

15.16 - TURBOPROP ENGINES

INTRODUCTION

The Turbopropeller engine is the most efficient method of propulsion for aircraft operating in the speed range of 300-450 mph (480-720 km/hr) at altitudes from sea level to 20 000 ft (6 000 m). Within this range they have the highest propulsive efficiency and the lowest fuel consumption of any engine configuration. As the aircraft speed increases over 450 mph the propeller will rapidly lose efficiency as the blade tips experience sonic airflow resulting in a shock wave formation that destroys thrust. The feature that singles out the Turboprop from most other gas turbine configurations is the method by which it converts its energy into thrust. Turbojet and turbofan engines extract a minimum amount of energy to drive their compressors and gearboxes and then convert the remainder into high velocity exit gas to produce reaction thrust. Turboprops use a propeller to convert turbine power into thrust and do not rely on gas exit velocity. To achieve this, they usually have additional turbine stages and turbine blades that are designed to extract the maximum amount of energy from the gas flow to drive the propeller. Turboprops are so efficient they can convert 80% to 90% of the energy in the gas flow into useful work.

The Turboprop (Turbopropeller) engine is a combination of a gas turbine engine, reduction gear box, and a propeller. (*Figure 16-1*) Turboprops are basically gas turbine engines that have a compressor, combustion chamber(s), turbine, and an exhaust nozzle (gas generator), all of which operate in the same manner as any other gas turbine engine. However, the difference is that the turbine in the Turboprop engine usually has extra stages to extract energy to drive the propeller.



Figure 16-1. A PT-6 Turboprop engine.

GAS (FREE TURBINE) AND GEAR COUPLED ENGINES

There are two types of multiple stage turbine configurations in Turboprop engines: (1) gear coupled, also known as fixed turbine, and (2) free turbine. In a gear coupled or fixed turbine engine, all turbine stages are connected to a single shaft. This shaft not only turns the engine compressor but also turns the propeller through a gear reduction gearbox. In a free turbine, the turbine stages are connected to two completely independent shafts. One shaft turns the engine compressor. The second shaft turns the propeller through a reduction gearbox. Although three turbines are typical, as many as five turbine stages have been used for driving the two rotor elements, propeller, and accessories. (*Figure 16-2*)

GAS COUPLED

In this type of engine there is no mechanical connection between the gas generator and the power turbine section. The gas generator shaft is separate from the shaft that drives the reduction gearbox and the propeller. The shafts are described as having only a fluid connection or in other words, they are gas coupled. The two shafts are independent of each other and only the gas flowing across their turbines joins them. The free turbine design allows the propeller to operate at its most effective speed whilst the independent gas generator section can operate at the optimum RPM for compressor and turbine efficiency. The fluid nature of the coupling with the power turbine enables the propeller to be run at low RPM to reduce blade tip speed and noise. This design is also useful in helicopter engines as it removes the need for a clutch mechanism. The rotor transmission can be driven at its correct speed by the free turbine whilst the gas generator runs at its best operating speed. Free turbine engines are easy to start because the gas generator starts independently and is not impeded by the air drag on the propeller. In fact, the gas generator can be operated with the propeller held stationary. These engines have good cold weather starting characteristics.

Another advantage is that dynamic forces or vibrations created by the propeller do not transmit back into the gas generator section. One drawback is the slow response time experienced during the acceleration of a free turbine engine. A rapid acceleration of the gas generator does not necessarily produce an instant

acceleration response in the power turbine and the propeller. This characteristic is not useful in situations like a 'go around' or a fast application of power in reverse pitch during short landing runs. The ability to accelerate the propeller from low to maximum speed is limited by the response times of the free turbine and the propeller itself. (Figure 16-2)

GEAR COUPLED TURBINES

Another Turbopropeller configuration is the fixed shaft or direct drive layout. The fixed shaft incorporates the compressor and the gas generator and power turbines on a common shaft that is directly coupled to the reduction gearbox and propeller shaft. The single shaft is coupled to the reduction gearing. This arrangement is described as being gear coupled. The single shaft engine is responsive to rapid power changes. A change from minimum to maximum power output is limited only by the response time of the propeller. At low engine speeds most of the energy absorbed by the turbines is used to drive the compressor and ancillary gearbox leaving little power to drive the propeller. In this condition the drag of the propeller could slow the engine to a stop so the propeller blade angle has to be reduced to zero. This feature is particularly important during engine starts where the propeller drag load has to be reduced to enable successful start acceleration. Again, when the engine is accelerated from low to high RPM, the propeller blade angle has to be held back in a low or fine blade angle to permit the acceleration to occur unimpeded by the propeller load. Once the engine power has developed, the propeller blade angle may then be increased or

coarsened to absorb it. Further increases in engine power cause corresponding increases in RPM and blade angle. Engine speed can be held constant by varying the propeller blade angle to increase or decrease the propeller drag load.

Smaller turbo prop engines, such as the PT-6, are used on single and twin engine designs; the power ranges from 500 to 2 000 shaft horsepower. Large commuter aircraft use Turboprop engines, such as the P&W 150 and A E 2100 that can deliver up to 5 000 shaft horsepower to power mid sized to large Turboprop aircraft. (Figure 16-3)

REDUCTION GEARS

The function of the reduction gear assembly is to reduce the high rpm from the engine to a propeller rpm that can be maintained without exceeding the maximum propeller tip speed (speed of sound). (Figure 16-4) Additional power takeoffs are available for propeller governor, oil pump, and other accessories. A propeller brake is often incorporated into the gearbox. The propeller brake is designed to prevent the propeller from windmilling when it is feathered in flight, and to decrease the time for the propeller to come to a complete stop after engine shutdown.

The reduction is achieved through a series of both spur gears and epicyclic gears. Smaller reductions will be achieved using spur gears but the larger, high torque reductions will normally use epicyclic gears in order to prevent torque couples forming which would necessitate

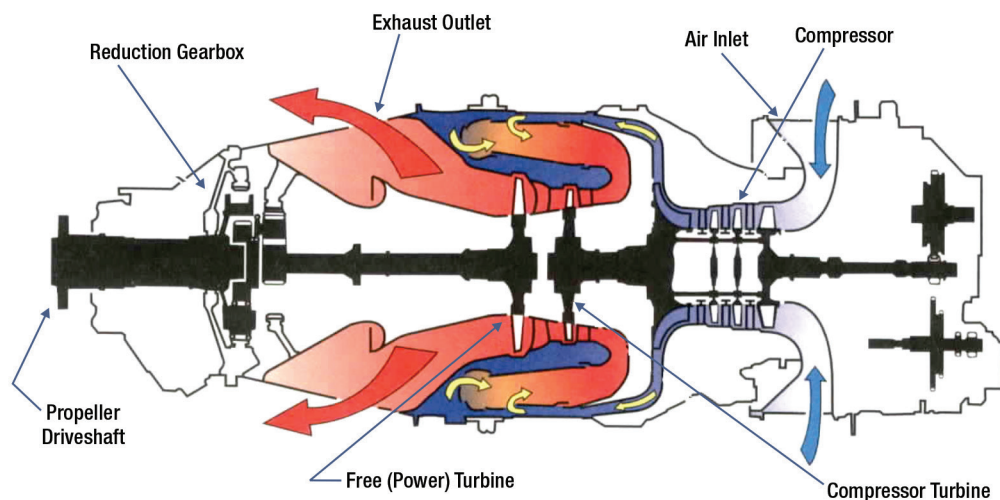


Figure 16-2. Free Turbine engine; propellers driven by a free turbine rotates independently of the compressor turbine.

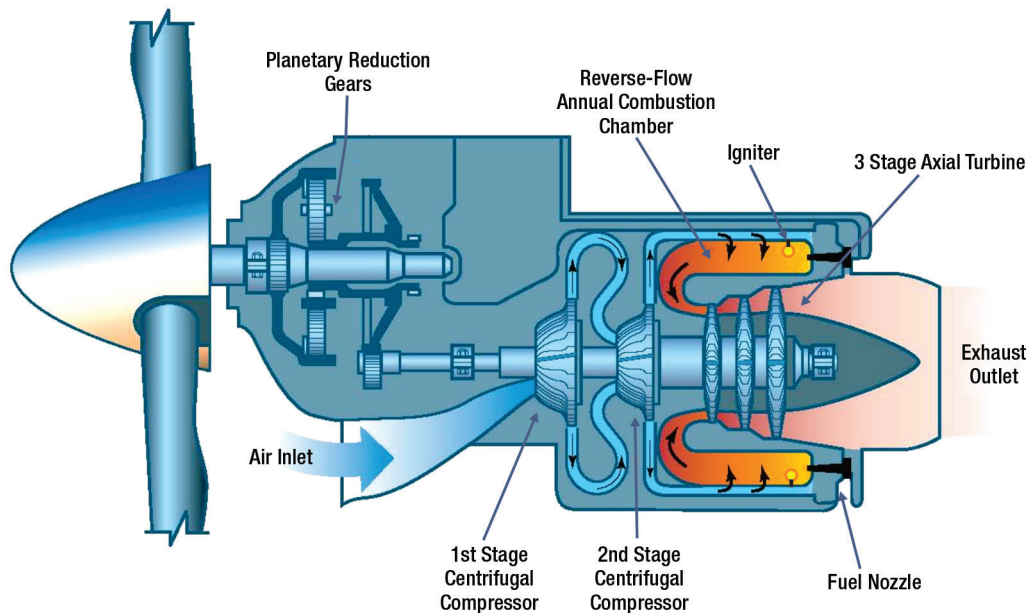


Figure 16-3. Fixed shaft Turboprop engine; propellers directly linked to compressor turbine.

the use of stronger (heavier) casings. The reduction ratio is dependent upon the relationship between the size of the driving and fixed gear.

There are two main types of reduction gears available to the designer: The parallel spur gear type; and the epicyclic type.

PARALLEL SPUR GEARS

Parallel spur gears have the advantage of being mechanically simple. They can be either straight cut or helical. Straight cut gears are easier to cut and have the lowest frictional losses. However, they are very noisy. Torque changes can also result in high loading on the individual gear teeth with high sideways loads requiring large heavy duty bearings. Helical engagement of

the gear teeth allows a more gradual onset of torque changes, leading to quieter but less efficient transmission of power. The gear teeth angle introduces an axial component which must be handled with either a ball or a tapered roller bearing. (Figure 16-5)

EPICYCLIC REDUCTION GEARS

The epicyclic arrangement incorporates a sun gear wheel on the power turbine shaft that drives a number of planet gear wheels that are engaged with either a fixed or rotating ring gear or annulus. The reduction gear ratio is unaffected by the number of planet gears or the number of teeth on them, but instead found by dividing the sum of the gear teeth on the ring gear and the sun gear wheel by the number of teeth on the ring gear. (Figure 16-6)



Figure 16-4. Reduction gearbox.

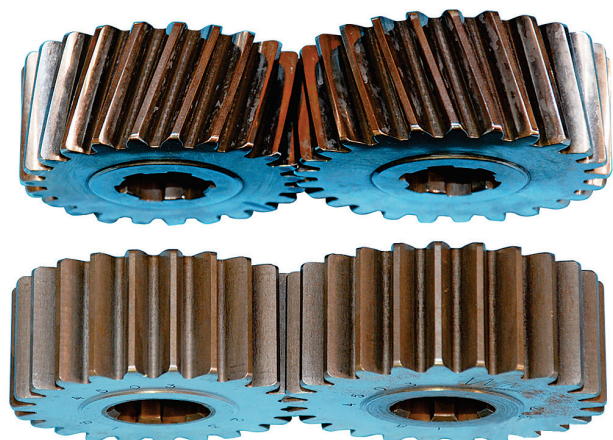


Figure 16-5. Helical (top) versus straight (bottom) gear types.

Fixed Annulus

With a fixed annulus arrangement, the outer fixed gear ring or annulus is fixed in a stationary position. The planet gears are attached to a cage or carrier that is connected to the propeller shaft. When the power turbine shaft turns the sun gear it causes the planet gears to walk around the fixed ring gear. As the planet gear carrier rotates it drives the propeller shaft in the

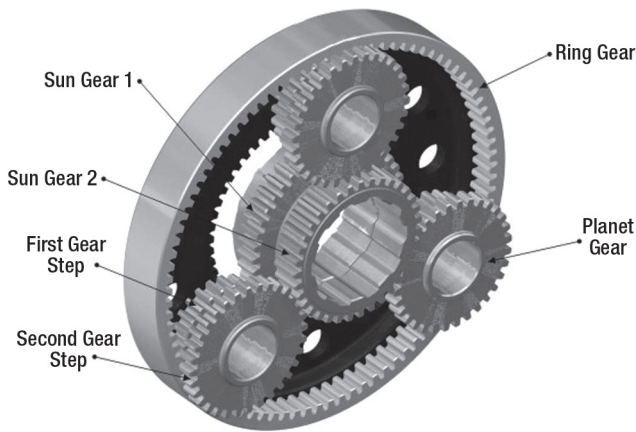


Figure 16-6. The basic epicyclic gear arrangement.

same direction of rotation as the power turbine shaft. The propeller rotates at a speed that is dependent on the reduction gear ratio.

Rotating Annulus

The planet gears in this arrangement rotate on fixed pinion shafts. The power turbine shaft drives the sun gear and this turns the planet gears which in turn drive the ring gear. The ring gear is connected to the propeller shaft and it will drive it in the opposite direction of rotation to the power turbine shaft.

INTEGRATED ENGINE AND PROPELLER CONTROLS

The Turbopropeller provides an efficient and flexible means of using the power of the engine at any condition in flight (alpha range). (Figure 16-7) For ground handling and reversing (beta range), the propeller can be operated to provide either zero or negative thrust. The major subassemblies of the propeller assembly are the barrel, dome, low-pitch stop assembly, overspeed governor, pitch control unit, auxiliary pump, feather and unfeather valves, torque motor, spinner, deice timer,

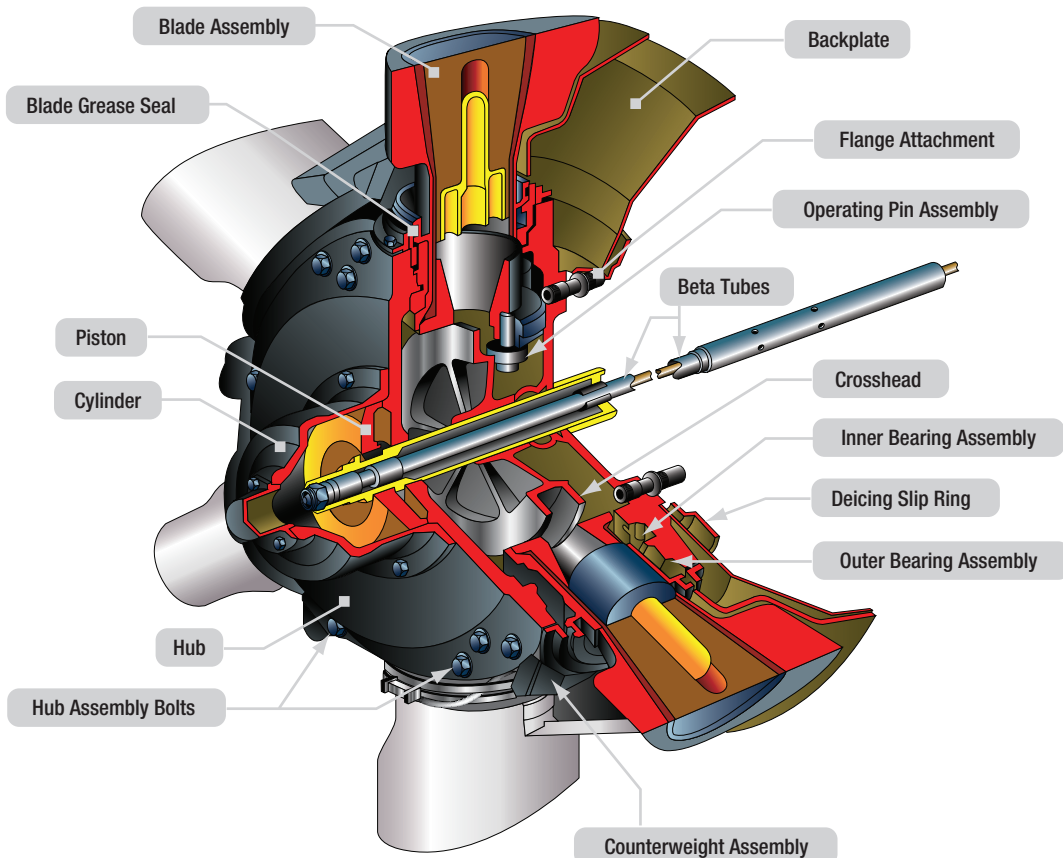


Figure 16-7. A Turboprop propeller hub assembly.

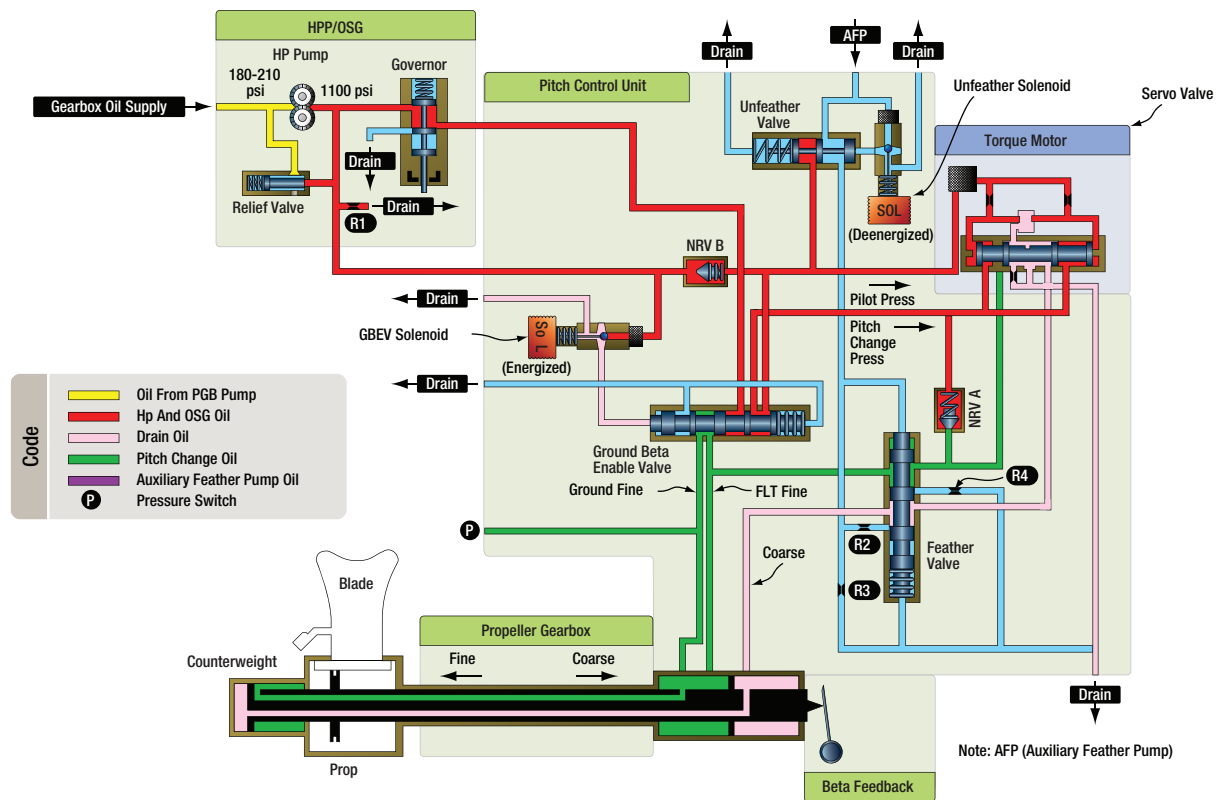


Figure 16-8. Propeller control system schematic.

beta feedback assembly, and propeller electronic control. Modern Turboprop engines use dual Full Authority Digital Engine Control (FADEC) to control both engine and propeller. The spinner assembly is a cone-shaped configuration that mounts on the propeller and encloses the dome and barrel to reduce drag.

The synchrophasing system is designed to maintain a preset angular relationship between the designated master propeller and the slave propellers. Propeller operation is controlled by a mechanical linkage from the cockpit-mounted power lever and the emergency engine shutdown handle (if the aircraft is provided with one) to the coordinator, which, in turn, is linked to the propeller control input lever. Newer designs use electronic throttle control that is linked to the FADEC controller.

Turbopropeller control assemblies have a feathering system that feather the propeller when the engine is shut down in flight. The propeller can also be unfeathered during flight, if the engine needs to be started again. Propeller control systems for large Turboprop engines differ from smaller engines because they are dual acting, which means that hydraulic pressure is used to increase and decrease propeller blade angle. (Figure 16-8)

CONTROL LEVERS

The throttle quadrant, containing the integrated engine and propeller controls is mounted on the center pedestal between the Captain and the First Officer so that both can operate the levers. On a multiple engine aircraft, the lever for number one engine is on the left and the rest of the engines will be consecutively to the right of it. A second lever attached to the front of each power lever are called rollover levers which operate reverse thrust. (Figure 16-9)



Figure 16-9. A typical dual lever controller on a twin engine Turboprop.