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# KLINE-FOGLEMEN AIRFOIL COMPARISON STUDY FOR SCRATCH- BUILT FOAM AIRPLANES

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**There have been many claims about the performance traits of the various KF airfoil renditions. To help confirm the facts and possibly separate the fiction, two traditional airfoils along with several KF airfoils were flown and evaluated. Flight characteristic scores were recorded for each wing. The majority of airfoils had sufficient positive attributes to indicate that they may be the best selection for a specific application or set of objectives.**

## Introduction

This past year, there have been many claims about the performance traits of the various KF airfoil renditions. Since most wings are built once for a given aircraft, it's not always clear which flight traits are the direct result from an airfoil, the product of other aircraft design elements, or a combination of the two. This tends to occur most often when someone designs a new aircraft, using a new experimental airfoil. It is natural to want to attribute the positive flight characteristics exhibited by this new aircraft to the new airfoil design. Consequently, it is difficult to know which information is myth, and which information is actually fact. The intent of this study was to evaluate the flight performance of several versions of the KF airfoil.

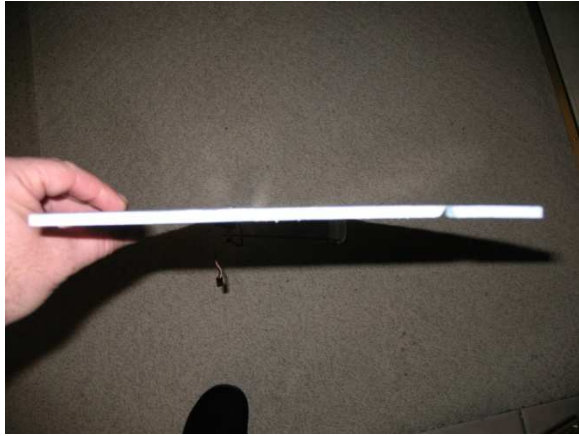
## Methods and Evaluation

### Choosing a Method

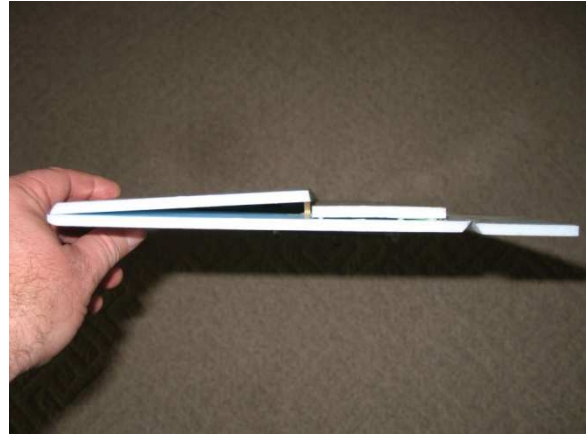
The method I chose for this airfoil test was to design an Experimental Test Bed (XTB) airplane that would permit the installation of different wings. This XTB was created in such a way that other design elements that can affect airplane flight characteristics were minimized. It was a simple box type shoulder wing fuselage, similar to an Ugly Stick. The wing was held in place with rubber bands for easy exchange. Each of the wings were designed with a 40" wingspan, a 10" wing chord, 2" wide ailerons, and had no dihedral. The wing saddle had zero degrees incidence as did the elevator stabilizer. Two traditional airfoils were included in the study along with a variety of KF airfoils. All wings were test flown for evaluation on the exact same fuselage.



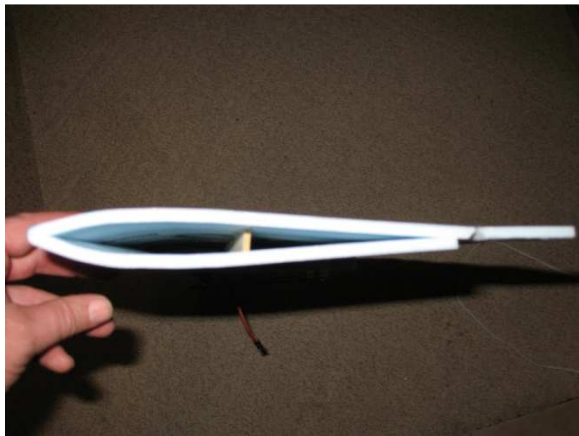
## Control Airfoils and Test Airfoils Defined



**Traditional Flat-plate Airfoil**



**KF m3 Airfoil**



**Traditional Symmetrical Airfoil**



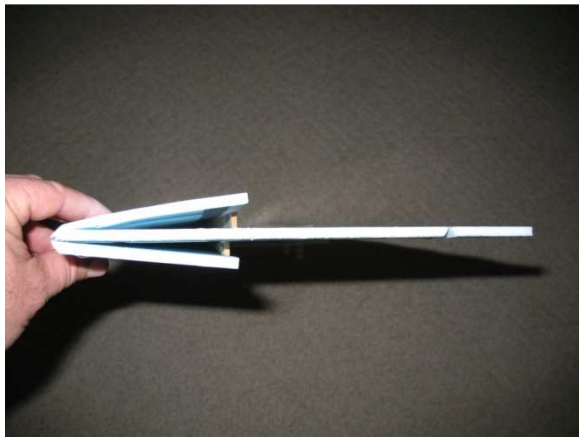
**KF Bottom-Step 40% Airfoil**



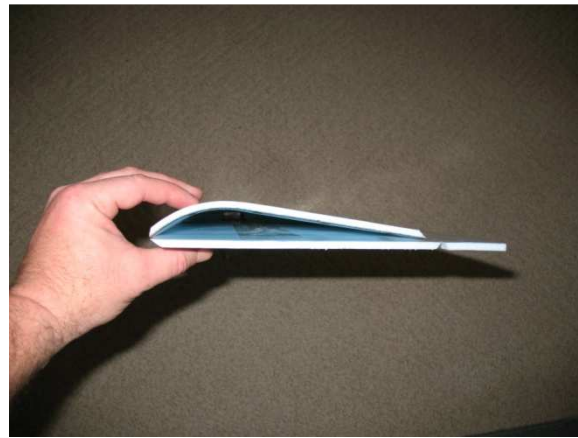
**KF Top-Step 50% Airfoil**



**KF Bottom-Step 50% Airfoil**



**KF Top & Bottom Step 40%**



**Traditional Clark-Y**

## Method of Evaluation

Since all aspects of the aircraft remained the same throughout this test except for the airfoil being used, the resulting flight performance differences are attributed directly to the airfoil in use.

Each airfoil was installed on the XTB and flown by two pilots, myself and my son (Kaos2 & 30V2). We each formed our own opinions and compared them after the flights were complete. The results were documented against several subjective categories.<sup>1</sup>

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<sup>1</sup> There may be some who criticize the use of subjective data simply because it's subjective. My response to that criticism is that in my 30+ years of flying RC, I've observed one thing that remains true of all RC pilots. If you hand the controls of a great flying plane to any RC pilot, they immediately know they have a great flying plane on their hands. If you hand the controls of a poor flying plane to any RC pilot, they immediately know that they have a poor flying plane on their hands. This knowledge is completely independent from what one might observe in a video or by watching nearby, because this information is based on their feel, and is totally subjective. I claim that it is the subjective information about how a plane handles that is most significant to RC pilots.

## Evaluation Criteria & Scoring Defined

Each airfoil was evaluated against ten flight characteristic categories.

**Top Speed** - A score indicating how fast the plane was able to travel in level flight at wide open throttle.

**Slow Speed** - A score indicating how slow the plane was able to continue to fly on its wing, as opposed to prop hanging or harrier style flight.

**Pitchiness** - A score indicating how abruptly the plane responded to elevator inputs.

**Roll Rate** - A score indicating how quickly the plane responded to aileron inputs.

**Inverted Flight** - A score indicating how the plane handled inverted.

**Stall** - A score indicating how the plane stalled and stall recovery.

**Glide** - A score indicating how far the plane was able to glide from a given altitude.

**Grooving or Smoothness** - A score indicating how well the plane maintained its course, particularly in turns, without additional control inputs.

**High Alpha Flight** - A score indicating how well the plane maintained high alpha flight (harrier style flight).

**Adverse Yaw** - A score indicating how much the airfoil caused the plane's nose to yaw, or pivot, in the opposite direction of an aileron induced bank.

## Results

**Airfoils Tested**

Criteria	Flat Plate	Symmetrical	Top-Step KF 50%	Top-Step KF3	Bottom-Step KF 40%	Bottom-Step KF 50%	T & B -Step KF 40%	Clark-Y
Top Speed	5	4	3	3	3	1	2	4
Inverted flight	3	4	5	4	3	1	3	3
Stall	1	3	5	4	5	4	3	2
Pitchiness	1	5	5	5	5	5	5	5
Slow Speed	2	1	4	3	4	3	2	5
Roll Rate	4	5	3	3	2	1	2	4
Groove	1	5	4	4	3	1	3	3
High Alpha	1	2	5	4	5	3	3	2
Glide	2	4	2	3	2	1	1	5
Adverse Yaw	3	4	4	5	4	1	3	4
<b>Score Total</b>	<b>23</b>	<b>37</b>	<b>40</b>	<b>38</b>	<b>36</b>	<b>21</b>	<b>27</b>	<b>37</b>

The scoring system is a five point system where a score of 5 indicates the best performing airfoil in that category and a score of 1 indicates the poorest performing airfoil in that category. Please note that a score of one does not mean that a given airfoil is a bad performer; it just means that of the various airfoils tested, it was the poorest performing airfoil in that category. Numbers assigned between 1 and 5 depict performance between the strongest and poorest performers, and are relative.

## Discussion

### Initial Impressions

One of the first things that immediately became clear during this study was that airfoil selection for an airplane has a dramatic effect on the aircraft's handling and performance. Nearly every time we changed wings, the XTB felt like a completely different plane. The wing not only produced the lift necessary for flight, but it had an impact on each of the other controls as well.

### Airfoil Scoring

The table displaying the airfoil scores requires some further discussion. Airfoil scores that are only one number apart are very close in performance, and the differences may only be observed when an airfoil can be exchanged on the same aircraft. Airfoils that were given the same score were so close in performance that no discernable difference could be noted.

The scores in pitchiness were all the same except for the Flat-Plate airfoil. My hypothesis for this result is that pitchiness is more directly related to the thickness of the leading edge than the rest of the airfoil shape.

Since the Symmetrical airfoil is not traditionally known for its glide performance, it was surprising to find that the Symmetrical airfoil outperformed the others in the glide tests, with the only exception being the Clark-Y airfoil. The Clark-Y and Symmetrical airfoils were the most aerodynamically clean wing designs. A possible explanation for this observed gliding result is that due to the low inertia that small foam airplanes possess, the reduction of drag may be of greater importance to extending glide than the lift generated by Bernoulli's Principle.<sup>2</sup> Since the Clark-Y airfoil produced significantly more lift than the symmetrical airfoil, it is also clear that additional lift produced in addition to an aerodynamically clean design will further extend glide.

Additional evidence was observed to support the idea that Newton's 1<sup>st</sup>. and 3<sup>rd</sup> Laws of Motion<sup>3</sup> play a greater role in flight performance of small foam airplanes than Bernoulli's Principle. The stall test did not display the abrupt type of stall that would normally be expected from a Symmetrical airfoil. Newton's 3<sup>rd</sup> Law of Motion indicates that the force exerted on the bottom of the wings as they fall through space is equal, so most

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<sup>2</sup> The Bernoulli principle states that the internal pressure of a fluid decreases as its velocity increases. This principle is used in many everyday objects, including spray paint cans and airplane wings.  
<http://www.seed.slb.com/qa2/FAQView.cfm?ID=976>

<sup>3</sup> Newton's first law states that every object will remain at rest or in uniform motion in a straight line unless compelled to change its state by the action of an external force.

The third law states that for every action (force) in nature there is an equal and opposite reaction.  
<http://www.grc.nasa.gov/WWW/K-12/airplane/newton.html>

airfoils would display similar stall characteristics. This idea was supported by the fact that even the worst performing airfoil in the stall category exhibited a stall with very manageable characteristics for all average pilots.

### **Airfoil Performance Summary**

Of the eight airfoils evaluated, there were four airfoils that were considered to be the top contenders. Listed in the order they appear on the chart, they are: Symmetrical, Top-Step KF 50%, KFm3, and Clark-Y.

The **Symmetrical airfoil** created an airplane that had very good all around flight characteristics. The plane was very well mannered as it grooved through our test flight. It's only real weaknesses were that it wouldn't fly as slowly as the others tested, and it didn't like flying in a high alpha attitude. The symmetrical foam wing is best suited for aerobatic aircraft not required to fly well slowly.

The **Top-Step KF 50% airfoil** was another all around great performer. The strength of this airfoil seemed to be its slow flight performance without sacrificing good handling in the other categories. This airfoil received the top scores in the three categories that pertained to slow flying. It also tied for a top score in pitchiness, and was the best performing airfoil flying inverted. There were no glaring weaknesses for this airfoil, but its weakest points were top speed, roll rate, and glide. The Top-Step KF 50% foam wing is best suited for aircraft requiring good performance over a broad flight envelope.

The **KFm3 airfoil** was a great all around performer as well. The KFm3 produced the best score in the adverse yaw

category and it was also the best performing airfoil of the stepped varieties in the glide category. This airfoil was very similar in flight performance to the Top-Step KF 50%, though the previous airfoil edged it out slightly in the slow flight and inverted categories. The KfM3 foam wing is also best suited for aircraft requiring good performance over a broad flight envelope.

The **Clark-Y (Flat Bottom) airfoil** was recently evaluated and added to the airfoil study. It immediately became clear why the venerable Clark-Y airfoil is a favorite. This airfoil is a high lift, low drag champion taking top honors in slow speed flight, and glide. Its weakest performance came in the high alpha flight and stall categories due to its tendency to wallow or drop a wing. The Clark-Y foam wing will best suite aircraft designed for top performance in high lift and low drag. It is also an excellent choice for gliders.

The **Flat-Plate airfoil** was a good performer in most categories. Its strengths were in speed and roll rate while its weaknesses were in pitchiness and the slow flying categories. Nearly everyone who has flown a RC foam airplane has experience with the flat plate airfoil, so these strengths and weaknesses shouldn't come as a surprise to most reading this review. The flat plate airfoil is best suited for airplanes designed with an objective for simplicity, yet delivering reasonably good flight performance.

The **Bottom-Step KF 40% airfoil** was also a good all around performer. In fact, the scoring for the Bottom-Step KF 40% airfoil tied with the symmetrical airfoil score. The roll rate and inverted flight performance were the weakest performance categories of this airfoil.

Those weaknesses along with the fact that the flight characteristic strengths of this airfoil were equal or better in one of the two top-step KF airfoils was the reason this airfoil didn't get a better recommendation. The Bottom-Step KF 40% foam wing is best suited for aircraft designed for good slow flight characteristics, yet is not expected to deliver a high level of maneuverability.

The worst handling airfoil evaluated was the **Bottom-Step KF 50%**. To my knowledge, nobody has suggested placing a bottom step at the 50% location on the wing, but the reason it's not recommended was made clear in this study. This wing made the airplane a complete frustration to fly. Though the scores indicate that it faired nearly the same as the Flat-Plate, it wasn't even close. The only reason the Bottom-Step KF 50% fared as it did in the scoring is because it did a few things well, and negative scores were not permitted by the scoring system in the other categories. A Bottom-Step KF 50% airfoil is not a recommended airfoil to use in any aircraft.

The **Top & Bottom-Step KF 40% airfoil** was recently evaluated and added to the airfoil study. It was immediately obvious that this airfoil displayed a high level of drag when compared to other popular KF designs. It was also noted that this airfoil didn't really excel in any specific area. The airfoil suffered poor performance in top speed, glide, and roll-rate categories. Since the airfoil design had equal steps on both the top and bottom surfaces of the wing, the airfoil flew like a high drag symmetrical airfoil. It should be noted that aileron authority diminished considerably in high alpha inverted slow flight. This airfoil is best suited for

aircraft designs seeking improved slow flight characteristics over the traditional symmetrical airfoil.

### **Additional Considerations**

When reviewing airfoil options, there are additional considerations that may factor into the decision making process. One such category is cost and materials. The Flat-Plate airfoil had the most expense due to the fact that carbon fiber is required to strengthen the wing. Each of the other types of airfoils were assembled using much cheaper spruce for the wing spar. Since each of the other airfoils had a spar glued between the top and bottom skins, the airfoils had sufficient strength without requiring the use of carbon fiber.

Another consideration for airfoil selection is building ease. The Flat-Plate wing is by far, the easiest wing to build. It requires little more than cutting the wing shape, creating a slot for the carbon fiber reinforcement, and gluing the carbon fiber in place. All of the KF airfoils were on par with regards to difficulty. Since the KF versions required two skins, a spar, and taping the leading edge, they are a bit more difficult to create than the Flat-Plate. The Symmetrical airfoil was the most difficult since it required all of the same elements as the KF airfoils, plus attention had to be given to ensure the camber was equal on the top and bottom skins.

### **Conclusion**

It was enlightening and beneficial to perform the airfoil comparison test because, testing each airfoil on a fuselage that remained unchanged provided insight on how these airfoil varieties perform relative to each other. It was

interesting to note that of the four top performers, two were traditional airfoils, and two were of the stepped variety.

Evidence was collected indicating that glide performance improvements were better achieved through drag reduction than improved lift. Additionally, it appeared that wing area had a greater impact on stall characteristics than the shape of the airfoil.

Since all of the wings produced for this study were inexpensive, and rather simple to assemble, the differences noted were for that sake of thoroughness, and should not preclude the average builder from selecting the airfoil of their choice.

Just as the airfoil shape had a significant effect on the way the other controls responded, other aircraft design elements can have an effect the way an airfoil appears to respond. This is the reason this study attempted to isolate the airfoil characteristics by the neutral design of the XTB craft. However, other aircraft design elements can accentuate, compensate, or detract from these observed airfoil traits.

It's clear from the results of this study that the various thicker airfoil types offer improved flight characteristics over a Flat-Plate design. It is also clear that the various KF designs offer improved flight performance in all areas pertaining to slow flight performance, but at the expense of additional drag. Additionally, the scoring table provides information for airfoil selection that can be used to match an airfoil to an aircraft's intended flight envelope or your preferred flying style.



**XTB with KfM3 wing installed**

### **Summary of Stepped Airfoil Characteristics**

It is my belief that it is possible to summarize the general performance changes that can be expected if selecting a stepped airfoil over the flat plate variety for radio controlled foam airplanes.

- Reduced pitchiness due to the increased thickness of the leading edge
- Handling in windy flight conditions is improved
- The step improved slow flight characteristics
- The step increased drag
- The step reduces aileron response
- The height of the step is proportional to the improvement in slow flight
- The height of the step is proportional to the increase in drag
- The height of the step is proportional to the reduction in aileron response

***NOTE: There is a point of diminishing returns relative to the proportional rules of thumb.***

In addition to the performance changes, the stepped airfoils produce a very strong wing without the need for expensive spar materials (i.e. CF) and the majority of the stepped designs are exceedingly simple to build. The spars may be spruce, balsa, or even foam, depending on the application.