The Pratt & Whitney PW1000G & CFMI LEAP-X are a few years away from entering service. Both have utilised designs and ben configured to provide a large fuel saving over current A320 powerplants. The engines' designs and their probable in-service performance are scrutinised.

PW1000G & LEAP-X: designs & performance

In June 2013, Pratt and Whitney (PW) announced the successful first flight of the PW1100G engine. The PW1100G family (PW1124G, PW1127G, PW1133G) will be one of two engine options to power the Airbus A320neo aircraft family. The other engine option is offered by CFM International's (CFMI) LEAP-1A series.

While CFMI's LEAP engine family is an optimised conventional turbofan, the PW1100G uses a rare configuration of a geared fan to achieve an ultra-high bypass ratio.

The PW1100G's & LEAP-1A's designs are examined to analyse and compare likely durability and in-service performance. Both have been configured to provide a large fuel burn saving over current A320 powerplants. This has been achieved in both cases through ultra-high bypass ratios.

Fuel efficiency

The fuel efficiency of an aircraft depends on: airframe drag, engine drag, and the engine's operating efficiency.

Engine drag is affected by the shape and size of the engine, and the effects of its exhaust gases.

Two factors determine engine operating efficiency: thermal efficiency and propulsive efficiency. The mechanical losses in transmissions, gearboxes, and all forms of inter-mechanical conversions are disregarded here.

An engine's thermal efficiency depends on how efficiently it extracts mechanical work from a unit mass of fuel burned. Thermal efficiency is the energy conversion that takes place inside an engine's core. This includes the compressor, combustion chamber, and the turbines that extract mechanical energy from the hot, expanding gases.

Propulsive efficiency

When the aircraft is static, still air enters the engine at zero speed. The resulting acceleration of the air mass generates 'static' or 'gross' thrust.

The speed at which air enters the engine during flight is equal to the aircraft's forward speed. While the air's exit speed may be higher than when on the ground in static conditions, the air mass experiences an overall smaller acceleration during flight. This smaller degree of acceleration is compensated by a higher rate of air mass flow into the engine. The engine nevertheless generates lower overall thrust compared to static conditions. In flight the engine generates 'net' thrust.

In turbojet and turbofan engines, propulsive efficency is improved by the exit speed of the engine's exhaust gases being closer to the aircraft's forward speed (and therefore the entry speed of the gases into the engine).

An overall smaller average acceleration of the air mass therefore results in higher propulsive efficiency by means of a high bypass ratio. This is the ratio of the mass of air passing through the intake fan and bypassing the core, to the mass of air passing through the core. The CFMI LEAP-1A will have a bypass ratio of about 11:1, while the PW1100G has a bypass ratio of about 12:1.

In a turbojet, the mechanical energy generating thrust is the hot expanding gases that leave the engine at high speed through the turbine. This configuration has a low propulsive efficiency because all of the exhaust air passes through the core, and so has a high exit speed.

In a turbofan, the hot gases expand as they pass through the core engine's turbine. The turbine is mounted on a shaft that turns the intake fan, which has a wider diameter than the core engine, so some of the air bypasses the core.

The intake fan also has a wider diameter than the turbojet's intake fan. This means that a turbofan can have the same thrust as a turbojet by accelerating a larger mass of air to a lower exit speed.

As an example, the net thrust can be delivered either by an engine that exhausts gases at 600kts (1,010 feet (ft) per second (ft/s)), and has a mass flow rate of 970lbs per second, or by an engine that exhausts gases at 350kts (505ft/s), and has a mass flow rate of 1,386lb/s. The second engine will have a higher propulsive efficiency, but as can be seen, requires a larger mass flow rate.

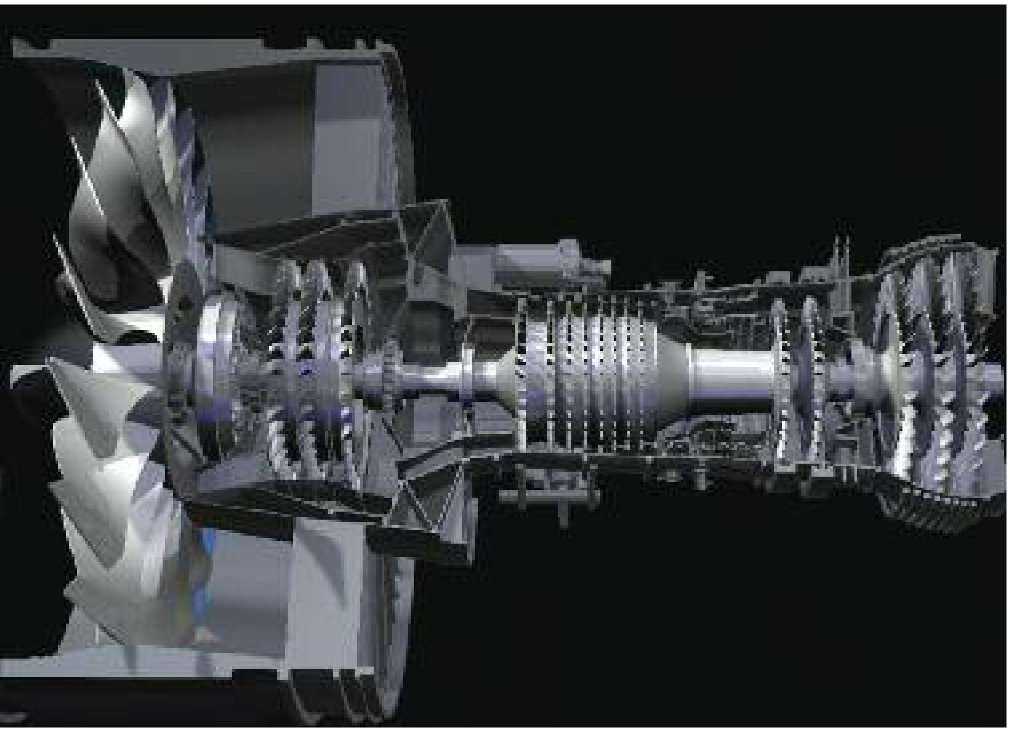
Propulsive efficiency approaches 100% as the air mass exit speed gets closer to the aircraft's forward speed. It is, however, impossible to achieve 100% propulsive efficiency for two reasons: first, if the exhaust gas exit speed equals the aircraft's forward speed, the engine would be generating zero net thrust; and second, the mass of air that would have to be ingested would be disproportionately high compared to an engine's realistic fan diameter size.

Ingesting a larger mass of air per second, and keeping the exhaust velocity low, requires an intake fan with a larger diameter. A turbofan's core engine, however, still needs sufficient power to turn the intake fan.

Turbofan constraints

A large fan has three problems. The first is that it presents more drag to the oncoming airflow, which offsets, to some degree, gains in propulsive efficiency.

The second problem is that a larger fan makes the engine heavier, again offsetting improvements in propulsive efficiency, which affect fuel burn.



The PW1000G achieved a high bypass ratio through the use of a reduction gearbox placed between the intake fan and the LPC. The gearbox allows the LPC and LPT to turn at higher RPMs than the fan, and so reduces the number of core engine stages required to turn the fan.

The third is that the wider and larger the fan gets, the faster is the lateral speed of fan blade tips for a given rotational speed, in revolutions per minute (RPM). A higher fan blade tip lateral speed induces more drag. A large amount of energy is therefore required to overcome the drag that results from high lateral speed of fan blades at high RPMs. This is different from the drag that the blades pose to the oncoming air stream. A high lateral blade tip speed is also noisy.

An example is the fan of an IAE V2500, which powers the A320 and turns at a maximum speed of 5,650RPM. The fan diameter is 63.5 inches (1,613mm). The distance covered by the blade tip in one revolution is 5.36ft X π = 16.40 ft. 16.4ft X 5,650 RPM = 93,930 ft/minute. This is equal to 1,564 ft/s, which is about 1.4 times the speed of sound at sea level. This fan tip speed is responsible for the chainsaw sound that can be heard from an A320's engine at take-off and initial climb.

If the PW1100G's 81 inch diameter fan is turned at the same RPM rate, the blade tips travel at 2,000 ft/s. This is almost twice the speed of sound, and about 28% faster than the V2500's fan blade tip speed.

A turbofan engine suited for a subsonic airplane must have a larger diameter fan to produce the same thrust, with low exhaust velocities and a higher propulsive efficiency, than a turbojet.

The design constraint is therefore that fan revolutionary speed has to be reduced as fan diameter and bypass ratio increase. Limiting the fan's revolutionary speed is required to prevent the blade tips from attaining high velocities that result in excessive noise and wasted energy. This limitation imposes several constraints.

Conflicting requirements

The core of the engine, which is the 'true' jet engine relegated to the role of a gas generator, comprises a large number of disks, with a small diameter compared to the fan. Rows of these bladed disks, some of which form the low pressure compressor (LPC), followed by the high pressure compressor (HPC), ingest only some of the total air ingested by the larger diameter fan. This air is compressed by a ratio of at least 25:1 in the HPC, before mixing with fuel and being ignited in the combustion chamber.

On the IAE V2527-A5, for example, only 17.24% of the air ingested by the fan enters the compressor. The LPC has four stages, of disks, to initially compress the air. These LPC disks run at the same RPM as the fan at the front of the core engine, at a maximum rate of 5,650RPM at take-off.

The air is further compressed in the 10-stage HPC, which turns at a rate of up to 14,950RPM, a higher RPM than the fan and LPC. It is this high rotational speed that allows the 10 stages to compress the air to required levels. By the tenth stage the air is compressed to 32.8 times that of the air entering the nacelle. The small diameter, high RPM, HPC stages generate most of the compression.

The low contribution of the V2500's four LPC stages (mounted on the same shaft as the intake fan) to the overall compression, means that the HPC requires 10 stages. If, however, the LPC could deliver a higher compression, the HPC would require fewer stages to achieve the same compression. For the LPC to generate higher compression, it must rotate at a higher speed. The LPC, however, is mounted on the same shaft as the fan, whose rate of rotation is limited, which in turn limits the compression that the LPC can achieve.

A slower rotational speed for the LP shaft, on which the LPC and LPT is mounted, means more stages are needed to achieve the required level of compression in the compressor, and for the turbine to extract sufficient energy to turn the fan. Conversely, reducing the number of compression stages in an engine reduces the number of discs/stages (and therefore blades), shortens the engine's length, reduces engine weight, decreases system complexity, saves cost, and improves efficiency.

PW1000G

PW's PW1000G series of geared turbofan engines are a result of more than 15 years of development that started with work on the PW8000. The PW1000G was originally planned as a V2500 and a CFM56 replacement for narrowbody airliners such as the A320 and the 737. The PW8000 was announced in 1998.

A PW 30,000lbs thrust demonstration geared turbofan engine flew for the first time during the conceptual phase in 2008, on PW's Boeing 747SP Flying Test Bed, and later on an Airbus A340 Flying Test Bed.

The PW1000G 'Geared Turbofan (GTF)' Family will power the Mitsubishi Regional Jet (RJ), the Bombardier C Series, the A320neo family, and the Russian Irkut's MC-21 series. The family has a gross thrust range of 15,000lbs to 33,000lbs, but the architecture remains unchanged throughout.

The PW1000G's configuration of one fan upstream is followed by: a reduction gearbox between the fan and the LPC that allows the LPC to rotate at a faster speed; two LPC stages; eight HPC stages; two high pressure turbine (HPT) stages (to turn the HPC); and three low pressure turbine (LPT) stages that turn the LPC and the fan. A listing of the number of bladed disks is referred to as the 'stage count', and in the case of the PW1000G family of engines is: 1-G-3-8-2-3. The 'G' refers to the reduction gearbox.

The reduction gearbox is a planetary gear system, with the low pressure (LP) shaft driving a sun gear, which sits within 5 planetary gears held by a fixed framework. The planet pinions have a

The PW1000G's reduction gearbox is a planetary system. The LP shaft turns the sun gear. This has been developed and tested over more than 15 years.

fixed oil pressure line into their shaft bearings that goes through a seal diaphragm to connect to the nacelle support vane. The outer ring gear is bolted to the fan hub and 2 sliding seals allow it to turn.

The PW1000G series has different nomenclature variant numbers. The engines for the A320 and the MC-21 are similar, but have different nomenclature numbering. PW numbers its engines as PW-[Generation]-[Airframe manufacturer]-[Thrust Class in thousands of pounds of thrust]- **[**Geared**]**. This therefore makes a 27,000lbs engine for the A320neo the PW1127G, and the same thrust-rated engine for the MC-21 as the PW1427G. That is, the use of 1 for the second digit denotes Airbus, and 4 denotes Irkut.

The PW1100G series, for the A320neo family, features an 81-inch diameter fan, and a bypass ratio of 12:1, one of the highest ever. The HPC is expected to rotate at a maximum of 20,000RPM, and the LPC at 10,000RPM. The gear ratio of the gearbox is 3:1, implying the LPC stages rotate at three times the rate of the fan, which is expected at to turn at a maximum of 3,500RPM. This results in optimal performance of both the fan and the LPC. This will be compared with the existing, highest thrust-rated powerplants for the A320: the V2527-A5, and the CFM56-5B4. At such rotational speeds, the tip of the PW1100G's 81-inch fan is expected to reach 1,214 ft/s.

Further innovation

PW had planned to use a variable area fan nozzle (VAFN). The VAFN, also known as the fan variable area nozzle (FVAN), attempted to adjust a flap assembly that would vary the fan exit area through which the fan bypassed air is discharged. This would vary the speed of the exhaust gases, optimising thrust and fuel economy at each flight phase. PW has patented the first system of its kind for high bypass turbofan engines. This is a simpler, and inexpensive system of variable area nozzles, compared to military jets.

PW, however, dropped the idea, "after the fan section demonstrated better performance across the flight spectrum". The VAFN is a method to further improve propulsive efficiency, but was dropped when the gains expected were offset by a loss in engine reliability and overall increase in weight associated with adding another mechanical system.

CFM LEAP-1A

CFMI has not opted for a geared turbofan approach. Instead, it has decided to optimise a conventional twin-spool turbofan configuration, which has the fan, LPC and LPT mounted on the same shaft. All three modules therefore rotate at the same RPM. The HPC and HPT are mounted on the inner shaft and rotate at a higher speed.

CFMI has tried to achieve two objectives: increased propulsive efficiency, and increased thermal efficiency.

The LEAP-1A on the A320neo family will have a bypass ratio of 11:1. This compares to the CFM56-5B's bypass ratio of 5.5-6.0:1.

A bypass ratio of 11:1 in the LEAP-1A has been partly achieved through use of a wider diameter fan. This has only been made possible in the LEAP-1A's conventional two-shaft configuration by its core engine's high thermal efficiency.

The LEAP-1A's fan diameter is 10 inches wider than the CFM56-5B's at 78 inches. The LEAP-1A's high bypass ratio is also due to its narrower core. The wide fan and narrow core combine to generate the high bypass ratio of 11:1.

The narrow core is only able to provide power to rotate a larger fan, in comparison to older generation two-shaft turbofans, because the LEAP-1A's fan is made of light material, the engine has a leaner combustion, and the engine utilises a relatively large seven-stage LPT.

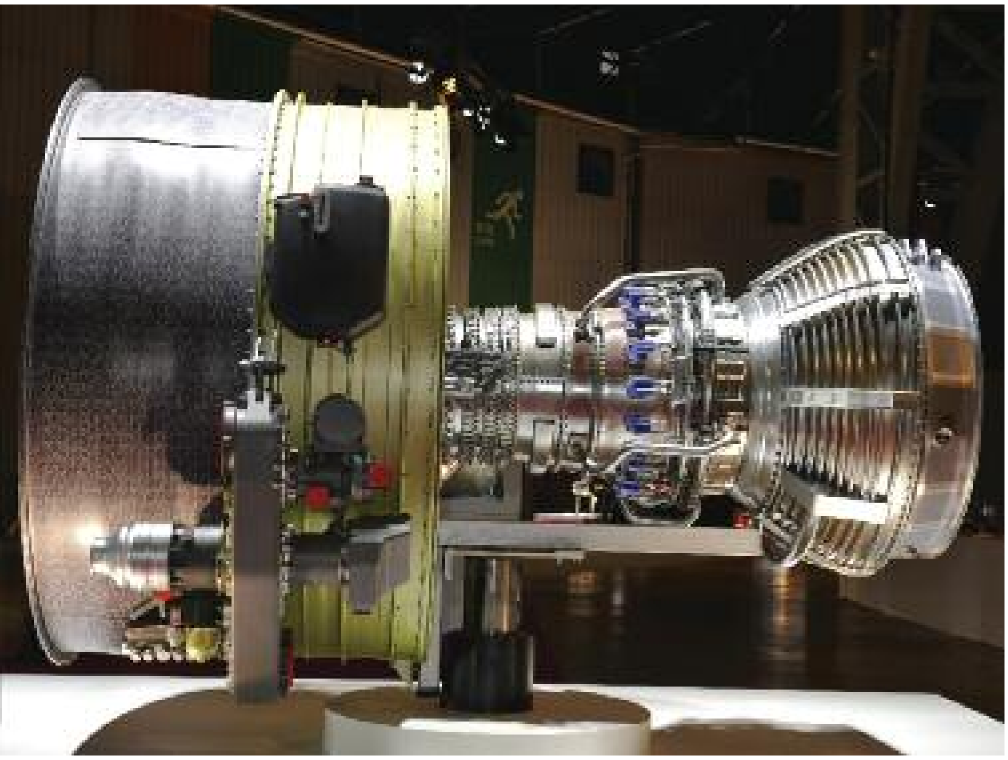
The LEAP's and LEAP-1A's architecture is based on the core compressing a smaller volume of air and having a higher combustion temperature than the CFM56 family and other narrowbody turbofan engines. The smaller volume of air allows the LEAP's core to be narrow.

The configuration of high combustion temperatures and pressures is necessary to provide sufficient energy for the LEAP engine to turn a large fan. High combustion temperatures improve thermal efficiency, and also reduce CO2 emissions. The LEAP's high combustion temperatures could not be withstood by the CFM56-5B and other turbofans of the same generation.

General Electric (GE) has long been working on raising the temperatures that can be withstood by its turbines. There are several technologies that GE and Snecma have introduced into the LEAP.

An effect of high combustion temperatures is higher levels of NOx emissions that result from fuel combustion. These have been offset by the use of a second generation twin annular pre-swirl (TAPS2) combustor. This is used to deliver more uniform temperatures in the turbine, and also reduces NOx. The TAPS2 has also been incorporated so that the LEAP can comply with CAEP VI regulations on NOx emissions. In fact, CFMI claims that through the use of TAPS2, the LEAP will have NOx emissions 50% lower than CAEP VI requirements.

A second technological feature to deal with high combustion temperatures has been the use of ceramic matrix composite (CMC) materials in the HPT. This will be used in the HPT blade shroud from service entry to withstand the high combustion temperatures. An advantage



The LEAP-X has achieved an ultra-high bypass ratio of 11:1 through the combined used of a wide fan and narrow core engine. The small core can turn the large fan because the fan is made of light material, the engine has higher combustion temperatures and leaner combustion, and the core has a large seven-stage LPT.

of CMC material in the HPT blade shrouds is that the shroud ring does not require cooling air, which is tapped off from the HPC in conventional designs.

CFMI has also incorporated 'advanced cooling' to keep the turbine blades cool at the higher combustion temperatures. HPT blades will be made from the same alloy as used in the current CFM56-5B. The improved cooling and use of CMC for HPT shrouds will apparently allow the LEAP to have the same exhaust gas temperature (EGT) as the CFM56-5B series, despite the LEAP's higher combustion temperatures.

CFMI plans to use CMC material in HPT blades from 2020. These will be lighter, more thermally stable, potentially more durable, and will not need internal cooling provided by bleed air.

The LEAP's ability to extract sufficient energy to turn a large fan is partly made possible by the use of a two-stage HPT. This compares with all CFM56 family engines having a single-stage HPT.

While the LEAP's fan is larger than the CFM56-5B's, CFMI has offset this with an advanced fan design. First, the LEAP1-A's fan has 18 wide-chord fan blades, compared to the CFM56-5B's 36 fan blades. The LEAP's fan configuration first reduces drag. The fan blades are also manufactured from 3-D woven carbon fibre composite, as is the fan case, so the fan blades are lighter, and promise greater durability. These lower weight fan blades offset the fan's larger size.

The LEAP's wider fan diameter means it has to turn at a slower rotational speed than the CFM56-B for reasons previously described. For this reason the LEAP-1A requires a seven-stage LPT, three more stages than the CFM56-5B.

These additional stages will clearly add weight, but this has been partially offset through the use of a titanium aluminide material for the LPT blades. These reduce blade weight by 50%.

The LEAP's and LEAP-1A's configuration affects its in-service performance and maintenance costs in several ways.

The first is that the LEAP-1A's core has 22 core engine stages compared to the CFM56-5B's 18 core engine stages.

The LEAP will therefore have more life-limited part (LLP) discs than the CFM56-5B. LLPs are high-cost items. The larger number of stages has been partially offset, however, by CFMI incorporating the use of blisks to serve as a single LLP for several stages.

A second impact of an increased number of engine stages is the use of a two-stage HPT, significant because HPT blades are a high-cost item in engine maintenance shop visits. A third is the three more LPT stages.

A fourth consequence of an increased number of stages is that the LEAP-1A's core will be longer, and so more prone to flexing than the CFM56-5B's shorter core. CFMI has aimed to offset this by using stronger engine frames and cases in the fan hub and the turbine centre.

The LEAP-1A has the issues of more stages and higher combustion temperatures to be considered against the PW1000G's gearing system that could carry a higher risk in relation to reliability and maintenance costs.

CFMI has been cautious in the engine design, committing to 'proven performance', 'low-risk execution', and 'leading technology'. The proven reliability of the LEAP's conventional engine design gives it an advantage over the PW1000G series, which has not yet had the chance to demonstrate benefits of a geared turbofan engine of such dimensions in a commercial airliner.

LEAP-1B vs LEAP-1A

The competition to the A319, A320, and A321 are the 737-700, 737-800 and 737-900. The 737-900's thrust requirement is 24,200-27,300lbs, which is about 6,000lbs less than the 30,000-33,000lbs thrust required by the A321.

The 737-800 can operate with a thrust range of 24,200-27,300lbs, while the A320 operates with a thrust range of 25,000-27,000lbs, in which case engine thrust ratings are similar. The 737-700 can operate with engines featuring a thrust of 20,600-26,300lbs, and the A319 can operate with engines rated at 22,000-23,500lbs thrust. In all cases, a 737NG can operate with lower engine thrust than its A320 family counterpart, with the largest gap seen between the 737-900 and the A321.

The design of a family of engines is determined by the highest thrust requirement. In the case of the PW1100G family, the fan diameter of 81 inches was based on the need for 33,000lbs of thrust for the PW1133G to power the A321neo. The PW1127G and the PW1124G share the same design and turbomachinery, but operate at less extreme conditions.

In comparison, the 737-9MAX needs a thrust of 27,000-28,000lbs. The 737 family and A320 family have similar cruise speeds. This means that if the exit speed of exhaust gases from each engine's fan were equal, the A321's engine intake fan will need a wider diameter to move a larger mass of air, compared to the 737-9MAX's powerplant.

It is for this reason that the LEAP-1A, which will power the A320neo family, has a fan diameter of 78 inches; while the LEAP-1B, which will power the 737MAX family, has a smaller fan diameter of 69 inches. This has prompted Boeing to state, "The A320neo pays the economic price for the A321neo's engine thrust needs," with a larger, heavier engine with more turbine stages that offer more drag for the same thrust.

The PW1000G's large intake diameter fan means it is likely to experience high drag, and so is likely to have longer take-off runs than A320s with current generation engines.

PW1000G performance

The PW1000G GTF engine has, theoretically at least, a reduced reliability in comparison to a standard twin spool turbofan design, because of the inclusion of the extra mechanical gear system. The engine now houses three shafts, all turning at different speeds, and the gear system also adds weight.

The GTF's main benefit, however, is that the weight gain from the above is offset by the reduced number of engine stages, which has many benefits: decreased part count, increased reliability, and reduced weight. It remains to be seen how increased mechanical complexity and decreased stages counter each other in terms of reliability and on-going maintenance costs.

It seems unlikely, with the larger fan and gear system, that the GTF will be lighter than existing IAE or CFM engines that power the A320 with the highest available thrust. Interestingly, the maximum thrust ratings for the PW1127G, as published by PW, remain unchanged from what IAE and CFMI offer for the A320 at 27,000lbs of thrust.

What changes, however, is the amount of drag that the new engine experiences due to its larger size. If there is no significant weight difference between the existing engine options (2,500 kg) and the PW1100G series, there may be a performance penalty, marked by slower cruise speeds for the same thrust setting, possibly slower max cruise speeds, lower rates of climb, and possibly degraded single-engine performance. The single-engine performance difference is expected to be prominent, with a possibly larger yaw, and a reduced climb gradient, lowering obstacle clearances.

Since the gearing ratio between the LPC and the fan is 3:1, the equivalent moment of inertia of the fan, as seen by the LP spool, is only 1/9th of the actual moment of inertia.

The PW1100G's fan radius is 27% more than the IAEV2527-A5's fan, which makes the PW1100G's fan volumetric efficency about twice that of the V2500. This implies crudely that the GTF's air mass flow rate is double that of the V2500's, assuming the same material is used to make fan blades in both engines.

With double the air mass and 27% larger diameter, the moment of inertia of the PW1100G's fan is about 3.3 times that of the V2500's. This makes the equivalent moment of inertia of the GTF's fan, as seen by the low pressure spool, just 33% of the IAE's, despite the larger mass flow and diameter. In simple terms, this means the PW1100G requires only about a third of the energy to spool it up compared to the V2500.

Considering that the PW1100G's LP spool has only three LPC and three LPT stages, as opposed to the V2500-A5's larger and heavier four compressor and five turbine stages, the overall equivalent moment of inertia of the PW1100G's LP spool is at least 25% less than the V2500-A5's. This means the PW1100G's LP spool requires less energy.

With the PW1100G's LP spool estimated to spin at twice the rotational speed of the V2527's, and the engine's overall moment of inertia about 25% less for the PW1100G, the spool-up time may be reduced to about 50% of that in a V2527-A5. This allows thrust to be made available faster, increasing safety margins through enhanced engine response times.

With the PW1100G's increased drag, the V1 take-off speed will be lower, while the take-off run is expected to be longer than current A320s powered by high-thrust IAE and CFM engines.

While the PW1100G series engine is expected to contribute to 11.5% of the proclaimed 15% fuel burn savings on the A320neo, its operating performance may not be as good as that of the high-thrust, sharklet-equipped A320 in high altitude, terrain-challenged operations.

The PW1100G's noise emissions are expected to be lower, however. The slow turning, large fan produces less noise, making the aircraft quieter for passengers and communities around airports.

The PW1000G series, and especially the PW1100G family, may face some initial problems, possibly due to using the largest turbofan bypass ratio, and adopting a gearing system of an unmatched scale. This is despite promising double digit fuel burn savings.

The slow rotational speed of the fans contribute to low noise, and so should enhance the passenger experience and could even reduce flight-related fatigue.

The reliability of such a huge geared turbofan engine is not yet known, casting initial doubts on dispatch reliability for airlines. Further, the PW1100G's prime focus on propulsive efficiency will incur more drag than the LEAP-1A. This one-sided effort towards better fuel savings increases drag, and may cost the Airbus A320's take-off, climb, and cruise performance, especially on short runways, and/or with adverse terrain.

If PW succeeds with the GTF, the geared engine architecture may play a role in future engines.

The GTF was selected by Airbus as the lead engine and has won most of the early large customer selections (ILFC, IndiGo and Lufthansa). The most controversial aspect of this engine is the gear. Although the gearing system was a concern earlier in development. PW is doing enough to counter this, and the number of orders indicate that this is not a major issue for customers.

It does not appear that the same upgrade path is possible on the LEAP-X. The most important point is PW's ability to deliver on the conventional aspects of the engine, since some operators have bad memories of the technically troubled PW6000 programme. The GTF is also further along its testing process than the LEAP-X. If the GTF can be executed well, and PW can avoid the pitfalls that

The LEAP-1A/1B has employed several technologies to counter the negative effects of high combustion temperatures. These include the use of a TAPS combustor, and ceramic material composite (CMC) in HPT shrouds. CMC material may also be used in HPT blades a few years after service entry.

beset the PW6000, then the GTF is likely to be preferred on the A320neo.

LEAP-1A performance

The CFMI LEAP-1A, with the reduced drag footprint, increased thermal efficiency, and optimised propulsive efficiency (although probably not as optimised as the PW1100G's), may lead to similar fuel burn savings, with a lesser penalty on performance.

CFMI's approach to performance has been to raise the bypass ratio by moving to higher core temperatures and pressures. This move is supported by new and more advanced materials.

A key application of new materials will be the use of CMC blades in turbines for the LEAP-X. Cedric Goubet, Executive Vice Principal at CFMI, at the 2014 Singapore Airshow spoke on CMCs and their utilisation within the LEAP-X. Goubet emphasised that "the CMC is a first in a civil application and the challenge is to flawlessly produce such a sophisticated material in large volumes."

The main benefits of CMC are: its reduced density, because it reduces the weight of the part or blade by two-thirds; and its ability to withstand high temperatures. Snecma and GE engineers therefore hope to use it in the future (sometime after entry into service) for HPT blades. The latter components would then not require their current complex cooling air channels. Goubet added that Snecma and GE may switch to CMC on the LPT's larger blades, since it may save weight.

To give this context, GE's advanced programmes department has estimated that incorporating CMC turbine blades on a GE90-sized engine could reduce the overall weight by about 455kg (1,000lb), about 6% of 7,550kg dry weight of a full-sized GE90-115. In addition, replacing the turbine blades with ones that could weigh two-thirds less than conventional blades, means that they also require less turbine structure to support them. This translates to smaller supporting hardware, which benefits the overall engine design.

The CMC blades also do not require cooling in the same way metallic blades do. Bleed air for turbine cooling is no longer required, so specific fuel consumption (SFC) could be further improved. The flipside of this risk, is that the LEAP uses ceramic coatings that have no maintenance, repair & overhaul (MRO) requirements. Introducing total ceramics versus metal-coated ceramics may introduce as much risk as PW is introducing with the GTF.

Separately, 3D-printed components are being used in the LEAP programme. "On development engines, some LPT vanes are made using an additive layer manufacturing process with titanium alloy," Goubet says. On production engines, fuel nozzles will be partly made from a nickel alloy via 3-D printing.

It appears that the CMC HPT blades could be ready to go into service in 2020, about four years after the engine should enter service. There is a concern that higher cooling requirements for the non-CMC HPT-equipped engines will negatively affect fuel burn performance as more bleed air is taken from the HPC, and higher temperatures will reduce blade life on the early engines.

It would not be surprising if the LEAP X programme does not have a similar entry into service as the CFM56 with many technical upgrades to follow. A drawback is in the spool-up time, which may be considerably longer than the PW1100G's. This is because of the LEAP's higher number of stages. CFMI has positioned the LEAP-1A as the lower risk alternative compared to the GTF on the A320neo, despite the LEAP's higher number of moving parts and stages.

Either engine option will affect the A320's performance, and may be unable to match up to the climb performance, safety and statistical reliability offered by today's sharklet-equipped A320 with either the V2527-A5, or the CFM 56-5B4. This is the price, however, paid for fuel burn and efficency savings.

Summary

Both CFMI and P&W have made excellent technical strides and are pushing the technological boundaries and physical limitations of jet engine technology and materials as we know them today.

Airlines and operators are likely to see performance margins they have only dreamed of before. They can expect the best fuel burn, lowest noise and emissions and extended on-wing intervals. This is only possible because these two manufacturers keep innovating. With the introduction of CMC turbines and further GTF enhancements on the LEAP engine, further improvements can be expected across the board.

PW can tweak its fan:LPC gear ratio to achieve 25% better fuel burn and lower noise and emissions than current engines. CFMI will likely add more ceramics to allow the LEAP to generate an ultra-high bypass ratio while maintaining or even exceeding the CFM56-5B's on-wing performance.

One final issue is that PW could incorporate technologies used by the LEAP family: CMC and 3-D aerofoils and the equivalent of TAPS. It will be harder for CFMI to incorporate a geared fan into the LEAP.

Further to this, with Rolls-Royce's announcement in February 2014 that its next generation engine design, called the ultrafan programme, which will replace the current Trent family, will incorporate a geared design, it would appear that GTF technology is well and truly the future.