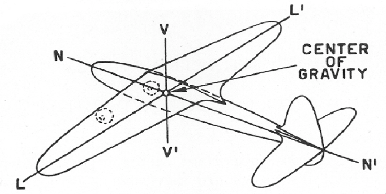
GRANT ON LONGITUDINAL STABILITY

This is the third in a series of articles abstracting information concerning Stability from the 1941 book "Model Airplane Design and Theory of Flight," written by the famous Charles Hampson Grant. Let the reader understand that I'm going to be liberally using Grant's exact words and illustrations, condensing them, and for ease of reading the constant use of quotation marks is omitted.

by George White

The first two articles in this series dealt with Grant's defining the types of stability and discussed the factors influencing and methods of achieving lateral and directional stability.



Grant defines stability as the capacity of an airplane to overcome any tendency to displace or turn from normal flight — or to return to normal flight after displacement.

As can be seen from the diagram above, there are three kinds of stability to deal with, i.e. **Longitudinal stability** which refers to the maintenance of normal flight about axis, L-L^1. **Directional stability** which refers to the maintenance of normal flight about the vertical axis, V-V^1. **Lateral stability** which refers to the maintenance of normal flight about the axis running through the center of gravity on axis N-N^1.

As discussed in the previous articles, critical to achieving stability in a model is the establishment of the center of gravity (c.g.) both vertically and laterally. Having done that, this article will discuss **Longitudinal Stability.**

When an airplane is longitudinally stable, the nose and tail will resist any tendency to dive or nose up into a stall; and when experiencing any such displacement about axis L-L^1, will return to level flight.

Lack of longitudinal stability is evidenced in two ways:

(a) Upon being launched the ship may nose up into a stall, or dive under power, from which maneuvers it fails to regain equilibrium.

(b) It may fly properly for a short distance, then nose up or down suddenly because of a gust of wind, from which it does not recover.

In the first instance, the plane is forced out of flight position by a feature of incorrect adjustment or design existing **within** the plane itself; while the second is caused by an **external** factor.

Grant divides factors governing longitudinal stability into two classes.

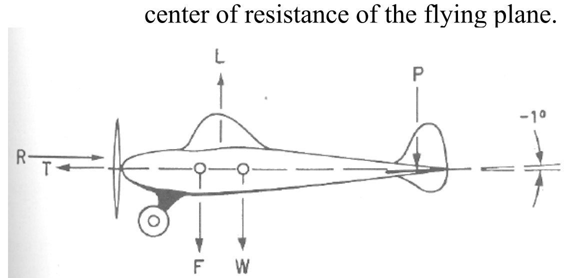
(1) Those tending to displace the plane from normal flight attitude.

(2) Those that resist this action, or cause the ship to recover from displacement.

Each of these two factors will be examined in turn.

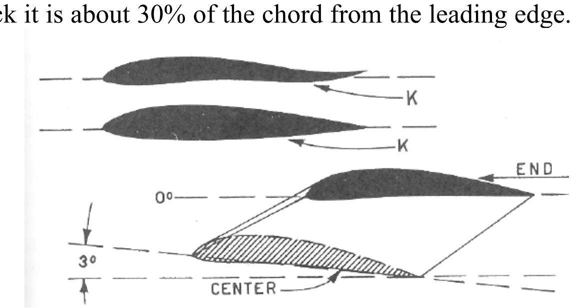
Displacement or Disturbing Factors: These are:

1. Position of c.g. relative to wing lift
2. Type of wing section
3. Size of wing chord
4. Difference in angle between wing and stabilizer
5. Speed
6. Stabilizer moment arm
7. Position of thrust line or propeller pull relative to center of resistance of the flying plane.



Displacement factor #1, position of c.g. relative to wing lift is illustrated in the diagram above. If the c.g. is located at W, behind the center of lift, it will tend to pull the tail down and create a stall unless the stab is designed to carry part of the load. When a non-lifting tail is used the c.g. must be located ahead of the line of lift (F) . Grant's rule in this instance is to locate the c.g. of 1/3 the chord back from the leading edge.

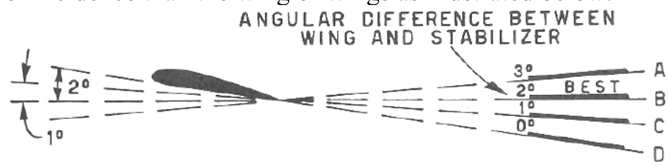
Displacement factor #2, **type of airfoil**. The point on the median line where lift acts vertically on the wing is called the center of lift. Insofar as longitudinal stability is concerned, it is not fixed, but changes with any variation in angle of attack. At small angles of attack lift acts at a point 50%-55% of the chord back from the leading edge. As the angle of attack increases, the center of lift moves forward until at 10º angle of attack it is about 30% of the chord from the leading edge.



Grant offers three methods for reducing the shifting of the center of lift. The upturned trailing edge and the use of a symmetrical airfoil will accomplish the job. Neither airfoils are as efficient in terms of lift as a flat or undercambered airfoil, but the purpose here is to reduce center of lift shift. The third method is to sweepback the wing and wash out the angle of incidence toward the outer ends.

Displacement factor #3, **chord size**. On any given airfoil section, movement is a percentage of the chord. Since the movement of the center of lift amounts to about 1/3 of the chord, the smaller the chord, the less actual movement occurs. He offers a convenient rule: "never make the average wing chord greater than 1/6 of the wing span. Also, never make the average wing chord greater than 1/3 the distance between the wing center and the stab center (i.e the distance from wing center to stab center should be equal to at least 3 times the average wing chord).

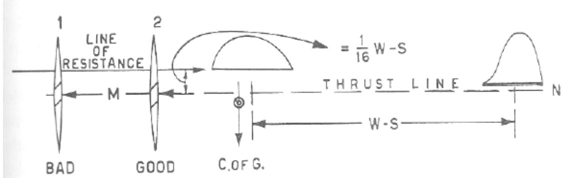
Displacement factor #4: Difference in angle between wing and stab. Grant recommends that the wing normally be set at an angle of incidence relative to the thrust line of 2º to 3º. If the stab has a greater lifting angle of incidence than the wing, the tail will lift and the model will dive. If the stab is set at angles of incidence less than that of the wing, depending upon speed, a stall is encouraged. Grant advises to have as little difference in angle between the wing and stab as possible— usually the stab should be set at 2º or 3º less angle of incidence than the wing or wings as illustrated below.



Displacement factor #5, Speed. If the stab is set at an angle less than the wing, given sufficient speed, it will tend to make the model climb or stall. It then may be asked why, if at considerable speed it tends to produce a deviation from level flight, should there be any difference. The reason is that this difference is important to recovery, so a slight difference must be maintained.

Displacement factor#6, **Stabilizer Moment Arm.** It should be obvious that the shorter the stab moment arm, the greater will be the displacement angle for any given stab movement, and the longer, the less displacement angle and the more easily the plane will recover. Experience has shown that the stab moment arm should be approximately 1/2 the wing span. The length should never be less than 2/5 the wing span with rubber models. Gas models may have a moment arm of as little as 1/3 the span. However, the shorter in either case, the greater the tendency to stall and dive. The faster the model flies, the longer this moment arm should be.

Displacement factor#7, **Position of thrust line or propeller pull relative to center of resistance of the flying plane.** Another factor tending to throw a plane out of equilibrium longitudinally is the location of the point of power application and the direction this power acts relative to various components of the entire airplane.



Grant states that as a rule, the best location for the thrust line is at a point about 1/16 of distance W-S (stab moment arm) below the wing center section measured from the leading edge. The thrust line should act in a direction parallel to the longitudinal axis MN. In this position, it will nose up the model slightly under full power. Using negative stab angle will do the same thing, but that adds an additional load on the wings and reduces flight capacity. The thrust line may be lower than this **if** the c.g. is below it The governing factor is to avoid placing the thrust line (center line of prop shaft) below the c.g. because the plane will tend to glide steeply or dive sharply at the end of flight. In low wing monoplanes the thrust line is almost always above the line of resistance, therefore negative incidence on the stab is required to reduce the diving tendency under power. In order to have the least disturbing effect, the point of power should be as close to the c.g. as possible. By having the prop a considerable distance from the c.g. the disturbing effect has to be corrected by other factors.

Corrective Factors: These are:
1. Angle of stab chord to line of flight (center line of prop shaft) as compared to wing angle to line of flight.
2. Distance of stab from wings(stab moment arm W-S above)
3. Stab area
4. Position of c.g. relative to center of lift, considered in a vertical plane.

Corrective Factor #1, **stab chord angle compared to wing angle.** This is both a disturbing and a correcting factor. When the stab is set at an angle of 2º less than the wing to the line of flight, the disturbing factor is small. When greater than that there is a tendency to stall at high speed. From the results of experiments is was found that the stab should be so placed that it is 2º or 3º less than the wing's angle of incidence where the wing center section is near or slightly above the thrust line and the wing has normal dihedral. As the wing increases in height relative to the stab moment arm, the stab angle can be reduced. This can be visualized in the diagram above where if the wing height is increased, the line of resistance will tend to push the tail down, reducing the need for the stab to do so.

Corrective Factor#2, **distance of stab from wing**. This factor was discussed above in displacement factor #6.

Corrective Factor#3, stab area. One of the greatest faults of scale models is that the stab is too small for steady flight and to overcome stalling tendencies. The larger the stab area, the less the plane will deviate from normal flight and the less the wing angle of attack will vary. The less it varies, the more efficient the wing which allows longer flight on less power. Grant provides some rules as follows:

1. When the c.g is above the thrust line and the nose is long, make the stab 45% of the wing area.
2. When the c.g. is below the thrust line, make the stab 30%-35% of the wing area, 25% for gas models.
3. When the c.g. is below the thrust line with a short nose and the prop close to the wing, 25% of the wing area.
4. In biplane models, use 5% less than that shown above.

Grant makes no rules for scale models other than to say that the stab should range from 25% to 45% of the wing area for most all models.

Corrective Factor#4, position of c.g. relative to center of lift.
Grant makes an unusual argument for having the c.g aft of the center of lift, requiring upward pressure on the stab. He recommends a positive stab angle of 1/2º to 1º, although it should still be about 2º less than the wing incidence relative to the thrust line. His point is that any spin tendency with this arrangement can be corrected by adding 10% to the fin.

The reader will notice no mention of "downthrust" as a correcting factor. Grant's book goes to great length proving that there is no such thing as “downthrust,” but that will have to be the subject of another article.