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POWER REQUIREMENTS OF INDOOR MODEL AIRCRAFT HAVING TANDEM LIFTING SURFACES

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The indoor model is a free-flying rubber-powered model aircraft designed to achieve maximum flight duration through light construction and proper aerodynamic configuration. So fragile it can be flown only indoors, a world competition model weighs approximately one gram, is powered by a motor of equivalent weight, and under ideal conditions in sufficiently large halls is capable of single-flight durations exceeding forty-five minutes. World competition regulations established by the Federation Aeronautique Internationale restrict only wing span, thus design problems arise from a different direction from those of man-carrying aircraft. With the wing planform largely determined by the given span, the designer is faced with the problem of coordinating the horizontal tail surface area and center of gravity location of the ship with respect to the wing to minimize power consumption and thus to achieve maximum duration.

Tailplanes of man-carrying aircraft are used exclusively for stabilizing purposes but on a model it is possible to obtain lift from them as well. This implies a center of gravity aft of the center of lift of the wing. Under certain conditions a model will perform significantly better with the center of gravity 15 to 50% of the wing chord behind the center of lift of the wing.

The builder, in the "design" of his model, is then confronted with decisions on three important related variables: How large shall he make the horizontal tail surface? How far aft is the center of gravity to be placed? What angle of wing incidence is best? These variables, unfortunately, are not independent. A large stabilizer, for example, admits of a farther aft center of gravity than a small one and may, in fact, require it for equivalent performance. Aerodynamic design has hitherto been largely empirical in nature, values for the above variables being chosen by the builder on the basis of prior experience (or upon values embodied in the latest record-breaking model). No mathematical solution, valid for indoor models, to establish optimum model dimensions and to determine force vector locations and surface settings, is known. There exists a stability equation for man-carrying aircraft which incorporates the above variables. This equation is linear and plots as a straight line whose slope denotes the degree of stability or instability. This equation is, however, linearized by aerodynamicists using two important simplifications which render it invalid for indoor model aircraft design, namely, that the wing provide all of the lift, and that the wing lie on the action line of the propellor thrust vector.

Several years ago the author developed a computer program to analyze the level flight performance of indoor models. This was accomplished through stability-type calculations, making provision, however, for stabilizer lift, and high wing. The program calculated and plotted the moments of all forces about the center of gravity on a skeletonized model for varying relative wind angles (the "angle of attack"). At the angle of attack for which the total moment is zero the model will be in stable flight about the pitch axis, i.e., nosing neither up or down, and the required power, also calculated and plotted by the computer, can be ascertained. By repeating the process while varying any parameter for the skeletonized model the effect of this parameter upon the power required becomes evident. Obviously, one searches for the configuration which requires the least power. In an attempt to establish useful design criteria the major effort was concentrated upon the effects of the three variables mentioned earlier, stabilizer size, center of gravity location, and wing incidence. The computer program and the results thereof were discussed in detail in an earlier paper by this author (Erbach, 1967). These results lend themselves to graphical portrayal and were presented in this manner. A typical graph of the analysis is shown in figure 1 where power required is plotted against the center of gravity location for varying angles of incidence at a given stabilizer size.

In developing the computer program certain assumptions were necessary to bridge gaps in aerodynamic information available. Lack of practical application has retarded research in low speed aerodynamics and the characteristics of airfoils of the type used on indoor models are, therefore, rather incomplete. One might suppose, for example, that the center of lift, i.e., that fore and aft location where the lift vector intersects the wing, be at the midpoint of the wing profile. This is not the case; for the common type of wing cross section the wing lift vector moves forward as the angle of attack is increased. A study of the literature available suggested that, for conditions existing during normal flight of an indoor model, the center of lift could be assumed as a first approximation to be at the quarter point of the wing, that is, one-fourth the distance to the rear on the wing profile. Furthermore, no information exists on the downwash, the downward velocity imparted to the air as the wing produces lift. Again, as a first approximation, it was considered that the downwash would at all times be uniform. The effect of this is one of slightly increasing the theoretical angle of incidence since the stabilizer, located behind and below the wing, is in a mass of air moving downwards at very low, constant velocity.

The results obtained through the computer program were to some extent unexpected. It was therefore decided to set up a test program as similar as possible to the computer work to verify (or invalidate) the calculated results. Unfortunately, it is difficult to measure the energy consumption of the model in level flight. Instead, a series of glide tests was undertaken. In gliding attitude the power required is determined very simply as the rate at which potential energy of altitude is being expended (power, inch ounces per second = weight, ounces x sinking speed, inches per second). The motor and propellor were replaced by a moveable clay weight which could be positioned longitudinally to vary the center of gravity location. The same parameters were varied in the same manner as was done during the computer flight simulation. Inasmuch as the propellor thrust normally acts virtually through the center of gravity of the model it was felt that the approach used, although it could not guarantee the correctness of the theoretical work, might, at least, tell us whether we were "in the ball park". As events were later to prove, we were far better than just in the ball park.

A competition model of dimensions similar to those used in the computer analysis was selected. Such models have built in means for motor torque compensation such as assymmetric wing planforms and it would, therefore, have been preferable to use a model especially constructed for non-power tests. Doubt over the feasibility of the project suggested preliminary exploration with an existing craft; even a poorly made ship represents a minimum of fifteen to twenty hours of construction time. The results of the preliminary testing with the available ship were so far beyond expectations that the test project was carried through to its conclusion with it. Since, in the computer analyses, models having stabilizers of 20%, 30%, and 40% of the wing area were investigated while the test ship had a 40% stabilizer, two smaller stabilizers, geometrically similar to the largest one, were constructed.

The test procedure was quite straight forward. The model was glided repeatedly from a pre-determined altitude. The duration of each glide was recorded. If the glide path were straight enough to enable a distance measurement this was also recorded. After sufficient glides to ensure that consistent results were being obtained one of the three paremeters under investigation was changed and the process begun anew.

To standardize the operation the model was launched from the same height, 85 inches, for each flight, the odd height representing the upper edge of a molding circling the auditorium used for the flights. "Sighting in" the nose of the model for accurate elevation control was thus achieved. Ideally, machine launching should have been used but this was not practical. Since changes in ship parameters alter flight attitude and velocity the launch must be altered accordingly. Such adjustment is almost instinctive on the part of an experienced builder but difficult to program into some mechanical gadget. The success of hand launching can be judged by the fact that on three occasions three successive flights at the same parameter values were timed with durations within 0.1 second of each other; on sixteen occasions three successive flights were timed within 0.4 second. Such accuracy can be considered no less than remarkable when it is noted that a 0.4 second flight differential could be produced by an undetectable vertical air disturbance having a velocity of only eight inches per minute, less than 0.01 mph, during the duration of the flight.

An occasional flight would be an obvious abort. The launch would be improper, the model would circle more than anticipated and strike a wall, a draft would upset the model. Such flights were recorded for completeness' sake, together with an explanatory note but the flight time was not averaged in.

For each set of values of the parameters at least three glides, for averaging purposes, were made. If deemed necessary additional glides were made. As the center of gravity moves aft across its minimum power value the model flight pattern changes from stable to unstable, stalling, flight while in the vicinity of the minimum power value the model glides and settles most slowly. Under the latter conditions the model is very susceptible to slight disturbances in the ambient air and stalls readily. At aft centers of gravity it was, then, difficult to distinguish between erratic flight due to air disturbances and incipient model instability. When doubt, triggered by irregular flight durations, existed, additional flights were made. These were continued until some regularity appeared or until a sufficient number of flights for a meaningful average had been made.

Plots of the results obtained for each size of stabilizer are shown in figures 2, 3, and 4. As in the computer analysis, the power required is plotted against center of gravity for varying angles of incidence. The curves are, in general, convex up, reaching a minimum power for a particular center of gravity location, and form a family of sorts. As the incidence is increased the curves become more flattened and the center of gravity for minimum power moves forwards. While for each angle of incidence and stabilizer size there is but one center of gravity location for minimum power, the higher incidences tolerate a broader range of center of gravity locations without the penalty of greater increased power. From figure 2 the following can be obtained:

Angle of incidence	Center of gravity for 0.4 inch oz./sec. power		G. G. Range	G. G. Location for Min. power
	Forward	Aft		
2°	73%	82%	9%	77½%
4°	62	74	12	70
6°	50	66	16	62½
8°	40	62	22	55

Similar tables with similar results could be made for the other stabilizer sizes. No information akin to this exists for powered flight. One can, however, on the basis of the glide graphs, tentatively conclude that higher incidences are superior. There would not appear to be a single optimum power flight

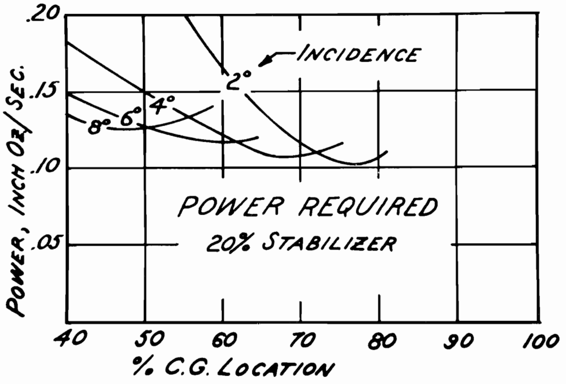

FIG. 1

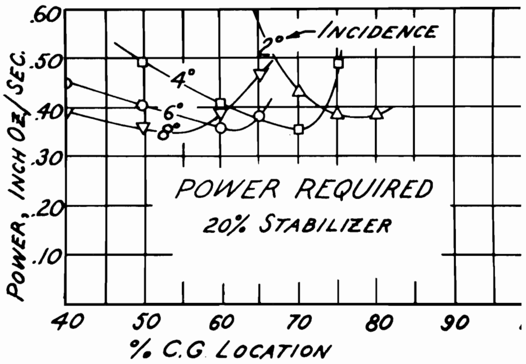

FIG. 2

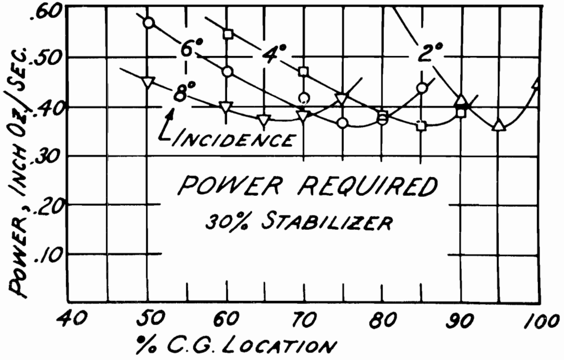

FIG. 3

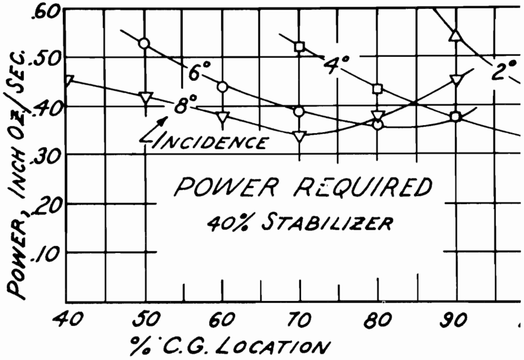

FIG. 4

configuration since the power is constantly changing from a maximum at the start of the flight to the non-powered, glide conditions at the close of the flight with the flight attitude correspondingly changing from steep climb through level flight to glide. With power conditions constantly changing the model configuration having the lowest power requirements over the widest range would seem the logical choice.

Slight irregularities, especially in figure 3 for the 30% stabilizer, can be noted in the spacing of the curves, and to this we will refer again later. It appears that these irregularities are merely due to incorrect incidence settings. The operation of setting the wing incidence is rather awkward and a task difficult to perform with any accuracy due to the type of wing mount employed on these ships. For lightness the construction employs a circularly cross sectioned wing mounting post which slides in a tightly fitting tissue paper tube. On the test model a motion of but 3/16" of either front or rear strut produces the two degree variation in incidence between the successive curves. In any event, for an inaccurate incidence setting the resulting curve for this setting is merely mislabeled, not invalidated.

As one inspects the graphs of figures 2, 3, and 4, other items become apparent. A sort of "envelope" connecting the minimum power points of the given curves can be drawn. This represents the optimum glide configurations for a given stabilizer. The envelope is virtually straight but has a very slight positive slope for the 20% stabilizer, a similarly slight negative slope for the 30% stabilizer, and is inexplicably slightly concave downwards for the largest stabilizer. While no explanation is available for these inconsistencies, several observations could be made. Firstly, the tests did require three different stabilizers, and although these were carefully constructed, there would be unavoidable differences in construction and profile. Secondly, the aerodynamic regime under which these tests were performed (Reynolds numbers in the vicinity of 5000) is notorious for inconsistency.

In figures 5, 6, 7, and 8 the computer-derived curves and the experimental curves are depicted side by side. By the simple expedient of making the original graphs to an inch scale for the test results and to a centimeter scale for the computer work the two sets of results were placed into reasonable juxtaposition. Thus, in viewing these four figures this casual ratio should be kept in mind. Where a pair of curves lie one above the other, the use of a different ratio would have brought them into closer alignment. Further, where a pair of curves have differing slopes, it is possible that the specified angle of incidence for the test ship is slightly in error. The correct incidence might have produced better agreement. For example, on figure 5, the 30% stabilizer test curve has a high slant, relative to the theory curve. The test might have been made at an incidence setting of slightly less than 2°. Comparison of this test curve on figure 2, from which it was obtained, with its neighbors shows this curve apparently slightly out of position in the

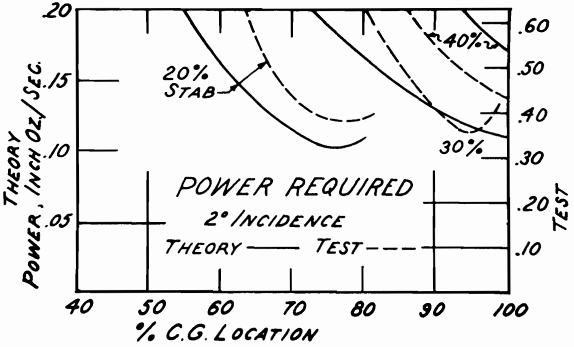

FIG. 5

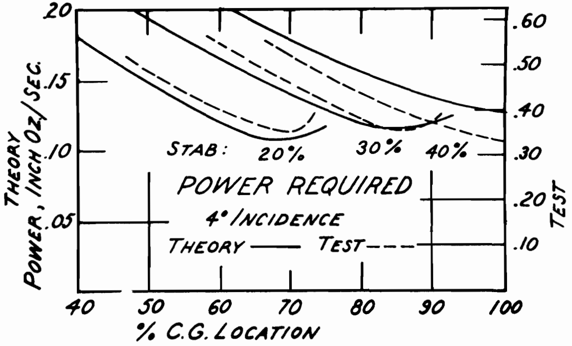

FIG. 6

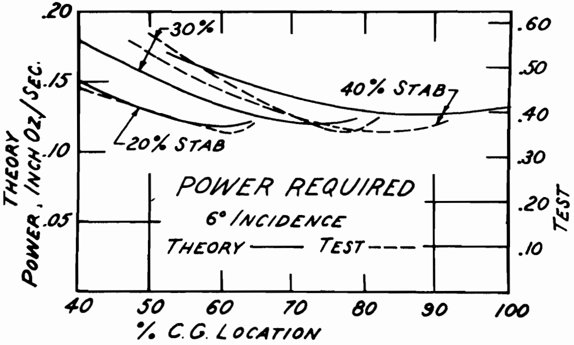

FIG. 7

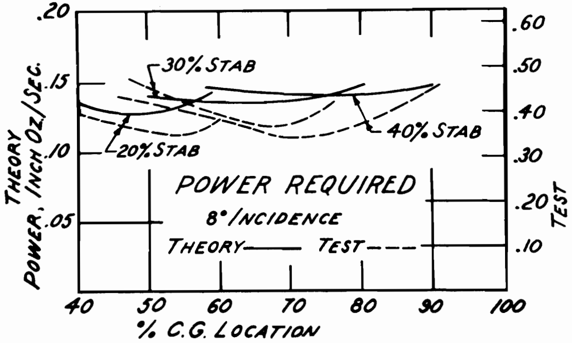

FIG. 8

direction of lower incidences.

One anomaly appears in the test curves. In figure 4, for the eight degree incidence curve a reversal of curvature which would indicate a leveling out of the curve at far forward centers of gravity appears. Such leveling out must, in fact occur with extreme forward centers of gravity, regardless of incidence. Obviously, if the model weight remains constant while the center of gravity is moved farther and farther forward a condition will eventually be reached for which the model will plummet vertically. There will be no lift in the usual sense, the model will reach a terminal velocity governed by weight and drag, and at this stage additional forward movement of the center of gravity will have no effect. It is not possible to say whether, due to the high incidence, this limiting velocity was being approached or whether other unknowns were responsible for the reversal in the power curve.

The experimental work seems to verify the computer analysis, though the former represents glide conditions, the latter level flight. It is difficult to see how much improvement can be made to bring the curves of figures 5, 6, 7, and 8 more nearly into coincidence. There will always be inaccuracies inherent in the experimental work: Virtually undetectable drafts, as mentioned earlier may alter glide times, structural rigidity of the model is sacrificed for the lightness necessary to long flights. The model has an ill defined airfoil of unknown characteristics; neither structure nor covering of supporting surfaces maintains a desired profile.

No clearly "optimum" model configuration is discernable from the experimental work. The 40% stabilizer model appears to have a very slight advantage under glide conditions. The experimental model, however, was ballasted to maintain a constant weight regardless of stablizer size to correspond with conditions of the computer analysis. This placed the configurations with smaller stabilizers at a slight disadvantage, inasmuch as the use of smaller stabilizers would normally result in slightly lighter models with slightly reduced power requirements.

The glide tests give good indication of the model's overall capabilities. The two best flights of the test model, under maximum conditions, were just under 28 minutes. Based on experimental work done on motors and propellors, and using a power required value of 0.35 inch ounce per second, approximately the minimum from the graphs, the model should have flown 28.3 minutes.

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