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Airline Economics

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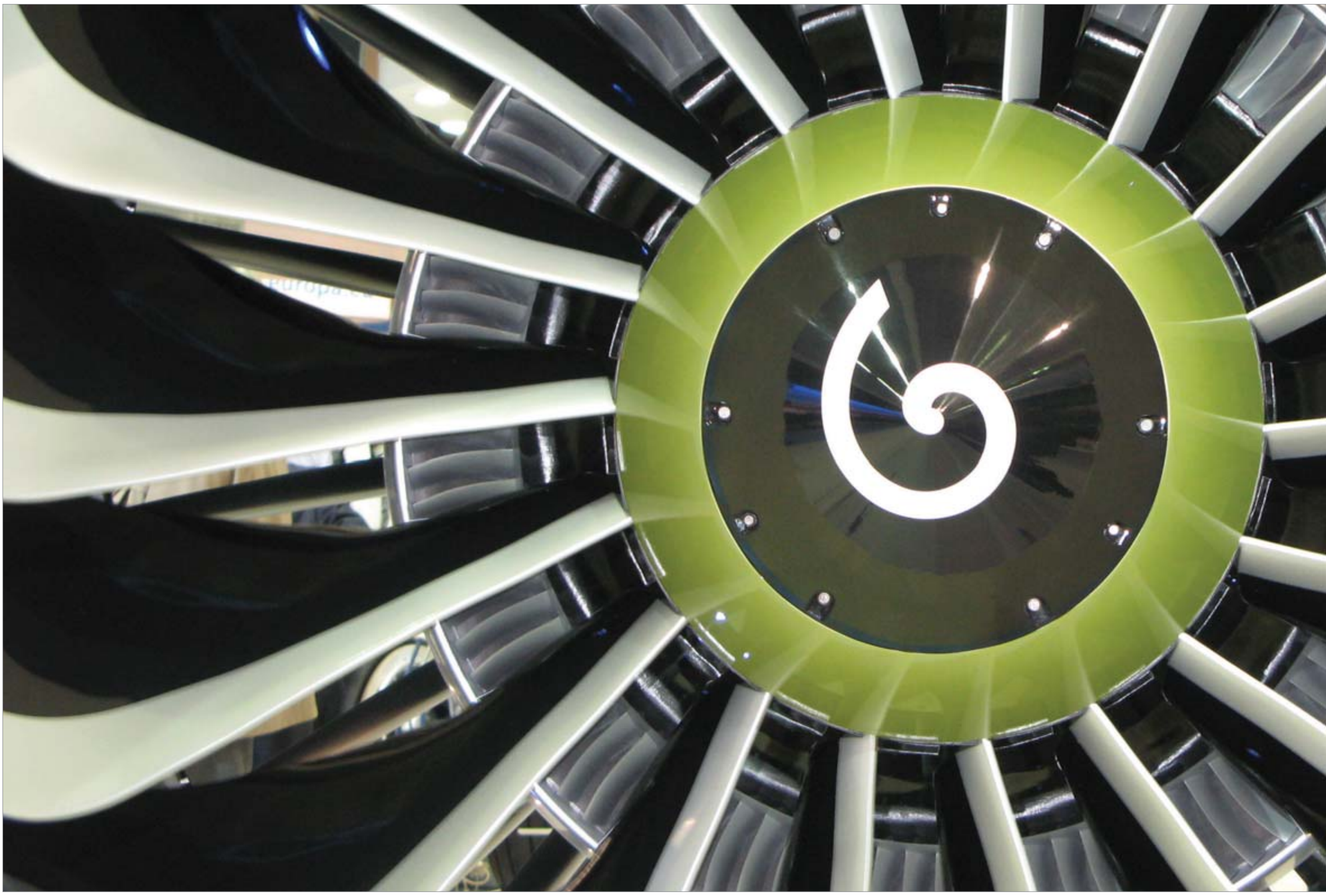

A question of confidence

David Cook pulled engines out of fighter jets in his RAF days and sold engines to airlines when he worked for a major engine manufacturer. Now as president of independent ASM Consulting he offers his views on the new engines being offered for the A320neo.

The 2011 Paris Air Show saw a torrent of orders for the Airbus A320 new engine option (A320neo) with 380 firm and 284 option aircraft booked. But for each aircraft order announced there was also good news in the engine manufacturer's chalets, with engine selections being confirmed at the same time. Under normal circumstances there would be nothing unusual in that. However, the A320neo offers a choice of two significantly different engines, engines that might well change the aviation landscape in the years to come. What are these engines? How are they different and why are they potentially so important?

To begin our analysis, a bit of basic physics. Newton's second law of motion explains that the force acting on a body is equal to the mass of the body multiplied by the acceleration imparted on that body, and this is a fundamental of jet propulsion. Military engines generate thrust by accelerating a mass of air rearwards at very high velocities. Commercial engines generate thrust by accelerating a significantly larger mass of air rearwards at a relatively slower velocity. The part of the engine responsible for producing this accelerating force – thrust – is the fan that generates around 75% of the engine's thrust, the remainder coming from the exhaust jet. The ratio of the amount of air that passes through the fan compared with the amount of air passing through the central part of the engine – the core – is called the bypass ratio (BPR) and most commercial engines today are considered to be 'high' bypass ratio engines, with BPRs in the order of 5 or 6 to 1.

Over the years commercial engine manufacturers have faced challenges to improve their products in response to the demands of their airline customers. The biggest challenges they have

faced in recent years have been to reduce fuel consumption while also reducing engine noise. The high bypass ratio engine responded well to this challenge: the slower fan airflow reduced noise while improved engine thermodynamics associated with the high BPR concept have contributed to an average improvement in fuel consumption of 1% per year over the past 50 years. However, in more recent times the industry focus has changed. While noise is still a major issue, the debate regarding climate change has increased attention on fuel burn, not just from the point of view of airline economics but also in terms of the sustainability of oil reserves and the generation of greenhouse gases such as carbon dioxide. A step change in fuel consumption was required from the engine designers, large enough to satisfy the operators but also large enough to justify launching a new aircraft – or re-engining existing aircraft families.

Aircraft engine design is a fine balance of compromises. The engine must be safe, reliable and efficient, at ground level as well as at altitude, in fine weather or foul, and produce low levels of noise and harmful emissions while costing nothing to maintain. In general terms (and my engine designer friends will be quick to point out this is a very broad statement) the simplest way to improve the fuel consumption of a high BPR engine is to increase the BPR even more and make better use of the air that flows through the core to generate the mechanical power necessary to turn a larger fan producing more thrust. The two engines offered on the A320neo have much higher BPRs than their current equivalent engines, and are elegant examples of how the various design compromises can be resolved to achieve similar results while using two radically different concepts.

The engines proposed for the A320neo have fan diameters considerably larger than the current A320 family engines, and this shows there are also considerations with regards to the engine's installation on the aircraft. It's all very well for the engine designer to improve fuel burn by increasing BPR, but the increased frontal area of the larger fan will impose an increase in drag on the aircraft, as will the increased surface area of the nacelle surrounding the engine. While such things can be estimated using the sophisticated modelling tools available to the design engineer today, the net benefit brought by these new engines will only be realised once they have flown on the airframe and their performance has been measured in flight.

But to understand these engines better, let's 'lift the hood' on the Pratt & Whitney (P&W) 'Purepower' PW1100G and the CFM International Leap-X engines to figure out how they work and what is so different about them, starting first with the PW1100G. Note that neither of these engines exists yet and so these virtual guided tours are based on information already in the public domain as well as individual briefings given to me by the respective engine manufacturers.

Approaching the PW1100G from the front, the 81" diameter fan is impressive but what is most noticeable is just how much daylight we can see through the fan blades, dramatically illustrating the 12:1 bypass ratio. The blades are wide-chord, metallic and, while P&W remains coy about their actual structure, I would imagine they are similar to the hollow titanium blades found on the V2500 family. This is in itself a surprise as most engine manufacturers are turning to carbon composite for their fan blades. Evidently P&W hopes to demonstrate good damage tolerance and performance while designing a fan that is still light enough to allow the use of a carbon composite fan case capable of withstanding a blade failure scenario.

Opening up the casings displays a three-stage low-pressure compressor and short, compact eight-stage high-pressure compressor. Each high-pressure compressor stage is a 'blisk', where the compressor blades are an

A320 ENGINE CHARACTERISTICS

	Current Airbus family						Airbus Neo family					
Engine manufacturer	IAE			CFM			P&W			CFM		
Aircraft model	A319	A320	A321	A319	A320	A321	A319	A320	A321	A319	A320	A321
Engine model	V2500-A5 Series			CFM56-5B Series			PW1100G Series			CFM Leap-X Series		
Thrust range	22,000 to 33,000 lbs			22,000 to 33,000 lbs			23,500 to 32,100 lbs			22,000 to 33,000 lbs?		
Fan diameter	63,5"			68,3"			81"			78"		
BPR	4.9	4.8	4.5	6	5.7	5.5	12			10+		
Cruise sfc (lbs/lb/hr)	0.543			0.545			V2500-A5 minus 15%			CFM56-5B minus 16%		
Noise (epndB margin to stage 4)	19-20	19-20	15-16	16-21	14-17	8-16	Stage 4 minus 16dB			Stage 4 minus 10-15dB		
Nox (margin to CAEP 6 limits)	8%	7%	1%	32%	28%	20%	CAEP 6 minus 50%			CAEP 6 minus 50%		

integral part of the disk. The combustion chamber looks familiar, a trademark P&W 'Talon' design but using state-of-the-art technology to obtain NOx emission levels 50% below the latest Committee on Aviation Environmental Protection (CAEP) 6 standards. Behind the combustor is a two-stage high-pressure turbine driving the high-pressure compressor and a three-stage low-pressure turbine using what looks like rather conventional materials. So far so good – a short, simple engine using recognisable technology with low parts count contributing to low maintenance costs. But going back to the front of the engine, there is a large steel casing sitting between the fan and the low-pressure turbine shaft. It is a planetary gearbox, transmitting power from the low-pressure drive shaft to the fan via a number of smaller 'planet' gears, and it is this unit that makes the Purepower series of engines so different.

As previously mentioned, there is a need to increase BPR while improving core efficiency. As fans get larger they must rotate more slowly, to avoid the blade tips going supersonic, but to improve core efficiency one would normally look to increase combustion temperatures and have the turbines spinning faster – a classic engine design conundrum. The Purepower engines are what are called geared turbofan (GTF) engines: instead of the low-pressure turbine driving the fan directly through the low-pressure shaft, the fan is driven through a gearbox, thus allowing both the low-pressure turbine and the fan to rotate at their most optimal speeds. The use of a gearbox does, however, bring with it some issues. As a component,

> **"The Purepower engines are what are called geared turbofan engines: instead of the low-pressure turbine driving the fan directly through the low-pressure shaft, the fan is driven through a gearbox"**

the gearbox is rather large and heavy, but P&W would argue the weight penalty of the gearbox is offset by the use of a shorter, lightweight, high-speed engine core. Some might also question the effect of such a key component on the engine's reliability and cost of maintenance. P&W would respond by pointing out there are no expensive life-limited parts in the gearbox, that the shorter core has fewer rotating parts and aerofoils, and that the concept has been extensively tested to demonstrate its reliability.

Although the Purepower series of engines has been described as being a new engine concept, there is in fact nothing new about geared turbofans. Both the Garrett TFE731 and the Lycoming ALF 502 engines use gearboxes and have clocked up many hours of business jet and airline operation. While these engines have had reliability issues, few of the known problems have been associated with the gearbox. Although the engine industry pretty much turned away from geared fan technology back in the 1980s, P&W has been quietly working away, refining the concept through more than 30 years of testing and development. The proof will, of course, come once the engine enters service but the gearbox is not expected to be a source of problems for the airlines.

Turning now to the CFM Leap-X engine. The fan diameter is slightly smaller than the PW1100G, 78", and the wide-chord fan blades are black, suggesting they are made from carbon fibre. The Leap-X fan blade is a very sophisticated design, using the latest in composite materials technology to produce a blade that is both light, strong and damage-tolerant. While the three-dimensional weave structure of the blade fibres is hidden beneath an aerodynamically smooth coating, the same weave pattern of interlocking strands is clear to see in the structure of the fan casing, giving the engine a modern, jazzy look.

Viewed from the side, the engine gives the impression it is noticeably longer than the PW1100G and, on opening the casings, it is clear why. Behind the fan is a three-stage low-pressure compressor followed by a 10-stage high-pressure compressor, the first nine stages of which are blisks. The combustor is an updated TAPS low-emissions design, offering NOx levels 50% below CAEP 6. However, it is in the turbines that the real difference between the Leap-X concept and its predecessors in the CFM stable can be found. There are two stages of high-pressure turbine rather than a single stage in the CFM56-5B and seven stages of low-pressure turbine rather than four. The original CFM56 design was optimised towards low maintenance costs, hence nine stages of high-pressure compressor and a single-stage high-pressure turbine. To achieve the levels of fuel economy demanded by the market today, considerably more attention has been focused

ENGINE DEVELOPMENT PROGRAMME TIMELINES

Programme	2010	2011	2012	2013	2014	2015	2016
Bombardier 'C' Series / PW1500G Series	FETT	Flight test	Certification	EIS			
Mitsubishi Regional Jet / PW1200G Series		FETT	Certification?		EIS		
Airbus NEO / PW1100G Series						EIS?	
COMAC C919 / Leap-X1C Series							EIS?
Airbus NEO / CFM Leap-X Series							EIS?

FETT = First engine to test   EIS = Entry into Service on the aerodynamic efficiency of the core, hence the additional high-pressure turbine stages in the Leap-X. Similarly, to drive the fan slowly, at optimum efficiency, three additional stages have been added to the Leap-X's low-pressure turbine to squeeze the last drop of energy out of the exhaust gases. One final point for the more discerning – the N°4 bearing, the Achilles heel of previous CFM56 models, has been redesigned, which should further enhance reliability.

Something not present in this engine is the telltale grey of ceramic composite material, which is a surprise. When the Leap-X programme was originally launched, at the Farnborough Air Show in 2008, extravagant claims were made about the use of exotic materials to achieve performance improvements. While these materials will eventually find their way into the engine in time, CFM emphasises that, as the Leap-X engine intended for the A320neo will operate at temperatures similar to today's engines, it will be built using relatively traditional base materials. Some new heat-resistant coatings will be used, and blade cooling will be improved, but the only ceramic material will be found in the high-pressure turbine shrouds. This choice of materials is important because while some would argue more stages and more rotating parts contribute to increased maintenance costs, this would be an over-simplification. Cost of spare parts, availability of repair techniques and competition in the parts-repair market are also important factors in driving repair costs down, and these criteria are facilitated by using materials that are known to the industry and repairable in an airline's workshop.

There are the two engines presented in a virtual head-to-head comparison. On the one hand is the PW1100G: a GTF engine, short and compact, and with fewer rotating parts so maintenance costs should be low. Its gearbox is, in some people's minds, a major unknown. On the other hand is the Leap-X: longer, but with a smaller fan diameter and more rotating parts. It is relatively conservative in its choice of materials. But here is a contradiction in the engine manufacturers' marketing strategy: initially the Purepower engine series was presented as a fairly low-tech, rugged design but P&W would now have customers believe the engine is stuffed full of new technology. Conversely, it was initially believed the Leap-X engine was to be a jewel of all the latest technology available to the industry today, but CFM now insists it is not such a leap (no pun intended) in the dark and that all the new technology incorporated into the engine has been tested and proven to bring measurable benefit. What is clear is that all this new technology, whether from P&W or CFM, has a price. It has long been a tradition in the engine industry that engines are sold by thrust, not hardware, which is why a customer would pay significantly more for a high-thrust engine on an A321 than for a lower-thrust model, built using exactly the same hardware, on an A319. Analysis of recent media reports suggests airlines are going to be paying more than $1 million an engine extra, in terms of list price, for these new models compared with the previous models at equivalent thrusts.

So, which engine do you choose for your brand new A320neo? So far this article has focused on the technical characteristics of the engines and, if you were a technical vice-president of an airline there would be plenty for you to discuss and debate. However, readers from a financial background might be more interested in analysing these two engines from a risk perspective.

While these two engines are often described as being 'new' engines, there is, in reality, no such thing. All engines are produced following extensive design and test programmes and these two engines are no exception. P&W has been working on the geared turbofan concept for more than 30 years, ever since its abortive attempt to secure an International Aero Engines GTF application on the Airbus A340 in the mid-1980s. The Leap-X engine is the offspring of a technology acquisition programme launched in the latter years of the 20th century aimed at equipping CFM with the technology it felt it would need to support a new Boeing aircraft that, as everyone believed at the time, would enter service around 2013. And so, as such, neither engine should present a big risk in terms of technical maturity. But the aviation world is full of surprises, as CFM found out when it introduced the CFM56-7B, a low-risk derivative of a well-established engine family. While the engine has settled down and is now providing excellent service, it did experience

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some quite unusual, and unforeseen, problems in the beginning.

Many airlines that have ordered the A320neo have justified their choice of engine based on their appreciation of the respective manufacturer's track record. P&W has extensive experience on the A320 family through its IAE joint venture and, as stated before, it has been working on the GTF concept for a long time. P&W is also further into its engine development programme than CFM, and can probably back up sales pitches with more hard data.

The Purepower series of engines has also been selected for other aircraft, such as the Mitsubishi Regional Jet, the Bombardier C Series and the Irkut MC21. Pre-production engines are flying, hardware is being tested, components are being torn down and examined in microscopic detail. P&W claims that by the time the PW1100G enters service on the A320, the Purepower GTF engine concept would have already accumulated more than one million operating hours on other aircraft programmes. CFM is also into a heavy programme of component testing but its engine will not enter service until several months after the PW1100G.

In justifying the choice of the Leap-X engine, customers such as SAS and Air Asia refer to their previous experience with CFM products. It is one thing to be able to relate to previous product experience, but this is the crucial issue with both of these engine programmes – not only are they revolutionary concepts in their own right but they are also completely different from their manufacturers' previous product lines. P&W has never put a GTF into service before and the Leap-X probably has more in comparison with GE's GenX engine than with other engines in the CFM product line. This suggests that, in these cases, previous experience has rather limited value as an engine selection criterion. So how do you choose? In the end it comes down to a question of confidence. Who do you believe will be better able to respect programme milestones? Who is better able to accommodate the head-spinning ramp-up required to introduce several programmes to the market at the same time? Who is better able to manage their supply chain to avoid problems that could ground the whole fleet? Who is better able to sort out technical problems quickly if things do go wrong? Both manufacturers have valid arguments to answer these questions – but only time, and experience, will tell.

"If a lessor is looking to acquire a large number of A320neos for leasing to the airline community, which engine model should it select? The answer is simple – both"

The choice of an engine is difficult enough for an airline but how does an aircraft leasing company make its choice? If a lessor is looking to acquire a large number of A320neos for leasing to the airline community, which engine model should it select? The answer is simple – both. Both engines offer step changes in fuel economy backed up by comprehensive OEM fleet hour maintenance agreements. Both engine manufacturers are committed to making these programmes work to ensure their future in the civil aero-engine business. Both engines are available on a number of different aircraft applications (the American Airlines order has signified the launch of the 737 re-engined with the Leap-X). The market (with a little help from Airbus) will, in the long term, ensure a more or less 50/50 split in market share with regards to A320neo engine selections.

But the market should not get over-excited about re-engining programmes. Engine manufacturers are used to playing the long game and we should not forget what this is really all about – the engine selection for the next generation of single aisle airliners (NGSA). With Airbus, and now Boeing, committed to re-engining programmes, the timescale for an NGSA has certainly been pushed out to the right, but both engine suppliers have their sights firmly fixed on this longer-term objective. And they are not alone – Rolls Royce, although marginalised for the moment in this particular market segment due to its unwillingness to join P&W in a new IAE-type joint venture, is quietly pursuing its own mid-thrust engine development programmes. And who's to say that, in the meantime, there might not also be new entrants into this market – the Chinese, for example? In 10 years' time the fight to secure a place on one of these re-engining programmes might, in hindsight, seem just a minor skirmish compared with the battle to equip the next generation of completely new single aisle aircraft.