USNTPS-FTM-No. 103

U.S. NAVAL TEST PILOT SCHOOL FLIGHT TEST MANUAL

FIXED WING STABILITY AND CONTROL
Theory and Flight Test Techniques

Chapter 6, Asymmetric Power

NAVAL AIR WARFARE CENTER
AIRCRAFT DIVISION
PATUXENT RIVER, MARYLAND

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FIXED WING STABILITY AND CONTROL
Theory and Flight Test Techniques

This Flight Test Manual, published under the authority of the Commanding Officer, U.S. Naval Test Pilot School, is intended primarily as a text for the pilots, engineers and flight officers attending the school. Additionally, it is intended to serve as a reference document for those engaged in flight testing. Corrections and update recommendations to this manual are welcome and may be submitted to:

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BACKGROUND AND PURPOSE

This manual is primarily a guide for pilots and engineers attending the U.S. Naval Test Pilot School. However, it may be used as a guide in any fixed wing flying qualities investigation. The text presents basic fixed wing stability and control theory, qualitative and quantitative test and evaluation techniques, and data presentation methods. In most sections, more than one technique is described for each test. Generally, the best technique for a particular investigation will depend on the purpose of the investigation, the amount of instrumentation available, and the personal preference of the individual test pilot. The approach of the qualitative stability and control testing presented herein is an attempt to associate all flying qualities tests with particular pilot tasks required in the performance of the total mission of the airplane. The pilot's opinion of a particular flying quality will consequently depend primarily on the pilot workload while performing the desired task. Quantitative evaluation techniques presented may be used to substantiate pilot opinion or gather data for documentation of airplane characteristics. The performance of both qualitative testing and quantitative evaluation is considered essential for any successful flying qualities investigation.

CHAPTER SIX

ASYMMETRIC POWER

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FIGURES

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EQUATIONS

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$N_T = F_N \; y_p$	*eq 6.1*	6.2
$F_{N_{Prop}} = \dfrac{550\eta_p \; BHP}{V}$	*eq 6.2*	6.3
$C_{n_{T_{Prop}}} = \dfrac{550\eta_p \; BHP}{V \;\; W} \; \dfrac{C_L \; y_p}{b} = \dfrac{550\eta_p \; BHP \; y_p}{V \; qSb}$	*eq 6.3*	6.3
SIDEFORCE $\quad C_{y_\beta} \; \beta + C_{y_{\delta_r}} \; \delta_r + C_L \; \varphi = 0$	*eq 6.4*	6.3
YAWING MOMENT $\quad \dfrac{F_N}{W} \; C_L \; \dfrac{y_p}{b} + C_{n_\beta} \; \beta + C_{n_{\delta_r}} \; \delta_r = 0$	*eq 6.5*	6.3
ROLLING MOMENT $\quad C_{\ell_\beta} \; \beta + C_{\ell_{\delta_a}} \; \delta_a = 0$	*eq 6.6*	6.3
$\delta_{r_{Equilibrium}} = \dfrac{-\,{}^{F_N}\!/_{W} \; C_L \;\; {}^{y_p}\!/_{b}}{C_{n_{\delta_r}}}$ (ZERO SIDESLIP)	*eq 6.7*	6.4
$\varphi_{r_{Equilibrium}} = \dfrac{-\;C_{y_{\delta_r}} \;\; \delta_r}{C_L}$ (ZERO SIDESLIP)	*eq 6.8*	6.4

$$\delta_{r_{\text{Equilibrium}}} = \frac{\begin{vmatrix} C_{y_\beta} & 0 \\ C_{n_\beta} & -\frac{F_N}{W} C_L \frac{y_p}{b} \end{vmatrix}}{\begin{vmatrix} C_{y_\beta} & C_{y_{\delta_r}} \\ C_{n_b} & C_{n_{\delta_r}} \end{vmatrix}} = \frac{-\frac{F_N}{W} \frac{y_p}{b} C_L C_{y_\beta}}{C_{n_{\delta_r}} C_{y_\beta} - C_{y_{\delta_r}} C_{n_\beta}}$$

eq 6.9 6.6

$$\delta_{r_{\text{Equilibrium}}} = \frac{-\frac{F_N}{W} \frac{y_p}{b} C_L}{C_{n_{\delta_r}} \left\{ 1 - \frac{C_{y_{\delta_r}}}{C_{n_{\delta_r}}} \frac{C_{n_\beta}}{C_{y_\beta}} \right\}} \text{ (ZERO BANK ANGLE)}$$

eq 6.10 6.6

$$\beta = -\frac{C_{y_{\delta_r}} \delta_r}{C_{y_\beta}} \text{ (ZERO BANK ANGLE)}$$

eq 6.11 6.6

$$\beta = \frac{-F_N/W \, C_L \, y_p/b}{C_{n_\beta}} \text{ (ZERO RUDDER)}$$

eq 6.12 6.7

$$\varphi = \frac{-C_{y_\beta} \beta}{C_L} \text{ (ZERO RUDDER)}$$

eq 6.13 6.8

$$\frac{L_0 - L_i}{W} C_L \frac{y_p}{b} + C_{\ell_\beta} \beta + C_{\ell_{\delta_a}} \delta_a = 0$$

eq 6.14 6.10

$$\delta_{a_{\text{Equilibrium}}} = -\frac{1}{C_{\ell_{\delta_a}}} \left\{ \frac{L_0 - L_i}{W} C_L \frac{y_p}{b} + C_{\ell_\beta} \beta \right\}$$

eq 6.15 6.10

CHAPTER SIX

ASYMMETRIC POWER FLYING QUALITIES

6.1 THEORY

6.1.1 General

The asymmetric power flying qualities problem is invariably a lateral-directional control problem. Yawing and/or rolling moments generated by the asymmetric power condition must be counteracted by airplane stability and pilot control inputs. Although asymmetric power control problems are generally confined to the low airspeed flight regime, serious airplane departures from controlled flight may be encountered with asymmetric engine failures at very high airspeeds. Asymmetric flying qualities may also result from the asymmetric carriage of external or internal stores.

Basically, two aspects of flight on asymmetric power must be considered:

1. <u>Regaining</u> of control immediately following failure of one or more engines.

2. <u>Maintaining</u> control in steady flight with one or more engines inoperative.

The steady or equilibrium flight condition with asymmetric power will be considered first. (Note: Most of the stability derivatives and symbols utilized in this discussion have been introduced previously. Therefore, many of these derivatives and terms will not be redefined here.)

6.1.2 Steady Straight Flight on Asymmetric Power

6.1.2.1 THE DIRECTIONAL CONTROL PROBLEM

Flight on asymmetric power is characterized by a <u>yawing moment</u> generated by the asymmetric condition (Figure 6.1). It is important to consider the factors influencing the magnitude of this yawing moment since the degree of difficulty associated with asymmetric power flight is generally directly related to this parameter. If the inoperative engine is assumed to generate no thrust or drag, the yawing moment generated by the asymmetric condition, N_T, may be developed as follows (Figure 6.1):

$$N_T = F_N \; y_p \qquad \textit{eq 6.1}$$

Where:

F_N = thrust developed by operative engine, pounds.

y_p = distance from center of gravity to asymmetric thrust vector measured in wing plane, feet.

In non-dimensional form, the yawing moment coefficient, C_{n_T}, may be expressed:

$$C_{n_T} = \frac{N_T}{qSb} = \frac{F_N y_p}{qSb}$$

$$\text{or for level flight } \left(\frac{W}{qS} = C_L\right):$$

$$C_{n_T} = \frac{F_N}{W} \, C_L \, \frac{y_p}{b}$$

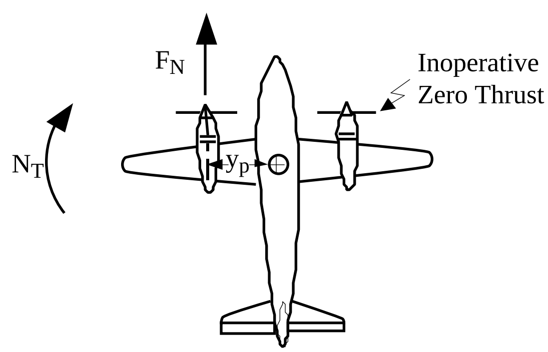


Figure 6.1
Yawing Moment Due to Asymmetric Power

Note that the asymmetric power yawing moment coefficient increases with increase in operative engine thrust, distance of operative engine from airplane center of gravity, and increase in lift coefficient (or decrease in airspeed).

Expressions for the thrust, F_N, developed by the operative engine will be different for jet and propeller-driven airplanes. For the jet, the thrust is simply F_N. However, for the propeller-driven airplane:

$$F_{N_{Prop}} = \frac{550 \eta_p \; BHP}{V} \qquad \textit{eq 6.2}$$

Where:

- 550 = horsepower constant, foot-pounds/second.
- η_p = propeller efficiency factor.
- BHP = brake horsepower, HP.
- V = airplane true airspeed, feet per second.

Thus, for the propeller-driven airplane:

$$C_{n_{T_{Prop}}} = \frac{550 \eta_p \; BHP}{V \;\; W} \; \frac{C_L \; y_p}{b} = \frac{550 \eta_p \; BHP \; y_p}{V \; qSb} \qquad \textit{eq 6.3}$$

The equilibrium equations for sideforce, yawing moment, and rolling moment may now be written as follows for the asymmetric power condition, ($C_{n_{\delta_a}}$ and $C_{\ell_{\delta_r}}$ are assumed to be zero for simplicity):

SIDEFORCE
$$C_{y_\beta} \beta + C_{y_{\delta_r}} \delta_r + C_L \varphi = 0 \qquad \textit{eq 6.4}$$

YAWING MOMENT
$$\frac{F_N}{W} C_L \frac{y_p}{b} + C_{n_\beta} \beta + C_{n_{\delta_r}} \delta_r = 0 \qquad \textit{eq 6.5}$$

ROLLING MOMENT
$$C_{\ell_\beta} \beta + C_{\ell_{\delta_a}} \delta_a = 0 \qquad \textit{eq 6.6}$$

(Note: Operative engine is assumed to be the port engine. If the starboard engine were operative, the asymmetric power yawing moment would be negative.)

Since the directional control problem with asymmetric power is of interest at present, expressions will be derived for the rudder required for steady heading, equilibrium flight under three flight conditions.

6.1.2.2.1 No Sideslip

If the pilot maintains zero sideslip, and expression for the rudder requirement may be obtained easily for the yawing moment equation:

$$\delta_{r_{Equilibrium}} = \frac{-\,{}^{F_N}\!/\!_{W}\; C_L \;\; {}^{y_p}\!/\!_{b}}{C_{n_{\delta_r}}} \text{ (ZERO SIDESLIP)} \qquad \textit{eq 6.7}$$

Several important relationships may be gathered from the last equation:

1. The rudder requirement increases with increasing asymmetric thrust, F_N .

2. The rudder requirement increases with increasing lift coefficient (decreasing airspeed).

3. The rudder requirement increases with lateral engine placement from the center of gravity.

4. The rudder required for equilibrium is inversely proportional to rudder control power.

Note that for zero sideslip, some bank angle must be used to balance the sideforce generated by the rudder input. From the sideforce equation:

$$\varphi_{r_{Equilibrium}} = \frac{-\,C_{y_{\delta_r}}\;\delta_r}{C_L} \text{ (ZERO SIDESLIP)} \qquad \textit{eq 6.8}$$

For a positive asymmetric yawing moment (starboard engine inoperative), trailing edge left (positive) rudder deflection is required; thus, a negative (left) bank angle is necessary to maintain equilibrium flight (Figure 6.2). In most cases, the bank angle requirement is fairly small (approximately 5 degrees).

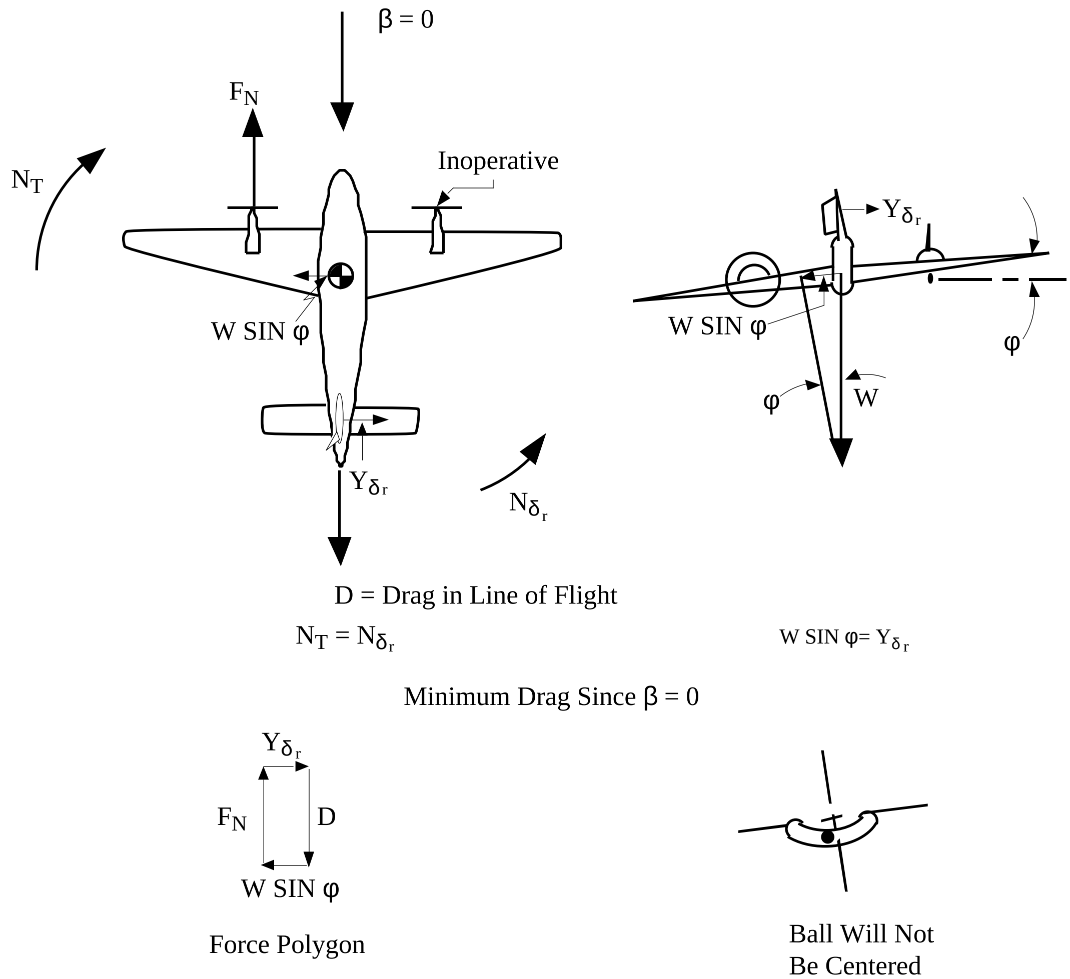


Figure 6.2
Equilibrium Asymmetric Power Condition with Zero Sideslip

6.1.2.2.2 No Bank Angle

If the pilot maintains <u>zero bank angle</u>, an expression for the rudder requirement for equilibrium, steady heading flight may be obtained via a determinant solution of the sideforce and yawing moment equations:

$$\delta_{r_{Equilibrium}} = \frac{\begin{vmatrix} C_{y_\beta} & 0 \\ C_{n_\beta} & -\frac{F_N}{W} C_L \frac{y_p}{b} \end{vmatrix}}{\begin{vmatrix} C_{y_\beta} & C_{y_{\delta_r}} \\ C_{n_b} & C_{n_{\delta_r}} \end{vmatrix}} = \frac{-\frac{F_N}{W} \frac{y_p}{b} C_L \; C_{y_\beta}}{C_{n_{\delta_r}} C_{y_\beta} - C_{y_{\delta_r}} C_{n_\beta}} \qquad \text{eq 6.9}$$

$$\delta_{r_{Equilibrium}} = \frac{-\frac{F_N}{W} \frac{y_p}{b} C_L}{C_{n_{\delta_r}} \left\{ 1 - \frac{C_{y_{\delta_r}}}{C_{n_{\delta_r}}} \frac{C_{n_\beta}}{C_{y_\beta}} \right\}} \text{ (ZERO BANK ANGLE)} \qquad \text{eq 6.10}$$

The only difference between the equation and the one derived for zero sideslip is the term in braces. This term can be rationalized as <u>increasing</u> the rudder requirement over the zero sideslip case; the increased rudder requirement will be necessary to balance the sideforce due to sideslip, C_{y_β}.

For zero bank angle, the <u>sideslip</u> required for equilibrium may be obtained from the sideforce equation:

$$\beta = -\frac{C_{y_{\delta_r}} \delta_r}{C_{y_\beta}} \text{ (ZERO BANK ANGLE)} \qquad \text{eq 6.11}$$

If the asymmetric yawing moment is positive, the rudder requirement is positive, therefore, the sideslip angle must be <u>positive</u> (right sideslip). The balance of moments and forces is shown in Figure 6.3.

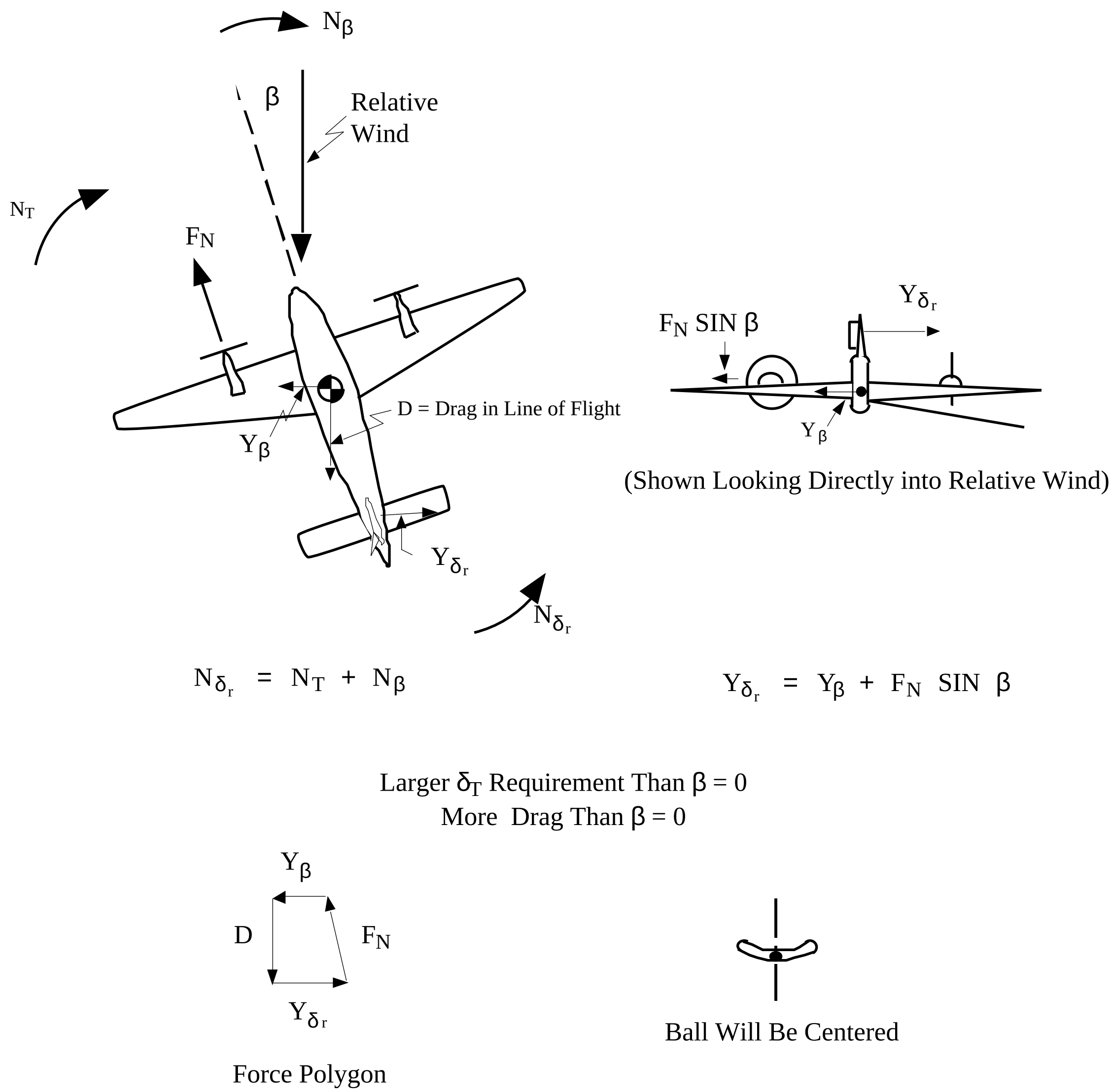


Figure 6.3
Equilibrium Asymmetric Power Condition with Zero Bank Angle

6.1.2.2.3 No Rudder Requirement

It is possible to balance the airplane in steady heading equilibrium flight under asymmetric power with <u>zero rudder required.</u> From the yawing moment equation, the sideslip required to balance the asymmetric yawing moment may be obtained:

$$\beta = \frac{-\,{}^{F_N}\!/\!{}_{W}\; C_L \;{}^{y_p}\!/\!{}_{b}}{C_{n_\beta}} \quad \text{(ZERO RUDDER)} \qquad \textit{eq 6.12}$$

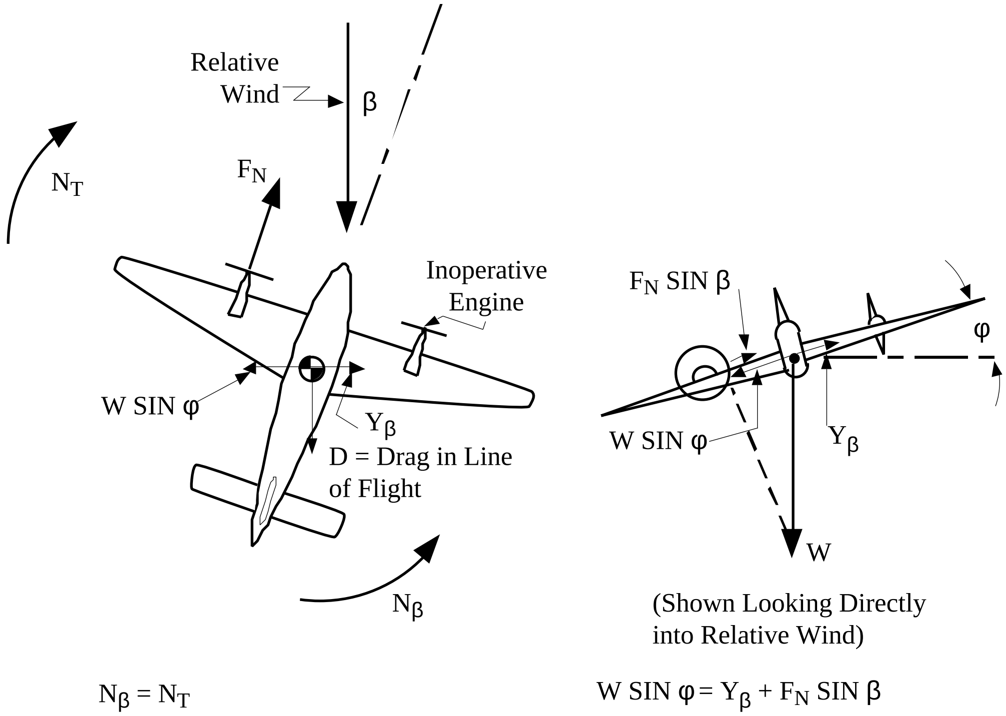
For a positive asymmetric yawing moment, the sideslip requirement is negative (left sideslip). The sideslip angle required for this condition is generally quite large, particularly at low airspeeds, high operative engine power, and with low directional stability.

The bank angle required to balance the sideforces for the zero rudder deflection condition may be obtained from the sideforce equation:

$$\varphi = \frac{-\,C_{y_\beta}\,\beta}{C_L} \quad \text{(ZERO RUDDER)} \qquad \textit{eq 6.13}$$

For a positive asymmetric yawing moment, the sideslip angle must be negative; therefore, the bank angle must be negative (left bank angle). This bank angle is generally quite large (approximately 15 degrees) at low airspeeds. The balance of forces and moments is show in Figure 6.4.

At first glance, the equilibrium condition shown if Figure 6.4 might seem to be a desirable state of affairs since the pilot is required to hold no rudder input. However, the drag is high, there is a possibility of losing directional control due to vertical tail stalling, and the flight condition is uncomfortable because of the large side acceleration due to gravity. Usually, the pilot will achieve equilibrium in a flight condition somewhere between the conditions shown in Figures 6.2 and 6.3. (The operative engine will be banked down about 3 degrees and there will be a small sideslip from the inoperative engine side. If the directional trim system is sufficiently powerful, the rudder force requirement for steady heading flight can be trimmed to zero.)



Large β and φ required; more drag than β = 0 or φ = 0.

Potentially dangerous since vertical tail may stall due to large β; very uncomfortable for pilots and passengers because large φ generates large side acceleration due to gravity.

Force Polygon

Ball Will Not Be Centered

Figure 6.4
Equilibrium Asymmetric Power Condition with Zero Rudder Deflection

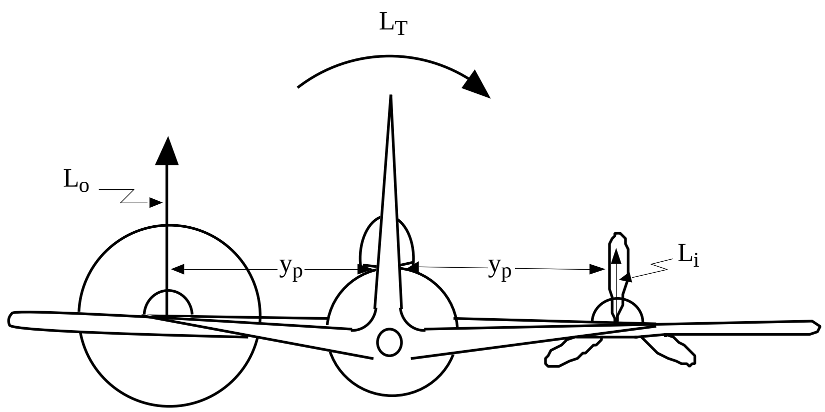
6.1.2.2.3 The Lateral Control Problem

Lateral controllability under equilibrium asymmetric power conditions is generally not as severe as the directional control problem. For pure-jet airplanes, minimum control speeds are almost always based on directional controllability. However, for propeller-driven airplanes under asymmetric power conditions, the differences in slipstream over the wings may generate large rolling moments (Figure 6.5). If the wings are almost completely immersed in propeller slipstream, the rolling moment generated by the asymmetric power condition may limit minimum airspeeds. Sideslip from the operative engine side coupled with positive dihedral effect (negative C_{ℓ_β}) complicates the lateral control problem. The lateral control requirement to counteract the rolling moments generated by asymmetric power and sideslip may be obtained from the equilibrium rolling moment equation:

$$\frac{L_0 - L_i}{W} C_L \frac{y_p}{b} + C_{\ell_\beta} \beta + C_{\ell_{\delta_a}} \delta_a = 0 \qquad \textit{eq 6.14}$$

(Note: If the asymmetric power rolling moment is in the left-wing-down direction, the first term of the equation will be preceded by a negative sign.)

$$\delta_{a_{\text{Equilibrium}}} = -\frac{1}{C_{\ell_{\delta_a}}} \left\{ \frac{L_0 - L_i}{W} C_L \frac{y_p}{b} + C_{\ell_\beta} \beta \right\} \qquad \textit{eq 6.15}$$



Higher dynamic pressure over wing with operative engine generates unbalanced lift vectors and rolling moment, L_T, toward inoperative engine wing

$$L_T = L_0 \; y_p - L_i \; y_p = y_p \left(L_0 - L_i\right)$$

$$C_{\ell_T} = \frac{L_T}{qSb} = \frac{y_p \left(L_0 - L_i\right)}{qSb} = \frac{L_0 - L_i}{W} C_L \frac{y_p}{b}$$

Figure 6.5
Rolling Moment Due to Asymmetric Power

6.1.3 Equilibrium Asymmetric Power Conditions

The previously discussed directional and the lateral control problems with asymmetric power will result in various equilibrium states. If an airplane displays conventional lateral-directional stability derivatives as shown on page V-33, the equilibrium flight conditions resulting from the failure of a right engine will be as shown in Figure 6.6.

Several things should be noted in Figure 6.6. Control of the airplane may be limited by either rudder or aileron. Although the rudder deflection required is reduced if the airplane is banked into the operating engine, high bank angles may be uncomfortable to the pilot and may be geometrically restricted in the take-off and landing environment. Furthermore, in order to maintain a constant vertical velocity with increasing bank angles, C_L must be increased with the resulting increase in induced drag and stall speed while increasing sideslip angles will result in higher form drag. These performance and control considerations will determine the optimum equilibrium flight condition and this optimum will probably be specified as a function of bank angle since that is the most obvious parameter to the operational pilot.

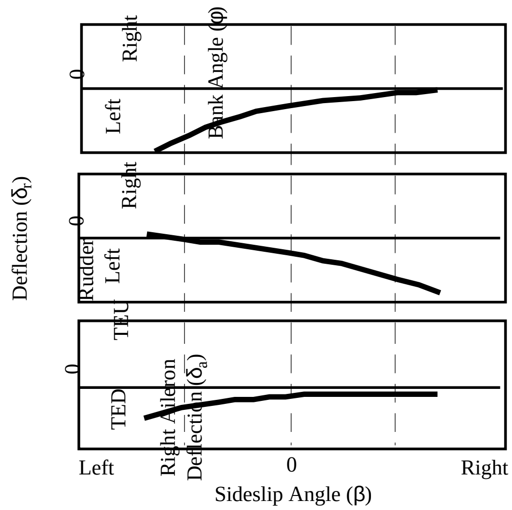


Figure 6.6
Asymmetric Power Equilibrium Flight Conditions Right Engine Failed

6.2 REGAINING CONTROL FOLLOWING SUDDEN ENGINE FAILURE

6.2.1 Engine Failure During Flight

When the pilot intentionally secures as engine in flight, the transient motions are generally mild and easily controlled if adequate control authority is available. However, sudden engine failures may occur under low altitude, low airspeed, high power flight conditions in a high lift or high drag configuration, such as during take-off or wave-off. The sudden engine failure in these cases may generate severe, potentially divergent rolling and/or yawing transients. The pilot may induce a similar situation by sudden application of asymmetric power to initiate a wave-off from an engine-out-approach.

The same factors which cause lateral-directional control problems in steady asymmetric flight conditions also are applicable to the sudden or dynamic engine failure. However, the control authorities required to arrest the motion following a sudden engine failure are usually larger than the control authorities necessary to maintain equilibrium flight. The severity of airplane response following a sudden engine failure is difficult to predict by theoretical analysis; the pilot delay time in recognizing the asymmetric power condition and applying appropriate control inputs influences the magnitude of the rolling and yawing motions. Actual flight test of critical conditions is the only means of establishing safe flight boundaries. The following hypothetical situation may aid in understanding some of the problems encountered with sudden engine failures (Figure 6.7).

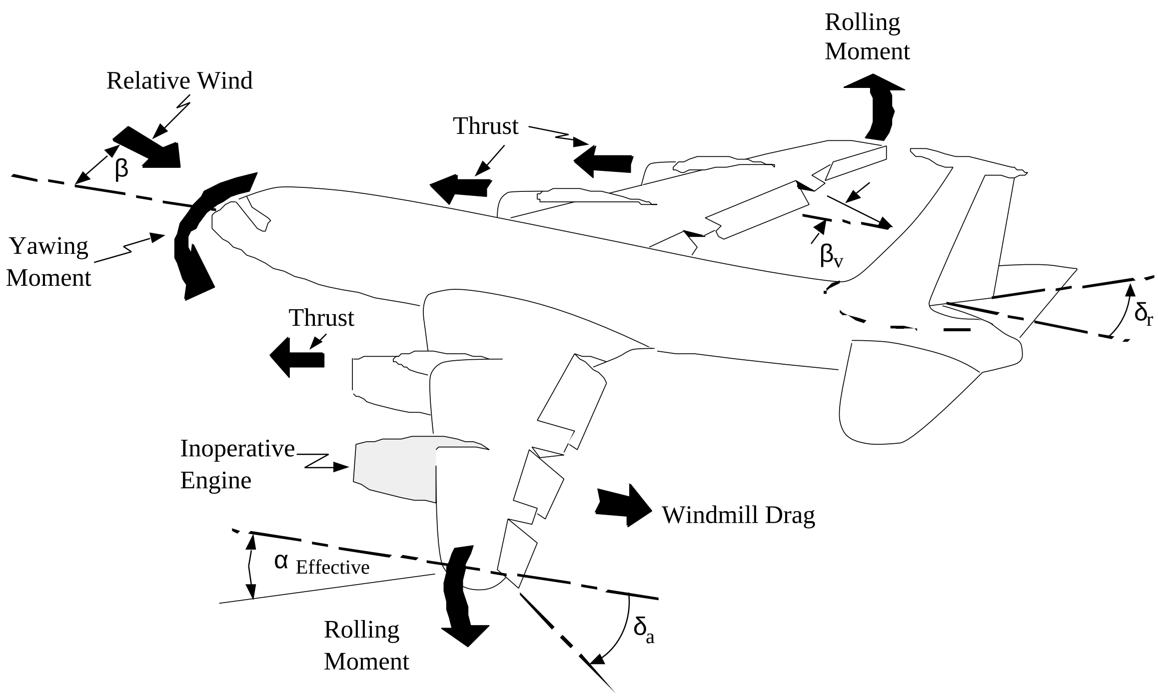


Figure 6.7
The Sudden Engine Failure

1. Assume the airplane is in a critical phase of flight, take-off configuration, take-off power on all engines, just after lifting off the runway.

2. The pilot experiences a sudden power failure on the left outboard engine. Because of the surprise factor, the pilot does not immediately react to the situation. The large yawing moment generated by the asymmetric power causes a large sideslip angle to develop <u>from the operative engine side</u>. If the sideslip angle reaches large enough proportions, the vertical tail may stall. An increase in drag accompanies the increase in sideslip, compounding an already (possibly) serious performance deficiency.

3. A rolling moment toward the inoperative engine will probably be generated by the yaw rate. This rolling moment will be increased if the airplane exhibits positive dihedral effect. Propeller-driven airplanes may rapidly diverge in roll due to slipstream effects, particularly if the wings are completely immersed in slipstream prior to the engine failure.

4. The pilot will likely apply large rudder and lateral control inputs to attempt to arrest the yawing and rolling motion. The large rudder input increases the tendency for the vertical tail to stall and may result in "rudder lock" if the control system is reversible. The lateral control input may generate an adverse yawing moment which increases the yawing moment toward the inoperative engine side. The large lateral control deflection, coupled with the rolling velocity, may cause the down-going wing to exceed stall angle of attack.

5. If the pilot is unable to achieve equilibrium flight with full lateral and directional control inputs, a <u>power reduction</u> on the operative engine side and/or an <u>increase in airspeed</u> will be required to prevent catastrophic consequences. Obviously, these measures may not be possible in a low altitude, marginal performance flight condition.

6.2.2 Engine Failure During Take-off

Engine failure on the ground during a take-off run is always a dynamic situation since the pilot must either abort his take-off or continue to accelerate to a lift-off airspeed. The ground minimum control speed will differ from the flight minimum control airspeed because of several things.

1. The inability to use bank angle and restrictions on the use of sideslip.

2. The moment arms for the vertical stabilizer and rudder are changed since they are taken from the airplane center of gravity in flight but generally act from the main landing gear while on the ground.

3. Additional yawing moments are produced on the ground by the landing gear and vary with the amount of side forces and differential longitudinal forces on the landing gear, the amount of steering used, and the runway condition.

4. Cross wind components essentially determine the take-off sideslip angle. Since the airplane must, in general, maintain the runway heading during take-off, the cross wind, in conjunction with the airplane's ground speed, will determine the magnitude of the sideslip and whether it is helping or hindering directional control of the airplane during a sudden engine failure.

6.3 ASYMMETRIC POWER PROBLEMS AT HIGH AIRSPEEDS

For the high performance, multiengined airplane, the failure of an engine or engines at high airspeed may be a more serious consequence than engine failure at low airspeeds. Asymmetric engine failure at high airspeeds may generate sideslip excursions large enough to exceed sideslip limitations and cause structural damage or catastrophic component failures.

For proper jet engine operation at very high Mach Numbers (over 2.0), the engine inlet shock wave pattern must be fashioned to provide the correct pressure in the engine for the given engine speed. If a disturbance (pressure of temperature fluctuation, abrupt power lever movement, etc.) upsets the shock pattern-pressure relationship, the shock wave may actually be expelled from the engine inlet. This phenomenon, known as "inlet unstart," can cause severe pressure fluctuations, compressor stalls, and engine failure. When engines are located in close proximity, one "inlet unstart" may trigger "inlet unstarts" on adjacent engines.

Asymmetric power problems at high airspeeds in high performance multiengined airplanes may be compounded by reduced directional stability at high supersonic Mach numbers and high altitude. These problems may result in limiting maximum airspeed or Mach numbers as <u>functions of engine thrust settings</u>. Another possible solution is to fail the corresponding engine on the opposite wing <u>automatically</u> in the event of engine failure in a flight condition where asymmetric thrust is <u>catastrophic</u>.

6.4 DEFINITIONS RELEVANT TO ASYMMETRIC POWER

Terminology used to describe airspeeds and conditions associated with asymmetric power flight is not standard throughout the aviation industry. The differences between civilian and military regimes are particularly noteworthy. When describing asymmetric power problems, the speaker or writer must be very careful to define the terminology of the presentation so that no misunderstanding is possible. The following definitions are <u>generally</u> considered to be standard by <u>most</u> flight test activities.

6.4.1 Critical Engine

The critical engine is that engine of a multiengined airplane, the failure of which produces the most critical condition to the pilot. The most critical condition will probably occur at high thrust and low airspeed (high C_L) as is the situation during take-off or wave-off. Under this condition, lateral or directional control cannot be regained and maintained following a sudden engine failure below a certain airspeed. The critical engine is the engine for which this minimum airspeed is higher than that associated with failure of any other engine. The critical engine may generally be predicted for a propeller airplane. Providing that the airfoil surfaces (wings, vertical, and horizontal stabilizers) are symmetrically attached to the fuselage and that the available control surface deflections are symmetric, the critical engine may be predicted from several factors: (1) as the angle of attack increases (high C_L), the down-going propeller blade sees a relatively higher local angle of attack than the up-going blade, which results in moving the thrust vector laterally on the propeller disk toward the down-going blade side, and (2) air flow swirl about the fuselage created by the rotating propeller(s) can affect the flow at the vertical tail so as to create a sideslip angle in one direction or the other, depending on the direction of the rotation of the propeller(s).

For clockwise rotation of the propeller(s) (as viewed from the rear), the above effects usually result in the left outboard engine being the critical one.

For jet-powered airplanes, the differences observed between flying qualities with left or right engine(s) inoperative are usually small enough to be attributed to differing maximum of idle thrust between the engines. Thus, the critical engine is not clearly defined by asymmetric flying qualities considerations. For these cases, other considerations, such as hydraulic or electrical power generated by individual engines and the consequences of loss of various airplane functions, may be used to determine the critical engine.

6.4.2 Minimum Control Ground Speed, V_{mcg}

The minimum control ground speed is the lowest speed at which directional control can be maintained on the ground when the critical engine fails during the take-off roll. The allowable deviation from the runway centerline and the pilot technique utilized influence the value of this speed.

6.4.3 Minimum Control Airspeed, V_{mca}

The minimum control airspeed is the lowest airspeed at which control of the airplane is possible with the critical engine inoperative. It may be defined by an equilibrium or static condition in which the critical engine has been failed prior to approaching the minimum conditions. It may also be defined by a sudden or dynamic condition in which the critical engine is failed at various airspeeds approaching the minimum conditions. For both cases, V_{mca} may be limited by lateral or directional control deflection available to counteract rolling or yawing moments and/or the control forces involved. At any rate, there will be a different static and dynamic minimum control airspeed for each:

1. Power setting utilized on the operative engine(s).

2. Configuration.

3. Condition of the inoperative engine(s) (feathered or wind-milling).

4. Bank angle utilized in the static condition.

5. Pilot if limited by control force requirements.

6.4.4 Safety Speed

Safety speed is defined as the lowest possible airspeed on a multiengine airplane at which the average pilot can maintain steady, straight flight without loss of altitude in the take-off configuration in the event of a sudden, complete failure of the critical engine. The pilot may make full use of all flight controls, may make configuration changes (retract landing gear, flaps, etc.), and the propeller of the failed engine may be manually feathered after allowing a suitable delay for an average pilot to regain steady, straight flight and identify the failed engine. Use of automatic feathering systems is permitted; however, the power on the operating engine(s) may not be reduced and no trim inputs may be utilized. Generally, it is the airspeed which should be attained after take-off before any attempt is made to climb (a pilot's handbook number). Safety speed may be established based on stability and control or performance characteristics, or both. The take-off safety speed for civil airplanes (transport category), commonly referred to as V_2, depends on both flying qualities and performance. Generally, there is a different safety speed, or V_2, for each flap setting used for takeoff; it may also vary with gross weight.

6.4.5 Refusal Speed

Refusal speed is defined as the maximum ground speed from which the airplane can be brought to a full stop in the remaining runway available after failure of the critical engine. This speed depends on stopping technique (maximum effort is normally utilized) as well as the length of the runway. Refusal speed is low for short runways and high for long runways (Figure 6.8). It is also sometimes called Accel/Stop speed, Emergency Distance speed, or V_{stop}.

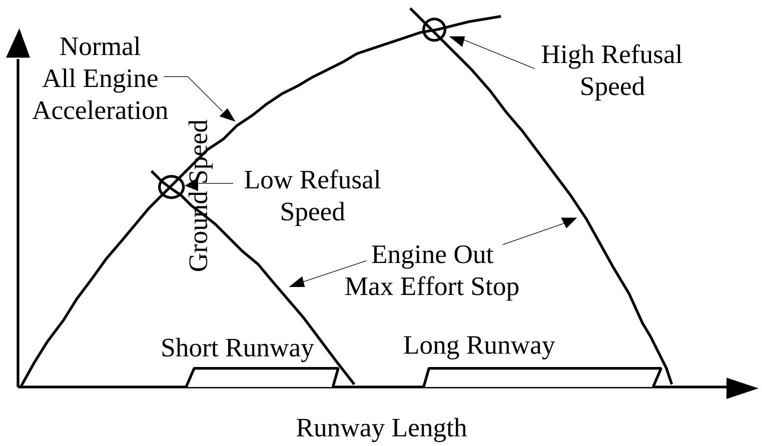


Figure 6.8
Refusal Speed Varies Directly with Length of Runway

6.4.6 Minimum Continue Speed

Minimum continue speed is the minimum ground speed to which an airplane can accelerate on the take-off roll, lose the critical engine, and continue the take-off with engine failed, becoming airborne just at the far end of the runway. This speed varies inversely with runway length; i.e., it is relatively low for long runways, etc. It is frequently referred to as Engine-Out Go Speed or V_{go}. If minimum continue speed is less than refusal speed, there is a "safe band" within which the pilot can either continue the take-off safely or abort the take-off safely (Figure 6.9). However, if refusal speed is less than minimum continue speed, there is a "dead man zone" within which the pilot can neither continue the take-off without running off the end of the runway nor abort the take-off without running off the end (Figure 6.10).

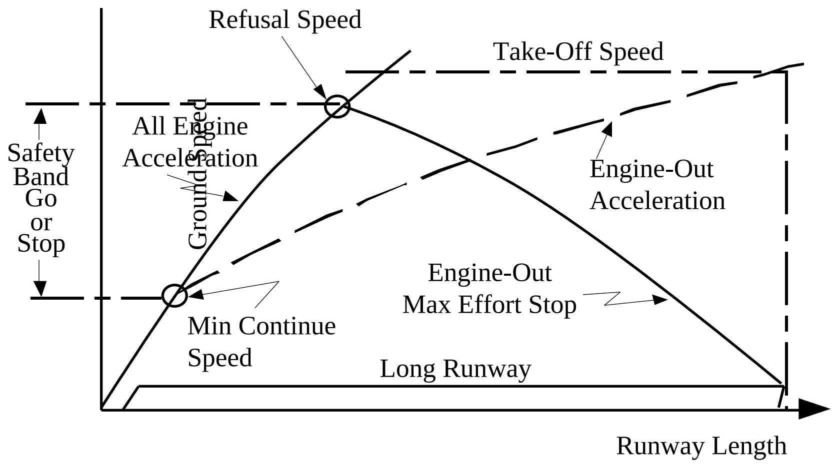


Figure 6.9
Refusal Speed Higher than Minimum Continued Speed

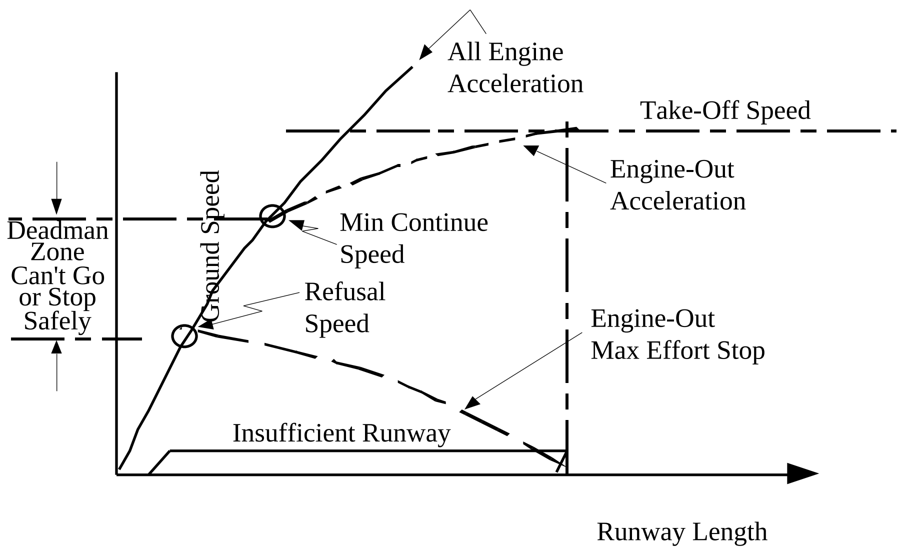


Figure 6.10
Minimum Continue Speed Higher than Refusal Speed

6.4.7 Critical Engine Failure Speed

If refusal speed and minimum continue speed are equal, the runway distance required to complete the take-off is equal to the distance required to stop. This speed is sometimes referred to as the Critical Engine Failure Speed or Decision Speed (V_1). The total runway distance required to accelerate to this speed, then stop or go after the engine failure, is called the Critical Field Length (Figure 6.11).

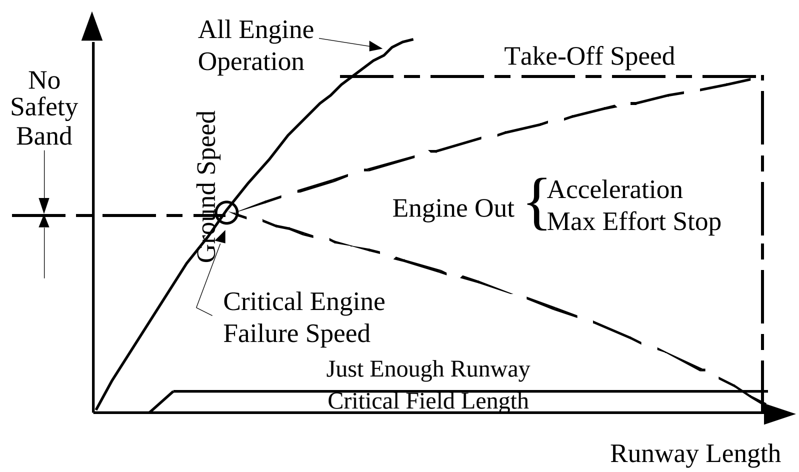


Figure 6.11
Critical Engine Failure Speed and Critical Field Length

6.4.8 Minimum Trim Airspeed

Minimum trim airspeed is the minimum airspeed at which steady heading flight can be maintained without pilot control force inputs with the critical engine inoperative. A different minimum trim airspeed exists for each configuration, power setting on operative engine(s), condition of inoperative engine, and bank angle (if limiting factor is directional trim). Minimum trim airspeed is most appropriately applied to an engine-out cruise condition with power for level flight or engine-out climb with normal rated power on the operative engine(s) and the inoperative engine feathered. These conditions relate to the problem of operation for relatively long periods during climb or cruise with an engine out.

6.5 TEST PROCEDURES AND TECHNIQUES ASYMMETRIC POWER

6.5.1 Preflight Procedures

A safe, yet rigorous, investigation of asymmetric power flying qualities must be conducted on all airplanes which may be expected to encounter asymmetric power. Thorough preflight planning is mandatory for these tests. The purpose and scope of the investigation must be clearly defined, then a plan of attack or method of test can be formulated.

Preflight planning must start with research. The airplane must be studied carefully - the flight test team can probably predict (roughly) the airplane's reaction to asymmetric power merely by looking at the airplane. Of course, a study of the lateral-directional control system is essential. All available information on normal lateral-directional flying qualities, rolling performance, and asymmetric power flying qualities and performance should be reviewed. Much useful information may be obtained by conversations with pilots and engineers familiar with the airplane. Additionally, the following points should be considered:

1. The function and influence of various flap settings; i.e., the airplane lift-to-drag ratio for various flap settings.

2. The consequences of engine-out operation of electrical, hydraulic, or pneumatic systems. Emergency electrical and/or hydraulic units may be required in the test airplane, particularly if a situation may arise where no normal electrical or hydraulic power is available.

3. The ability of the electrical system to carry the combined load of propeller feathering and landing gear or flap retraction.

Although the basic considerations of flight with asymmetric power are the same for both military and civil airplanes, the emphasis attached to the asymmetric power flying qualities varies. In the civil case, safety is the most important factor; the airplane must meet rigid minimum requirements before it is placed in operational commercial use. The same emphasis on safety will probably be applicable to large military transport airplanes as well.

For the commercial transport category airplanes, extensive ground and flight tests must be performed to determine safety speeds (V_2), refusal speeds (V_{stop}), minimum continue speeds (V_{go}), critical engine failure speeds (V_1), and critical field lengths. Based on these tests, the commercial transport airplane is certificated to operate from various runway lengths with various combinations of gross weights and center of gravity positions. The military transport airplane may be required to satisfy similar requirements. In many cases, the military transport has already been certificated as a commercial transport, and the minimum requirements for military operations already satisfied.

For the majority of military multiengine airplanes, operational effectiveness, vice safety, may be the most important design factor, particularly for combat aircraft. This fact lays a heavy burden on the test pilot designated to conduct asymmetric power tests on military airplanes. The test pilot must attempt to safely evaluate all asymmetric power conditions which may confront the operational pilot. If possible, the flight test team should attempt to extrapolate the results of the test to future service modifications, such as increased gross weight, increased engine output, etc.

Testing the engine-out characteristics of a military, multiengine airplane should include at least the following:

1. Determine the critical engine in the most critical configuration (probably take-off or wave-off).

2. Determine normal take-off acceleration (ground speed versus runway distance).

3. Determine take-off acceleration with the critical engine failed.

4. Determine abort deceleration with the critical engine failed.

5. Determine the minimum control ground speed with the critical engine failed.

6. Determine the minimum control airspeed, both static and dynamic.

7. Determine the minimum trim airspeed in pertinent configurations (probably

Engine Out Power and Engine Out Cruise (Power of maximum range)).

8. Evaluate approach, landing, and wave-off characteristics with asymmetric power.

The test conditions - altitude, configurations, center of gravity, and trim airspeeds - must be determined. Test conditions should commensurate, as much as possible, with the <u>mission environment</u> of the airplane. However, safety considerations dictate the investigations of asymmetric power flying qualities be performed in such a manner that the most critical conditions are approached with a reasonable build-up program. Altitude for conducting initial tests wherein engines are actually secured should never be less than <u>4000 feet above ground level</u>. After <u>adequate build up</u> and with <u>written permission</u> from higher authority, the altitude restrictions may be relaxed so that engines may be secured in the very low altitude environment. Generally, <u>simulated failures</u> yield equally valid results at very low altitudes with much less risk. The airplane gross weight utilized for asymmetric power <u>flying qualities</u> investigations should be the <u>lightest normal service loading</u> for the configuration of interest. The light weight provides the best asymmetric power performance characteristics as well as allowing the maximum airplane response to a sudden engine failure. Additionally, for tests involving <u>banking</u> to balance the airplane under asymmetric power conditions in level flight, the <u>bank angle</u> required is inversely proportional to airplane gross weight. Center of gravity positions are not particularly critical for asymmetric power investigations; however, the most aft operational center of gravity positions should be utilized if feasible.

The amount and sophistication of instrumentation will depend on the purpose and scope of the investigation. A good, meaningful qualitative investigation can be performed with only cockpit and hand-held instruments. If accurate quantitative information is needed, automatic recording devices should be utilized. For initial tests on a new airplane, or for test on airplanes which may exhibit severe characteristics, telemetering pertinent parameters to a ground station may be required. A qualified engineering observer, with communications to the test pilot, should continually monitor the flight test records.

The final step in preflight planning is the preparation of pilot data cards. These data cards are best constructed from blank cards for each particular test. The cards should list all quantitative information desired and should be easy to interpret in flight. Adequate space should be provided for pilot comments.

6.5.2 Flight Test Techniques

When assessing the asymmetric power flying qualities of multiengine airplanes, the mission of the airplane and the influence of engine failure(s) on that mission must be considered. The failure of one or more engines asymmetrically generally results in an emergency condition. The primary mission of the airplane can usually not be accomplished in this situation; therefore, the mission reverts to regaining control of the airplane, cruising to a suitable landing spot, and accomplishing a safe carrier or filed landing. The pilot cannot expect flying qualities under asymmetric power conditions to be particularly pleasant; however, the pilot rightly expects acceptable characteristics which permit the airplane to be at least controllable. Some airplanes may, however, be designed to carry stores asymmetrically or to shut down engines asymmetrically for increased endurance and should therefore retain pleasant flying qualities even in these configurations.

6.5.2.1 PRELIMINARY TESTS

Certain preparatory tests are necessary before the asymmetric power tests are performed.

6.5.2.1.1 Check-Stalls

The airplane should not be stalled with asymmetric power until the stall characteristics and asymmetric power characteristics have been determined. A stall speed should, therefore, be determined for each test configuration with all engines at idle power. In subsequent asymmetric power tests, the stall speed should be regarded as minimum speeds; if the stall speed is reached prior to reaching minimum control speed, the asymmetric power investigation should be terminated. (This rule may be unduly restrictive for airplanes with the wings immersed in propeller slipstream. If so, additional check-stalls should be performed in theses airplanes with symmetric power representative of the test configuration.)

6.5.2.1.2 Sideslip

It is most important to determine if the airplane is prone to vertical tail stall or rudder lock prior to embarking on asymmetric power tests. Therefore, for each test configuration, steady heading sideslips, up to maximum permissible or obtainable sideslip angle, should be performed with symmetric power. The airspeed generally used for this test is approximately 1.4 times the stall speed previously determined for the configuration. The variation of indicated airspeed error and angle of attack with sideslip angle should also be noted because of the obvious impact of these characteristics of safety of flight with asymmetric power.

6.5.2.1.3 Failure Simulation

Power settings should be determined which simulate the drag characteristics of a failed jet engine or the drag characteristics of both a windmilling and a feathered propeller. These simulated power settings are convenient and relatively safe means of conducting asymmetric power testing and will be used by operational pilots for engine-out training. Since these drag characteristics will obviously vary with airspeed, a representative airspeed and configuration should be used to determine the simulation. This should be done both with propeller windmilling and with the propeller feathered for propeller airplanes. Determination of the simulation power setting will in general be an iterative process as follows:

1. Determine a static minimum control airspeed in the representative configuration (probably Power Approach) using idle thrust for jets and throttle closed, propeller windmilling for propeller airplanes.

2. Increase airspeed to a safe margin (at least 1.4 times the minimum control airspeed just determined) and secure the critical engine.

3. Carefully slow to approximately 1.2 times the previously determined minimum control speed and stabilize in level flight using power from the operative engine(s). This airspeed should be representative of take-off and approach airspeeds.

4. Without changing power on the operative engine(s), restart the secured engine and vary its power so as to re-stabilize in level flight at the airspeed determined in paragraph 3. This power setting should then be a good failure simulation.

5. Continue asymmetric power testing using the failure simulation to more precisely determine the minimum control airspeeds, etc.

6.5.2.1.4 Critical Engine

Several assumptions may generally be made in determining the critical engine. If we assume that the take-off configuration is representative of the most critical configuration, that idle thrust or idle power is approximately the same as that from a failed engine, and that the engine with the highest minimum control speed in a dynamic failure will also have the highest minimum control speed in a static case, then the critical engine may be determined as follows:

1. Determine a static minimum control airspeed, wings level, in the take-off configuration using idle power on the left outboard engine and maximum power on the remaining engines. Trim should probably remain at the take-off setting as this is the most representative case.

2. Alternate the test with the right outboard engine. The idle and maximum power settings used above should be adjusted slightly to ensure that the exact same power asymmetry exits in each direction so that thrust differences caused by engine trim at maximum power do not affect the test.

3. The engine with the <u>highest</u> minimum control airspeed may then be assumed to be the critical engine.

6.5.2.2 CONTROL IN STEADY FLIGHT WITH ASYMMETRIC POWER: MINIMUM TRIM AND MINIMUM CONTROL AIRSPEEDS IN EQUILIBRIUM FLIGHT

The pilot will generally be able to cope with sudden failures under normal cruise flight conditions with little difficulty. Therefore, the primary purposes of asymmetric power flying qualities investigations under cruise conditions are:

1. To determine the degree of difficulty the pilot will encounter in a long-range cruise task with asymmetric power.

2. To provide a "build-up" to more demanding and critical tests in take-off and wave-off flight conditions.

Obviously, an infinite number of minimum trim and minimum control airspeeds could be determined as the result of variations in configuration, power setting, and bank angle. The test pilot should determine appropriate conditions, in which to evaluate these minimum trim airspeeds. For minimum trim airspeed determinations, several obvious conditions would include engine-out climb and engine-out cruise. Engine-out climb initial conditions would be: critical engine simulated failed (and feathered for propeller airplane), maximum continuous (normal rated) power on the operating engine(s), and zero bank angle. Engine-out cruise would require: critical engine simulated failed (simulated feathered for a propeller airplane), power set on operating engine(s) to provide level flight at engine-out maximum range airspeed, and zero bank angle. Since the drag due to sideslip may be reduced by flying in a slight bank, it may be advisable to determine the minimum trim airspeed in the above configuration using the bank angle for minimum drag. It is obviously desirable to be able to climb, hands off, at the optimum maximum range engine-out climb airspeed and to cruise, hands off, at the maximum range engine-out cruise airspeed.

6.5.2.2.1 Minimum Trim Airspeed

The minimum trim airspeed may be determined as follows:

1. Stabilize in the desired configuration at approximately twice the stall speed determined in the preliminary tests.

2. Establish the critical engine in a simulated feathered condition and the other engine(s) at the desired power setting.

3. Trim all control forces to zero in steady heading flight, initially maintaining zero bank angle.

4. Smoothly and slowly reduce airspeed by means of longitudinal control inputs while maintaining steady heading flight. Continue to trim all control forces to zero as the airspeed decreases.

5. Eventually an airspeed will be reached where one or the other of the lateral or directional trimmers is at its limit. Below this airspeed, the pilot cannot trim all control forces to zero in steady straight flight. This is the minimum trim airspeed for the test conditions and the limiting trim axis (lateral or directional) should be noted.

6. If the limiting trim axis was directional, the test may be continued by applying a small bank angle (usually 5 degrees) towards the good engine.

7. Care must be exercised to obtain data only when the airplane is stabilized in unaccelerated flight conditions. Primarily, outside visual references should be used to maintain bank angle as desired and zero yaw rate; cockpit instruments should be cross-checked frequently. The ball of the needle-ball instrument should be perfectly centered in its race during wings level tests. It is an excellent indicator of lateral accelerations resulting from unbalanced lateral forces.

8. Altitude variance during the determination of minimum trim airspeeds should not exceed ±1000 feet from the test altitude.

6.5.2.2.2 Static Minimum Control Airspeed

The test pilot must carefully define both configuration and trim settings for static minimum control airspeed testing. In general, the primary interest should be in critical flight evolutions such as take-off and wave-off. Trim controls may be left at some specified setting during static minimum control testing or may be used to their full range as required depending on what the test pilot determines is most representative. The most critical condition will usually be the take-off case. When testing for this condition, the trim settings should be those normally recommended for take-off. Static minimum control airspeed may be determined as follows.

1. For the initial determination of V_{mc} (static), stabilize at approximately twice the stall airspeed in the desired configuration and set the desired asymmetric power (simulate the failed engine using the previously determined power setting). Subsequent investigation of V_{mc} (static) may be made by stabilizing initially at approximately 1.4 times the V_{mc} previously determined.

2. Smoothly and slowly reduce airspeed by means of longitudinal inputs while using lateral and directional controls to maintain steady, straight flight with zero bank angle. If testing for the engine failure after take-off case, trimmers must remain at the settings recommended for take-off with symmetric thrust. If desired, stabilize at predetermined airspeed intervals (3-5 KIAS increments) and record estimated or measured control forces and deflections; otherwise continue to decelerate at a rate which should not exceed 0.5 KIAS/second.

3. Eventually, an airspeed will be reached where either full directional or full lateral control surface deflection is required to maintain steady heading, wings level flight. In some cases, the strength capacity of the pilot will be reached prior to full control deflection. This airspeed, below which steady heading, wings level flight cannot be maintained, is the <u>minimum control airspeed for the test conditions</u>. This airspeed and the limiting factor (usually directional or lateral control deflection or force) should be noted.

4. If the limiting factor is directional control deflection or rudder force requirements, minimum control airspeed can be <u>reduced</u> by banking toward the operating engine(s). (Obviously, different minimum control airspeeds could be determined for each bank angle utilized. Empirically, <u>5 degrees</u> of bank has generally been used as an approximation to the optimum bank angle considering both performance and flying qualities.) If appropriate, minimum control airspeed and limiting factor with 5 degrees of bank should be determined.

5. If at any point during the minimum control airspeed tests, the pilot loses lateral or directional control of the airplane, control may be regained by increasing airspeed and reducing power on the operative engine(s) (or increasing power on the simulated inoperative engine).

6. After determining minimum control airspeeds with the critical engine in a simulated feathered condition, the airspeeds may be checked with the critical engine actually secured and the propeller actually feathered.

7. The static minimum control airspeed does not imply that the airplane is unsafe to fly at a lower airspeed either by slightly reducing the power asymmetry or by accepting a resulting yaw rate. If the power asymmetry is maintained, the airplane may or may not be safe to fly below the minimum control airspeed depending upon whether the departure from controlled flight is a mild (but steady) yaw rate or it is more violent or radical.

6.2.5.2.3 Qualitative Investigation

After the quantitative tests described above, the test pilot should conduct a qualitative investigation of the flying qualities exhibited at representative cruise airspeeds with asymmetric power. The pilot should be able to trim all control forces to zero at these airspeeds without undue effort. Turns and heading changes, representative of maneuvers required in instrument or visual cruise conditions, should be performed to determine if excessive pilot coordination, control forces, or control movements are required. Generally, bank angle changes of up to 30 degrees from wings level are considered adequate for most maneuvering on asymmetric power.

6.5.2.3 CONTROL IMMEDIATELY FOLLOWING AN ENGINE FAILURE: MINIMUM CONTROL AIRSPEEDS WITH SUDDEN ENGINE FAILURES

The difficulty the pilot experiences in maintaining control of the airplane following sudden, asymmetric power failures increases with the following factors:

1. Increase in the operating engine power output. For a constant throttle or power lever position (assume full or maximum), engine thrust usually increases as altitude decreases.

2. Decrease in airspeed.

3. Decrease in excess power available for climb and acceleration.

Thus, the take-off and wave-off flight conditions, characterized by high power settings, low airspeeds, low altitude, and high drag configurations, are generally the most critical for the investigation of sudden engine failures. The asymmetric power flying qualities in these conditions should allow the average operational pilot to regain and maintain control of the airplane at all airspeeds representative of operational procedures.

Minimum dynamic control airspeed for the average pilot experiencing a sudden failure of the critical engine may be determined as follows:

1. Stabilize at approximately twice the stall speed (or 1.4 times the static minimum control speed) determined in the preliminary tests in the desired configuration at a safe test altitude. Power should be maximum obtainable or allowable on all engines and trim should be set for a symmetric power take-off (take-off configuration) or for a normal symmetric power approach (wave-off configuration).

2. Smartly reduce the power on the critical engine to minimum power, simulating a sudden failure. The test pilot should pause a reasonable time interval to account for the surprise factor of a sudden engine failure under operational conditions. Engine failure cues should be determined (yaw, roll, audio, or cockpit instrument) and a suitable reaction delay time should then be specified and used for continued testing. In no case should recovery control inputs be applied until

1 second has elapsed, a 20 degree bank angle change has occurred, or the sideslip limit is reached (whichever occurs first). After the time delay, steady, straight flight conditions should be regained at the original stabilized airspeed. Longitudinal, lateral, and directional control inputs may be used as required to effect the recovery to controlled flight.

3. The test pilot should note control forces and positions required while regaining control and to maintain steady, straight flight with less than 5 degrees of bank. If automatic recording devices are available, the entire maneuver, from "power chop" to steady, controlled flight, should be recorded.

4. Reduce the airspeed at which engine failure is simulated by small increments (5-10 KIAS) and repeat steps 2 and 3. An alternative method of build-up would be to make several power chops at each stabilized airspeed starting with a very slow power reduction (approximately a static condition), resetting symmetric power, and incrementally increasing the speed of the power reduction until it becomes a true power chop.

5. Eventually an airspeed will be reached where control can barely be regained or where, in the test pilot's opinion, the aircraft motions following the engine failure and while control is begin regained become unacceptable. Full control defection requirements may not be a good indication that limiting conditions have been reached since the pilot may elect to use full deflections at speeds higher than V_{mc} (dyn) to quicken the recovery; however, excessive control forces or excessive pilot skill and coordination requirements may well define a limit. The limiting factor must be specifically defined by the test pilot. It must also be noted that by definition, V_{mc} (dyn) cannot be lower than V_{mc} (static) for the same conditions.

6. Based on the test results, the minimum dynamic control airspeed must be decided upon. Such factors as ease of regaining and maintaining control, control forces and deflections required, and reaction time allowed must be taken into account. The airspeed recommended must allow an adequate safety margin for average pilot skill and proficiency.

7. If control of the airplane is lost during these tests, the pilot may regain control

by <u>increasing airspeed</u> and <u>reducing power on the operative engine(s)</u> (or increasing power on the simulated inoperative engine). Particular caution should be exercised at slower airspeed test points since exaggerated nose-up pitch attitudes will be required to <u>stabilize</u> with symmetrical power at the slow airspeeds. Therefore, <u>airspeed decrease</u> may be quite rapid after <u>power reduction</u> on the critical engine.

8. After the minimum dynamic control airspeed is decided upon, the airspeed may be checked by <u>actually failing</u> the critical engine and <u>feathering</u> the propeller at the minimum airspeed.

The static and dynamic minimum control airspeeds determined at altitude may be extrapolated to sea level as shown in Figure 6.12.

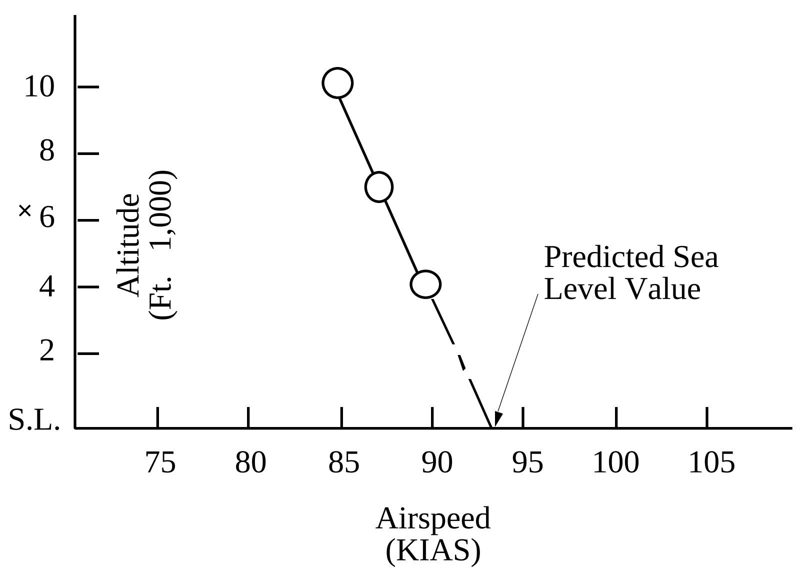


Figure 6.12
Extrapolation of Minimum Control Airspeed to Sea Level

The maximum power available at each altitude during the flight tests should be carefully noted and engine thrust or power available curves as a function of altitude should be consulted to ensure that no asymmetric thrust anomalies occur in the extrapolation altitude band.

6.5.2.4 MINIMUM CONTROL GROUND SPEEDS WITH SUDDEN ENGINE FAILURES

Minimum control ground speed testing is <u>extremely critical</u> and should generally be conducted after the test pilot is familiar with asymmetric power flying qualities in flight. The build-up to the minimum control ground speed must be slow and deliberate since there is no altitude and only limited area in which to recover control of an airplane following engine failure. Consideration must be given to runway length and width, arresting gear, brake temperatures, air crew escape system parameters and airfield crash and rescue equipment. Various methods may be used for minimum control ground speed testing depending upon the engine type, flight controls, and mission of the airplane; however, the following method may be used as a guide.

1. In the take-off configuration set the critical engine at a simulated failed power. Slowly accelerate with full rudder into the operating engines by adding power on the operating engine(s). Maintain directional control and accelerate down the runway by modulating the operating engine(s) until an airspeed is reached where full asymmetric power is controllable. This will be the minimum control ground speed. During the acceleration the ailerons should be neutral, asymmetric braking should not be used, and nose wheel steering should be used only if its use is recommended for normal take-offs. During initial tests, the crosswind should be zero or slightly into the operating engine(s). As the test pilot becomes more familiar with asymmetric power on the ground, the minimum control speed tests should be conducted with increasing crosswind components into the critical engine.

2. An alternate method would be to initially accelerate using symmetric power. The power on the critical engine would then be slowly reduced, while slowly applying rudder up to full rudder into the operating engines until an airspeed was reached where the airplane could be controlled with the power on the critical engine reduced to its failed simulation setting. This speed would be the minimum control ground speed.

3. Once the minimum control ground speed has been determined it should be verified by conducting power chops of the critical engine from a symmetric power take-off configuration. A safe build-up in airspeed and power chop quickness should be utilized just as in dynamic minimum control airspeed testing.

6.5.2.4.1 Safety Speed

Safety speed allows for failure of the critical engine in configuration take-off followed by configuration changes to reduce drag and conversion to a climb without loss of altitude. Thus, safety speed will be the higher airspeed of:

1. Minimum control ground speed.

2. Minimum dynamic control airspeed in configuration take-off.

3. That airspeed from which a climb can be initiated with the critical engine failed, after allowing for any deceleration, which the average pilot might experience during engine failure and subsequent propeller feathering and configuration change, without loss of altitude.

6.5.2.5 APPROACH AND LANDING CHARACTERISTICS WITH ASYMMETRIC POWER

The final phase of the asymmetric power investigation involves the determination of approach and landing characteristics. From these tests, the acceptability of asymmetric power flying qualities during VFR and IFR approaches and filed and carrier landings is determined. Additionally, optimum techniques for these evolutions may be derived and/or recommended techniques may be evaluated. The following points should be kept in mind while evaluating approach and landing characteristics with asymmetric power.

1. The critical engine may be placed in a simulated feathered condition vice actually secured. (For propeller-driven airplanes, the propeller control should be placed to full increase or maximum RPM on final approach in case a symmetric power wave-off is necessary.)

2. Standard traffic patterns and altitudes need not be adhered to; steep turns should be avoided.

3. Excessive crosswinds and turbulence unduly increase pilot workload for initial tests. Close attention to the crosswind must be given during each separate portion of the evaluation.

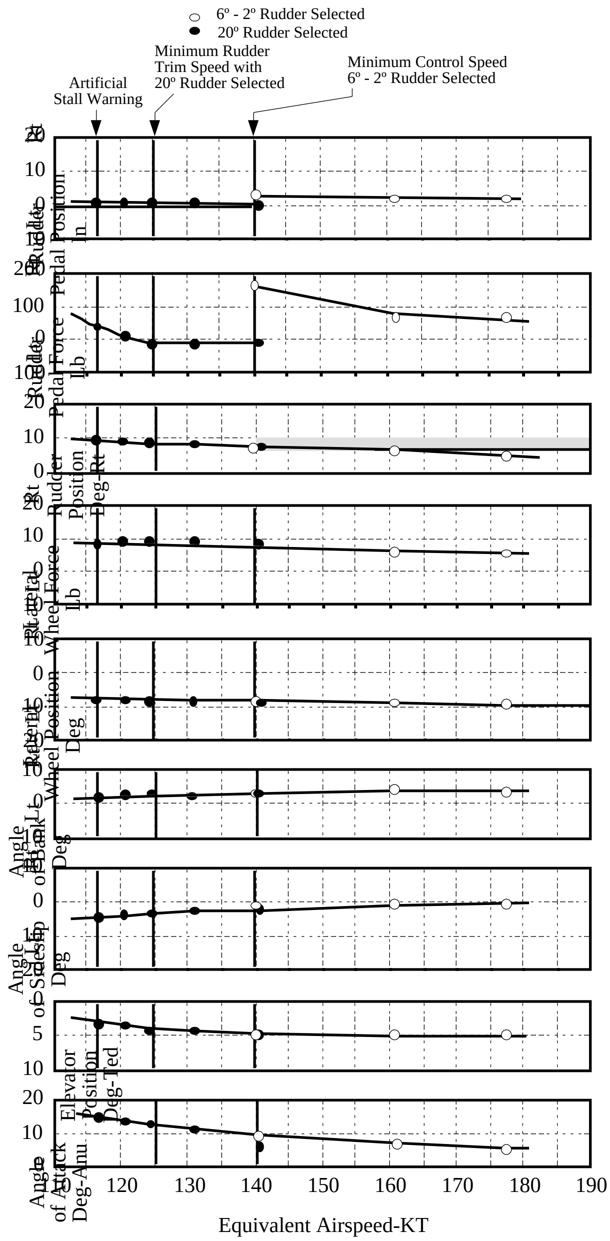
4. The tendency for the airplane to swerve toward the operative engine(s) with power reduction at field touchdown may be diminished by smooth power reduction, rudder inputs, braking, and nosewheel steering (if available). This swerve tendency may be particularly pronounced on twin-engine turboprop airplanes. For this type, initial power reduction at field touchdown should be only to FLIGHT IDLE. After counteracting initial swerve, the operative engine may be brought to GROUND IDLE. Use of reverse thrust asymmetrically may result in loss of directional control. (However, symmetrical reversing may be employed by using the symmetric operative engines on four-engine airplanes.)

6.5.3 POSTFLIGHT PROCEDURES

As soon as possible after returning from the flight, the test pilot should write a brief, qualitative report of the asymmetric power flying qualities. This report should be written while the events of the flight are fresh in the pilot's mind. The test pilot's qualitative opinion will be the most important portion of the final report of the asymmetric power flying qualities.

Asymmetric power characteristics in steady, equilibrium flight conditions are effectively presented as plots of pertinent control forces and positions versus airspeed (Figure 6.13). For dynamic characteristics (sudden engine failures), time histories should be presented if automatic recording devices were utilized (Figure 6.14).

The terminology used in the technical report regarding minimum speeds and conditions must be explicitly defined. Expressions utilized to describe airspeeds and conditions associated with asymmetric power are not standard throughout the aviation industry. Thus, when describing the test results, the writer must be extremely careful to precisely define each expression which possibly could be misinterpreted.



Model ____________ Airplane

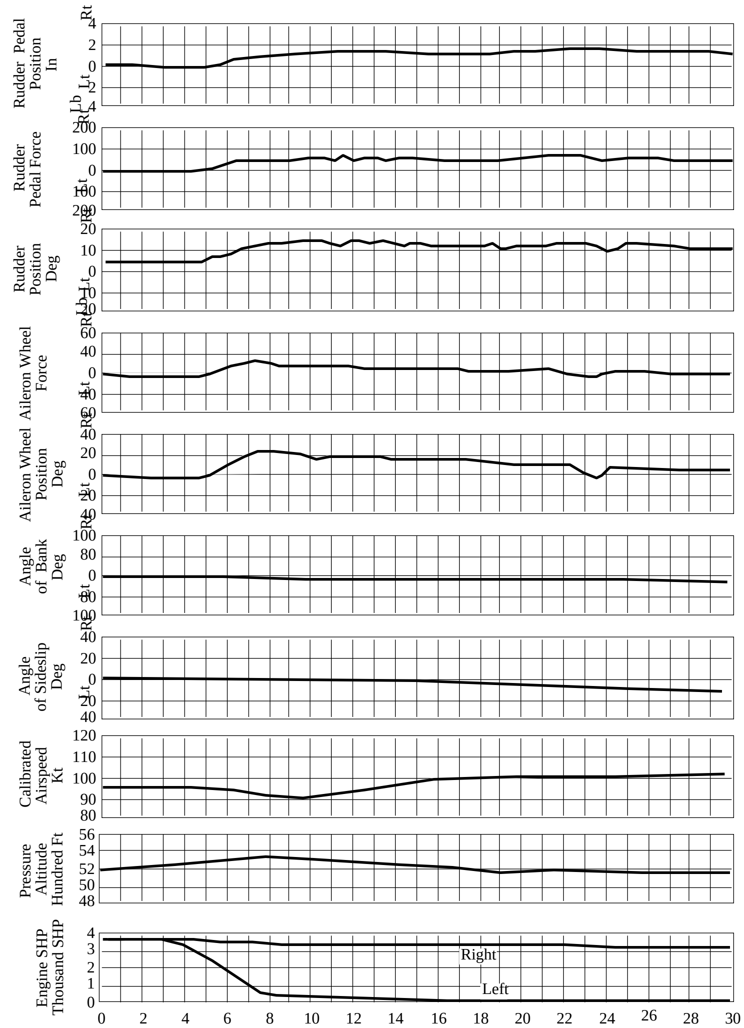
BuNo ______________

Pilot: ________________ Date: 2 December 1966

Configuration: P (Single Engine) Loading: Normal Transport

Figure 6.13
Static Asymmetric Power Characteristics
(Left Engine Secured, Propeller Feathered)

Gross Weight - 42,350 Lb
CG Position - 33.2 MAC
Stability Augmentation - On
Power Chopped to Flight Idle



Model_____________Airplane

BuNo ________________

Pilot: __________________ Date: 2 December 1966

Configuration: Takeoff Loading: Normal Transport

Figure 6.14
Time History of Simulated Left Engine Failure in Configuration Take-Off

6.6 SPECIFICATION REQUIREMENTS

Requirements for asymmetric power flying qualities are contained in the following applicable paragraphs of Military Specification MIL-F-8785C of 5 November 1980, hereafter referred to as the Specification.

3.3.9 Lateral-directional control with asymmetric thrust.

3.3.9.1 Thrust loss during take-off run.

3.3.9.2 Thrust loss after take-off.

3.3.9.3 Transient effects.

3.3.9.4 Asymmetric thrust- rudder pedals free.

3.4.2.1.3.1 One-engine-out stalls.

3.4.2.2 Post-stall gyrations and spins.

3.4.8 Transients following failures.

3.4.9 Failures.

3.4.10 Control margin.

3.6.1.1 Trim for asymmetric thrust.

The requirements of the Specification may be modified by the applicable airplane Detail Specification. Some comments to assist in interpretation of the requirements in the paragraphs listed above may be helpful and are presented below.

3.3.9 Lateral-directional control with asymmetric thrust - This is a general paragraph which contains the all-important sentence, "following sudden asymmetric loss of thrust from any factor the airplane shall be safely controllable." Any dangerous characteristic exhibited under any representative operational flight condition is a violation of the requirement. Additionally, the requirements stated in 3.3.9.1 through 3.3.9.5 must be met.

3.3.9.1 Thrust loss during take-off run - Normally, no asymmetric tests will be made on the take-off run at TPS.

3.3.9.2 Thrust loss after take-off - This paragraph refers to a sudden failure of the critical engine (worst case) in the take-off configuration. The pilot must be able to achieve and maintain straight flight following the sudden failure at all airspeeds above V_{stop} + 10 knots. No configuration change is permitted other than operation of automatic devices, such as autofeather. The bank angle used in the steady equilibrium condition must not exceed 5 degrees and rudder and aileron forces are to be within the stated limits with trim set for symmetric power take-off.

3.3.9.3 Transient effects - Note that no response to the simulated engine failure is permitted for at least 1 second.

3.3.9.4 Asymmetric thrust - rudder pedals free. This paragraph describes a maneuver utilized as a indication of the static directional stability in the worst asymmetric condition. Trim is set for wings level steady heading flight at a speed of $1.4V_{min}$ with symmetric normal rated power. After failure of the critical engine (a propeller may only be feathered if the automatic feathering system normally operates in the configuration under test) the pilot must be able to maintain straight flight at this and all higher speeds by banking without making any rudder inputs and allowing the airplane to sideslip. For most airplanes as speed is increased above $1.4V_{min}$ the test will become progressively less demanding. However, for certain airplanes the problem may become more acute at very high speeds.

3.4.2.1.3.1 One-engine-out stalls - This paragraph requires that in the event of a stall occurring at or above V_{mc} (as might be the case, for example, with a heavy airplane) the resulting stall shall be recoverable. Power may be reduced on the good engine(s) during recovery if required.

3.4.2.2 Post-stall gyrations and spins- - This paragraph effectively specifies that no concessions will be permitted for airplanes with asymmetric thrust in the entry to and recovery from post-stall gyrations and spins, though power may be reduced on the good engine(s) as required during recovery. These test will not normally be conducted at TPS.

3.4.8 Transients following failures - This paragraph refers to airplane motions following any airplane system or component failure. Failures resulting in asymmetric thrust are adequately covered under 3.3.9 and no additional requirements are stated here.

3.4.9 Failures - The relevant requirement in this paragraph is that the pilot shall be provided with immediate and easily interpreted indications of a failure resulting in asymmetric thrust. The requirement related to dangerous flying qualities is covered in 3.3.9.

3.4.10 Control Margin - With regard to the reference to "transients from failures in the propulsion ... and other relevant systems," this paragraph really says the same things as paragraphs 3.3.9 to 3.3.9.5.

3.6.1.1 Trim for asymmetric thrust - This paragraph requires that in the worst asymmetric case it shall be possible to trim elevator, aileron, and rudder forces to zero at all level flight cruise speeds from best range speed for the engine-out configuration to the maximum speed obtainable with normal rated thrust on the functioning engine(s). Or, in other words, minimum trim speed should be less than maximum range speed for the engine-out configuration.

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