**Centrifugal twisting force.** This is the opposing force to the aerodynamic twisting moment. Because this force is greater, it tries to move the blades toward a reduced blade angle.

A propeller is designed to withstand the effect of these forces, but the forces are nonetheless important factors in design and operation. The effect of these forces accumulates across the length of the blade with the greatest stress at the hub. As the rotational speed of the propeller increases, so too do the stresses acting upon it. Given the various forces acting upon a propeller, it is not difficult to understand the serious problem associated with even small nicks or scratches that could weaken the integrity of the propeller.

**Propeller aerodynamics**

To understand how a propeller moves an aircraft through the air, it is necessary to look at it from an aerodynamic rather than a mechanical perspective. Figure 5-6 depicts the side view of a propeller detailing the blade path, blade chord, and relative wind. The illustration reveals two types of motion associated with the propeller blades: **rotational** and **forward**. As a blade moves downward, it simultaneously moves forward. This has a significant effect on the relative wind making it strike the blade at an angle that is between straight ahead and straight down. This angle that the relative wind strikes the blade is called the **angle of attack**. The relative wind hitting the descending blade is deflected rearward causing the dynamic pressure on the engine side of the blade to be greater than the pressure on the back of the blade. Again, within limits, as the blade angle increases, so too does the angle of attack. On a wing, this situation is called lift; on a propeller it is **thrust**. Thrust is the result of the camber of the blade and the angle of attack of the blade.

**CONSTANT-SPEED PROPELLER**

A propeller **governor**, as part of the constant-speed propeller construction, maintains propeller rpm by automatically varying the blade angle. Propeller rpm—on a reciprocating or turbine engine—is set by the pilot by moving a control lever in the cockpit. The full forward position moves the blade angle to its shallowest position, which yields the maximum rpm possible, consistent with the available power, and is designated the normal takeoff and initial climb prop setting. The shallow pitch is also used on landing for two reasons: in case the pilot must abort the landing (and needs maximum performance to initiate a climb) and to prepare for reverse pitch (if needed) after landing. Engagement and operation of **reverse thrust** is accomplished with the thrust levers, but the prop levers should be in the full-forward position.

Moving the propeller lever to its full-aft position places the blade angle in a very steep pitch situation that results in the minimum rpm possible. Minimum rpm is consistent with maximum long-range economy cruise; however, the actual propeller rpm operating range of turboprops is very narrow. In the Beech King Air C90A, for instance, the normal operating range is 1800 to 2200 rpm. In most turboprop aircraft, the
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![Diagram of propeller forces](image)

**Fig. 5-6. Propeller forces.**

most aft position of the prop lever is just forward of a detent that prevents accidental movement of the lever farther aft.

Different aircraft have different methods for moving farther aft of that position, such as lifting the lever or shifting it to one side, but movement past the low rpm position will cause the propeller to move into the feather position. Some aircraft use feathering buttons rather than aft movement of the prop lever; the result is the same. To review:

- Low (shallow) pitch = high rpm
- High (steep) pitch = low rpm

The option to select a specific blade angle allows the pilot to select the most efficient propeller blade angle of attack for any given phase of flight, such as takeoff, cruise, or descent. Similar to the lift-to-drag curves calculated for wings, engineers have determined the same information for propellers. The most efficient propeller angle of attack is between $+2^\circ$ and $+4^\circ$. This should not be confused with the blade angle required to maintain the angle of attack; the actual blade angle will vary slightly depending upon the forward speed of the airplane. Remember, for any given propeller rotational speeds, the angle of attack will vary as forward speed increases or decreases; angle of attack is the product of rotational speed and airspeed. The propeller’s control system is actually divided into two modes: flight operation and ground operation.

**Flight operation mode**

In the flight operation mode, the constant-speed propeller will make small adjustments in blade angle to assure maximum efficiency under slightly varying conditions, with limitations. By consulting the aircraft operating manual, the pilot is able to select the desired speed of the propeller given the conditions of flight. It is important to remember,
however, that unlike reciprocating engines, the turboprop operating speed range is very limited. Typically, on takeoff, the propeller levers are set full forward for maximum rpm and are kept in that position until cruise level-off. A second, slightly slower rpm setting of 1900 is used to handle all cruise conditions. To vary performance from maximum cruise to maximum range power, for instance, the pilot checks the appropriate performance chart and sets the torque as indicated; the rpm remains unchanged.

**Torque.** The measured amount of shaft horsepower absorbed by the propeller—torque—is the primary control of aircraft performance in flight. The pilot sets engine torque with the *power lever*, which is the turbine engine’s equivalent to the throttle. Moving the power lever for each engine sends a signal from the flight deck to the fuel control unit requesting a specific amount of engine power. The fuel control unit and the propeller governor are interconnected and operate together to establish the precise combination of rpm, fuel flow, and propeller blade angle to provide the requested power. As the power levers are moved forward, the torquemeters and the exhaust temperature indicators will reflect an increase. The governor maintains a constant propeller rpm even as the engine power increases.

To maintain a constant rpm, the blade angle automatically increases to take a bigger bite of air. It is the increased air load that prevents the propeller from speeding up as the torque increases. The net result is that the increased torque goes to processing a greater mass of air per second, which results in more thrust. So, in the flight operation mode, the propeller blade angle and fuel flow for any given power lever setting are governed automatically according to a predetermined schedule.

**Power vs. engine speed.** To the experienced reciprocating engine pilot, it is a somewhat confusing characteristic of the turboprop engine that a change in power does not relate to engine speed, but instead to turbine inlet temperature. During flight, the propeller maintains the engine speed at a constant rpm known as *100 percent rated speed*. This is the design speed of the engine that provides maximum efficiency and power. If the pilot desires more power and pushes the power lever forward, the fuel control unit simply schedules an increase in fuel flow.

The result of more fuel is an increase in the turbine inlet temperature, which effectively means more energy is available to turn the turbine. The turbine is forced to absorb the extra energy that is transmitted to the propeller in the form of torque. If there were no governor, the propeller speed would increase; instead, the blade angle increases to maintain a constant engine rpm and the propeller is able to take a larger bite of air.

**Negative torque signal.** Thus far, the operational condition discussed has been the engine turning the propeller. Occasionally, conditions can occur when the propeller attempts to turn the engine. There are several possible causes for a negative torque situation, but the engine is protected from an actual occurrence by a *negative torque signal* (NTS) system. Potential negative torque situations are:

- Temporary fuel interruption
- Air gust load on the propeller
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- Normal descents with lean fuel scheduling
- High compressor air bleed loads at low power settings
- Normal engine shutdown

So, two ways of inducing a negative torque situation are something trying to turn the propeller faster than scheduled, or something causing engine speed to suddenly slow down to fewer than scheduled rpm. In either case, the NTS system immediately signals the propeller governor to increase the blade angle until the negative torque situation ends.

**Propeller feathering.** The term feathering refers to the ability to turn the propeller blades in such a manner as to make the blade leading edges face directly into the ambient air flow; essentially a 90° blade angle. The result is that the propeller creates no aerodynamic forces. When an engine fails, the forward motion of the aircraft continues to create a relative wind. The relative wind will continue to turn the propeller of the failed engine—which is also called windmilling. Do not allow this to happen for two reasons.

The first reason is safety. A windmilling propeller creates a tremendous amount of drag that, when combined with the thrust being created by the operating engine, causes a very strong yawing movement toward the inoperative engine. The slower the airspeed, the more pronounced the problem and, if uncorrected, this condition of asymmetric thrust will result in loss of aircraft directional control. In addition, it is important to realize that because of the tremendous drag imposed by the inoperative engine and windmilling propeller, very few twin-engine aircraft are even able to hold altitude with a windmilling propeller. Perhaps even more revealing, most twin-engine aircraft lose more than 80 percent of their climb capability even with a feathered propeller. It is imperative that the multiengine pilot be well trained and current in the proper single engine procedures for the aircraft being flown. Under any condition other than cruise, an engine failure requires prompt, positive action.

The second reason to not allow an engine to windmill is damage control. If the engine has failed by itself, there must be a reason. If the reason is either a mechanical or foreign object ingestion problem, continuing to allow the propeller to turn could result in significant engine internal damage. In most systems when the engine is inoperative the oil pump is also not operational. The result of a windmilling prop is that the shaft continues to turn in bearings that are not being lubricated. Any of these situations can rapidly lead to major engine damage. For all these reasons and more, concern about a windmilling propeller is so serious, especially during takeoff and initial climb, that manufacturers incorporate an autofeather system.

**Autofeather systems.** Depending upon the manufacturer, there are different types of autofeather systems. The thrust-sensitive signal system (TSS) arms itself whenever propeller-positive thrust is in the takeoff range. A subsequent loss of thrust on that engine causes the system to automatically feather the propeller.

Other autofeather systems are pilot selectable. Most aircraft operating handbooks call for the activation of autofeather during the critical takeoff and initial climb seg-
Constant-speed propeller

When activated, this type of system typically compares the torque of one engine against the other. If one engine’s torque drops below a preset value, the system automatically feathers that engine’s prop. This system has a safeguard built in that precludes accidental feathering of a propeller when the pilot has retarded one thrust lever for whatever reason. Most autofeather systems will completely feather a propeller in 5–15 seconds.

Ground operation mode

In the ground operation mode, things are somewhat different. If the power levers are brought all the way back to the flight idle position, it is possible to physically lift the levers out of their flight idle safety detent and move them back farther into what is known as the beta range. In this area of operation, the coordinated rpm/blade angle schedule that governs normal flight operations is no longer appropriate. As a result, whenever operating in the beta range, the propeller blade angle is no longer being controlled by the propeller governor, but is directly controlled by the position of the power lever itself. (See the heading **Turbopropeller assembly** in this chapter for more information about beta range.)

**Reverse thrust.** When the power lever is full aft and stopped at the flight idle position with the prop levers full forward to maximum rpm, the propeller blades are sitting on the low pitch stop. The low pitch stop is a mechanical device that physically prevents the blades from rotating from the lowest possible blade angle position to reverse. When the power lever is first lifted above the flight-idle safety detent and moved aft, the low pitch stop is automatically opened to allow the propeller blade angle to rotate into full reverse position. This provides reverse thrust for slowing down the aircraft after landing, or for taxiing. In some aircraft, it is possible to slowly back up the aircraft.

As the power lever continues to move farther aft, the blade angle stays the same but the engine, which has been at idle, begins to accelerate causing an increase in reverse thrust. It is important to recognize that similar to reverse thrust in the turbojet engine, the term reverse thrust does not imply any reversal of the engine. In the case of the propeller, the blade angle rotates through the lowest normal flight blade angle setting past the low pitch stop and continues beyond until the blades have rotated far enough around to create thrust opposite to the direction of aircraft movement. The propeller is now trying to push the aircraft backward. For most propellers, reverse-thrust blade angle is between −5° and −15°.

All turboprop operating handbooks specify a minimum speed on landing roll below which full reverse should no longer be used. This is the speed below which the propellers will move foreign objects forward faster than the forward speed of the aircraft. Use of full reverse when slower than the published speed increases the potential for foreign object ingestion or prop damage, and reduced forward visibility because sand and dust will be kicked up in front of the aircraft. Use of reverse during taxi should be done with caution; however, reverse does minimize brake wear.
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Be particularly careful about using reverse thrust to back up the aircraft. While it is very impressive to those watching you back your pretty, new cabin-class turboprop into a parking space, you look pretty dumb when you hit the brakes and the airplane sits down on its tail.

PROPELLER SYSTEM OPERATION

The turboprop combination provides one of the most flexible yet efficient systems for converting power to thrust. Turboprop system operations vary based upon the manufacturer of the system; however, each system accomplishes the same task, which is moving the aircraft through the air in the most efficient manner possible. The following general description of how a constant-speed, feathering, reversible propeller operates is based upon a Hartzell system.

Reduction gear assembly

The output shaft of the engine drives a reduction gear assembly that reduces the fast engine rotational speed to a more suitable range for propeller operation while maintaining a constant engine rpm. Depending upon the manufacturer, the assembly might also incorporate other additional features (FIG. 5-7). The illustrated assembly, for instance, incorporates an NTS system, propeller brake, and an independent dry-sump oil system. The illustration also shows the torquemeter assembly (upper right-hand corner).

Fig. 5-7. Reduction gear assembly.