

Radi■ C■ntr■lled
Soaring Digest

February 2014

Vol. 31, No. 2



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Front cover: Dave Beardsley's High End reaches the peak of its climb on tow. Photo by Bill Kuhlman
Konica Minolta Maxxum 7D, ISO 100, 1/500 sec., f8.0, 500mm

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By Neal Pfeiffer

(Reprinted from *Bungee Cord*, the Voice of the Vintage Sailplane Association, Volume 39 No. 4, Winter 2013)

Back cover: NASA Image of the Day: In a view from high altitude, height can be a difficult thing to gauge. The highest of clouds can appear to sit on a flat plane, as if they were at the same elevation as the ocean or land surface. In this image, however, texture, shape and shadows lend definition to mushrooming thunderheads over the Indonesian island of Flores. The Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Aqua satellite acquired this image on the afternoon of December 2, 2013.

<<http://earthobservatory.nasa.gov/IOTD/view.php?id=82521>>

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In the Air

One of our earliest articles for *RCSD* was published in the April 1989 issue. It presented a mechanism for achieving true gapless control surfaces based on an idea by Harald Buettner of PRECOMTEC, presented at a 1986 TWITT (The Wing Is The Thing) meeting, and mentioned in TWITT Newsletter #2. A PDF of our On the 'Wing... article is available at <<http://www.rcsoaringdigest.com/OTW/on-the-wing1/14GaplessControls.pdf>>.

A similar control surface mechanism by FlexSys <<http://www.flxsys.com>> is now scheduled for testing on full size aircraft.



Wind tunnel testing at the University of Michigan
<<http://www.flxsys.com/fixedwingaircraft.shtml>>

FlexSys uses monolithic jointless compliant mechanisms for actuation and claims their system is scalable and works with a wide variety of materials including metals, GFRP and CFRP. We can envision applications in F3B, DS and other disciplines. Time to build another sailplane!

The *two* Newton 'sine-squared' laws

The first quantitative theory of wing lift, based in Newton's previous theory of comparative 'resistances' (drags).

Philip Randolph, amphioxus.philip@gmail.com

In his *Principia* Newton used a 'sine-squared' analysis to compare the resistances of a sphere and a circular flat plate to flows. That's his first 'sine-squared' law. Others, probably at least a century later, inserted a 'scoop' notion into his analysis to build a second 'sine-squared' law. It predicted the force of an oddly sparse particle flow hitting an inclined plate of fixed area. That's the second Newton 'sine-squared' law. From that force normal to the plate lift and drag components could be derived.

This second Newton 'sine-squared' law yielded the first quantitative theory of wing lift. It's mentioned in most aerodynamic histories. Occasionally it is briefly explained, but so briefly that I misinterpreted it three ways before I understood it. I actually convinced a Ph.D aerodynamicist of my initial misinterpretation. Subsequently I had to explain its correct version to a publisher of aerodynamics books and articles. An operating systems designer temporarily convinced me that Newton had made two mistakes. Not. Misinterpretations buzzed like flies. Newton's analysis was immaculate, if not useful outside of shock waves of hypersonic vehicles near the edge of space. My experience convinced me that a few brilliant aerodynamicists assume that everyone understands the correct derivations and what they say, while few do. Hence this article.

The second Newton 'sine-squared' law was initially non-existent. It was not explicitly derived by Newton. It was only a potential implication of Newton's Proposition XXXIV, in Book II of his 1687 *Principia*. The part of Newton's Proposition XXXIV analysis that dealt with particle impacts on an inclined flat plate was only a step in a more complicated analysis. In Proposition XXXIV Newton was analyzing drag ('resistance') of spheres rather than the lift of idealized wings. But it is such an obvious byproduct that it is known as Newton's particle theory of lift or as Newton's 'sine-squared' theory of lift.

What Newton made explicit was the force of a *single* stream of particles striking an imaginary inclined flat plate tangential to a sphere. He used the trigonometric sine function to get the force normal to the plate. He again used the sine function to get the component of force in the direction of drag – he was interested in minimal drag shapes of ship bows. He didn't bother with the component of force that we call lift for a plate of constant area but varying angle of attack. We'll see that this meant he didn't derive the second 'sine-squared' law of the force for flat plate 'wings' of fixed area at angles of incidence. That was by later theorists.

Interest in wing lift forces and consequent use of Newton's analysis for lift probably followed Sir George Cayley's 1804 experiments in flight and his 1899 silver medallion showing the resolution of the total aerodynamic force on a wing into lift and drag. Before Cayley interest in forces normal to flow or travel was not focused on wings, but on the curve of balls spinning on axes crosswise to travel. In 1687 Newton would comment on the aerodynamic force that would make a tennis ball curve, but only as a brief hypothesizing about the prismatic bending of light. In 1742 Benjamin Robins published his experiments on the veer (lift) of round shot spinning on an axis crosswise to travel. Wing lift was not yet analyzed.

on plates normal to flows. We'll see that this is different from the familiar, second, later 'sine-squared' derivation of the forces on a plate of fixed area at various angles of incidence to flow.

The purpose of Newton's Proposition XXXIV was a comparison of the forces of discrete particle flows on a circular flat plate normal to flow and on a sphere of equal radius. For anyone nerdy that's a fascinating analysis offering perspective on the 1687 state-of-the-art. While Newton and Leibniz had independently developed the calculus, it wasn't yet the streamlined tool that makes such *analysis* possible for a modern calculus student. (Solving such analyses is more difficult. The writing of mathematical truths as equations is often

The purpose of Newton's Proposition 34 was a comparison of the forces of discrete particle flows on a circular flat plate normal to flow and on a sphere of equal radius

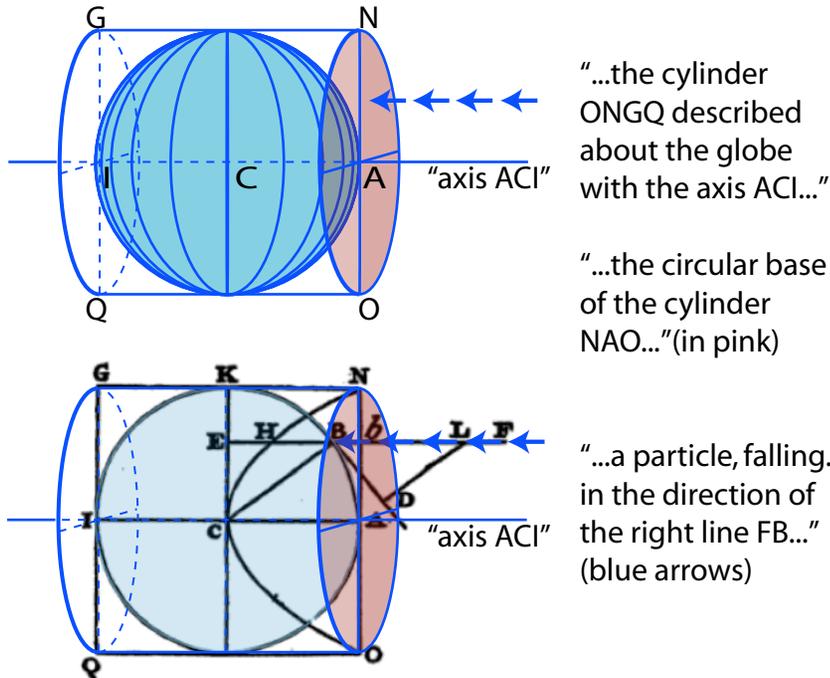
Newton's particle impact analysis and each of two 'sine-squared' relations wildly underestimated the forces of flows on objects under normal atmospheric conditions. More realistic models of flows would wait for later theorists. Still, these were the pioneering quantitative theoretical studies of aerodynamic forces.

And the first Newton 'sine-squared' relation? Newton did use 'sine-squared,' but in comparison of impacts on spheres and

much easier than solving the equations.) Rather than a calculus analysis, Newton used an elegant trigonometric argument in his comparison, using his own, prior, and distinct 'sine-squared' relation. That's the second half of this article.

Newton's analysis of particle impacts on spheres did lead to the 'sine-squared' law for flat plate lift. So we start with his diagram of sphere impacts.

Proposition XXXIV. Theorem XXVII. Book II. Sec. VII. Newton compared the force of non-interacting particles impacting on the circular flat-plate end of a cylinder with particles hitting a sphere of similar radius. Follow Newton's wording describing the base of the cylinder and direction of impact.



"...the cylinder ONGQ described about the globe with the axis ACI..."

"...the circular base of the cylinder NAO..." (in pink)

"...a particle, falling... in the direction of the right line FB..." (blue arrows)

Newton specifies the comparative forces of impacts on cylinder base and sphere as follows:
 "...a particle, falling upon the globe obliquely in the direction of the right line FB, ...is to the efficacy of the same particle falling in the same line perpendicularly on the cylinder, to move it in the same direction, as BE^2 to BC^2 ." The ratio of forces, sphere to cylinder base, is 2/1.

Fig. 1

Fig. 1: Parsing Newton. Newton's descriptions can be difficult to follow. This should make what he was describing clear.

A simplified model based on explicitly unusual conditions

PROPOSITION XXXIII. Theorem XXVII.

Cor. 2...in a medium, whose parts when at a distance do not act mutually with any force on one another, the resistance is in the duplicate ratio¹ of the velocity...¹

PROPOSITION XXXIV. Theorem XXVIII.

IF IN A RARE MEDIUM, CONSISTING OF EQUAL PARTICLES FREELY DISPOSED AT EQUAL DISTANCES FROM EACH OTHER, A GLOBE AND A CYLINDER DESCRIBED ON EQUAL DIAMETERS MOVE WITH EQUAL VELOCITIES IN THE DIRECTION OF THE AXIS OF THE CYLINDER, THE RESISTANCE OF THE GLOBE WILL BE BUT HALF SO GREAT AS THAT OF THE CYLINDER.²

- Isaac Newton, *Principia* (On the Shoulders of Giants), Edited with commentaries by Stephen Hawking, 1687, 2002

Newton wasn't attempting every-day realism. Rather,

- First, Newton explicitly started with a simplified model of atmosphere, a 'rare medium' of non-interactive particles, such as one might find at 100,000 feet elevation, or in the upper atmosphere of Mars. As a consequence about the only thing Newton's 'sine-squared' law comes close to modeling are the shock waves around the forward surfaces of hypersonic vehicles. The 'sine-squared' analysis of resultant forces

¹ 'Duplicate ratio' means 'squared.'

would prove highly inaccurate for motions in normal atmosphere.

- Second, Newton also specified inelastic collisions of the particles with surfaces. This was probably because his simplification was building toward a naval application. There the motion of fluid particles impacting a ship's bow doesn't look like an elastic bounce. In his simplified model, particles impacted a bow, gave up a portion of their momentum to it, and slid off tangential

rough that individual molecules hitting a surface can impart forces in a variety of directions. The average would increase 'resistance' or drag compared to a frictionless impact.

These conditions don't correspond to subsonic flight in thick atmosphere. Rather, they are a simplification. Much mathematical modeling starts with a workable simplification and then is adjusted toward reality or acceptable results.

reflected" (inelastic collisions) and the object "therefore meets a resistance but half so great as in the former case..." The third case is mixed.³

The second case, where discrete particles didn't bounce off surfaces, became accepted as one of the conditionals of the Newton 'sine-squared' theories.

And Newton was also aware of a few of the other fundamental forces of fluid

Much mathematical modeling starts with a workable simplification and then is adjusted toward reality or acceptable results.

to its surface. If he had been modeling lift of flat plates in his 'rare medium' he probably would have specified an elastic collision, and we'd have a 'double-sine-squared law,' since elastic collisions impart twice the force of inelastic collisions.

- Third, but only implied: The collision with a surface would be friction free. This stems from Newton's assumption that the resultant forces on the target object are normal to its surface. It's not a realistic condition for 'particle impacts.' At a molecular level surfaces are so

Newton was rigorously careful in his Propositions to say, 'If this were the case (a rare atmosphere), then this would happen.' Still, to parody Newton's *Principia* style, it's a bit like "If we had green eggf and ham, therefore, I fay, Denver omeletf would be green. QED."

Newton was highly aware of other possibilities for the nature of atmosphere. In Proposition 35 Newton considered three cases of objects moving through mediums. First, particles would bounce from the object they hit (elastic collisions). Second, the particles "are not

dynamics – centrifugal and centripetal forces, pressure, and viscosity. Newton uses the term 'pressure' a number of times in *Principia*, although until Johan Bernoulli pressure was conceived of as a normal force against surfaces rather than as internal pressure. Pressures are notably absent in the conditions of Proposition XXXIV. Readers will be aware that the particle collisions of Proposition XXXIV only imply forces on the sides of objects facing flows.

And a century-and-a-half before five theorists added viscosity to Leonhard

Euler's 1752 fundamental equations of fluid dynamics to make the Navier-Stokes equations, Newton modeled viscous shear forces:

**“The resistance arising from the want of lubricity.”
Newton on viscosity.**

SECTION IX
Of the circular motion of fluids.
HYPOTHESIS.

THE RESISTANCE ARISING FROM THE WANT OF LUBRICITY IN THE PARTS OF A FLUID, IS, CÆTERIS PARIBUS, PROPORTIONAL TO THE VELOCITY WITH WHICH THE PARTS OF THE FLUID ARE SEPARATED FROM EACH OTHER.⁴

– Isaac Newton, *Principia*, Section IX, Book II.

John D. Anderson, Jr., in *A History of Aerodynamics*, explains that the above sentence converted to algebraic notation is known as the Newtonian shear-stress law. In a velocity gradient the velocity differences per distance-normal-to-flow (dV/dn) give rise to shear friction. The ‘want of lubricity’ translates to the viscosity coefficient, μ (mu). τ (tau) is the ‘shear stress.’

$$\tau = \mu (dV/dn)$$

Virtually all fluids, including air, exhibit shear stress. In contrast to fictional, ideal, inviscid (frictionless) Eulerian fluids, fluids that exhibit shear stress are known as Newtonian fluids.⁵ In contrast to his hypothetical ‘rare medium,’ here Newton modeled common reality.

What the second ‘sine-squared’ law says

The second ‘Newton’ ‘sine-squared’ law, probably from the 19th century, models the resultant normal force of a discrete particle flow impacting on an inclined plate of given area. As the plate tips to lower angles of incidence the cross sectional area of the flow it ‘scoops’ out decreases, and the normal component of individual particle impacts decreases, *each by the sine of the angle of incidence. Thus ‘sine-squared.’*

Given Newton’s conditions, the form of the ‘sine-squared’

equation for the force on a flat plate inclined to flow is:

$$R = \rho V^2 A \sin^2 \alpha$$

From which the modern components of the resultant force R, lift and drag, can be separated.

$$L = R \cos \alpha = \rho V^2 A \sin^2 \alpha \cos \alpha$$

$$D = R \sin \alpha = \rho V^2 A \sin^3 \alpha$$

$$L/D = \cos \alpha / \sin \alpha = \cot \alpha^6$$

where:

R is the force normal to an inclined plate

ρ (rho) is density of the particle stream

S is the total surface area of the plate

α is the angle at which particles hit the plate.

Since the sines of small angles of attack are small, the ‘sine-squared’ is miniscule. Thus the Newton formulation unrealistically indicates almost no resultant force (lift and drag) at the small angles of attack at which wings fly.

The derivation is seldom spelled out. It was the first quantitative theory of lift and drag, albeit for explicitly unusual conditions. There are two questions that need to be answered, Why V^2 ? and why ‘sine-squared.’

Why V^2 ?

First, why is velocity squared? We need to have a better answer than ‘because Edme Mariotte said so in 1673,’ and better than ‘everyone knows this is the case.’

The momentum impulse (p) transferred by a single particle hitting normal to a plate in inelastic collision is:

$$p = m\Delta V$$

In an inelastic collision normal to a non-moving surface, ΔV (the change in velocity) is complete, so

$$p = mV$$

Force (such as lift, drag, or their vector sum R) = $\Delta m\Delta V/\text{sec}$

If the velocity of a stream of particles doubles, the momentum impulse per particle impact doubles and the mass per second also doubles (twice as many particles arriving per second), so the force quadruples. If V triples, the momentum impulse per particle impact triples and three times as many particles arrive per second, so the force R increases by 9. Thus the force of a stream of independent particles increases with the square of particle velocity.

$$F_{\text{Stream}} = mV^2/\text{sec} = \rho V^2 S$$

Interestingly, the same argument works to explain why the force of real flows (with pressures from interactive molecules) on subsonic wings (and other objects) increases approximately with the square of velocity; momentum change per molecule and number of molecules per second both increase with velocity, so force changes with V^2 .

Why 'sine-squared?'

And second, why sine-squared?

- The first sine is the 'scoop' area A of a plate of area S . As its angle of incidence α reduces from 90° to 0° its 'scoop' area is reduced from S to zero, by:

$$A = S \sin \alpha$$

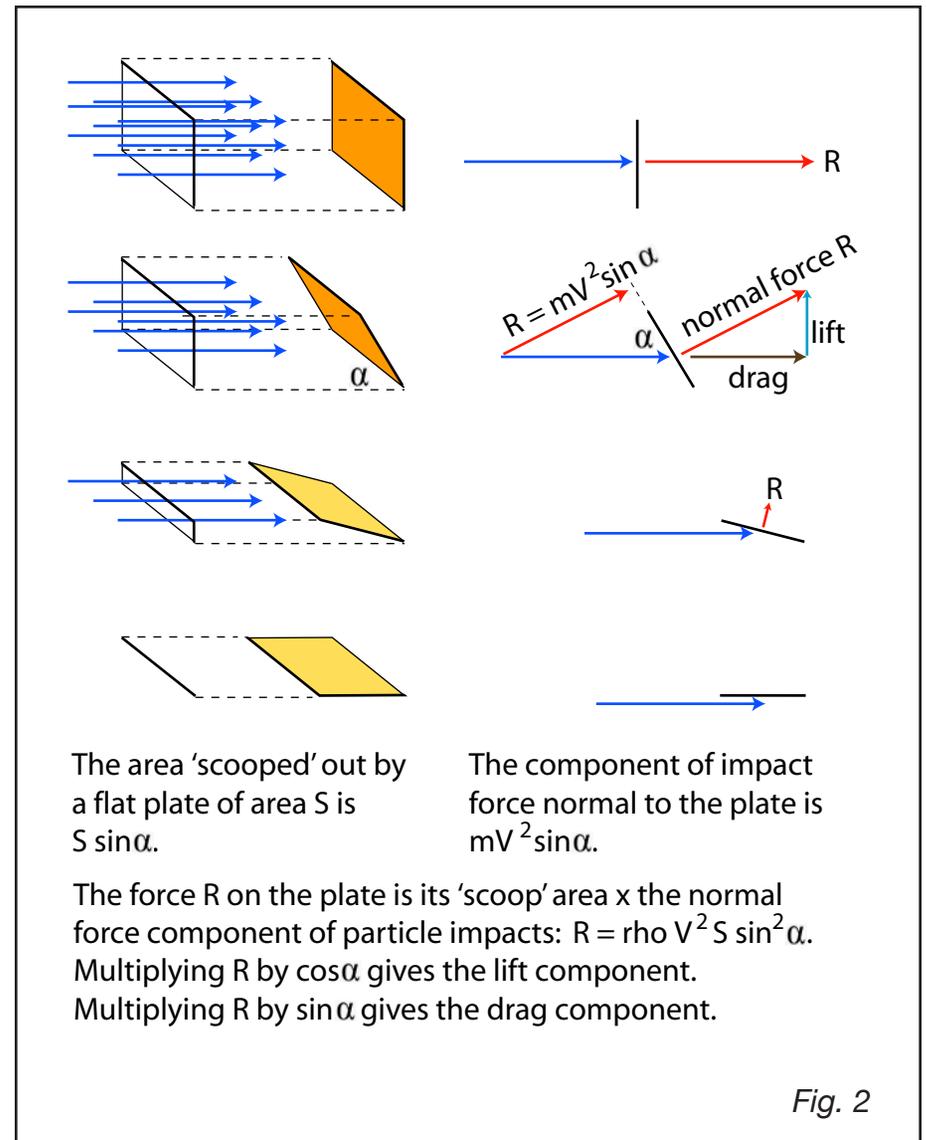
- The second sine is the component of the flow's potential force which turns into pressure normal to the inclined plate on impact. This is given by

$$R = \rho V^2 A \sin \alpha$$

Substituting ' $S \sin \alpha$ ' for scoop area ' A ' gives drag D :

$$D = \rho V^2 S \sin^2 \alpha.$$

Fig. 2: The combination of the 'scoop' of a flat plate at some angle of incidence to flow and the component of force normal to the plate yield the 'sine-squared' resultant normal to the plate, from which lift and drag may be derived.



Proposition XXXIV. Newton's 3D analysis: a cylinder circumscribing a parabolic solid as a representation of forces! Newton's comparison of resistances of a sphere and its circumscribed cylinder

In Proposition XXXIV Newton compared the forces of a flow of discrete particles impacting a sphere versus those impacting normal to the flat circular-plate base of its circumscribed cylinder. It's a trigonometric rather than a calculus argument.

Newton used four stages in his comparison of impacts against plates and spheres:

- First, a particle impacting normal to a plate.
- Second, a single particle stream impacting at a simple angle of incidence to a flat plate (from which later theorists derived the 'sine-squared' relation for the resultant force normal to a flat plate of fixed area and varying angle of attack).
- Thirdly, Newton derived the force in the 'resistance' or drag direction of a particle stream impacting at a simple angle on the surface of a sphere. The force normal to the sphere's surface was yielded by

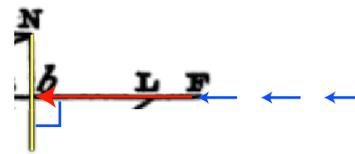
$$R = mV^2 \sin \alpha.$$

The component of that force in the 'resistance' or drag direction was $R_n \sin \alpha$. So for drag:

$$D = \rho V^2 S \sin^2 \alpha.$$

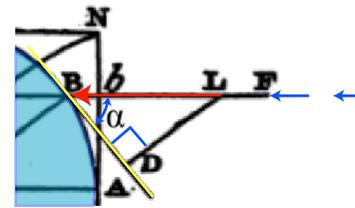
Newton took the ratio of a particle hitting a flat plate compared to a particle hitting the surface of a sphere as $\sin \alpha$ to $\sin^2 \alpha$. (He wrote "BE² to BC²" rather than using trigonometric terms, even though they were already in use and though Newton added to their

Four stages of Proposition 34, inelastic frictionless collisions by particles of a rare medium



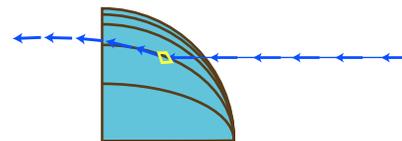
A particle strikes a flat plate at right angles with force $F = mV/\text{sec}$.

A stream of particles hits with force $F = \rho V^2 \text{sec}$.

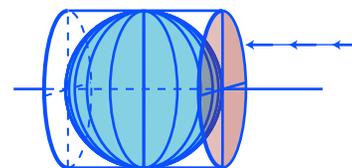


A particle impacting at a simple angle of incidence to a flat plate! & tangential to a vertical slice of a sphere. The force imparted to the plate and sphere is $F = mV/\text{sec} \sin \alpha$. The force of a stream of particles is

$F = \rho V^2 A \sin \alpha$

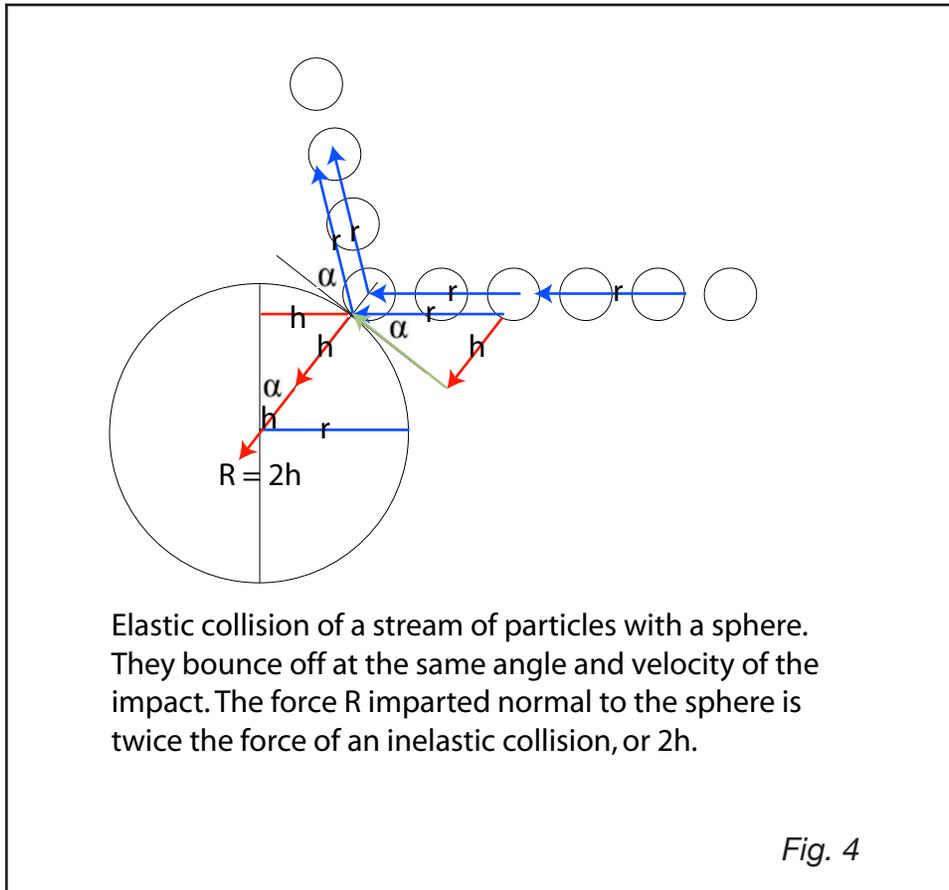


Newton's description of the force of a stream of particles hitting a sphere (in modern terms) was: $F = mV^2 \sin^2 \alpha$



Newton made an elegant proof that the force in the resistance direction of particles hitting a circular plate is twice that of particles hitting a sphere. In his argument he used a 'sine-squared' relation. It was not the same as the 'sine-squared' law for flat plate forces, apparently developed much later.

Fig. 3



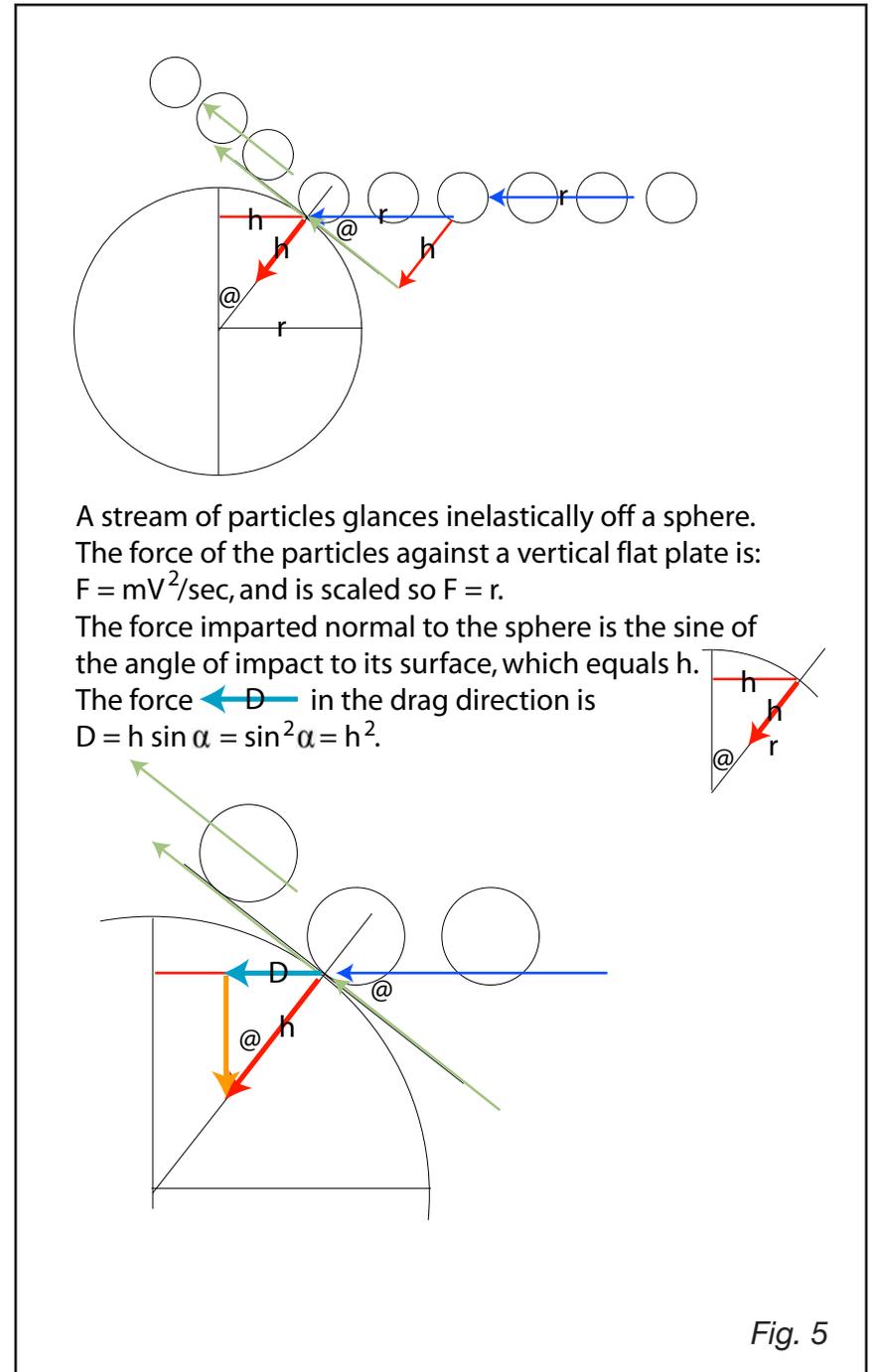
math.) Newton didn't construct a calculus equation of the impact of particles on a sphere.

- Fourth, Newton finally used elegant geometric reasoning rather than calculus in his comparison of impacts on a plate versus a sphere.

Fig. 3: Four steps in Newton's discrete particle impact analysis.

Fig. 4: Elastic collisions

Fig. 5: Inelastic collisions



The divergence of the two 'sine-squared' theories.

Note that each of the two 'sine-squared' theories start by taking the normal component of the particle flow by multiplying its potential force by the sine of its angle of incidence. That's the first 'sin α .' Newton's second 'sin α ' gives the component of force in the drag direction. That's Newton's 'sine-squared.'

Whoever carried the initial argument onto the normal resultant force on a flat plate of given area at varying angles of attack interjected a different second step into Newton's process. The 'scoop' area was their second 'sin α ,' yielding the well-known 'sine-squared' theory for the normal force R. Multiplying R by Newton's second 'sin α ' yields the drag force on the flat plate wing, a sine-cubed relation. Multiplying R by $\cos \alpha$ yields the lift force, a sine-squared-cosine relation.

Parsing Proposition XXXIV: Newton's own 'sine-squared' relation of the resistance forces on a plate versus a cylinder.

...the efficacy of a particle, falling upon the globe obliquely in the direction of the right line FB, to move the globe in the direction of its incidence, is to the efficacy of the same particle falling in the same line perpendicularly on the cylinder [base], to move it in the same direction, as BE^2 to BC^2 .

Parse: Newton asserts the ratio of impact forces on the cylinder base to those on the sphere as BE^2 to BC^2 . BE/CB is $\sin \alpha$. BE^2 to BC^2 is 'sine-squared' α . But it's not the 'sine-squared' applied to an inclined flat plate by later theorists. This is Newton's 'sine-squared,' for a different purpose, his plate-versus-sphere comparison.

And how did Newton achieve this 'sine-squared' relation for impacts on the surface of a sphere? Newton conveniently scaled the force of a single stream of discrete particles

impacting a sphere as equal to the radius of the sphere. Given that scaling, the resultant force normal to a sphere's surface of a single stream of particles impacting it is the local 'height' of the hemisphere. That is, the resultant R_{np} normal to the sphere's surface is:

$$R_{np} = mV^2 \sin \alpha$$

Newton was computing 'resistance' (drag). The drag of a single stream of particles D_{ps} is given by the component of R_{np} in the drag direction:

$$D_{ps} = mV^2 \sin^2 \alpha$$

Then Newton makes his elegant one-to-two ratio of forces. Again, key to his analysis is that he verbally scaled the vector representing the force of impact against the cylinder base so that its length equals the radius of the sphere and circumscribing cylinder. This allows him to represent forces as proportional to the volumes of the solids he describes!

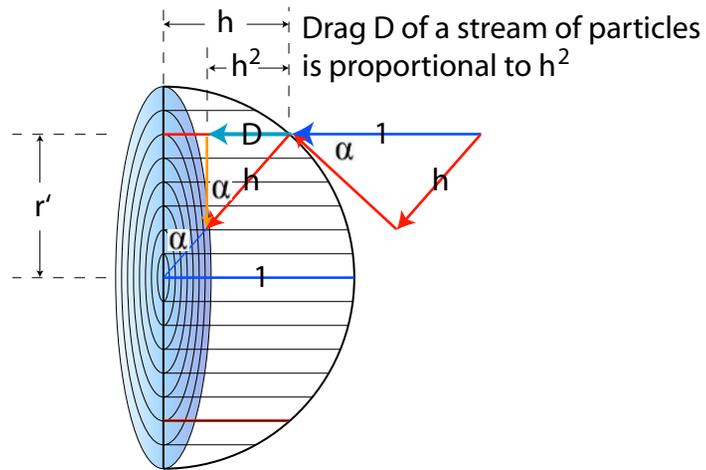
Therefore if in bE ...we take bH equal to BE^2/CB ; then bH will be to bE as the effect of the particle on the globe to the effect of the particle on the cylinder [base].

Here he splits out BE^2/CB as a description of a parabola. He rotates the parabola on axis AC to form a solid. He then says

...and it is known that a paraboloid is half its circumscribed cylinder.

He concludes that the ratio of forces on the sphere to the cylinder base are as the volume of the solid paraboloid to its circumscribed cylinder, one half.

That is, the ratio of resistances will be $BE/CB \times BE/bE$. But CB and bE are each the radius of the sphere, and equal. BE/CB is $\sin \alpha$. Thus he asserts sine-squared alpha as the ratio of globe to cylinder resistances.



The potential impact force (blue arrow) of a stream of particles is scaled to equal the radius of the sphere: 1. The inelastic collision makes a pressure force component h normal to the sphere surface. Since $h = 1 \sin \alpha$, h is equal to the height of the circle at radius r' . Particle drag $D = h \sin \alpha = \sin^2 \alpha = h^2$ at radius r .
 $h^2 = 1 - r'^2$ (unit circle formula)
 $r=0$ to $1 \int 2\pi r' h^2$
 $r=0$ to $1 \int 2\pi r'(1-r'^2)$

Fig. 6

Fig 6: Checking Newton by Archimedes rectangles. Your author added the sine-squared average 'heights' (h^2) of ten concentric cylinders times their base areas to approximate the force of Newton's particle flow against a sphere. No surprise. Newton's one-to-two ratio of sphere to circular flat plate resistance was indeed correct.

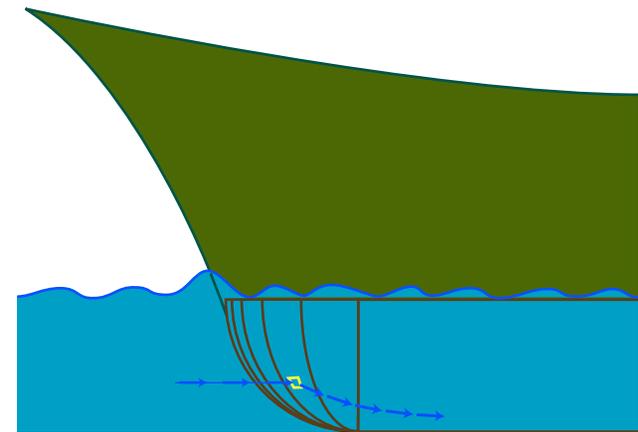
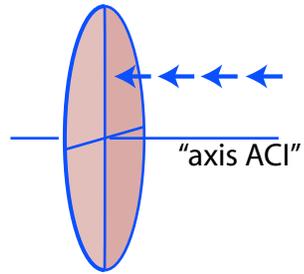


Fig. 7

Other comparisons "by the same method"?

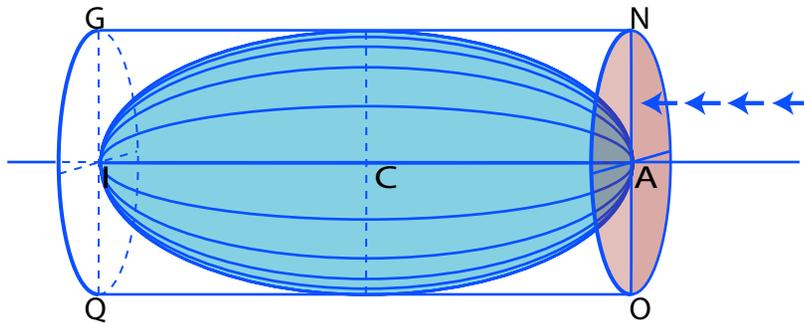
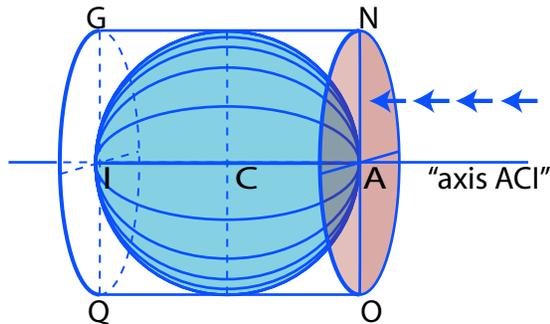
By the same method other figures may be compared together as to their resistance...Which Proposition I conceive may be of use in the building of ships. – Isaac Newton, *Principia*, Proposition XXXIV. Theorem XXVIII. Scholium.⁷

Fig. 7: The part of a ship's bow below the waterline is often approximately ellipsoidal. Newton's 'resistance' analysis was reportedly applied in ship design, although probably with questionable results. Just how it was used and with what adjustments is another question.



A flat plate is an ellipsoid with major axis of zero length.

A sphere is an ellipsoid with major and minor axes of equal length. Newton showed it would have half the resistance of the plate.



Newton asserted that "by the same method" (geometrical comparisons) the resistances of other shapes could be derived.

Fig. 8

"By the same method..." and verifying Newton's one to two ratio of sphere and cylinder base resistances to particle flows

I confess I fail to understand Newton's subsequent argument. Was he elaborating on 'the same method?' I couldn't tell. But if not, if he were moving on to a different analysis, then perhaps by 'the same method' he had meant the comparison of the resistance of a solid ellipsoid to a flat plate of radius equal to its minor axis. (Recall that a sphere is an ellipsoid with equal radii of its major and minor axes.)

Fig. 8: A circular flat plate and a sphere are two points on the continuum of ellipsoids. Newton wrote "By the same method other figures may be compared together as to their resistance." He may have been referring to the resistance of ellipsoids of varying ratios of major to minor axes.

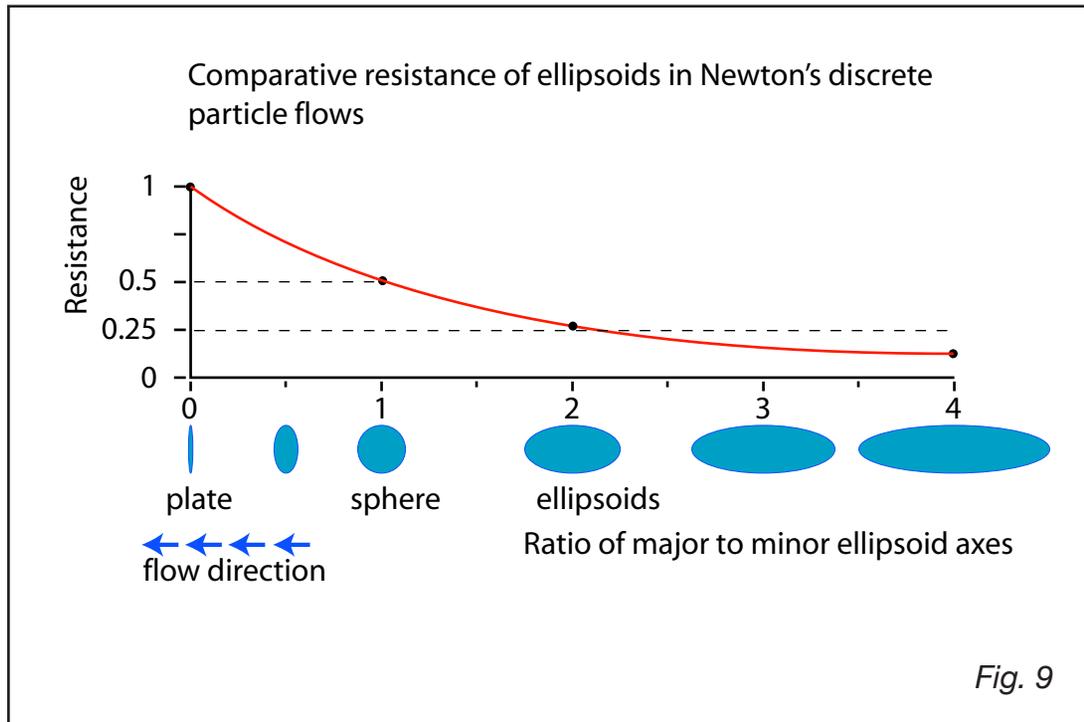
Fig.9 Graph of S. Allmaras' equation for the resistance of ellipsoids to particle flows given the conditions Newton specified in his Proposition XXXIV.

Steven Allmaras derived the formula for Newton particle resistance for various ellipsoids:

$$Cd_ratio \text{ sphere to plate} = (1 - a^2 + 2 a^2 \text{Ln}[a]) / (1 - a^2)^2$$

He notes: "Where a is the aspect ratio of the ellipse (a = 0 is flat circular plate, a = 1 is sphere), and Ln[] is the natural log (as opposed to log base 10). The equation is fairly nasty for both a=0 and a=1, and you have to take limits to get the appropriate drag ratio. The drag coefficient itself is just 2π times the above ratio." – S. Allmaras, Ph.D., email 1/8/14.

Dr. Allmaras' equation does verify the accuracy of Newton's trigonometric approach; the resistances of sphere and cylinder base to Newton's particle flows is one to two. QED.



To all who have made
donations to
RC Soaring Digest...



We sincerely appreciate
your support and your
continued readership.

<<http://www.rcsoaringdigest.com>>

(Endnotes)

- 1 Newton, Isaac, *Principia*, ed. Stephen Hawking (Philadelphia: Running Press, 2002), 252.
- 2 *Ibid.*, 254.
- 3 *Ibid.*, 256–257.
- 4 *Ibid.*, 296.
- 5 Anderson, John D., *A History of Aerodynamics*, 38.
- 6 *Ibid.*, 39–40.
- 7 Newton, *Principia*, 255.
- 8 Allmaras, Stephen, PH.D., “Newton Ellipsoid Resistances,” email, January 8, 2014.



Repairing a *Smooth Genie Pro*

Dion Dunn, dion9146@gmail.com

In a sick and twisted kind of way, I actually enjoy repairing an airframe almost as much as building it the first time around. I think it ties back to my love of old things or preserving things. I don't know.

I cut out the bad sections of the boom/tail and have started the reconstruction. Last night I inserted and epoxied a piece of 0.060 CF Unidirectional laminate on the starboard side. The boom is once again stiff, and in perfect alignment. I won't close it up and finish it off until I get the 0.060 CF push rod installed and connected to the bellcrank. Once it is in there, there is no going back!

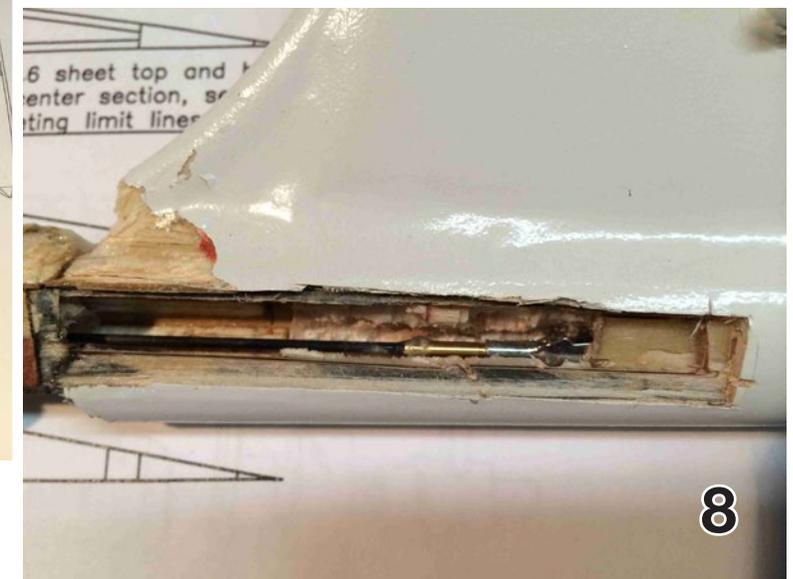
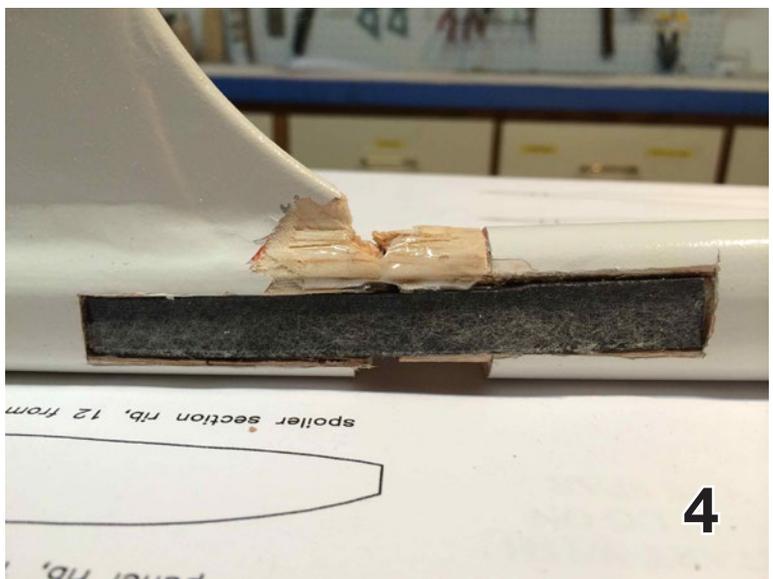
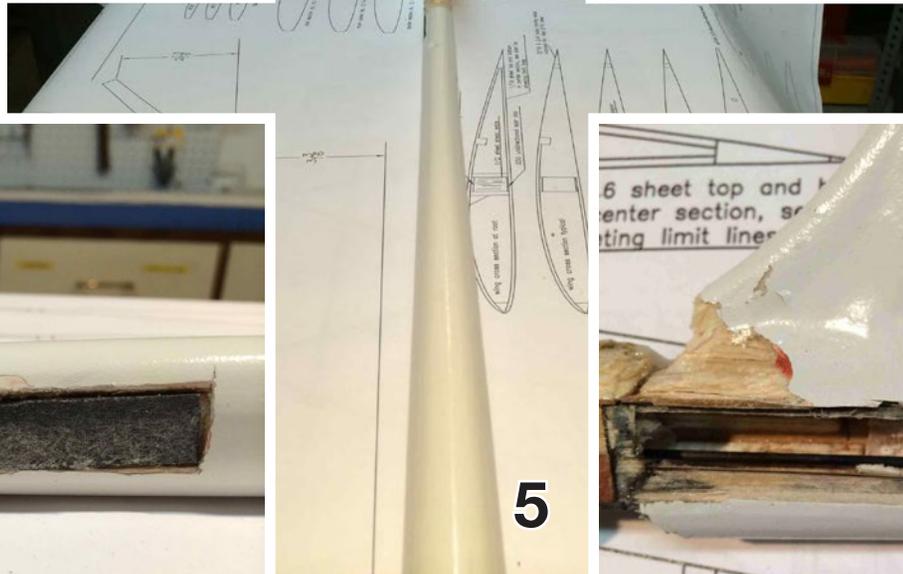
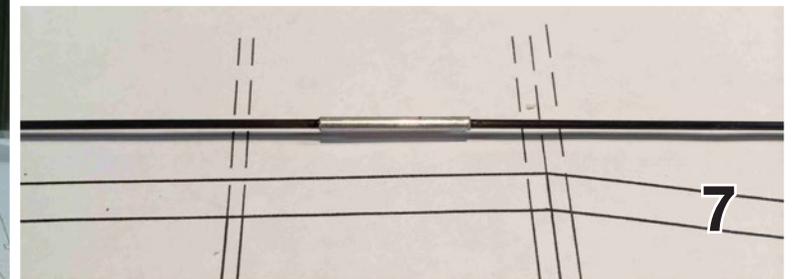
Photos 1-5

I spliced two 24" pieces of 0.060 CF rod together using a 3/4" length of aluminum tube with an 0.060 ID. I roughed up the CF, used medium CA, and butt welded it together. Similar story on the bellcrank end with the adjustable pushrod end. After it was all cured, I did a scientific pull test (ie, pull on both ends as hard as I could) to make sure nothing moved. All good.

Photos 6-7

The fuselage already has a straw tube running down the length of the interior, so I fed the servo end of the pushrod up to the front of the fuselage, and after careful alignment and a tricky





bit of twirling of the left hand in a tight spot, I was able to get the new rod screwed tight into the clevis which was already attached to the bellcrank.

Photo 8

Oh, I forgot to add that the rudder is pull-pull cable, so no pushrods needed.

Now I can button it all up with more CF, ply, balsa, and glass, paint, and I guarantee you won't be able to see the repair. No cheapo backyard hack repairs on my airplanes. If I can't fly em well, they might as well look good.

After fitting a filler piece of 1/16", 5-layer plywood to the open gap over the pushrod, I used Titebond and ordered take-out Chinese...

Then comes another layer of .060 CF uni laminate coated with a nice layer of epoxy and cabosil to add some thickening, a piece of SaranWrap, soft balsa compression spacer and some clamps. Pretty soon we will have both sides equally stiff, then I can start the cosmetics.....

Photo 9

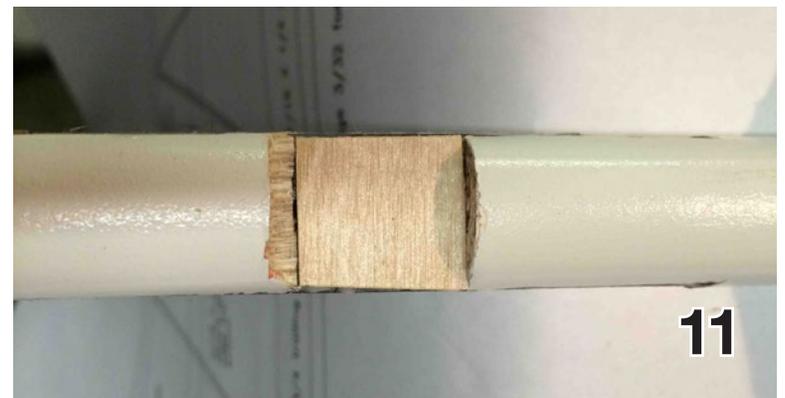
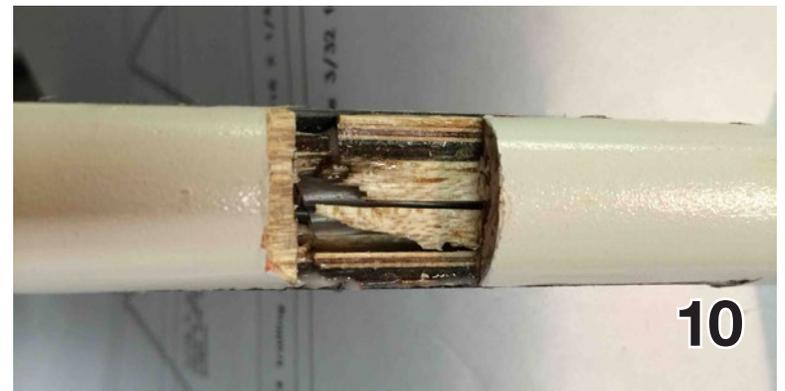
This morning I removed the clamps and now have a super strong tail boom once again.

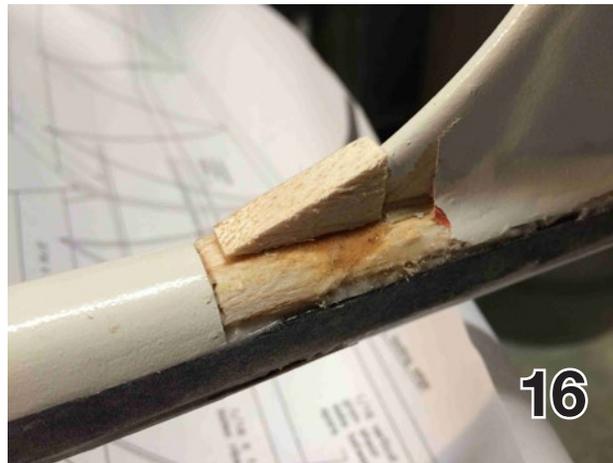
The next gap I needed to tackle was the bottom. The first thing I did was cut a cross grain piece of 1/32" 3-ply to add a bit of strength. Then that piece was covered by a piece of contest grade balsa (you know, the really lightweight stuff). A quick hit with the micro-plane and fine sandpaper, and she is good to go.

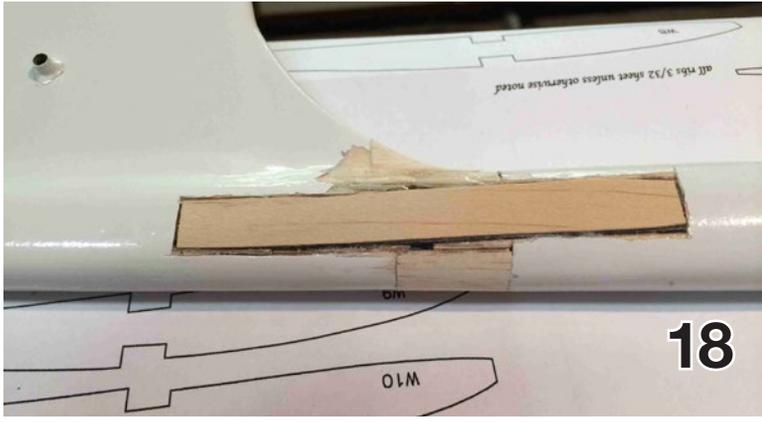
Photo 10 -14

Flip the fuselage over, and I started thinking to myself - I know the pushrod moves freely, but let's make sure we didn't have any other damage to the bellcrank that I don't know about. So I hooked the stab back up for the first time since the accident, and took the following video. Honestly, I never thought I'd see that again. Smooth as silk and almost zero resistance. <<https://www.youtube.com/watch?v=MkLjavGRYNo>>

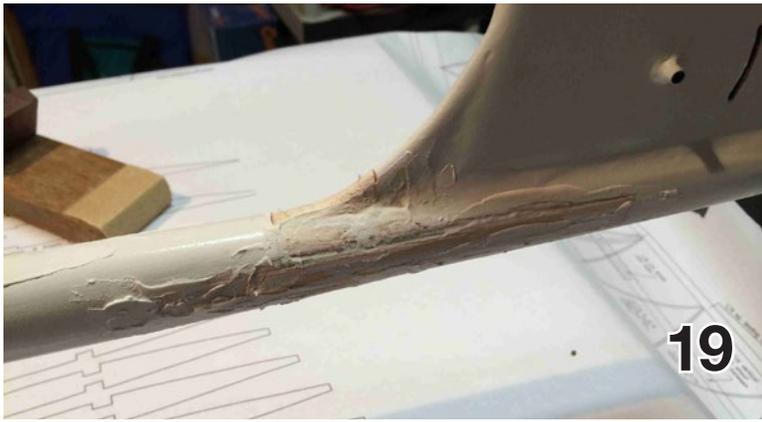
And finally, the top. The front edge of the fin was pretty mangled, so I cut it off square and trimmed back some of the fiberglass. In order to fill the ugly uneven gap, I mixed up my own filler mix that i have used before. It's a combination of Titebon on balsa dust - yes, I have about a cup of fine







18



19



20

balsa dust that I keep around for special occasions.

Just like any filler, I pressed it into all of the nooks and crannies, and now I'll wait for it to dry. Next up, the cosmetic fillers...

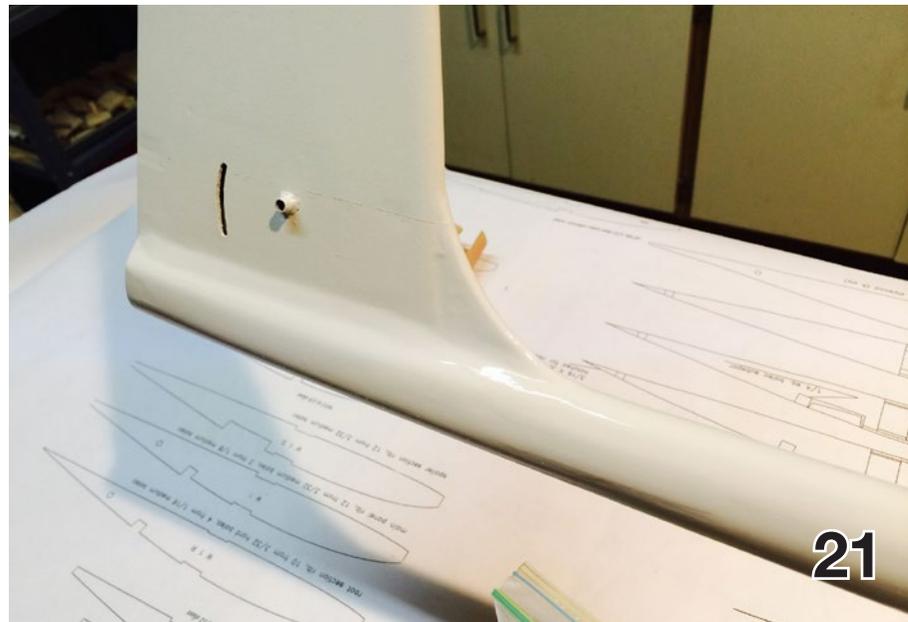
Photos 15-17

I used more of the competition grade balsa to make my short fin and sand it to shape. I also added some 1/32" balsa filler strips to build out the sides. Then I used lightweight Spackle for the fairing material. It's light, dries fast, and sands easily. Plus, I get the stuff in a tube and it keeps for a long time. After a couple of coats of filler and sanding, I was also able to get the .5 oz fiberglass skin on it with a first coat of poly. I'll probably end up putting 3-4 coats of poly on it before paint.

Photos 18-20

After a little red spot filler and sanding over the fiberglass, she got a couple of coats of paint. I have a tape line on the fin that I will blend in with some rubbing compound after the paint hardens, but I think it turned out pretty good.

Photo 21



21



Designing for the Three Abilities

Chuck Anderson, chucka12@outlook.com

If I were a serious contest flyer, I would be buying what the real experts fly but my physical handicaps keep me out of that class. I still enjoy designing models and flying contests so designing a sailplane to match my skills and physical handicaps allow me to place higher at contests and enjoy all phases of my hobby. I even occasionally bring home a trophy. This article explains how I did that. Maybe it will give you ideas.

When RES became a popular event, I pulled my 1983 sailplane out of the attic and even built a new version with a more modern airfoil. By 2000, I needed a better contest RES sailplane so I designed one. Since I gave up flying F3B many years ago, I have designed my sailplanes to give me the best chance of getting a 10 minute flight and a landing considering my skills and handicaps.

I emphasize the three abilities and compromise performance as necessary to achieve these goals. The three abilities are stability, visibility, and controllability. My article on the Three Abilities in the April, 2008 *RC Soaring Digest* explains why. This article tells how I used the three abilities to design my 2006 sailplane, LilAn II.

I began design of the first LilAn while recovering from an illness in December 1999. Since I couldn't work in the shop, I spent my spare time researching and writing specifications for an RES sailplane. For the first time in many years, I did some real designing before starting construction and actually wrote a specification for my new design.

The LilAn is an RES sailplane designed around my skills and handicaps. It will be of conventional construction and as large

as possible within the limits of standard winches and my ability to launch it in moderate wind. It must be able to thermal at the limits of my visual range with minimum control input. Normal flying will be with controls in low rate with control throws set at the minimum required for launching and landing with high rate for flying when more control power is needed. Linear approximation of elliptical dihedral as used on my 1974 Tern IV will be used for its good handling qualities. Speed, sink rate, and zoom performance will be compromised if necessary to give the stability required to maximize overall performance. The model must fit in my van by removing only the outer wing panels and be ready to fly within two minutes after arriving at the model field. Sailplanes with wing spans over 148 inches are difficult for me

to launch in wind so wingspan will be less than 142 inches. Aerodynamic design will be based on my two most recent designs; Aurora and Sirius II. The Aurora was a composite full house sailplane I designed in 1995 and the Sirius II was a 1999 update of my 1983 sailplane. My 1974 standard class Tern IV weighed 32 ounces but was seldom flown with less than 4 ounces of ballast. Models with wing loading of 8 oz per square foot have always thermalized well for me and lighter wing loadings make the model harder to fly in turbulence. Light weight models are usually more fragile so I no longer go to extremes to reduce model weight and reduce the need for adding ballast.

Not much stab area is required for pitch control but small stabs do not provide satisfactory pitch damping and decrease pitch stability. Many years ago, I built three stabs with areas of 8%, 12%, and 16% of the wing area and flew them on the same model. All were satisfactory for pitch control but the bigger stabs were easier to fly smoothly. The only disadvantage of the large stab was the extra weight that had to be added to the nose.

Larger models are more visible but maximum size has already been set by launch requirements. Modern low drag fuselages are harder to see at long range. About 10 years ago, I was using a Compulsion as my main unlimited competition model and bought a model that had a Compulsion wing mounted on an Ava fuselage for a backup. I expected the Ava-Compulsion hybrid to fly like the Compulsion and was surprised how much harder it was to work distant thermals because I couldn't see it as well as the Compulsion. When I designed the LilAn II fuselage, I resisted the temptation to make the fuselage as slim as possible.

Model criteria developed from these studies resulted in a wing span of 138 inches and a root chord of 11 inches. Wing Area turned out to be 1250 square inches and aspect Ratio of 14.1 for a wing loading of 8 oz. per/sq. ft. The wing planform will be

conventional with straight $\frac{1}{4}$ chord line. The dihedral will be a linear approximation of elliptical dihedral. My experiments with nonplanar wings were reported in the June 2013 issue of *RCSE*. The tail will be cruciform for ease of transmitter programming and simple pushrod installation. The stab will be 15% of wing area for good pitch damping. The spoilers will be in the outboard wing panels to minimize pitch effects when deployed.

I selected the SD 7032 for the root airfoil transitioning to the SD7037 at the first dihedral joint. The SD7032 is a thicker version of the SD7037 airfoil and was used for additional wing strength at the root. These airfoils were used for both Aurora and Sirius II with good results. Wing structure will be that used on the Sirius, the last built up wing for which I did a full structural analysis.

There were two changes made before the first LilAn was built in 2001. The first change was to use a Legion fiberglass



Sirius II



LilAn I



LilAn I final fin and rudder



fuselage given to me by Roy Simpson at the 2000 Nats. It was a very clean fuselage with a very heavy molded fin. I cut off the fin and substituted a balsa fin from my Aurora cutting over two ounces from the tail. The second change was to switch to the more fashionable Schumann wing planform

The LilAn had very good performance but failed to live up to the controllability requirement and the carbon fiber reinforced spruce wing spars failed when it hit a very strong thermal at the start of a zoom at the 2001 Nats. The LilAn was repaired sufficiently to withstand careful launches and a series of modifications to improve controllability were tested whenever I had the time and was in the mood for experimenting. Final modifications were completed in the summer of 2004. Dihedral of the outer wing panels was increased and a large increase in fin and rudder area was necessary to bring controllability up

LilAn II Prototype



LilAn II by Charlie Bair

to the Sirius that I had been flying since 1983.

After the LilAn wing failure, I abandoned spruce and now use only carbon fiber for spar caps. While I can do stress analysis of wood wings, modern composites came long after my last aircraft structures class. Since I had no experience with carbon fiber spars, I did the next best thing. I copied the real experts. After searching all the notes on carbon fiber that I had collected, I decided to base my wing spars on Mark Drela's Bubble Dancer.

The LilAn had a 5-panel wing with fashionable Shuemann wing planform. I have followed development of the Shuemann wing since it first appeared in *Soaring* but have never found any wind tunnel data that verified the Shuemann wing's theoretical advantages so I went back to the wing planform I have used for the last 30 years for LilAn II. The carbon fiber reinforced spruce I-beam spar was replaced by a carbon fiber spar based on Mark Drela's Bubble Dancer. The spoilers were moved from the outboard panels to the center wing to reduce roll inertia

and allow spoiler actuation by pull strings from a servo in the fuselage. Removing spoiler servos from the outer wing panels also speeded up time required to assemble the model.

Airfoils evaluated for LilAn II were AG35, MH32, SA35, and DP19. None showed any significant advantage over the others so I selected the AG35 because the flat bottom simplified construction.

The Legion fuselage was too short and had a stylish pointed nose so I built a set of molds and laid up a new fuselage that I could use for Unlimited and RES sailplanes. The new fuselage has a longer tail boom and a tangent ogive nose replaced the pointed nose which let the battery and servos move forward.

Flight testing went well and the wing could take full pedal-to-the-metal launches so I built a new version with a few improvements based on initial flight tests. The dihedral of the outboard wing panels was increased from 7.5 degrees to 10 degrees, one degree of washout was added to the outboard wing panels, and the height of the fin and rudder was increased by 1/2 inch. Photographs taken while building the second LilAn II were used to illustrate an RC Group build thread on "Building Without Plans or Lasercut Ribs." I had intended for the prototype to be my backup RES model for 2007. Unfortunately, it failed it's final structural test — high speed oak tree penetration!

The LilAn II prototype dimensions were:

Wing Span 132 inches

Wing Area 1150 square inches

Aspect Ratio 15

Weight 68 oz.

One LilAn was built at 60 ounces but showed no better thermal performance

so no special effort was made to minimize weights of later versions and they were built from my stock of balsa that had already been picked over for the best wood.

The 48 inch span center wing panel lets the LilAn fit in my Honda van by removing only the outboard wing panels.

The Sirius charge mounted in my van lets me charge all batteries on the way to the field. Since the outboard wings have no servos or controls, it only takes a couple of minutes to tape the outer wing panels in place and be ready to fly.

Designing a model around my handicaps has let me continue flying long after I would have had to quit if I had been flying many of the very high performance sailplanes now on the market. LilAn has even let me win a few trophies over the last 6 years.

For me, the LilAn performs at least as well as the Ava Pro and it's my own design. Seven LilAn IIs have been built by Charlie Bair and me. A new LilAn fuselage was modified to house electric motor and prop and flown with a LilAn II wing for ALES contests. LilAn has one other advantage. The LilAn materials cost less than half as much as the Super Ava I bought to fly RES in the 2006 Nats when the LilAn II wasn't quite ready.

Finally, the origin of the name. About 30 years ago, while researching a construction project, I ran across one of the definitions of Lil and thought that it would be a good name for a model. Lil is a 5000 year old word from Sumer meaning Sky. Combine Lil with the Sumer word for God give LilAn or SkyGod.



A pair of LilAns

TRIM, SLOP, BALANCE

Gordy Stahl, GordySoar@aol.com

I have written a bunch of articles on these topics, but it seems as soon as I complete one a light comes on that calls for yet another article on the topic.

This time I had purchased a basket case of a mistreated, used and abused Super AVA with both an electric launch fuselage and a standard fuselage. I stripped all the covering, replaced superglue-covered broken ribs, replaced all the wiring harnesses, updated the wing connectors, tidy'd up the receiver mountings, repaired cracks in the fuselage pods, installed the latest slop-free metal cased micro-digital servos... and even cut flaps into the center panel so that it could function well in ALES or RES events depending on the fuselage choice. It was a LOT of work but very rewarding as it looks new.

But it was the flying of the two fuselages that had me a bit stumped. Now at this point in the hobby I never bother with measuring CG since I know that all our birds balance at about 45% of root chord. So I basically do a rough thumb balance - check to see that its more than halfway toward the leading edge - and then give it a light hand toss. I know if does pitch up, just floats out and doesn't drop her nose first at the end of the flight, its likely pretty good.

Both fuselages have their own stab and tail surface servos. The electric-launch fuselage servos are mounted in the back just in front of the vertical on the side of the boom with very short bits of linkage, and so there is no flexing or loose movement of the elevator... none. The RES fuselage has the servos in the nose



Which Is It? CG - Incidence - Elevator Slop - Flexing

with carbon pushrods securely attached their full length, and very little movement of the elevator when firm pressure is applied to the elevator trailing edge.

The Electric Launch version flew the way AVA's do... mindlessly, predictably, regardless of conditions or airspeed. However the RES version (same wing remember!) acted weird. Flying along hands off, it would suddenly balloon nose up. Then, with the slightest touch of down to compensate, it would dive fairly dramatically. Once settled it was fine.

Now is a good time to recount an important story about chasing the wrong fix:

I was at a contest and had just landed as I walked past a fellow pilot at the winch preparing to launch a Supra. He was messing with his transmitter program settings. I asked what was up and he said, "I can't seem to get this thing to launch well! I have moved the tow hook around, played with various trailing edge launch camber settings, put up and down elevator compensations in, yet I can't seem to get the right settings." I had been watching his launches and recognized his problem.

I told him to hold his model firmly because I was going to press on the back

of the plane a bit. I put my finger on the back of his horizontal stabilizer and with the lightest pressure and was able to deflect it down more than 1/4"!

As I pushed you could see the pushrod buckling along its unsupported length! I then reminded him that it is the tail that directs the nose - specifically the trailing edge of the elevator - and as the model's airspeed increases so does the workload on the elevator's trailing edge... and never more so than when you want your model to pull up out of the bucket part of the launch ping.

The reason for recounting the story was that the pilot had spent weeks trying to figure out his launch problem, working endlessly with transmitter program gimmicks and tow hook settings, because those things were there to work with. He didn't realize the possibility that it might be something so simple, after all he had "carbon pushrods and powerful digital servos!" The servos, it turns out, weren't actually being used to do what he'd installed them to do because of the install. With all the other things that should be responsible for a good launch - camber, elevator compensation, tow hook location - well, they were just too in-your-face to believe one of them was causing

his frustration.

The one thing I left out was his comment about "maybe it's my CG causing the bad launch, I added more lead to the nose..." ARGH!!!

So that leads me to the next story about adding extra lead to fix something:

I showed up at a field one day in another part of the USA to do some flying with the local guys. A relatively new pilot who'd just moved up to a molded 3-meter ship came over and asked me if I'd help with its set up and balance because it just didn't seem to fly well. Now that could mean he didn't have the thumbs for a well tuned ship, but it usually meant somebody had helped him out by adding some extra lead to the nose. You know, to make it more stable for him.

After a quick check of things, I gave it my usual left handed gentle flat toss and, as usual, it nosed down toward the ground just in front of us. After pulling a few ounces of lead, it finally glided straight ahead about halfway across the field. He was elated and amazed. We put it up on the winch and found it didn't launch very high, but he got the longest most relaxed flight of his life on that first flight and continued the day that way.

I explained that he'd need to move the tow hook back in order to get a better launch but to fly it as is for awhile. A few weeks later I got an email from him saying that the local expert said that the "CG" was too far back and that's why the model didn't launch well, that moving the tow hook back would be dangerous, that the designer knew more about where the CG should be than Gordy did, so he put the lead back in and now it launches better again.

You of course likely already know what the extra nose lead did while the model was on tow - the added lead meant that in normal flight, the model needed more up trim to hold level. Sure, it would cause it to porpoise with airspeed changes, but on tow it would force the nose to rotate against the tow line pull. Instead of thinking through what causes what, and what controls what, he didn't get what he wanted, he got what he was given.

All these things can affect your models flight characteristics :

- Flexing wood or foam elevators and tail booms
- Sloppy hinges that allow the elevator to deflect under pressure
- Sloppy servo shafts
- A servo that drifts

- Sloppy connector holes
- Loose covering on the elevator
- Incidence - a big one for V-tails and articulated horizontal stabilizers ("standard" split stab/elevators)
- Balance point

With a **full flying stabilizer**, the modeler can adjust its angle in reference to the chord line of the wing (a line drawn through the airfoil starting at the pointy edge in front to the center of the trailing edge). Since it is the tail that directs the nose, then if the line drawn through the horizontal stabilizer is not parallel to the wing chord line, the model will go where the elevator is angled. Nose lead is used to keep the airfoil doing what we want it to, but often nose lead is used to "fight" the elevator's guidance, or to hobble the model to compensate for a lack of pilot skill, or to dampen pitch reaction in the case of a talented contest pilot.

The confusion happens when the model has a **fixed horizontal stabilizer** (the front part that doesn't move). That setting IS the elevator trim, but it's unmovable with the transmitter trim lever. It's fixed. Okay, sure you can sort of change things by bending the back part, but the back part is small compared to the front part, so the front part can be a bully,

depending on the model's airspeed, since airspeed empowers or un-powers tail feathers.

The Origination of the Dive Test and Why It Can Be Deceiving:

In the early years, most models had fixed stabs with elevators (articulated stabs), but they also had flexy... well everything! And to complicate things more, if their airspeed got high enough say in a dive, the wings would blow up or off! So lead was used as an active part of the airframe's design "protection," and a lot of how models were balanced came from the full size design mandate of designing to protect the pilot inside against uncomfortable flight characteristics and g-forces. Models were mostly designed with a lot of up incidence (the alignment of the horizontal stab to the wing chord line) and extra nose lead to keep the sailplane from porpoising with minor airspeed changes, but mostly to protect the model from tucking (increasing its dive angle as airspeed increased during a dive) and blowing up in the air.

Sailplane guys quickly picked up on the Dive Test to check to insure their models didn't "tuck" into an increasing speedy destructive dive. Plenty of up incidence set in the horizontal stab, so when the

pressure increased - twisting the stab edge down and forcing the elevator down - they only were forced down to just about level, not beyond. Yes, a lot of extra nose lead was needed for calm level flight, but the models were protected against tucking.

(One caveat - not all sailplane pilots followed this practice, many advanced builder pilots were aware of all this, and were building and setting up so that they didn't need the crooked stab settings/extra lead, and were winning.)

Fixed stab incidence locks that part of the equation, changing the nose weight changes what the wing wants to do, but that changes what the stab should be doing, so the pilot is stuck with what angles are glued. That knowledge drove the trend toward full flying stabs. But what incidence has to do with this story, is that if your model has a fixed stab, your changes to a desired change are limited.

Wait a second! Some of the newest molded competition sailplane designs now have V-tails or fixed articulated horizontal stabs - have the gods gone crazy???

Nope! Now that airframes, servos, linkage systems and materials have made our models mostly flex-free and

slop-free, AND we now know that pretty much all task sailplanes will balance well for task flying at about 45% of root chord, using a fixed stabilizer makes a lot of good sense. Instead of changing incidence as with a full flying stabilizer, the articulated stab changes its camber to change the pitch direction of the nose.

They are simpler to build, the fixed part is always providing some constant uniform direction, and the elevator can be tiny. So less weight, less force, smaller servos, thinner pushrods and likely smoother more defined pitch control is possible. And for those who think V-tails look sexy, a bonus!

Okay so back to my AVA project:

You'd think at this point I should know what would cause my RES fuselage set-up to track erratically! Well, it didn't seem like I had enough loose deflection at the stabs trailing edge, and there was nothing in the linkage that might cause the model to pitch up, or tuck, yet it did both. Ah hah! It must be a wonky servo. The servo must be drifting in flight. Lame guess, I know, but I replaced it anyway... and it didn't change anything.

I went over all the linkages, etc. just to insure that for sure that was not

the cause, then flew it again... with no change.

I had only one card left - and it was gonna kill me to use it. Add some lead to the nose... ARGH!

Well guess what? It turns out that the balance point was right on the cusp of being neutral. The model glided out of my hand, didn't pitch up or down on a firm toss, but it did seem to settle a bit "back" when I held it to a stop in the air on a hand toss. But it also couldn't decide what angle to fly at, so the too little bit of nose weight kept it confused in flight. Turns out "a little dab'll do ya" applied in this case. Nose weight is good if its just enough. Too many pilots don't find the spot during their initial prep that is just a bit too little, then add. They add to too much already.

In the end, it was the simplest reason.... and in the end I did my investigations in the right order... simplest last!

Hope this adventure helps you this season with your soaring projects! If you have questions or comments feel free to write to me at GordySoar@aol.com

TOM'S TIPS

Contour Gauge

Tom Broeski, T&G Innovations LLC, tom@adesigner.com

I needed a contour gauge a bit deeper than what is available (for a reasonable price) at Home Depot, Walmart, Harbor Freight, etc. Most have a measuring depth of around 2". Soooo... I made exactly what I needed.

Materials:

A bunch of sticks.

(2) 1 inch to 1.5 inch x 1/4 inch strips. Whatever length you want the gauge to be.

(2) Machine screws with nuts.

(2) Plastic tubing cut to width of sticks. These slip over the screws, but are not needed for skewers or small sticks.

You can use skewers, popsicle sticks, stirring sticks, tongue depressors, etc. I found that tongue depressors are thinner than popsicle sticks, so decided they would be best for my application. I use it mostly for woodturning, but figured it would come in handy for copying other profiles.

Just cut your strips to length, drill holes for the screws, add the tubes and screw together. Then you can stack your sticks in and adjust the tightness. You want it loose enough that the sticks will move, but not so loose that they fall out.



Assembled contour gauge ready to use

It really comes in handy when you want the shape or measurement of a servo tray or bulkhead when you can't get inside to measure. Don't forget to subtract two times the wall thickness!

Need to get the airfoil shape for a specific part of a wing? Not many other ways to do it. The thinner the sticks, the smoother the contour. Really nice if you need to get the shape of a rib for a built up plane when you don't want to rip the wing apart or don't have the plans.



Contour gauge parts



Contour gauge holder with plastic tubing over screws



Above: Outside servo tray contour

Right: Servo tray contour allowing for fuselage wall thickness



Wing contour

A "ROTISSERIE" FOR GLIDERS

Neal Pfeiffer

Reprinted from *Bungee Cord*, the Voice of the Vintage Sailplane Association, Volume 39 No. 4, Winter 2013

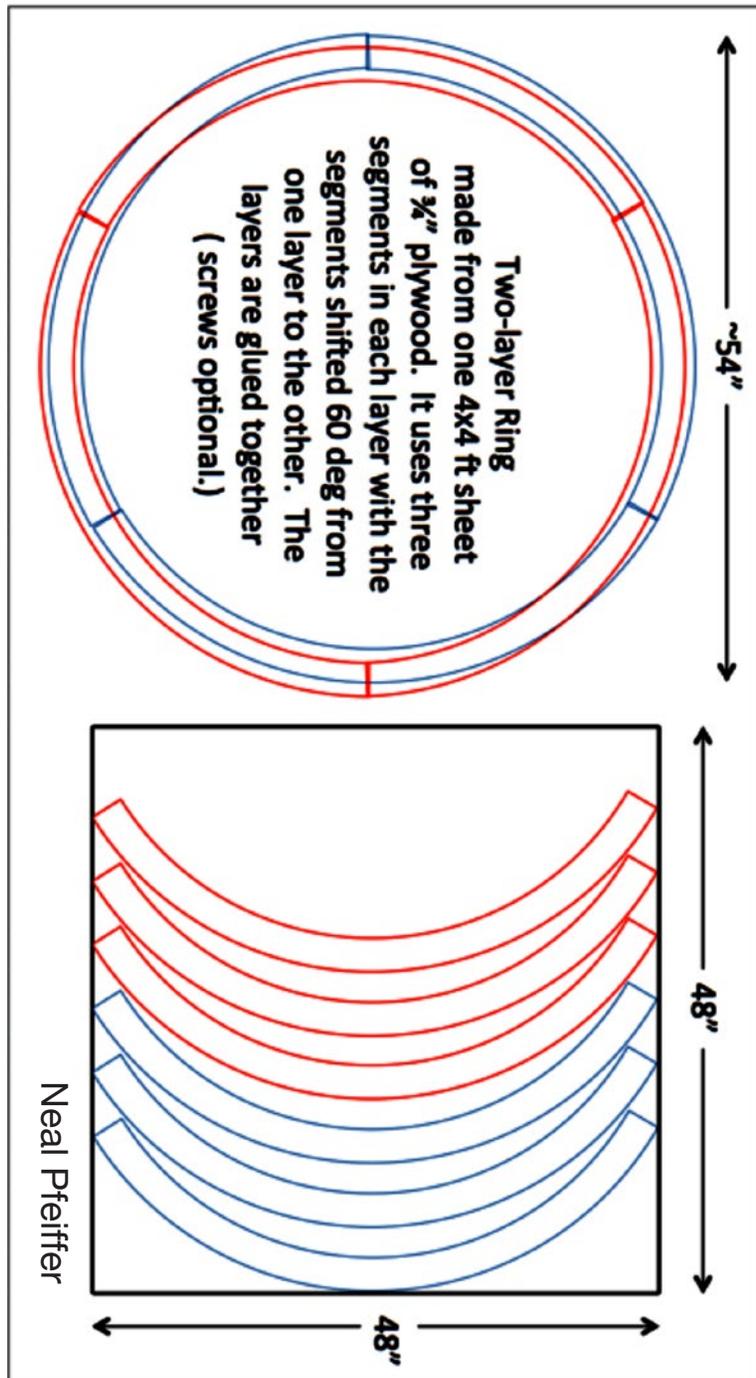
Although this shop fixture was constructed for handling full size sailplanes, there have been a number of instances where one of these would have come in handy while constructing our scale and cross-country machines. Easily scaled and relatively inexpensive, we think this solution is certainly worth consideration. — B²

Not everyone has access to fancy equipment to rotate the glider when working on it, but everyone surely would like to have something to help keep the glider in a rotated position. So Neal came up with a "rotisserie" design that you can build from plywood to make the hard work of sanding, etc. much easier.

The drawing below shows how to make a wooden ring from a single 4x4-foot sheet of plywood. Six 120-degree segments may be cut from the sheet with material left over to build a roller base. The segments are glued together in two layers so that they overlap by 60 degrees. The layers are shifted slightly in the figure to highlight each ring. The resulting ring has an outside diameter of about 54" and inside about 48".

Neal Pfeiffer sanding the nose of the Ka-6BR fuselage, held tightly in position in a ring, similar to those used in the Schempp-Hirth factory.





The Ka-2b is shown installed in a wooden ring or "rotisserie" with additional supports made from 2"x4" lumber.

Vintage Sailplane Association

A Division of the Soaring Society of America



Promoting the acquisition, restoration and flying of vintage and classic sailplanes and gliders and preserving their history since 1974.

For membership information, please go to the VSA website:
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