## 3.0 HANDLING AND STABILITY CHARACTERISTICS

The handling qualities of general aviation aircraft can influence the fatal in-flight airframe failure (FIFAF) accident rates in several ways. Stapleford and DiMarco listed four ways in their discussion of possible contributing factors in general aviation FIFAF accidents[5]. The following factors can be affected by handling qualities:

- The probability of the pilot losing control.
- The aircraft response after loss of control.
- The possibility of the pilot inadvertently overstressing the airplane.
- The overall loads and load distribution due to pilot control actions and turbulence.

Several studies of the handling and flying qualities of general aviation aircraft, conducted by NASA and earlier by NACA, have included the V-tail Bonanza. In 1948 an NACA Technical Note was published that compared flight measurements of five light airplanes[6]. In 1951 an NACA Research Memorandum was published that concentrated on the flying qualities of a Beech B35 Bonanza[7]. In 1965 a NASA Flight Research Center working paper was written that compared the flying qualities of the Beech S35 airplane with the Model B35[8]. A NASA Technical Note was published in 1966 by the Flight Research Center that evaluated the handling qualities of seven general aviation aircraft[9]. While the seven aircraft are not specifically identified, it is known that the Model 35 Bonanza and the Model 33 Debonair are two of the airplanes included in this study.

Beech Aircraft Corporation has documented aerodynamic and handling characteristics of the airplanes they have produced. Recently at the University of Texas in Austin, Professor Ronald Stearman and some of his engineering students have studied the V-tail Bonanza and conducted some tests including a flight test program to evaluate the Dutch roll characteristic[10, 11].

The results of the above studies are generally consistent and are used as the basis for the discussion in this chapter. Longitudinal stability and control is discussed in Section 3.1. Section 3.2 discusses lateral stability and control. Spiral divergence and overspeed tendencies are discussed in Section 3.3 which covers control under IFR conditions. The Model 33 handling and stability characteristics are compared with those of the V-tail Bonanza in Section 3.4.

### 3.1 LONGITUDINAL STABILITY AND CONTROL

Longitudinal stability characteristics of the V-tail Bonanza do not pose any particular problem to the pilots that would contribute to FIFAF accidents. In terms of dynamic longitudinal stability, pilot-induced short period oscillation disappears completely in less than one cycle[7]. The longer period phugoid mode is also stable and well-damped[8].

The low stick force required for elevator control has been frequently listed as a contributing factor to FIFAF accidents. According to Adams and Whitten[7] the stick force levels of the Model B35 were considered to be in a satisfactory range. There

was no indication that the stick force per "g" would tend to become low even at the highest speed tested. The issue of light stick force contributing to Bonanza FIFAF accidents is not clearly resolved from these studies.

### 3.2 LATERAL STABILITY AND CONTROL

The V-tail Bonanza has a Dutch roll characteristic that is not sufficiently damped to provide the pilot with satisfactory handling qualities in turbulent air[7]. Dutch roll involves coupled motion in roll and yaw, but in the case of the Bonanza the motion is predominately yaw and the resulting lateral oscillations are frequently referred to as a "tail-wagging" characteristic. As a result of their study which included the Model S35, Barber and Haise[8] state: "The damping of the Dutch roll oscillation is light enough to cause this mode to be continually excited by moderate turbulence and is aggravated by the high frequency of the oscillation." In the NASA study of seven aircraft[9] the authors suggest that the Dutch roll oscillations of one aircraft (S35 Bonanza) at high speeds are severe enough to cause the pilot to be concerned about exceeding the structural loads of the airplane.

These study conclusions are based on test pilot impressions and the results can be inconclusive. For example, another statement from the NASA study[9] is not consistent with the comment above regarding structural loads: the pilots commented that all aircraft are unsatifactory for precise tracking tasks in turbulant air but indicated that none of the aircraft has unacceptable lateral-directional dynamic charactristics. Dutch roll is not unusual in high performance general aviation aircraft and these studies involving the Models B35 and S35 along with pilot interviews identify it as an inherent characteristic of the V-tail Bonanza.

An attempt by the pilot to damp out Dutch roll can worsen the situation. For example if the pilot happens to apply full rudder to reduce yaw at the point of maximum yaw, even at a speed equal to or below the maneuvering speed, the ultimate air loads can exceed the tail strength.

Extreme yaw can sometimes cause a nose-down dive-type motion according to Stearman[11]. The plane normally can recover from the dive motion with the pilot's hands off the controls. If this occurs at a high speed (above the maneuvering speed), perhaps in bad weather, an inexperienced and/or inattentive pilot may attempt to control the plane, incurring a maneuvering load which could exceed the strength of the control surfaces. The yaw-induced pitch motion is a natural phenomenon and is not unique to V-tails. At a large yaw angle, all tail configurations produce a pitching moment causing the plane to nose down[10]. In an early study of five light airplanes[6], this pitch over motion was noted: "The pitching moment due to sideslip was generally desirably small at small angles of sideslip, although at large angles of sideslip an appreciable nosing-down tendency was measured on several of the airplanes."

According to Stearman, the induced motion is caused by the flow separation on the trailing surface of the trailing tail during the yawing motion. This separation is influenced by the body wake flow. One may expect that if the body wake can cause the separation on a V-tail, it should have the same effect on a straight tail. In fact it should be more likely to affect a straight tail rather than a V-tail in level flight because the most of V-tail surfaces are high relative to the fuselage and a good portion of the surface can be above the body wake stream. However, as the airplane is rolling in the Dutch roll, different portions of the V-tail surfaces will be submerged in the body wake. It is not clear how the flow on the lifting surface behaves under this circumstance. A study of effectiveness of a control surface

which is totally or partially submerged in a wake would be an interesting subject for research and development. However, it is not an appropriate recommendation for this study, because the task force does not believe the induced pitching motion from extreme yaw oscillations is a significant contributing factor to FIFAF accidents.

### 3.3 CONTROL UNDER IFR CONDITIONS

The known factors associated with many in-flight airframe failure accidents are consistent with a well-developed scenario that appears plausible. A VFR pilot, or an IFR pilot with little recent experience, decides to fly in marginal or rapidly changing weather conditions. The pilot finds himself suddenly flying in IFR conditions. Any kind of a disturbance that causes the aircraft to bank can initiate a divergent spiral. Banking provides a component of the gravity vector to increase the airspeed while the airplane is losing altitude. The increased speed results in higher forces on the airplane. The resultant flight path is a spiral, and if allowed to continue, can lead to excessive airspeed. In an attempt to ease out of a spiral, a pilot may pull back on the controls. If the wings are not leveled at the time of this action, the spiral will be tightened. If the airspeed is sufficiently high when up elevator is applied, air loads due to dynamic pressure can overstress the wing or tail surfaces.

The factors associated with this scenario include loss of visual orientation in IFR conditions, an aircraft with a neutrally stable or unstable spiral mode, an overspeed characteristic, and an inexperienced or inattentive pilot. An experienced pilot will level the wings before attempting to arrest his or her descent by pulling back on the stick. Directions for recovery from spiral instability have been widely publicized.

Spiral divergence is a property associated with most general aviation aircraft and the V-tail Bonanza is no exception. This characteristic can be overcome by installing an autopilot or a wing leveler. The Mooney M20 had a wing leveler added as standard equipment in 1965.

Early flight tests on the Bonanza Model B35 identified spiral divergence as a negative factor which might affect the instrument flying qualities[7]. The test results indicated that the airspeed continued to increase after the controls were released. Another report that compared test results of the Model S35 with B35 handling characteristics concluded that while the spiral mode on the B35 had been quite objectionable, the S35 spiral characteristic was acceptable[8].

The Model 35 is frequently referred to as a clean airplane with low drag. As a result there is an implication that either in a dive or a spiral the airplane will gain speed faster than other airplanes. In fact, the primary effect of reduced drag is that the aircraft can reach a higher terminal velocity[5].

Flight tests were conducted on the Model B35 to evaluate speed increase during a dive[7]. With a power setting for steady level flight of 140 mph, the test aircraft was placed in a dive at various angles. With the airplane pitched down five degrees, the velocity approached 174 mph. At ten degrees pitch down, it took 40 seconds for the aircraft to exceed its maximum allowable speed of 202 mph. In a 14 degree dive, the maximum allowable velocity was exceeded in 22 seconds.

The Model 35, while not unique, has the essential characteristics to fit the scenario for spiral divergence leading to structural failure. It should be noted that

the Mooney M20, with its wing leveling device, has a perfect record in the accident category involving in-flight structural failures. The wing leveling device removes an essential factor from the spiral scenario. The Beech Model 33 is also noted for its impressive safety record of low accident rates in all categories. In particular, there has been only one reported incident of in-flight airframe failure since production began in 1960. The Model 33 does not have an autopilot or wing leveler as standard equipment.

### 3.4 MODEL 33 HANDLING CHARACTERISTICS

The Model 33 and the Model 35 configurations are very similar, the major difference being the empennage. The V-tail on the Model 35 is designed to perform the same functions as the conventional tail on the Model 33. There is some disagreement on the question of whether the Model 33 and Model 35 have the same handling characteristics, but the differences are thought to be minimal. According to an aviation consultant who has studied the handling qualities of both airplanes, all of the important handling parameters are indistinguishable between the two airplanes[12].

Published data on the handling and stability parameters of the Model 33 are limited. Barber[9] compared the handling qualities of seven general aviation aircraft and purposely avoided identifying them. However the Model 33 and Model 35 can be identified as two of the seven. The discussion of the handling qualities of the seven aircraft does not lead the reader to believe that the two aircraft had identical characteristics. The Model S35 was singled out as having an unacceptable Dutch roll characteristic because of poor damping. The Model 33 was singled out as having a marginally acceptable high frequency Dutch roll. There were other apparent differences but both airplanes were reported to be acceptable in terms of spiral instability.

The issue of non-instrument rated pilots trying to operate in IFR conditions was investigated by Cornell Aeronautical Laboratory for the FAA[5]. A Beech Debonair Model 33 was used for the study. Of the 26 pilots tested in one experiment, which involved the pilot in a simulated condition of being lost and trying to establish his position, nine of the pilots lost control. In a second test which required the pilot to make a 180 degree turn under IFR conditions, 18 of the 26 pilots exceeded safe operating limits.

The handling qualities of the Model 33 and the Model 35 are probably somewhat different. However, any differences are not believed to be great enough to be factors that affect their respective FIFAF accident records.

## 4.0 STRUCTURAL INTEGRITY

Design for airframe structural integrity is not an exact science. The ability of a wing or stabilizer to survive flight loads depends not only on its strength but also on how well the loads have been estimated. Many are difficult to estimate with accuracy and cannot be measured until the airplane is available to fly. Even then, some load effects such as lift distribution and gust response are difficult to determine. Flight loads are measured early in the production life of a Transport Category fleet, but such measurements are not common practice in the general aviation industry.

Structural integrity assessment of a general aviation airframe must thus rely upon the established practice for flight load estimation, as specified in CAR 3, and FAR-23. The question of whether the manufacturer has complied with the applicable regulations must be separated from the question of load estimation accuracy, but the second question is as important as the first.

Assessment is less difficult than design because strength test results are available in the type certification support documents. However, the available tests generally do not cover all the conditions which need to be investigated, and the assessment must make use of stress analysis to fill in the gaps. Stress analysis is also essential for correlating critical loads with the failure modes observed in both accidents and strength tests.

The principles underlying structural integrity assessment are discussed first. Section 4.1 deals with the procedures for estimating flight loads and how those loads relate to what the airplane is doing. Section 4.2 outlines the subjects of wing and empennage construction, how the flight loads stress the structure, and how the structure can fail. The discussion is tailored to general aviation loads and Bonanza construction.

Sections 4.3 and 4.4 cover the assessment of the Model 35 wing and empennage, respectively. When estimating the empennage design loads, Beech considered other cases besides those required by regulation. Section 4.4 begins with a description of the Beech load estimates and their relation to the airworthiness requirements. Section 4.4 also includes a comparison to the Model 33 to contrast its conventional tail to the V-tail.

The discussion throughout Section 4 is limited to the issue of static strength. Load redistribution and vibratory effects caused by aerodynamic loading will be dealt with in Section 5.

### 4.1 FLIGHT LOADS AND THE V-n DIAGRAM

A good starting point for understanding flight loads is to consider the airplane in steady level (1g) flight in smooth air. The lift produced by the wing and fuselage counteracts the airplane's weight, but the center of lift is generally aft of the center of gravity (c.g.)[13]. The wing loading also produces a nose-down moment about the center of lift. Thus, the airplane generally is trimmed with a down-load on the tail to prevent nose-down pitch, especially for forward c. g. conditions. The total lift force is the sum of the weight and the tail load. This equilibrium state can be thought of as a see-saw balanced on the fulcrum of lift (Figure 4-1). The tail load is thus small compared to the airplane's weight because the tail load has a much longer

lever arm. In practice, thrust and drag also affect the balance, but their minor contributions do not change the basic picture presented here.

The airplane's c.g. location varies with fuel and useful load. The location is more forward with only the pilot and full fuel onboard and more aft with a full passenger and baggage load and minimum fuel. Thus, the lever arm from the center of lift to the airplane's c.g. changes as the gross weight varies, and this in turn changes the trim tail load. In many cases, for example, the c.g. of a heavily loaded airplane can be directly over or even aft of the center of lift, and the corresponding trim tail loads are zero or upward, respectively (Figure 4-2).

As noted in the figure, the airplane manufacturer establishes forward and aft c.g. limits. These limits serve to assure that the pilot can maintain control of the airplane in situations other than steady flight[13]. The forward limit leaves the pilot with enough up-elevator available to recover from a dive or to flare when landing. The aft limit leaves the airplane with enough longitudinal stability to prevent

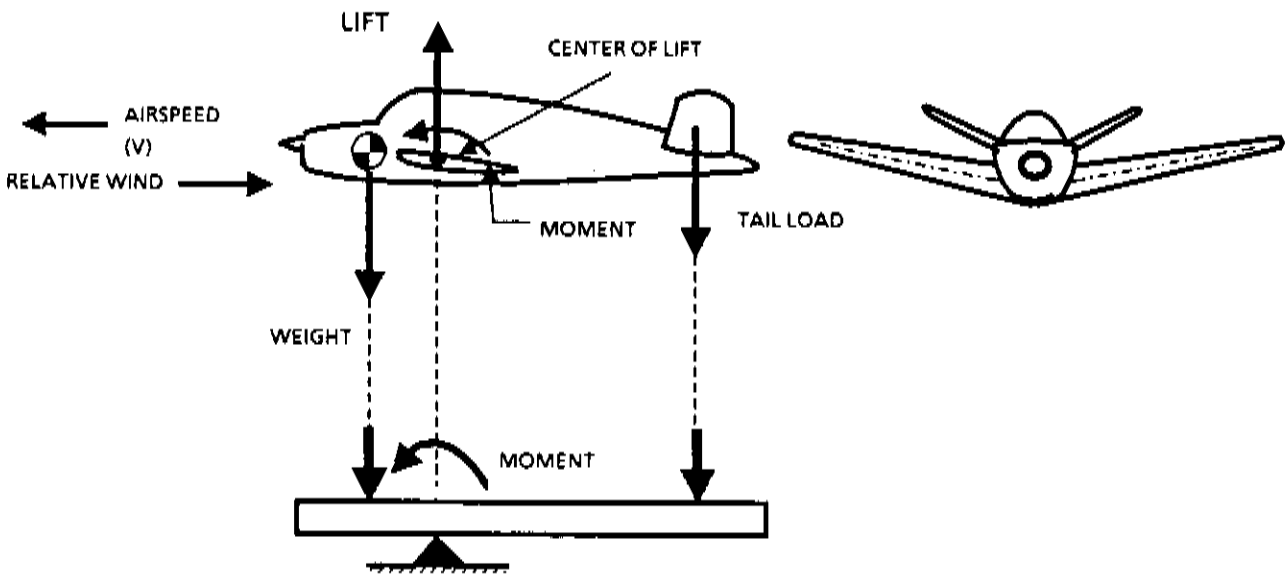


FIGURE 4-1. MAJOR LOADS FOR STEADY LEVEL FLIGHT

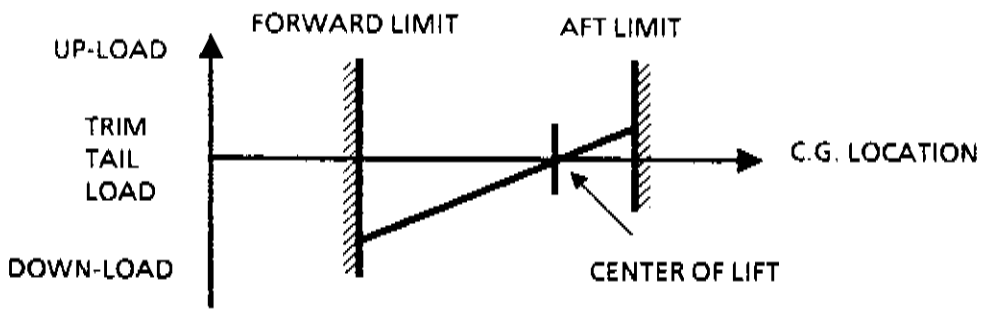


FIGURE 4-2. EFFECT OF C.G. LOCATION ON TRIM TAIL LOAD

prolonged violent pitch oscillations in turbulent air. Pilots must be especially attentive to weight and balance because the aft c.g. limit can often be exceeded when the airplane is within maximum gross weight. This is an insidious situation because the airplane controls easily on takeoff in smooth air. If the airplane happens to encounter turbulence in flight, the disturbance and/or pilot over-correction in the situation of low longitudinal stability can place the airplane at higher positive or negative angles of attack. It is then possible to literally fly the wings (or tail) off the airplane by developing maximum aerodynamic load above maneuvering speed.

The relative wind (Figure 4-3) creates the aerodynamic pressures which develop lift on the wing and fuselage and the trim load on the tail.

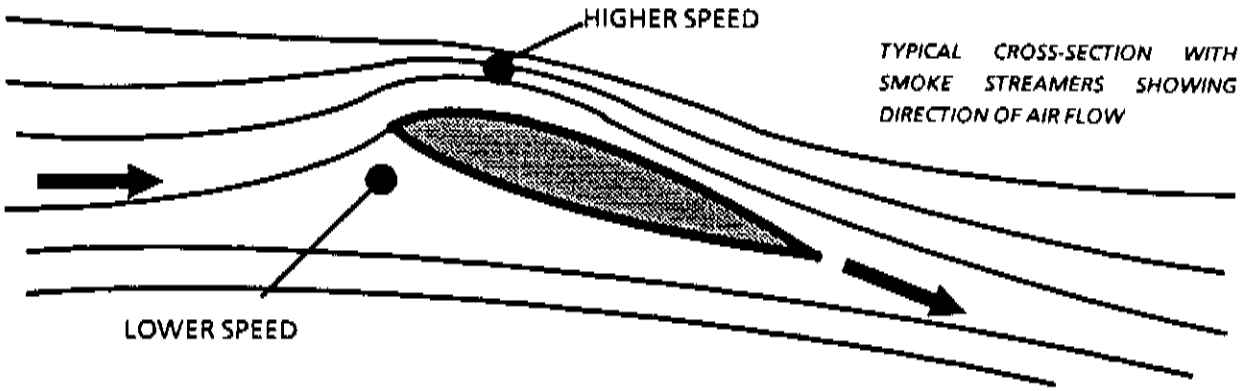


**FIGURE 4-3. AERODYNAMICS OF AN AIRFOIL**

The aerodynamic nature of lift means that the total lift force increases as the square of the wind speed and the lift increases linearly with the airfoil's angle of attack[17]. The linear increase in lift continues only to an angle of about 14 to 16 degrees, however, before the airfoil stalls. At such large angles, the flow over the upper surface of the airfoil is subjected to intense acceleration near the leading edge, and thus a very high local speed, before returning to freestream speed near the trailing edge. The corresponding gradient from low to high pressure has the effect of detaching the flow from the airfoil surface and leaving a dead wake (Figure 4-4). This is the phenomenon of stall, which destroys lift and thus imposes a natural limit on flight loads.*

A wing behaves generally like an airfoil, but the wing's planform and finite span introduce spanwise changes in the lift distribution. The planform itself has a direct effect, i.e., each short segment of the span contributes lift in proportion to the segment's chord length. Thus, a tapered wing generates more lift from the inboard part of its span than from the outboard.

* The limit can be exceeded in transient conditions if the airfoil's angle of attack is rapidly increased from below to above the stall angle. The flow will remain attached and the linear proportionality of lift will continue for a time on the order of the chordlength divided by the wind speed (typically a fraction of a second).

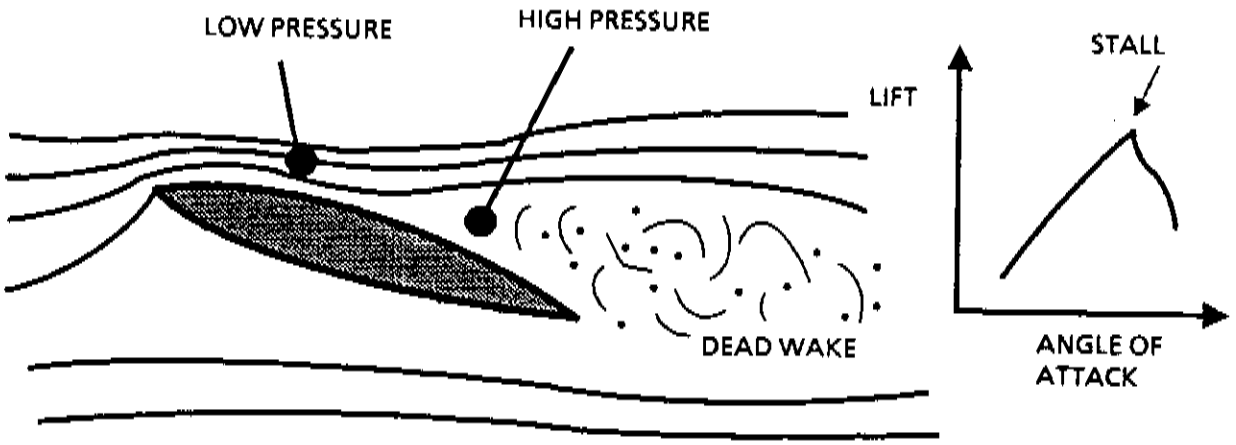


**FIGURE 4-4. FLOW AROUND A STALLED AIRFOIL**

A second spanwise effect arises from the fact that air can flow around the wing tips and will do so because of the pressure differential from below to above the wing. This flow creates wake vortices and induced drag as well as redistributing the lift inboard. The effect on lift is most pronounced near the wing tips. Figure 4-5 contrasts the spanwise lift distribution of an actual wing with the effect of taper alone.

Still another difference arises when the wing is combined with a fuselage. That part of the wing which is inside the fuselage cannot contribute any lift. The fuselage contributes lift in place of the hidden part of the wing, but the fuselage may be less efficient than the wing. Conversely, the fuselage efficiency may not be much different, but wing-body interference may reduce the efficiency of the wing[14]. Thus, when a fuselage is added to the wing shown in Figure 4-5, the lift may be redistributed either outboard or inboard, as shown in Figure 4-6.

Spanwise lift distribution has an important effect on wing bending (Section 4.2). For a given total lift (e.g., approximately the airplane gross weight in steady level flight), the actual distribution for the wing-fuselage combination may bend the wing more or less than the theoretical distribution of the wing alone. In the era during which the Bonanza was designed, the theoretical distribution could not be calculated accurately and the fuselage effect had to be determined by means of wind tunnel tests. Furthermore, the fuselage effect on spanwise lift distribution is different for different angles of attack. The issue of the fuselage effect will appear in Section 4.3 in the Model 35 wing assessment.

The stabilizers have a spanwise distribution of tail load similar to the wing lift distribution. The fuselage effect is different at the tail, however, and the wing-fuselage wake adds other complications which are difficult to predict or measure. Airplane designers adopt a simplified approach, therefore, by assuming a spanwise tail load distribution corresponding to the planform effect alone (dashed line in Figure 4-5). This assumption is conservative for assessing the bending effect of the tail load. Beech followed this practice in the design of the Model 35 V-tail.

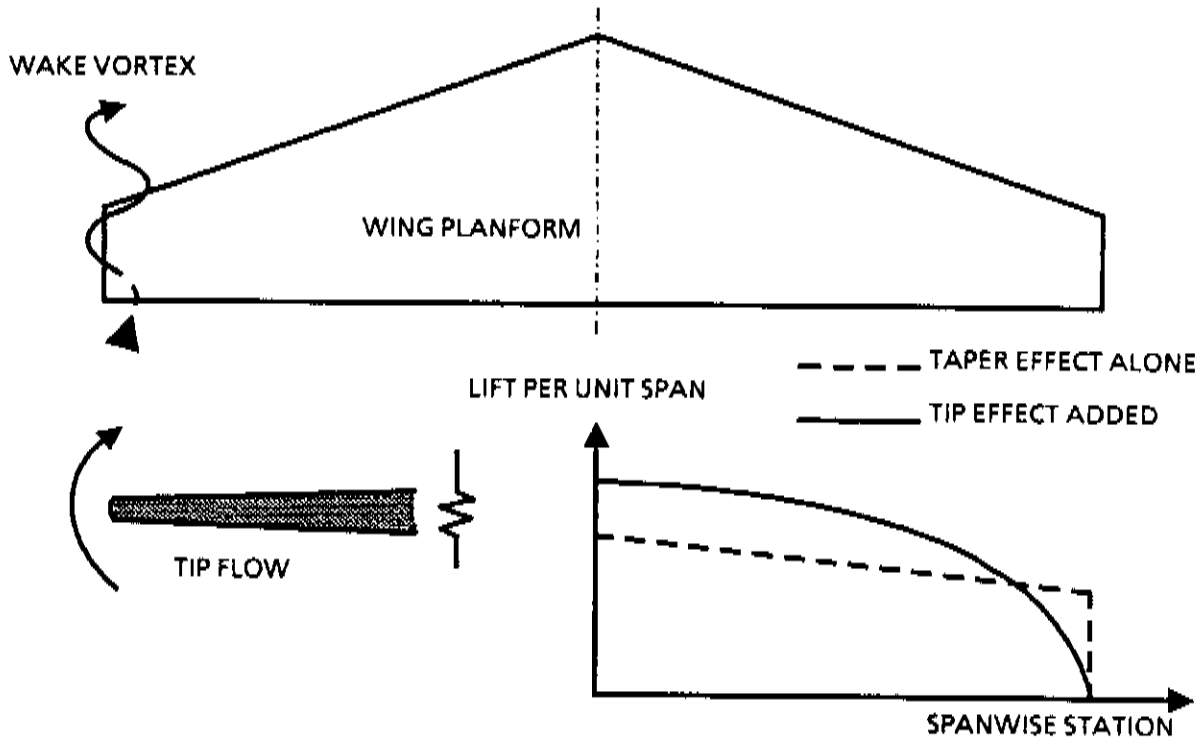


**FIGURE 4-5. WING LIFT DISTRIBUTION**

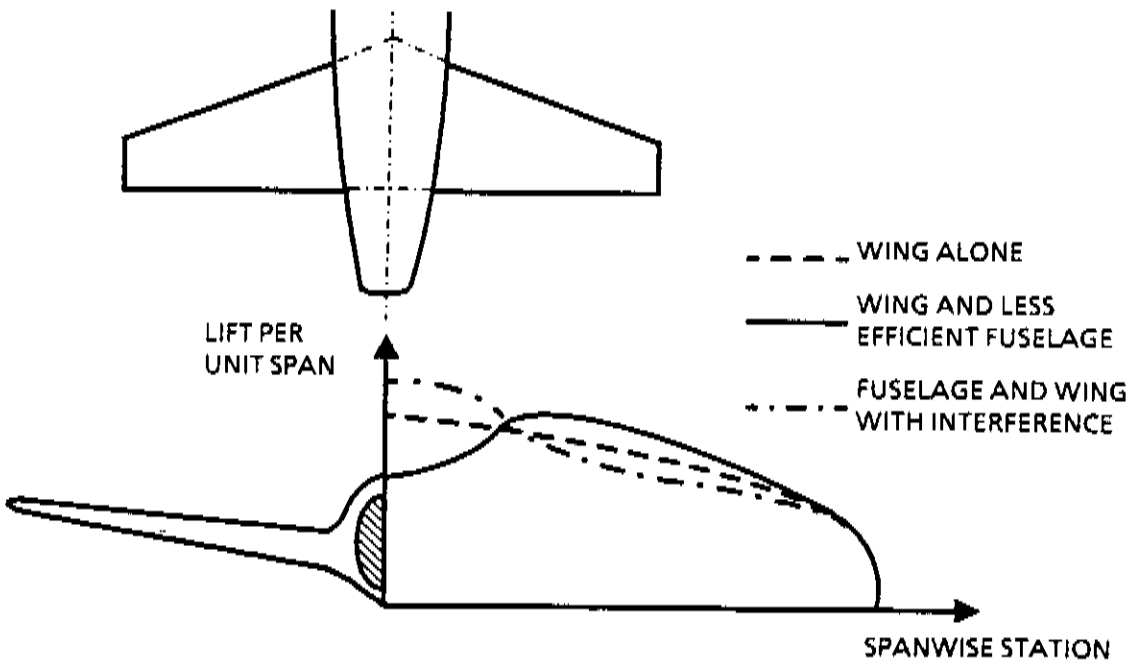


**FIGURE 4-6. FUSELAGE EFFECT ON LIFT DISTRIBUTION**

The envelope of flight loading conditions specified by the maneuver and gust criteria of CAM 3.185 and 3.187 are shown in the V-n diagram in Figure 4-7 for the utility aircraft. The critical flight loads for the wing are to be defined by the combinations of air speed and load factor on and within the boundaries of the V-n diagram in which flight load factors are the ratio of the aerodynamic force component to the weight of the airplane.

As shown in Figure 4-7, the airplane is assumed to operate in the range between its stall speed, $V_S$, and its design dive speed, $V_D$, which is 11 percent above the redline speed. These limits appear as vertical lines on the diagram. In addition, the maneuver speed, $V_A$, and a typical cruise speed, $V_C$, are identified.

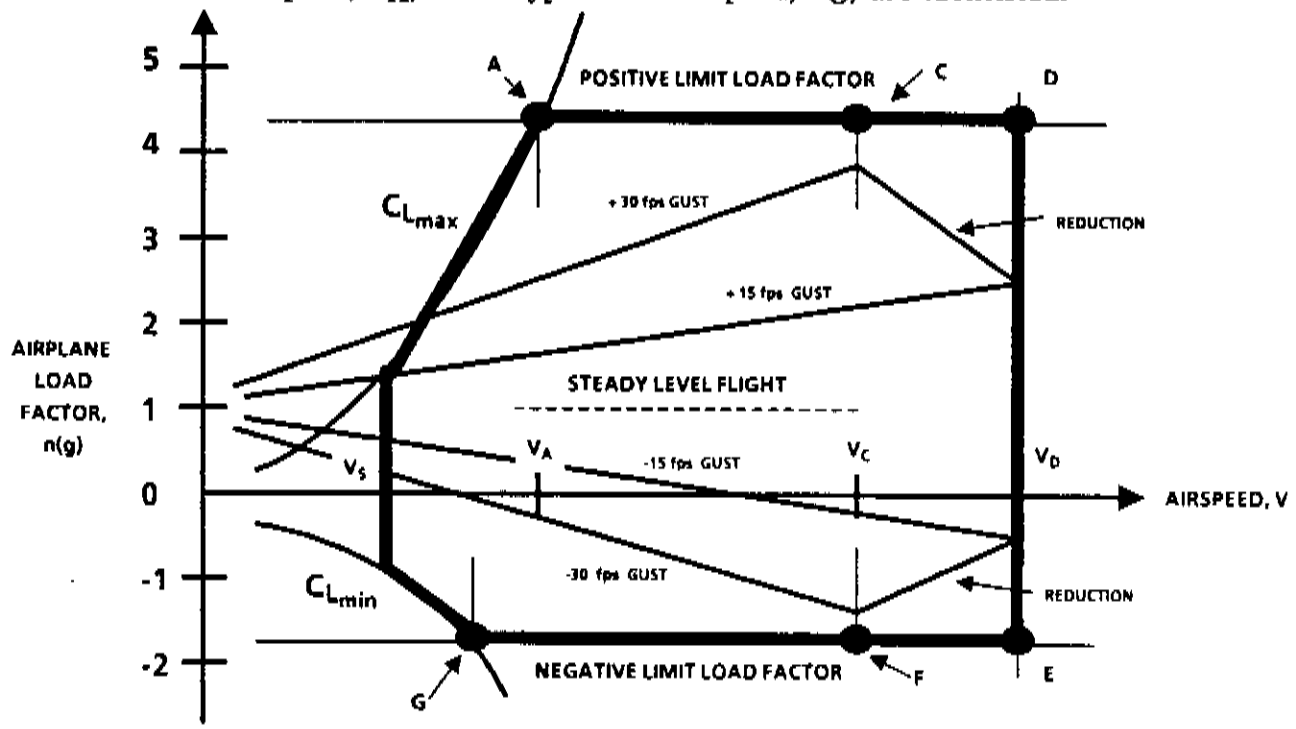


FIGURE 4-7. V-n DIAGRAM FOR HYPOTHETICAL UTILITY CATEGORY AIRPLANE

In terms of load factor, the airplane is assumed to operate in the range between the positive and negative limit load factors corresponding to its type certification category (see Section 2.5 and Table 2-5). These limits appear as horizontal lines on the diagram.

If the airplane is being flown at or below its maneuver speed, it is assumed that the pilot may execute any possible turn, pullup, or pushdown up to the airplane's aerodynamic limit, i.e., with the wing at maximum angle of attack before stall. The wing lift and load factor are then proportional to the velocity squared, and these limits appear as parabolic curves on the diagram.

Finally, the gust effects are plotted. The airworthiness regulations require the designer to assume 30 foot per second (fps) gusts at all speeds up to $V_C$ and 15 fps gusts at $V_D$. Between $V_C$ and $V_D$ the gust effect is approximated by a straight-line reduction from 30 to 15 fps. The reduction of gust effects for speeds exceeding $V_C$ can be justified by an argument that, at such speeds, the airplane is normally flown

at altitudes above the reach of ground-generated thermals and should encounter correspondingly milder gusts.

The limit load factors shown in Figure 4-7 correspond to a Utility Category airplane (4.4g, - 1.8g)[15-17]. In this hypothetical example, similar to the Bonanza A35 and later models, the gust lines happen to lie within the speed and load factor limits at all potentially critical points. The envelope of extreme conditions is indicated by the boldface outline on the diagram. Also shown for reference is a dashed line corresponding to steady level flight.

The V-n diagram envelope provides the basis for flight loads estimation because it represents the extremes of expected operations. In practice the designer considers a few discrete points, such as A, C, D, ..., G in Figure 4-7, to check for critical loads. Generally, the upper boundary points (A,C,D) determine the critical loads for wing static strength. Vibratory aerodynamic effects such as wing flutter (Section 5) may occur at airspeeds well above $V_D$.

The V-n diagram is not a descriptor of critical tail loads. The fact that the balancing tail load is quite small for steady level flight was mentioned earlier. In a similar manner, calculations for airplanes following accelerated flight paths show that the balancing tail loads remain modest even at the positive and negative limit load factors.

Therefore, critical tail loads must be sought from other conditions usually involving short-term transient effects. These transients generally involve sudden changes to the tail angle of attack, in some cases perhaps exceeding the stall angle but momentarily maintaining the tail load until the flow has a chance to detach. The airworthiness regulations require the designer to consider both maneuver and gust transients of the following types:

- Maneuvers - sudden elevator or rudder deflections for both checked and unchecked maneuvers; maximum yaw with neutral or "pro-sideslip" rudder.* The sudden deflections are assumed to be to the maximum elevator or rudder angles possible on the airplane, i.e., as limited either by mechanical stops or pilot effort. The unchecked maneuver involves deflection of the control surface in one direction only; the checked maneuver consists of positive and negative deflection in rapid sequence. The yaw condition originally assumed the airplane to be at a 15-degree angle of sideslip with respect to the flight path.** The maximum airspeed for consideration of the foregoing conditions is $V_A$, the maneuver speed of the airplane.

- Gusts - vertical gusts in accordance with the gust-line limits on the V-n diagram; a lateral gust of 30 fps at $V_C$, the airplane cruising speed. In these cases the gusts are to be treated as if the respective part of the empennage experiences an instantaneous increase in angle of attack to the relative wind.

*"Pro-sideslip" rudder means rudder deflected in the direction that will tend to increase the yaw angle.

**This requirement was changed (FAR-23) to 15 degrees times a factor of 1.3 to account for dynamic overshoot.

Beech considered these cases, which are outlined in Section 4.4, in the design of the Bonanza. The foregoing cases, like the points taken from the V-n diagram, are discrete points among which one hopes to find the most critical load. There is less assurance that the transient load cases do include the most critical tail load (the V-n diagram contains the most critical wing load), however, because the rapid transient aerodynamic effects on the tail are not as well understood as the quasi-steady conditions associated with turns, pullups, etc. As a result, the task force went further in its assessment of V-tail structural integrity, deriving continuous curves like the schematic shown in Figure 4-8.

Besides specifying the transient conditions that the designer must consider, the airworthiness regulations also permit the use of certain chordwise distributions of tail load and certain simplified methods to determine the load magnitudes. These load distributions* (Figure 4-9) only approximate actual chordwise load distributions:

- Distribution 1 - to be used for all maneuver loads except as noted below (1945). Distribution 1 was later modified to Distribution 1a in CAR 03 (1946).

- Distribution 2 - to be used for gusts, recovery loads on the horizontal tail in checked maneuvers, and Maneuver Condition J (yaw with neutral rudder).

- Distribution 3 - to be used for Maneuver Condition H (yaw with pro-sideslip rudder) and for balancing tail loads.

Distribution 3 implicitly includes an effect of chordwise pressure reversal for large control surface deflection, i.e., the load is increased by a percentage, and the increase is subtracted as an opposing load on the control surface. Thus, Distribution 3 imposes an extra twisting load on the control surface. The amount of extra load is required to be 20 percent of the load on the fixed surface in the case of a vertical fin and rudder, or 40 percent of the load on the fixed surface for a horizontal stabilizer and elevator configuration when the wing flaps are retracted. No extra load is required on the stabilizer-elevator for cases in which the flaps are deflected.

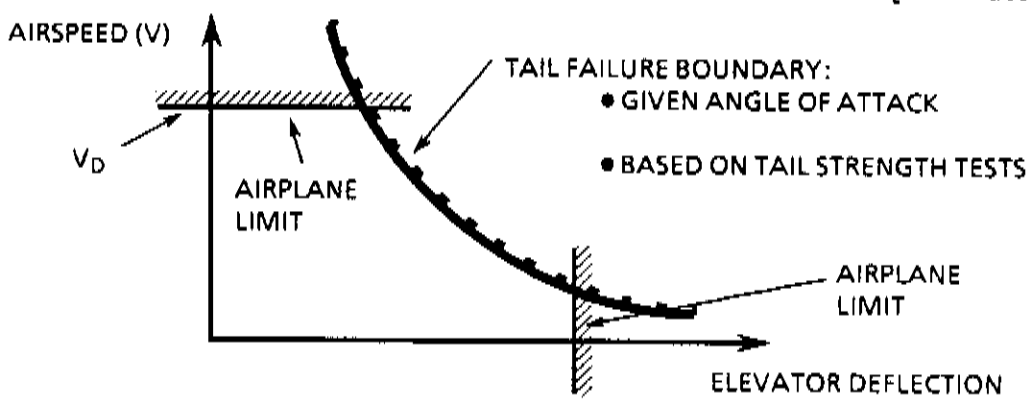


**FIGURE 4-8. SCHEMATIC FAILURE BOUNDARY CURVE**

*The numerical identifications 1, 1a, 2, 3, letter identifications of and maneuver conditions used in this report follow Beech Aircraft Corporation's notation system.

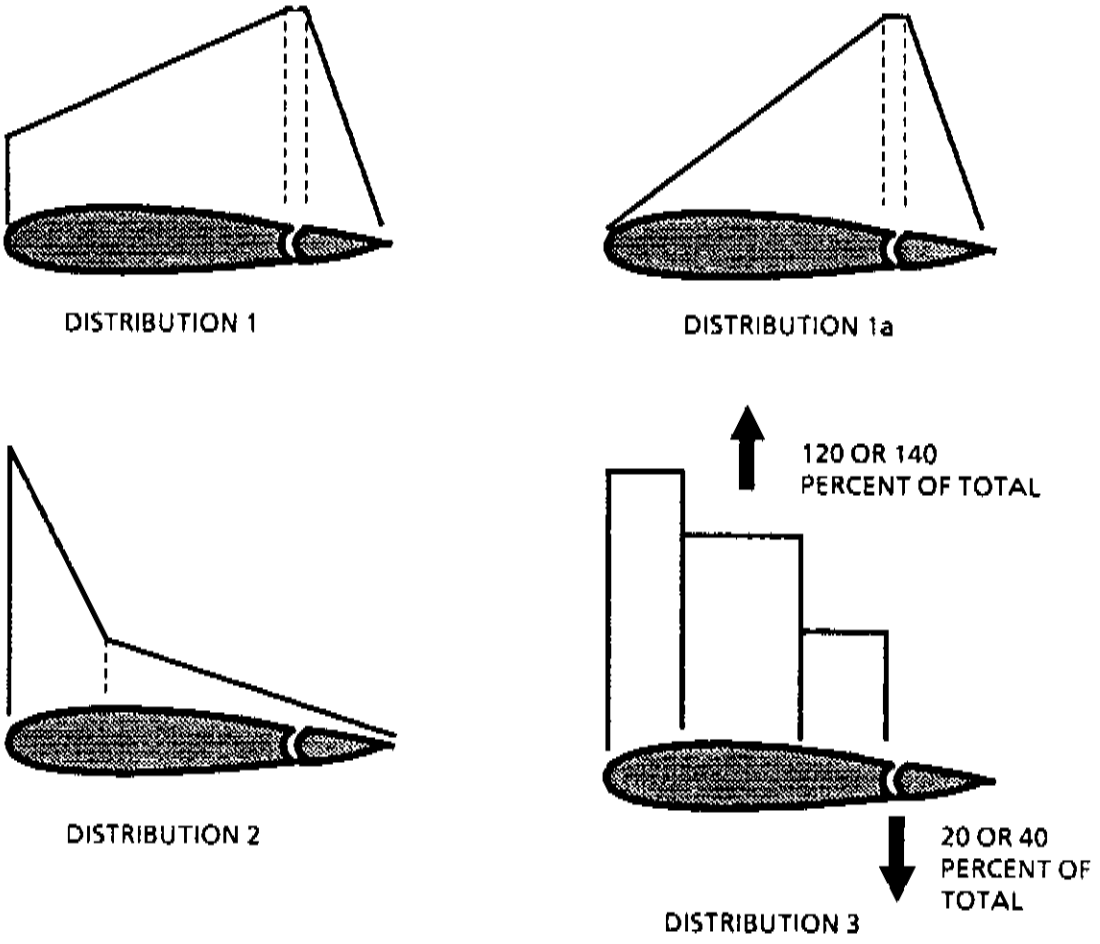


**FIGURE 4-9. CHORDWISE DISTRIBUTIONS FOR TAIL LOADS**

There is one provision that requires consideration of combined loads for a specific case. When the horizontal tail is engaged in a checked maneuver, the maneuver load must be added to the balancing load acting on the tail with the airplane at a constant load factor. Such combination is not required for unchecked maneuvers.

It is apparent from the foregoing discussion that the tail-load provisions of the airworthiness regulations were written with conventional tails in mind. When a conventional tail is being designed, there is no ambiguity in separately applying the regulations for lateral loads on the vertical tail and vertical loads on the horizontal tail, respectively. However, the V-tail has a high dihedral angle and combines rudder and elevator functions in the same control surface. The design of the Bonanza thus gave rise to ambiguities requiring special resolution. The issue was addressed in a series of letters between Beech Aircraft Corporation and CAA[18]. The following guidelines were incorporated in CAM 3 circa 1954:

- Normal loads - normal tail loads were to be computed in accordance with the formula:

$$T = H/\sin\theta \qquad \text{for horizontal loads} \qquad (4\text{-}1)$$

$$T = V/\cos\theta \qquad \text{for vertical loads} \qquad (4\text{-}2)$$

where T is the load normal to the tail surface, H is the required horizontal load, V is the required vertical load, and where Figure 4-10 defines the dihedral angle $\theta$. T, V, and H are the loads per individual (left or right) V-tail surface. Calculation of T by the above formula is intended to account for the fact that the loads H and V are based on projected areas instead of the true planform area.

- Control surface deflection - the worst case required for combined loading was limited to 2/3 full elevator plus 2/3 full rudder. This combination is apparently at the limit of pilot effort for the Bonanza (see Section 4.4).

One issue that CAM 3 did not resolve concerns the V-tail application of combined loads. The combination of balancing and checked maneuver loads is required by the regulations under the provisions for horizontal tails (CAM 3.216), while no guidance was given for V-tails (CAM 3.211) regarding the other possible combined loading conditions. Logic would suggest, however, that the balancing load should be combined with unchecked rudder maneuver loads.

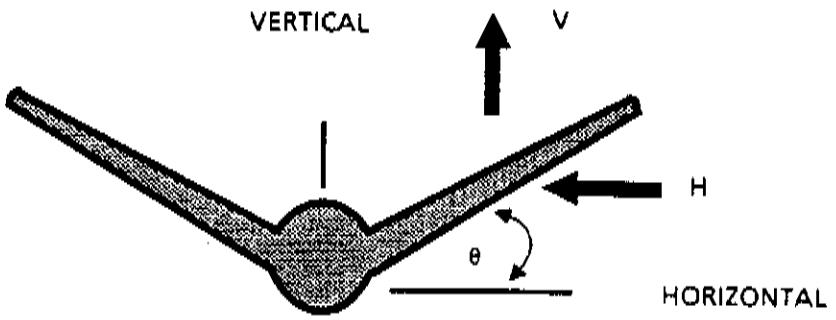


**FIGURE 4-10. DEFINITION OF V-TAIL LOAD PARAMETERS**

One other factor that influences flight loads is control stick force. The airworthiness regulations do not deal directly with stick force, but it should be considered when assessing airplane accidents. The two common measures of this property are stick force per "g" and stick force per degree of elevator deflection at various speeds. Stick force per "g" is generally measured in flight tests, while stick force per degree of elevator deflection can be estimated from tail-load calculations and the mechanical advantage built into the airplane's control system. Low values of both properties indicate an easily handled airplane. Low values also indicate an airplane for which certain flight loads might not be limited by pilot effort. A low stick force per "g" means that high-g pullups are easy to execute, while low stick force per unit elevator deflection means that a pilot can easily impose large transient loads on the tail.