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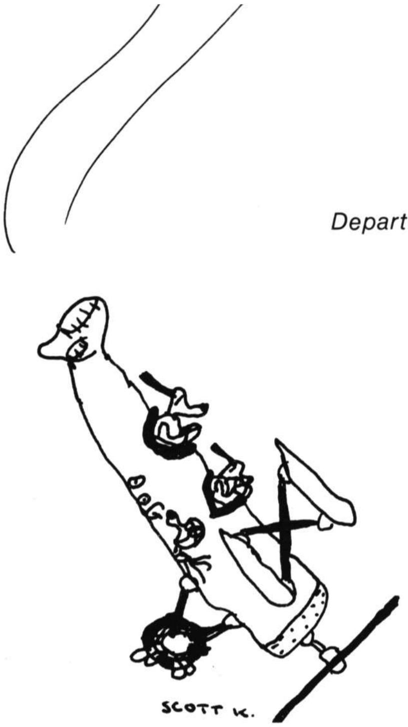
SPINS,



WILL YOUR AIRCRAFT RECOVER ?

The spinning motion of an aircraft is extremely complicated to analyze. Most theoretical studies have involved a large computer and the NASA spin tunnel at Langley Field. The reason for this is that the normal theory for most aircraft studies assumes that various aerodynamic parameters vary linearly with small changes of the aircraft's equilibrium position. This is clearly not true for the spinning motion of the aircraft. However, there are many aspects of the spin that are well understood on the basis of research and experience in the past forty years. The NACA and now NASA have been actively engaged in spin reseach for at least this period of time. Most of the results that are applicable to light aircraft are the result of experiments which have been conducted on models in the spin tunnel, radio controlled models, and full sized aircraft. After many years of data acquisition and study, several design parameters have been identified as relevant to spin recovery. The primary ones are mass (weight) distribution of the aircraft, the relative density or the weight of the aircraft compared to the weight of the displaced air, and the tail design.

The mass distribution is called the Inertia Yawing Moment Parameter. It is computed by calculating the moments of inertia of the aircraft about the rolling axis and about the pitching axis subtracting these and dividing by the mass of the aircraft times the wing span squared. For most light aircraft this number is fairly close to zero. That is, the weight is distributed almost equally along the wings and body. Weight along the wings increases the moment of inertia about the roll axis (I_x) while weight along the body increases the moment of inertia about the pitching axis (I_y). Figure 1 is a diagram of the moment balance in a developed spin. The aerodynamic moments tend to pitch the aircraft nose down while the inertia moments tend to pitch it nose up. If the aerodynamic moment is altered by power application or aileron deflection, it may also pitch the nose up resulting in a flat spin. This may or may not be recoverable depending upon the aerodynamic characteristics of the aircraft.

The relative density, u, can be computed at sea level from Figure 2. As an example the Super Acro Sport with a wing loading (W/S) of 11.24 lb./ft.^{2} and a wing span (b) of 19½ feet gives a relative density (u) of a little less than 8 as shown by the dotted lines on Figure 2.

The last, and perhaps most important, parameter is the tail design. The Tail Damping Power Ratio (TDPR) has become the design parameter to insure satisfactory recovery from a developed spin. This parameter was first suggested in 1939 by Seidman and Donlan, NACA TN 711. They based this parameter on the results of flight tests performed in a Fleet biplane in 1932 and described in NACA TN 421.

From 1939 until at least 1971 the NACA and now the NASA have used the experimental formula of Siedman and Donlan as a criterion for satisfactory spin recovery in aircraft. Hundreds of experiments have been conducted in free flight, the NASA spin tunnel, radio control models, and other wind tunnel tests. As a result of these data the spin criterion has been refined by Neihouse and is reported in NACA TN 1045 of 1946. These results have been summarized in reports by the NASA in NASA TR R-57 of 1960 and the most readable of all by J. S. Bowman, Jr., NASA TN D6575 of 1971, which can be purchased for three dollars from the National Technical Information Service, Springfield, Virginia 22151.

The remainder of this article will present the method that has been used to predict good or poor recovery from spins. Figure 3, which is used in most of the reports concerning tail design, is used to define the various letters

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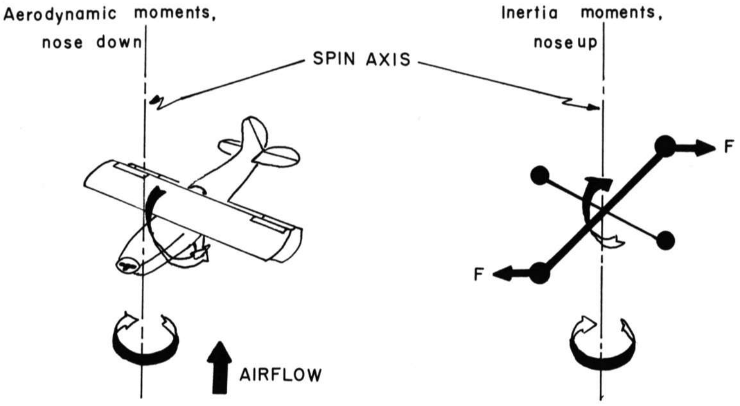


FIGURE 1. Balance of Moments in a Developed Spin

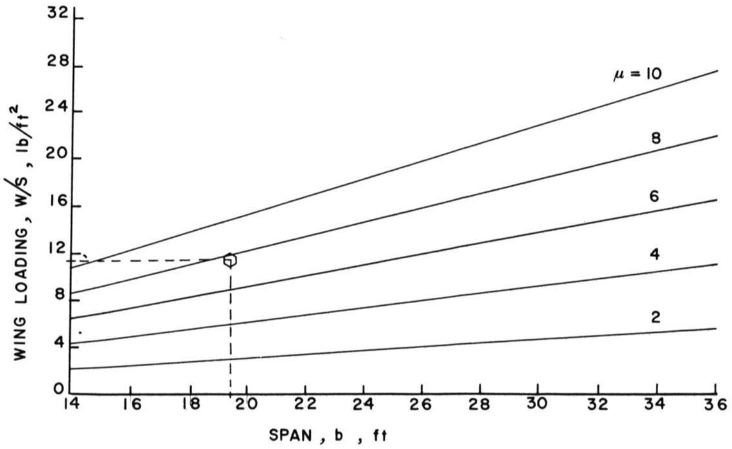
in the formula for Tail Damping Power Factor (TDPF). There are two essential parts of this expression; the Tail Damping Ratio (TDR), which is the fuselage contribution to the damping of the rotation and the Unshielded Rudder Volume Coefficient (URVC), which is the contribution from the rudder area that is not in the wake of the horizontal tail during a spin.

The Tail Damping Ratio is calculated by determining the side fuselage area **under** the horizontal tail, called S_F. This area is multiplied by the square of the distance from the center of gravity of the aircraft (usually at the rear limit) to the centroid (center of gravity) of the area S_F. This is called L. This product S_FL^2 is divided by the wing area S, multiplied by the wing semi span squared $(b/2)^2$. This combination

$$TDR = \frac{S_FL^2}{S(b/2)^2}$$

is called the Tail Damping Ratio. The results of many tests have shown that the spin angle of attack (flatter or steeper) depends strongly upon this number. If the TDR is less than 0.019 the spin angle of attack is taken to be 45^0, if the TDR is greater than 0.019 the angle of attack is taken to be 30^0. This spin angle of attack is used to determine the location of the horizontal tail wake which diminishes the rudder effectiveness. Once the angle of attack is established by the TDR, one draws a line at that angle plus fifteen degrees from the leading edge of the horizontal tail and at that angle minus fifteen degrees from the trailing edge. The spin angle of attack is shown by the dark arrow for the two cases of TDR larger than and smaller than 0.019.

FIGURE 2. Chart for Relative Density Parameter



The Unshielded Rudder Volume Coefficient (URVC) may now be calculated. The unshielded rudder is that portion of the **movable** vertical fin which is not inside the wake of the horizontal tail during a spin. The actual wake on a particular aircraft may not be just as shown, but all the data indicate that this guess of the wake location predicts the spin recovery properties of the aircraft. There are two terms to be considered, the contribution by the unshielded rudder above the horizontal tail and secondly the contribution by the rudder below the horizontal tail. The rudder area above the wake line is called SR1 and the distance between the center of gravity of the aircraft and the centroid of this area is L_1. Similarly the rudder area below the horizontal tail and outside its wake is called S_{R2} and the corresponding distance to the center of gravity is L_2. These areas and distances are combined into the URVC in the formula.

$$URVC = \frac{S_{R1}L_1 + S_{R2}L_2}{S(b/2)}$$

In this formula the distances are not squared.

The product of the Tail Damping Ratio and the Unshielded Rudder Volume Coefficient is the Tail Damping Power Ratio (TDPR). Figure 4 shows the results of the many years of data correlation. If the numerical value for the TDPR is less than that indicated for satisfactory spin recovery, then it would be unwise to let a spin develop in that aircraft. If the numerical value of TDPF is

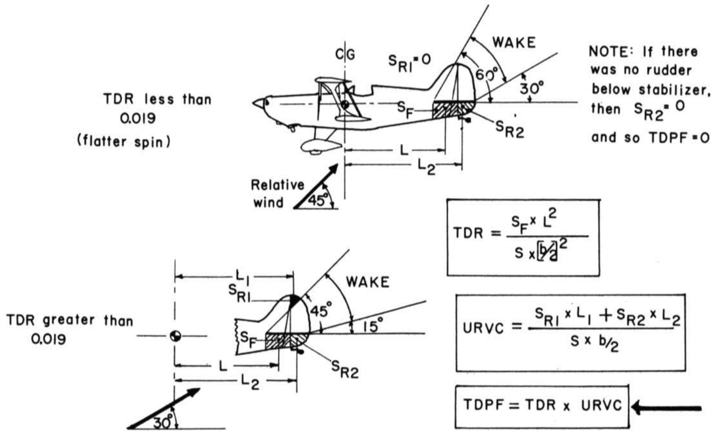


FIGURE 3. Diagram for Tail Damping Ratio and Unshielded Rudder Volume Coefficient.

greater than 0.0007 then the aircraft will recover from any spin. Since for most light aircraft ($\frac{I_x - I_y}{mb^2}$) is close to zero, a TDPF of 0.0004 will be satisfactory. As an example, say an aircraft has a TDPF of 0.0001 and a u equals 10. The chart indicates that this aircraft will not recover from a spin with only rudder control, since the number 0.0001 is below the solid line for u equals 10. Note that since this value is above the dotted line for recovery by use of rudder and elevator, the aircraft would recover if both controls were used. If your aircraft has a TDPF of 0.00005 or less, it would be unwise to spin it intentionally. These numbers do not say that a stall with some rotation is not recoverable but that it would be unwise to let a spin progress after it started.

There are two different lines for satisfactory recovery, one with rudder alone and one with rudder and elevator. That is some aircraft will recover from a developed spin by just rudder reversal, the elevator may be left full back (Citabria, Decathlon, Pitts S-2A all fall into this category). Others must have elevator control applied to effect a spin recovery; an example is the Aerobat.

All the figures and calculations are for erect (positive g) spins. For inverted spins, one just turns the drawing upside down and determines the areas and horizontal tail wake again. For inverted spins the TDR is normally larger than 0.019 and thus only one wake is shown in Figure 5.

Flat spins normally will not occur if the Tail Damping Ratio is larger than 0.019 unless some other destabilizing element is present such as engine power and aileron deflection. In many good aerobatic aircraft, flat spins are no more dangerous than any other spin and in some may be safer than landing. If the Tail Damping Ratio is less than 0.019, it is this author's opinion that intentional flat spins may not be recoverable, and intentional flat spins should not be attempted in any aircraft that will not recover by rudder alone from a developed spin. For most aircraft the Tail Damping Ratio is much larger for inverted spins due to the presence of the fixed vertical fin. It is for this reason that one finds the inverted flat spin easier to recover from than the erect flat spin.

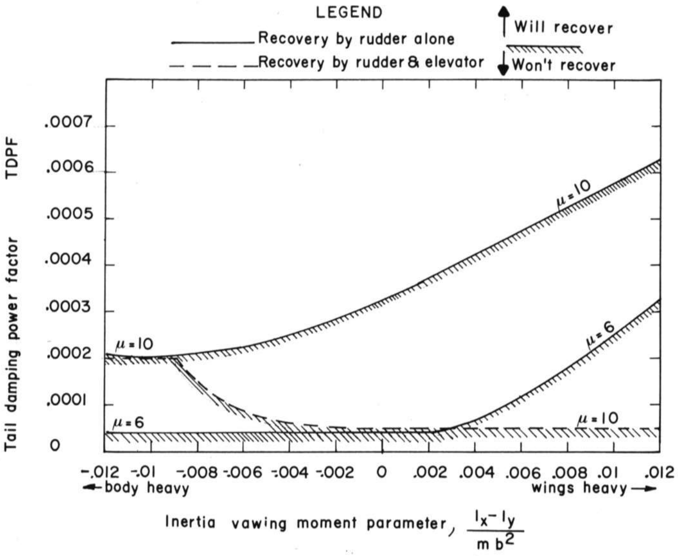
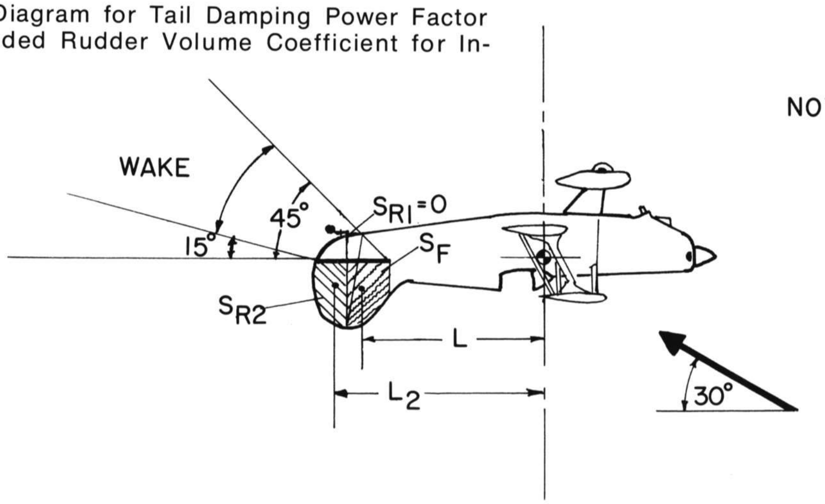


FIGURE 4. Spin Recovery Design Requirements

It is strongly recommended that you determine the spin recovery properties of your aircraft **before** attempting any aerobatics in it. Unintentional spins may be obtained under a variety of classes of mistakes while performing aerobatics, and it is for this reason that one should know the spin recovery prediction for their aircraft. As a matter of safety, one should not attempt flat spins of any kind without proper instruction from an aerobatic school that has competent instructors and quality aircraft. Like many other aerobatic maneuvers one may become disoriented and not follow the correct procedure to complete the recovery.

FIGURE 5. Diagram for Tail Damping Power Factor and Unshielded Rudder Volume Coefficient for Inverted Spins.



NOTE: Problem if "T" tail is used, then TDR = 0 and inverted flat spin will <u>not</u> recover.