ASYMMETRIC FLIGHT

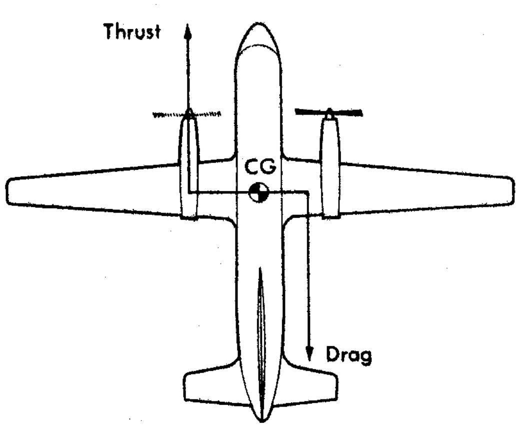
INTRODUCTION

This section provides a discussion of the asymmetric flight of multi-engine airplanes following loss of power from an engine(s) mounted laterally either side of the centerline. Unusual configurations will not be considered in the discussion on handling, although the degradation of performance obviously still applies. Additionally, though thrust is the total output of a turboprop engine and its propeller as a system, only the effect of the propeller will be considered, because the propeller normally contributes the most thrust.

The term 'engine' in relationship to a turboprop airplane refers to the total powerplant system; that is, the engine and propeller assembly. Aircraft manuals give details of the technique and speeds required when using asymmetric power. Thus, the following information should be considered a general overview. Aircraft manuals should be reviewed for the specifics on a given airplane.

BASIC CONDITIONS

If a multi-engine airplane suffers engine failure when airborne, there are two immediate effects. The initial effect is the yawing that occurs due to the asymmetry of the thrust line (see Figure 1). The size of this initial yawing moment depends upon the engine thrust, the distance between the thrust line and the airplane's center of gravity (CG), and the airplane's directional stability, which tends to oppose the asymmetric yawing moment. The yawing moment is also affected initially by the rate of thrust decay of the 'dead' engine and ultimately by its drag. In addition, the yaw is aggravated by the drag effect of the windmilling propeller. The total moment can be very large, particularly when the airplane is at high power and low speed.



The second effect is roll, which occurs when the airplane continues to yaw towards the failed engine, resulting in a decrease in lift from the ‘retreating’ wing and a yaw-induced roll towards the failed engine. This roll is reinforced by the offset of the wings and the loss of the slipstream lift in airplanes with the propeller in front of the engine. This effect can be very pronounced, but it is well within the capacity of the ailerons to counter in all but the most abnormal cases outside design limits.

It is important to understand that, although the yawing moment is the root cause of the problem, on those airplanes with considerable slipstream lift, it is imperative to counteract the roll with aileron in addition to controlling the yaw with rudder. If the yaw and roll are not corrected, the airplane will spiral into the failed engine.

FORCES ACTING ON THE AIRPLANE

An airplane can maintain a constant heading under asymmetric power with an infinite number of bank and sideslip combinations; that is, of aileron and rudder settings. If we examine the yawing and rolling moments and the side forces acting on the airplane, we will see why this is the case.

The forces acting on the airplane, in the plane of the wings are:

a. The sideforce on the fuselage and fin, due to sideslip. The total force is stabilizing, and will act behind the CG.
b. The sideforce on the rudder hinges, caused by rudder deflection, which pivots the airplane about its CG.
c. Any lateral component of weight, produced by banking.
d. Thrust from the live engine(s).
e. Total drag.

In addition to these major factors, there are the minor, but appreciable, effects of:

Torque. Propeller torque, which increases with power, tends to roll the airplane in the opposite direction to that of the propeller’s rotation. Torque has a slight effect on the margin of control while using asymmetric power. If this torque reaction tends to lift the dead engine, its effect is beneficial. On airplanes with contra-rotating propellers, there is no torque effect, since the torque of each half of the propeller counteracts the other.

Asymmetric Blade Effect. When the plane of rotation of the propeller is not at right angles to the flight path, the center of thrust of the propeller does not coincide with its physical center. For example, if the left propeller rotates in a counterclockwise direction when viewed from the rear (as on the typical design from the United Kingdom) and the propeller is tilted upwards relative to the airflow (as when flying at a low airspeed and high nose-up attitude), then the downward-moving blade (the one on the left side of the propeller) will experience a greater angle of attack than the upward-moving one. The thrust line will be thus be displaced to the left, increasing the yawing moment. This is the principle behind the ‘critical engine’ – the one whose loss results in the farthest offset of the thrust vector from the centerline of the airplane. (For the typical U.K. design, the right engine is the critical engine, as its loss results in the airplane experiencing the larger thrust vector offset from the operating left engine. For the typical U.S. design, the propellers rotate in a clockwise direction when viewed from the rear, and the left engine is the critical engine. Some airplanes have propellers that rotate in opposite directions depending on which side of the airplane they are on, so the loss of either engine has an equivalent effect.)

Slipstream Effect. One engine can have a greater effect than the other on the yawing characteristics of the airplane due to the spiral path of the slipstream meeting the fin and rudder at a different angle of attack depending on the direction of rotation of the propeller.

Drag of Failed Propeller. The amount of drag on the airplane will depend on whether the failed propeller has been feathered. A windmilling propeller produces more drag than a feathered one, and the total drag of the airplane therefore is increased and offset towards the failed engine.

BALANCED FLIGHT

In steady asymmetric flight at a constant heading and height, the forces and any moments produced by the forces must add up to zero. A convenient way of representing this is to draw a polygon of forces representing the forces 'a' to ‘e’ above. The sides of the polygon, when drawn to vector scale (direction and magnitude), will form a closed figure if the forces balance (see Figure 2). The following definitions apply:

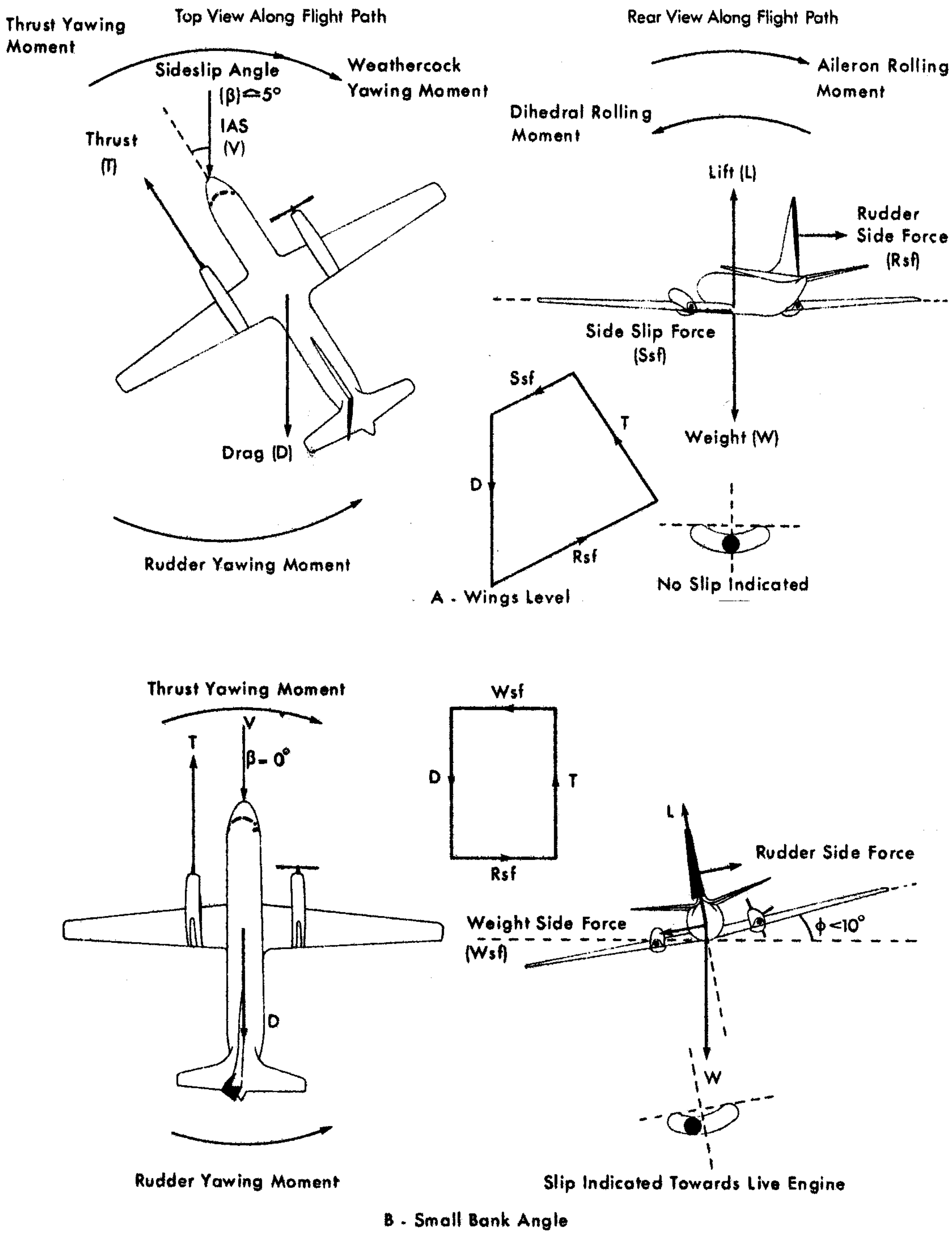
Sideslip angle is the angle between the longitudinal axis and the relative airflow.

Yaw angle relates the longitudinal axis to a reference azimuth.

Wings Level (Figure 2A). In wings-level balanced flight, the airplane will be sideslipping or ‘crabbing’; that is, the airplane’s heading and direction of travel will be different. The yaw caused by the asymmetric thrust will be offset by the rudder. Secondary forces to be considered are:

a. The horizontal force generated by the fuselage acting as a lifting body. The angle of attack will be the sideslip angle. This force will act at the aerodynamic center of the lifting body, approximately at the quarter-chord point, although this will be complicated by other structures acting as lifting bodies, such as engine nacelles. The fin contribution renders the total force a stabilizing one.

b. The rudder side-force.



Figs 2A and 2B Forces Acting in Asymmetric Flight

Small Bank Angle (Figure 2B). If a small amount of bank, up to 5°, is applied towards the live engine, the sideslip angle is reduced. The weight component acting along the plane of the lowered wing will oppose the rudder side-force. The reduced lift vector will require an adjusted angle of attack, but the smaller sideslip angle improves overall performance.

> **CAUTION**. It can be demonstrated that, with adequate directional stability available, it is possible to control an airplane in asymmetric flight without using the rudder (Figure 2C). If bank is applied towards the live engine, the airplane will attempt to turn against the torque about the CG due to the asymmetric thrust. A stable situation will occur when a sideslip develops towards the live engine and the weathercock yawing moment produced by the airplane's directional stability will balance the thrust yawing moment and the weight component produced by the bank will balance the sideslip side force. The sideslip towards the live engine will produce a rolling moment that must be balanced by the ailerons. In this case, the airplane is at a large angle of bank in steady heading flight and the slip ball will be well displaced towards the live engine.
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> Attempting to control an airplane in asymmetric flight without using the rudder is potentially dangerous, since the large sideslip angle required could, on some airplane types, lead to fin stall and subsequent loss of control. In addition, adverse aileron yaw may significantly increase the yawing moment to be controlled, and the drag produced by the extreme yaw attitude may be so high that level flight cannot be maintained. In practice, no attempt should be made to counter the asymmetric yawing moment by banking towards the live engine and leaving the rudder central or free.

In steady heading (zero sideforce) asymmetric flight, the slip ball (lateral accelerometer) acts as a pendulum. In wings-level controlled asymmetric flight, the slip ball will be central, but with corrective bank and rudder applied towards the live engine, the slip ball may be displaced up to one ball's width towards the live engine. The slip ball must be monitored during asymmetric flight, particularly when maneuvering and increasing power. The slip ball must be kept central, or near central with small angles of bank applied so that any uncontrollable deviation of slip (lateral acceleration) gives immediate warning of loss of directional control. If the slip indicator moves away from the central position in wings-level flight and cannot be re-centralized by rudder, increased bank towards the live engine must be applied or power must be reduced on the live engine or the nose must be lowered to increase airspeed (IAS). A combination of all three may be necessary to regain control. The slip indicator is of paramount importance when going around on asymmetric power because it is at low speeds and high power settings that the greatest care is required.

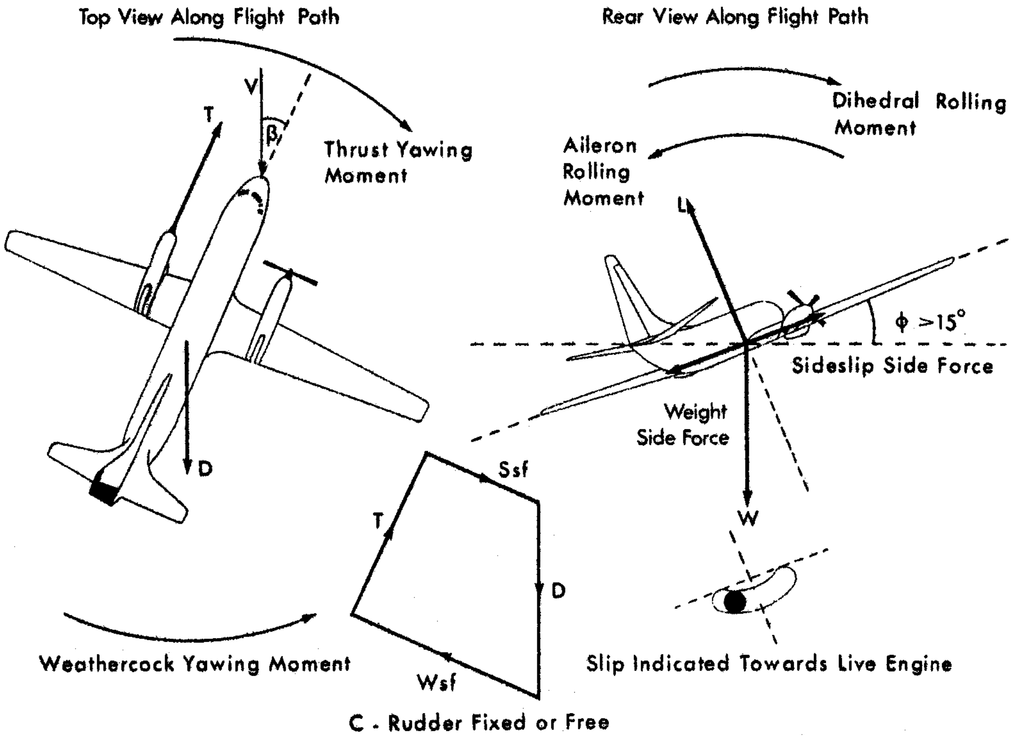

Fig 2C Forces Acting in Asymmetric Flight

RUDDER RESPONSE

The airplane's response to the rudder is of prime importance for the prevention of yaw. Response to rudder by a given airplane depends on the airspeed (IAS). If the IAS is decreased while maintaining a constant thrust (power) setting under asymmetric conditions, an airspeed will be reached below which the airplane can no longer be directionally controlled with the rudder at its maximum deflection. Below this speed, the airplane will yaw and then roll uncontrollably. For this reason, the Airplane Flight Manual (AFM) will always give a minimum speed giving an appropriate safety margin to protect against loss of control. The various speeds for asymmetric flight are dependent on airplane configuration and flight phase; they are defined below. **Note that the V_{MCA} listed in the AFM has been established with a 5^{o} bank angle into the live engine.**

IDENTIFICATION OF A FAILED TURBOPROP ENGINE

Loss of power will normally be shown on the torque meter. Other indications may or may not change, depending on the nature of the malfunction. Engine failures during cruise or, especially, descent may not cause any significant yaw, and thus the crew may not be aware of the failure until power is applied. For free-turbine engines, the drag from a windmilling propeller can be very large. Some powerplant installations automatically feather, or partially feather if the torque drops below a certain figure. Refer to the Airplane Flight Manual for the conditions under which autofeather will work, the level of crew interaction required, and all necessary follow-up abnormal procedures.

FACTORS AFFECTING CONTROLLABILITY

These are:

a. ***Power Output of Live Engine*.** As the force giving the yaw is proportional to the thrust on the live engine, more rudder is required to maintain directional control as the thrust is increased for a given IAS. Therefore, the higher the thrust from the live engine, the higher the IAS at which the pilot reaches full rudder deflection and directional control is lost.

b. ***Critical Engine*.** The critical engine is the engine that, when failed, gives the greatest yaw. Due to slipstream torque and asymmetric blade effects, one engine on propeller-driven airplanes may produce a greater adverse effect for the same settings than the other engine (see discussions above). For 3- or 4-engine airplanes, the critical engine will always be an outer engine because the moment arm is greater.

c. ***Altitude*.** Since the thrust from the live engine for a given throttle setting decreases with height, the asymmetric effect for full power at altitude is less than at sea level.

d. ***Temperature*.** Temperature affects density and therefore the thrust (power) available from a turboprop engine.

e. ***Weather* Conditions.** On a day with rough and gusty conditions, the margin of control is reduced. If the rudder is almost fully over in one direction, a very limited amount of movement is available for any correction necessitated by air turbulence.

f. ***Loading (CG Position)*.** If the airplane has an aft CG at the time of engine failure, the effective moment arm of the rudder is reduced, since all yawing movements take place about the CG. The greater the permissible limits in the travel of the CG, the larger the difference between the effect of engine failure at the two CG limits.

g. ***Flap Setting*.** The position of the flaps may have a marked effect on the airflow over the tail surfaces. As this effect varies between different airplane types, no general rule can be stated. If flap setting has a significant effect on controllability, that information will be provided by the appropriate manuals.

h. ***Asymmetric Drag*.** Asymmetric drag on the same side as the dead engine may be produced by a windmilling propeller engine running at idle. Feathering the propeller of the failed engine and placing such items as cooling shutters to the minimum drag position can reduce asymmetric drag. Consult the type-specific checklist for details.

j. ***Strength and Skill of the Pilot*.** On many airplanes in a high thrust/low speed condition, the foot loads are considerable. In these situations, the pilot's physical strength and leg length have an important bearing on the amount or rudder that can be applied, as do the position and availability of trim tabs. Note that V_{MCG} and V_{MCA} speeds limit the maximum rudder-pedal force to 150 lb. and do not assume exceptional skill.

V_2 (SAFETY SPEED)

V_2 is the speed to which the airplane should be accelerated after takeoff. It is a speed that provides a safe margin above the stall speed for maneuvering before the flap retraction height is reached, and that provides a safe margin above V_{MCA}. It increases with all-up weight. The ability to accelerate in asymmetric power condition depends on the amount of power that can be used without losing control and the reduction that can be made in drag. Engine failure in the most adverse configuration and at the highest weight makes it essential that drag be minimized so that the airplane can accelerate to a safe speed on the amount of power available. The undercarriage and flaps should therefore generally be raised, and the propeller feathered. As always, follow the specific procedures in the AFM.

V_{MCG} (MINIMUM CONTROL SPEED - GROUND)

V_{MCG} is the minimum speed that, in the event of a sudden and complete failure of the critical engine on the ground at takeoff power, enables continued airplane control with the use of rudder alone and without reducing power on the live engine(s). It also enables the ability to maintain a path parallel to the runway centerline, within 30 feet of the centerline. The effect of nosewheel steering has been disregarded in the derivation of V_{MCG}, although the nosewheel is assumed to be in contact with the ground. V_{MCG} varies with airfield altitude and temperature.

V_{MCA} (MINIMUM CONTROL SPEED - AIR)

V_{MCA} is the minimum speed that, in the event of sudden and complete failure of the most critical engine in takeoff configuration, enables continued directional control and steady flight using full rudder deflection and a maximum of 5° of bank away from the failed engine. V_{MCA} varies directly with air density.

ASYMMETRIC FLIGHT - CREW ACTIONS

The following is a general guide giving the basic principles of how to control an airplane following engine failure during various flight regimes. Reference should be made to the Manufacturer's Handbook and Airplane Flight Manual for the specific guidelines and procedures for a specific airplane type.

Takeoff

- If an engine failure occurs after V_1, the takeoff must be continued.
- Control the yaw with rudder input; if necessary, use aileron to assist the rudder. Accelerate to V_2 for the climb.
- The landing gear should be retracted as soon as the airplane is safely airborne.
- Directional control should be maintained by use of full rudder, with aileron, as required, to maintain up to 5° bank towards the live engine. Maintain airspeed at V_2; it is essential not to allow the airspeed to fall below V_2, as the airplane will become increasingly difficult to control.
- As soon as a steady climb is established, feather the propeller of the failed powerplant.
- Fly accurate airspeed and use gentle control movements to maintain the correct attitude. This will give optimum climb performance.
- At a safe height, normally at least 400 feet above the runway surface and with assured obstacle clearance, the airplane should be accelerated to the appropriate enroute climb speed. Retract the flaps.
- If engine failure occurs above V_2, this higher speed should be maintained provided that obstacle clearance has been achieved. If the airspeed is higher than the normal speed recommended for climbout (for example, V_2+10 or V_{FTO}), the pitch attitude should be increased to achieve the normal climb speed. As always, follow the AFM procedures.
- In most circumstances, the yaw due to powerplant system failure is identified visually, either by reference to the external cues or to the lateral accelerometer instrumentation. In some airplane types, the dominant visual cue may be the roll attitude. Though aileron should be used to raise the wing, the rudder is the primary control to prevent further roll and assist in roll recovery. Take the time to positively identify the failed engine.
- Maintaining directional control with rudder also aids in the identification of the malfunctioning powerplant, or, for four-engine planes, the side of the airplane where

the malfunction has occurred. A common memory aid is "Dead leg - Dead engine"; that is, the leg with increased foot force is on the side of the good engine, and the leg without any foot force is on the side of the malfunction. While it is good practice to trim the airplane, early use of directional trim may mask vital cues in determining the location of a malfunction. In addition, when the airplane is accelerated to the enroute climb speed, a trimmed airplane will begin to yaw away from the malfunction as the rudder effectiveness increases with increasing airspeed.

Cruise

- It is relatively difficult to identify a powerplant failure during cruise, particularly in modern airplanes equipped with yaw dampers or stability enhancement. Often, the engine instruments or audio cues will provide the first signs. Observe the indications, and compare the values to those that would be normally expected. Crosscheck indications between powerplants to ensure the correct identification of the failed powerplant system.

- Always follow the procedures outlined in the AFM.

- For situations where no specific guidance is available, revert to basic principles: for airplanes with torque indications, high torque usually indicates that the propeller is giving thrust. Check the engine turbine temperature; if it is below the value for flight idle, a flameout may have occurred. Verify this suspicion by checking the other engine instruments. If the engine has flamed out, it cannot provide power to the propeller, whatever the propeller indications are displaying.

- Movement of each power lever in turn may assist in the identification of the powerplant that is not providing thrust, but caution must be taken to limit large yaw and potential loss of control. As always, flying the airplane is the first priority.

- For malfunctions where the engine is still operating, the propeller should always be feathered. A number of accidents have occurred where the flight crew kept the engine running as a contingency or for the use of ancillary services, and neglected to feather the propeller. Later in the flight, during approach at low speed, or during goaround, the excessive drag from the windmilling propeller resulted in loss of control and loss of the airplane. For this reason, do not keep the powerplant with the malfunction running for contingency purposes. Modern airplanes certificated to FAR/JAR 25 regulations are safe to fly on one engine; they can meet all performance and airframe system integrity requirements.

Descent and Approach

- As discussed above for the cruise regime, it can be difficult to identify powerplant malfunctions during descent and approach. Additionally, the malfunction may not be apparent until power is increased for approach or goaround causing the airplane to yaw or roll rapidly.

- Control the yaw with rudder. If necessary, use aileron to assist the rudder. Always fly the airplane as the first priority.

- Take time to correctly identify the malfunction. Consider a goaround or fly a holding pattern to ensure that all Airplane Flight Manual procedures are complete.

- It is important to select the correct approach and landing speeds following a powerplant malfunction. These may not be the same as the normal speeds. The Manufacturer's Handbook or Airplane Flight Manual will show the minimum speeds to be used. These have been selected to give a safe margin from the minimum control speeds when using full power (as in goaround).

- Once the airplane is stabilized at the approach speed, the rudder trim should be centralized because this will give the pilot appropriate rudder feel in the event of a goaround, or during a reverse-thrust landing roll. In most airplanes, the rudder is the most-effective direction control at high airspeed even on the ground.

- If, for any reason, the propeller of the failed powerplant systems has not been feathered, the recommended power setting or torque value for minimum drag must be set and maintained. This is not the same as an idle setting; a flight idle power setting will result in significant drag in many cases. Note that this setting may vary with airspeed.