Effect of Propeller on Airplane Dynamics

The propeller creates considerable unfavorable forces that need to be trimmed out to keep the airplane flying in a desirable manner. Many airplanes are rigged to help make some compensation for these forces. In discussing the forces produced by the propeller, the concept of propeller *disk* is often used to describe the rotational plane of the propeller, illustrated in Figure 2-27.

Undesirable propeller forces typically become worse with higher thrust levels and/or an increased angle of attack of the aircraft. All of the propeller effects will vary with the speed of the aircraft because at some high power setting, greater thrust exists at lower speeds (remember an aircraft accelerates until thrust equals drag and an aircraft in equilibrium has no excess thrust until power is increased). The deflection of wing flaps also tends to magnify the effects.

Yawing Moments and Sideslip

The most obvious propeller forces to the pilot are those that yaw the aircraft and are discussed first. Yawing moments are generated by the rotational velocity imparted to the slipstream by the propeller (spiraling slipstream), and, asymmetrical thrust (P-factor). For an airplane with a propeller that spins clockwise as viewed from the rear, the moments cause a left yaw.

Spiraling Slipstream

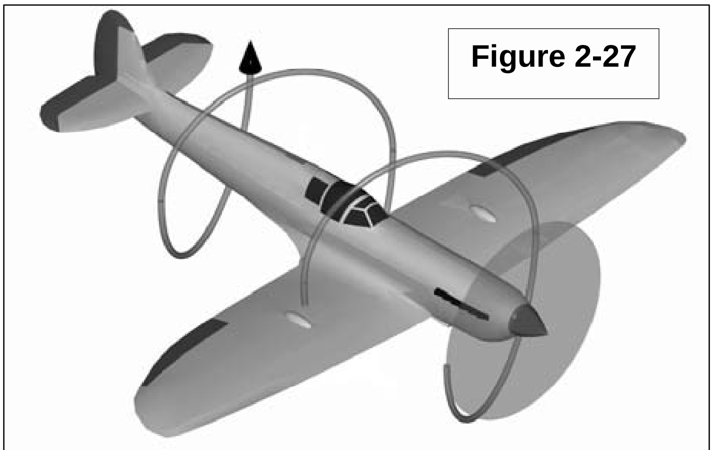


Figure 2-27

The magnitude and effect of the spiraling slipstream varies greatly between aircraft designs, as such, no easy rules of thumb can be provided to isolate these forces from other propeller phenomenon. It is the result of the air circulating around the aircraft because the propeller imparts such motion to it (Figure 2-27).

The rotating air changes the direction of the local airflow at the side of the fuselage and vertical stabilizer, causing a yawing moment to the left (for clockwise prop rotation), illustrated in Figure 2-28 (it may also contribute to a pitching moment and rolling moment, discussed later). This phenomenon varies with aircraft design, power setting, angle of attack, and airspeed, both in effect and magnitude.

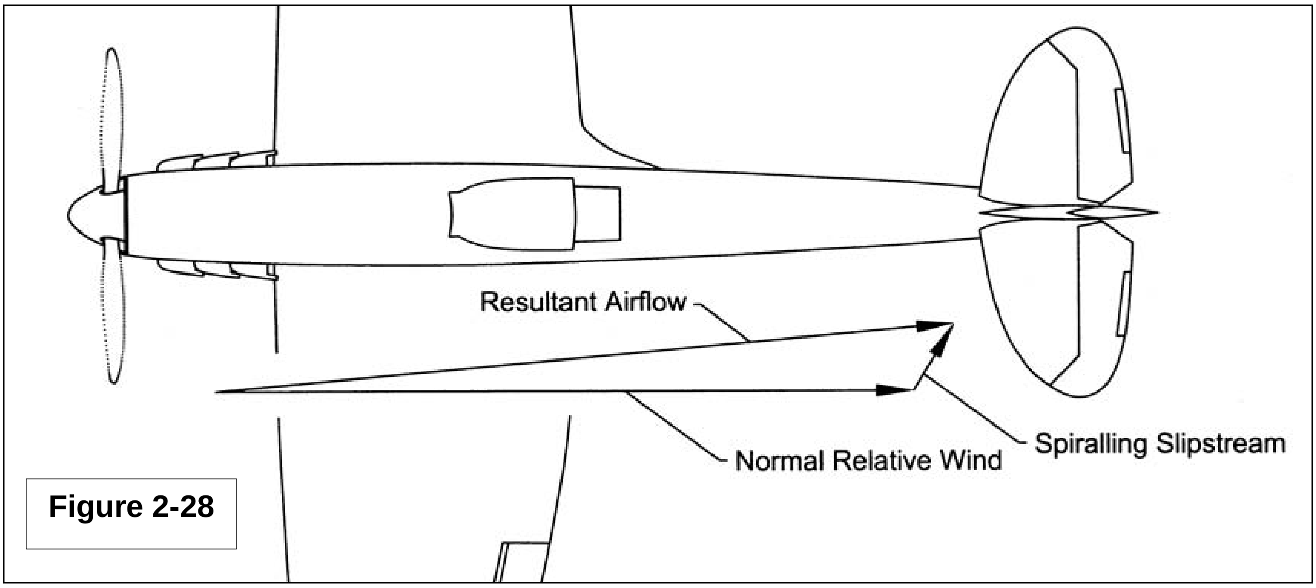


Figure 2-28

The yawing moments produced by the propeller are mainly caused by the spiralling slipstream. It depends on the airplane, but for conventional configurations about half of that yaw is caused by the slipstream striking the fuselage aft of the CG, and the other half is from the slipstream striking the vertical stabilizer. Wind tunnel research on conventional single-engine aircraft indicate that about 6/7 of the total yawing moment is produced by the spiraling slipstream and the rest is from asymmetrical thrust, discussed in the next section.

Much rudder is often needed to compensate in some flight conditions, so much so that very little is available for maneuvering (less control authority). Although spiraling slipstream occurs constantly, it imparts more influence to the airflow at slow speed and higher power settings. On most certificated aircraft, it's been partly rigged out (discussed shortly). The magnitude of this rigging can sometimes be seen by diving the aircraft as fast as it can go safely, and it will probably require significant *left* rudder to keep the ball centered at high speed.

Compensation for spiraling slipstream doesn't eliminate the problem, it is a compromise between efficiency in a desired flight condition and sufficient control authority.

Asymmetrical Thrust (P-Factor)

When the airflow into the propeller isn't perpendicular to the propeller plane or disc, the thrust produced isn't symmetrical about the disc. One half of the disc produces more thrust and the other half produces less. This asymmetrical thrust is also known as P-Factor. For an aircraft in straight flight but pitched up slightly, the down going blade pushes more air back than the up going blade. The reason for this is illustrated in Figure 2-29. The propeller on the bottom is viewed directly from above the aircraft when the aircraft has its longitudinal axis pointed into the wind. The propeller on the top is also viewed from above the aircraft, but the airplane is pitched up in relation to the relative wind. Note the size of the blade on the right side of the prop (down going blade) compared to the size of the blade on the left side (up going blade).

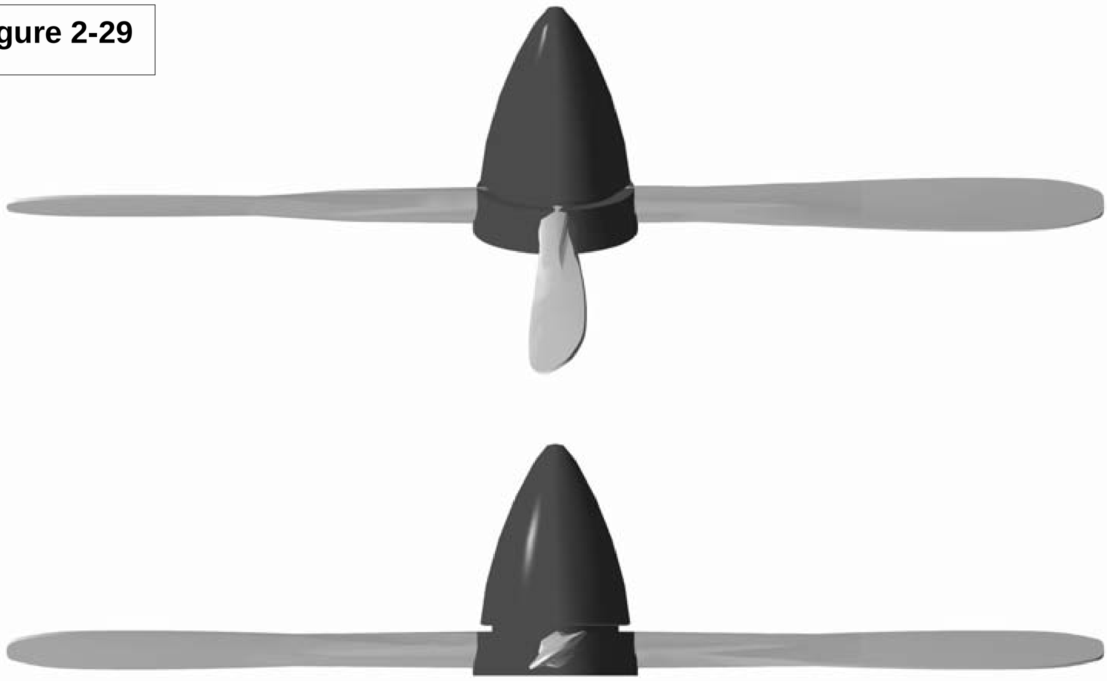


Figure 2-29

The reaction to this is a left yaw of the aircraft (for a prop which rotates clockwise as viewed from the rear) because the thrust being produced on the right side of the aircraft (down going blade) is about twice as much as the up going blade on the left side (Figure 2-30) (the converse effect is that if an aircraft is flying in slightly yawed flight, a pitching moment is produced).

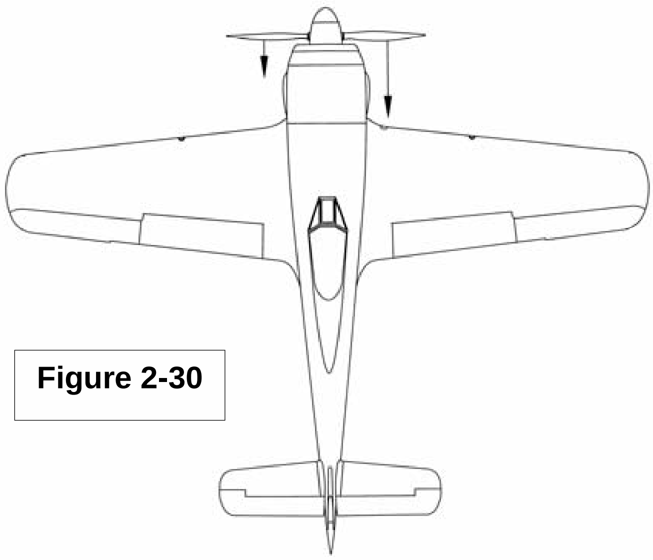


Figure 2-30

The magnitude of this effect is greater with increasing horsepower, propeller size, and pitch. Nothing really can be done about this because it will occur anytime the propeller is producing thrust and the relative wind is at an angle to the propeller disc. P-factor also produces a vibration, because the loads on the propeller blades are constantly fluctuating. Three and four bladed propellers reduce the overall vibration due to P-factor.

More Yawing Moments

Torque and gyroscopic precession also cause aircraft reactions.

Torque is a relatively light force in a small plane with an average engine, but does help create differences in roll rate from one direction to the other. Because aileron deflection may be required to overcome torque, the asymmetrical aileron drag results in yaw and requires more rudder deflection.

Gyroscopic precession will only affect an airplane while it is *changing* attitude, and this can be hard to separate from asymmetrical thrust which also starts producing a yawing or pitching moment as soon as the aircraft starts to rotate in pitch or yaw.

A thrust axis which isn't aligned with the longitudinal axis of the aircraft may also contribute to a yawing moment or pitching moment, or both.

The Overall Effect of Yawing Moments

Right rudder is needed to counteract the left yaw produced by spiraling slipstream and asymmetrical thrust, but then the situation gets more complicated. When right rudder is used to prevent yaw, it results in left translation of the aircraft (relative to the earth) because the vertical stabilizer/rudder is now producing a left side force (left side of Figure 2-31). To prevent left translation of the aircraft, some more right rudder must be used to offset the left side force (right side of Figure 2-31). The aircraft is now going in the correct direction, but is translating with respect to the airflow. In addition, if the airplane were banked slightly to the right to offset torque, more right rudder will be required (from adverse yaw).

Figure 2-31

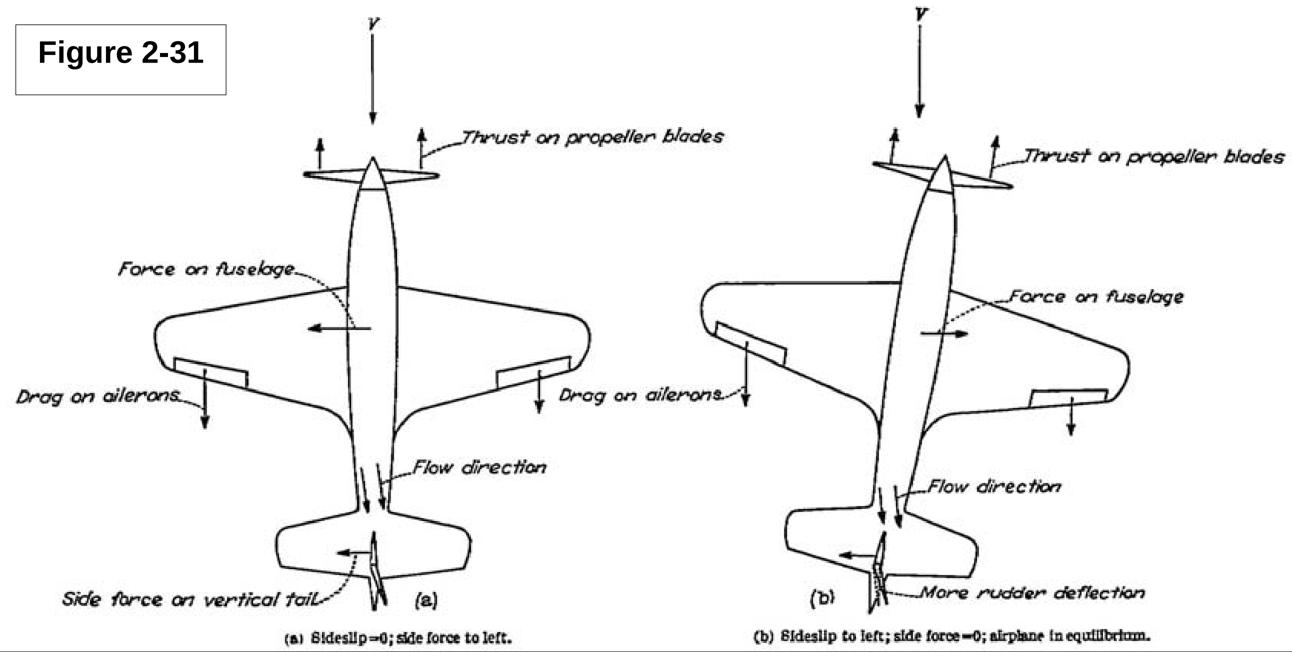
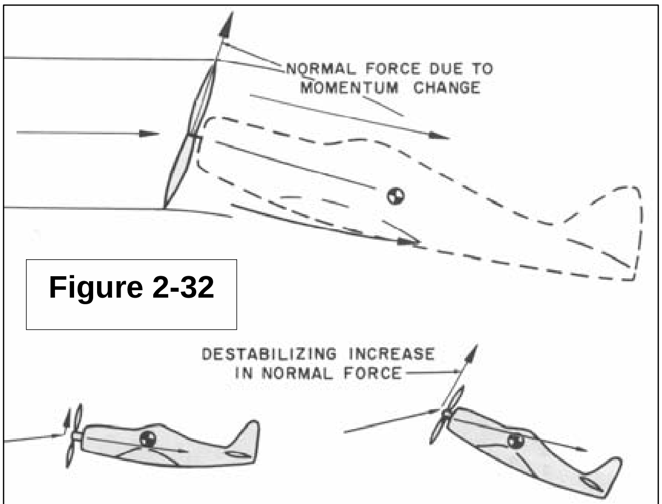


Figure 2-32



Pitching Moments

The propeller and its thrust cause a number of pitching moments. They may occur during a power change, speed change, and in steady flight, especially at high power and high angles of attack. Deflection of wing flaps tend to magnify these effects. Pitching moments from the propeller aren't always obvious to the pilot because airplanes require frequent elevator adjustments anyway due to speed changes, configuration changes, etc..

Moment of Propeller Normal Force About the Center of Gravity

Propellers produce an upward lift component (perpendicular to the thrust line) due to the altering of airflow as it passes through the propeller (Figure 2-32). Because of this, a pitching moment is produced that requires some trim to counteract during flight. For a conventional tractor airplane, it attempts to rotate the aircraft nose up and gets worse as the aircraft angle of attack and power are increased. This is a relatively small force compared to the other propeller forces that attempt to pitch the aircraft.

Moment of Propeller Axial Force About the Center of Gravity

When the line of action of the thrust (propeller axial force) passes above or below the vertical CG of an aircraft, aircraft pitching moments are produced when thrust exists (Figure 2-33). The magnitude of this effect increases with angle of attack and thrust. It may be most noticeable during large power changes.

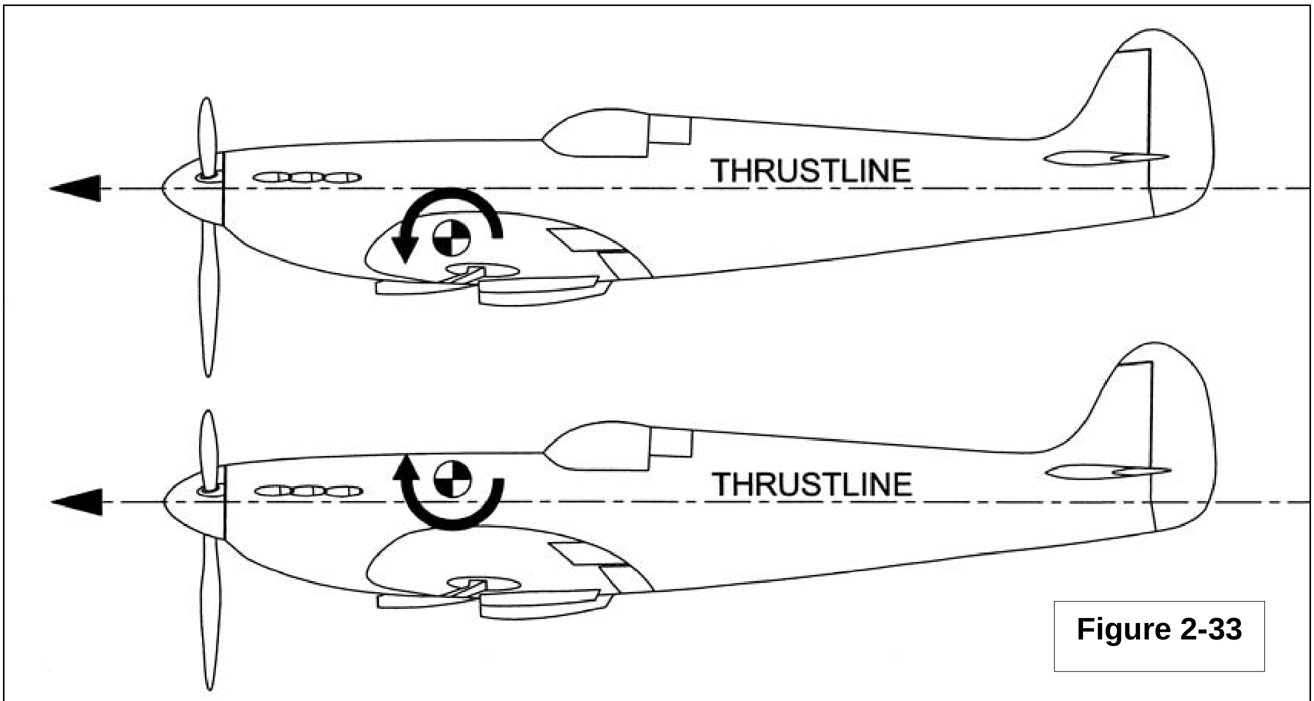


Figure 2-33

Increased Angle of Downwash, Increased Dynamic Pressure at the Tail, and Change in Pitching Moment of the Wing Due to the Action of the Slipstream

These effects are all related and interact with each other to produce various moments on the aircraft.

An increase in propeller normal force (discussed earlier) increases the downwash angle of the wing relative to the incoming airflow, thereby changing the angle that it strikes the horizontal stabilizer. The change in angle of attack of the stabilizer changes its lift and creates a pitching moment.

The increased velocity of the air at the horizontal stabilizer increases its effectiveness.

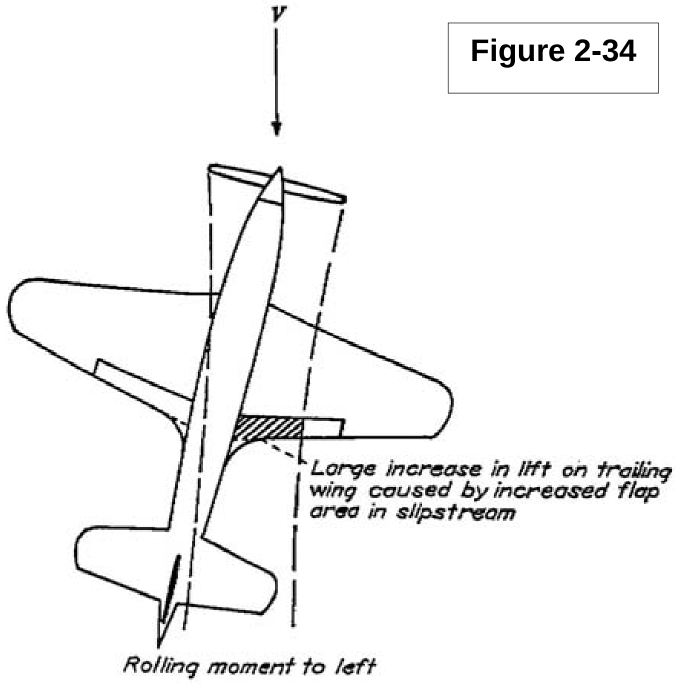
The increased velocity of the air at the wing changes its pitching moment, requiring more elevator deflection.

The most common overall effect of these three phenomenon is to produce a nose-up moment of the aircraft at slower speeds and higher thrust levels. These effects tend to reduce the longitudinal stability of the aircraft.

On some aircraft configurations, the action of the spiraling slipstream may strike the horizontal stabilizer and cause a pitching moment, similar to the yawing moments discussed earlier. For most airplanes though, the influence of the wing downwash on the horizontal stabilizer is so great that any action of the spiraling slipstream on the horizontal stabilizer is lost in the airflow and the effect is negligible. A sideslip may also cause a pitching moment, which is usually nose down in tractor airplanes.

Tilting the thrust axis so that it points downwards one or two degrees (such that the thrust tries to rotate the aircraft nose down) has shown to make a significant increase in the stability of the aircraft when it is at high power and low speeds, however, this results in a certain amount of trim drag at high speeds.

Figure 2-34



Rolling Moments

A sideslip may induce a rolling moment with power-on because the slipstream strikes more wing (Figure 2-34). Engine torque may contribute to a rolling moment depending on the size of the engine/prop in relation to the aircraft. Spiralling slipstream may contribute to a rolling moment if it alters the direction of the airflow over the wing.

Rigging for Propeller Phenomenon

This is one of the biggest hassles of rigging since no matter how well everything is done, airplanes with propellers want to follow a different path. Some things may be done to minimize the effects of the propeller during certain flight conditions, while other things may be done to enhance performance. If the powerplant is really big in relation to the rest of the airplane, some things will have to be done just to maintain some semblance of control.

Experimenting with the thrust axis to create yawing or pitching moments may significantly improve performance or handling in a particular flight regime. Proper rigging of the thrustline can reduce trim drag and increase control authority in a relatively narrow band of the aircraft flight envelope, or change stability in another. Because of the number of factors involved, it is impossible to provide guidelines as to the proper angles, and some requirements for control are directly in contrast with the desire for reduced trim drag.

On average, a propeller loses about 2% efficiency when the inflow of the air to the propeller disk is not perpendicular to the disk, for angles less than ten degrees, and the loss in efficiency increases rapidly for greater angles. The overall loss in propulsive efficiency is small compared to the pitching or yawing moments that are produced, which require trim (drag) to cancel out.