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Dynamic Modeling

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Use of Free-Flight, Dynamically-Similar Models In Estimating Full Scale Aircraft Behavior

The January 1987 issue of **Sport Aviation** carried a provocative article by Molt Taylor and Jerry Holcomb on the use of free-flight, dynamically-similar models in estimating certain important full-scale parameters by way of simulation.

It is the purpose of this article to expand on the principles so ably introduced by Taylor and Holcomb. It provides numerical scaling factors and remarks appropriate to designing and building the model, flying it and subsequently extending the test data derived therefrom to full scale.

As defined here, a dynamically similar model is one whose size, propulsive power, weight and weight distribution are all in scale with the full size aircraft being simulated. It is a model which, like its full size counterpart but unlike a recreational model, responds to **inertial** as well as aerodynamic forces. The objective is to have it **fly** in scale with its full size counterpart.

The model is assumed to be non-instrumented and radio controlled. Flight test data are taken by eyeball, a stopwatch and maybe a tape measure. The model is built to a high degree of perfection and flown by experts. Its behavior is judged by persons having a well-developed sense of what it is trying to tell them. In short, the model is an engineering tool, designed, crafted and used like the precision instrument it is.

It should be recognized early on that even very accurately scaled models do not represent true, miniature analogs of full scale when compared on the basis of performance, as will be seen as this article develops. However, much can be learned from them and, if one takes the test data derived therefrom with a pinch of salt, much of it can be extended with modest validity to full size.

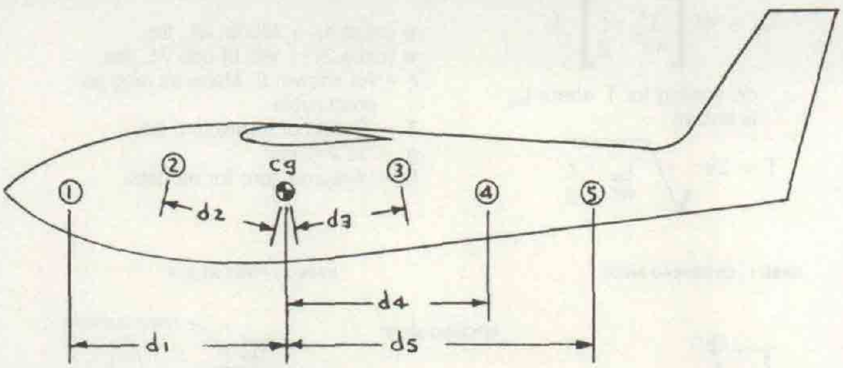
Models can be particularly useful where the design departs significantly from what we have come to consider "conventional" and/or the flight behavior of the model turns out to be gross, radical or erratic. In both cases, significant clues to full size behavior are offered. (Taylor and Holcomb state that they learned a great deal from the fact that their model crashed. **That** can be considered a solid data point!) However, such clues can be considered valid only if the model is **dynamically similar** to the aircraft being simulated. This is to say that the propulsive power, the weight and the **distribution** of that weight are all in scale with full size. A model built only to linear scale and little else may be considered simply a recreational model; having limited use as an aid to full-scale design.

The thoughtful experimenter is drawn to consider what the "big boys" (the major manufacturers) are doing, or not doing, with free flight, dynamically similar models. On the one hand it is probably safe to say that if such models were as useful to full scale design as we would suppose, the majors would be making extensive use of them. Such does not, however, appear to be the case.

On the other hand, unlike homebuilders such as Taylor and Holcomb, nobody ever accused the manufacturers of personal airplanes, at least, of being particularly innovative. But they **do** have computers which (of course) solve all the problems.

Fig. 1 - Example Calculation for Pitching Moment of Inertia of Full Size Aircraft

Note: This calculation is shown only to illustrate technique. A complete calculation would show scores of weight items in the table below instead of only 5.



Weight Item	Wt. (w), lbs.	Mass, slugs*	d, ft.	d^2	I = Mass x d^2	I_o
1	250	7.76	7.0	49	380.2	5.2
2	100	3.11	4.0	16	49.8	
3	500	15.53	4.0	16	248.5	3.0
4	80	2.48	10.0	100	248.0	
5	50	1.55		144	223.2	
					1149.7	8.2

$I_{cg} = 1149.7 + 8.2 =$ **1157.9 slug ft.^{2}**

*Mass = w/32.2

Measuring "Scale" In A Dynamic Model

By way of definition, in the kind of recreational model we see flying on weekends, "scale" refers, of course, to that fraction of full size to which the model is built. Size in this case refers to linear dimensions such as span, length, etc.

In dynamic models the term "scale" has an additional connotation, depending on the specific factor under consideration. The scale is not linear, but is expressed in terms of linear scale. For example, although a 1/5 scale model would have a wing span 1/5 as long as its full size counterpart, the scale **weight** would not be 1/5 the weight of the full size aircraft, but 1/125. This is because weight varies as the cube of linear dimensions.

You can prove this to yourself by considering the case of an ordinary tin can. If you double its size you double everything about it; its diameter, its height and the thickness of its "skin". When you double the diameter and height you find you have squared the area (multiplied it by four), so if you stop right here you have squared the weight. However, since you also double the thickness of the skin you in effect add four times **more** to the "area". In sum, you no longer have area but **volume**, which for the double-scale can is now 8 times the original volume, bringing 8 times the weight. 8 is 2 cubed, right?

Going in the other direction, if you cut the can to half size, the weight scales to 1/2 cubed, which is 0.125, or 1/8. The 1/2 scale can now weighs 1/8 that of the original one.

Weight varying as the volume represents the **dimensional conversion** of weight to linear scale. Dimensional conversion is symbolized by the Greek letter, Lamda (λ) and is the reciprocal of linear scale, e.g., in a 1/5 scale model λ would equal 5.

Dimensional conversions for other factors to be scaled in a dynamic model appear in Table 1 as "scaling factors". Although the other factors shown in the Table cannot be analyzed as simply as was done in the tin can analogy for weight, they **have** been analyzed and tested against full scale aircraft. The physics is valid.

The essentials of Table 1 are adapted from a work (Ref. 1) published 37 years ago by a brilliant young engineer named Ernest G. Stout, who in time came to guide the technical fortunes of the WW II Consolidated-Vultee Aircraft Corporation (now General Dynamics). Stout introduced aircraft dynamic modeling to the U. S. in 1938 and reports having experienced a high degree of success with it.

Model Size and Weight

For a number of reasons it is advisable to make the model as large as practicable. First, the larger the model the less difficult it is to hold the weight to scale values.

Consider, for example, a 1/8 scale model of the Cessna 172, which has a wing span of 35.8 feet and (in one version) a gross weight of 2645 pounds.

According to Table 1, weight varies inversely as the cube of λ. The weight of the model would, then, be 2645 pounds divided by 8 cubed, or 5.16 pounds. A model having a span of 4.48 feet (35.8/8) might be difficult to build on a budget of only 5.16 pounds.

The situation is made even more pressing by the requirement (explained later) that only about half of this weight be in the model itself, the remaining half being represented by the installation of movable ballast weights. These ballast weights are needed to permit adjustment of the model's Moment of Inertia, more of which later.

Going from 1/8 scale to, say, 1/5 scale makes a large difference in model weight and thus tends to make building it easier and more accurate. A 1/5 scale model of the Cessna 172 would weigh just over 21 pounds, half of this (10.16 lbs.) going into the model itself and half into ballast. Building a model with a span of 7.16 feet (35.8/5) for 10.6 pounds doesn't seem outside the limits of practicability. If it turns out to be so in a specific case, the model should be made even larger.

Another reason for making the model large relates to Reynolds Number (RN), which is based partially on wing chord. As explained later, so long as the Reynolds Number is above 120,000 or so the increase in airfoil drag coefficient with decreasing RN is not likely to be serious, although it should be considered when extrapolating model data to full scale. Similarly with the decrement in maximum lift coefficient.

The 1/5 scale model Cessna, having a wing chord of just under a foot and flying at a scaled maximum speed at sea level of 64 miles per hour (see Table 1), would be flying at a wing RN of about 614,000, which is comfortably above the suggested 120,000 minimum. However, the farther removed from 120,000 the more accurate the extension of model flight data to full scale.

A third reason for making the model large is that its dynamic behavior in flight (pitching, rolling, yawing) is more quantifiable than in a small model because small models tend to be more "twitchy" in flight which makes eyeball assessment of their behavior more difficult.

A fourth reason for using a large model is that measuring its Moment of Inertia tends to be more accurate.

Model Airfoil Selection and Reynolds Number

According to Schmitz (Ref. 2), depending upon the chord of the wing and the speed of flight, airfoils intended for use on full size aircraft suffer a performance loss when used on models; the drag coefficients are higher while the maximum lift coefficients are lower. Just how much the loss in performance is difficult to say because good test data on models tend to be in short supply. This makes extrapolation of performance to full size less than accurate. In order to ease the problem somewhat, Schmitz recommends the use of thinner, more highly cambered and sharper-nosed airfoils.

In reviewing some basic aerodynamics, one notes that the main reason for the difference in airfoil performance between model and full size is because the air flow interacts differently with the model than with the full size aircraft. This difference is reflected, of course, in the familiar term, Reynolds Number.

Reynolds Number is an expression which relates the viscous and inertia forces in the airstream boundary layer. Numerically, it equates (at sea level) to about 800 times the wing chord in inches, times the flying speed in miles per hour. A model having a wing chord of six inches and flying at 25 miles per hour is operating at a wing RN of about 120,000.

The reader will note the frequent recurrence of Reynolds Number in this article. This is because much of the "problem" with models can be assigned directly to their characteristically low RNs.

The message carried by Reynolds Number is that some very low drag coefficients and high maximum lift coefficients can be achieved where the flow is smooth (laminar) and the flow **remains attached to the surface**. As is generally known, however, laminar flows tend to be very unstable, breaking away from the surface with little provocation. And of great significance is the fact that any time the flow separates from the surface there results a quick and dramatic increase in drag. Whereas low RNs encourage laminar separation, high RNs encourage the flow to remain attached.

If the flow is turbulent **but still attached** the drag will be higher than in attached, laminar flow, but lower than in separated flow. Turbulent flow tends to delay separation.

Achieving attached laminar flow at RNs below about 100,000 is virtually impossible with any practical airfoil construction.

Some idea of the influence of RN on drag may be seen in data provided by Hoerner (Ref. 3). His data show a 12% thick streamlined section operating at an RN of 100,000 to have about 2.5 times the zero-lift drag coefficient of the same section operating at 1,000,000 RN. A 20% section operating at those same RNs shows a drag coefficient close to 4 times higher at the low end of the RN range than at the high end.

Trying to extrapolate model RN data to full size may be considered an exercise in futility. Drag, which is a prime ingredient in speed performance, doesn't scale at all at low RNs, and hardly at all at high RNs. Test data are needed for the specific airfoil or shape involved, measured at the Reynolds Number involved.

In order to minimize the effects of low RN, modelers often purposely force the flow to become turbulent, this by leading edge trip wires, thin, sharp-nosed airfoils or combinations of these and other strategems.

Models flying at RNs above 120,000 or so show considerably less influence on drag and maximum lift than do models operating below that value. For this reason it would seem prudent to use wing sections not over 12% thick on models used to simulate full scale aircraft, even though the latter might have thicker sections. Structural considerations will, of course, bear heavily on the decision.

Fig. 2 - Determining Moments of Inertia via Compound Pendulum

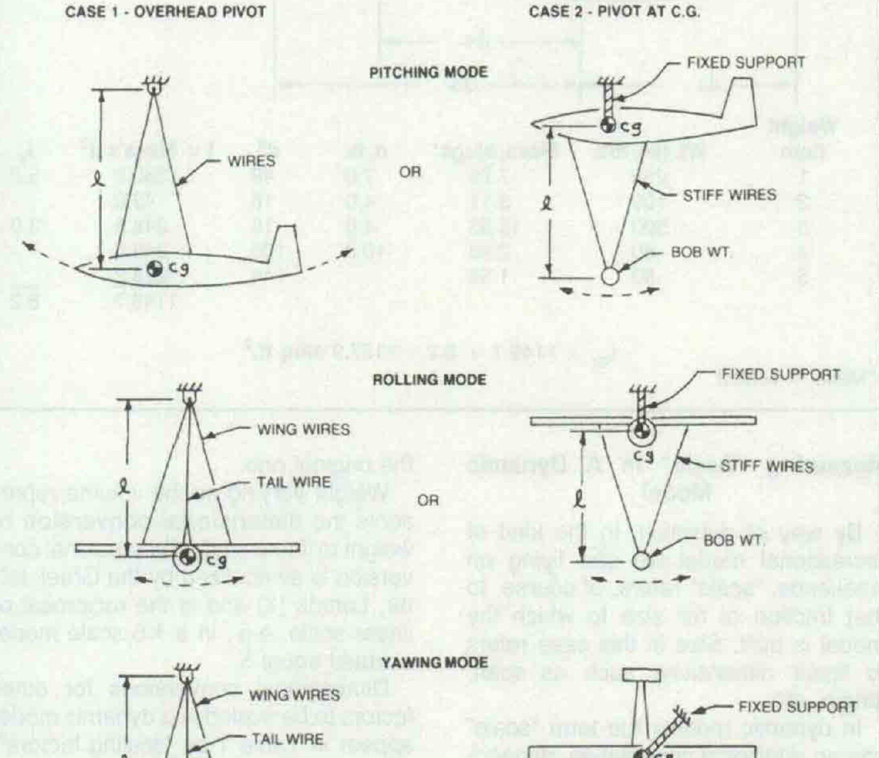
Basic Equations (Fits Both Cases Shown Below)

$$I_{cg} = w\ell\left[\frac{T^2}{4\pi^2} - \frac{\ell}{g}\right] - I_o$$

or, solving for T where I_{cg} is known:

$$T = 2\pi\sqrt{\frac{I_{cg}}{w\ell} + \frac{\ell}{g}}$$

w (case 1) = Model wt., lbs.
w (case 2) = Wt. of bob wt., lbs.
ℓ = As shown, ft. Make as long as practicable.
T = Period of oscillation, sec.
g = 32.2 ft/sec^2
I_o = Assume zero for models



Scaling the Model to Fit the Power Available

As Table 1 shows, power varies as λ raised to the power of 3.5. The 1/5 scale model used as an example in the Table requires 0.57 horsepower in order to scale with the 160 horsepower of the full scale aircraft.

The question arises, what does one do if a motor of the required power is not available? The answer is, one rescales the model to whatever powerplant is available. Determining the new scale is simple, but a calculator capable of handing fractional exponents is needed.

Using the above case as an example, consider the use of a motor rated at 0.40 horsepower; the closest to 0.57 horsepower assumed available. Simply divide the full scale power by 0.40 and raise the result to the power of 1/3.5, or 0.2857. λ turns out to be 5.54 instead of 5, and the model scale is no longer 1/5, but 1/5.54. For quick reference and for those users having calculators of limited capability, Table 2 does this job for selected ratios of full scale power to model power.

One can use motors as small or as large as desired so long as the model is scaled to fit. In using small motors, however, be advised (again) that if the model turns out so small that Reynolds Number considerations become significant, extending flight test data to full scale will suffer. The same can be said of model weight, where as stated earlier, the smaller the weight the more difficult to manage.

It is recognized that since model airplane (reciprocating) engines are normally rated in terms of displacement rather than horsepower, some difficulty can be extected in relating the two. How to solve this problem is left to the ingenuity of the reader; displacement seldom correlates with horsepower from one engine to the other.

Although knowing the rated horsepower of the engine is essential, even more useful would be a curve of full throttle horsepower versus rpm because with this curve one could **throttle** the engine to the required output, assuming the engine were big enough in the first place.

If the experimenter can handle the weight of batteries, some good electric motors are commercially available. Such motors are commonly rated by horsepower, or watts, from which horsepower can be easily derived.

Propeller Scaling

If all the propeller linear dimensions, rpm and blade angles are scaled in accordance with Table 1, the propeller helix angle (V/nD) of both the model and full scale propellers will be equal, and so will the power coefficient (C_p). Thus, the power absorbed by the propeller will be in scale with full size, as will the thrust.

However, the influence of the lower Reynolds Number of the model propeller still needs to be considered because of the increased blade drag coefficient; propellers do have small chords.

The Reynolds Number of the Cessna 172 propeller at the three-quarter radius (the usual propeller reference radius) at 2750 rpm and 144 miles per hour is on the order of 1,250,000. The RN of the 1/5 scale model propeller, taken at the same radius fraction, at a scaled 6160 rpm (see Table 1) and 64 miles per hour computes to about 165,000. Although this is close enough to the recommended 120,000 minimum to warrant some concern there's not much one can do to raise the RN without unduly complicating the whole scaling exercise. Thus, in this instance the modeler is left with the option of ignoring the problem or trying to guess the effect — or rescaling the whole model to fit the propeller. The author's vote would be to ignore it and hope for the best. However, if the model is so small that the propeller RN is really threatening 120,000, the logical option would be to make the model larger.

Since reciprocating model engines normally turn up much faster in terms of rpm than do full size aircraft engines, some difficulty will likely be encountered in getting the propeller to scale both in rpm and power absorbed. One solution to this problem would be to use a speed reduction drive; to make the propeller rpm lower than the rpm of the engine. This would at least make it more acceptable if not solve the problem completely. Such reduction drives are commercially available on the model market.

Using a reduction drive requires, of course, the design of a propeller capable of absorbing scaled power at less than scale rpm; a larger diameter propeller with, perhaps, non-scale blade angles. As is generally known, propeller design is a science in itself, one certainly beyond the scope of this article.

Dynamic Behavior and the Moment of Inertia

In considering the dynamic behavior of the model (pitching, rolling, yawing) as a precursor to full scale one needs observe that dynamic events occur at faster rates in the model than in full scale. However, although practical considerations might mitigate against instrumenting the model to determine the dimensions of these events, one can at least approximate the **time** during which they occur. Time can be scaled. As Table 1 shows, it varies as the square root of λ.

For example, a 1/9 scale model ($\lambda = 9$) can be expected to pitch close to 3 times (the square root of 9) as fast as the full-size aircraft for a given control input. Stated the other way around, the full-size airplane will pitch about a third as fast as a model in this scale. As a clue to subsequent full scale behavior in flight test, the test pilot is sure to tuck this away in his memory bank.

In order to make the model pitch, roll or yaw "in scale", it is vital that its moment of inertia about the appropriate axes through the CG be in scale, too. This requires, of course, that the moment of inertia of the full size aircraft be known, at least in close approximation, beforehand.

Moment of inertia is a measure of a rotating body's resistance to acceleration. To illustrate: Consider the rather absurd case of two flywheels of identical dimensions, one made of iron and the other of balsa.

Clearly, if the same torque is applied to both flywheels the lighter flywheel will come up to a given rpm more quickly than the heavier one. It will also come to a stop quicker when the same braking torque is applied.

Applying this analogy to airplanes, and continuing the absurdity of the example to make the point, consider two airplanes of identical dimensions and, like the flywheels, one of iron and the other of balsa. If these aircraft are rotated in pitch about their respective CG's from the same input from the tail (from elevator movement, say), the balsa aircraft will respond much faster than the iron one. This is because its pitching moment of inertia is lower.

Moment of inertia (or in this case, **mass** moment of inertia) is simply the product of the mass of each part of the aircraft and the square of its distance from the aircraft CG; the products all being subsequently added together. (Also refer to the example shown in Figure 1.)

Mass, of course, is simply the weight of the object (for convenience, in pounds) divided by "g" (32.2 feet per second squared). To keep the units consistent, distance is measured in feet. The product comes out in units of slug feet squared. Moment of inertia is symbolized by the letter "I" and, since the I is taken about the aircraft CG, it is symbolized by "I_{cg}". When considering pitch, roll and yaw separately there is no confusion in calling any one of them I_{cg}. When considering them in combination, the identification has to be changed in order to keep the bookkeeping straight.

It is not normally considered practical to **compute** the I_{cg} of a model, as is almost always the case in full scale airplanes because the model's individual parts are too small and light to yield anywhere near accurate values for the I_{cg}. And here is where models pay off; you build the model and determine its I_{cg} by **test**. The procedure is explained later.

As stated earlier, the example Cessna 172 has a gross weight of 2645 pounds and a 1/5 scale model **system** should weigh just over 21 pounds.

The model itself should actually weigh about half this value because you'll be adding identical **movable ballast weights** on each side of the CG to bring the total weight to 21 pounds without altering the CG position. Using two weights in this manner takes care of the "pitch" mode, such weights being sufficient if only the pitching behavior is of interest (frequently the case). If rolling and yawing behavior (such as maneuvering, spinning, etc.) are also of concern, two additional weights need be disposed equally about the CG, in a spanwise direction. This means that the individual ballast elements will be lighter than in the case of pitch only, the decrement in moment of inertia being made up by moving the weights farther apart.

The reason for doing all this is to permit your actually measuring the I_{cg}, and altering it later by moving the weights if needed to reflect the proper scale.

There are two approaches to testing, each employing the principle of the **compound pendulum** and each giving the same answer. (Also refer to the sketches shown in Figure 2.)

One method involves hanging the model, say, from a single point in the ceiling of your workshop, on two wires or cords, one well forward of the CG and the other well aft. You now have a compound pendulum. By giving the model a small, gentle push in the appropriate direction and timing its oscillations, you can determine the oscillatory period (T), which is simply the total number of seconds divided by the total number of cycles. (Recall that one cycle is one complete swing, to and fro.) Of course, the greater the number of cycles (should be at least 30) and the longer the suspension the greater the timing accuracy, which is vital. Small errors in timing beget large errors in I_{cg}. Knowing the period, the weight (w) of the model and the vertical distance (ℓ) of the CG from the pivot point in the ceiling, you can calculate the I_{cg} of the model, using the upper equation shown in Figure 2.

Another technique is to make the CG of the model itelf the pivot point and complete the compound pendulum by hanging a bob weight below it on a pair of fairly stiff wires or lightweight (wooden) struts. Needless to say, it is vital that friction at the pivot point be held to a minimum. The actual weight of the bob is unimportant; maybe 1/4 the model weight. You can now go through the same timing exercise as before and from the data thus obtained calculate the I_{cg}.

It is more than likely that the I_{cg} determined from your first test will differ from the I_{cg} required. In this case move the ballast weights in the model a little (equidistant from the CG so as to not alter its position) and test again. Repeat this procedure until the required I_{cg} is obtained. Lock the weights down for flight.

Again using the Cessna 172, which is reported to have an I_{cg} in pitch of 1346 slug feet squared, as an example and noting from Table 1 that moment of inertia varies as the fifth power of λ, the pitching moment of inertia we need develop in the 1/5 scale model is 1346 divided by 3125, or 0.431 slug feet squared.

To achieve this value let's hang the 21.16 pound model 6 feet from the ceiling and start it swinging. We continue, timing the oscillations and moving the ballast weights until we measure a period per oscillation of 2.74 seconds as calculated from the equation for T in Figure 2. We can test to see if this 2.74 seconds actually gives us 0.431 slug feet squared by introducing the 2.74 into the equation shown in Figure 2 for I_{cg}. This checks out close enough for all practical purposes to the required 0.431 slug feet squared.

A small caveat: The term "I_o" appears in the upper equation of Figure 2 and again in Figure 1. This term represents the I of the bob weights around **its own** CG and for precision it should be computed. It *also represents* the I of items in the model or the airplane about **their** CG. Since I_o takes into account the **shape** of the weight item as well as its mass, calculation usually calls for digging out the physics texts for an equation suited to the shape. This can be more trouble than it is worth because the value of I_o is sure to be miniscule compared with the I_{cg} of the model as determined without it; probably less than 1%. Hence, it can usually be neglected. In computing the I_{cg} of a full size airplane some accounting for the I_o's of large, heavy items such as the engine, fuel and crew is often taken, even though their impact on the result is sure to be small.

Scaling Factors For Estimating Full Scale Behavior

Contrary to the implication carried by the title of this article, most of what is written here deals with scaling the design of the model down from full scale. However, scaling the model's **behavior** up to full scale remains the objective.

Note that the term "behavior" is emphasized over performance. This is done for good reason; pitching, rolling and yawing behavior is more confidently extended to full scale than, say, speed, which is one element of performance.

As the reader might certainly gather by now, it does not appear feasible to extend model speed performance in its various parameters to full scale with accuracy. Again the main culprit is Reynolds Number. One can only hope that the data derived from the model will at least be indicative of full scale performance.

Schmitz gives one experimental data point of interest in this connection; a manned sailplane he examined showed a maximum lift to drag ratio of 20. However, the best L/D a 1/10 scale model of the sailplane could generate was 10. Schmitz neither showed a correlating scaling factor nor derived one, mainly, one might suppose, because of the lack of sufficient data on the effect of Reynolds Number in the low RN range involved.

If one is prepared to accept model data on these terms, one may proceed in extending the data to full scale in ac-

Table 1 - Scaling Factors

$\lambda = \dfrac{\text{Full Scale Linear Dimensions}}{\text{Model Linear Dimensions}}$

Model Design

Parameter	Model Should Be:	Example for 1/5 Scale Model (λ = 5): Full Scale	Model
Linear Dimensions	Full Scale/λ	Span: 35.8 Ft.	35.8/5 = 7.16 Ft.
Area	Full Scale/λ^2	Wing: 174 sq. ft.	174/25 = 6.96 sq. ft.
Volume, Mass, Force	Full Scale/λ^3	Gross Wt. = 2645 lbs.	2645/125 = 21.16 lbs.
Moment	Full Scale/λ^4		Full Scale/625
Moment of Inertia	Full Scale/λ^5	Pitch: 1346 slug ft.^{2}	1346/3125 = 0.431 slug ft.^{2}
Linear Velocity	Full Scale/$\sqrt{\lambda}$	Max: 144 mph	144/2.24 = 64 mph
Linear Acceleration	Same as Full		Same as Full Scale
Angular Acceleration	Full Scale x λ		Full Scale x 5
Angular Velocity	Full Scale x$\sqrt{\lambda}$		Full Scale x 2.24
Time	Full Scale/$\sqrt{\lambda}$		Full Scale/2.24
Work	Full Scale/λ^4		Full Scale/625
Power	Full Scale/$\lambda^{3.5}$	Rated: 160 hp	160/280 = 0.57 hp
Wing Loading	Full Scale/λ	15.2 psf	15.2/5 = 3.04 psf
Power Loading	Full Scale x$\sqrt{\lambda}$	16.5 lbs./hp	16.5 x 2.24 = 37 lbs./hp
Angles	Same as Full		Same as Full Scale
R.p.m.	Full Scale x$\sqrt{\lambda}$	Rated: 2750 rpm	2750 x 2.24 = 6160 *rpm*

Full Scale Performance from Model Test

Parameter	Full Scale Should Be:	Example for 1/5 Scale Model (λ = 5): Measured Model Perf.	Derived Full Scale Perf.
Time	Model x$\sqrt{\lambda}$		Model x 2.24
Maximum Speed	Model x$\sqrt{\lambda}$	64 mph	64 x 2.24 = 144 mph
Max. Climb Rate	Model x$\sqrt{\lambda}$	344 fpm	344 x 2.24 = 770 fpm
Takeoff Distance	Model xλ	160 ft.	160 x 5 = 800 ft.
Pitch, Roll & Yaw Rates	Model/$\sqrt{\lambda}$	50°/sec.	50/2.24 = 22°/sec.

cordance with Table 1. Consider the following examples:

Take-Off Distance

Take-off distance is a linear dimension, of course, and distance is directly proportional to λ. As the lower part of Table 1 shows, if a 1/5 scale model were to get off the ground in, say, 160 feet, the full scale aircraft would be expected to take-off in 160 times 5, or 800 feet.

This assumes, of course, the absence of Reynolds Number effects. Such is not precisely true, of course, because the low RN's encountered in the ground roll represent higher values of the drag coefficient, which impact the take-off acceleration. But in this case the drag may be considered secondary in importance to the mass of the aircraft because during most of the ground roll the greater part of the propulsive power is taken up in accelerating the mass up to take-off speed, while little is used to overcome aerodynamic drag. The reverse is true, of course, once the aircraft is in flight and climbing out.

As a point of interest, Stout reports that a 1/8 scale, dynamically similar model of the XP4Y-1 flying boat left the water at a speed and in a time (and thus in a distance) in scale with the full size aircraft. However, he appears to have "fudged" a bit on the model by incorporating full-span leading edge slots, which the full scale airplane didn't have.

Thus, although scaling model take-off performance up to full scale as illustrated is not entirely accurate, some good clues are offered.

Parenthetically, determining take-off distance by calculation alone is often unrewarding because of the large number of variables involved. Calculated distances seldom match those measured in test. It is likely that an accurately scaled model would, in spite of the reservations just expressed, do a better job because most of the variables are already "in the model" and its environs, and the model knows it — probably better than the computer does.

Stout's model, by the way, had a span of about 14 feet and weighed close to 80 pounds, representing a full scale span of 115 feet and a gross weight of 40,000 pounds, respectively. His model would be considered **large** in comparison with today's recreational models. But it apparently paid off for him.

Rate of Climb

Rate of climb is normally expressed in feet per minute; a velocity. Thus, full scale climb rate would equate to the model's climb rate times the square root of λ.

As shown in Table 1, if a 1/5 scale model were to show a climb rate of 344 feet per minute the climb rate of the full scale aircraft would compute to 344 times the square root of 5, or 770 feet per minute. Note from the Table that **angle** of climb would remain the same.

Table 2 - Factors Used in Scaling Model to Power Available*
(For Users Having Calculators of Limited Capability)

$$\lambda = \left[\frac{\text{Full Scale HP}}{\text{Model HP Avail.}}\right]^{.2857}$$

Full Scale HP / Model HP Avail.	λ
100	3.73
200	4.54
400	5.54
600	6.22
800	6.75
1000	7.20
1200	7.58
1400	7.92
1600	8.23
1800	8.51
2000	8.77

*Interpolation OK

Roll Rate

Roll rate is an angular velocity which can be expressed in degrees per second. Table 1 shows that angular velocity in full scale varies inversely with the square root of λ. If a 1/5 scale model showed a roll rate of, say, 50 degrees per second the full scale aircraft would be expected to roll at 50 divided by the square root of 5, or about 22 degrees per second.

Concluding Remarks

Although dynamically similar models offer clues to the behavior of full scale aircraft, "clues" have different scales of validity.

As has been suggested here, clues to aerodynamic performance (speeds) have a lower level of validity than those relating to inertial behavior (pitch, roll, yaw).

The lower credibility of aerodynamic clues is not seen as a serious obstacle to full scale design, however, because **calculating** estimated performance in full scale is no longer the complicated process it used to be. Books aimed specifically at the homebuilder are now available to ease the burden and improve the understanding. Two of which come immediately to mind are Crawford's "A Practical Guide to Airplane Performance and Design" and Strojnik's "Low Power Laminar Aircraft Design". Both are frequently advertised in **Sport Aviation**.

The higher credibility of clues to inertial behavior comes in good measure from the fact that Reynolds Number is seldom a factor of consequence. Thus, if the model's size, power, weight and moments of inertia are accurately scaled, what you see in the model is likely to be what you get in the full size aircraft — in proper scale, of course.

Unlike calculating aerodynamic performance, calculating dynamic behavior is a task of monumental dimensions, one best left to the professionals. In support of this advice, pick up any text on aircraft dynamics. If you can get past the first page you have real mathematical talent — and probably make your living at it. Unfortuantely, insofar as is known to this author, no books on aircraft dynamics aimed specifically at the homebuilder exist.

Not to worry. If you'll reflect on the proposition that errors in predicting aerodynamic performance are less likely to be threatening to life and limb than errors in predicting pitch, roll and yaw behavior, you'll stop searching for that non-existent book or that professional and build a **model** instead. In so doing you stand a fair chance of beating the professional at his own game.

Finally, a suggestion to those modelers who build solely for competition. For a **real** competition, make your models not only in linear scale, but in **dynamic** scale as well.

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3. Hoerner, S. F. — "Fluid Dynamic Drag". Published by the author. Available in most technical libraries. Also determine publisher's latest address fromthe American Institute of Aeronautics and Astronautics (AIAA) in New York or Los Angeles.

Table 3 - λ Raised to Powers Used in This Article
(For Users Having Calculators of Limited Capability)

λ	$\sqrt{\lambda}$	λ^2	λ^3	$\lambda^{3.5}$	λ^4	λ^5
4	2.00	16	64	128	256	1074
5	2.24	25	125	280	625	3125
6	2.45	36	216	529	1296	7776
7	2.65	49	343	907	2401	16807
8	2.83	64	512	1448	4096	32768
9	3.00	81	729	2187	6561	59049
10	3.16	100	1000	3162	10000	100000

About the Author

Stan Hall is a long time member of EAA and has been a frequent contributor to **Sport Aviation** over the years . . . but that is only the tiniest tip of the iceberg in his long and illustrious career. A professional aircraft designer since 1940, Stan has specialized in preliminary and conceptual design, with capabilities in structural and aerodynamic analysis, actual construction and piloting. Through employment with several aerospace giants over the years, he has been a member of the engineering teams that designed such notable aircraft as the North American AT-6, B-25 and P-51; the Northrop XB-35 and YB-49 Flying Wings, the XP-61 and XP-79 fighter bombers and the SX-4 research aircraft; and the Douglas SCG-8 and SCG-15 cargo gliders. With the coming of the space age, Stan was a member of the engineering team that designed the Lockheed Agena spacecraft . . . was project leader to the team that designed, built and flew the Lockheed QT-2 Quiet Reconnaissance Aircraft (which he accompanied to Viet Nam as a company representative) . . . was manager of airframe design and experimental flight testing of the Lockheed YO-3A (he holds the design patent for the quiet recon aircraft) . . . and was staff engineer on the Navy/Lockheed Surface Effect Ship program. Today, Stan is an aviation consultant, approved as an engineering subcontractor to Lockheed Missiles and Space Company, in which capacity, he has done 38 conceptual designs for RPVs, some of which were solar powered.

Amazingly, in the midst of such a busy professional career, Stan has somehow found the time to also fly as a corporate pilot and to personally design, build and fly 10 aircraft of his own. He is an internationally known sailplane designer (EAAers built scores of his Cherokees) and has been a member of the Soaring Society of America's Hall of Fame since 1974. Today, he is an active, 5000 hour commercially certificated pilot, with multi-engine, instrument and glider ratings.

EAA Membership Honor Roll

This month we continue our recognition of persons who have qualified for the EAA Membership Honor Roll. When you receive your new or renewal EAA Membership Card, the reverse side of the attached form will contain an application with which you can sign up a new member. Fill in your new member's name, enclose a check or money order and return to EAA Headquarters and you will be recognized on this page in SPORT AVIATION — and there is no limit to how many times you may be so honored here.

Introduce your friends to the wonderful world of EAA . . . and be recognized for your effort. The following list contains names received through the months of June 10.

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Milwaukee, WI

DENNIS G. WILLIAMSON
Madison, WI

THOMAS H. IRLBECK
Somerset, WI

ROBERT A. KRUPKA
New York, NY

JOHN S. TUMILOWICZ
Wadding River, NY

CARL F. BACHLE
Jackson, MI

PATSY CUTRONE
West Norwalk, CT

THOMAS D. MILTON
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PAUL HEDIGER
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Newburyport, MA

WILLIAM E. SCHADLER
Fredericksburg, PA

TUGDUAL BERTHO
Cachan, France

JOHN R. SINGER
Manitowoc, WI

Dynamic Modeling

by **Stan Hall, EAA 10883**
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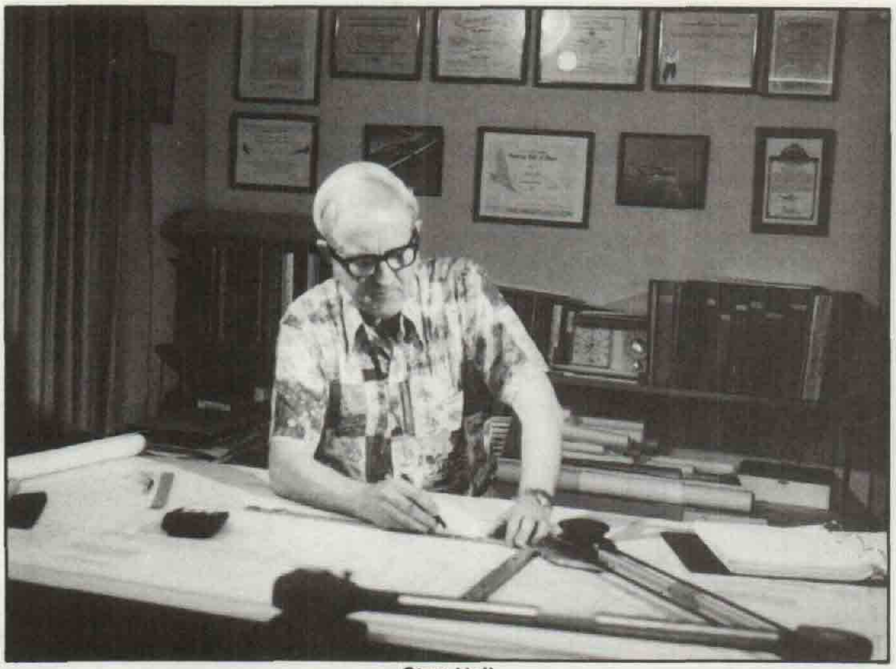
Conclusion

Testing of Structurally-Scaled, Sacrificial Models As An Aid To Full Scale Design



Stan Hall

The July issue of SPORT AVIATION carried an article by this author on the use of free-flight, dynamically-scaled models in estimating the behavior of full scale aircraft still on the drawing board. The article postulated that a properly scaled and carefully built model can aid in the design of its full size counterpart if the observer is skilled in interpreting its behavior and if he recognizes the several limitations inherent in the method.

The present article deals with the other half of the problem, the **structure**. Ordinarily, little engineering skill is required to configure the outside shape of a simple airplane. But in order to assure that the aircraft will be structurally sound the designer needs all the skill he can get. Marginal aerodynamics seldom kills; unsound structures guarantee it.

The question arises, where does an innovative yet relatively untutored, enthusiastic but nevertheless responsible first-time designer turn for help, particularly if he can't afford the services of a professional?

The answer is, he doesn't need help if he can load-test his structure. If it won't do the job he can redesign, rebuild and test again. Whatever the benefits of this approach, however, it is clear that this can become very expensive, not to mention frustrating and time consuming.

It is the premise of this article that load testing properly scaled and carefully built models can, with minimum limitations in the method, show directly what, if anything, needs be done in full scale to assure structural integrity, and do so at a minimum of cost, time and frustration.

A professional structures engineer can promise little more. Testing answers questions unanswerable by other means, in unambiguous terms.

The technique involves determining the loads and torques to be applied to the full scale aircraft (referred to as the "prototype" here), scaling them down to model-size, testing the model and, finally, scaling the test data back up again to full size. If the model takes the scaled-down loads it is likely that its full size counterpart will take the scaled-up ones. If it doesn't, well, back to the drawing board. Better to erase a line than erase a life.

The principles outlined in this article can be applied to essentially any structure of the aircraft. However, to illustrate how they are applied, it is the wing that is emphasized.

Model Testing and FAR 23

Determining the proper test loads and torques and their points of application on the model depends, of course, on knowing what they are in the prototype. Although determining these values is beyond the scope of this article, it is recommended that the designer derive them from reliable criteria such as found in Federal Aviation Regulations, Part 23, entitled, "Airworthiness Standards; Normal, Utility and Acrobatic Airplanes" (FAR 23).

In order that model test data be properly extended to prototype design, the neophyte designer needs to be clear as to the meaning of some terms used frequently in this article and in FAR 23. These easy-to-understand terms are, "limit load", "ultimate load", "yield stress" and "ultimate stress".

Limit loads represent the highest load the aircraft structure is likely to encounter during its lifetime. When the aircraft is designed to limit loads, the applied stresses resulting therefrom are set against the "yield stresses" allowed in the material. Yield stesses are those which cause the material to take a permanent "set".

Ultimate load is, in most cases, and by FAA regulation, 1.5 times the limit load. When the aircraft is designed to ultimate loads, the resulting applied stresses are set against the stresses at which the material will fail, hence, "ultimate" stresses.

Data on the allowable yield and ultimate stresses for materials may be found in the various texts and reports on the strength of materials.

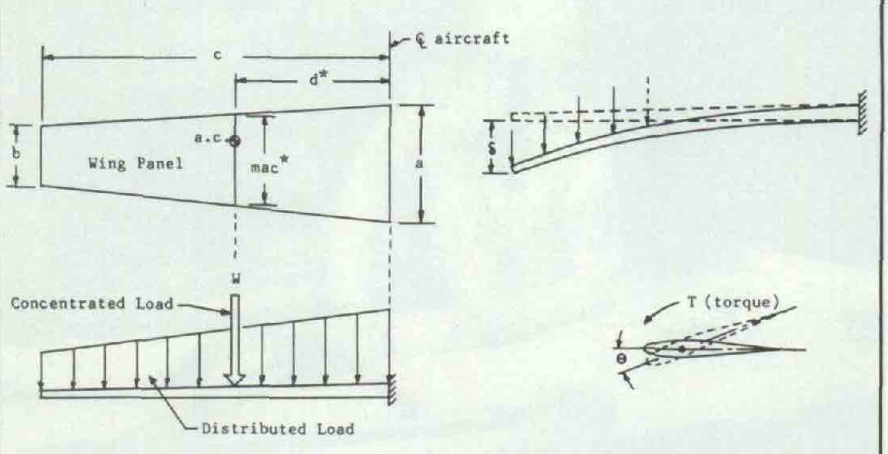
In Type Certification, the FAA requires rigid adherence to the criteria set forth in FAR 23. The designers of homebuilt aircraft are exempt from this requirement since homebuilts are, of course, normally licensed in the Experimental category.

Even so, the FAA criteria derive from decades of development and refinement performed by legions of very capable engineers, builders and pilots. The criteria make a great deal of sense and prudence suggests that they be used by all designers, including those interested only in the Experimental certificate.

In Type Certification the FAA requires substantiation of wing strength at all four (sometimes five or even six) corners of the Basic Flight Envelope (the V-n diagram) by test or by test supplemented by engineering analysis. By the way, the V-n diagram and how to con-

Table 1 - Scaling Factors for Structural Testing
(For equal stresses in model and prototype)

$$\lambda = \frac{\text{Prototype Linear Dimensions}}{\text{Model Linear Dimensions}}$$



Parameter	Model should be:	Example for Wing: Prototype	1/2 Scale Model (λ = 2)
a, ft.	Proto/λ	5.49	5.49/2 = 2.75
b, ft.	Proto/λ	2.75	2.75/2 = 1.38
c, ft.	Proto/λ	17.00	17.0/2 = 8.5
d, ft.	Proto/λ	7.55	7.55/2 = 3.78
mac, ft.	Proto/λ	4.29	4.29/2 = 2.15
W, lbs.	Proto/λ^2	4455	4455/4 = 1113
W, psf	Same as proto	63.6	63.6
δ, in.	Proto/λ	6.0	6.0/2 = 3.0
T, ft.lbs.	Proto/λ^3	1600	1600/8 = 200
θ, radians	Same as proto		
f**, cps	Proto x λ	6	6 x 2 = 12

$$* \text{ mac} = 0.67\left[a + b - \frac{a \times b}{a + b}\right], \quad d = \frac{c(a + 2b)}{3(a + b)}$$

** Resonant vibration frequency

struct it are shown in FAR 23.

The regulations require that the structure neither yield at limit load, to the extent of jeopardizing the operation of the aircraft, nor fail at *ultimate* load.

In testing, in order to establish that the structure will not fail at ultimate load, one has, of course, to exceed the limit load and, as this load is passed on the way to ultimate load, the structure is sure to take on a serious, permanent deformation, rendering it useless for more than one test. Demonstrating structural integrity at four or more points on the V-n diagram implies the availability of four or more identical test structures. Obviously, this can (and does) get expensive.

It is supposed that the designer of a homebuilt aircraft, although keen on assuring that his wing will be safe at all significant points on the V-n diagram, is not financially disposed to do so. Of course, since he is going only for the Experimental certificate, he doesn't have to.

Nonetheless, he needs **some** kind of test to assure himself that his aircraft will at least meet the critical points on the V-n diagram.

It is proposed here that those points are two in number, and that they can be satisfied with two tests on **one** test specimen, one model. One test (bending) is to be destruction. The model is sacrificed. The other test, which precedes the bending test is a test of torsional stiffness. This test does no harm to the wing.

It is not believed that these abbreviated tests over-simplify the problem, particularly when the likely alternative available to the unsopisticated designer is to do no testing at all, trusting to luck or Divine Intervention that his aircraft will somehow hang together.

The Scaling Factors

A structural test model needs, of course, to be scale geometriccally. It also needs to be scaled structurally.

Geometric scale is by definition expressed in terms of linear dimensions. Thus, a 1/5 scale model would have a wing span of 1/5 that of the prototype. Its **scale factor** would be five.

Structural scale is not always the same as geometrical scale. It is, however, expressed in terms of geometric scale and is symbolized by the Greek letter Lambda (λ). Depending on the structural parameter involved, numerical values for load, stress, deflection or other structural, entity can be transferred from model to prototype, or the reverse, by multiplying or dividing λ or λ raised to some specific power.

Structural scaling factors are shown in Table 1 and derive from the established premise that geometrically similar (scaled) structures of different sizes, if made of the same material, fail at the *same stress (e.g., pounds per square inch)*.

As described in the aforementioned SPORT AVIATION article, in free-flight, dynamically similar models, force (or weight) is proportional to λ cubed and moment (or torque) is proportional to λ raised to the fourth power. In structures, however, in order to yield the same stress in the model as in the prototype, force or weight needs to be proportional to λ squared and torque to λ cubed.

When this is done, bending deflection is seen to vary directly with geometric scale while torsional deflection angle remains unchanged. Test wing loading will be the same in the model as in the prototype and thus so will the aircraft speed at which the stresses will be the same. Similarly, the resonant frequency of vibration (as in flutter) will vary inversely with λ. A half-size tuning fork, for example, will vibrate at twice the frequency of its full size counterpart.

When a model structure fails, one can be reasonably assured that under scale conditions of load and point of load application, the full size structure will fail in close to the same place and in much the same manner as the model. This is very potent information, information which can be applied directly to full scale design.

Scaling and Building the Model

In order to permit extension of model test data to full scale, the structure of the model must, *as indicated earlier*, be accurately in scale with the prototype. This means, for example, that **all** the dimensions of a half-scale model structure be half those of the prototype structure, including material thicknesses, bolt sizes, rivet diameters and spacings, rib and stiffener intervals, etc. What is needed is true geometric scale in every structure that takes load which, except as indicated later, includes almost everything.

In composite structures in half scale this means half the number of cloth *layers, of the same filiment diameter*, or vice versa. Scaling does not apply to foam because we are talking **density** in foam, not size. Size effects will take care of themselves.

Fig. 1 - Example Calculation of Limiting FAR 23* Wing Flutter Speed as Derived From Measurement of Twist in 1/2 Scale Model Wing.

FAA Requirement: Wing torsional Flexibility Factor (F) must be less than $200/V_D^2$.
V_D = aircraft design diving speed, mph. (185 mph in this example).

FAA Requirement Restated: Limiting flutter speed ($V_{limiting} = \sqrt{200/F}$) must be higher than V_D.

Model Data

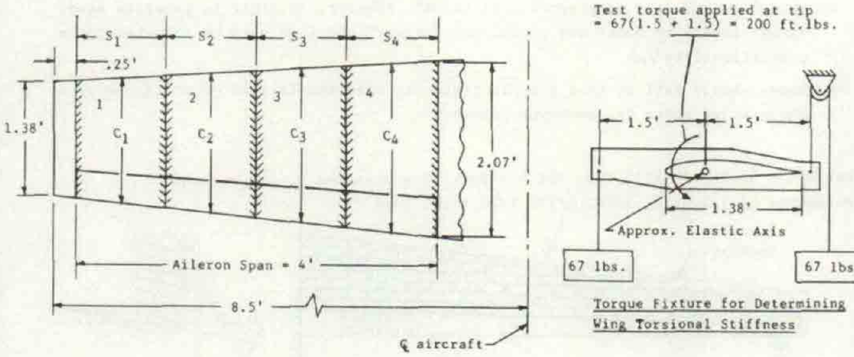


Table for Calculation of F

(rad. = deg./57.3)

① Element	② S, ft.	③ C, ft.	④ C^2	⑤ θ, rad.	⑥ ⑤ / 200	⑦ ② x ④ x ⑥
1	1.0	1.50	2.25	.0803	.00040	.0009
2	1.0	1.66	2.76	.0586	.00029	.0008
3	1.0	1.82	3.31	.0436	.00022	.0007
4	1.0	1.98	3.92	.0314	.00016	.0006
						F = .0030

$V_{limiting} = \sqrt{200/F} = \sqrt{200/.0030} = \underline{258 \text{ mph}}$**

Margin = 258 - 185 = 73 mph

* Refers to FAA Airframe and Equipment Engineering Report No. 45, upon which this calculation is based/

** Same for prototype as for model

It is recognized that problems may arise in procuring materials in scale thickness or bolts in scale diameter. In such cases the experimenter needs to scale the entire model to those thicknesses or diameters that are available. Clearly, some good planning is required.

In the case of steel bolts, one must not be tempted to compensate the lack of model-scale steel bolts with, say, aluminum rivets of larger than scale diameter, hoping that balancing diameter off against material strength will give the same stress. This may work in one loading mode and not another, and bolts are commonly called upon to provide strength in more than one mode; shear and **bearing**, for example. In order for the applied stresses to be the same in the model as in the prototype, the materials must be the same.

Let the record show that techniques do exist for accounting for the use of different materials in the model and in the prototype. The designers of bridges and dams do it all the time. But it requires a special skill. For us homebuilders, better to stick with the same materials.

Scaling the thickness of fabric covering is, of course, unnecessary because fabric is not considered a structural material in the sense that it enters into the solution of structural strength. Fabric can, therefore, be omitted entirely in a model designed for load testing. The same goes for nails in wooden structures.

In principle, the model should be as large as practicable in order to minimize the multiplying effect of errors in building and test loading when applying the results to full scale design. Also, the larger the model the more likely are material thicknesses in proper scale likely to be available, particularly in the case of metal aircraft.

It is, as implied earlier, unnecessary to reflect in the model everything provided in the prototype — only those structures which contribute to the basic strength. Ailerons, for example, can be considered in this category. Thus, a model wing need not have an aileron, control systems, fuel tanks, ancillary bracketry, etc. which influence basic strength to only a minor extent or not at all.

The Torsion Test

The highest torsion in a wing without sweep normally occurs at the maximum design diving speed. As defined in FAR 23 this is speed V_D. Although the bending test discussed later calls for testing the specimen to destruction, it isn't necessary to twist the wing off in test to establish its suitability for flight at this speed because there is another FAA requirement which, from a practical viewpoint, can be considered to effectively cover the torsional strength requirement. This is the **torsional stiffness** requirement.

A wing which is strong enough in torsion is not necessarily **stiff** enough to prevent flutter. However, a wing that is stiff enough to accommodate the flutter requirement will in most cases involving conventional structures be **strong** enough to handle the torsion. So a test of stiffness is in order.

Fiberglass structures are particularly vulnerable to questions regarding the relative importance of torsional stiffness- and torsional as well as bending strength. In some fiberglass sailplane wings, for example, it is torsional stiffness that designs the wing, not strength. As a direct consequence of high torsional stiffness in such wings, the **bending** strength is also high, bringing bending limit load factors from an original 5 or 6 to 10, 12 or even higher.

The FAA, in Airframe and Equipment Engineering Report No. 45, "Simplified Flutter Prevention Criteria for Personal Type Airplanes", specifies torsional stiffness in terms of a Flexibility Factor, a factor which must not exceed $200/V_D^2$. This applies only to aircraft flying at equivalent airspeeds below 260 knots, at or below 14,000 feet altitude, and having no heavy, concentrated weights (like engines and fuel) in the outer wing panels. It is further restricted to aircraft having fixed-fin and fixed-stabilizer surfaces, and no T-tails or tail booms.

In torsion testing with the wing root restrained, a torque of arbitrary value is applied at the tip and the resulting torsional deflection angle measured at four points along the span of the aileron. From these and other data the Flexibility Factor is derived. If this factor turns out lower than $200/V_D^2$, fine. The implication is, if the aileron is properly mass balanced, the critical wing flutter speed will be above V_D. If not, the wing needs to be stiffened in torsion.

Typical techniques for improving the torsional stiffness involve using thicker skins, adding more glass to the outer surfaces or designing in thicker wing sections to begin with. Model testing will give a strong clue as to the proper course of action.

It should be kept in mind that, although in the stiffness test the angular deflection is measured only along the aileron span, the whole wing twists. Thus, if torsional stiffening is required, it should be done over the whole wing; around the chord perimeter if stiffening is to be achieved by adding to the skin thickness.

Figure 1 shows a numerical example of how to compute the torsional flexibility factor from a test of stiffness. The technique comes directly from the FAA report (No. 45) mentioned earlier.

The Bending Test

The highest bending stresses occur at the corners of the V-n diagram. Figure 2 shows two methods of satisfying by test, point A on the diagram, considered here to represent the critical point for bending. Parenthetically, since points A and D on the diagram carry the same load factor, if point A is satisfied, so too, automatically, is point D.

One bending test method tests the whole wing and its attachments whereas the other verifies only part of the wing, a critical part but nonetheless only a part.

In the first instance the wing is turned upside down in a fixture which exactly simulates the wing attachments to the aircraft and sandbags are spread over the wing in some true-to-life distribution. The bags are placed, starting at the root and working outboard, a few bags at a time. The figure shows a starting (and arbitrary) increment of 1/2 the total load, followed by increments of 1/4, 1/10, 1/10 and 1/20. It is desirable to measure and plot the deflection of the wing at intervals along the span at each load increment to detect any potentially dangerous departures from a smooth bend in the wing. Sharp discontinuities mean trouble.

Note from the illustration that in this method the wing chord reference line is tilted downward 10 degrees. This causes a portion of the test load to induce a chordwise component in the forward direction, thus simulating what actually occurs in flight. The 10 degrees used in the figure is, by the way, arbitrary, but probably conservative.

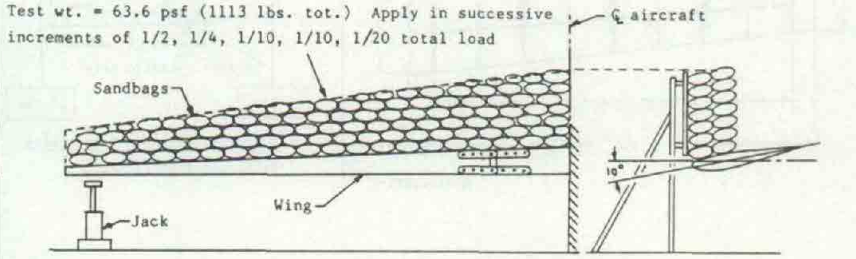
The amount of load required on the model derive, of course, from λ, the scaling factor for bending. As shown in Table 1, the load should be whatever the prototype calls for, divided by λ squared.

Fig. 2 - Example Calculation and Suggested Techniques for Test Loading 1/2 Scale Model Wing in Bending to Destruction

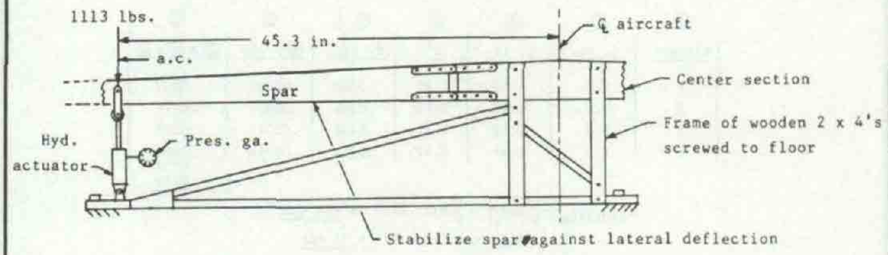
		Prototype (λ = 1)	Model (λ = 2)
①	Aircraft gross weight	1400 lbs.	1400/4 = 175 lbs.*
②	Limit wing load factor (n_1)	4.4	4.4
③	Limit load carried by wing = ① x ② / λ^2	6160 lbs.	6160/4 = 1540 lbs.
④	Limit load carried by 1 wing panel = ½ ③	3080 lbs.	1540/2 = 770 lbs.
⑤	Wing panel weight	110 lbs.	110/4 = 28 lbs.
⑥	Test load on panel = 1.5 x (④ - ⑤)	4455 lbs.	1.5 x 742 = 1113 lbs.**
⑦	Wing panel area	70 sq.ft.	17.5 sq.ft.
⑧	Distributed test load = ⑥ / ⑦	63.6 psf	63.6 psf
⑨	Dist. from aircraft centerline to wing a.c.	90.6 in.	90.6/λ = 45.3 in.
⑩	Test load at a.c. (if ⑧ not used) = ⑥		

* Actual weight will be proportional to $1/\lambda^3$. However, in order to generate equal stress levels in model and prototype, "weight" and load need be adjusted to be proportional to $1/\lambda^2$.

** Model should fail at this load or higher to forecast failure of prototype at or above value shown in prototype column.



Method of Checking Entire Wing for Normal and Chordwise Strength



Method of Checking Normal Bending Strength of Spar Inboard of a.c., and Fittings at Root

As to the distribution of the load along the span and along the chord, this problem has occupied aeronautical researchers since time immemorial and, as a result, some techniques leading to precise distributions have been developed. Unfortunately, they are both sophisticated and complex, far beyond, in the author's view, the needs (and perhaps the capabilities) of some designers of homebuilt aircraft.

Whereas computing the distribution by so-called "rational" (read complicated) methods accurately shows that each square foot of wing area carries a different load, one is not likely to go seriously wrong by assuming that each square foot carries the **same** load. This vastly simplifies the loading problem. The foregoing assumption does not, however, apply to chordwise distribution, which tends to peak at or near the leading edge. Calculating **this** distribution is also a highly complex undertaking. However, so long as the test load is based on the total area of the chordwise element involved, stacking the sandbags forward, say, of the first third or so of the chord should have the desired effect.

Those few homebuilders who engage in structural testing commonly test their full scale wings only to limit load, not ultimate. They do this for the simple reason that they don't wish to break them, and in the frequently erroneous belief that if the wing doesn't yield at limit load, it won't fail at 1.5 times that load.

Although many aircraft materials fail at or near 1.5 times yield stress, some do not. The designer should not, therefore, rest easy with this so-called 1.5 "safety factor". It may not be there. Also, in some structures loads have a way of **redistributing**, forcing stiffer structures to take load away from the more flexible ones, sometimes causing overloading and failure of the stiffer structures. Here, the numerical value of the "safety factor" becomes very elusive.

Composites represent a special case because they don't seem to **have** a yield point; like window glass they tend to break without warning. In recognizing this circumstance the FAA requires (in Type Certification) that composite structures be designed (and tested) to loads twice the limit loads, or more, instead of only 1.5.

The only reliable way by which the allowable limit load in composites can be determined is to test to destruction and divide the failure load by 1.5. If the limit load calculates to less than required, redesign is in order.

One of the beauties of testing the model to destruction is that the load factor, redistribution and selective overloading hassle is eliminated. The failure mode can be seen directly, and there is no doubt as to the value of the allowable limit load or how to placard the aircraft so that this load is never exceeded.

The second loading method shown in Figure 2 checks only the spar root fittings and a portion of the spar. Here, the entire load is concentrated on the spar at a point corresponding to the aerodynamic center (a.c.) of the wing. This is done conveniently and safely through the use of a hydraulic actuator. Disintegrating wings and falling sandbags constitute a real hazard.

The concentrated load technique has the advantage of simplicity, but the disadvantge of restricting its usefulness to that part of the wing inboard of the actuator. Spars have been known to fail **outboard** of that point.

Concluding Remarks

Long association with homebuilding convinces the author that the designers of homebuilt aircraft, perhaps because they don't know how, seldom test or even perform rudimentary stress analyses. The remarkable difference between how these otherwise responsible designers view the importance of structural strength versus how the professionals see it may be noted in the fact that the latter not only go to great lengths to stress-analyze, but they do extensive **testing** as well. They know probably better than anyone that the science of stress analysis has not yet become so advanced as to substitute entirely for testing.

By failing to expand upon his knowledge of structures the unsophisticated designer of homebuilt aircraft, particularly if he also markets kits, makes his customers unwitting test pilots. The customer deserves better.

On the other hand, the customer himself needs to accept responsibility for his own safety. It would seem right and proper that the potential purchaser of a kit (or **any** homebuilt) make pointed inquiries regarding how and to what extent the kit provider can substantiate the structural integrity of his product. If the answer is evasive or otherwise unsatisfactory, it would also seem right and proper that he go elsewhere.

The purchasers of Type Certificated aircraft normally need have little concern of structural safety if the aircraft is properly maintained and flown because from the time the first 3-view drawing is made until the aircraft's last day of service, tight regulations by the FAA stand vigilant watch.

Unfortunately, the price we homebuilders pay for "freedom" from what we often perceive as unduly restrictive government regulation is that we have no way of knowing "for sure" that our aircraft are as structurally sound as those enjoying the benefits of extensive engineering. It would seem prudent, then, that organizations such as our EAA, SSA, NASAD and other responsible groups who stand at the forefront of sport aviation take a harder look for solutions.

Finally, it is recognized that there are inherent dangers in treating the very complex science of structural engineering in so truncated a manner as presented here. However, no designer yearning to design his own airplane is likely to be persuaded to go out and get an engineering degree before he starts. Truncated or not, he needs practical guidance, guidance he can understand and is willing to apply. Perhaps encouraging the structural testing of **models** would be a good place to start.

EAA Membership Honor Roll

This month we continue our recognition of persons who have qualified for the EAA Membership Honor Roll. When you receive your new or renewal EAA Membership Card, the reverse side of the attached form will contain an application with which you can sign up a new member. Fill in your new member's name, enclose a check or money order and return to EAA Headquarters and you will be recognized on this page in SPORT AVIATION — and there is no limit to how many times you may be so honored here.

Introduce your friends to the wonderful world of EAA . . . and be recognized for your effort. The following list contains names received through the months of June 10.

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Elephant Butte, NM

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Morgan Hill, CA

MARK FIDLER
Miami, FL

WM. BARTLETT SMITH
St. Joseph, MO

RALPH W. WOODS
Paoli, PA

ALAN H. CLAIR
East Amherst, NY

CURTIS N. HEINTZ
Springfield, MO

ROBERT LEE WINKLER
League City, TX

DON SIMONS
Auckland, New Zealand

DAVID A. STUART
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D. E. DUCKWALL
Bunker Hill, IN

JOHN SCHLADWEILER
Pierre, SD

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STEVE GEARY
Milledgeville, IL

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TERRY CLEKIS
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JOAN TERRELL
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AMERICO MAZZIOTTI
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