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NEWSLETTER

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ISSUE 305 JANUARY 31, 2012

Why Should You Airfoil Your Fins?

By Bart Hennin

This newsletter article will show you (in simple terms) how to design extremely low drag model rocket fins that are also highly efficient aerodynamically. This means your rockets will look more professional, fly higher, faster, and straighter, and recover from in-flight disturbances (such as wind shear) much more quickly!

A comprehensive review of fin shape and fin airfoil theory as applied to model rockets is beyond the scope of this single article. But we WILL review the basics so you can design a wide variety of maximum efficiency fins for any number of your favorite model rockets.

Our design choices for our fins will be based not only on what works, but on what we want to accomplish: Do we want to go for maximum altitude or maximum speed? Do we want to go supersonic or stay subsonic? How can we change the fin's cross-section to give it added strength without sacrificing good aerodynamics?

We will also discuss how to modify existing model rocket fin designs (when assembling a kit, for example) to get much better flight performance out of our models.

In designing a model rocket fin (or modifying existing kit fins) we need consider three things: fin plan-form shape, fin cross-section shape (airfoil), and fin radial taper.

Plan-Forms? Airfoils? Radial Tapers? ... Are They Worth The Bother?

Selecting a proper fin plan-form and to a larger extent, adding a proper airfoil and radial taper to your rocket's fins can take a little additional effort but it's WELL WORTH IT!

Most model rocket kit photos today show the rocket fins with "squared" edges (perhaps because it's the easiest and fastest to do). However, this is generally the worse (by far!) fin design to use. Simply "rounding" your fins' leading and trailing edges can reduce the "*fin drag"* dramatically (up to 75% less than squared edges).

Moreover, adding an efficient airfoil shape to your fins can further reduce fin drag up to 85% less than that of round edge fins (or up to 96% less than fins with squared edges). This means your model rockets will fly faster and much higher!

The additional advantages of efficiently designed fins are as follows...

- Your fins will produce MORE "lift force" at smaller angles of attack and so bring the rocket back on course more quickly.
- Your rockets will have superior dynamic response - They will recover from in-flight disturbances (such as wind shear) much more efficiently.
- Your fins will produce much less induced drag - "Induced drag" is the additional drag produced when a fin is at an angle of attack (and thus generating a course correcting "lift" force in response to an in-flight disturbance).
- Because we have lighter fins (when airfoiled), we have less mass at the tail end of the rocket which increases the stability margin of the model.
- The reduced tail mass ALSO reduces the "longitudinal moment of inertia" of the rocket which (without getting technical) improves the rocket's dynamics such that it corrects its course faster and more efficiently (ref *Peak Of Flight Newsletter #192* http://www.apogeerockets.com/education/downloads/Newsletter192.pdf).

The result is that your rocket will spend a significantly larger portion of its flight flying vertically (which increases peak altitude). Also, a considerably larger portion of the rocket's "energy" is conserved (not lost to drag) which again increases peak altitude (and speed).

PLUS... In the case of scale models, your fins will look much more detailed and realistic!

With all the above benefits, it's well worth taking the time to select and build a proper fin design for all of your model rockets.

Fin Plan-form - Which Is Best?

The short answer is....it depends. What are we trying to accomplish? *{Tim's Note: It also depends on the size of the fin. See Technical Publication #16 at: http://www.apogeerockets.com/technical_publication_16.asp}*

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Is it: 1) aerodynamically efficient, 2) strong, and 3) "buildable"?

We must also choose a fin plan-form shape that is consistent with the speed regime our rocket is flying. A fin that is efficient at subsonic speeds (speeds slower than sound) will be extremely inefficient at supersonic speed (speed faster than sound) and vice versa.

At subsonic speeds (which covers most model rockets), an elliptical plan-form shape is (theoretically) the most efficient. If you want proof, look at the wing and tail shape of the very fast, highly maneuverable British WW II Spitfire (refer to photo 1).

In practice, however, this shape is very difficult to build (especially with an associated proper airfoil!). A more practical fin shape that is virtually as efficient as an elliptical fin (but much easier to build and add an airfoil to) is the so called "clipped delta" Plan-form. Although the elliptical shape is "technically" slightly more efficient then the clipped delta, the difference in performance is so very tiny as to be negligible in practice. The geometry of a "clipped delta" fin is shown in figure 1.

Photo 1: Bristish Spitfire with its elliptical wing shape.

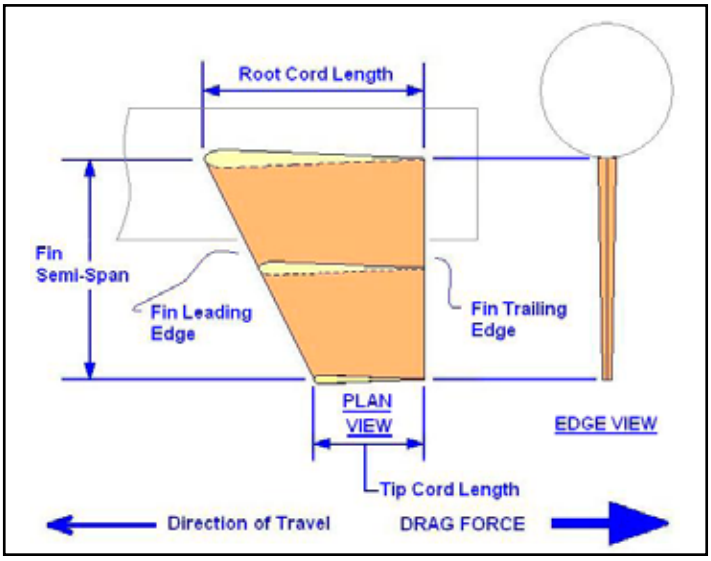

Figure 1 " Typical "Clipped Delta" fin

Referring to figure 1, we recall that a fin's "root edge" is the edge of the fin that is glued to the rocket's body. Its "tip edge" is the fin edge opposite (farthest away from) the "root edge". Similarly, a fin's "leading edge" is the front or forward edge of the fin and the fin's "trailing edge" is the back or rearward edge of the fin.

British WW II Spitfire " The Spitfire's aerodynamically efficient elliptical wings and tail surfaces gave this aircraft its legendary speed and maneuverability

The fin's "semi-span" is the length measured perpendicular from the fin's root edge to the fin's tip edge (in other words, the radial distance the fin extends outwards from the rocket's body tube).

The fin's "cord length" is simply the distance from the

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fin's leading edge to the fin's trailing edge (measured parallel to the rocket's body tube). This distance can of course vary as we move across the fin's semi-span (as is the case for the clipped delta).

An efficient "clipped delta" fin typically has a "fin root cord length" equal (or roughly equal) to its "semi-span length". The "fin tip cord length" is typically half the "root cord length".

One is of course free to play around a bit with these dimensions (see "aspect ratio" below) but the above length ratios will generally give you a good starting point providing a solid balance between strength requirements and aerodynamic efficiency.

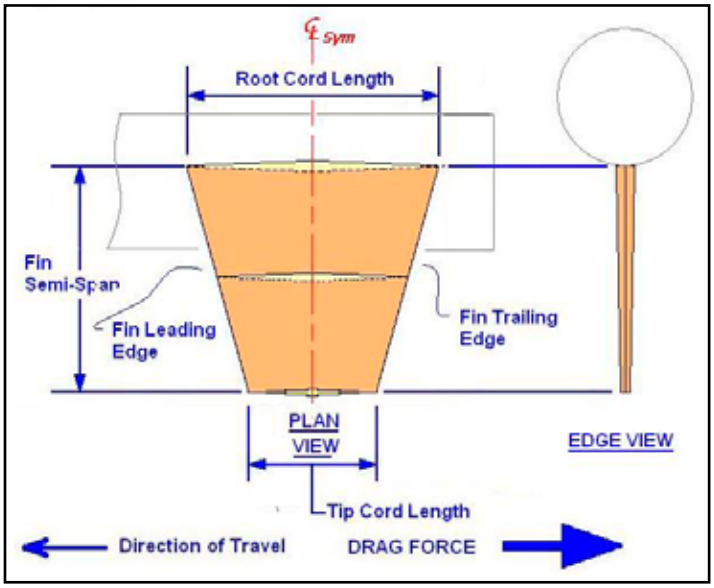

Figure 2: Typical "Symmetrical Trapezoid" fin.

At supersonic speeds, an optimum Plan-form shape is the "symmetrical trapezoid" whose geometry is shown in figure 2.

Whereas the "clipped delta" fin is swept back on its leading edge only (with its trailing edge left straight), the "symmetrical trapezoid" is swept back on its leading edge and also swept forward on its trailing edge. The sweeps are symmetrical.

You'll see this type of fin on many real rockets, like the Nike Ajax (ref photo).

So which plan-form should we use? Well, if your model

Photo 2: Nike Ajax Two Stage Surface To Air Missile. Note the symmetrical trapezoid fins on the booster.

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rocket is subsonic (the most likely case) and you want to optimize for speed and/or altitude, you'd likely want to pick the "clipped delta" plan-form. Of course if you are building a scale model of a supersonic rocket such as the Nike Ajax and want the rocket fins to look like the real thing, you'd pick the symmetrical trapezoid layout (but then you are no longer optimizing for speed/altitude but for "looks", which is also a fine goal!).

So you may ask, "If my rocket can potentially go from subsonic to supersonic speed, which speed regime should I optimize for? That's a good question. Again in selecting a fin design, we look at what our GOAL is.

If our goal is to achieve the 'highest altitude', we'd choose to optimize the model for SUBSONIC speeds (since the rocket will indeed spend MOST of its flight time in this speed regime even if it does go supersonic momentarily).

On the other hand, if our goal is to maximize SPEED (and specifically we WANT to go supersonic) then we'd choose to optimize the model for SUPERSONIC speeds since we no longer care about altitude. We just want that extra "push" to punch through the sound barrier (no matter how briefly).

By the way, if you've never gone "supersonic" but would like to, Apogee's cool looking Aspire rocket kit CAN DO THIS! http://www.apogeerockets.com/aspire_rocket.asp#supersonic. On this page you'll also find a link to a FREE technical report that tells you how to build the Aspire to go supersonic!

Just remember... when our goal is to maximize speed, the rocket's final altitude will be reduced because higher speeds produce tremendously higher drag forces (even with aerodynamically efficient fins!).

To see exactly WHY higher model rocket speeds translate into LOWER peak altitudes, you can check out Apogee's FREE technical publication #1 located here: http://www.apogeerockets.com/technical_publication_01.asp

Aspect Ratio

One final factor to consider when choosing (or designing) a fin plan-form shape is the fin *"Aspect Ratio"*. This parameter is basically an indication of the fin's "slenderness" (ref figure 3 for a visual example of aspect ratio).

The specific definition is

Aspect Ratio = Fin Semi-Span^2 / Fin Area

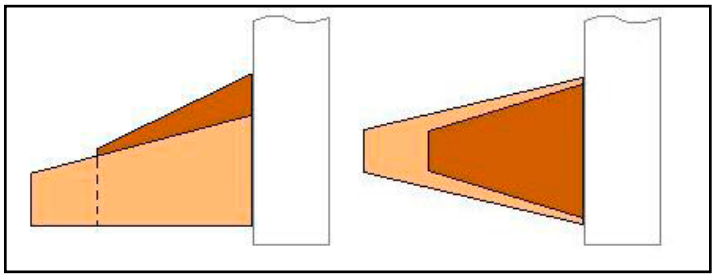

Figure 3 - Aspect Ratio Illustrated " The two schematic examples above illustrate fin "Aspect Ratio". In each example, the light colored fins have a HIGHER Aspect Ratio (are more slender) than the dark colored fins.

All else being equal, a higher aspect ratio fin will be more aerodynamically efficient then a lower aspect ratio fin.

Here's why. Air flowing close to the rocket body tube tends to be turbulent. Air farther away from the body tube tends to have smoother flow. Fins work most efficiently in smooth airflow. Since, generally speaking, higher aspect ratio fins "reach" into air farther away from the rocket's body tube MORE of the fin ends up in SMOOTH airflow, increasing the fin's overall efficiency!

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HOWEVER THERE'S A CATCH. Higher aspect ratio fins tend to be structurally WEAKER than low aspect ratio fins. High speeds compound the problem! So again we must strike a balance between strength and aerodynamic efficiency.

As said above, one is free to play around with fin plan-form dimensions but we ALWAYS want a good balance between strength requirements and aerodynamic efficiency. A good rule of thumb is to not let the fin semi-span exceed the fin root cord by very much more than 1 - That is the fin semi-span length should NOT be "a lot longer" than the fin root cord length AND the fin tip cord shouldn't be "much less" than HALF the fin root cord.

For further detail on how "strong" your fins should be, refer to Tim Van Milligan's book *Model Rocket Design & Construction.* http://www.apogeerockets.com/design_book.asp

Note that although the above illustrates "optimum" fin plan-forms, you are NOT required to restrict yourself to using only these shapes (although if you are building model rockets for altitude or speed contests you would be much more restricted).

If you are not building "competition" models and you simply LIKE the look of those radically swept back fins, or you have a kit that has fins of a different shape, you need not fret.

A fin's aerodynamic efficiency and low drag characteristics are affected more by fin cross section (airfoil) than plan-form. This means you can "SUPE UP" any model rocket kit (with virtually any type of fin plan-form) simply by adding a good airfoil to your kit fins!

Airfoil Geometry " What Exactly IS an Airfoil?

An "airfoil" is simply a curved or tapered fin cross section that allows air to travel over the rocket fins much more easily.

Below, we will review the basic geometry of model rocket airfoils and also illustrate some optimum airfoil cross sections for the benefit of rocketeers who wish to maximize flight performance of any model rocket (including kit models).

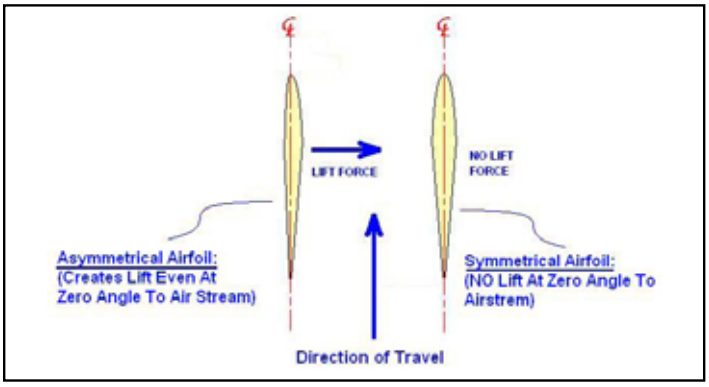

Figure 4: Asymmetrical airfoils produce lift even at zero angles of attack which is UNDESIRABLE For Model Rockets (unless you're trying to induce a spin).

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Airfoil Geometry: The most basic requirement for model rocket fin airfoils is that their cross sections must be as symmetrical as possible (reference figure 4).

This is necessary so that NO lift forces are generated when the rocket is at zero angle of attack (in other words, if our model rocket is flying straight, we don't want the fins providing any side forces that may cause the rocket to spin and/or deviate from its course!).

A second basic requirement, when making fin airfoils, is that all of the model rocket's fins should be as identical as possible. Differences in fin geometry from one fin to the next on the same model rocket can create "asymmetrical drag" which may cause the rocket to spin and/or deviate from its proper course.

Any spinning or deviation from straight vertical flight robs the rocket of energy (in the form of increased drag and/or non-vertical flight) which would otherwise go towards increasing the rocket's altitude (and speed).

Figure 5 lays out the basic geometry of a typical model rocket fin airfoil. This is the geometry that seems to work best for rockets traveling at subsonic speeds.

First, we recall again that "cord length" is the measured distance from the fin's leading edge to its trailing edge. We also recall that "fin semi-span" is the distance from the

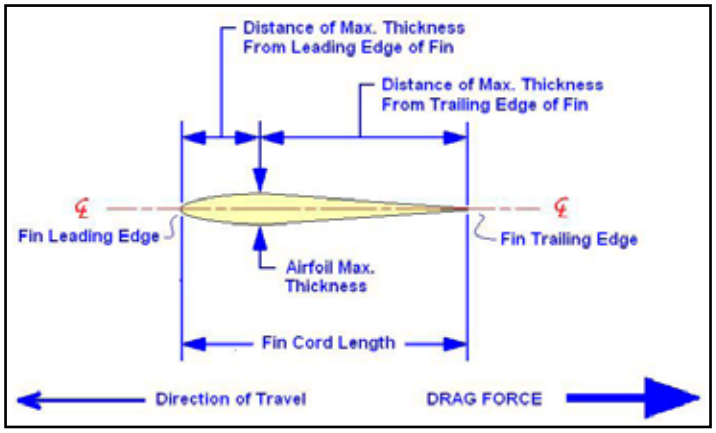

Figure 5: Typical Airfoil Cross Section Commonly Used For Model Rockets In The Subsonic Flow Regime (Fin Thickness Exaggerated For Clarity).

root edge of the fin (the edge that contacts the rocket body tube) to the fin tip edge (the part of the fin farthest out from the rocket body tube).

Notice from figure 5 that the fin's leading edge is rounded. The trailing edge is sharp. There is a fin maximum thickness that occurs at a fixed percentage of the fin cord length back from the leading edge.

For a rocket traveling at subsonic speeds the above

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geometry generally gives fins a very low drag profile and a very efficient dynamic response ability to counter in-flight disturbances.

NOTE: Technically speaking, the (theoretically) best fin leading edge shape is a parabolic taper from leading edge back to fin maximum thickness. HOWEVER (like in the case of an "elliptical plan-form" discussed earlier) a parabolic cross section is impractical to build accurately. In fact, a spherically rounded leading edge with flat tapers works just as well for all practical purposes.

The question arises, "What is the optimum distance back from the leading edge for maximum thickness to occur?"

The answer is...it depends. Again we need to consider the "speed regime" of the model rocket we are flying. We need to ALSO consider the "angles of attack" the fins are likely to encounter (again "angle of attack" is the angle at which the fin is tilted relative to the direction of airflow).

Let's consider the angle of attack first. From wind tunnel tests, we know that basically the larger the fin's angle of attack, the larger will be the corrective "lift" force generated (and the larger will be the corresponding "induced drag" force generated). If the fin's angle to the airflow becomes large enough, the airflow will "separate" from the fin and lift will suddenly fall off to practically zero. This is called a "stall" and the angle of attack at which this occurs is called the "stall angle".

A model rocket that experiences a "stall" will generally tumble out of control. Such an occurrence usually results from models whose stability margin is too low for wind conditions. In some cases, a model rocket that is sufficiently stable on a calm day may become unstable on a windy day! (reference http://www.apogeerockets.com/education/instability.asp).

Interestingly, an airfoil (because it generates lift more efficiently) can increase the fin's effective "stall" angle. This is desirable because it essentially increases the amount by which a model rocket can rotate and still correct itself rather than "stalling" and tumbling out of control. MORE importantly, an efficient airfoil acts more quickly to correct the rocket's flight path reducing the angle of attack significantly.

The biggest factor affecting a fin's stall angle is the fin's leading edge radius - The larger the better. This would seem to imply we want the fin maximum thickness to occur as close to the fin's leading edge as possible (as shown in figure 6) as this creates the largest leading edge radius.

This type of airfoil consists of a spherically rounded leading edge with 100% cord length taper from fin maximum thickness at the leading edge to a sharp trailing edge. This airfoil is by its nature also the SIMPLEST to make since there are NO leading edge tapers needed.

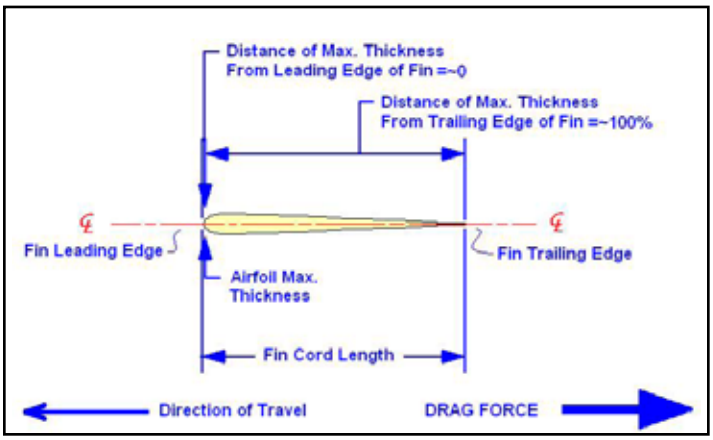

Figure 6: Simplest airfoil cross section. Allows for maximum Leading Edge Radius (fin thickness exaggerated for clarity).

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Though this fin gives us the maximum stall angle and also lower drag (than a flat fin with rounded leading and trailing edges), there is also the speed regime to ponder.

Most model rockets fly subsonic. Again from wind tunnel tests, it's found that drag is minimized when the fin maximum thickness occurs at 25% to 33% (1/4 to1/3) of the fin cord length BACK from the fin's leading edge. Granted, this shallows up the fin's stall angle a bit, but fortunately (unlike airplane wings), model rockets encounter relatively small angles of attack. Thus, it is a sound engineering 'trade-off' to set the maximum fin thickness back from the leading edge (and settle for a marginally smaller leading edge radius and slightly smaller stall angle to get a significant reduction in drag).

For all practical purposes, the difference between full thickness occurring at 25%, 33%, (or any value in between) back from leading edge is negligible. That is, two identical model rockets will fly essentially just as well whether their respective fin airfoil maximum thicknesses occur at 1/4 of, or 1/3 of the fin cord back from the fin's leading edge.

The IMPORTANT thing is, once the placement of fin maximum thickness is chosen, we must keep that placement CONSISTENT across the entire fin semi-span. If 25% of root cord back from fin leading edge is chosen as the place for maximum thickness, then we must keep the maximum thickness at precisely 25% at every point across the fin semi-span.

Of course producing such an airfoil shape requires some added effort as we now need to create not only the applicable trailing edge tapers but also the corresponding leading edge tapers. However, this is very doable! You can refer to Tim Van Milligan's book Model Rocket Design & Construction http://www.apogeerockets.com/design_book.asp to learn how to make these airfoils.

Airfoil Geometry For Supersonic Speeds

For model rockets that do go supersonic, a typical optimum airfoil shape often seen is the symmetrical diamond cross section (reference figure 7). Again we are free to choose the fin's maximum thickness at any fractional point of the fin cord but 50% of fin cord is optimum. Also, whereas a "rounded" leading edge has lower drag at subsonic speeds, a SHARP leading edge is best at supersonic speeds.

So we now have defined optimum (or very near optimum) fin cross-sections for both subsonic and supersonic speed regimes. Next, we'll consider how strength and stiffness of fin material may affect our selection of airfoil cross-section.

Strength Considerations & Fin Flutter

In deciding upon an airfoil cross section, we must always consider the strength and stiffness of the fin mate-

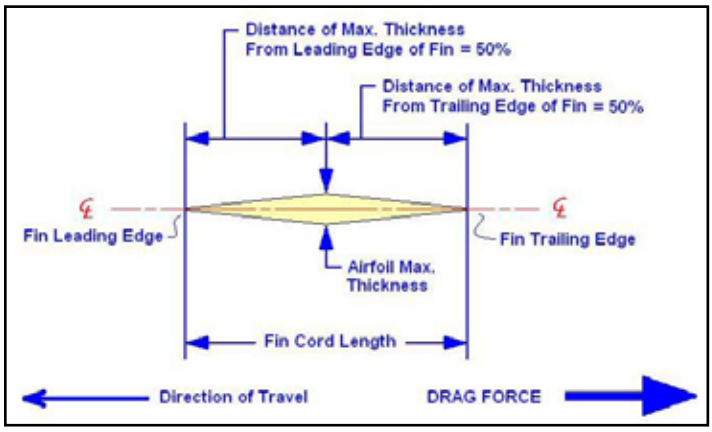

Figure 7: Symmetrical diamond cross section. Most efficient at transonic & supersonic speeds.Maximum fin thickness occurs at 50% cord length (fin thickness exaggerated for clarity).

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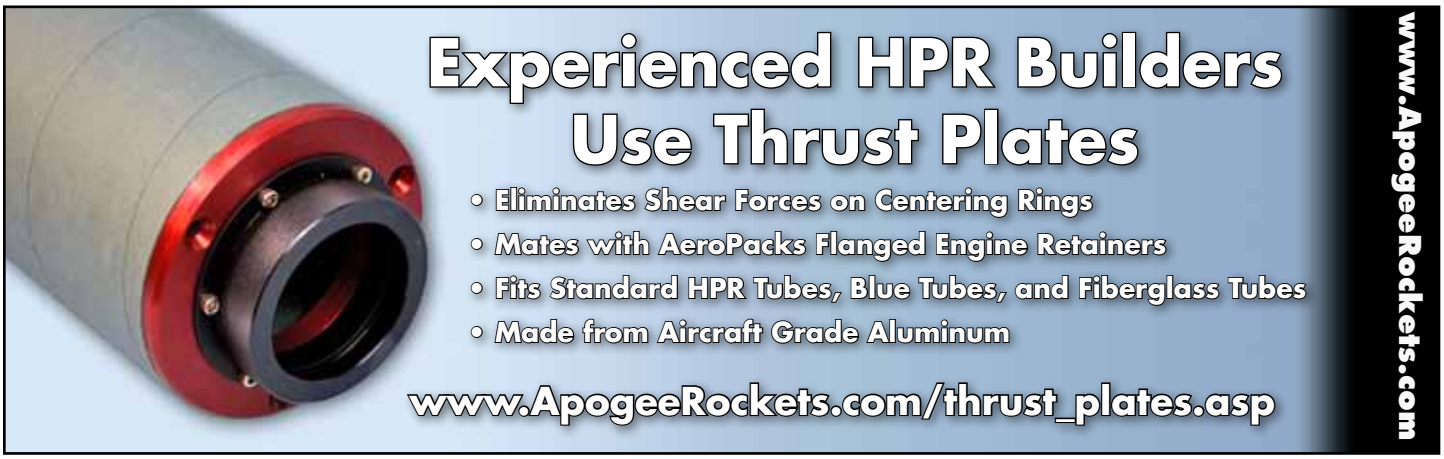

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rial. Sometimes the optimum airfoil shape fails to leave the fin with enough thickness to have sufficient strength and rigidity.

Thin sections of fins are not only less strong, but are also more susceptible to vibration. If the vibration frequency happens to occur at the natural frequency of the fin (which is a function of rocket speed, fin geometry, and material "rigidness") this can lead to a phenomenon called "fin flutter", which greatly increases the fin's drag (more than canceling any aerodynamic advantage of the airfoil). In some cases "fin flutter" can shatter the fins while the rocket is in flight! (reference Apogee Peak Of Flight newsletter #291 to learn more about fin flutter - http://www.apogeerockets.com/education/downloads/Newsletter291.pdf).

Thus, in order to have safe flights, we sometimes may need to forgo an "aerodynamically optimum" airfoil in favor of a cross section that is STRONGER and/or STIFFER but still offers SOME aerodynamic advantage.

For supersonic rockets, a good example of a higher strength, stiffer cross section (that still gives a solid aerodynamic advantage - i.e. lower drag) is called the "symmetrical double diamond" and is shown in figure 8.

This cross-section is a simple modification of the symmetrical diamond cross section (shown in figure 7). All we've done is widen the leading edge and trailing edge taper angles a bit so that the maximum fin thickness is reached BEFORE the middle of the fin (in the example maximum thickness occurs at 33% cord length from both

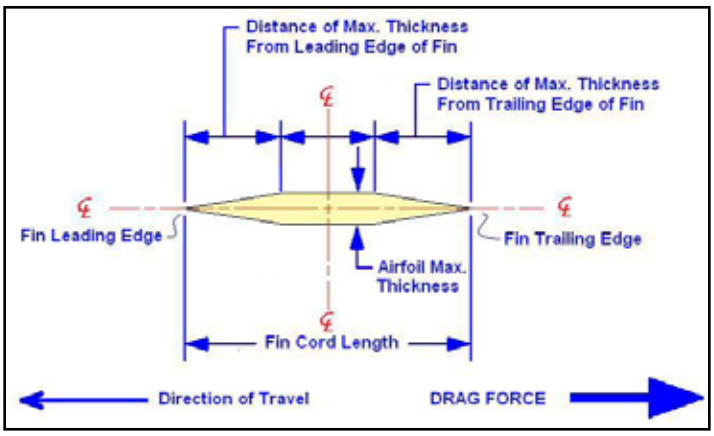

Figure 8 - Symmetrical double-diamond cross section. most efficient at transonic & supersonic speeds (fin thickness exaggerated for clarity).

leading and trailing edge but it can occur in as little as 10% or any chosen point in between).

This allows the central section of the fin to be at FULL thickness over a WIDE portion of the fin cord. This adds considerable strength and stiffness to the cross section while still retaining much of the supersonic aerodynamic advantage!

For supersonic speeds, it's still best to have leading and trailing edges (wedges) come to as sharp an edge as is practical. It's also best to keep the leading and trailing edges symmetrical (equal angles, extended over equal percentage of fin cord). This puts the maximum thickness

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section of the fin in the central part of the fin cross section.

Many real rockets (which DO go supersonic) feature fins with symmetrical diamond or symmetrical double diamond cross sections. So if you build scale models, you'll run into these! Again the booster stage fins of the Nike Ajax surface to air missile (see photo) are an example of a symmetrical diamond cross-section design.

SO... If one wants to ADD strength to a supersonic fin, one can decrease the percentage of cord length (from the leading and trailing edges) where maximum thickness occurs from 50% to 33% , 25%, 10%. etc.

Conversely, if one can afford to sacrifice some strength, one can increase the percentage of cord length (from the leading and trailing edges) where maximum thickness occurs. That is, instead of having your wedges run 33% of cord length, you can have them run 40%... or 45%.

The lower the percentage of cord length you choose to extend your wedges, the lower the corresponding aerodynamic advantage of the fin cross section but the HIGHER the strength of the fin. The limiting case of course is choosing 0%, which results in the poorest aerodynamics at greatest fin strength.

Similarly, we can modify a fin airfoil for a subsonic model rocket to add strength and stiffness to the fins and still retain a significant aerodynamic advantage. A very good "strength added" type fin for a subsonic model rocket is illustrated in figure 9.

Our desire is to increase the strength of the fin while retaining as low a drag a profile as possible. Just as we did with the previous supersonic fin example, we add strength and stiffness to our subsonic fin by extending the thicker portions of the fin cross section.

We recall that we can make the leading edge taper as

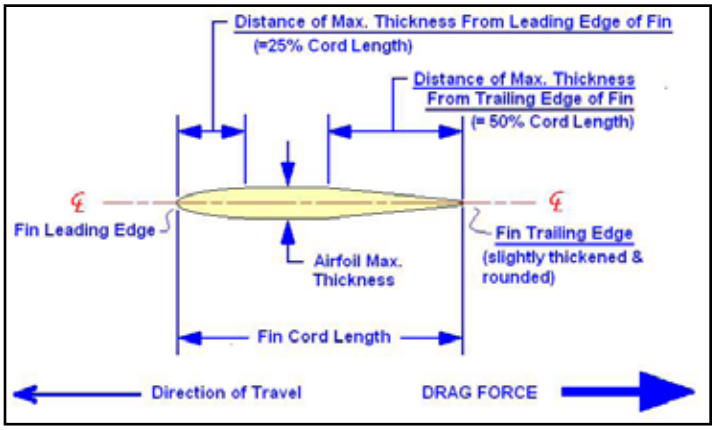

Figure 9: Beefed-up subsonic airfoil (fin thickness exaggerated for clarity).

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small as 25% of the fin cord length without losing any significant aerodynamic advantage, so this is where we choose our leading edge tapers to end. We then extend the fin's full thickness another 25% of fin cord back, making our trailing edge tapered span only 50% of the fin cord length (instead of 75%).

Shortening the fins' trailing edge tapers means 1) we have more of the fin at full thickness and 2) we have a higher average thickness (and thus stiffness) of the trailing edge taper.

One additional good option is we can also slightly thicken the trailing edge a bit and round it off.

ASIDE: If you've viewed many of the Apogee website "How To" videos, you'll already know that you can also add strength and stiffness to fins by coating their thinner tapered sections with water thin CA glue. The glue soaks into the fin wood fibers and binds them more strongly together (after the CA is dry, you re-sand the fin smooth).

Again, once you've decided which airfoil shape you want to use, you can refer to Tim Van Milligan's book Model Rocket Design & Construction for techniques on how to make these airfoils http://www.apogeerockets.com/design_book.asp. Just modify the techniques as needed to get your desired cross section!

What Is The Benefit Of A Radial Taper And When Do We Need One?

Radial tapers are desirable for reducing the aerodynamic drag on your rocket fins by keeping the fins airfoil section (or ANY other chosen fin cross-section) constant across the span of the fins (i.e. from root to the tip).

Consider figure 10, which compares two airfoiled fins where one fin (left in diagram) has NO radial taper and the other (right in diagram) DOES have a radial taper.

Note that on the non-radial tapered fin the airfoil gets "fatter" towards the fin tip. In other words, the "slope" of

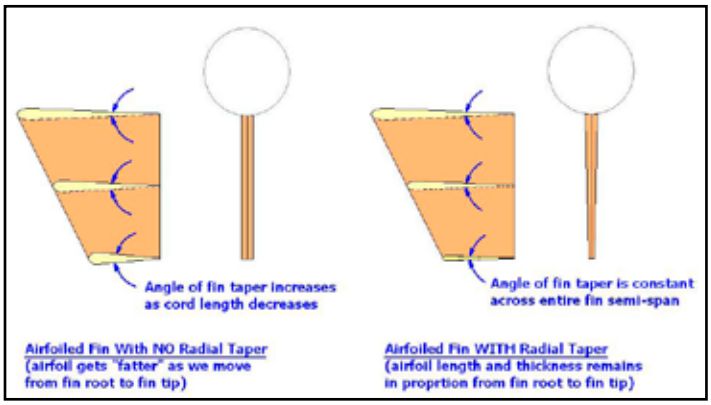

Figure 10: Radial tapered fins (right) versus non-radial tapered fins (left).

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our fin airfoil taper is not constant across the entire fin semi-span. Instead, the slope of the fin airfoil taper *INCREASES* as the fin cord shrinks. That is undesirable.

We'd LIKE to keep our airfoil slopes constant across the entire fin semi-span (see figure 10, right side). We do this by applying a radial taper to the fin so that its thickness decreases uniformly along the fin's semi-span. This results in an airfoil slope that remains unchanged from fin root to fin tip.

Specifically, we want a radial taper where the ratio of fin tip thickness to fin root thickness is equal to the fin tip cord length divided by the fin root cord length. In other words, if our fin tip cord is HALF the fin root cord, we want our fin tip "thickness" to be HALF our fin root cord thickness.

For information on how to apply radial tapers to your model rocket fins refer to *Peak Of Flight newsletter #271* www.ApogeeRockets.com/education/downloads/Newsletter271.pdf. It shows how you can build and use a sanding jig to create precise radial tapers for all of your model rocket fins.

An easy way to "picture" what we are saying above is to actually think of the fin airfoil cross-section as an actual "picture." If we reduce the size of a photograph by making it narrower, but leave the height unchanged we end up with a distorted image. To preserve the proportions of any reduced image, we must shrink it by the same proportion in both the width AND the height directions.

So, if our fin tip length is HALF the fin root length, we are in essence "shrinking" our airfoil in the horizontal direction by 50%. To preserve airfoil's "proportions" we must also "shrink" the airfoil's vertical dimension (fin thickness) by the same amount.

Interestingly, you can use the same fin sanding jig shown in newsletter #271 to sand precise airfoils into your fins too. Complete instructions to do ALL types of airfoils may be addressed in future newsletter issues. But for now, let's briefly consider the simplest airfoil as an example (ref figure 6) and see how we might use the sanding jig shown in newsletter #271 to make it.

Recall that this is the airfoil with no leading edge tapers. It consists of a rounded leading edge with only a trailing edge taper running over 100% of the fin cord length.

Let's assume we've selected (per figures 6 & 10) a "clipped delta" plan-form with the fin tip cord length being HALF the fin root cord length. This means, as we said above, that we need to apply a radial taper to our fin so the fin tip thickness is half the fin root thickness (i.e. 1/4 the fin thickness is removed from each side of the fin). Pages 12-14 of newsletter #271 illustrate how to do this.

Once our radial taper is done, we can simply rotate the fin (in the sanding jig) by 90 degrees and follow essentially the same instructions to apply the airfoil taper. The difference is, where we were sanding a radial taper across the fin's semi-span to HALF the root thickness, we are NOW sanding a taper across the fin's root cord length to zero thickness (sharp trailing edge).

The sanding jig shown in newsletter 271 essentially uses two "metal tipped walls" (set to different heights and specific widths apart) to give us a well-defined and precise sanding slope.

For this airfoil (reference figure 11), we would set our lower wall to zero height and our upper wall to double the fin maximum thickness height (using wood stock the fins came from to measure this height).

NOW, if we set our clipped delta fin with its trailing edge

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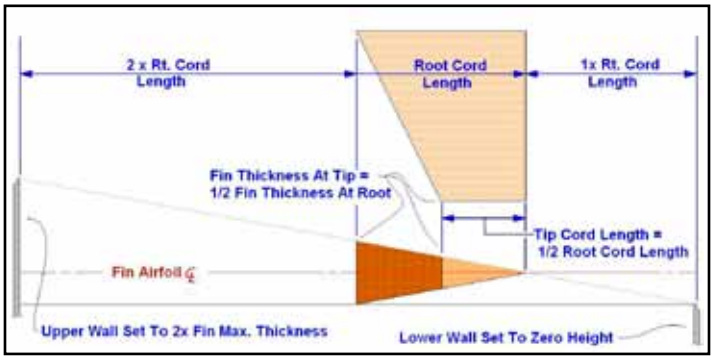

Figure 11: Using a radial taper sanding jig to also sand airfoil tapers (thicknesses exaggerated for clarity)

parallel to the lower wall but 1 root cord length away from the wall (reference figure 11), and set our upper wall TWO root cord lengths ahead of the fin's root cord leading edge, we would get the proper sanding slope to do our airfoil (by similar triangles).

The side view of the fin shown schematically in figure 11 illustrates that the airfoil sanding slope is the same across the entire fin semi-span. The light tan area represents the side view of the fin tip and the dark tan area, and the light tan area represents the larger (double size) fin root cross section. They are "similar triangles", which is why the sanding slope is the same at both root and tip.

In other words, once the jig spacing is set up (based on root cord length) to give the proper sanding slope for the airfoil, we're good for the entire fin semi-span because (for a radially tapered fin) the slope of our airfoil taper is CONSTANT across this entire semi-span!

Newsletter 271 also shows how to make a "shim" to keep the fin level when we sand our slope into side 2 of the fin. We would need to retain that shim to level the fin for sanding our airfoil. Then to sand side 2 of our airfoil we would need to make a 2nd 'shim' to keep the fin level. Refer to newsletter 271 for more detail.

Is It Possible To Create A Good Airfoil WITHOUT A Fin Radial Taper?

If you don't want to bother with radially tapering your fins but still want to take advantage of the superior aerodynamics offered by airfoils, you can do so! In cases where the fin tip cord length is EQUAL to the fin root cord length (that is the fin cord length stays constant across the entire fin semi-span) there is no need to radially taper the fin.

Remember that the whole purpose of having a radial taper is to keep the ratio of fin tip thickness to fin root thickness equal to the fin tip cord length divided by the fin root cord length. If the fin tip cord length is EQUAL to the fin root cord length, then the fin tip thickness is ALSO EQUAL to the fin root thickness. Thus NO radial taper is needed!

What plan-form shapes meet this criteria? There are TWO...a rectangular fin or a parallelogram shaped fin. Apogee's Publication #16 contains complete info on this. www.ApogeeRockets.com/technical_publication_16.asp

Granted, this means you will no longer have an aerodynamically "optimum" fin plan-form but as we said earlier, a proper airfoil on any plan-form fin STILL makes for much better flying!

In Summary

This article has revealed a number of "optimum fin" design ideas for you to use to create your own aerodynamically efficient, extremely low drag model rocket fins, which in turn will allow your model rockets to fly faster, higher and straighter!

Whether your goal is to "SUPE-UP" an existing model rocket kit, design your own rocket, or create your own "competition" model rockets, the fin types reviewed here will deliver great performance and give you a very good starting place for your own experimentation.

We've seen that a fin is at its optimum when it has 3 things - an efficient plan-form, a proper symmetrical airfoil and a precise radial taper. *Of these three factors, a proper symmetrical airfoil has the strongest effect on the fin's efficiency.*

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We've also seen that ideally, a fin radial taper is required when the fin's cord length varies across the fin semi-span. Specifically, the fin's tip thickness to root thickness must equal the fin's tip cord length to the fin's root cord length for any airfoil (or other fin cross section) to remain in proportion across the fin semi-span.

We can avoid the need for a radial taper by using a fin plan-form whose fin cord length is constant across the full semi-span of the fin (the two plan-form shapes that meet this requirement are a rectangle or a parallelogram).

We've also recognized that what's optimum for subsonic speeds is quite different from what's optimum at supersonic speeds.

Specifically, the "clipped delta" plan-form is an example of an optimum plan-form for model rockets at subsonic speeds and the "symmetrical trapezoid" is better for model rockets at supersonic speeds.

We've seen that when considering fin "Aspect Ratio", there is a trade off. Higher aspect ratios are more efficient BUT also weaker structurally so a 'trade off' must be made to balance strength requirements with aerodynamic requirements.

Likewise we've seen that different fin cross sections are required for subsonic versus supersonic flight. Specifically, a rounded and tapered leading edge (with fin maximum thickness occurring at 25% - 33% of the fin cord length back from the leading edge and a taper to a sharp trailing edge) is great for fins in the subsonic speed regime.

Conversely, a sharp leading edge and trailing edge (with fin maximum thickness occurring at 50% of fin cord length) is an optimum configuration for the rockets reaching the supersonic speed regime.

We've reviewed variations on these optimum fin cross sections that give higher strength to the fins, yet retain much of their aerodynamic benefit.

Even model rocket kits that have heavily swept back fins can benefit heavily from application of an airfoil and (where applicable) a radial taper to its fins.

Most importantly, we've seen that we must make our design decisions based on what our flight goals are and that any design is subject to certain "engineering trade-offs" (speed versus altitude, lower drag versus strength etc.) when selecting fin shapes and airfoils.

About the Author

Bart Hennin graduated in 1984 with a BaSc in Mechanical Engineering from the University of Windsor, Ontario. His senior year thesis was *"Optimization Of A Model Rocket For Highest Altitude"* which earned a top of the class mark of A+. Following graduation, Bart worked for several years in auto manufacturing engineering, then migrated to technical sales, and eventually ended up in general sales and marketing.

Bart is currently married and is living in New York state. Bart says that his family consists of one obnoxious cat named Thor.

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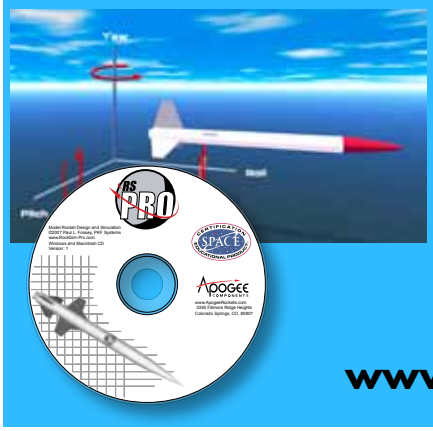

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