12 COMPUTER EVALUATED AERODYNAMIC DESIGN CRITERIA FOR INDOOR MODELS

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There are many factors governing indoor model aircraft duration. The effects of some as, for example, weight, are so immediately apparent that indoor builders exercise all possible control over them. Others mask each other so that optimum values are not always easily determinable and may, in fact, be impossible to ascertain in flight tests. Consider three such variables: wing incidence, center of gravity location, and stabilizer size. As the center of gravity is moved aft the wing incidence must be lowered. Moving the center of gravity rearward, to a point, increases the duration but it also loads the stabilizer more heavily. This leads to the feeling that the stabilizer size should be increased to reduce its area loading. Is there, then, an optimum combination of center of gravity location, wing incidence, and stabilizer size?

This problem has been attacked by several people using the static stability analysis method employed for full size aircraft. This analysis links such variables as center of gravity, tail area and moment, wing moment, and wing angle of attack. Thus it appears to be precisely what is wanted for our purposes. Unfortunately, this method, while a starting point, is insufficient for indoor models. This stability analysis for man-carrying ships is predicated upon two important assumptions, firstly, that the wing provides all of the lift and carries all of the weight of the ship and, secondly, that the wing and stabilizer are at the same level. Even casual inspection of man-carrying ships reveals that these assumptions are reasonable. Stabilizers have either thin slab or symmetrical, i.e., non-lifting sections, while parasol wings are conspicuous by their absence. Loads on the horizontal tail surfaces are very small. Forward center of gravity locations near the quarter point of the wing, result in relatively neutral stabilizers and are essential for stability.

On the other hand, indoor design anticipates obtaining lift from the stabilizer by the use of aft center of gravity locations, while the wing is perched with its mean chord in the vicinity of a chord's width above the stick. In rare cases builders have reported using centers of gravity at 100% of the wing chord. In such extremes the stabilizer may provide up to 20% of the total lift - a quarter that of the wing! Such a stabilizer, having an area roughly a third that of the wing, has a unit area loading approaching that of the wing. Every change in center of gravity location, as may result from switching propellors or motors, and every change in incidence, changes the relative amounts of wing and stabilizer lift (and wing and stabilizer drag). Under these conditions the assumption that the wing provides all of the lift is invalid.

A cogent reason exists for the approximations used by the aerodynamicists in static stability analysis. By assuming that the wing supports all of the weight and that the wing is at the same level as the stabilizer the theoreticians have been able to derive a relatively simple static stability formula which plots as a straight line. The slope of this line determines, in a manner of speaking, the stiffness of the airplane's flight, that is, its eagerness to return to straight, level flight when nosed up or down, or its inability to do so when disturbed.

An exact mathematical analysis is virtually impossible for indoor models. Any change in pitch attitude changes not only the wing and stabilizer lifts and drags but also, because of the high wing, changes the moment arms of these forces about the center of gravity. In an attempt to obtain some useful correlation between center of gravity location, wing incidence, and stabilizer size a somewhat different approach, made feasible only by the computer, was used. The speed of the computer makes possible thousands of calculations (in this case for stability) in a matter of moments. Proper programming makes possible the printing out of such results in graphical form almost as quickly. Hence, it was decided to devise a program which would, in effect, fly a skeletonized indoor model on a digital computer. (Both an IBM 7040 and an IBM 360 were used). The program would calculate values for the level flight static moment curve for this model, together with power required values and plot the results, static moment and power required, against angle of attack. By comparison of the power required at zero moment (stable flight) for various configurations of the model the most efficient configuration could be ascertained. The method does not provide a theoretical solution with a neat, simple equation for calculus manipulation to evaluate maxima or minima. It does, however, enable us to obtain answers to pertinent, long standing questions. Even more, it not only enables us to obtain optimum values for any variable but also enables us to see in graphic form how changes in this variable affect the required power, and thus how closely we must control this factor.

Method

To accomplish the above, a skeletonized C tractor of rather standard outline was blocked out: The tail location relative to the wing was fixed, values for total weight, wing height, wing chord, stabilizer size, wing incidence (relative to the stabilizer), and center of gravity were chosen. Incidentally, all numerical values were entered into the program on separate punch cards so that changes in any one of them could be made by the substitution of a new card with the desired value.

Obviously, suitable airfoil characteristics must be included in such a program. Unfortunately, little information on low speed airfoils is available. It was decided to use the McBride B-7 airfoil characteristics for the major portion of the work although others were later used for comparison. No center of pressure locations are available for any of the indoor airfoils. The center of pressure for non-reflexed airfoils moves forwards as the angle of attack increases and, at the angles of attack of interest in our work, hovers within one or two percent of its most forward position, the 25% chord station. As an approximation, therefore, the calculations were made considering wing and stabilizer lifts to be at the 25% station.

The several stages in the computer program proper were as follows:

1. A specific wing angle of attack (computer indexed) was chosen.

2. The flying speed for this angle of attack was calculated.

3. The separate wing and tail lifts and drags at this speed were calculated.

4. The moment arms from the center of gravity were calculated for each of the lifts and drags.

5. The moment about the center of gravity was calculated for each force.

6. The moments were summed to obtain the total moment.

7. The power required was calculated.

8. The total moment and power required values were simultaneously printed out and plotted for this angle of attack.

9. The angle of attack was computer indexed by two degrees and all steps were repeated (normally fron angles of attack of 2^o through 12^o) to obtain a computer plotted graph of total moment and power required. Incidentally, a smaller loop made a series of calculations for centers of gravity ranging from 30% to 100% by 10% increments at each angle of attack.

The complete program was run a number of times with incremental changes in chosen variables to ascertain the effect of these variables. As the original intent was to study the relationship between center of gravity, wing incidence, and stabilizer size the work was concentrated on them. As the study proceeded it became evident that other factors, such as wing height, were of very little consequence. Admittedly, this brute force method lacks elegance. This lack is compensated by the fact that it works and provides useful, understandable results.

The result of a pass of this program through the computer is a plot of the moments of one particular model configuration at varying centers of gravity and the power required curve for this configuration against the angle of attack. At the angle of attack for which the moment curve crosses the zero moment line (the X axis) the model is in equilibrium and the power required can be read from the power curve. The power required can be neither greater nor less than this for level flight of that particular configuration and center of gravity.

Results

While the computer determined graphs are of some use in themselves, the information from them is better condensed for easier understanding. Our primary interest lies in ascertaining model configurations having minimum power consumption. To this end appropriate cross plots have been drawn. Figures 1, 2, 3, and 4 show the relationship between power required and center of gravity location (as a percent of wing chord) for several sizes of stabilizer, at wing incidences of 2^o, 4^o, 6^o, and 8^o respectively.

By examining any one curve it can be seen that for a given stabilizer size and wing incidence there is only one center of gravity for which the power required is a minimum. It is, theoretically at least, possible to have the center of gravity too far aft. As the incidence is increased the curves flatten out. At 6^o and 8^o incidences (Figs. 3 and 4) the curves for the 40% stabilizer are virtually level for the commonly used centers of gravity. This could be the reason that large stabilizers are so popular. Rather than being so efficient, these stabilizers are simply more tolerant of poor design and adjustment!

Comparing the curves of any one figure shows that small stabilizers have a lower minimum power requirement and that this value is attained for forward centers of gravity. The graphs indicate sufficient reduction in power required by configurations having 10% stabilizers in comparison to those having 30% or larger stabilizers to warrant experimentation with such configurations, adjusting carefully in the vicinity of the optimum settings indicated by the graphs.

These graphs give no hint of wing angle of attack. This must be obtained by reference back to the appropriate computer printouts. Amazingly, it was discovered that for angles of incidence of 2^o, 4^o, and 6^o the angle of attack at minimum power is 6^o wihin a very small fraction of a degree. For 8^o incidence the minimum power is practically constant for angles of attack from 6^o to 8^o.

Comparison of the curves from the several graphs for any given stabilizer size shows that lower wing incidences are more efficient. The previous paragraph gives a clue why this is so. Minimum power occurs at a (relatively) fixed wing angle of attack. Thus low wing incidences mean higher stabilizer angles of attack; the horizontal tail surface is providing lift, not just drag. An illustration of this situation is found in the model world: The hand launched glider. Its best alignment finds wing and stabilizer set as near to the same incidence (0^o - 0^o) as possible. There has not previously been a satisfactory explanation for this. Glider experts simply knew that such settings resulted in minimum power consumption, i.e., lowest sinking speed.

Figure 5 shows the results of check runs upon another airfoil, the JAL 850, at 6^o incidence. This airfoil has characteristics far superior to those of the McBride B-7 yet the power required curves for both airfoils are very similar with only minor variations in shape and values. Though there is no explanation for this as yet, the conclusion is confirmed in the model world. The best models of outstanding builders fly equally well despite frequent use of home-brew airfoils of unknown quality, light wing construction which can not maintain the build-in airfoil under flight loads, and covering materials which refuse to contour properly. (paper ships!)

The present day indoor model has a fixed longitudinal wing location. What we call adjusting is merely an attempt to find the wing incidence which will result in the lowest power consumption. Why this is so can be seen by comparing the curves for a given stabilizer size on the sequence of graphs, figures 1 through 4. The model will fly stably, but not efficiently, over a wide range of center of gravity locations and incidences. With changes in incidence the location of the center of gravity for minimum power sweeps over a wide range. For example, at 2^o incidence a 30% stabilizer requires minimum power for a 100% center of gravity location, as the incidence is increased to 8^o the center of gravity location for minimum power moves forwards to the 65% station. Since the center of gravity of our model is fixed we try to obtain the wing incidence setting which requires minimum power for the existing center of gravity location.

Speculation

It might be instructive at this stage to make a crude calculation for flight time. The ship configuration used in the computer analysis was a C tractor of 0.070 ounces flying weight. In common practice this would represent a model of 0.035 ounce weight with a 0.035 ounce motor. Rubber, depending upon its quality, will store upwards of 30,000 inch ounces of returnable work per ounce of rubber. The motor, then, will provide, at most, 1050 inch ounces of energy (0.035 ounces times 30,000 inch ounces per ounce). Let us assume, after studying the graphs, that a complete model will require 0.15 inch ounces of work per second - we can not hope to attain the minimum values of the skeletonized computer model for our actual ship. From other experimental work we have done we have found that the propellor consumes, on the average, approximately as much power as the rest of the model. The total power consumption is then 0.30 inch ounces per second. The maximum flight time will be the total work available divided by the amount needed per second:

Flight duration = 1050/0.30 = 3,500 seconds or about 58 minutes! This is certainly not bad for any approximation, first or otherwise. We can not be sure just how much energy is provided by the motor, how much power is consumed by the various model components, what losses due to torque control measures occur.

Test Work

How does the computerized model agree with actuality? An extensive series of glide tests has been made upon a mediocre model of indifferent airfoil, a model whose general dimensions correspond with those of the computer model. While the exact power values differ substantially, the shape of the computerized flight curves has been confirmed to a surprising degree.

One series of tests was made with a 33% stabilizer on the actual model. The graph of figure 6 shows the results of these tests and the correspoinding results for the closest comparable computer model, the configuration having a 30% stabilizer. Because of differences in what might be called model quality different vertical scales have been used for each model to superimpose the results. The solid curves represent the computer model, the dashed lines and plotted points (each point representing the average of at least three glides), the real model. Considering that no aerodynamic correction factors have been included in the computer program the agreement between computer and real model is rather good, falling off only at centers of gravity so far aft that the real model was stalling and not gliding smoothly, a feat the computer had not been programmed to duplicate.

Figure 6 does not, however, constitute experimental verification of the families of curves of varying stabilizer sizes in figures 1 through 4. It is a plot that cuts across figures 1 through 3, verifying the shape of the individual curves. It also shows that the form of solution which has been developed provides reasonable answers for normal model configurations and normal flight attitudes.

Parenthetically, the glide tests also agree with full fledged flights of the model. Several years ago the ship was flown in Lakehurst, its two best flights being just under 28 minutes. Assuming the model was flown at its minimum power requirements as shown by the glide tests (0.35 inch ounces per second) and making calculations similar to those for the computer model in the previous section the maximum flight time for the actual model would have been 28.3 minutes.

Conclusions:

The method developed to fly, as it were, an indoor model on a computer does work; it gives results which to a limited extent have been verified by glide tests. While it can not be said with certainty that the graphs of performance characteristics are valid for all configurations or sizes of models, still similar analyses of the effects of other variables indicate only minor alterations in the curves for any reasonable configuration of C tractor. There is no reason to expect substantial difference for smaller or larger ships.

Several important assumptions were made to enable a workable computer solution. The center of pressure was assumed to have a fixed location at the commonly used angles of attack. The effect of wing downwash on the stabilizer was assumed negligible and was ignored. The agreement between computer and experiment would seem to indicate that these assumptions are reasonable. While refinements of the computer program could include center of pressure travel and downwash as variables such refinements would not appear warranted at the present "state-of-the-art."

One important discovery of the computer work deserves further investigation. This discovery is that major variations in airfoil characteristics have a relatively minor effect on the power required curves, and on the minimum power. This unexpected, and hard-to-believe, characteristic of indoor model configurations would appear to be the reason that indoor models even exist, since the builder is guaranteed satisfactory power performance from almost any airfoil.

The glide tests would indicate that a model's potential can be evaluated by such tests. High power consumption in the glide will assure poor duration in powered flight. Rough and ready calculations for duration as made in the text will give an indication of still air flight time.

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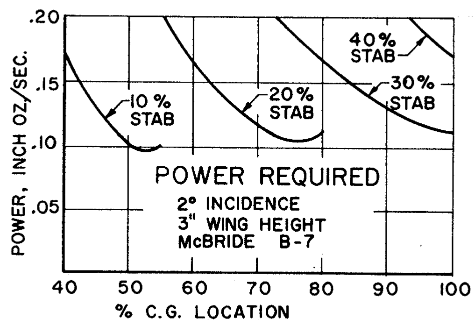

FIGURE 1

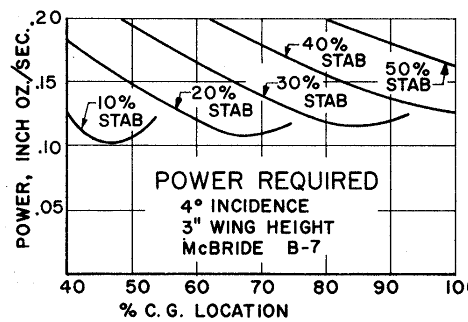

FIGURE 2

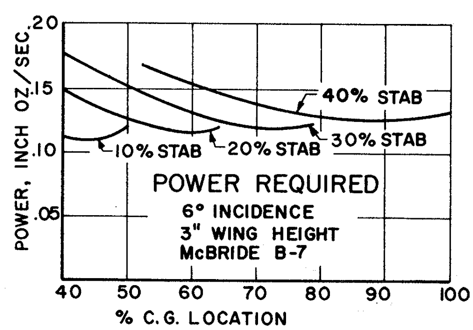

FIGURE 3

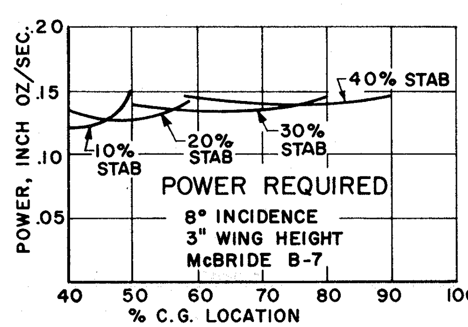

FIGURE 4

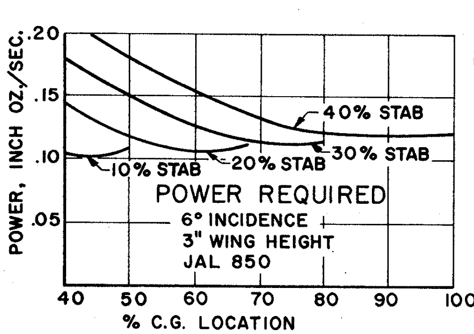

FIGURE 5

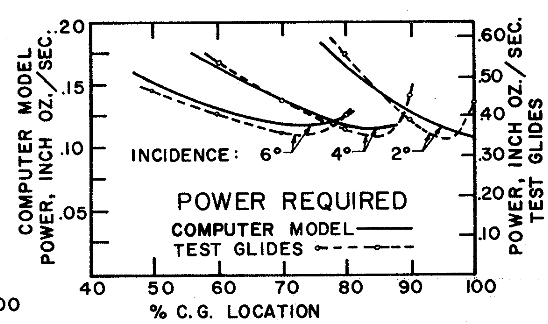

FIGURE 6