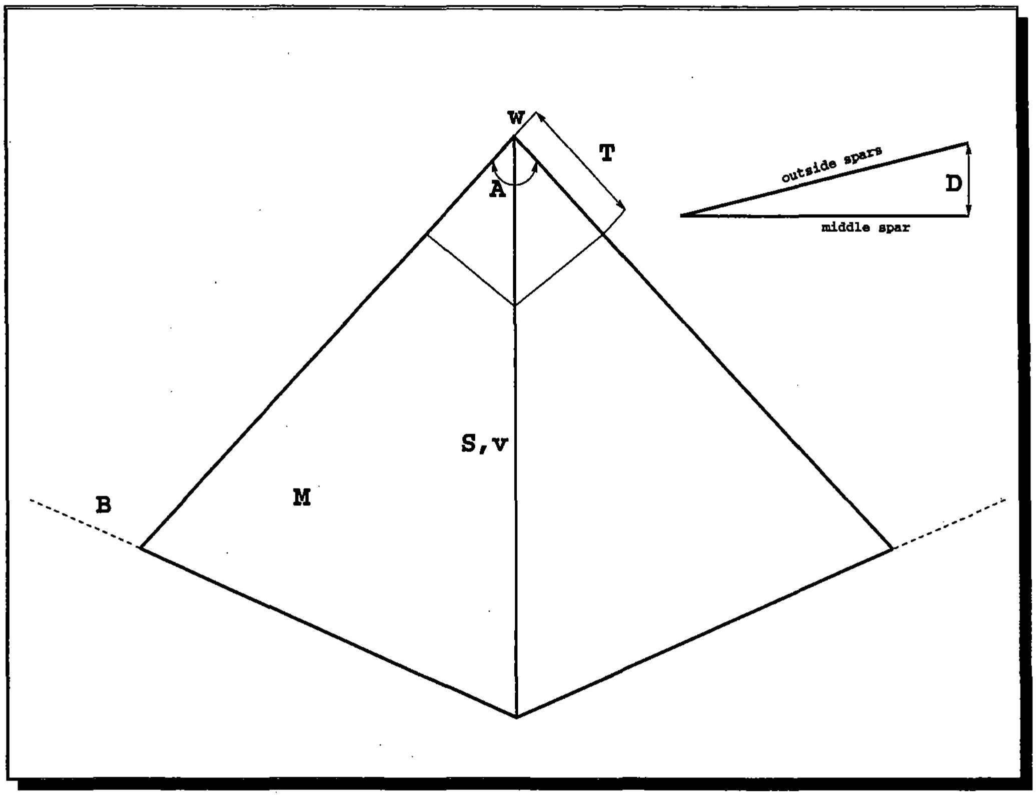

Figure 1: Basic parameters of a flex wing glider

4 The flex wing glider design used

A typical rogallo wing flex wing glider design (see Fig. 1) was used for all experiments. Construction details are as follows:

Spars: spruce, length 12″, 15″and 18″resp., square crosssection of thickness 1/16″, 3/32″and 1/8″resp.

Springs: QCR design and mount, 0.015″, 0.020″, 0.025″, three coils on every spring.

Angle: 90° angle between outer spars.

Tight area: The length of front area where the covering material is stretched tight was 25% of spars length.

Spars dihedral: 1/8 of spars length.

Covering material: 0.40mil garbage bags.

We use a Kevlar thread to set the angle between outer spars. The thread also serves as "spring watcher" (is one spring is "tired" the thread on its side becomes loose).

5 Selection of trimming parameter

Parameters S (length of spars), v (weight of spars) and M (covering material) are given by a design selection and unsuitable to serve as a trimming parameter.

Parameter (w) (weight of springs) can be easily replaced by adding a weight to nose area and further, replacing the spring is an operation that requires a decomposition of whole glider (unpractical).

Parameter (A) (the angle between outer spars) has the capacity to be a trimming parameter, but any change in this parameter will also affect the B parameter (the amount of billowness). For this reason we will consider the A to be a constant for given design.

The length of the area covered tightly (T) also can be a trimming parameter, However, we did not observe a clear relationship between the value of T and the behavior of a flex wing glider.

Spars dihedral (D) affects the flex wing behavior in more complex way. Increasing the amount of dihedral adds more roll stability and even some lift, but also increases the tendency to turn. Also, setting and measuring the D parameter is difficult because springs are quite flexible and the value of D during the flight appears to be different from the value of D for a glider lying on the table. Furthermore, just increasing the value of D is not sufficient to correct the behavior of a flex wing glider which is nose heavy or does not have enough billowness.

For the reasons described above, we selected the B parameter for our trimming parameter. We observed that increasing the amount of billowness (B) can shift the behavior of a flex wing glider from *dive* to *stall* and the relationship between the value of B and observed behavior is clear and easy to understand.

6 A little more about the B parameter

We observed that the amount of billowness at the rear part of an flex wing glider works as a counter-weight to a front mass. No billowness ($B = 0$) make the glider to dive, too much of it ($B > B_{glide}$) and the glider stalls (see Fig. 2). Further, we observed that a flex wing glider with an insufficient amount of billowness ($B < B_{minimal}$) cannot be trimmed by just adding a weight to the front or the back.

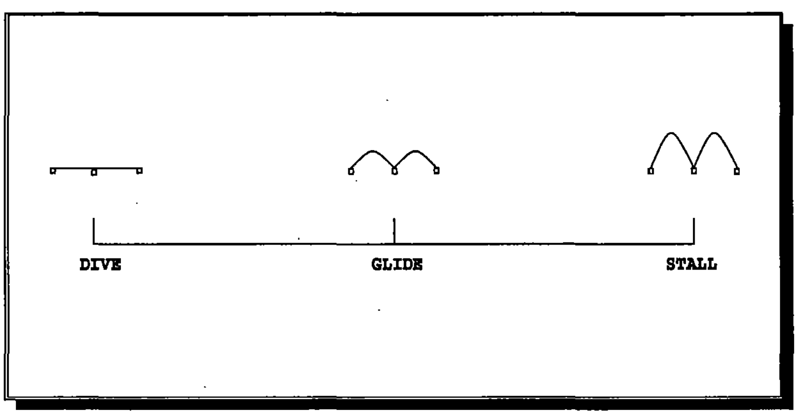

Figure 2: The effect of rear billowness on the overall behavior of a flex wing glider

These observations led us to the idea of using the amount of billowness (B) as the only trimming lever. In order to do so, we needed to find a way, how to measure this B parameter.

7 Building the billowness into a flex wing glider

Fig. 3 explains how we add the exact amount of the billowness to a flex wing glider. We lay the covering material on a flat table and straighten it to remove all wrinkles. The we take the skeleton of a flex wing glider and lay it flat on the covering material. We trace the skeleton on the covering material and then add selected length (*B* length) on the dotted line.

This method allows us to measure the amount of billowness as a simple length and also the triangular shape of added covering material will create nice, even and rogallo-like billows.

After the covering material is marked for cutting, we first attach the covering material to the middle spar. Then, the rear parts of outer spars are attached to the covering (the *T* length from the nose is left unattached). In the last step, the front parts of outer spars are attached to the covering material, with the attention to tightness of the covering material at this area. The covering material should be stretched just enough but not to the point where it starts pulling the spars together (this can add an incurable turn to the glider). The Kevlar thread is a good indicator for this problem.

When all the covering material is attached to the spars, we remove the unneeded parts of covering material and correct the dihedral *D* (if needed). We try to build the amount of dihedral (usually 1/8 of *S*) to the springs directly, but sometimes corrections are necessary.

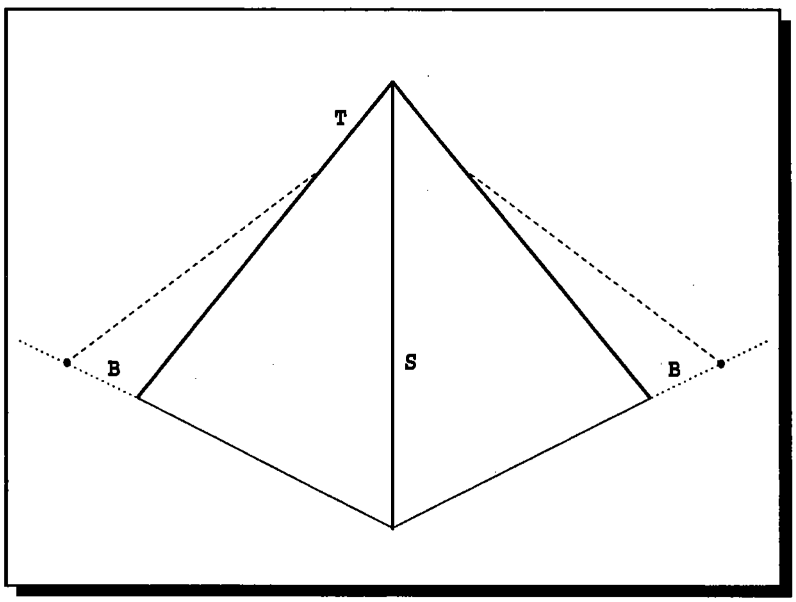

Figure 3: Adding the billowness to a flex wing glider.

8 The method verification

To verify that this method can produce reproducible results, we have built nine flex wing gliders in three different sizes (12″, 15″and 18″). See the table 2 for the parameters of gliders and the results of their trimming.

The covering material information is omitted from the table because the same material (0.40 mil garbage bags) was used for all flex wing gliders built during this research.

Each flex wing glider built had to pass a number of tests before it was considered trimmed. Tests were as follows:

Living room glide: the researcher tossed the glider for a short glide in the living room. The toss was executed with minimal force possible and the glide behavior was observed. It was noted that some flex wing gliders when tossed a little harder may look like gliding well, but they will start to dive after they lose the energy from the toss.

Dead point stall: the researcher tossed the glider from the balcony (5 meters AGL) with the nose up. The glider quickly arrived to the stall, turning nose down. Glider which failed to pull out from the resulting dive before hitting the ground was not considered well trimmed.

Roll over: The researcher tossed a glider in inverted position ("belly" up). Gliders failing to roll over to its normal position was examined for correct amount of dihedral and gliders that transitioned into dive were retrimmed. Like the "Dead point stall" test, this test was also carried out from the balcony.

Pull out: The glider was dropped from the balcony, nose down. Gliders hitting the ground before transitioning in to horizontal glide, failed this test.

Force toss: The glider was tossed with maximum possible force down from the balcony. This usually results in damped stall behavior. Gliders which did not achieve a smooth glide before touching the ground were retrimmed.

Tube launch: The researcher positioned on the balcony, blew the glider out from the BT-5 tube (ejection plug was used for a piston). Gliders that failed to transit into stable and smooth glide were retrimmed.

Bad weather glide: On a windy day (winds 5–10mph) all gliders were tested for their capability to glide against the wind and their capability to glide with the wind.

During this experiment we observed a number of interesting points:

- A flex wing glider that glides well inside the room may dive or fail to pull out from dive. This can be remedied by adding certain amount of billowness.
- Flex wing gliders with a light stall tendency glide well with the wind.
- Flex wing gliders that are well trimmed are capable of gliding against the wind. Decreasing the amount of rear billowness causes the glider to quickly turn with the wind.

The Table 2 shows, that there are only small differences in the amount of billownes (B) needed to achieve a stable glide for gliders of same (or almost same) values of basic parameter of a flex wing glider.

One of the possible causes for those small differences between gliders is a difficulty to cover the front area with perfectly the same amount of tightness (we observed that the tightness can affect the glider behavior significantly).

S ["]	v [g]	w [g]	A [°]	T ["]	B ["]	D ["]
12	2.122	0.191	90	3.00	1.500	1.500
12	1.910	0.205	90	3.00	1.250	1.500
12	2.112	0.200	90	3.00	1.500	1.500
15	5.259	0.313	90	3.75	1.875	1.875
15	5.191	0.318	90	3.75	2.000	1.875
15	5.274	0.304	90	3.75	1.875	1.875
18	5.610	0.505	90	4.50	2.250	2.250
18	5.322	0.512	90	4.50	2.250	2.250
18	5.898	0.508	90	4.50	2.250	2.250

Table 2: Verifying the trimming method

9 Balancing the nose weight with the amount of billowness

To further examine and understand the effect of the rear billowness on the flex wing glider behavior we set up the following experiment (15″ flex wing glider was used):

1. The flex wing glider is built with chosen amount of billowness (sufficient for safe glide).
2. The nose weight is gradually added by 0.50 gram units (weighted fishing leads were used) until following kinds of behavior are observed:
   (a) The stall behavior disappears (if present at the beginning).
   (b) The glider glides well.
   (c) The glider dives.
3. After recording all points required, the covering material is torn off the glider and the glider is covered again, with a different amount of billowness and the experiment is repeated.

This experiment (results are shown on Fig. 4) uncovers number of interesting points:

- The best glide is provided by the amount of nose weight just above the "stall" value. Such gliders also have a high reliability in the transition from the dive.
- There is a maximum amount of rear billowness (B_{max})that improves the "load capacity" of a flex wing glider. Adding more billowness only creates a flex wing glider with a very loose covering. We believe that the excessive amount of covering materials also adds "dead weight" to the glider and causes fluttering and turns. In our case, $B_{max} \approx 5''$.
- The length of the "glide" interval (the difference between "stall" and "dive" value for a given amount of billowness, B) is small for small values of B and grows with the value of B until the maximum amount of "active" billowness is reached.

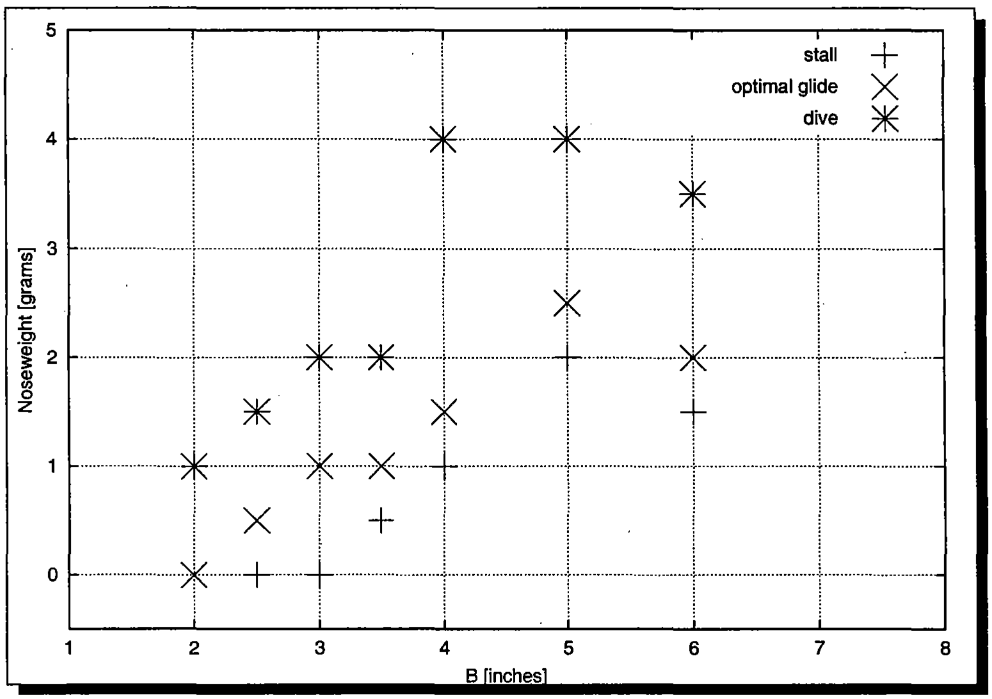

Figure 4: The dependence behavior of a flex wing glider on the amount of rear billowness (B). The $\boxed{+}$ points represent the maximum amount of nose weight that can be added without removing the stall behavior, $\boxed{\times}$ points stand for the amount of nose-weight that provides the best glide (slow, smooth and almost horizontal) and $\boxed{*}$ points show the amount of the nose weight which causes the glider to dive. All values were measured inside on the same day.

- There appears to be an optimal amount of the billowness for which the "glide" interval is largest. In our case, $B_{optimal} \approx 4''$.

10 Conclusions and further work

Considering the nature of flex wing gliders, we prefer not to draw a hard conclusions from our experiments. However, number of points is worth of noting:

- It is possible to define a set of parameters well describing a flex wing glider. It is also possible to build two (or more) (close to) identical gliders with a (close to) identical behavior. This provides an easy method for reproducing successful designs and keeping track of design attempts in concise way.

- The amount of billowness (B) is a parameter playing important role in trimming a flex wing glider. Moreover, this parameter can be easily measured and the overall behavior of a flex wing glider depends on B in clear way (lesser values of B cause the glider to dive, higher values of B make the glider to stall and there is range of values of B for which glider exhibits smooth glide and reliable transitions from dives).

- It is possible, that there is an optimal weight for a flex wing glider of given size, which will require an optimal amount of billowness to trim the glider. This optimal amount of billowness will provide the largest possible "glide" interval (the difference between "stall" and "dive" nose weights) and thus allow for the maximal tolerance to outer factors (damage by ejection, weather influence).
- The best stability in transitions and slowest glide were observed for flex wing gliders trimmed near to their "stall" behavior.
- A flex wing glider, due to it very small weight, can be carefully trimmed by a weight to its nose or rear. However, such a glider, while it may glide well inside the room, can be unreliable in transitions and less than optimal weather. On the other hand, flex wing gliders trimmed using the amount of billowness as a trimming parameter, are more stable in the glide and react well to the disturbances (such as wind gust or transition after the ejection).

Learning from our experiments, we modified the trimming procedures previously used by our team. We trim our flex wing gliders by changing the amount of billowness (B) until we get the glider which glides and transitions well. For new gliders we completely avoid trimming by nose or rear weight and use the amount of billowness as the only trimming parameter. We also subject the glider to number of tests (described on pg. 6) and continue in its trimming until it passes all tests. The only situation where we use nose/rear weight to trim the glider is during the competition where retrimming by changing the amount of billowness is unpractical (because it requires re-covering of the whole glider).

In a future research, we would like to explore the effects of the size of tightly covered area on the behavior of a flex wing glider and also pay more attention to possible optimal weight of a flex wing glider (ie. such weight that requires $B_{optimal}$ amount of rear billowness, where $B_{optimal}$ provides the largest possible difference between "stall" and "dive" nose weights).

A Research cost

spruce wood for spars	$2.00
Kevlar thread	$0.50
10000″ of Marquee transparent tape	$8.90
garbage bags (covering material)	$2.47
CyA glue	$2.17
1 BT-5 tube	$1.09
1 13mm ejection plug	$0.08
thread (for attaching springs)	$0.87
music wire (0.015″, 0.020″, 0.025″)	$1.40
Total	$19.48

Table 3: Research costs

References

[1] WOLF D., Competition Rocketry: Flex-wing Gliders, *SR,* Jan/Feb, 1995, Vol **38**, No. 1, page 47–49

[2] GASSAWAY G., How to Build and Adjust Flex-wing Boost Gliders, *AS,* Sept, 1986, Vol **29**, No. 9. page 12–13

[3] KATZ, A., The Flex-Wing Boost/Glider, *MR,* Mar, 1976, Vol. **XVIII**, No. 2, page 4–5

[4] COOK, D., Flex Your Wings! Applying The Rogallo Wing Glider to Model Rocketry, *MR,* Sept, 1976, Vol. **XVIII**, No. 8, page 6–7

[5] BEYERS, C., Flexies — The Choice of Champions? A Simple How-to on Flexie Construction *MR,* Dec, 1980, Vol. **22**, No. 12, page 6–7

[6] BROWN, K., QCR Technical Report — Secrets of Flexie Boost Gliders

[7] GORMLEY, K., Flex-Dihedral Optimization, *NARTS TCR 12,* NARAM 36