Pratt and Whitney Gear-Based Turbofan Engine

Jeremy Cuddihy, Neil Wimer, Kurran Kelly

I. INTRODUCTION

Before an analysis is made on the Pratt and Whitney turbofan engine, how this engine works must be realized. Each main component in the turbofan engine will be analyzed in order to determine how planetary gear reduction works and why it is necessary in this application. A full understanding of this engine and how the planetary gear reduction works will enable a more effective strength and life analysis of the gears and journal bearings.

Figure 1: Diagram of high bypass, turbofan engine.

A. General Engine Analysis

A turbofan engine is controlled by three main components; the fan, compressor, and turbine. Turbofans are designed to push enormous amounts of air through the bypass portion of the engine which creates thrust when slightly accelerated through the engine’s nozzle. Rather than creating thrust solely through the combustion process, turbofans use combustion to power the fan at the front of the engine. The fan sits at the front of the turbofan engine and controls how much “volume” of air enters the engine. After being pulled into the engine by the fan, part of the air enters the core of the engine where combustion and extraction of energy occurs, and part of the air bypasses the core. In the PW1000G turbofan engine, most of the air bypasses the core of the engine (bypass ratio of 11:1).

Figure 2: Cut away view core of engine and compression and turbine stages.

The air that enters the core of the engine goes through a series of processes that allow energy to be extracted. The first process in the core of the engine is a high and low, axial compression process that is performed in stages by stationary and rotating airfoils. After the air is compressed, it enters the combustion chamber where compressed air and fuel is mixed and ignited. Power is extracted from the high pressure ignition process through sequential, high and low pressure turbines. After exiting the turbines, the air is forced through a nozzle which assists in creating thrust.

B. Gear Reduction
It was previously mentioned that the components inside of the engine’s core operate at different speeds. This is enabled by gear reduction and co-axial shafts. The fan, low pressure compressor, and low pressure turbine are attached to and controlled by a low-speed shaft, while the high pressure compressor and turbine operate off of a high-speed shaft. Gear reduction enables these shafts to move at different, more effective speeds.

The planetary gearset in the PW1000G engine is of the utmost importance because it redirects and distributes all power associated with the engine. The planetary gearset consists of a sun gear, five planet carrier gears, and an output ring gear. The input to the gearset comes from the turbine and is transferred through the sun gear as an output into the ring gear. The five planet carrier gears serve as idlers between the sun and ring gears and transfer energy between them. With the sun gear being the input and the ring gear being the output, a gear ratio can be calculated by dividing the diameters of the two gears. In the PW1000G, the gear ratio is 3:1 which means that the high-speed shaft spins three times faster than the low-speed shaft.

With 32000 horsepower being transferred through the sun gear, axial loads can get out of control in a hurry. All of the gears used in the gearset are helical, so to offset the effects of axial loads, the PW1000G utilizes herringbone gears. Herringbone gears use opposite helical patterns which produce opposite, offsetting thrusts, which means that a thrust bearing isn’t required. This reduces maintenance and manufacture costs drastically.

II. ADVANTAGES OF MULTIPLE SPEEDS WITHIN ENGINE

Gear reduction within the engine allows for multiple loops of speed. This is desired to minimize wear and tear. By allowing for multiple speeds, compression and extraction of energy can be maximized, and emissions can be minimized. In the case of the fan at the front of the engine, a slower speed is desired in this application. A slower fan speed allows for a maximum volume of bypass air which creates more thrust. This means that more power is created at a lower cost with fewer emissions (less fuel burned, fewer emissions).

Figure 3: Axial Compressor.

A. Multi-Stage Axial Compression

All common turbofan engines use multi-stage, axial compression, and the PW1000G features 13 compression stages. By using multiple-stage compression, a higher combustion pressure can be achieved compared to single-stage compression. Single-stage compression is limited by the relative velocity between the compressor rotor and the air moving through the compressor, while multiple-stage compression allows for a progressive increase in pressure and an overall larger pressure increase throughout the system. The gearing in the PW1000G allows for high and low compression stages using multiple stages in each stage. By allowing for staging within stages, this broadens the compression spectrum, power range, and flexibility of the engine. By increasing the
combustion pressure, more mass is forced through the system and more power is produced to power the fan at the front of the engine. By creating more available power for the fan, a larger fan can be used, which moves more air through the engine creating more thrust. Since turbines work opposite of and feed off of compressors, multi-stage turbines have the similar advantages. Multi-stage turbines allow for a more complete energy extraction from the combustion process. Multi-stage compression and extraction allow maximum efficiency and flexibility within the motor.

B. Slower Fan Rotation

Rather than creating thrust by large accelerations through a nozzle, the turbofan slightly accelerates a large volume of air through the engine's nozzle. In order for a fan to operate at full capacity, the fan must spin more slowly than the high speed loop within the core of the engine (enables contact between the air and each fin as opposed to “cutting” of the air). Gear reduction has enabled the PW1000G to create more power to turn a larger fan. This means that the PW1000G produces fewer emissions and produces more power than earlier turbofan engines.