Everything You ever Wanted to Know About

5$_0$5 FINS

But Dennis [Surtees?] Was Afraid I'd Tell Him

by Bransford Eck

Transcribed for the 'Net by Dave Stetson

INTRODUCTION AND SUMMARY

Years ago I concluded that people believe what they want to believe. Never have I been more convinced that this is true than in my discussions with people who build 505 centerboards and rudders. I had hoped that my March 1976 article in Tank Talk shed a little light on a complex subject. Alas, this was not the case. Apparently, witchcraft is still more in vogue than mathematics.

Those of you who pay attention to minutia will recall an observation I made about being suspicious of "compromise" sections. Perhaps the knowledge of how NASA-Langley personnel build sections for their airfoil research work will help to put things in perspective. Their 6-inch sections (approximately the same as a 505 board tip) are built accurately to *two ten thousandths of an inch*. Their 24-inch test specimens are accurate to *two thousandths of an inch*. Failure to loft and execute to this accuracy will prevent the development of the low drag potential of a given section. It is unlikely that anyone has ever really built a 00-series or a 63-series board. I know mine aren't that accurate.

Through some work I'm doing in another area, I have recently obtained a copy of the code used by NASA in their airfoil research work. This code was written by R. Eppler of the University of Stuttgart. The techniques are based on a fundamental paper (Ref.1) which he wrote in l957, and were rediscovered by Liebeck in 1972 (Liebeck must not have had a good library or he wouldn't have reinvented the Wortmann wheel). Eppler is a German mathematician. I find his writing only barely scrutable. He is an associate of the Wortmann who is the professor in charge of the wind tunnel at Stuttgart. I drop these names to show the pedigree of those whose credentials you must duplicate before you start mouthing off.

The Eppler code is probably the most advanced two-dimensional calculation tool in the free world. It calculates circulation so it is not dependent on the thin foil assumptions. It does not adequately account for drag when large amounts of separation are present. It does, however, reduce the lift coefficient correctly and makes a proper approximation of the maximum obtainable lift coefficient in the presence of large amounts of separation.

Both of you who read my March 1976 article may recall that I alluded to the effects of Reynolds numbers and how they modify the results shown in "Theory of Wing Sections" -(Ref . 2). I did not attempt to quantify that concern at that time because I could not. The Eppler code gave me a tool with which to predict the performance of any arbitrary section at any Reynolds number and angle of attack. It also can be used as a design tool ("inverted" mode). By specifying the desired velocity distribution at various angles of attack, one can have the code describe the profile which will produce the input velocity distribution.

I have used the code in both the design and analysis modes. The results are very interesting. The reasons that the 63-series is junk at low Reynolds number are apparent. The leading edge is too sharp. The cause of the velocity peak in the 00-series is a slightly too large nose radius.

Detailed boundary layer calculations also may be performed using the Eppler code. These calculations report the European version of shape factor, H32. This parameter is the ratio of energy thickness to momentum thickness. Knowing its value, we can determine four things:

1. Location of transition from laminar to turbulent boundary layer.

2. Location and magnitude of laminar bubble.

3. Magnitude of trailing edge separation (stall).

4. Location of stagnation areas. The boundary layer calculations are also used to predict Cl, Cd, and Cm for various angles of attack (α) and Reynolds number.

By brute forcing the assumption of desirable velocity gradients and executing ~70 separate cases, I have come up with what 1 believe to be the best section one can use for Cl > 0.5 and Reynolds number between 0.125 and 1.0 million (values of Reynolds number versus speed and chord are shown in Table 1.)

Table 1

REYNOLDS NUMBER AS A FUNCTION OF SPEED AND CHORD
(MILLIONS)

SPEED, MPH	1.8	4.0	6.0
CHORD, in.			
15	0.305	0.675	1.02
14	0.285	0.630	0.950
12	0.245	0.540	0.815
9	0.183	0.405	0.610
8	0.160	0.352	0.532
6	0.122	0.269	0.405

The nomenclature I nave used is as follows: E1161 is the run number , -24 is the location of the point of maximum thickness (24% aft of leading edge and the last four digits are percent thickness (091 is 9.15% of chord thickness). The dominant feature of the recommended thickness distribution (E1161-24 series) are: a forward (24%) position of the maximum thickness, transition from laminar to turbulent boundary layer forward of the point of maximum thickness, prompt reattachment of the turbulent boundary layer, trailing edge separation which progresses forward slowly with increasing angle of attack, a ±5 degree wide low drag bucket, and some sacrifice low drag properties at low angles of attack to improve performance at high angles. The E1161-24 series is very forgiving. The maximum values of Cl are very high for the low Reynolds numbers, but there are still trades to be made. What we must do is determine what the actual required Cl is. The calculation method presented in March 1976 Tank Talk is valid, but what is not available is a table showing required righting moment versus speed. This is critical since the design Cl is a function of l/V^2.

This leads to a problem. I believe we are making our boards too small. Small boards will be fast at high speed but will be in trouble at moderate speed and maximum righting moment. This tells me that we need minimum board areas of ~600-650 sq. inches. You can't fit such a board into a stock Parker trunk.

I would appreciate input from anyone who has done a speed versus righting moment approximation. Maybe if everyone would try to quantify estimates of what the speed is in relation to where the crew is in the boat (and record the crew weight) we could come up with a reasonable approximation.

The subsequent paragraphs will take you through the figures and point out the reasons that the following conclusions are drawn:

<u>Conclusions</u>.

1. 505 boards should have a minimum area of 600 - 650 square inches, depending on crew weight.

2. 505 boards and rudders operate (to windward) at Reynolds numbers of 0.125 to 1.1 million.

3. Sections which optimize for these Reynolds numbers transition to a turbulent boundary layer forward of the point of maximum thickness.

4. The pressure gradients should be kept gentle.

5. The trailing edge angles should be kept low.

6. Maximum thickness used should be in the 9 to 11 percent range depending on structural requirements and trunk widths.

7. Sections with lower drag at C1 < .5 can be developed but Cl max is reduced. Until Cl

max is better defined, prudence requires use of a forgiving thickness distribution.

8. If you are imprudent and think you are that accurate a helmsperson, I will send you the E1160-28 thickness distribution. I'm always interested in experiment.

9. Lofting and execution are crucial. Proper section geometry, especially at the tip, will require contour milling on a tape controlled machine with good spline-fit software.

10. The notion that useful ad-hoc changes to existing section thickness distributions can be made is poorly founded.

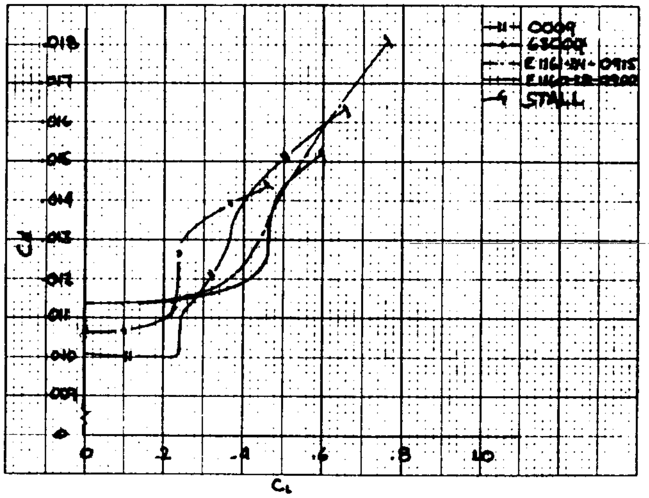
11. The notion that improvements can be made to sections or planforms because "it looks better" is very prevalent and very wrong.

12. Never has a subject which has such a sound technology base been so productive of bullshit.

<u>Section Development:</u>

The Cd vs Cl behavior of a number of thickness distributions is shown for various Reynolds numbers in Figures 1 through 4. I investigated over 170 thickness distributions with the Eppler code before selecting two for detailed study. The selected distributions (E1160 and E1161) used α increments of Δ + .25 and Δ + .60 in developing the desired velocity distribution. The range Δ+ .20 to Δ + .75 was covered in the investigation. The location of velocity recovery initiation was varied systematically within each thickness distribution. In general, within a given thickness distribution, moving the draft aft decreased the width of the low drag bucket, decreased the minimum Cd and decreased the maximum Cl. Attractive subsets of the E1160 series include E1160-28 and E1160-32. The attractive subsets of the E1161 series are E1161-24 and E1161-28.

Figures 1 through 4 show the trends quite clearly. The E1160-28 series has a wider bucket than the E1161-24, but Cl max is rather low. If we could show



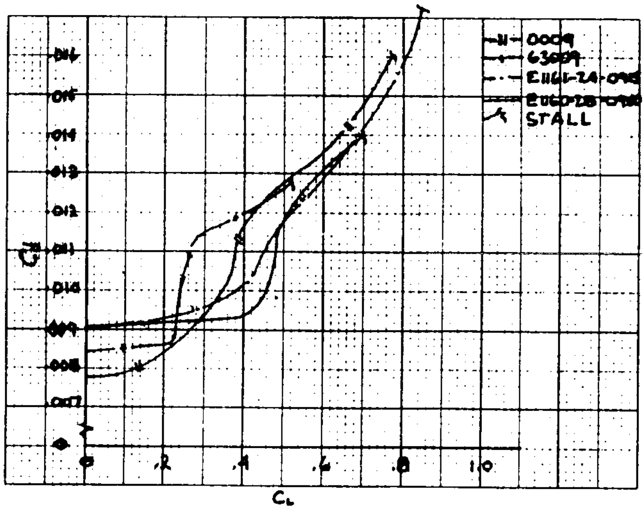


Figure 2. Drag Polar for Various Thickness Distributions at a Reynolds number of 250000.

that the required lift coefficient was always below ~.45, the E1160-28 would be the distribution of choice. If Cl max were not a consideration and the required Cl could be shown to be .4 or less, the E1160-32 series would be superior. I have chosen the E1161-24 distribution for detailed study and recommend its use because of its flexibility. It shows less drag and greater Cl max than the -00 series for the Cl and the Reynolds number ranges of interest. Lower drag solutions are available at the risk of premature stall.

The 63-series is shown for historical reference. This is a bad low Re section; it exhibits a narrow low drag bucket, poor Cd vs C1 characteristics at the Cl and Re of interest and a very low Cl max. Clearly, one does not want to use a 63-series section anywhere on a 505.

It should be noted that the curves shown in Figures 1 through 4 underestimate Cd at high Cl. This is because the drag associated with separation (both laminar and trailing edge) is not handled by the code. I have looked at the H32 calculation results in detail and it appears that the relative differences between the curves are correct. All should show higher drag prior to stall. This affects the 00 and E1161-24 series most because their stall is less abrupt than the 63- and E1160-28 series. Basically, what happens is that the separated laminar boundary layer does not reattach at high angles of attack and low Reynolds number, if the point of maximum thickness is too far aft. If the laminar separation occurs far enough forward, reattachment occurs and stall is from the trailing edge forward.

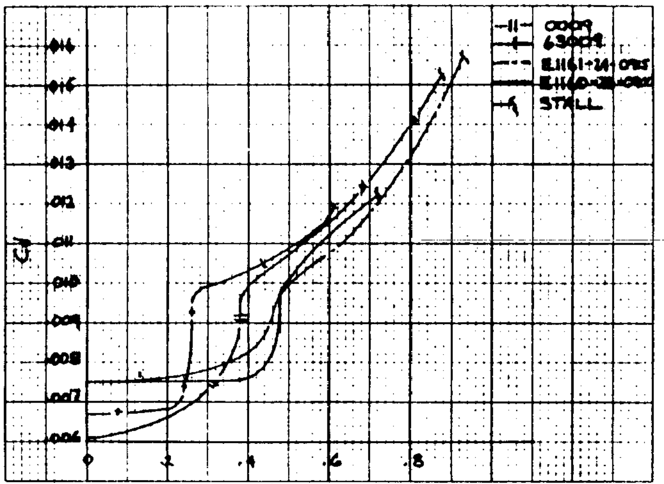


Figure 3. Drag Polar for Various Thickness Distributions at a Reynolds number of 500000.

Planform Selection.

Both of you remember the planform discussion from my last article. Nothing has changed except the growing realization that we are making our boards too small. This is another reason to use elliptic trailing edges. This area distribution will get more area into a Parker trunk than straight leading and trailing edges. Bram's (Dill's) boards require modification to fit Parker trunks. They have more area than Mark's. Mark could get a longer board into his trunk if he built the trunk to maximum dimensions. Currently, his trunk aft edge ends two inches forward of the maximum allowable aft location. I think this is a mistake. So, looking at what the builders do, one is forces either to use elliptical trailing edges to get the area or modify the trunks. (Howie, you might consider this in your new boats.) Now, if you still want to use a too small board with straight leading and trailing edges, here’s the story.

Sweep. Hörner (Ref. 10) showed some advantage to sweeping the leading edge by 5 degrees. Large amounts of sweep are not useful at low mach numbers. Weaver (Ref. 3) has shown great effects on Cd reduction with sweep. What is rarely reported is that the differences he shows wash out below mach 0.7. This was my beef with Jeffery (Ref. 11). The effects of sweep on drag are simply irrelevant at our mach numbers.

Foils which are swept back stall first at the tip. The displacement of the pressure distributions along the span sets up spanwise pressure gradients which cause a spanwise drift of the boundary layer fluid toward the upper surface tip. The resulting thickening of the boundary layer on the outboard portion of the foil promotes tip stall. Highly swept foils require some form of twist (wash, Dennis) to prevent tip stall. Swept forward foils stall first at the root. This may have been why we put our boards forward with some success in the olde days.

If you are interested, Sears (Ref. 4), Jones (Ref. 5) , Kuethe (Ref. 6), and Sivells (Ref. 7) have all published in this area. You will notice most of my references are old. This is because the Reynolds numbers of interest to us were of interest to DaVinci and Newton.

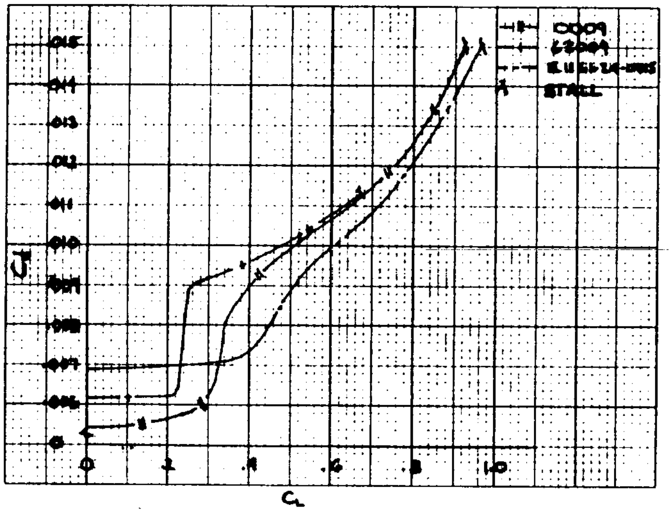


Figure 4. Drag Polar for Various Thickness Distributions at a Reynolds number of 750000.

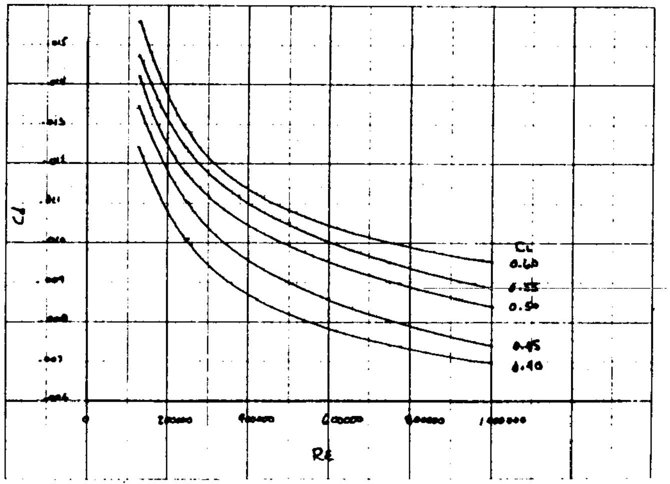


Figure 4A. Cross Plot of Figures 1-4 showing the Effect of Reynolds Number on Drag Coefficient for Various Lift Coefficients for an t1161-24-0915 Thickness Distribution.

Taper. Many have shown that minimum induced drag results from a finite foil having an elliptic circulation distribution. Many more have continued to improve on the theory by doing things which "look good." Oh well. From a practical standpoint it is hard to hurt yourself too much trying to improve on what is known to be best.

Glauert (Ref. 8) solved the basic equation, not by assuming that the foil lift distribution was known, but by assuming that everything was known about the foil's geometry, speed and orientation. This allows for the direct solution of the circulation (τ) distribution. This solution requires expansion of the sine terms of a Fourier series with a lot of messy algebra. So, trust me or look up the reference. Anyway, it reduces to two equations.

$$Cd_i = \frac{Cl^2}{\pi AR}(1+\delta) + Cd_o \qquad \textbf{(1)}$$

and

$$\alpha_i = \frac{Cl}{\pi AR}(1+\tau) + \alpha_o \qquad \textbf{(2)}$$

There is an elaborate proof that δ and τ are always positive values. Therefore, any deviation from elliptical circulation distribution must result in increased drag. Examination of Figure 5 shows that the minimum values of δ and τ occur at tip chord to root chord ratios of ~.4. At taper ratios of ~.4, the absolute values of δ and τ are small, so it is possible to make straight sided foils whose performance is virtually indistinguishable from that of proper elliptic foils.

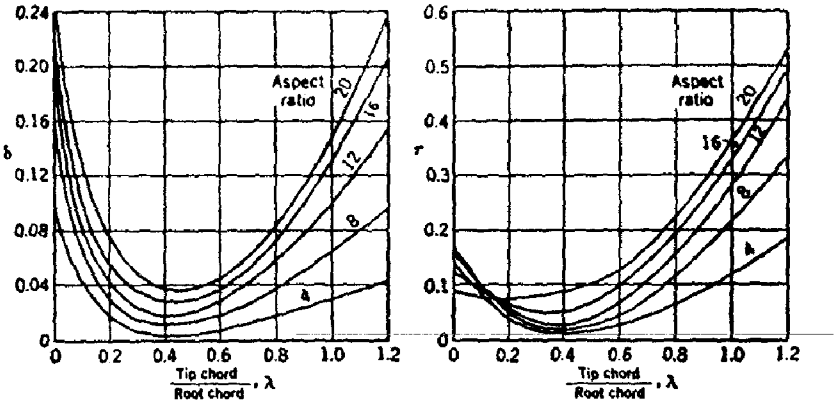


Figure 5. Values of δ and τ for Various Aspect and Taper Ratios.

Careful readers will note that I have referred to the circulation distribution (τ) as elliptical, not to an elliptical planform. If the slope (a) of the Cl vs α curve, α_o and Cl are not independent of span, an elliptical τ distribution requires that the product α_o α_o Cl must vary elliptically with span. Take that, you eyeball specialists.

There is one thing to remember in using Fig. 5. Lower taper ratios (smaller tip chords) lead to lower Reynolds numbers at the tip for a given speed. Lower Reynolds numbers lead to higher drag coefficients for a given section. Figure 5 must be modified for the scale effects of Reynolds number. I have riot worked out the details; however, a cross plot of Figures 1 through 4 for a constant lift coefficient and the application of the aspect ratio correction for Ca would provide the means for performing the necessary trade-off. The proper application of the above

requires the solution of $1/A\sum_{z=0}^{tip} Cd_i \Delta A_i$ (where z=0 is the root) to obtain the average Cd.

Correction of this average Cd for the aspect ratio then results in a proper application of Figure 5 in the flow regime of interest. By performing serial calculations on arbitrarily varied planforms, an optimum Reynolds number specific planform may be developed.

Given all of the above and the need for 600-650 square inches of area, a planform which has a 15 inch root, a 7 to 8 inch tip, a straight 25 percent chord line and an elliptical trailing edge is probably the best you can do. A better solution would be longer span. This requires a movable pivot to get the board in the trunk as well as a longer trunk than is currently in vogue. As long as you have good gaskets, I believe maximum trunks are a good idea. But you'll have to take it up with your builder. Mine wouldn't do it.

Slope of Lift Curve with Thickness.

An elliptical circulation (τ) distribution leads to a constant downwash angle across the span. This leads to the minimum induced (tip vortex) drag. The normal correction which is made for drag coefficients and angle of attack is based on the assumption that the lift distribution is elliptic and the slope of the infinite aspect ratio lift versus angle of attack curve is 2π/radian (about 0.11 per degree). Jones (Ref. 9) has shown that one must make a correction for three dimensional flow because "the fluid has more places to go" as it passes over a three dimensional body. Consider that the maximum or "edge" velocity around an infinite cylinder is 2V (where V is the free stream velocity), while that around a sphere is only 1.59V. This reduction in velocity -- because the fluid has more degrees of freedom ("places to go") results in a decrease in lift in relation to an infinite aspect ratio foil (two dimensional flow).

From the above, we may calculate the slope of the lift curve for a thin foil as:

$$a = 2\pi \frac{AR}{AR+2} \qquad (3)$$

The inappropriate use of this equation will get you into a lot of trouble. When we apply the "more places to go" condition, we see that the value of the lift reduction (for elliptic lift d distribution) may be expressed as an efficiency.

$$E = \frac{Foil\ \ Perimeter}{2\ \ span} \qquad (4)$$

Note: Define perimeter as tip, leading and trailing edges. Omit the root chord.

This efficiency is a direct measure of the reduction in the foil "edge velocity." Edge velocity determines the circulation about the foil through the Kutta condition; therefore, the edge velocity reduction directly reduces lift. Combining **we** may express the new lift coefficient as:

$$Cl = \frac{2\pi\alpha_g AR}{EAR+2} \qquad (5)$$

I have gone through this exercise not because it is profound but because it may help you to visualize what the drivers are in maximizing the lift resulting from a given geometric angle of attack. The closer E is to one, the closer Cd is to the theoretical (two dimensional) value. Looking back at (4) we see that E equals one, when half the perimeter equals the span. In other words, long and thin. Now, let's look at where the "make it thicker toward the tip" notion originated.

If, when performing a Joukowski transformation, we place the center of the Z circle a little (m) to the right of the origin (so that C1 + m = r) the Z circle transforms into a symmetrical foil. If we define E as small and equal to m/Cl, the foil chord length becomes:

$$C = 4Cl(1+\epsilon^2) \tag{6}$$

The thickness of the foil is dependent on the amount of displacement (m) between the circle center and the origin. Thickness increases, therefore, as the ratio of m/Cl increases. If we substitute Eq. (6) into the general equation for lift, we obtain:

$$L = \frac{\ell v^2}{2g_c}[4Cl(1+\epsilon^2)]2\pi\alpha \tag{7}$$

and:

$$Cl = \frac{2\pi(1+\epsilon)}{(1+\epsilon^2)}\alpha \tag{8}$$

The slope of the lift curve is then:

$$\frac{dCl}{d\alpha} = \frac{2\pi(1+\epsilon)}{(1+\epsilon^2)} \tag{9}$$

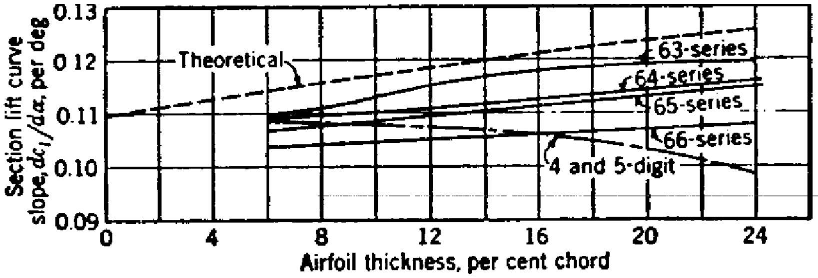


Figure 6. Effect of Thickness on Slope of Lift Curve.

and we see that the slope of the theoretical lift curve <u>increases</u> with airfoil thickness.

The dotted curve shown in Figure 6 is a plot of Eq. (9). Experimental curves for 6-series foils show agreement with the trends of the theory. Note, however, that the 4 and 5 digit foils (this includes the 00-series) go <u>against</u> the theory.

The conclusion that thick 505 fin tips are useful because they increase the lift coefficient is incorrect. First, the apparent theoretical advantage is based on an inviscid flow assumption. Second, even those experimental data which show some agreement with theory do so at Reynolds numbers which are not of interest. Third, the theoretical increase in Cl over the range of 8 to 12 percent thickness cannot result in a decrease in area which will counterbalance the increased form drag which results from increased foil thickness.

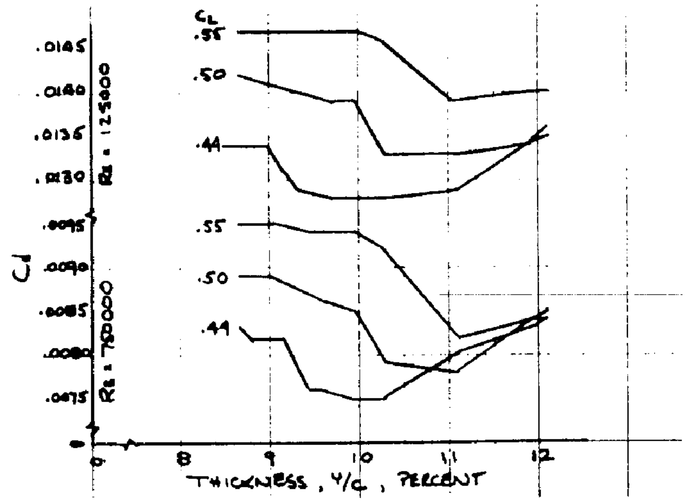


Figure 7. Effect of Percent Thickness (Y/c) on Drag Coefficient for Various Lift Coefficients and Reynolds Numbers.

There is, however, another point to be made for increasing foil thickness. The width of the low drag bucket for any thickness distribution is controlled by the maximum section percentage thickness. The value of holding thickness constant while reducing chord is now seen to be a function of the design lift coefficient (Cl). Figure 7 shows how the width of the low drag bucket varies with thickness for an E1160-24 thickness distribution. It is clear that there is an optimum percent thickness for each design lift coefficient. Further, we see that this optimum cannot be obtained with a 15 inch root-chord board and the 1.4 inch centerboard trunk width limitation. It is also clear that Kyrwood trunks are wrong to be 1.25 inches wide when the rule allows 1.4. Notice in Figure 7 that the optimum thickness is only a function of Cl and not of Reynolds number. Reynolds number affects the magnitude of the drag but not the location of the minimum drag. This is most important since it allows the selection of a single optimum thickness for all values of speed for a constant Cl. Now we have our dilemma. What should be the design Cl? I don't know since I have no good data on the relation of hull speed to required righting moment. If anyone has a good plot of where the crew is in relation to speed through the water, we could better quantify design Cl using the moments balance procedure described in my March 1976 Tank Talk article. My best estimate is that Cl max probably is in the range .4 to .5 for centerboards of 600 square inches area. If this is correct, and it's a big "if," optimum thickness is in the range of 9 to 11 percent. My previous recommendation of not exceeding 10.8 percent for 00-series sections is consistent with the results shown here for the E1161-24 thickness distribution. If it turns out that CR max is 0.6 to 0.7, we are out of luck because we cannot fit boards of optimum thickness for these values of Cl max into our trunks. The best procedure is to determine the Cl max you need for your crew weight and board area (if you are trunk limited) and the optimum thickness from Figure 7.

Remember that we are dealing with Cd in Figure 7, not drag (D). Minimum Cd is only minimum D if area is constant. You do not necessarily win by making area larger to drop the required Cl. Note that for Re = 750000 and 9.8 percent thickness, the area increase implied in going from Cl = .55 to Cl = .44 is 20 percent, while the drag coefficient reduction implied is .0094 to .0075, or 21.2 percent. A small gain would appear to be realizable. Remember, however, that span is fixed at about 50 inches below the water. The only way we can increase area 20 percent is to increase the root chord. A 20 percent chord increase from a 9.8 percent full trunk thickness section would result in a 1.7 inch thick foil. This cannot be accommodated in the trunk. Further, the increased area results in decreased aspect ratio, which increases induced drag (remember Figure 7 is for two dimensional flow and must be corrected for three dimensional flow).

The results shown in Figure 7 are instructive but they must be used with great care. My primary points in presenting them are to show that arbitrary (read, "it looks good") selection of spanwise thickness may be very harmful, and trunks should be built as wide as the rules allow.

Maximum Lift Coefficient

Normally, when one thinks of maximum lift coefficient, the assumption is that the section with the greatest thickness will produce the greatest Cl. This is generally true at Reynolds numbers above one million. It is not true at low Reynolds numbers. The reasons for this condition are apparent from observation of Figure 8. These curves were developed from the H32 calculations in the boundary layer analysis portion of the Eppler code. This code sets a flag when H32 equals 1.46. This is the value of shape factor at which turbulent boundary layer separation occurs. By plotting the arc length at which this value is reached against angle of attack, one may discern the effects of trailing edge separation on Cl. Separation causes reduced circulation, and therefore reduced lift. The mechanism is as I described in my previous article. When the trailing edge angle is too high, the flow will not remain attached, and separation occurs. The code does not predict the drag which results from this separation accurately. However, it does reduce the lift coefficient correctly. As a result, the code under predicts drag at all angles of attack after the initiation of trailing edge separation.

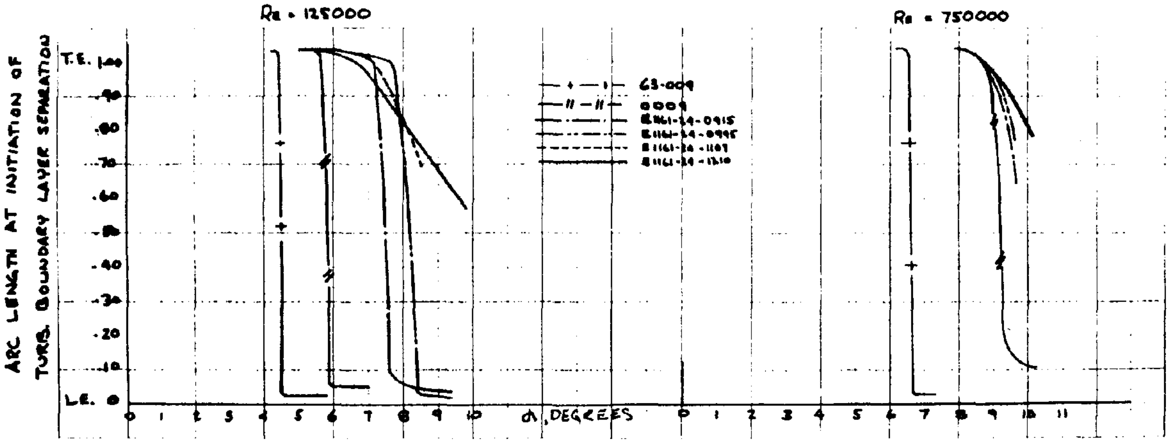


Figure 8. Effect of Reynolds Number on the Initiation of Turbulent Boundary Layer Separation for Various Thickness Distributions and Angles of Attack.

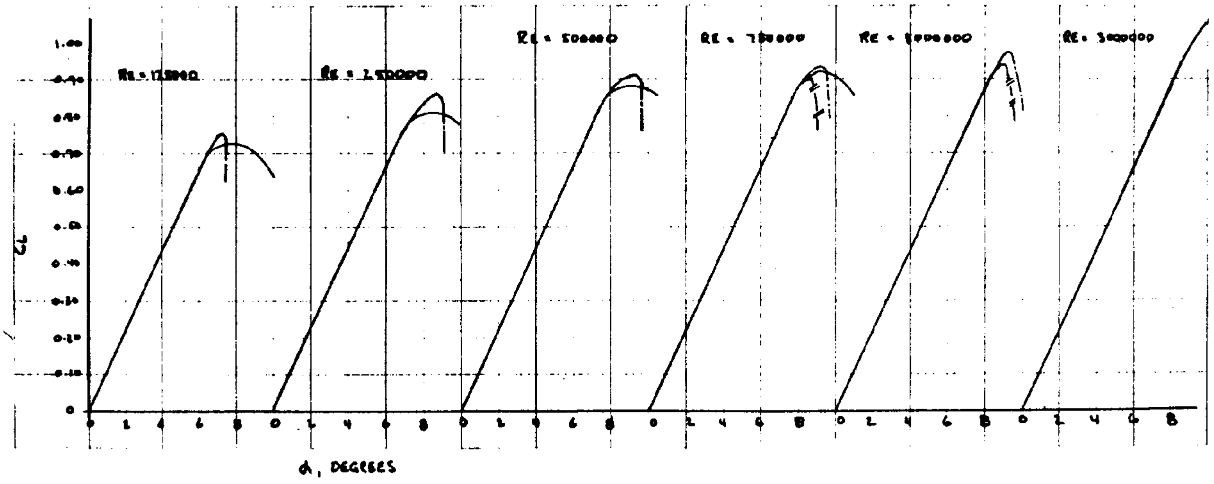


Figure 9. Effect of Reynolds Number on Maximum Lift Coefficient.

Examination of Figure 8 again shows that the 63- series should be avoided at low Reynolds number. Gross stalling occurs at a Cl of ~.5, while the 00-series holds on until ~.61. A 9 percent E1161-24 thickness distribution section will produce a maximum Cl of ~.79 and a 10 percent section of this type is good to a Cl of greater than .83. The flexibility of the E1161-24 thickness distribution is very important when we consider the disequilibrium and power conditions of 505 sailing. At higher Reynolds numbers (> 750000), we see that the 63- series still sucks, but the 00-series is hanging on. We also note that at this higher Re, maximum Cl increases directly with thickness within the E1161-24 family.

Trailing edge separation is another reason that thick foil tips are a bad idea. Remember that the onset of separation is also the onset of high drag. In highly loaded conditions at low Reynolds number, thick tips will lead to tip stall and very high drag. This condition is made worse by the three dimensional flow problems of the tip. Based on the above, it seems reasonable to conclude that centerboard sections of greater than ~11 percent thickness are unwise. Luckily, the is consistent with the conclusions we drew in the previous section from Figure 7.

Figure 9 is a summary of the performance of a number of sections. Note that while the maximum Cl's obtainable from the 9 percent sections are greater than the 12 percent sections at some Re, the stall of the thinner sections is more abrupt. Unless you are a very accurate helmsperson, you may want to use a thicker rudder to give you more warning before a stall. This is a high drag option, but it may save the odd broach. If you don't get out of shape too often, a 10 percent rudder section is probably OK for you. The 00-series curves shown in Figure 9 are for historical reference. It is interesting to see how the differences wash out as Re increases.

Velocity Distribution and Lofting.

Figure 10 shows the velocity (u/V) and thickness distributions for an E1161-24-0915 section. There is a small peak in u/V, followed by a gradual fall-off. No plateau is evident. Velocity recovery is .835, and the gradients are gradual. A concave pressure recovery is used. At the lift coefficients of interest, laminar to turbulent boundary layer transition occurs well forward of the point of maximum thickness (X/C = 0.24). The H32 calculation shows some laminar separation, but reattachment is prompt and certain.

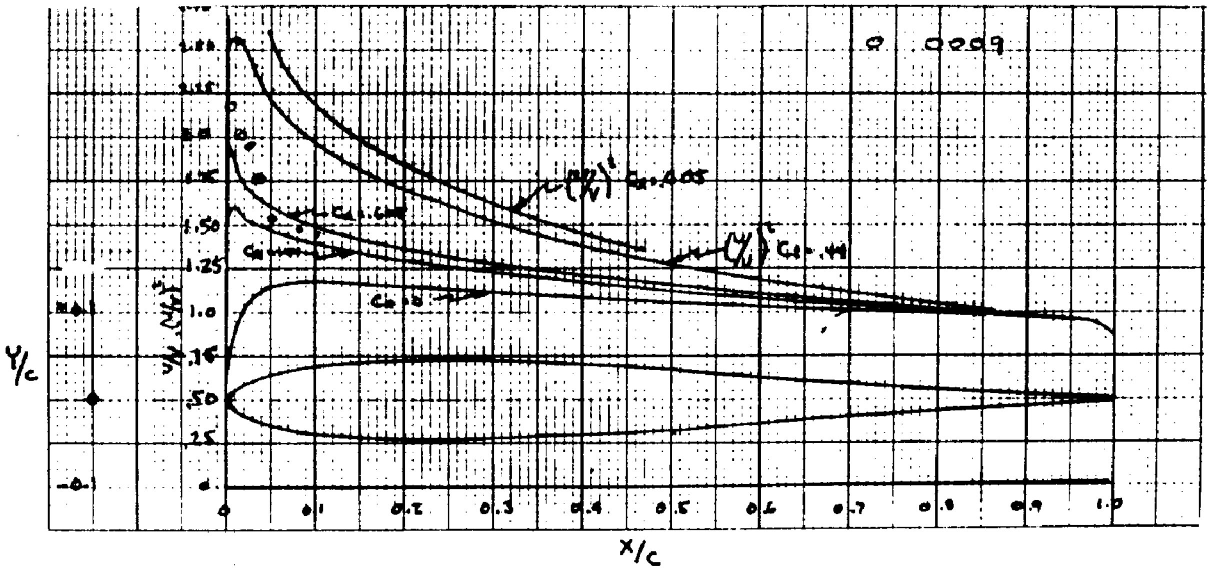


Figure 10. Velocity and Pressure Distribution for an E1161-24-0915 Thickness Distribution.

I have plotted u/V for the 0009 section in Figure 10 for reference purposes. This is to show the very large effect that inaccurate lofting can have on u/V (hence drag). Figure 11 shows the first 15 percent of 00- and E1161-24-series sections. The pressure peak shown by the circles in Figure 10 occurs because of the deviation in leading edge entry shown in Figure 11. This looks like a reasonable difference at this scale, but remember it is <u>ten times</u> scale for a 10 inch chord. Very large differences in performance occur with very small changes in thickness when you are working with small chord sections. These leading edge differences are only .00086 inches when working with a 10 inch chord section. Do not sluff this off. The performance advantages available do not accrue unless you build it by the numbers. If you can't build to this kind of accuracy, you cannot expect to obtain optimum foil performance. What you will need is access to a tape controlled contour mill. Be very careful with the leading edge strength. If you ding it, it is unlikely you can put it back together by eye.

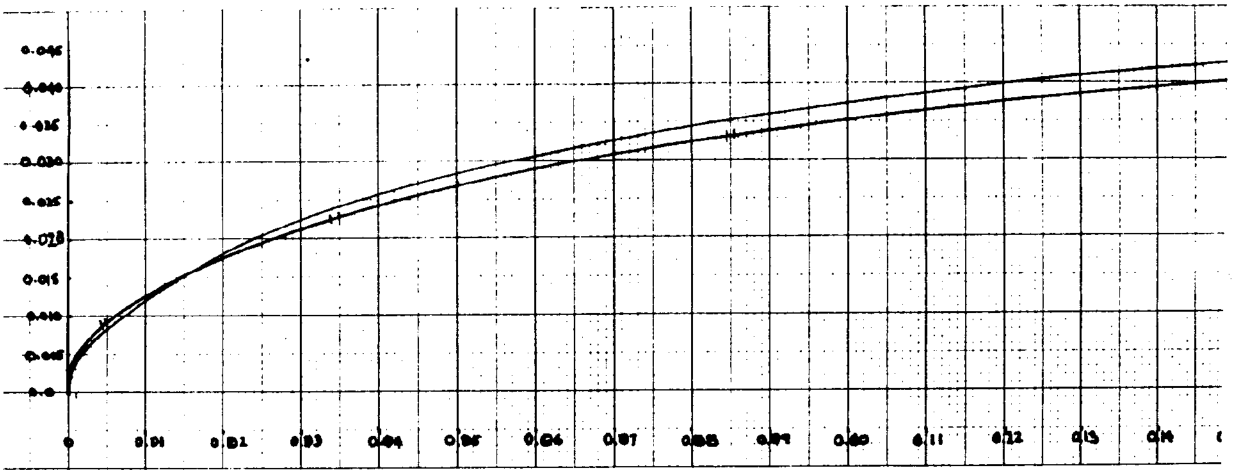


Figure 11. Comparison of the First 15 Percent of NACA 0009 and E1161-24-0915 Thickness Distributions.

Maybe now you will understand why I am not very tolerant of people who say they blend different parts of different thickness distributions to get 'good" sections. If someone is using a board like that and he is fast, you can bet he would be faster if he used a proper board. It is very easy to get taken in by good sailors who are bad hydrodynamicists. What you see is the result. They win. They are usually very positive and strong of opinion. This is often why they are good sailors. Confidence. Remember, however, that it is possible (even likely) that winning has more to do with shifts and tactics than it does with centerboard design. Winners are convincing because they are seldom in doubt. Often wrong, but seldom in doubt. If you are going to invest the time in building a board yourself, build it right. Offsets are presented in Table II for the E1161-24 thickness distribution of interest. If you want dimensions for sections in the cracks, or want to take a chance that the required Cl is low enough to use an E1160-32 distribution (8% reduction in Cd at Cl = .4), write. I will send them in a plain brown envelope. No salesperson will call.

REFERENCES

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TABLE II

OFFSETS FOR VARIOUS THICKNESS SECTIONS OF THE E1161-24-SERIES THICKNESS DISTRIBUTION

Airfoil 1161 9.15%			Airfoil 1128 9.31%			Airfoil 1162 9.62%			Airfoil 1170 9.95%			Airfoil 1173 11.90%		
N	X	Y	N	X	Y	N	X	Y	N	X	Y	N	X	Y
0	1.00000	0.00000	0	1.00000	0.00000	0	1.00000	0.00000	0	1.00000	0.00000	0	1.00000	0.00000
1	0.99674	0.00013	1	0.99673	0.00013	1	0.99671	0.00013	1	0.99670	0.00013	1	0.99663	0.00013
2	0.98715	0.00065	2	0.98712	0.00066	2	0.98706	0.00066	2	0.98702	0.00066	2	0.98672	0.00069
3	0.97168	0.00165	3	0.97162	0.00168	3	0.97149	0.00170	3	0.97140	0.00171	3	0.97074	0.00181
4	0.95068	0.00300	4	0.95057	0.00305	4	0.95035	0.00311	4	0.95019	0.00312	4	0.94904	0.00337
5	0.92432	0.00462	5	0.92416	0.00470	5	0.92384	0.00480	5	0.92358	0.00485	5	0.92183	0.00532
6	0.89288	0.00659	6	0.89268	0.00671	6	0.89224	0.00687	6	0.89187	0.00697	6	0.88944	0.00778
7	0.85682	0.00896	7	0.85656	0.00913	7	0.85600	0.00938	7	0.85551	0.00954	7	0.85237	0.01081
8	0.81664	0.01174	8	0.81632	0.01197	8	0.81563	0.01232	8	0.81503	0.01257	8	0.81116	0.01442
9	0.77288	0.01490	9	0.77251	0.01518	9	0.77170	0.01567	9	077099	0.01603	9	0.76642	0.01857
10	0.72613	0.01838	10	0.72571	0.01873	10	0.72479	0.01936	10	0.72399	0.01984	10	0.71879	0.02318
11	0.67699	0.02209	11	0.67654	0.02252	11	0.67553	0.02331	11	0.67465	0.02393	11	0.66893	0.02815
12	0.62610	0.02594	12	0.62562	0.02645	12	0.62455	0.02740	12	0.62361	0.02817	12	0.61751	0.03331
13	0.57408	0.02981	13	0.57359	0.03039	13	0.57248	0.03151	13	0.57151	0.03242	13	0.56518	0.03951
14	0.52155	0.03355	14	0.52106	0.03421	14	0.51995	0.03550	14	0.51898	0.03655	14	0.51261	0.04355
15	0.46913	0.03704	15	0.46866	0.03776	15	046768	0.03920	15	0.46663	0.04038	15	0.46040	0.04823
16	0.41741	0.04012	16	0.41696	0.04090	16	0.41595	0.04246	16	0.41505	0.04376	16	0.40915	0.05235
17	0.36694	0.04266	17	0.36654	0.04348	17	0.36563	0.04514	17	0.36481	0.04652	17	0.35941	0.05571
18	0.31827	0.04461	18	0.31793	0.04535	18	0.31713	0.04718	18	0.31642	0.04853	18	0.31168	0.05811
19	0.27189	0.04555	19	0.27161	0.04640	19	0.27096	0.04816	19	0.27037	0.04962	19	0.26643	0.05937

20	0.22825	0.04564	20	0.22805	0.04647	20	0.22755	0.04820	20	0.22711	0.04964	20	0.22406	0.05928
21	0.18767	0.04461	21	0.18754	0.04540	21	0.18721	0.04704	21	0.18691	0.04841	21	0.18478	0.05760
22	0.15035	0.04249	22	0.15028	0.04321	22	0.15009	0.04470	22	0.14991	0.04596	22	0.14859	0.05440
23	0.11657	0.03942	23	0.11655	0.04005	23	0.11646	0.04137	23	0.11638	0.04249	23	0.11569	0.04996
24	0.08669	0.03550	24	0.08670	0.03604	24	0.08669	0.03716	24	0.08666	0.03811	24	0.08643	0.04450
25	0.06097	0.03077	25	0.06100	0.03121	25	0.06103	0.03213	25	0.06105	0.03290	25	0.06110	0.03814
26	0.03962	0.02532	26	0.03965	0.02565	26	0.03970	0.02636	26	0.03974	0.02696	26	0.03993	0.03104
27	0.02275	0.01923	27	0.02278	0.01947	27	0.02283	0.01998	27	0.02287	0.02041	27	0.02308	0.02336
28	0.01042	0.01271	28	0.01044	0.01286	28	0.01047	0.01318	28	0.01050	0.01346	28	0.01065	0.01533
29	0.00270	0.00607	29	0.00270	0.00414	29	0.00271	0.00629	29	0.00272	0.00642	29	0.00277	0.00731
30	0.00000	0.00000	30	0.00000	0.00000	30	0.00000	0.00000	30	0.00000	0.00000	30	0.00000	0.00000