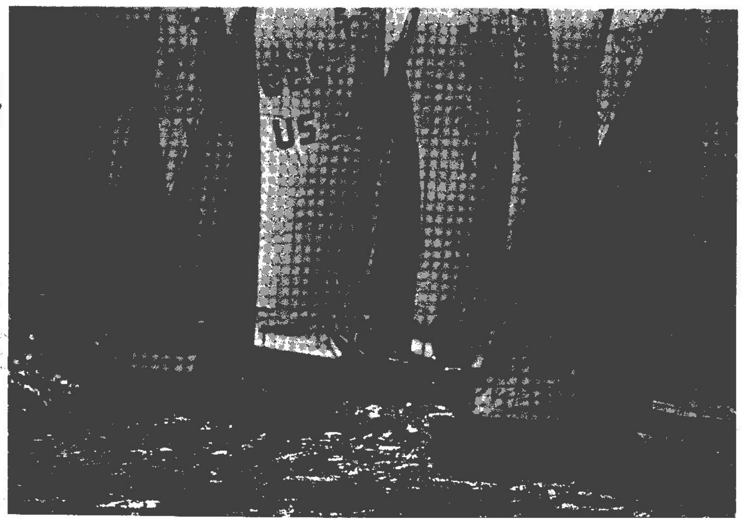
TANK TALK

INTERNATIONAL 505 YACHT RACING ASSOCIATION
AMERICAN SECTION

MARCH 1976



505 FINS - A DEFINITIVE WORK

Modestly authored by Bransford Eck

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Transcribed for the ‘Net by Dave Stetson

In 1969, I started a study of the effect of centerboard design on 505 performance. I have reached no conclusions, but I have formed some impressions. The framework of this study has been developed around the following topics:

<u>SECTION SELECTION</u>

- laminar
- conventional

<u>PLANFORM SELECTION</u>

- area required
- effect of aspect ratio
- gybing vs. non-gybing

<u>CONSTRUCTION METHODS</u>

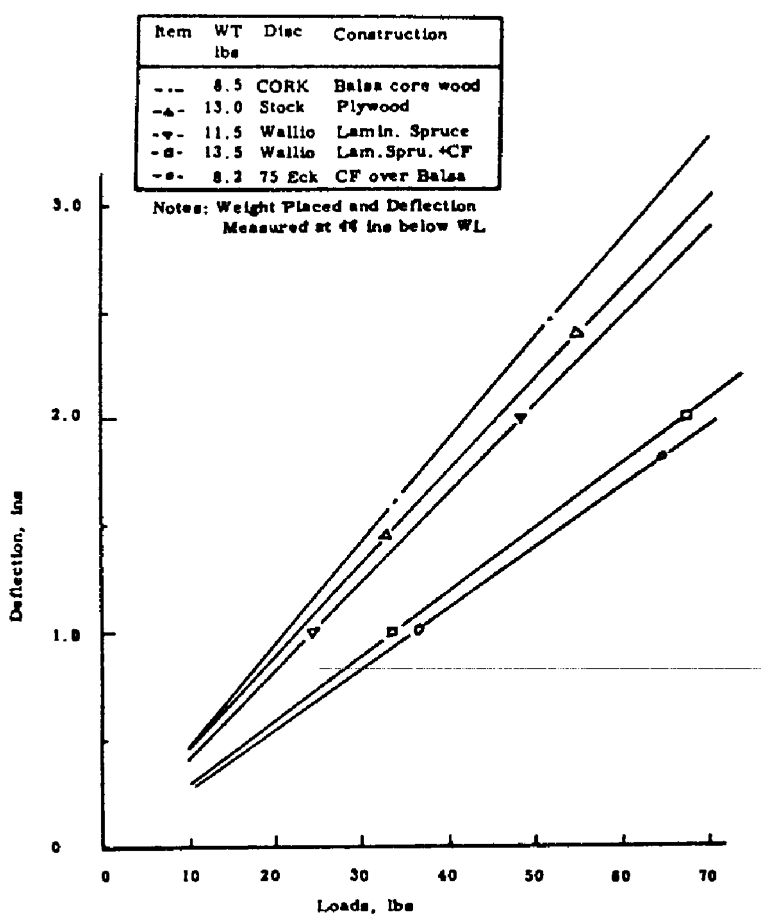
- solid wood
- hollow wood
- hollow wood reinforced with carbon fibres
- Balsa core, wood and fibreglass
- Balsa core, glass and carbon fibre

I will discuss planform and section selection in the following paragraphs. I have built at least one board using each of the above construction techniques. I believe that some problems with pointing are caused by too flexible boards and have concluded that "the stiffer the better" is a good rule of thumb. Deflection curves for various centerboards are shown in Figure 1. Other than that, a discussion of construction methods is beyond the scope of this article.

There are some areas of board design which are not easily analyzed. Most, however, can be, and some surprising things are apparent. Mainly, that the conventional wisdom concerning boards is not very well founded. Moffat (1), Walker (2), Marchaj (3), Jeffrey (4), and Lindsay (5) have published the broad outlines of how centerboards work. The fountainhead for most of these articles is an obscure publication by Dr. Ing. Sighard Höerner, entitled "Fluid Dynamic Drag" (6). Dr. Höerner is best known for his famous statement, "*Siehst Du, Willy, Ich hab dir gesagt dass das Hinterrad in der grenzeschicht liegt*" He has been extensively quoted since but rarely referenced. Mr. Jeffery's article, for example, lifts several figures directly from "Fluid Dynamic Drag."

The technical foundation of this article is laid on information from Ref. 6, "Theory of Wing Sections" (7), "Basic Wing and Airfoil Theory" (8), and NACA Report No. 824 (9). Considerable experimental evidence has been collected since I started this study, but it is yet to be systematized.

Figure 1. Load Deflection Curves for Various Construction Methods



SUMMARY

There is a tendency, when designing a board, to concentrate on one area, such as aspect ratio, type of section, planform, area, etc. This tendency should be stifled. All areas are important and each interacts with the other. If this notion is held firmly in mind, a near optimum board can be designed with very little grief. Failure to consider the whole will result in success only by chance.

If you are willing to believe without wading through the analytical development, start building immediately after finishing reading this list. If you are skeptical, press on.

(1) 505 fins are too heavily loaded to use laminar sections. Stick to the NACA 00-series for best performance. Make the root thickness as great as will f it in the trunk (~1.3 inches) and hold the thickness constant until about 2/3 down the span. Start holding a constant percent-of-chord thickness from 2/3 to the tip.

(2) Average 505 crew size requires a side force lift of about 160 pounds to be developed by the centerboard.

(3) Lift coefficient (Cl) of ~0.43 is required by 505s if the board is held around 650 in^2. This looks like the best area for general use. Specialized boards may have advantages but can be treacherous if wind speed changes suddenly. They are not recommended.

(4) The board should gybe reliably and be mechanically stiff. Maximum attainable gybe angle is 4.3° using my construction methods. This gybe angle leads to Cl ~0.45.

(5) Lower area than ~600 in^2 results in higher board angles of attack (leeway) than can be accommodated by reasonable qybe angles. They may also cause sail sheeting angle problems which may be mistaken for "overgybing" boards.

(6) Maximum span which can be fit into a trunk should be used. Root chord and planform should be chosen to provide 600 - 650 in^2 area using maximum span.

(7) A tip chord to root chord ratio of 0.34 to 0.40 should be used to minimize induced drag due to lift. Leading edge aft sweep of 5° also tends to minimize drag. Square tips are preferred. Höerner tips require loss of span to get into normal trunk. Otherwise, they have a theoretical advantage.

(8) High aspect ratio boards are not prone to stall per se. However, heavily loaded boards are prone to stall. If aspect ratio is increased by decreasing area without changing span, no decrease in induced drag will occur. This is contrary to the implications of a statement by Peter Barret in "Yacht Racing." Barret wasn't necessarily wrong, just sloppy in his use of how high aspect ratio is obtained with respect to span loading.

(9) Alleged effects of deeper than standard boards on stability are not necessarily founded in fact. See Figure 11 for increased crew weight required.

Before pressing on, let me warn you that this article is written for those who have a basic understanding of fluid dynamics. If I back off too far into explaining fluids, the thrust of what I'm trying to do will be lost. Similarly, if I oversimplify I will be only covering ground which has been heavily trod by others. If you can do algebra and take the time to read the references, you won't have a problem. If you are already a fluids specialist, you will wonder why I explain so many obvious points. So, let's all be tolerant and define our terms.

GLOSSARY

αo Angle of attack uncorrected for finite aspect ratio, degrees.

αg Angle of attack corrected for finite aspect ratio, degrees.

Cl Lift coefficient, dimensionless.

Clo Lift coefficient for two dimensional flow, dimensionless.

Cd Drag coefficient, dimensionless.

Cdo Drag coefficient- for two dimensional flow, dimensionless.

Profile Drag, Do

Drag generated by pulling the board through the water at zero angle of attack, lbs. Mathematically; (Cdo)(area)(dynamic head).

Induced Drag, Di

Drag induced as a concomitant to lift generation (lbs.). Induced drag is only a function of span loading. Contrary to popular misconception, *induced* drag cannot be decreased by increasing aspect ratio if span is not increased. Mathematically: (Cdi)(area)(dynamic head).

Drag, D

Drag generated by pulling the board through the water at some angle of attack, lbs. Mathematically: (Cd) (area) (dynamic head) D = Do + Di, in general.

Lift, L

The side force generated by pulling the board through the water at some angle of attack, lbs. Mathematically: (Cl)(area)(dynamic head).

Re

Reynolds number. A dimensionless scaling parameter used to predict full scale results from model tests (purists, forgive me). Mathematically: the ratio of dynamic to viscous forces.

Dynamic Head

Mathematically: $\frac{\rho V^2}{2g}$ or, for fresh water, $0.98V^2$.

where: V = Velocity of the fin through the water, ft/sec.

Span, ℓ

The depth of the tip of the board below the hull, ft.

Chord

The width of the board in the direction flow, ft.

Root Chord

The chord at the first spanwise station after the board emerges from the hull,

Thickness, t

The thickness of the board perpendicular to the direction of flow, inches.

Planform

Side view of the board.

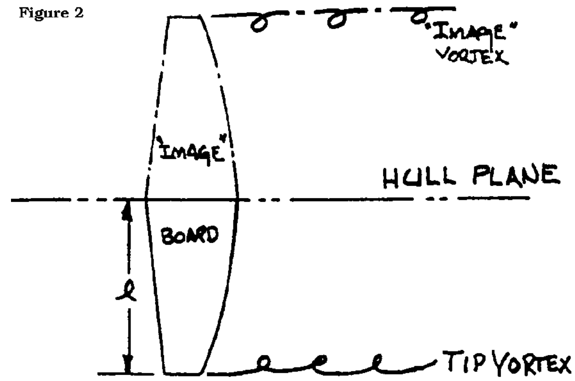
Profile

The fore and aft cross-section of the planform (also referred to as “section”).

Image

An imaginary mirror image of the real system (Figure 2).

Figure 2



Separation

Separation is a boundary layer phenomenon which occurs when the flow in the boundary layer does not follow the foil profile (Figure 3). A distinction is made here between boundary layer separation and bulk separation which occurs near stall. The sloppiness of the usage is acknowledged.

Low Drag "Bucket"

Discontinuous region on Cl vs. Cd curves (Figure 4; See Ref. 7)

Radian

57.3°

SECTION SELECTION

The selection of a section for a centerboard or rudder is relatively straightforward. There are two broad classes of sections which I'll call "laminar" and "conventional." The selection between them is easy if you take a minute to consider all of the theoretical evidence rather than just those enticing low drag buckets in "Theory of Wing Sections."

Laminar Sections. The longer the bound dry layer remains attached to the foil, the lower is the friction drag. Laminar foils t advantage of the fact that the boundary layer is stabilized by the pressure gradient which results from the fact that the boundary layer is stabilized by the pressure gradient which results from the changing thickness of the foil. As long as the foil is increasing in thickness in the direction of flow, the boundary layer is stabilized and tends to remain laminar. The are over which the boundary layer is laminar can be increased by moving the point of maximum thickness aft. This increases the distance over which the flow undergoes the favorable pressure gradient, keeps the boundary layer flow laminar, and therefore reduces drag. NACA 0010-35 or the NACA-66 series are typical of laminar foils.

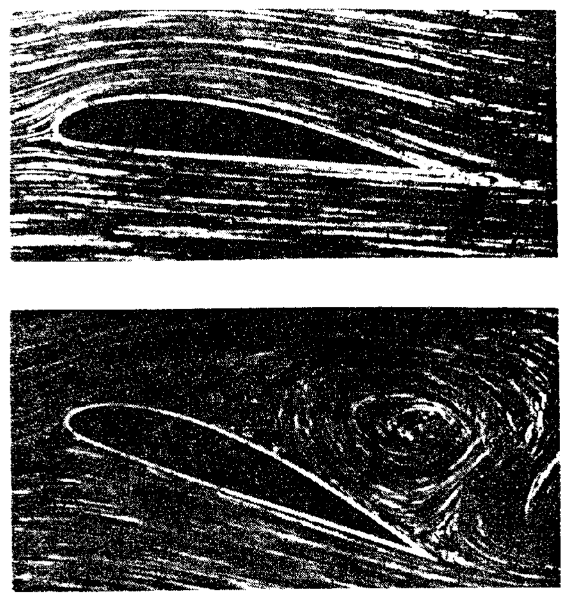


Figure 3

Conventional Sections. These sections are called conventional only insofar as they came first. The evolved from WWI Clark-Y, etc. sections. They have their maximum draft at the 30 percent point and have relatively blunt leading edges. They are best characterized by the NACA four-digit series. Figure 5 shows profiles of these sections and their chord-wise pressure distributions.

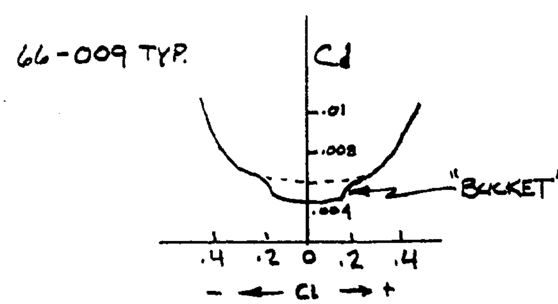


Figure 4

The Choice. Laminar section fins should never be considered for use on a heavily loaded board such as a 505. There are two basic reasons for this.

1. Most 505 fins operate at Reynolds numbers below one

million.

2. The design lift coefficient for a 505 centerboard is in excess of 0.35 (see following section on planforms). Laminar section low drag buckets are rarely more than ± .15 wide. This requires operation outside of the low drag region and results in higher than conventional foil drag.

The effects of the first of these facts are somewhat obscure, so I will just quote from NACA No. 824:

"…The effect on minimum drag of the position of minimum pressure which determines the extent of laminar flow is shown for some NACA 6-series airfoils. The data show a regular decrease in drag coefficient with rearward movements of minimum pressure(νmaximum thickness, Ed.)... It may be noted that the drag coefficient for the NACA 65-418 airfoil at <u>low Reynolds numbers is substantially higher</u> (emphasis mine) than for the NACA 0012, whereas, at high Reynolds numbers, the opposite is the case. The higher drag of the NACA 65-418 airfoil section at low Reynolds numbers is caused by a relatively extensive region of laminar separation downstream of the point of minimum pressure. This region decreases in size with increasing Reynolds numbers."

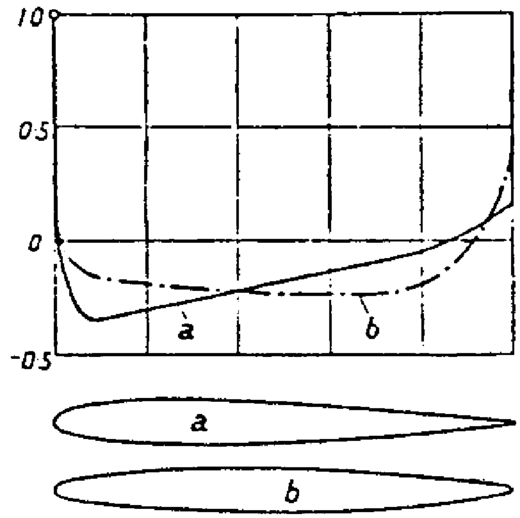


Fig. 5 —Theoretical distribution of pressure over two symmetrical profiles for zero angle of incidence, after Tani and Mituisi

There are several other references which note this low Reynolds number behavior. But the gist of it is plain. Extensive separation occurs because of the high trailing edge angle which exists when the maximum thickness point is moved aft. The streamlines do not follow the profile of the fin because the sides are converging too rapidly. Therefore, this produces a "separation burble" which grows with decreasing Reynolds number and causes increased drag. The lower trailing edge angles of the conventional sections result in lower drag at Reynolds numbers below about 1.1 million. The onset of this effect can be observed in the curves in "Theory of Wing Sections." Note how Cd increases with decreasing Reynolds number at Cl=0.4 for the 001035[1] and 6-series sections. Note how little change there is under these conditions with the 0009 section. Reynolds number of one million and lift coefficients of 0.4 are typical values for a 505, as will be shown.

The second reason for not using a "laminar" section is that the low drag bucket characteristic of these sections never extends to lift coefficients of the order required for a standard 505 board. It may be possible to build an extremely large board (approximately 8 square feet) and achieve a design lift coefficient which would be in the low drag bucket (such a lightly loaded board might indeed be laminar, but remember that the drag coefficient must be multiplied by the planform area when calculating the drag, and this will always result in increased drag for the conditions under which 505 foils operate. See figure 10 for effects of area on drag.)

The profile drag coefficients (Cdo) for various sections at the design lift coefficients studied in the next chapter are shown in Table 1.

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[1]See also NACA TN. No. 1591, Ref. 10

Table 1[2]

Comparison of Various Lift and Drag Coefficients for Various Symmetrical Sections of Infinite Aspect Ratio

Section	Cl[3]	Cd	% increase in Cd[4]	% increase in Cd	Width of Low Drag Bucket	% Cl Beyond low drag region
0009	0.2845	0.0058	—	—	±0.25	114
0010-35	0.2845	0.0065	12.1	12. 1	±0.12	237
64-0009	0.2845	0.0060	3.4	3.4	±0.15	190
66-0009	0.2845	0.0068	17.2	17.2	±0.10	285
0009	0.3438	0.0060	—	3.5	±0.25	138
0010-35	0.3438	0.0068	13.3	17.2	±0.12	287
64-0009	0.3438	0.0070	16.7	20.7	±0.15	229
66-0009	0.3438	0.0070	16.7	20.7	±0.10	344
0009	0.3919	0.0061	—	5.2	±0.25	157
0010-35	0.3919	0.0071	16.4	22.4	±0.12	327
64-0009	0.3919	0.0075	23.0	29.3	±0.15	261
66-0009	0.3919	0.0072	18.0	24.1	±0.10	392
0009	0.4580	0.0065	—	12.1	±0.25	183
0010-35	0.4580	0.0080	23.1	37.9	±0.12	382
64-0009	0.4580	0.0078	20.0	34.5	±0.15	305
66-0009	0.4580	0.0075	15.4	29.3	±0.10	458

These data are for Reynolds numbers equal to 3 million. Operating Reynolds number for a 50 board at hull speed will vary from 0.9 to 1.4 million, depending on planform selection. This reduced Reynolds number will accentuate the shortcomings of the laminar section for use a 505. Careful study of Table 1 shows that conventional sections are optimum over a much wider range of lift coefficients than are laminar sections.

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[2]Data from Reference 9 for two dimensional flow (infinite aspect ratio) sections at a Reynolds number of three million.

[3]The area implied in Cl of .2845 increasing to .4580 is 61%. Note that for all cases, the increase in Cd is less than 61%. Therefore it will always pay to decrease area if all other variables are constant. This is borne out in Figure 10.

[4]Note that for all cases examined, the 00-series sections are superior.

Under no circumstances do laminar sections offer an advantage, and under low Reynolds number and/or high loading conditions they may offer a significant disadvantage.

Spanwise Thickness Distribution. After selecting the NACA 00-series section, we must decide what thickness distribution to use al the board span. The centerboard slot width (35 mm - 1.40 ins.) limits the board thickness and the root chord section; therefore, become dependent on the choice of root chord length. Maximum root chord section for a 17 inch root chord board is 8.1 percent. Similarly, a 14 inch root chord board could use a 10 percent root section. It is best to use a board that fills the trunk. Thinner boards twist more and boards of lower thickness-to-chord ratio stall easier.

There is a theoretical advantage in holding the percent section constant, or decreasinq it, as the span increases toward the tip. I believe this advantage is difficult to realize in practice. Wings are usually cambered and given "wash" to account for structural twist under load. A centerboard must be a symmetrical section and wash and camber are not viable solutions. Thin, highly loaded, high angle of attack (caused by twist) board tips are very prone to stall, especially at low speed in choppy waters. Therefore, I recommend using a constant thickness (variable sections, to about 2/3 of the board span. The maximum section thickness I use in a board is 10.8 percent. I use 12-14 percent sections in rudders.

PLANFORM SELECTION

The planform is the side view of the board. Most stock 505 boards have a straight leading edge and an elliptical trailing edge. The argument about trailing edge shape is moot. The measurement requirements of a 505 lead you to using an elliptical trailing edge and a straight tip. It is true that the Höerner tip (this is a tip like a Laser -- rounded leadinq edge, straight trailing edge) gives some marginal imorovement in induced drag reduction. However, this gain can be achieved only at the expense of decreased span, given the required shape of a 505 trunk. It is also true that a 5 ° aft sweep reduces induced drag marginally. You can do this in a 505 by buildinq a constant 25 percent chord board instead of a straight leadinq edge board. Figure 6a shows the stock Parker planform.

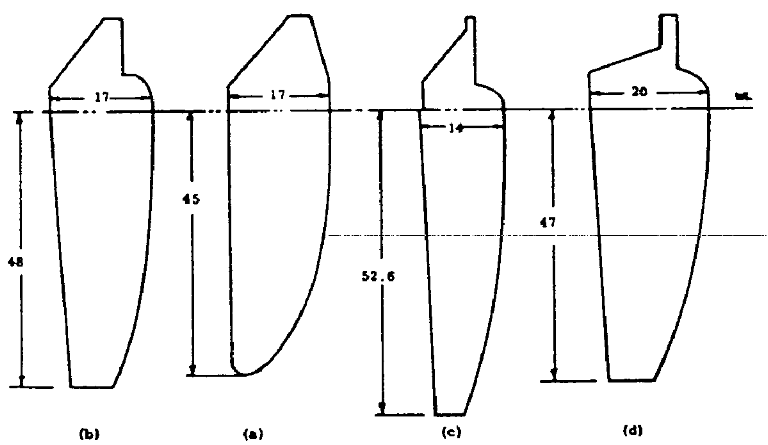


Figure 6. Various Aspect Ratio Planforms

Figure 6c is an extreme board which I built for the 1975 season. Figure 6d is the opposite extreme board which I built for Pete Wallio for the 1975 season. Both 6c and 6d require the pin to be moved forward from the usual balance position in order to sheath the board.

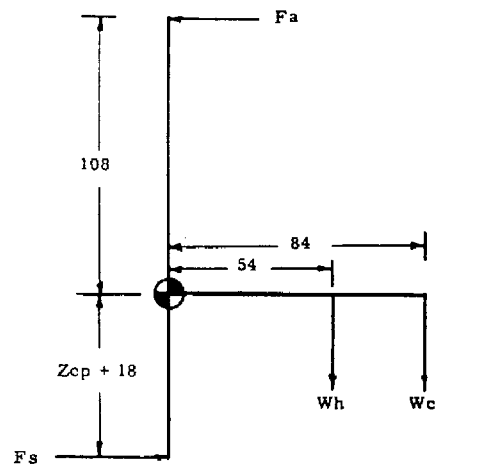
Required Area. There are several things you must do before selecting a planform. First, you must select the crew weight you will most likely be using, and then you must calculate your available righting moment. This is done by performing a simple moment's balance around the roll center. This is shown in Figure 7.

Solving for Fs when: Zcp = 22 in., the helmsman is 5'7", 175 pounds, and the crew is 6'2", 170 pounds, gives Fs = 160 pounds. -This means that the centerboard must develop 160 pounds of lift when the boat is sailed at maximum righting moment. It cannot be reouired to develop more lift because the hiking power (righting moment) is not available.

Once we know the required side force (Fs) and that the 505 hull speed is approximately 10 feet/second (I have ignored upwind planing since it is probably not possible with the light crew weight chosen. Also, at lower wind speeds than required to attain hull speed, the required lift coefficient tends to remain constant because the fin is moving slower through the water. Although less lift is required, less fin soeed is available to produce lift), we can construct a curve showing the angle of attack (leeway) vs centerboard area. This is accomplished using the relation:

$$F_s = Cl\frac{\rho V^2 A}{2g}$$

or for $F_s = 160$,
A in square feet: A = 1.65/Cl.



Where:

Fa = Aerodynamic Force, lbs
Fs = Hydrodynamic Force, lbs
Zcp = Centre of Lateral Resistance Distance from Hull Bottom, ins.
Wh = Weight of Helmsman, lbs
Wc = Weight of Crew, lbs

Note:

Fa = Fs in Static Equilibrium
(Fa) (108) + (Zcp + 18) (Fs) = (54)(Wh) + (Wc)(84)
(Assumes crew weight and height are not related i.e. all helmsmen are 5'7"; all crews 6'2")

Figure 7. Setup for Performing Static Moments Balance

Now we need to know something about lift coefficient (Cl). This is something like what you see in "Theory of Wing Sections" that everyone talks about -- only not exactly. The “not exactly” is because "Theory of Wing Sections" shows infinite aspect ratio (two dimensional) curves which are uncorrected for aspect ratio and for Reynolds numbers below three million. There is the problem. To my knowledge, none of the conventional wizards have bothered to calculate the effects of aspect ratio and Reynolds number on the board angle of attack (leeway).

Table 2 shows the area vs lift coefficient relation for two-dimensional flow.

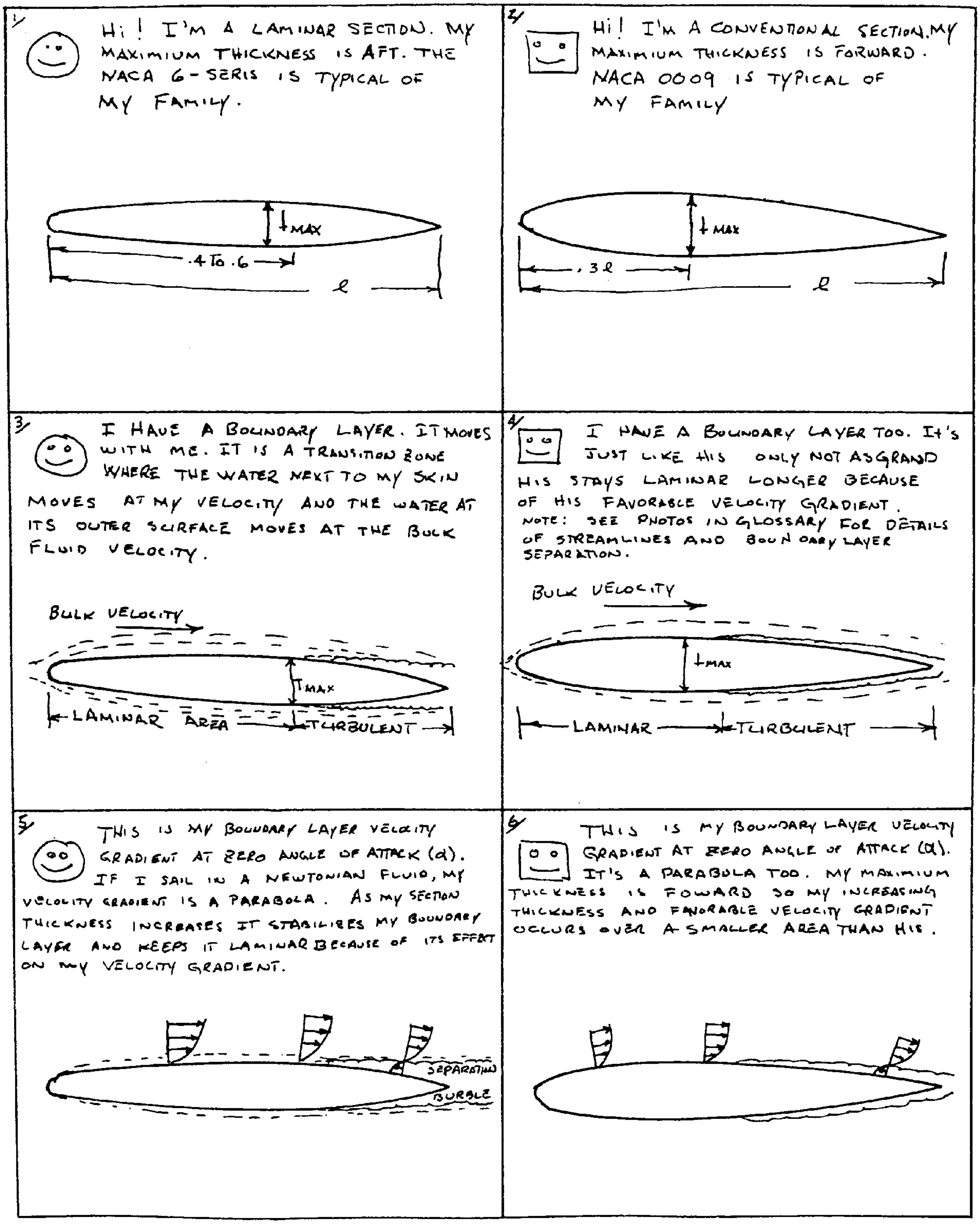
Table 2

Effect of Planform Area on the Required Lift Coefficient (Cl), Infinite Aspect Ratio Angle of Attack (α0) and Drag Coefficient (Cdo)

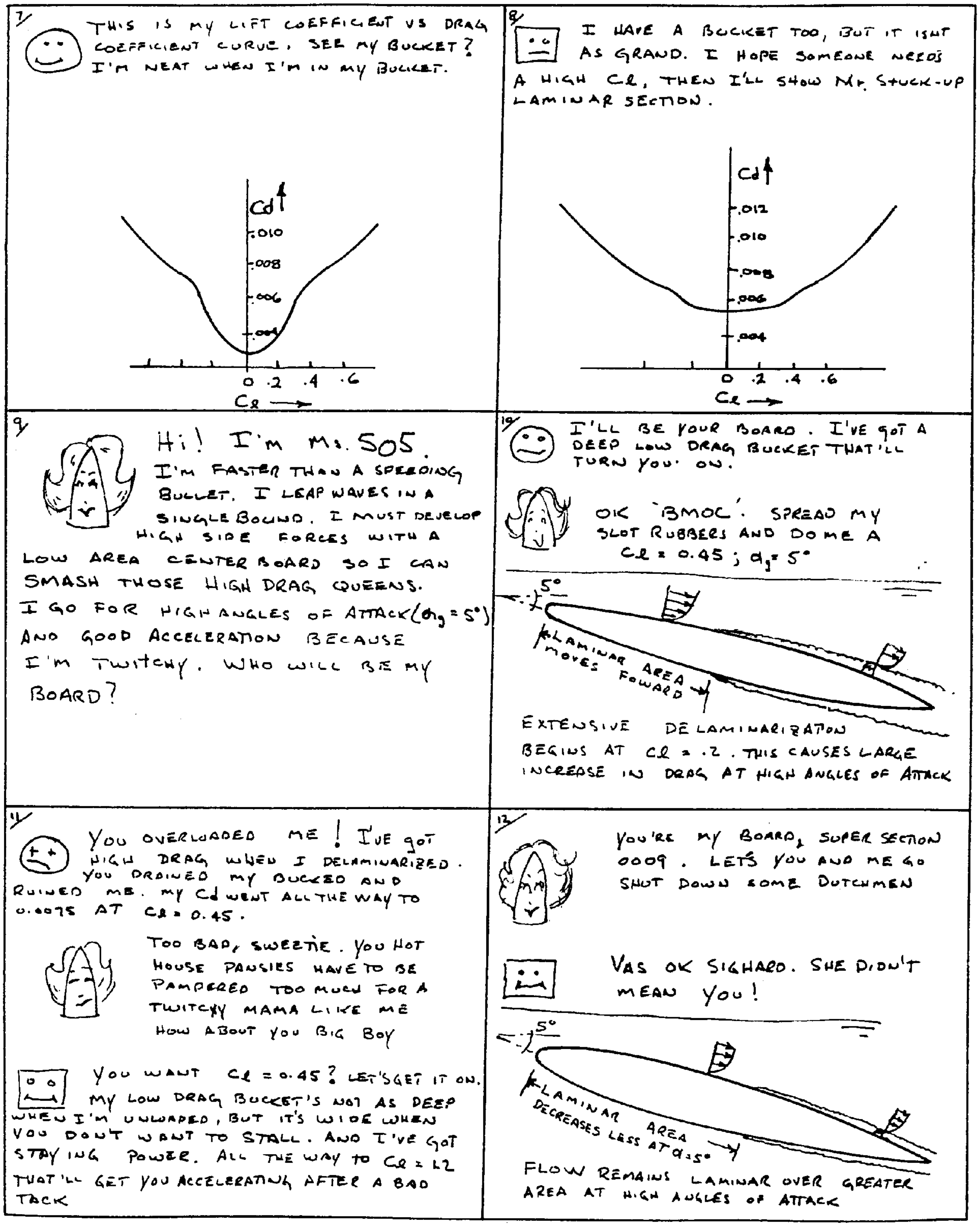
AREA		Cl	α0[5]	Cdo[6]	Span
in.²	ft.²		degrees		in.
835	5.80	0.2845	2.61	0.0058	52.6
691	4.80	0.3438	3.15	0.0061	52.6
606	4.21	0.3919	3.60	0.0062	52.6
518	3.60	0.4583	4.20	0.0065	52.6

[5] NACA 0009, Ref. 9.

[6] Slope of Cl vs. $\alpha 0$ = 0.1109 per degree.



1/
Hi! I'M A LAMINAR SECTION. MY MAXIMIUM THICKNESS IS AFT. THE NACA 6-SERIS IS TYPICAL OF MY FAMILY.
t MAX
.4 To .6
ℓ
2/
Hi! I'M A CONVENTIONAL SECTION. MY MAXIMIUM THICKNESS IS FORWARD. NACA 0009 IS TYPICAL OF MY FAMILY
t MAX
.3ℓ
ℓ
3/
I HAVE A BOUNDARY LAYER. IT MOVES WITH ME. IT IS A TRANSITION ZONE WHERE THE WATER NEXT TO MY SKIN MOVES AT MY VELOCITY AND THE WATER AT ITS OUTER SURFACE MOVES AT THE BULK FLUID VELOCITY.
BULK VELOCITY
TMAX
LAMINAR AREA
TURBULENT
4/
I HAVE A BOUNDARY LAYER TOO. It's JUST LIKE HIS ONLY NOT AS GRAND
HIS STAYS LAMINAR LONGER BECAUSE OF HIS FAVORABLE VELOCITY GRADIENT.
NOTE: SEE PHOTOS IN GLOSSARY FOR DETAILS OF STREAMLINES AND BOUNDARY LAYER SEPARATION.
BULK VELOCITY
t MAX
LAMINAR
TURBULENT
5/
THIS IS MY BOUNDARY LAYER VELOCITY GRADIENT AT ZERO ANGLE OF ATTACK (α). IF I SAIL IN A NEWTONIAN FLUID, MY VELOCITY GRADIENT IS A PARABOLA. As MY SECTION THICKNESS INCREASES IT STABILIZES MY BOUNDARY LAYER AND KEEPS IT LAMINAR BECAUSE OF ITS EFFECT ON MY VELOCITY GRADIENT.
SEPARATION
BURBLE
6/
THIS IS MY BOUNDARY LAYER VELOCITY GRADIENT AT ZERO ANGLE OF ATTACK (α). IT'S A PARABOLA TOO. MY MAXIMIUM THICKNESS IS FOWARD SO MY INCREASING THICKNESS AND FAVORABLE VELOCITY GRADIENT OCCURS OVER A SMALLER AREA THAN HIS.


7/
THIS IS MY LIFT COEFFICIENT VS DRAG COEFFICIENT CURVE. SEE MY BUCKET? I'M NEAT WHEN I'M IN MY BUCKET.
Cd
.010
.008
.006
.004
0 .2 .4 .6
Cl
8/
I HAVE A BUCKET TOO, BUT IT ISNT AS GRAND. I HOPE SOMEONE NEEDS A HIGH Cl, THEN I'LL SHOW Mr. STUCK-UP LAMINAR SECTION.
Cd
.012
.010
.008
.006
.004
0 .2 .4 .6
Cl
9/
Hi! I'M Ms. 505.
I'M FASTER THAN A SPEEDING BULLET. I LEAP WAVES IN A SINGLE BOUND. I MUST DEVELOP HIGH SIDE FORCES WITH A LOW AREA CENTER BOARD SO I CAN SMASH THOSE HIGH DRAG QUEENS. I GO FOR HIGH ANGLES OF ATTACK (α_g = 5°) AND GOOD ACCELERATION BECAUSE I'M TWITCHY. WHO WILL BE MY BOARD?
10/
I'LL BE YOUR BOARD. I'VE GOT A DEEP LOW DRAG BUCKET THAT'LL TURN YOU ON.
OK 'BMOC'. SPREAD MY SLOT RUBBERS AND DO ME A Cl = 0.45; α_g = 5°
5°
LAMINAR AREA MOVES FOWARD
EXTENSIVE DELAMINARIZATION BEGINS AT Cl = .2. THIS CAUSES LARGE INCREASE IN DRAG AT HIGH ANGLES OF ATTACK
11/
YOU OVERLOADED ME! I'VE GOT HIGH DRAG WHEN I DELAMINARIZED. YOU DRAINED MY BUCKED AND RUINED ME. MY Cd WENT ALL THE WAY TO 0.0075 AT Cl = 0.45.
TOO BAD, SWEETIE. YOU HOT HOUSE PANSIES HAVE TO BE PAMPERED TOO MUCH FOR A TWITCHY MAMA LIKE ME
HOW ABOUT YOU BIG BOY
YOU WANT Cl = 0.45? LET'S GET IT ON. MY LOW DRAG BUCKET'S NOT AS DEEP WHEN I'M UNLOADED, BUT IT'S WIDE WHEN YOU DON'T WANT TO STALL. AND I'VE GOT STAYING POWER. ALL THE WAY TO Cl = 1.2 THAT'LL GET YOU ACCELERATING AFTER A BAD TACK
12/
YOU'RE MY BOARD, SUPER SECTION 0009. LET'S YOU AND ME GO SHUT DOWN SOME DUTCHMEN
VAS OK SIGHARD. SHE DIDN'T MEAN YOU!
5°
LAMINAR AREA DECREASES LESS AT α=5°
FLOW REMAINS LAMINAR OVER GREATER AREA AT HIGH ANGLES OF ATTACK

Before we go on with area selection, it is first necessary to introduce the concept of aspect ratio and show how it modifies the two-dimensional results shown in Table 2.

Aspect Ratio

There is a pressure difference between the mass of fluid on either side of a foil generating lift. This pressure difference is a driving force for fluid on one side of the foil to flow to the other side. The greater the span, the less influence the flow at the tip will have on the flow at the root, and the more nearly two-dimensional the flow will be over the majority of the foil. Even though the details are as Jeffery indicates, if you think of the flow rolling up into a tip vortex to satisfy the pressure discontinuity at the foil tip, you won't go too far wrong. Now, if you think of a tip vortex as a loss (drag), there is only one further conceptualization necessary; i.e., the greater the distance of the tip vortex from its image, the lower the drag due to the tip vortex. ("Image" is an imaginary vortex which exists at the other end of the symmetrical "wing" system. (See sketch in glossary.)

Aspect ratio provides a means of determining how much the theoretical two-dimensional drag due to lift (induced drag) is increased by the spanwise flow component which exists in real-world three-dimensional flow. The concept of "span loading" is somewhat easier to follow in assessing this loss in that this axiom states that induced drag is only a function of span and not aspect ratio if the physical lift force on the centerboard is held constant. Or, stated another way, induced drag can only be reduced by increasing span, not by decreasing chord while holding span constant, as would be implied if it were truly a function of aspect ratio.

The calculation of aspect ratio for a centerboard is different from a rudder because the hull offers an end plate effect (axis of symmetry) which is not available to a rudder. I use a 1.7 "image" for calculating centerboards and 1.0 for rudders.

$AR = 1.7\ell^2/\text{Area}$; $Ar_r = 1.0\ell^2/\text{Area}$

From a practical standpoint, one needs to know only two relations to determine the effect of aspect ratio (or span loading) on drag and leeway angle. These are:

$$\alpha g = \alpha_0 + Cl/\pi AR$$

$$Cd = Cdo + Cl^2/\pi AR$$

where:

Cdo = two dimensional drag coefficient at design Cl (from curves)

αo = two dimensional angle of attack at design Cl (from curves) (note angles in radians)

αg = geometric angle of attack (leeway)

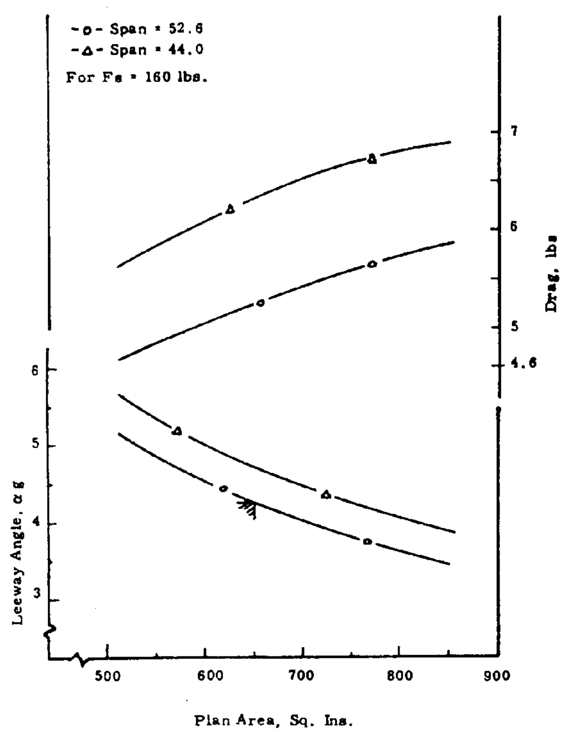
Table 3 shows how these corrections affect the values shown in Table 2.

Table 3

Effect of Planform Span and Area on Three Dimensional Flow Drag (D), Drag Coefficient (Cd), and Leeway Angle (αg)

AREA		Span	AR	αg	Cd	D	%[7]
in.^{2}	ft.^{2}	In.		Degrees		lbs.	Decrease
835	5.80	44.0	3.94	3.93	0.01234	6.93	—
691	4.80	44	4.76	4.47	0.01400	6.51	6.1
606	4.21	44.0	5.49	4.92	0.01510	6.16	11.1
518	3.60	44.0	6.35	5.52	0.01633	5.70	17.7
835	5.80	52.6	5.63	3.53	0.01037	5.83	15.9
691	4.80	52.6	6.81	4.07	0.01133	5.40	22.1
606	4.21	52.6	7.76	4.52	0.01210	5.10	26.4
518	3.60	52.6	9.08	5.12	0.01316	4.83	30.3

Figure 10. Effect of Plan Area on Leeway and Drag for Two Spans



The results of the calculations tabulated in Table 3 are plotted in Figure 10. Careful study of Table 3 and Figure 10 shows some surprising things about aspect ratio effects on both leeway (αg) and drag due to lift (Di) and friction (Do) on the centerboard. Total drag is calculated from:

$$D = Cd\frac{\rho V^2}{2g}$$

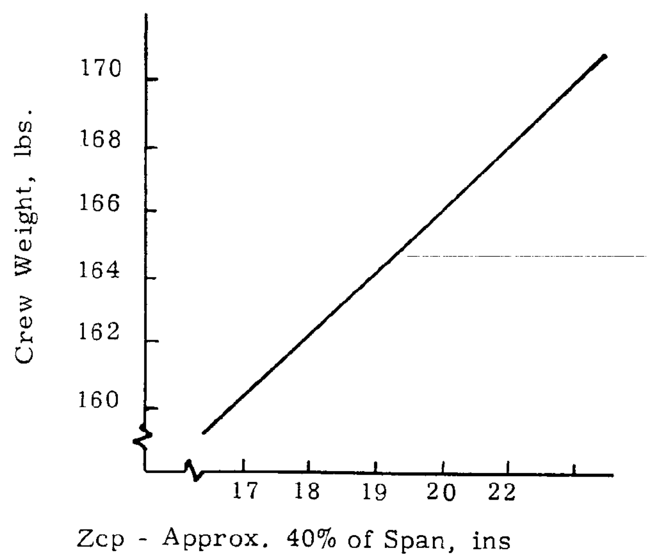
It is crucial that you think in terms of total drag and not drag coefficient, as these parameters do not always vary in the same direction. Notice, in Figure 10, that as the area of the board increases, the leeway angle (αg) decreases but the drag (D) increases. The increase in the leeway angle is of no consequence if the sail plan can be rotated to accommodate the change in angle of attack of the sails. This is the assumption made by Marchaj (3) and others. This assumption is not always valid, however, and is certainly not valid when the inboard

[7]Note that the highest drag 52.6 inch long board is only slightly worse than the lowest drag 44.0 inch board (15.9 vs. 17.7% decrease over base drag of 6.93 lbs.).

sheeting limitations of a 505 are considered. Second, notice that the same area boards having a span of 44 inches (this implies a wider root chord) insstead of 52.6 inches, suffer even greater losses in leeway angle and drag. These boards all generate a lift of 160 pounds. Marchaj (3) and others have shown that the lift to drag ratio is the cotangent of the pointing angle. Therefore, the change in pointing angle which occurs within the 52.6 span series is 0.40 and the variation between the best 52.6 span board (AR = 9.08) and the worst 44 inch span board (AR = 3.94) is 0.70. This result is true even if the effects of increased leeway on sail plan angle of attack are ignored.

The beneficial effects of greater span are seen to have sound theoretical basis. There is, however, an argument which states that long span boards make the boat harder to hold down. This is supposedly because the deeper center of pressure of the high span board generates a higher roll moment for a given amount of lift. Referring back to Figure 7, it is now apparent why I left the term Zcp as a variable in the moments diagram. By substituting varying Zcp (distance to center of pressure) into this moments diagram, one can construct a curve showing the crew weight change required to keep the boat on its bottom. Figure 11 shows a plot of the results of this exercise. As you can see, the practical effects of span changes are not great.

FIGURE 11. EFFECT OF CHANGES IN Zcp ON CREW WEIGHT REQUIRED TO GENERATE 160 LBS SIDE FORCE



It is true that people have problems with long boards in heavy air. I believe this has to do with a yaw couple which is set up when the boat is allowed to heel. If you sail it flat and don't get out of shape, a long board should not have a significant effect on heavy air stability. If you do get out of shape, the chances are that the yaw couple will lead to a broach -- fast. The longer the board, the greater the demands on the helmsman for quick and accurate steering.

We have seen that, for any board area under constant loading, increased span will improve pointing by decreasing drag; but we still have not selected board area. This selection will be made on a less than scientific basis; so first, we have to decide on whether or not we want to gybe the board.

Gybing vs. Non-Gybing. The board should gybe. But, it must be strong enough to prevent twist and the gybing strips and section thickness must be arranged to prevent negative gybing on the reaches.

A gybing board does two things:

- It decreases hull form drag by allowing the hull to track straight through the water instead of crabbing at the leeway angle.
- It allows the jib tack to be rotated more to leeward of the apparent wind for a given leeway angle, jib fairlead and boom position.

The effect of the second item above may be more important than the first. By allowing the sail plan to rotate to leeward by the amount of the gybe angle, the effective sheeting angle is increased and better drive can be obtained for the same course made good. Looked at another way, a gybing board allows the relative jib fairlead position to move inboard by the amount of the gybe angle. This is good for those occasions when pointing is everything and you want extreme inboard sheeting, but don't want those crew-destroying contraptions otherwise required to get extreme inboard sheeting. Anything that can be gained by greater inboard sheeting is good for pointing. It is not true, however, that the pointing angle is decreased by the gybe angle. Only what improvement in the sail. lift to drag ratio that can be effected by the altered sheeting angle will improve the pointing angle.

I recognize that the positive "it should gybe" statement will draw some negative response. Inference arguments will be made that there is no experimental evidence to show that gybing will help. While this may be true of observations made by some, it is not true of all (Cf. Bram Dally). The real problem is that very few boards (except mine) are specifically designed to gybe the amount of the leeway angle. Using the proposed method for area selection, it is seen that it will be impossible to overgybe the board although it will still be possible to oversheet the jib. Unless the board gybes the amount of the leeway angle, it is unlikely that any change in performance will be noted experimentally. Considering the haphazard manner in which gybe angles are usually selected, it is not surprising that the potential advantages of gybing boards have not been realized.

Now the selection of the board area can be made. I have been unable to build a reliable board with a greater than 4.3° gybe angle. If you can build one ... GOOD! Pick the area such that, with your righting moment and maximum side force, your leeway angle will be 4.3° (or however great you can make your gybe angle). See, I told you it wasn't going to be scientific. This is best done by constructing a curve like Figure 10 for the side force (Fs) you can develop with your maximum righting moment and determining the area which gives you a leeway angle equal to your gybe angle.

RECOMMENDATIONS

(1) A 505 board tip should be at least 48 inches below the hull.

(2) The area should be between 600 and 700 square inches.

(3) The gybe angle should be 4° (or however great you can reliably build it except never more than the leeway angle). Area should be selected by interaction of gybe angle (leeway) with curve of Figure 10 type for your Fs.

(4) Once you select your area, use the highest aspect ratio (longest length) possible. Note that the span interacts with the area when entering Figure 10 type curve with gybe angle (leeway).

If you follow these recommendations, win the start and cover the fleet, you will do very well.

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Bram Dally with negative stagger Beachcraft