Calculating Indoor Flight

by Walter Erbach

Introduction

A program capable of calculating power required for an indoor model in level flight is developed here. The program is based on the static moment method for calculating the stability of a man carrying airplane. Originally, I wrote the program in Fortran to evaluate the effects of three important elements of indoor model design; stabilizer size, center of gravity location, and wing incidence. To accomodate small home computers, I've converted it to Basic. Plotting calculated values for graphing, easily done with Fortran, was done manually to avoid computer specific programs. Many of the model's dimensions are necessary to the calculations. This means you can find the effect of wing height and distance between wing and stab.

Discussion

Many variables impact duration. Some, like rubber, are out of our control. Others are cut and try. To eliminate some uncertainty I devised a method to determine the effects of stabilizer size, C.G., and wing incidence on power required.

I wrote a program to remove the drudgery of calculating. I made hundreds of glide tests to verify the program(beyond belief!). I published the results in two earlier Sympo's. The program wasn't included then because of lack of computers. Some builders are now using these techniques, such as moving the wing fore and aft for adjusting (reinventing the wheel?). Additionally home computers now make it worth converting the program to Basic for those willing to do the bit of simple graph plotting the Fortran handled.

The program is ready to run and can be used by anyone. For a complete understanding, some knowledge of static stability analysis will help and is useful for making meaningful modifications. An explanation of the steps is in the appendix. The program does require a small amount of graph plotting for the answers. I know of no other way, short of an unduly complex program to get these results. The analysis requires X intercepts of curves based on discrete data values (lift and drag coefficients). Only enough of each curve need be drawn to find its intercept - and careful sketching may suffice.

Program

The program has been written on a Commodore 64. For other computers it should be necessary only to modify statements prior to the title "INDOOR MODEL POWER REQUIREMENTS" in accord with the protocols of the computer used. The program has been copiously annotated. Variables have been inserted individually as equalities preceded by an identifying REM to facilitate locating and changing them, rather than as data statements.(obviously, for ease of copying, all REM's can be eliminated). If duplicated correctly as it stands it will run immediately because typical values for a 150 sq.in. tractor have been placed into each of the variable slots.

The printouts provide all the necessary values for constructing the curves to be analyzed. Information for comparison graphs can be obtained by changing any variable in the program. The static moment method is based on graphical analysis. This method for determining aircraft stability requires calculating the nosing up and down tendencies for the aircraft (the "pitching moments") at flying speed for a given center of gravity location and for varying angles of attack. These pitching moments are plotted against angle of attack. Where the curve crosses the X axis the pitching moment is zero and the airplane is flying stably. (Should the curve not cross the axis a desirable option for the vehicle would be an ejection seat). If we follow the same procedure it turns out that we have enough information to determine, in addition, the power requirements at stability conditions!

The program which has been developed calculates and then prints out, for our graphical analysis, both the pitching moments of an indoor model and the power required. It uses two nested FOR/NEXT loops. The outer loop, J, indexes the angle of attack; the inner loop, K, indexes the CG. At low angles of incidence the program will run to completion while at high angles of incidence it will run only until it reaches the maximum angle of attack specified in the program, and for which lift and drag coefficients are given, 12 degrees. A typical printout at one angle of attack is shown in Figure 1. A complete run is at a given angle of incidence and contains a number of such tables at successively higher angles of attack to the maximum. The body of each table consists of a tabulation of the CG locations and the calculated moment about each; the heading lists other needed information.

Figure 1.

4° Wing Incidence for This Run
2° Wing Angle-of-Attack
40% Stab Area
3.96 ft/sec Calc. Velocity
0.196 in. oz/sec Power Required

C.G. Location % Wing Chord	Moment in. oz
30	-0.092
40	-0.054
50	-0.015
60	0.023
70	0.061
80	0.100
90	0.138

An outer loop (H) which indexes the wing incidence has been included in the program, but only for completeness. A go to statement bypasses it since a run at a given incidence provides sufficient material for analyzing at one sitting. If this bypass is removed the program will print out terrifying yards of tabulated results.

For analysis the calculated values from a run must be plotted. Fig. 2 shows a generic graph with the power curve and one moment curve (at one center of gravity location) to clarify the plotting procedure and the interpretation of the resulting curves. One complete run through of the program provides all of the information to plot a graph similar to that of Fig. 3. By following Figs. 2 and 3 graphing of the tabular values should not be a problem.

Figure 2.

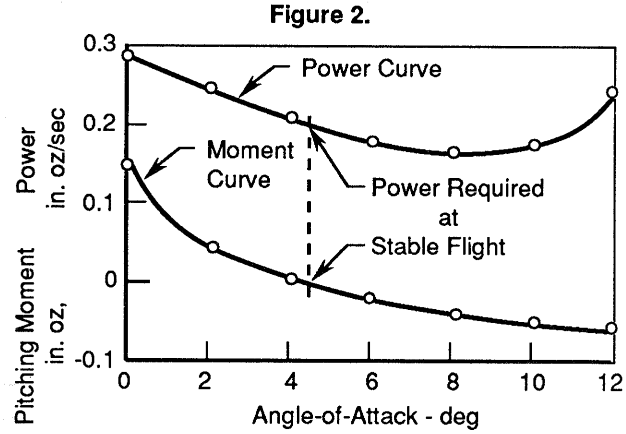
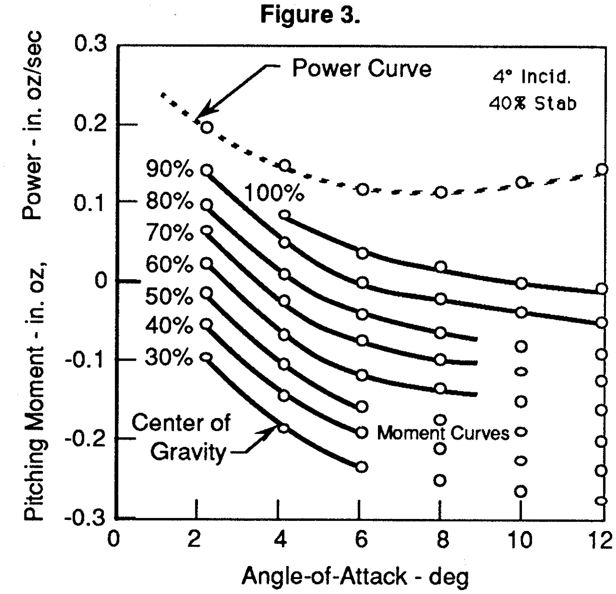


Figure 3.



The importance of this computer program lies in the analysis of the graphs. As an illustration, suppose that the computer model has an 80% CG location. Follow the 80% curve on Fig. 3 to its intersection with the X axis. This is slightly to the right of the four degree angle of attack. Tracing up from this point to the power curve we find approximately 0.14 inch ounces per second are required. Suppose we move the CG back to the 90% location and follow the procedure above. We find power needed has dropped to 0.12 inch ounces per second. However, upon moving the CG back to the 100% location we find the required power has increased! The power required changes with center of gravity and is a minimum at only one CG location. How can we find it? On the graph we trace down from the lowest point on the power curve to the X axis. Now we interpolate between the center of gravity curves as they cross the X axis and find the minimum power in this case occurs at a scant 95% CG. The wing should be moved to position the CG that far aft, or as close to it as possible while avoiding instability. From this first graph we should already begin to question the worth of a tandem wing model and understand the need of a wing which can be moved fore and aft, at least in preliminary testing, for maximum duration.

More important, however, is information gained not from one graph but from an analysis of a seies of runs to study the effects of the changes in some variable. As an illustration Fig. 4 shows a study of wing heights. Virtually no effect on performance for heights of one and four inches are seen. Fig. 5, another illustration, shows the effect of larger stabilizers. Notice the moment curves tend to flatten out horizontally as the stabilizer size is decreased. There is more restoring moment for larger stabilizers - ships so equipped will have a stiffer flight path and will recover more quickly from small disturbances. Fig. 6, is taken from a previous Sympo paper of mine to show readers, who do not have access to that material, how well the program simulates

Figure 4.

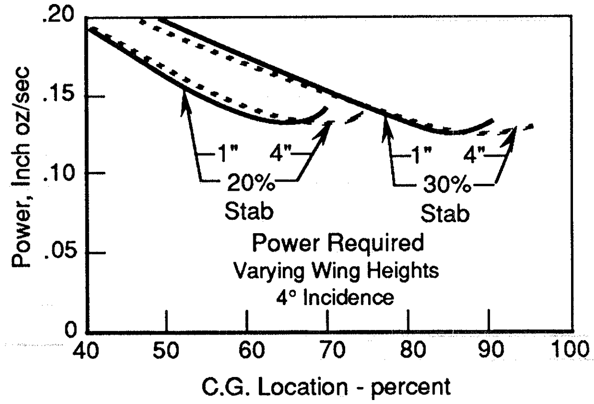


Figure 5.

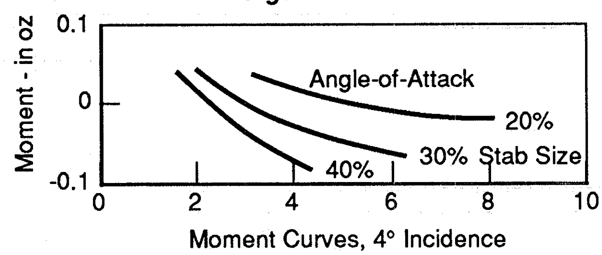
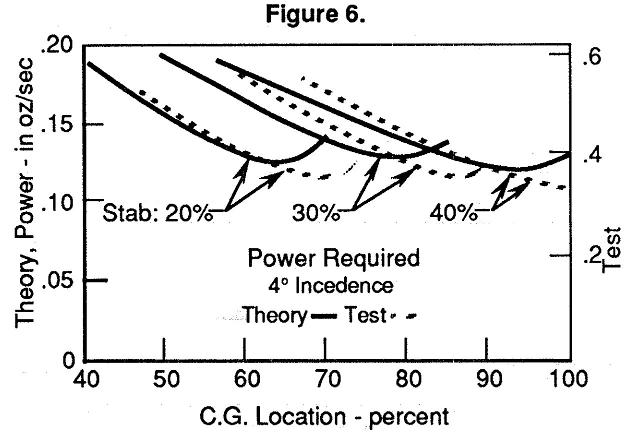


Figure 6.



actual flight. The agreement in the curves must be considered quite remarkable since indoor construction precludes accurate airfoils, structural stiffness, and precise incidence settings. It would appear from my experimental and theoretical work that the minimum power requires the farthest aft stable CG. Test glides with the model properly ballasted to flying weight should be made to obtain the optimum wing setting by moving the wing slowly forward until stability occurs. Then the wing should be moved slightly aft of this position for minimum power.

Appendix

Consider a stable indoor model with just enough power to maintain level flight. If in some way it is disturbed pitchwise to a nose high attitude the lift and drag forces will change, producing a nosing down effect (a "moment" to use the correct engineering terminology) to bring the model back to level flight. If the model is disturbed into a nose down attitude the same forces - but of different magnitudes and possibly of different sign (up rather than down or vice versa) - will produce a nosing up effect, a moment of the opposite sign but also acting to return the model to a level flight attitude. For the second step of this thought experiment let us ask: Will an increase in power, the motor wound more tightly, result in level flight ("cruise") at higher velocity? No; our experience tells us that unless we have tinkered with the model or its adjustment it will instead climb. A decrease in power will not result in lower level flight velocity but descent. While we have not proved it we can say with a fair degree of certainty that any indoor model will have only flight velocity unless we tinker, switch propellers or motors, alter the wing incidence or center of gravity or weight, and so on. If these changes made no difference in the model's actions we could not adjust the ship. The procedure to calculate level flight power is based on the above premise. An indoor model with a given motor and given settings has but one level flight velocity and therefore one level flight attitude.

Several important assumptions, given below, have been made to simplify the solutions and the computer program. Based on the results achieved, these assumptions are reasonable.

(1) In level flight the total wing and tail lift equal the weight of model. Minute upward or downward components of angled propeller thrust are ignored.
(2) The center of lift is fixed at 25% of the wing and stabilizer chord (from the leading edge). In actuality the center of lift is not fixed; it shifts forward or aft as the angle of attack changes. A study of available center of pressure data on single surface airfoils shows, however, that for normal angles of attack the center of lift hovers so closely about the 25% wing chord location that any deviation can be ignored.
(3) A skeletonized model consisting solely of wing and stabilizer is used. These are the primary, almost sole, lift and drag producers.
(4) Downwash from the wing is ignored. It was felt that the downwash would be negligible or virtually constant so that ignoring it would at worst be closely equivalent to a slight, but uniform, decrease in actual angle of attack of the stablizer.

In addition to the assumption above, dealing with the aerodynamics, we must assume certain characteristics of the model itself.

(1) An overall weight.
(2) An airfoil for which we have available the lift and drag coefficients to use in the calculations. The values in the program are for the McBride B7 airfoil from Frank Zaic's yearbooks. Others, for comparison, can be inserted instead.
(3) Wing area and center chord. Stabilizer area given as percent of wing.
(4) Distance between centers of lift of wing and stabilizer.
(5) Stabilizer/boom to be parallel to motor stick.
(6) Motor stick/tail boom form datum for measuring wing incidence.
(7) Wing height with respect to stabilizer/motor stick.
(8) Center of gravity to be located on

motor stick at a given percentage of wing chord from leading edge.

(9) Stabilizer angle of attack equal to motor stick angle with respect to horizontal. IMPORTANTLY, however, wing angle of attack is wing incidence plus the stick angle to horizontal.

As with the model of our thought experiment above, this assumed skeleton of a ship will have but one specific level flight attitude, velocity, and power. How are these found? In somewhat more detail the procedure is as follows: We pretend to "fly" this fictitious ship by having the computer push the model through the air at various angles of attack. This is to determine the angle at which it fly's stably. Because the wing and tail lift equal the weight we can calculate the velocity for each attempt. We can then calculate the separate lifts and drags of wing and stabilizer, and the moments of these forces about the center of gravity. From the total drag the power required can be calculated. If our work is correct we can plot the total moment and power against the wing angle of attack as in Fig. 2. The X intercept shows the wing angle of attack at which this fictitious model will fly. We can also read the power required in stable flight at the angle for which the total moment is zero. If, perchance, the moment curve does not intersect the X axis, the configuration we have selected is unstable. Going through this procedure over a range of values for a chosen variable enables us to ascertain the effect of changes in this variable. This brings us to the program proper. How can the velocity for the model be found? The standard formulae for lift and drag are:

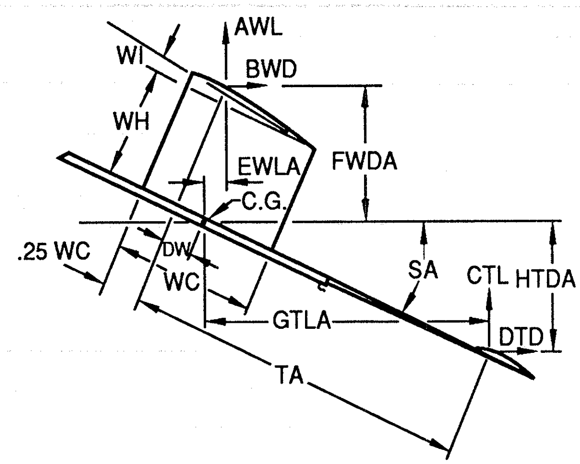
$$\text{Lift} = \text{Cl}*(\text{air density}/2)*\text{S}*\text{V}*\text{V}$$

$$\text{Drag} = \text{Cd}*(\text{air density}/2)*\text{S}*\text{V}*\text{V}$$

The equation is solved in reverse for the velocity since the total lift, the weight, is known. The program starts with the stabilizer at minus two degrees. The stabilizer angle plus the wing incidence is the wing angle of attack. Since the coefficients of drag and lift are given, the program sets up equations for wing and stabilizer lift - using for stabilizer area, the wing area times the size percentage (for example 40% or 0.4). It adds the two and sets them equal to the weight to solve for the velocity. With the velocity known the computer can calculate (at unchanged wing and stabilizer angles) the lifts and drags of wing and stabilizer.

With a bit of geometry and trigonometry on the side view of the model (Fig. 7) the necessary moment arms about the center of gravity can be computed. Items on the figure are identified in the program. Realize that the lifts are vertical, the drags, horizontal, with the arms perpendicular to the forces. Further, the arms are not constant: they change with angle of attack.

Figure 7. Identification In Program



The lifts and drags are multiplied by their respective arms about the center of gravity to obtain their moments. When they are then summed (being certain to use the proper signs) the result is the total moment. The power required (from physics, force times velocity) is obtained by multiplying the total drag (wing drag plus stabilizer drag) by the velocity. The values are printed out similar to Fig. 1, the center of gravity incremented by 10%, and the procedure repeated to 100% CG. Then the angle of attack is incremented two degrees and the entire above procedure again repeated.

It is difficult to type in even a small program error-free. The author, therefore, makes the offer of providing a checked, running program identical to the listed program on a 5 1/4 inch floppy for $10 (price includes disc and return postage). Being away from home occasionally he begs forebearance should turn-around time be more than 24 hours. He will gladly engage in correspondence on the program with the same provision.

```
10 OPEN4,4,1
20 CMD4:LIST
30 REM"*********************************
40 REM"*INDOOR MODEL POWER REQUIREMENTS*
50 REM"*COPYRIGHT 1990 BY WALTER ERBACH*
60 REM"*********************************
70 REM"P(N) CALCULATED POWER REQUIRED"
80 DIM P(8)
90 REM"LIFT & DRAG COEFFICIENTS FOR
100 REM"MCBRIDE B-7 FROM FRANK ZAIC'S
110 REM"YEARBOOK"
120 REM"L(N) IS COEFF. OF LIFT, TWO
130 REM"DEGREE INCREMENTS FROM -2 DEG."
140 DIM L(8)
150 L(1)=.06:L(2)=.135:L(3)=.2:L(4)=.25
160 L(5)=.3:L(6)=.35:L(7)=.395:L(8)=.44
170 REM"D(N) IS COEFF. OF DRAG, TWO
180 REM"DEGREE INCREMENTS FROM -2 DEG."
190 DIM D(8)
200 D(1)=.008:D(2)=.009:D(3)=.01
210 D(4)=.012:D(5)=.014:D(6)=.019
220 D(7)=.024:D(8)=.0335
230 REM"M(K) IS CALCULATED PITCHING MOM.
240 DIM M(8)
250 REM"MODEL AREAS AND WEIGHTS IN
260 REM"INCHES AND OUNCES. MUST
270 REM" CONVERT TO FEET AND POUNDS
280 REM"FOR CALCULATION AND RECONVERT."
290 REM"AW IS WING AREA IN SQ. INCHES"
300 AW =150
310 REM"SW IS WING AREA IN SQ. FEET"
320 SW=AW/144
330 REM "WC IS WING CHORD IN INCHES"
340 WC = 5.5
350 REM"WI IS WING INCIDENCE, DEGREES"
360 WI=4
370 REM "WH IS WING HEIGHT IN INCHES"
380 WH = 3
390 REM"CG IS DECIMAL LOCATION OF CG
400 REM"WITH RESPECT TO L.E. OF WING"
410 REM "W IS OVERALL WEIGHT IN OUNCES"
420 W = 0.070
430 WT=W/16
440 REM"PCW IS RATIO OF STAB AREA
450 REM"TO WING AREA."
460 PCW = 0.40
470 REM"TA IS LOCATION OF TAIL LIFT
480 REM"FROM 25% WING CHORD STATION
490 REM"TO 25% STAB CHORD STATION."
500 TA = 17
510 REM"DETERMINE VELOCITY FORMULA"
520 REM"WT=WING LIFT + STAB LIFT
530 REM"WT=CLW*(@/2)*SW*V*V+CLT*(@/2)*ST*V*V
540 REM"V=SQR(WT/(CLW*(@/2)*SW+CLT*(@/2)*SW*PCW))
550 REM"CLW AND CLT CHANGE IN EVERY
560 REM"LOOP. MUST READ VALUES FOR
570 REM"WING AND STAB ANGLE OF ATTACK"
580 REM"INITIAL CG=0.3; USED IN 780"
590 REM"CALCULATING LOOPS COME NEXT"
600 REM"OUTER LOOP H INDEXES WING INC."
610 REM"TO USE LOOP H REMOVE STATE-
620 REM"MENT 690 AND BE SURE WING
630 REM"INCIDENCE SET TO TWO DEGREES
640 REM"IN STATEMENT 360"
650 REM"MIDDLE LOOP J INDEXES WING
660 REM"ANGLE OF ATTACK."
670 REM"INNER LOOP K INDEXES CG FOR
680 REM"MOMENT CALCULATIONS."
690 GOTO 710
700 FOR H=1 TO 5
710 REM"ANGLES MUST BE IN RADIANS"
720 REM"STAB IS PARALLEL TO BODY"
730 REM"SA IS STAB,BODY, ANGLE, DEG.
740 REM"CONVERTED TO RADIANS IN
750 REM"STATEMENT #1080"
760 SA = 2
770 FOR J=1 TO 6
780 CG=0.3
790 REM"LIFT & DRAG CALC.,    /2=0.00119
800 VE = (WT/(0.00119*SW*(L(J+WI/2)+PCW*L(J))))+0.5
810 AWL=L(J+WI/2)*SW*(0.00119)*VE*VE*16
820 BWD=D(J+WI/2)*SW*(0.00119)*VE*VE*16
830 CTL=L(J)*SW*PCW*(0.00119)*VE*VE*16
840 DTD=D(J)*SW*PCW*(0.00119)*VE*VE*16
850 PRINT ""
860 PRINT""
870 PRINT WI" DEG. WING INCIDENCE FOR THIS RUN"
880 PRINT" "
890 PRINT WI-SA" DEG. WING ANGLE OF ATTACK"
900 PRINT PCW*100"% STAB AREA"
910 REM"REDUCE VE TO SENSIBLE ACCURACY"
920 VE=VE*100:VE=INT(VE):VE=VE/100
930 PRINT VE" FT/SEC CALC. VELOCITY "
940 REM"CALC. POWER FOR THIS ANG.ATTACK"
950 P(J)=VE*(BWD+DTD)*12
960 REM"CONVERT P(J) TO SENSIBLE DEC'L"
970 P(J)=P(J)*1000:P(J)=INT(P(J)):P(J)=P(J)/1000
980 PRINT P(J) "IN OZ/SEC POWER REQUIRED"
990 PRINT" "
1000 PRINT"CG LOCATION   MOMENT"
1010 PRINT"% WING CHORD  INCH OZ"
1020 FOR K=1 TO 8
1030 DW= WC*(CG -0.25)
1040 REM"K LOOP TO CALCULATE MOMENTS AT
1050 REM"SPECIFIED CG LOCATIONS
1060 REM"FOR ANGLE OF ATTACK OF J LOOP"
1070 REM"BODY ANGLE, NOT ANGLE OF ATTACK
1080 R=SA*6.28/360
1090 REM"NOW CALCULATE MOMENT ARMS
1100 REM"OF LIFTS AND DRAGS ABOUT CG"
1110 EWLA=WH*SIN(R)+DW*COS(R)
1120 FWDA=WH*COS(R)-DW*SIN(R)
1130 GTLA=(TA-DW)*COS(R)
1140 HTDA=(TA-DW)*SIN(R)
1150 REM"NOW CALCULATE THE STATIC
1160 REM"MOMENTS, ARMS TIMES FORCES"
1170 JMWL=+AWL*EWLA
1180 KMWD=+BWD*FWDA
1190 LMTL=-CTL*GTLA
1200 MMTD=+DTD*HTDA
1210 M(K) =JMWL+KMWD+LMTL+MMTD
1220 CO=CG*100
1230 REM"REDUCE TO SENSIBLE ACCURACY"
1240 M(K)=M(K)*1000:M(K)=INT(M(K)):M(K)=M(K)/1000
1250 P(J)=P(J)*1000:P(J)=INT(P(J)):P(J)=P(J)/1000
1260 PRINT CO, M(K)
1270 CG=CG+0.1
1280 NEXT K
1290 SA=SA-2
1300 NEXT J
1310 WI = WI + 2
1320 NEXT H
1330 PRINT#4
1340 CLOSE4

READY.
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References and Biography

1. Hewitt Phillips, "Wind Tunnel: Effects of Wing Spar Size", Journal of International Aeromodeling, Vol. 1, #2, 1939.
2. J.Wallace McBride, "Some Technical Notes on the Present Indoor Airfoil", Junior Aeronautics Yearbook, 1934, Frank Zaic.
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4. Aerodynamics for Model Aircraft, Avrum Zier, 1942, Dodd, Mead, and Co.
5. National Advisory Committee on Aeronautics, "Collection of Wind Tunnel Data on Commonly Used Wing Sections", Report No. 311.
6. IBID, "Aerodynamic Characteristics of Airfoils - VI".
7. Walter Erbach, "Computer Evaluated Aerodynamic Design for Indoor Models", Sympo '70, 1970 NFFS Symposium Report.
8. Walter Erbach, "Experimental Verification of Indoor Model Flight Analysis by Computer", Sixth Annual Symposium, 1973 NFFS Symposium Report.

Since present day aircraft design is compressible flow oriented (high speed), i.e. no good, in print, references to the static stability calculations exist. The explanation given in the text is as complete as any such references and should suffice. If you are interested, seek information in older (pre-WWII) books, especially on the aerodynamics of, or design of, the airplane - but avoiding discussions which treat only of the static moment coefficient rather than the static moment itself. Further, if the index does not show "stability, static" covering more than one page the book belongs back on the shelf.

Walter Erbach: Walt has been flying models since the 1930's. His indoor models appeared in Zaic's Yearbooks and he won Cabin in the Kansas City Auditorium at the '48 Nats. He's been a regular contributor to the symposiums and is a member of the NFFS Hall of Fame (see the '88 Sympo). He's a Professor of Engineering, Univ. of Nebraska, Lincoln.

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