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INDOOR WING CONFIGURATIONS FOR FÉDÉRATION AERONAUTIQUE INTERNATIONALE COMPETITION

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Indoor model aircraft are extremely light and fragile, free-flying craft—flown, as the name implies, indoors in large (often unsuitable) buildings with performance measured by flight duration. The model is designed and adjusted to fly a circular path to avoid sidewall collisions, climbing at the outset when the motive power is high and then slowly descending. Model fragility precludes flight under conditions where even very mild atmospheric disturbances could collapse the delicate structure of the ship.

Because reduction in weight results in easily discernible improvement in duration, evolution of these models has been largely empirical, concentrated on weight reduction with only scattered aerodynamic design criteria having been developed. The problem of weight reduction has, in fact, been attacked so enthusiastically for years that now a skilled technician can produce a flyable model having a wing spanning up to three feet but with an overall structural weight less than half that of a dime. The best of these large models will climb two hundred feet or more and fly upwards of forty-five minutes with duration limited not by model but by flying site. These models will be powered by twisted rubber strands of minute cross section, turning a propellor having a diameter roughly two-thirds of the wing span. Even at 100% efficiency, the total amount of energy available from such a motor—which normally weighs about as much as the model itself—would lift a brick only a strong hand's width, yet it will sustain the model in flight for well over a half hour.

The 1976 World Championships were held in England with fifteen countries participating. Of the 236 official flights, almost one-quarter were over a half hour. The six best official flights of the winning American team totalled only fifteen seconds more than those of the fourth-place Czechoslovakian team. On the average, the difference was only two and one-half seconds per flight for flights over thirty-five minutes, only one-tenth of one percent separating first and fourth place. Under these conditions one strives for perfection in every detail.

Indoor models fly at very low speeds, well under three feet per second, so the principles and formulas of strictly classical aerodynamics apply. However, these models differ in several essential respects from man-carrying ships, such as in the damping effect of the relatively large mass of air affected by a virtually weightless model, and in the use of a horizontal tail surface for lift as well as for stability by positioning the center of gravity well aft of the mid-point of the wing-cross section. Thus, the performance and design procedures which have been developed for man-carrying aircraft cannot be employed directly. Nonetheless, suitable analyses based on classical aerodynamics can provide valuable design information. In previous papers the author has presented computerized solutions for the optimum area of the horizontal tail surface and the fore-and-aft location of the center of gravity, and for the experimental verification of the computer solutions. Another critical problem created by regulations governing the World Championships is that of optimum wing area for the competition models.

American rules classify indoor model aircraft solely by wing area. There is no weight restriction; the model can be as light as the builder's abilities, both in construction and flying, permit. Under these conditions, one always employs a wing of the maximum-permitted area for a given class and strives for the lightest model one can successfully handle. However, the Fédération Aeronautique Internationale, which establishes regulations and homologates records for all international aircraft competition, man-carrying as well as model, places different restrictions upon the models flown in the international competitions. Ships flown in the world championships are span-restricted; the maximum allowable wing span is 70 centimeters. Furthermore, the model, sans motor, must weigh a minimum of one gram. The problem, then, is this: Does one use a slender or bulbously outlined wing? Now long, slender wings are very efficient aerodynamically; witness, for example, the sailplane. Unlike F.A.I. competition models, however, the sailplane is actually operating under a fixed wing-area requirement with the span limited only by the need for structural integrity. With a fixed span an increase in supporting surface area will reduce the flying speed but increase the "wetted" area. Reduced speed tends to reduce the power required; increased wetted area, to increase it. Is there, then, some optimum wing size?

From classical aerodynamics we can derive a result which will provide us the answer to the question. We can do this in relatively direct fashion by developing a formula for the power required. Power is force—in this case the drag of the wing—times velocity.

$$P = D \times V \qquad \text{Now } \frac{D}{L} = \frac{D}{W} = \frac{C_D}{C_L}$$

$$\text{So } D = \frac{C_D x W}{C_L}$$

$$\text{And } V = (W/(C_L x \frac{\rho}{2} x S))^{1/2}$$

By substitution we have

$$P = (\frac{C_D}{C_L} \times W) \times (W/(C_L \times \frac{\rho}{2} \times S))^{1/2}$$

$$\text{However} \qquad C_D = C_{DI} + C_{DO}$$

$$\text{and} \qquad S = \frac{B^2}{AR}$$

Hence, directly

$$P = \frac{(C_{DI} + C_{DO}) \times W^{3/2}}{(C_L)^{3/2} \times (\frac{\rho}{2})^{1/2} \times \frac{B^2}{AR}}$$

$$\text{Since} \qquad C_{DI} = \frac{C_L^2}{\pi x AR}$$

we have, by substitution and clearing,

$$P = \frac{(\frac{C_L^2}{\pi x AR} + C_{DO})}{(C_L)^{3/2}} \times (AR)^{1/2} \times \frac{W^{3/2}}{B} \times (\frac{2}{\rho})^{1/2}$$

This complex-appearing formula is the end point of our brief derivation. It contains all of the elements necessary to evaluate the theoretical optimum wing aspect ratio, and to provide this information in graphical form, easily understood. This was accomplished the easy way, by computer. While calculus might have been employed to establish a new formula for minimum power, such a new formula would have had, in itself, very restricted use and would have required additional analysis to determine, for example, how rapidly power requirements change with changes in aspect ratio. The computer program enabled swift calculation of power requirements, not only for changes in aspect ratio, but also for changes in other variables.

There are several terms in the derived formula which are either aspect ratio independent or actually fixed in value. These terms were assigned suitable values in the computer program and then the power requirement calculated over appropriate ranges of the terms of interest. The air density, for example, was fixed at its sea level value. The wing span is obviously fixed. The overall weight, W, of the model includes the motor weight, and so changes in the latter would alter the overall weight. As a very close rule of thumb, however, the motor weight is approximately equal to the structural weight of the model itself. For the calculations, therefore, W was set equal to twice the F.A.I. model weight.

Very little is known about the coefficient of profile drag for indoor models. Because of the extremely limited application to technical and commercial use at extremely low air speeds, the behavior of this coefficient is largely uninvestigated. Values calculated from some limited, published experimental work on indoor wings were in the vicinity of 0.10; values calculated from flight tests by the author were in the vicinity of 0.13 for the complete model. Normally this coefficient seems to remain virtually constant for a given wing or aircraft, regardless of flight attitude. In the computer analysis, therefore, three distinctly different values for C_{DO}—0.06, 0.10, and 0.13—were used simply to provide a check over the apparent range of this coefficient.

However, the coefficient of lift increases directly with increases in the angle between the wing and the relative wind up to the angle at which the air-flow pattern about the wing collapses and stalling occurs. Because of the ease of the computer calculations, a wide range of C_L values (from an unlikely, extreme low of 0.2 to the value of 1.0—about as high as is found in normal flight) was used.

A computer program to evaluate the power required for the various chosen values was developed. This provided immediate numerical answers which could be graphed to show precisely the effect of the several variables upon the power. These results have been plotted in the graphs of Figures 1, 2, and 3. The graphs show the variations in required power for changes in aspect ratio for incremental values of the coefficient of lift. Figure 1 is based on the profile drag coefficient of 0.06; Figure 2, on the coefficient of 0.10; and Figure 3, on the coefficient of 0.13.

We can immediately generalize from the graphs that in all cases high coefficients of lift result in low power consumption. The higher the coefficient of lift, the lower the power required. From the builder's point of view, this means simply that the wing should be set at the highest possible

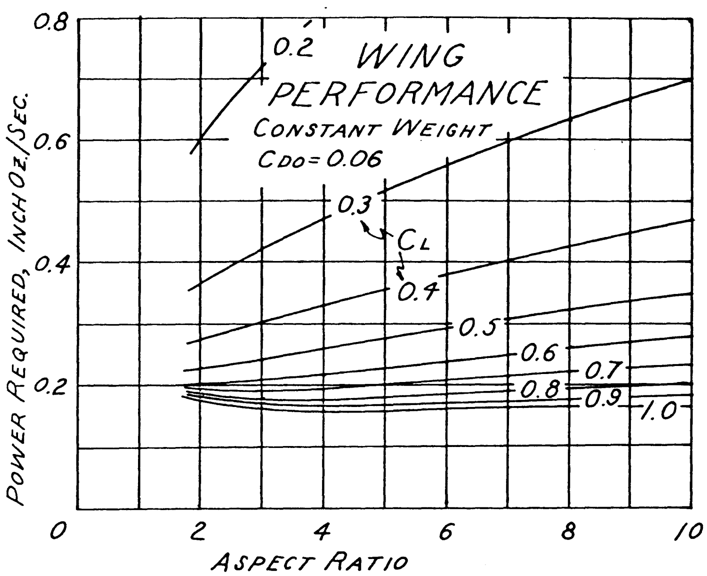

Figure 1. Wing performance constant weight C_{DO} = 0.06.

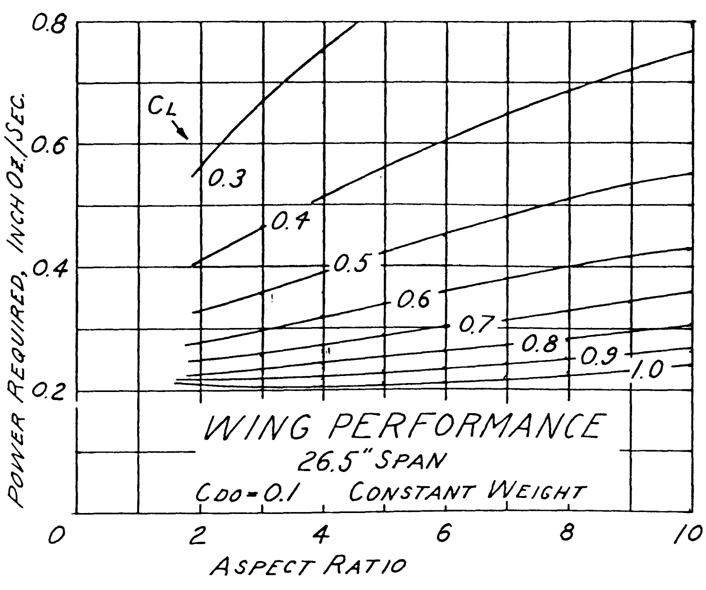

Figure 2. Wing performance 26.5 inch span C_{DO} = 0.1 constant weight.

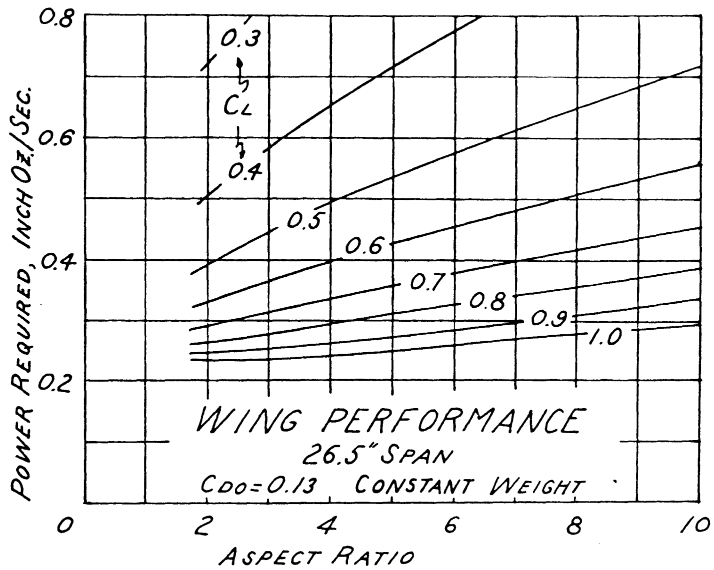

Figure 3. Wing performance 26.5 inch span C_{DO} = 0.13 constant weight.

angle since, at these low speeds, the coefficient of lift increases uniformly with the angle between lifting surface and relative wind up to stalling. This optimum wing setting can be most easily obtained experimentally through glide tests. The wing angle is increased by small increments after successive glides until the model no longer glides smoothly but stalls and has an erratic flight pattern. Then the wing angular setting is diminished slightly. The result is the setting with the highest usable coefficient of lift.

The fact that the highest lift coefficients result in greatest efficiency also makes it possible to generalize from the graphs about the optimum aspect ratio. For the high coefficients of lift aspect ratios in the vicinity of three to five result in lowest power consumption by the wing. This is most fortunate since structural integrity precludes very low aspect ratios. The delicate, flimsy wing structures are notoriously weak in torsion and must be maintained in accurate alignment by substantial amounts of microscopically thin, tungsten-wire bracing. Pudgy wing outlines are virtually impossible to brace satisfactorily. (It is true that the frameworks are also very weak in bending, but this bending in itself is not particularly bothersome. The major difficulty is caused by non-uniform fore and aft lift distribution over the wing, resulting in twisting of the wing. Anyone who has watched the wings of a large passenger carrying aircraft in flight has certainly seen the wings flexing up and down, but never twisting. Structural design must absolutely prevent this.)

The computer solution which has been developed has provided a thorough insight into the performance of the wing of the F.A.I. World Championship competition indoor model. When one considers the entire model, however, another important item affecting wing size appears. This is the power plant. Wings of high aspect ratios are of low area and must travel more swiftly to provide the same lift. Thus, even though the wing, per se, may not require more power for high aspect ratios, the remainder of the model does.

For non-lifting elements, the power required increases as the cube of the velocity. This becomes another persuasive argument favoring the lowest possible aspect ratio which can be satisfactorily used.

SYMBOLS USED

ρ = Air density

P = Power

V = Velocity

D = Drag

W = Weight

L = Lift

S = Wing Area

B = Wing Span

AR = Aspect Ratio, Ratio of span to average chord

C_L = Coefficient of lift

C_{DI} = Coefficient of induced drag, due to generation of lift

C_{DO} = Coefficient of profile drag, due to shape and skin friction

C_D = Total coefficient of drag, $C_{DI} + C_{DO}$

From Classical Aerodynamics

$$L = C_L \times \frac{\rho}{2} \times S \times V^2$$

$$D = C_D \times \frac{\rho}{2} \times S \times V^2$$

$$C_{DI} = \frac{C_L^2}{\pi \times AR}$$

$$AR = \frac{B^2}{S}$$