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GAS TURBINE ENGINES (CASA ATPL)

CHAPTER 10 – TURBOPROP

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INTRODUCTION

Turboprop aircraft in the 21st century have reached a degree of sophistication and fuel efficiency such that they have become the airliner of choice for the commuter section of the market. Turboprops are more efficient at low subsonic speeds. However, this advantage decreases with an increase in speed, and since the thrust is derived from the propeller and not the exhaust gas, it has a low noise level.

As described in Chapter 2, this configuration has the highest propulsive efficiency of any gas turbine combination at speeds below 450KIAS, which makes them well suited to this task. Some aircraft can cruise at Mach numbers approaching that of turbofan aircraft (the Russian TU 95 Bear cruises at Mach 0.73).

Aircraft like the De Havilland Dash 8 and the ATR72 are used for their short range, medium altitude and short field performance. They usually seat between 60 and 100 people.

CONFIGURATIONS

There are two configurations for turboprop power plants. They are;

- The Free Power Turbine Turboprop, and
- The Direct Drive Turboprop.

FREE POWER TURBINE

This configuration is the most common design for a turboprop. The free power turbine is on a separate shaft (spool) not connected to the compressor or any other spool. Instead, the power from the turbine is fed via a shaft to a reduction gearbox. From there it connects to the propeller via an output shaft. Refer to Figure 10-1.

Advantages over a direct drive turboprop include a lower starting torque (since the starter motor does not drive the propeller), and variable RPM with high torque at low RPM.

This is also called a Turbo Shaft Engine, used in Helicopters etc. This configuration is discussed in detail in Chapter 3.

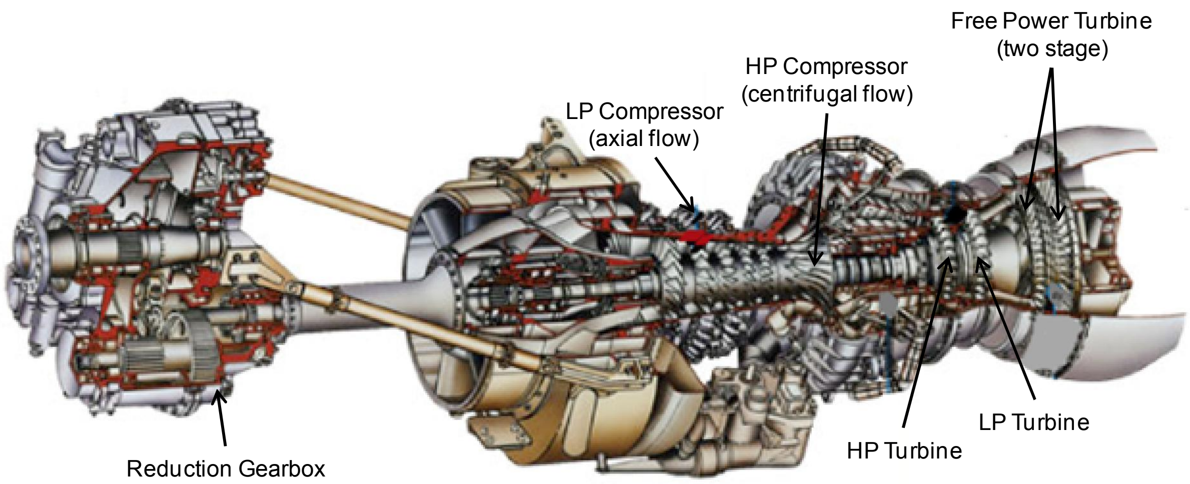

Figure 10-1 Free Power Turbine Turboprop

DIRECT DRIVE TURBOPROP

In this configuration the input shaft to the reduction gear box comes off the main compressor/turbine spool instead of having its own independent turbine. This was an earlier type of design but is still widely used (Rolls Royce Dart used in Fokker F27, and the Allison T56 in military C130 aircraft). Refer to Figures 10-2 and 10-3.

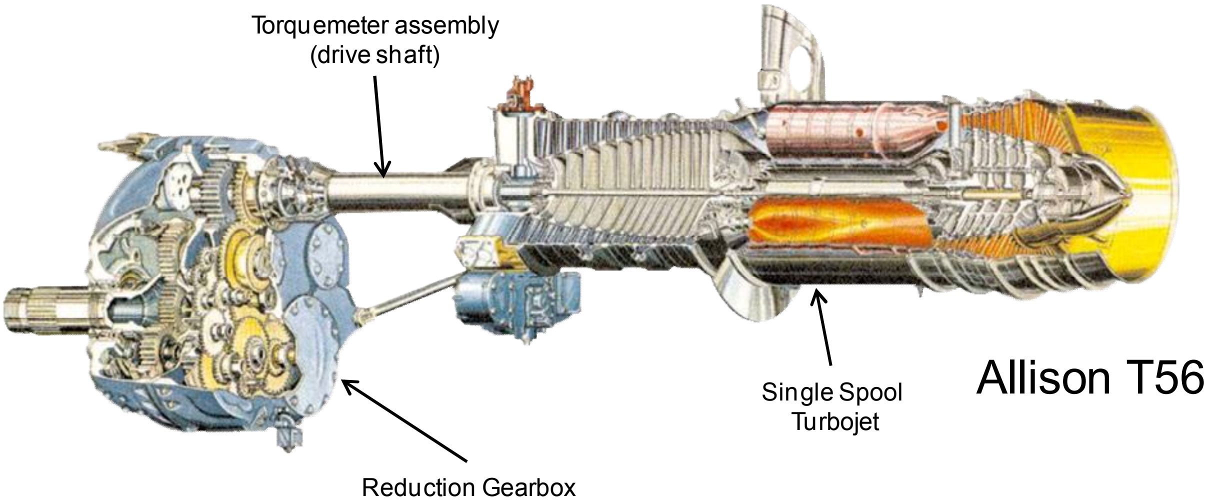

Figure 10-2 Direct Drive Turboprop with an Axial Flow Compressor

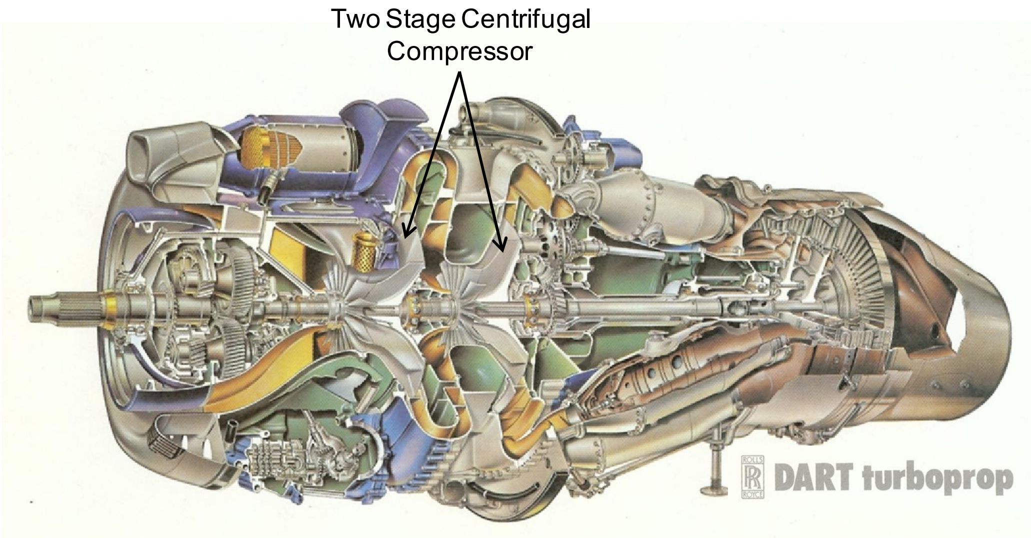

Figure 10-3 Direct Drive Turboprop with a Centrifugal Flow Compressor

In all turboprops, a reduction drive is necessary to reduce the very high turbine RPM to a manageable figure for use by a propeller or rotor. It is not unusual for a small turboprop engine to rotate at more than 50,000 RPM however most propellers rotate closer to 2,000 RPM, and a helicopter rotor RPM may be only one quarter of that.

PROPELLER OPERATING SPEED

Propeller drive configurations can be divided into variable and constant speed propellers.

Variable Speed propellers are also of variable pitch. This maintains an optimal angle of attack (maximum lift to drag ratio) on the propeller blades as aircraft speed varies. Early pitch control settings were pilot operated, either two-position or manually variable. Following World War I, automatic propellers were developed to maintain an optimum angle of attack. Automatic propellers had the advantage of being simple, lightweight, and requiring no external control, but a particular propeller's performance was difficult to match with that of the aircraft's power plant.

Constant Speed Propellers allow the engine to operate at its maximum efficiency, regardless of whether the aircraft is at take-off, climb, cruise or maximum speed. This is described in detail in propeller control later in this chapter.

PROPELLER ROTATION

Convention dictates that all propeller direction of rotation, (DOR) is determined by viewing from the rear of the aircraft. Generally speaking all modern aircraft turboprop DOR is clockwise.

Apart from conventional turboprop configurations already discussed, there are three other rotational configurations used in some aircraft. They are the;

- Contra-rotating,
- Counter Rotating propellers, and
- Propfans.

Contra-rotating propellers use a second propeller rotating in the opposite direction immediately 'downstream' of the main propeller so as to recover energy lost in the swirling motion of the air in the propeller slipstream. Contra-rotation also increases power without increasing propeller diameter and provides a counter to the torque effect of high-power piston engines as well as the gyroscopic precession effects, and of the slipstream swirl. The Russian TU 95 Bear is a good example. Refer to Figure10-4.

Figure 10-4 TU 95 with Contra-rotating Propellers

Counter-rotating propellers are sometimes used on twin, and other multi-engine, propeller-driven aircraft. The propellers of these wing-mounted engines turn in opposite directions from those on the other wing. Counter-rotating propellers generally spin clockwise on the left engine, and counter-clockwise on the right. The advantage of counter-rotating propellers is to balance out the effects of torque, eliminating the problem of the critical engine. These are sometimes referred to as “handed’ propellers since there are left hand and right hand versions of each prop.

The new Airbus A400M tactical lifter has this configuration on each wing, dubbed DBE (Down Between Engines). This allows the aircraft to produce more lift and lessens the torque and prop wash on each wing. It also reduces yaw in the event of an outboard engine failure. Refer to Figure 10-5.

Figure 10-5 A400M with Counter-rotating Propellers.

Propfans The propfan concept was intended to deliver 35% better fuel efficiency than contemporary turbofans, and in this they succeeded. In static and air tests on a modified DC-9, propfans reached a 30% improvement. This efficiency comes at a price, as one of the major problems with the propfan is noise, inside and outside, particularly in an era where aircraft are required to comply with increasingly strict FAA noise requirements for certification.

As with the Contra Rotating Rear Fans, Propfans use Free Power Turbine engines, geared to contra rotating propellers.

Currently only the Russian AN 70 transport aircraft is in service with propfans. Refer to Figure 10-6.

Figure 10-6 AN 70 fitted with Propfans

SCIMITAR PROPELLER BLADES

Since the 1940s, propellers with swept tips or curved "scimitar-shaped" blades have been studied for use in high-speed applications so as to delay the onset of shockwaves, in a similar manner to wing sweepback, where the blade tips approach the speed of sound. The Airbus A400M turboprop transport aircraft is a good example of the scimitar propeller concept. Refer to Figure 10-7.

Figure 10-7 A400M Scimitar Propeller Blades

PROPELLER CONTROL

Turboprop controls differ from turbofan and turbojet engines in that they have two ranges;

- A flight range called the ALPHA RANGE, and
- A ground range called the BETA RANGE.

ALPHA RANGE

In flight the Power Lever works in conjunction with the fuel control unit (FCU) on the engine. A characteristic of the turboprop is that changes in power output are not directly related to engine speed. During flight the propeller maintains a constant engine speed which is at or very close to 100% rated speed and is the design speed at which most power and best overall efficiency can be obtained.

Power changes are effected by changing the fuel flow. An increase in fuel flow would cause the engine (propeller) to increase in RPM. To maintain the RPM at 100% the propeller would have to increase the blade angle, therefore increasing thrust. Obviously, as fuel flow is decreased, RPM will decrease and the blade angle as well as thrust will be reduced.

BETA RANGE

On the ground, the Power Lever directly controls the blade angle of the propeller. It will schedule a blade angle (power setting), for ground idle and reverse.

A ramp in the power lever quadrant ensures that the lever must be lifted into the ground range. Ground air sensing is also used to prevent inadvertent selection of beta range in flight.

Inadvertent Selection of Beta Range In-flight

A DHC-8 aircraft was on descent with the power levers in the flight idle position. The first officer's hand was on the power levers. When the aircraft encountered turbulence, the first officer inadvertently lifted one or both of the flight idle gate release triggers and moved the power levers below the flight idle gate, into the beta range.

This resulted in a double propeller overspeed. When the power levers were returned to the flight range the propeller returned to their normal operating RPM.

The ATSB found that many DHC-8-100, -200 and -300 series aircraft did not have a means of preventing inadvertent or intentional movement of power levers below the flight idle gate in flight, or a means to prevent such movement resulting in a loss of propeller speed control. This design limitation has been associated with several safety occurrences.

CONDITION LEVER

As we can see the controlling lever is normally called a Power Lever instead of a thrust lever. On some aircraft an additional lever is used. This is called a Condition Lever.

The Condition Lever is used to start and stop the engine during normal operation. In flight, this lever is used to shut down the engine in an emergency, and to Feather the Propeller. Refer to Figure 10-8.

Figure 10-8 Propeller Control Levers

A major difference in the operating procedure between a turboprop and a turbojet is in dealing with a malfunction on the runway during take-off or landing.

If the malfunction involves the propeller the crew must identify the nature of the malfunction and the engine involved. The engine (propeller) must then be secured before the take-off can be rejected.

A turbofan powered aircraft does not have to secure an engine before rejecting a take-off.

PROPELLER SAFETY FEATURES

Because the propeller is a large mass spinning up to 2,000 RPM it has to be fitted with various safety features. A loss of control oil pressure leading to a decrease in blade angle (refer to AGK) with a corresponding increase in RPM, (overspeed), is considered to be one of the major malfunctions.

Some of the more common safety features are;

- Pitch Lock,
- Negative Torque System (NTS),
- Low Pitch Stop,
- Propeller Brake,
- Feathering,
- Safety Coupling (direct drive turboprop only), and
- Auto Feather (TSS).

Pitch Lock

This is normally triggered by a propeller overspeed, a control malfunction or a loss of control oil pressure. At a certain % RPM, the pitch lock mechanism engages and prevents the blade angle from reducing and increasing the overspeed. Loss of control oil pressure will have the same result. Effectively you end up in a fixed pitch situation. If control oil pressure is available the blade angle may be increased.

Negative Torque System (NTS)

Under certain operating conditions a turboprop power plant may encounter negative torque

Negative torque occurs when the propeller begins to rotate faster than the reduction gearbox and drives the engine. Torque sensing devices, usually located in the reduction gearbox act, via some form of control, to increase blade angle to maintain a stable RPM relieving the negative torque.

The NTS operates when the following conditions are encountered;

- Temporary fuel interruptions,
- Air gust loads on the propeller,
- High compressor air bleed loads at low power, and
- Normal shutdowns.

Low Pitch Stop

The minimum blade angle for safe flight is controlled by the low pitch stop. This is usually the <u>Flight Idle</u> setting. <u>Ground Air Sensing allows the Power Levers to be retarded into the Beta Range</u>

Propeller Brake

Propeller brakes are used on the ground to stop the propeller from windmilling for an extended period of time after shutdown. This reduces a hazard for ground personnel. Some older power plants use a mechanical device (friction cones), in the reduction gearbox, but the most common method is to feather the propeller on shutdown.

Some aircraft (ATR 42 for example), engage the propeller brake and feather the propeller while on the ground but allow the engine to remain at idle to supply electric and pneumatic services. This is only possible on an engine fitted with a free turbine.

Feathering

When shutting down a turboprop engine in flight is necessary to move the propeller blade angle to about 90°. This places the propeller blades in an aerodynamic lock, which prevents propeller rotation.

Feathering is also used as a form of a propeller brake on the ground.

Safety Coupling

This system is only fitted to a direct drive turboprop. The coupling is installed between the engine and the reduction gearbox. It disconnects the engine from the propeller should the NTS fail and the propeller drives the engine. This prevents a large negative torque and a high windmilling drag.

Auto Feather

Sometimes called a TSS (Thrust Sensitive System), this system is used on multi engine aircraft. It is thrust sensitive, and automatically feathers the engine if a significant power loss occurs on take-off.

This system must be armed by the crew.

Reverse

Although not a safety feature, reverse enables a turboprop aircraft to reduce its landing distance and to ground manoeuvre with ease. With the propeller in the Beta Range the power lever can schedule a negative blade angle (minus 10° to 12°) to provide the reverse thrust required.

To select reverse blade angle the power lever must be in the ground range (beta range), therefore it is not possible to select reverse in flight.

As with turbofan engine powered aircraft, reverse is not used to calculate any stopping distance.

Propeller Synchronising and Synchrophasing are covered in AGK 2.

TURBOPROP INSTRUMENTATION

Turboprops differ from turbofans in displaying power and thrust. Instead of measuring N_1 or EPR, a turboprop measures Torque or Horse Power. Torque is defined as a twisting moment, usually measured in Inch Pounds, although this can be converted and displayed as Horse Power.

This can be achieved using a hydro mechanical device, Refer to Figure 10-9, or a simple method of measuring the twist in a drive shaft. Refer to figure 10-10.

The hydro mechanical unit works using two shafts displacing oil in the torque sensing oil cylinder. Using helical splices and a pilot valve, differential oil pressure is sensed and this is then converted and transmitted to a cockpit gauge.

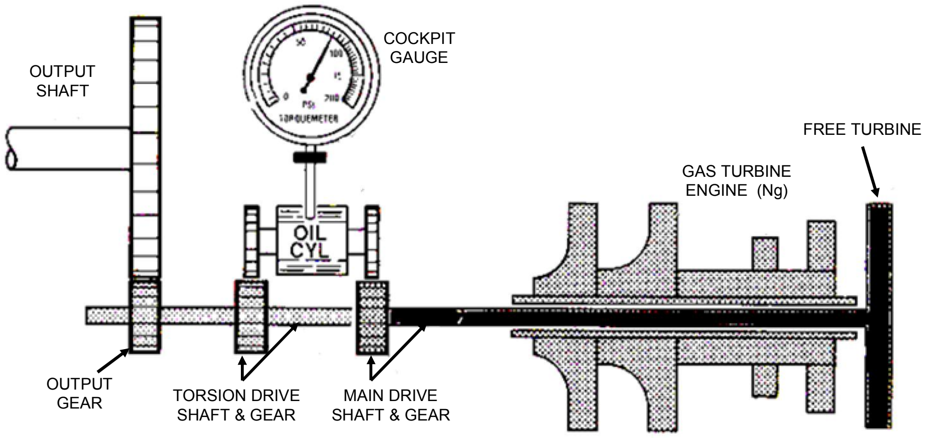

Figure 10-9 Hydro mechanical Torque Sensing (Free Turbine)

The torque meter measures the difference in twist between the drive shaft and a reference shaft. The reference shaft is secured to the drive shaft at one end. Small magnets measure the difference in twist between the two shafts.

This is then converted to read in torque or horse power. Refer to Figure 10-10

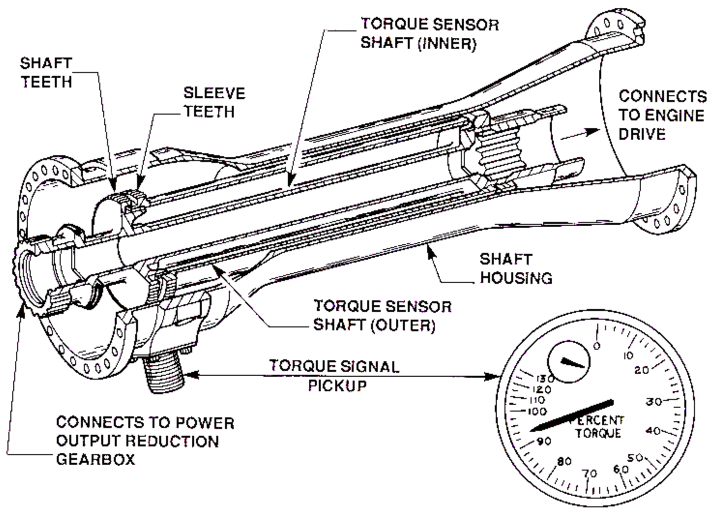

Figure 10-10 Direct Drive Torque Sensing (Torque Meter)