COMMERCIAL ENGINES

Climbing again

Sustainability the goal as industry ramps up to recovery

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Whatever next?

Propulsion manufacturers are ramping up output to meet strong post-pandemic airline demand, despite supply-chain pain. They are also seeking the technology breakthrough to deliver the ultimate environmental engine

Murdo Morrison London

It is an exciting but challenging time for the commercial engine sector. The rapid rebound in air travel since 2021 has led to airlines restoring and adding routes and frequencies. Many have also been confident enough about the medium- to long-term prospects to place hefty airliner orders.

This has, in turn, pushed Airbus, Boeing and the other airframers to set aggressive ramp-up targets for themselves and their suppliers, including engine manufacturers. However, stepping up production is not a case of simply pressing harder on the pedal.

Shortages of raw materials and structural issues had been creating supply-chain snags as demand for aircraft soared before the pandemic. Soaring inflation and experienced staff not returning to the industry meant problems just grew worse as Covid-19 receded.

At the same time, pressure for a more sustainable aviation industry is driving the development of radical and potentially disruptive technologies, including in propulsion, as manufacturers consider new materials, fuels, and architectures.

The next generation of powerplants is likely to deliver a much bigger step change in efficiency and carbon impact than the current engine types – such as the CFM International Leap, Pratt & Whitney PW1000 family, Rolls-Royce Trent XWB, and GE Aerospace GEnx – did over their predecessors.

Down the line, developers of hydrogen and electric solutions are convinced they can significantly or even totally displace the kerosene engine, despite the apparent limitations of weight and range both these emergent technologies bring.

So far this year, most of the engine manufacturers have reported strong performances. Safran, which co-owns CFM International, delivered 785 Leap engines in the first half, up on 465 in the same period in 2022. The Leap powers the Airbus A320neo family, Boeing 737 Max and Comac C919.

Gear change

Safran's fellow shareholder in CFM, GE Aerospace, significantly increased the pace of its commercial aircraft engine deliveries in the first six months. Likewise, RTX, which owns P&W, reported increasing activity for its engine division over the period.

During the pandemic, many experts feared that the widebody sector would be considerably slower to recover than single-aisles, because virtual conference tools – given an impetus by working at home – would replace much long-haul corporate travel.

That does not seem to be the case. Rolls-Royce, GE's main competitor in the widebody market, has said it expects large engine flying hours to return to between 80% and 90% of the 2019 figure this year based on data from its long-term service agreement customers.

The UK company, which is in the middle of a transformation programme under its new chief executive, also delivered impressive results in the first half of 2023 and predicts between 400 and 500 engine deliveries for the year, including business aviation products, up from 355 in 2022.

Supply-chain challenges and reliability issues, however, continue to dog the sector. In August, R-R chief Tufan Erginbilgic said he expects problems sourcing parts and raw materials to last into 2024 and possibly beyond, and that the company has had to build up inventory to cope with disruption.

P&W has been one of the worst

Rolls-Royce

"I think we are on track to deliver more than 20% [more] fuel efficiency. That is just the propulsion system"

Arjan Hegeman General manager of advanced technologies, GE Aerospace

R-R ran its UltraFan engine for the first time this year

affected, announcing in July that it was recalling 1,200 P1100Gs for inspections over concerns about potentially defective high-pressure turbine disks. The move requires engines to be taken off wings, partly disassembled and returned to the manufacturer.

It has infuriated some operators of the Airbus A320neo-family aircraft that the engine powers, including Hawaiian Airlines chief executive Peter Ingram, who has complained about having to ground jets because of a lack of spare engines.

Rival CFM says it will roll out a series of "improvement steps" for the high-pressure turbine blades on the rival Leap, designed to address premature wear issues seen on some aircraft being operated in harsh environments, such as the hot-and-high conditions of the Middle East and India.

Despite the short-term headaches, manufacturers have announced progress this year on upgrades for existing programmes, as well as longer-term technology projects. Several engines have also been involved in certification efforts for – or made their in-service debut on – new aircraft types.

In September, Airbus began the latest stage of the flight-test programme for the A321XLR, using a Leap-1A-powered example. MSN11080 is the third of three prototypes Airbus is using for the campaign.

Airbus plans to first certificate the CFM version of the A321XLR, which will be the longest-range narrowbody on the market, followed by a PW1100G-powered option. This reflects the "choice of customers", says the airframer.

15:1

Bypass ratio for NASA's proposed HyTEC smaller lean burning engine

Great leap forward

CFM also achieved another first with the entry into service in May with launch customer China Eastern of the CFM-1C-powered Comac C919. The C919 is China's first "modern" narrowbody and an attempt to break the Airbus/Boeing duopoly.

In the widebody arena, R-R outlined potential upgrades to the Trent XWB-97 for the Airbus A350-1000, for which it is the sole engine. While not revealing details, the manufacturer suggested features could be based on technologies from its long-running UltraFan study – of which more later.

In June, Airbus hinted that it could consider offering a second powerplant option for the A220 – formerly the Bombardier CSeries

Airbus

Airbus has begun flight tests of its ultra-long-range A321XLR

P&W has recalled 1,200 PW1100Gs for inspections

Airbus

– once it begins developing a larger variant of the twinjet. Versions of the P&W PW1500G are currently the exclusive engines on the existing -100 and -300 models.

One mooted new engine is unlikely to make it to market, however, despite the urging of one of the most influential airline bosses. In June, Emirates' Sir Tim Clark reiterated his call for Airbus to develop a re-engined "A380neo", possibly based on R-R UltraFan technology.

Noting that the engines currently on his superjumbo fleet, the Engine Alliance GP7200 and R-R Trent 900, were "designed in the 1990s", he suggested that an engine that could deliver a 25% fuel burn improvement would give Airbus a reason to bring the out-of-production double-deck airliner back to life, no doubt on the back of a sizeable new order from the type's biggest operator.

20-30%

Fuel-burn improvement industry and society expects for future powerplants

Longer term, two of the most potentially transformative projects being talked about publicly are CFM's open-fan RISE (for Revolutionary Innovation for Sustainable Engines), with GE and Safran both involved in that study, and R-R's UltraFan.

Incremental gain

Without a left-field alternative such as hydrogen or compact batteries emerging as a serious contender in the next 10 years, it seems likely that an improvement on current kerosene-burning designs will represent the next evolution of commercial airliner propulsion.

However, while previous developments have typically delivered fuel-burn improvements of 10-15%, it seems likely that manufacturers, airlines, and society at large will demand the next generation of powerplants to be 20-30% more efficient – not to mention quieter and cleaner.

"I think we are on track to deliver more than 20% [more] fuel efficiency," GE general manager of advanced technologies Arjan Hegeman predicted earlier this year. "That is just the propulsion system. The aircraft would add on that. The remainder of this decade is going to be filled with demonstrators to ensure the maturity of all those technologies."

CFM's RISE programme was launched in 2021. Open-fan engines are not new – GE flew one in the 1980s but ditched the effort – but they are radical. They are similar to traditional turbofans with one key visual difference: rather than having their fans enclosed in nacelles, they spin in open air.

Getting rid of the nacelle cuts weight and drag, and this provides an immediate boost to efficiency. Without the restriction of the casing, open-fan designs can also have wider fans, increasing bypass ratios.

However, there are obvious challenges: open fans in the past have been loud. Additionally, without being enclosed, in-flight engine failures could propel components directly through the fuselage with disastrous consequences.

GE has talked about solutions to both of these challenges. It reckons it can design airfoil shapes to bring sound levels below those of today's

narrowbody engines. Armoured fuselages could also mitigate what it believes is the extremely low risk of damaged parts entering the cabin.

CFM aims to begin flight testing a demonstrator this decade using an A380, the first step to developing a product 20% more efficient than today's engines. In June, GE said it had begun manufacturing components for the project, noting that RISE was moving from a "paper engine into real parts and real tests".

Bold ambition

GE insists the open-fan concept can deliver the 20% fuel saving target, despite scepticism about how such an engine would perform on wing from Boeing Commercial Airplanes chief executive Stan Deal – expressed at the Paris air show. Boeing would be number one target customer for any new CFM engine ahead of an expected launch of a 737 Max successor as early as later this decade.

"They are reporting numbers uninstalled," Deal said of early data from the engine manufacturer that seemed to provide evidence for the 20% claim. "Every engine runs better uninstalled than installed. There is always a knock-down effect to get pure fuel burn."

Rolls-Royce, meanwhile, ran its UltraFan development engine for the first time earlier this year, although details have been scant. Erginbilgic describes the demonstrator – which uses a geared-fan design rather than R-R's traditional three-spool configuration – as a "game-changer" with the "capability to improve the engines of today as well as the engines of tomorrow".

However, after an initial test phase, the manufacturer has paused further trials as it assesses likely market interest. "We will be putting the programme on hold until one of our airframe customers is ready to take on this new engine architecture," the R-R boss said in May. With no new widebody types on the horizon, that could be a long wait, although a surprise is possible.

Technologies from the project, such as its Advance3 core and high-temperature materials used in the hot section, could emerge in other engines, including the Airbus A350's Trent XWB, or even a possible new narrowbody engine, a sector R-R has expressed an interest in returning to at some point.

Under an initiative called Project Heaven, and with funds from the EU's Clean Aviation body, the company has been studying how UltraFan architecture might be deployed in a single-aisle engine jet, possibly running on liquid hydrogen, in the mid-2030s.

GE and P&W are both working on contracts under NASA's Hybrid Thermally Efficient Core (HyTEC) effort to develop a smaller engine with a 15:1 bypass ratio that burns 5-10% less fuel than today's turbofans and is also able to extract up to 20% of the engine's power as electricity to drive on-board electrical systems.

NASA hopes to begin HyTEC ground demonstrations by 2026 and have technologies market-ready by the next decade. P&W is also working on a European-funded project to develop a hybrid-electric modification of its geared turbofan.

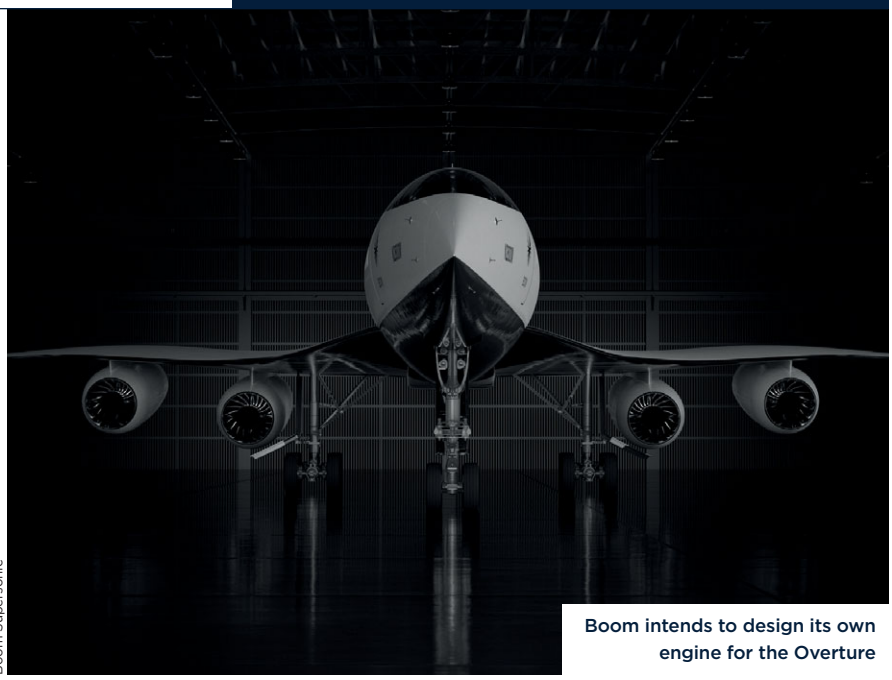
P&W executives at Paris did claim that achieving the holy grail of a 20% fuel economy on a new engine was possible, but probably not until the second half of the 2030s. "We think that timing is moving to the right, 2035 or later," P&W president Shane Eddy said. However, he admitted that timescale created an opportunity for manufacturers to mature technology.

There is one all-new commercial engine under development and it does not involve any of the traditional manufacturers. After being shunned by the big three, supersonic airliner start-up Boom disclosed plans this year to create its own powerplant for its in-development Overture passenger jet, the Symphony.

The two-spool design will have a 72in (183cm) fan, three low-pressure and six high-pressure compressor stages, plus a single high-pressure and three low-pressure turbine stages. It is intended to generate 35,000lb (156kN) of thrust with no afterburner.

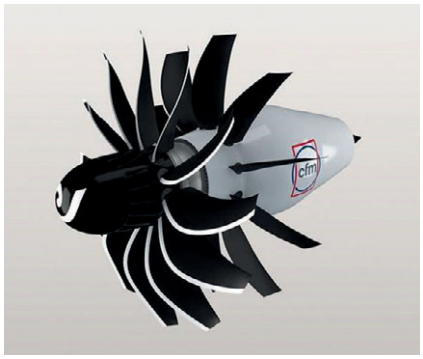
While major industry names such as Leonardo and Aernnova have committed to the aircraft programme, there remains doubt as to whether Boom, which is partnered with engine design house Florida Turbine Technologies, will have the funds and technical wherewithal to bring a clean-sheet engine to certification.

That has not deterred the company from pressing ahead with construction of its "superfactory" in Greensboro, North Carolina. An all-new supersonic engine is just one of the radical concepts – from open-fan designs to hybrid-electric and hydrogen power – that could make the jump from engineering office and design lab to market within the next decade.



Boom Supersonic

Boom intends to design its own engine for the Overture



CFM International

CFM RISE programme launched in 2021

Engine makers have won significant new business over the past 15 months as airlines bolstered fleet plans with a string of aircraft commitments. We look at the most significant developments

Order taking

Airbus

120
United Airlines order for Airbus A321neo and A321XLRs, for which it has selected P&W GTF engines

39
Number of GEnx-powered Boeing 787s which Riyadh Air has on firm order, together with 33 options

97
A320neo-family narrowbodies Jet2 has on firm order to be equipped with CFM International Leap-1As

Air India's 500-strong Airbus and Boeing orders saw big deals for engine makers

Graham Dunn London

Air India's orders for over 500 aircraft from Airbus and Boeing provided a big boost for CFM International as the airline opted for the latter's Leap engines to power the 400 narrowbodies contained in the commitments.

The Indian carrier, which has embarked on a major expansion plan following its privatisation and acquisition by Tata Sons, in February signalled its intent to acquire up to 290 Boeing jets, including 190 737 Max single-aisles, and 250 Airbus aircraft, including A320/A321neos.

Air India sealed the order at June's Paris air show and in July announced a deal with CFM covering Leap-1A engines for the Airbus narrowbodies. It is one of two engine models available on A320neo-family aircraft, alongside Pratt & Whitney's PW1100G geared turbofan (GTF), while the Leap-1B is the exclusive powerplant for the 737 Max.

Air India has been a CFM customer since it began operating A320s powered by CFM56-5B engines more than 20 years ago, and was already a Leap-1A operator after picking the powerplant for its existing A320neos.

Air India chief executive Campbell Wilson said: "The introduction on a greater scale of the Leap engine as well as our services agreement will help us to optimise our operations in terms of environmental footprint and operational cost, while benefiting our customers."

Another Indian carrier to place a large order at Le Bourget, IndiGo Airlines, which signed for 500 more Airbus A320neo family aircraft, is still to disclose an engine selection for these aircraft. It operates A320neo and A321neo aircraft with both the Leap-1A and the rival PW1100G, most recently in 2021 ordering CFM engines for a batch of 310 jets.

United leads P&W narrowbody activity

P&W secured a key win when United Airlines selected its GTF engines to power its first Airbus A320neo-family jets, which are set to enter service this year.

The Star Alliance carrier selected the PW1100G engine to power the 70 Airbus A321neo and 50 A321XLR aircraft it has on firm order.

United already has more than 250 P&W-powered aircraft in its fleet, including its A320s, which feature the International Aero Engines V2500 engine and PW4000s on its 767 and 777s. It also has Leap engines on its 737 Max jets.

At the start of October, United converted options on a further 60 A321neos, without specifying an engine selection.

P&W also secured follow-on business from Latin American carriers LATAM Airlines, VivaAerobus and Volaris for GTF engines on A320neo-family aircraft.

Mexican budget carrier VivaAerobus selected the PW1100G to power an additional 90 firm orders for the A321neo, having previously ordered 65 GTF-powered A320neo-family aircraft.

VivaAerobus chief executive Juan Carlos Zuazua said: "As we continue to grow and renew our fleet, we need the best engine technology, with lower operating costs and fuel efficiency. This GTF engine agreement with Pratt & Whitney is an important step towards further reducing our environmental footprint."

Volaris, another Mexican low-cost carrier, also opted for GTF engines to power an additional 64 A321neo aircraft. That means all 217 of its Neo fleet – both leased and purchased – will be powered by PW1100G engines.

"The additional GTF-powered A321neo aircraft will drive our growth while being mindful of our environmental footprint," said Volaris chief executive Enrique Beltranena.

LATAM Airlines meanwhile picked GTF engines for further A320neo family jets. The carrier had already chosen P&W engines to equip more than 40 A320neos. Without disclosing the number in the latest commitment, the engine maker said that combined with remaining options, the deal covers up to 146 aircraft. LATAM in October signed for 13 more A321neos.

Another airline picking P&W power for Airbus narrowbodies is German carrier Condor, which is taking GTF engines on a combination of 41 leased and purchased A320neo-family jets. When they enter service next year, the narrowbodies will be Condor's first GTF-powered aircraft.

Chinese carrier Shenzhen Airlines, which already operates GTFs on its A320neos, has picked the engine for six of the larger A321neos it is taking via ICBC Leasing.

China Aircraft Leasing Group (CALC) also intends to order PW1100G engines for up to 60 additional A320neo-family jets, marking another win for the US engine manufacturer.

CALC chief commercial officer Winnie Liu notes the lessor is a long-standing PW1100G customer, having been the "first Chinese lessor to select the GTF engine for its A320neo aircraft".

P&W also secured GTF business from Royal Jordanian Airlines, which will equip its future A320neo-family and Embraer E-Jet E2 aircraft with the powerplants; the PW1900G is the sole engine on the re-engined E-Jet.

Other notable E-Jet business this year includes orders from lessor Azorra and Spanish regional airline Binter Canarias.

P&W's PW1500G is also the sole engine option on the Airbus A220 and the engine manufacturer's business for the type included Delta Air Lines exercising purchase rights for another 12 GTF-powered A220-300s. This brings Delta's order to date to 107 firm A220 aircraft, plus purchase rights for another 38 jets.

Volaris signed follow-up order for GTF engines on its A321neos in June

Pratt & Whitney

CFM International

Avolon was one of a number of lessors to make fresh commitments for Leap-1B-powered Max aircraft

Engine sales leap from Max orders

Alongside the Air India order, CFM secured fresh commitments from a number of 737 Max customers.

Ryanair was a particular stand-out, the budget carrier in May agreed to acquire up to 300 Leap-1B-powered 737-10s. The deal, which includes 150 firm aircraft, received Ryanair shareholder approval in September.

At this year's Paris air show, Avolon ordered 40 more 737 Max jets for delivery between 2027 and 2030. The lessor has a committed fleet of more than 400 CFM-powered aircraft in its portfolio.

Avolon chief executive Andy Cronin said: "This commitment reinforces Avolon's effort to increase the proportion of new-technology, fuel-efficient aircraft in our fleet, supported by the 737 Max's use of the latest Leap-1B engines."

Other aircraft lessor commitments for Max jets include SMBC Aviation Capital signing for 25 and Aviation Capital Group for 13 during September, while 777 Partners last year commited to 66 of the re-engined narrowbody.

Several other announced 737 Max orders or commitments mean further engine business for CFM. Much of it has come from Asian carriers. Indian start-up Akasa Air ordered four more of the type in June – while flagging plans for a major aircraft order in future. Japan Airlines in March ordered 21 737-8s and Hong Kong start-up Greater Bay Airlines ordered 15 737 Max 9s. In September it emerged that Vietnam Airlines plans to order 50 737 Max jets.

Delta Air Lines' order at last year's Farnborough air show for 100 737 Max jets was followed by a similar-sized commitment for the type from US major United at the end of 2022.

Alaska Airlines, Air Algerie, IAG and WestJet are among those to order Max jets during the year.

CFM to equip Neos

UK carriers EasyJet and Jet2 have also made further Leap-1A commitments to power follow-on orders for A320neo-family aircraft since the last Commercial Engines Report.

EasyJet placed its follow-on order at last year's Farnborough air show, adding 56 A320neo-family jets. The low-cost carrier opted for Leap powerplants in making its first A320neo commitment in 2014. It was already a CFM56 customer on its A320 fleet.

Jet2 also this year chose Leap-1A engines to power more of its incoming A320neo-family jets. The latest commitment covers the 35 firm orders and 36 options the carrier announced in October last year.

In total, the airline has selected the Leap-1A to power 97 firm A320neo-family jets, plus a further 48 options – its entire orderbook with Airbus.

The UK leisure carrier's initial order for the type in 2021 was a notable decision from what until that point had been a predominantly Boeing operator; Jet2 took its first A321neo in May.

Another significant selection for CFM was confirmed in July 2022 when Air France-KLM finalised the purchase of 200 Leap-1A engines to power its incoming fleet of Airbus A320/A321neos.

Riyadh Air plans to begin widebody flights in the second quarter of 2025

Lewis Harper/FlightGlobal

Riyadh Air picks GE

Ambitious Saudi start-up Riyadh Air has picked GE Aerospace GEnx engines to power its on-order 787-9s. GEnx engines are one of two available on the Dreamliner, alongside the Rolls-Royce Trent 1000.

Riyadh Air in March announced an order for 39 firm Dreamliners and took options on 33 more as part of a wider Saudi widebody order, which included more 787s for Saudia, which already operates GEnx engines on its Dreamliners.

The engine deal was disclosed at the Paris air show. Riyadh Air is targeting the launch of services in 2025.

Riyadh Air chief executive Tony Douglas said: "The agreement highlights our determination to significantly extend Saudi Arabia's connectivity with the world. We look forward to fostering strong strategic relationships within the wider aviation ecosystem as we continue to shape our new digitally native airline to become one of the most sustainable and guest-centric carriers in the world."

Other new business includes China Airlines order for 17 GEnx-1B engines and spares to power its growing fleet of 787s, while Qantas has ordered another dozen 787s - a mix of -9s and -10s – which it has confirmed will again be powered by GEnx engines.

Silk Way West Airlines meanwhile has ordered a combined total of 16 GE9X and GE90 engines to power its fleet of 777 and 777-8F freighters.

> "The agreement highlights our determination to significantly extend Saudi Arabia's connectivity with the world. We look forward to fostering strong strategic relationships within the wider aviation ecosystem"
>
> **Tony Douglas Chief executive, Riyadh Air**

GE also picked up orders for 37 CF34-8E engines from Republic Airways for the carrier's fleet of E170/175 regional jets, on which the engine is sole powerplant.

The Indianapolis-based airline has an all-CF34-powered fleet as it operates 214 E170/175s.

"We are excited to extend this two-decade relationship with GE Aerospace with this order for CF34-8E engines and services," said Republic Airways chief executive Bryan Bedford.

Big Air India deal lifts Rolls-Royce

Rolls-Royce was another to pick up business from Air India's massive purchase earlier this year, securing its biggest order to date for the Trent XWB-97, the exclusive engine available on the Airbus A350-1000.

The Star Alliance carrier is taking 34 A350-1000s, as well as six A350-900s – which are powered by Trent XWB-84 engines.

It marks the first Indian airline order for the Trent XWB and the deal will make Air India the largest operator of the Trent XWB-97 in the world.

Air India chief executive Campbell Wilson said: "We are delighted to commence this partnership with Rolls-Royce. We are confident that they will provide us with the reliability and efficiency consumers expect of today's leading airlines, and thereby play an important part in Air India's comprehensive transformation and growth strategy."

Other A350s ordered during the year include September's follow-on deal for 50 A350-900/1000s by Air France-KLM, a further dozen A350-1000s for Qantas and Philippine Airlines firming an order for nine Airbus A350-1000s. Air Mauritius signed for three A350s while Air Algerie is taking a pair of A350-1000s.

The latter order is part of a wider fleet renewal which will also see Air Algerie taking five A330-900s, which are exclusively powered by Trent 7000 engines. Other new business for the A330neo includes Malaysia Airlines acquiring 20 aircraft, comprising 10 leased from Avolon and another 10 direct orders with Airbus. Avolon itself in September firmed an order for A330neos.

> "We are delighted to commence this partnership with Rolls-Royce. We are confident that they will provide us with the reliability and efficiency consumers expect of today's leading airlines"
>
> **Campbell Wilson Chief executive, Air India**

Philippine Airlines signed for nine A350-1000s, which are powered with Trent XWB-97s

Airbus

Counting on recovery

Cirium fleets data reveals the market performance and shares of the aircraft and engine manufacturers, as deliveries in the second half of 2022 and into this year continued to rise. This was on the back of a strong post-pandemic rebound in air travel and sustained long-term confidence among airlines

Airbus

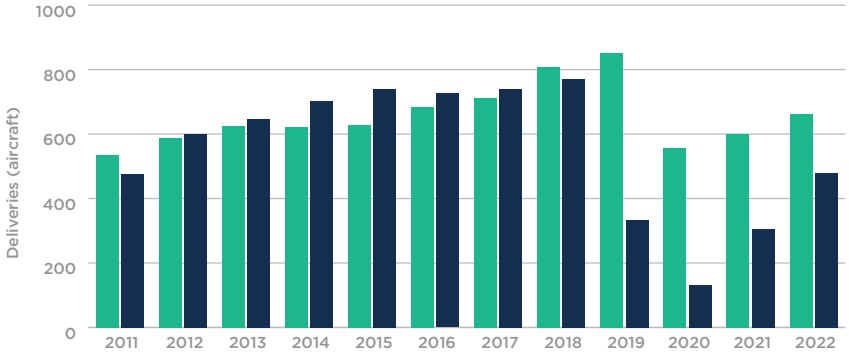
China's Juneyao Airlines took delivery this year of the first Airbus A321neo to be built at the Tianjin final assembly line

Top 10 mainline aircraft customers, 12 months to 30 June 2023

Rank	Airline	Units
1	Southwest Airlines	107
2	United Airlines	80
3=	IndiGo, Delta Air Lines, Ryanair	46
4	Wizz Air	36
5	American Airlines	32
6	Turkish Airlines	26
7	Spirit Airlines	25
8	Alaska Airlines	23
9	China Eastern Airlines	22
10	Akasa Air	18

Source: Cirium fleets data
Note: Data for Airbus, Boeing and Comac C919 deliveries to airlines

Mainline jet deliveries 2011-2022



Source: Cirium fleets data

● Airbus deliveries ● Boeing deliveries

Top 5 regional aircraft customers, 12 months to 30 June 2023

Rank	Airline	Units
1=	Porter Airlines, SkyWest Airlines	13
2=	Air China, Azul	11
3=	China Eastern Airlines, China Southern Airlines, Republic Airways	10
4	Horizon Air	9
5	Fedex	7

Source: Cirium fleets data
Notes: Includes ATR, Bombardier (CRJ), Comac (ARJ), De Havilland Canada, Embraer, Sukhoi and Viking Air types. Excludes corporate and military customers

Lufthansa

This GE Aerospace GEnx-powered Boeing 787 Dreamliner joined Lufthansa's fleet

Southwest Airlines, which operates CFM Leap-powerered Boeing 737s, accepted more aircraft than any mainline carrier in 2022, with 107 deliveries

Robin Guess/Shutterstock

Engine manufacturer rankings

Rank	Manufacturer	Deliveries in 12 months to 30 June 2023 Engines	Share	Backlog on 30 June 2023 Engines	Share
1	CFM International	1,356	57%	15,028	53%
2	Pratt & Whitney	638	27%	4,206	15%
3	GE Aerospace	192	8%	1,700	6%
4	Rolls-Royce	190	8%	1,534	5%
	Undecided			5,784	21%
	Total	2,376		28,252	

Source: Cirium fleets data. Notes: Data for installed engines based on Airbus/Boeing types. Excludes corporate and military operators

Airbus/Boeing fleet by manufacturer

Manufacturer	Airbus	Boeing	Total
CFM International	5,584	8,371	13,955
GE Aerospace	396	2,951	3,347
International Aero Engines	2,915	0	2,915
Rolls-Royce	1,641	1,163	2,804
Pratt & Whitney	1,870	801	2,671
Engine Alliance	127	0	127
Total	12,533	13,286	25,819

Source: Cirium fleets data. Notes: In-service and parked fleet at 30 June 2023. Boeing data includes former MDC types. Excludes corporate and military operators. Data is number of aircraft

A320 family engine manufacturer share

Manufacturer	Deliveries in 12 months to 30 June 2023 Aircraft	Share	Backlog on 30 June 2023 Aircraft	Share
CFM International	275	51%	2,501	37%
Pratt & Whitney	267	49%	1,574	23%
Undecided			2,680	40%
Total	542		6,755	

Source: Cirium fleets data. Note: Excludes corporate and military operators

787 engine manufacturer share

Manufacturer	Deliveries in 12 months to 30 June 2023 Aircraft	Share	Backlog on 30 June 2023 Aircraft	Share
GE Aerospace	51	82%	364	56%
Rolls-Royce	11	18%	88	14%
Undecided			196	30%
Total	62		648	

Source: Cirium fleets data. Note: Excludes corporate and military operators

ATR operator Azul was one of the top regional aircraft customers last year

Lewis Harper/FlightGlobal

Regional aircraft engine manufacturer share

Manufacturer	Deliveries in 12 months to 30 June 2023 Aircraft	Share	Backlog on 30 June 2023 Aircraft	Share
GE Aerospace	77	53%	447	50%
Pratt & Whitney*	60	42%	382	42%
Powerjet	7	5%	74	8%
Total	144		903	

Source: Cirium fleets data
Notes: Excludes corporate and military operators. *Including P&W Canada. Data for firm orders for ATR, Bombardier, Comac, De Havilland Canada, Embraer, Mitsubishi, Sukhoi and Viking Air

From tiny start-ups to some of the industry's biggest names, companies are looking beyond batteries to the universe's most plentiful element to solve aviation's zero-carbon challenges

Hydrogen hope

At their respective sites in Toulouse, two aerospace companies are devising a way to power a passenger aircraft with hydrogen. The contrast between the pair – a tiny start-up at the former Francazal air base and the world's number one airliner manufacturer at its sprawling Blagnac campus – could hardly be more marked.

However, both Beyond Aero and Airbus are convinced they are on the verge of unlocking one of the great challenges of sustainable aviation – how to practically replace carbon-burning engines with propulsion systems that run on the most abundant chemical substance in the universe, a process that emits only water into the atmosphere after combustion.

They are not, of course, the only ones pursuing the dream of zero-emissions flight. The past decade has seen dozens of would-be alternative propulsion disruptors emerge, including those working on electric vertical take-off and landing (eVTOL) designs, as well as fixed-wing platforms that rely on battery technology.

However, a sizeable subset – including Cranfield Aerospace Systems (CAeS), H2FLY, Universal Hydrogen, and Zero Avia – is betting on hydrogen, rather than batteries, as the breakthrough technology. The past year has seen significant moves in the field, including the first flight of an aircraft powered by liquid hydrogen.

Meanwhile, like Airbus, other big names in the industry are excited about the potential of hydrogen, and working on research projects, some with government backing. Among them are GE Aerospace, Embraer, GKN, Parker, Rolls-Royce (R-R), and Safran. There are also evangelists in the airline world, such as EasyJet chief executive Johan Lundgren, who wants to be the first with a hydrogen-powered fleet.

At Francazal – a rather forlorn former military air base south of the city enjoying a second life as a low-cost hub for aviation start-ups – sits Beyond Aero's Bleriot. The two-seat prototype – which has yet to fly – is a reworked G1 Aviation Spyl ultralight refitted with a sub-scale powertrain, comprising a pressurised gaseous hydrogen tank, a fuel cell and a 60kW electric motor driving a propeller.

Scaling up

However, the aim of Beyond Aero – which was started by three newly-graduated friends in 2020 – is to develop an 85kW hydrogen fuel-cell-powered eight-seat business aircraft with a range of 800nm (1,480km) by 2030. So why hydrogen rather than batteries, and a business aircraft instead of the regional transport most of its fellow hydrogen devotees are working on?

"Batteries are heavy, and this impacts range. That's why we're proposing a hydrogen fuel cell with hydrogen stored in gaseous state in tanks. The technology is already in use in trucks," says co-founder and chief technology officer Hugo Tarlé. He also believes there is a niche for a hydrogen powered business type, with four in five of all aircraft in the market falling within an 800nm range.

There is an additional reason to choose a business aircraft. The start-up has raised around $10 million in

In September, H2FLY completed the world's first flight powered by liquid hydrogen

"Batteries are heavy, and this impacts range. That's why we're proposing a hydrogen fuel cell with hydrogen stored in gaseous state in tanks. The technology is already in use in trucks"

Hugo Tarlé Co-founder and chief executive, Beyond Aero

funds but will need much more to bring the Beyond Aero One to certification. "Our current investors are big users of business aviation, so they understand the market," he says. "It's a market that exists already, with thousands of aircraft flying today. We are not inventing a new market."

The Beyond Aero One concept is a light jet, similar in size to the Pilatus PC-24, with underslung wings and an air inlet that sits on top of the fuselage where the wing frame joins. A patented thermal management system that effectively cools the fuel cell is crucial to the design, according to Tarlé. Hydrogen is stored in cigar-shaped tanks in a fairing underneath the fuselage, freeing cabin space.

At the other end of the scale, Airbus chief executive Guillaume Faury said in September that Airbus can bring a hydrogen-powered aircraft to market by the mid-2030s, suggesting that technology challenges are no longer the "bottlenecks". The airframer was one of the first to declare its hand on hydrogen, unveiling three aircraft concepts in 2020 as part of its ZEROe initiative.

Significant hurdles

However, Airbus is very far from a formal launch of a hydrogen-powered airliner. Faury admits that – even if technology makes it possible – there will be factors outside its control, such as regulatory requirements, as well as the availability of on-ground infrastructure and 'green' hydrogen – produced using renewable energy. "That's going to be where the challenge lies," says Faury.

One of the on-board hurdles that does remain with hydrogen, however, is that the substance has lower volumetric energy density than jet fuel, meaning a hydrogen aircraft would need to carry more fuel to achieve the same range. If the hydrogen is in liquid form, however, it potentially solves some of the practical challenges.

That is the route H2FLY has taken. In September, the German powertrain developer completed what it claimed was a world first, with a series of manned flights using a fuel cell-equipped aircraft powered by liquid hydrogen. The company had already

Universal Hydrogen's flight tests use a modified Dash 8-300

conducted sorties using gaseous hydrogen but says changing to liquid doubles its HY4 prototype's range to 810nm.

The flights in Slovenia were part of an EU-backed project called HEAVEN that aims to demonstrate the feasibility of using cryogenic liquid hydrogen to power an aircraft. H2FLY's proprietary system includes an evaporator that converts the liquid hydrogen to gas, which is used to power the fuel cell. Waste heat from the fuel cell in turn is used to make the evaporator work.

The company, which has been owned since 2021 by US eVTOL developer Joby, is partnered with regional aircraft manufacturer Deutsche Aircraft to develop a hydrogen-powered version of its D328eco. Eventually, it says, its fuel cell systems will be able to provide enough power to enable "real-world commercial aircraft applications".

H2FLY co-founder Professor Josef Kallo describes his company's efforts to develop a hydrogen powertrain capable of powering 40-seat-plus aircraft as "a moonshot – it can be done". Batteries are perfect for eVTOL and other lighter aircraft travelling around 50nm, he says, but hydrogen makes possible flights of 1,000nm or even 2,500nm. "This could really change aviation."

On the other side of the Atlantic, Universal Hydrogen also began in September a two-year flight test campaign on its De Havilland Dash 8-300 turboprop, modified to run on hydrogen with one of its two Pratt & Whitney PW123 turboprop engines replaced by a fuel cell system powering a Magnix electric motor. The Californian-based developer aims to have a hydrogen-powered aircraft in service in 2025.

"Low emission and safe combustion of pure hydrogen in aircraft engines is still a major challenge because the combustion behaviour is significantly different from that of conventional aviation fuels"

DLR

Network approach

Universal's eventual business plan is not so much to develop aircraft as such but a network of hydrogen fuel tanks, or modules, that can be swapped on and off aircraft. In September, it also disclosed that it has secured a supplemental type certificate allowing it to retrofit its liquid hydrogen modules on the ATR 72, which is also powered by the PW123.

Another start-up, ZeroAvia, said in July it had completed an initial flight test programme for its ZA600 hydrogen fuel cell powertrain on a modified Dornier 228 twin-turboprop. The Californian firm carried out 10 sorties from Kemble airfield in southwest England.

Universal Hydrogen

As with Universal Hydrogen's test aircraft, one of the Dorner 228's Honeywell TPE331 engines was replaced with the hydrogen powertrain.

In this instance, the UK government – in the guise of its Aerospace Technology Institute – has part-funded the programme. ZeroAvia has also attracted backing from Airbus, which will help ZeroAvia with its certification efforts. Chief executive Val Miftakhov describes Airbus's backing as "the strongest possible validation of the prospects for hydrogen-electric propulsion technology".

ZeroAvia, which also aims to have an initial product on the market by 2025, is also pitching its know-how at the regional jet market, noting at June's Paris air show that it believes its hydrogen-electric platform could be applicable to Bombardier CRJ-series aircraft, which Mitsubishi Heavy Industries now owns the type certificate for.

Modified testbed

In July, the UK's CAeS opened a facility at Cranfield University to house its Project Fresson efforts, aimed at modifying a Britten-Norman Islander to operate on hydrogen from late 2024. The aircraft will have its right-hand Lycoming IO-540 piston engine replaced with a zero-emission powertrain comprising a 240kW electric motor, Ricardo fuel cell and Reaction Engines intercooler.

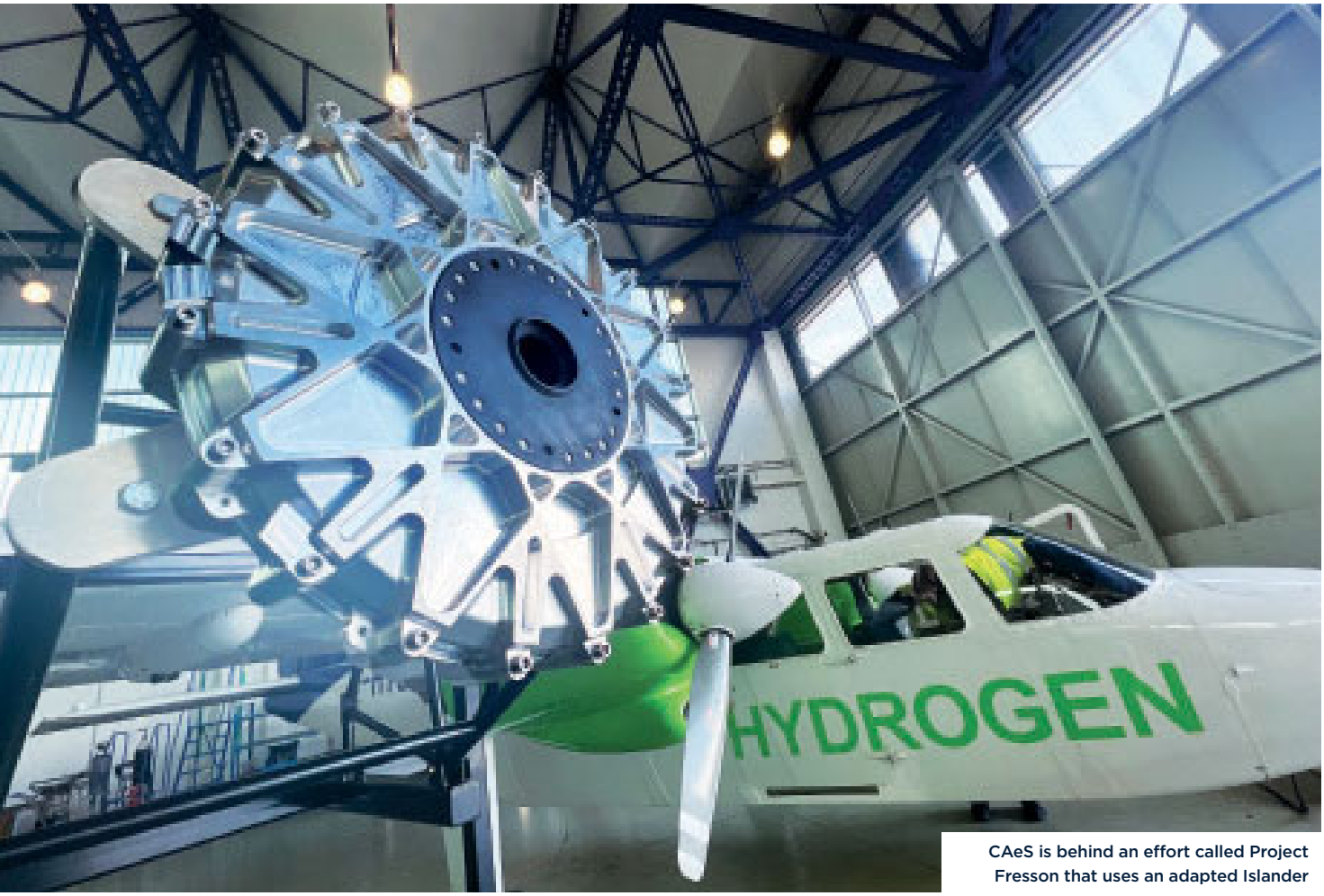
2029

Timeline for GKN and Embraer's development of planned H2GEAR 100-seat hydrogen-powered regional aircraft

Industry big hitters, apart from Airbus, are also working on hydrogen projects. In August, GKN, Marshall Aerospace and Parker Aerospace signed a memorandum of understanding to collaborate on a liquid hydrogen fuel system, capable of supporting applications using either hydrogen-electric fuel cells or hydrogen combustion.

GKN has been a hydrogen pioneer. At the Paris air show, the UK aerostructures manufacturer signed an agreement with Embraer to begin flight testing of a different hydrogen fuel cell powertrain, being developed as part of a UK government-backed initiative called H2GEAR to power a 100-seat regional aircraft, by 2028-2029.

Airbus-Safran space joint venture ArianeGroup has also conducted, in May, a proof-of-concept test of hydrogen conditioning that would be suitable for ›



CAeS

CAeS is behind an effort called Project Fresson that uses an adapted Islander

feeding an aircraft engine. Carried out on 12 May, the experiment marked the conclusion to a study called Hyperion that looked into ways of re-purposing equipment designed for the spaceflight industry for commercial aviation.

German aerospace laboratory DLR has been working with GE Aerospace to carry out trials of hydrogen combustion under realistic aircraft engine operating conditions, backed by an EU research fund. GE will convert a Passport business jet engine to use hydrogen fuel, which will be tested on an Airbus A380 as part of the airframer's ZEROe effort.

"Low emission and safe combustion of pure hydrogen in aircraft engines is still a major challenge because the combustion behaviour is significantly different from that of conventional aviation fuels," says DLR, which is using laser-optical techniques to measure the combustion process without interruption. "For the first time, we are investigating this challenging fuel under realistic conditions."

R-R has also collaborated with DLR, the UK's Loughborough University, and EasyJet to run the annual combustor of a Pearl 700 – the engine that powers the Gulfstream G700 – using 100% hydrogen fuel. R-R says tests using advanced fuel spray nozzles to control the combustion process have shown the fuel can be burned in conditions representing maximum take-off thrust.

Engineering feat

The exercise, it adds, involved overcoming "significant engineering challenges" including the fact that hydrogen burns hotter and more rapidly than kerosene. The nozzles were able to control the flame position using a system that progressively mixes air with hydrogen to manage the fuel's reactivity, says the UK company.

EasyJet – which flies CFM International CFM56- and Leap-powered A320 and A320neo family aircraft – has pledged to be the first to introduce a hydrogen-powered Airbus. While it praises the

Airbus

Airbus unveiled its ZEROe concepts in 2020

ZeroAvia

ZeroAvia hopes to have its hydrogen product on the market by 2025

fuel efficiency of its Neos over its earlier-generation Airbus narrowbodies, Lundgren says a further step may be needed to achieve its 2050 net-zero ambition, and hydrogen could be that "game-changer".

Other airlines are equally enthusiastic. Tony Thompson the founder and chief executive of a southern Californian start-up called Air Cahana, has spoken of his plan to fly ATRs retrofitted with ZeroAvia's hydrogen propulsion systems by 2030 from regional airports on the west coast and south-west. "A big part of what we're trying to do is clean up aviation, to decarbonise it," he told FlightGlobal in July.

Another start-up, Surcar plans to introduce De Havilland Canada Twin Otters fitted with ZeroAvia's hydrogen-electric powertrain on inter-island services and sightseeing tours in the Canaries. "Climate change threatens [the Canary Islands] and our way of life," says Surcar founder and chief executive Gerardo Morales-Hierro. "Working with ZeroAvia will help us to deliver cleaner flights."

Long road

From something that was almost science fiction a decade ago – or at least something restricted to the world of academia or industry's most futuristic research labs – the idea of passengers travelling on airliners powered by hydrogen rather than kerosene during the 2030s has become a very real prospect. Big business and big money are showing interest.

However, while initial studies show promise, serious technical hurdles remain. There are questions over onboard storage and the combustion process, whether fuel cells are the answer, the substance's safety, and, not least, how hydrogen fuel can be produced and made available to airlines in a way that does not cause as much damage to the environment as burning kerosene.

However, proponents are convinced hydrogen is the aviation fuel of the future and the great leap forward that will finally free the aviation industry from its carbon dependence before the mid-point of the century.

"Climate change threatens [the Canary Islands] and our way of life. Working with ZeroAvia will help us to deliver cleaner flights"

Gerardo Morales-Hierro Chief executive, Surcar

Gael Meheust, president and chief executive of CFM International, explains how the joint venture's latest programme could deliver 20% efficiencies over today's leanest-burning engines

RISE to the challenge

Q Let's look to the future first. Give us an update on the RISE programme.

A GE Aerospace and Safran launched the CFM RISE (Revolutionary Innovations for Sustainable Engines) programme in June 2021 with a target of more than 20% better fuel efficiency and 20% lower carbon dioxide (CO2) emissions compared with the most efficient engines in service today in support of the aviation industry's ambitious goal of net zero emissions by 2050.

We have more than 1,000 engineers worldwide developing a suite of pioneering foundational technologies, including advanced engine architectures like the open fan, a compact core, advanced combustion technology, thermal management and hybrid electric systems to be compatible with 100% sustainable aviation fuel (SAF). Technologies are also being matured to test direct hydrogen combustion.

We believe that the open fan engine architecture is key to reaching our 20% fuel efficiency target, which has the potential to be the single greatest generational improvement that we've ever achieved.

We have made tremendous progress, completing the conceptual design review for the open fan, as well as more than 100 tests to date as we progress through the technology maturation phase.

We are now moving from forging parts and component- and part-level testing to launching full- and sub-system tests. Early tests have included airfoil cascades, sub-section compressor testing and fundamental material and mechanical component-level testing, such as representative panels for fan blades.

We are learning a lot and are pleased with the results we are achieving.

All this work has kept us on track for RISE open fan ground and flight tests around mid-decade. We are working with both Airbus and Boeing on demonstration flight tests that will help prove out these technologies, leading to engine product launches that could enter commercial service in the 2030s, depending on airframer strategies.

Q Tell us more about the improvements you are making to the current LEAP product.

A The LEAP engine family has been the most successful new product introduction in our nearly 50-year history.

At the same time, it has also had the fastest ramp-up of engine flight hours ever in the industry; the fleet has logged more than 40 million engine flight hours and 18 million cycles in just over seven years. As a result, we have been able to learn things faster than ever before.

One of the biggest things we have learned is that the LEAP engine design is stable. In fact, the engine is performing better at this stage of its life-cycle (seven years) than the CFM56 in the same time frame. There has been no need to redesign any major component.

On the other side, though, we have learned that some parts of the engine are not as durable as we had intended, specifically in the Middle East and North Africa.

Because we are committed to keeping customers flying, we have invested in design improvements that will increase durability.

In 2024, we will be introducing two key upgrades. The first is a redesigned high-pressure turbine (HPT) blade and nozzle. We are using new casting and improved cooling technology to address distress modes and increase time on wing.

One of the biggest HPT durability challenges we

face is dust in hot-and-harsh environments. We have been validating the new design with a proprietary dust ingestion rig that has enabled us to exactly replicate the distress modes we are seeing in the field.

Working with geologists, we have actually engineered dust that reproduces the mineral content and particle size distribution observed in different regions.

Overall, we have logged more than 8,500 cycles total testing to date, including more than 3,700 cycles on the blade. We are on track to complete the endurance test plan early next year, with product introduction in 2024.

We are also working with Airbus to introduce optimised climb thrust that will further improve HPT blade life. The software and rating plug will be available in 2024.

The second upgrade we are planning to introduce next year is a unique reverse bleed system (RBS) that will mitigate carbon build-up (also known as coking) in the fuel nozzles.

Carbon build-up, which occurs post-flight, is not unique to the LEAP engine; any turbofan engine experiences it under certain circumstances. After engine shutdown, uncombusted fuel evaporation can cause the formation of carbon deposits on fuel nozzles. Over many cycles the build-up can grow in thickness and begin to impact performance. For customers, it has caused shorter time on wing, resulting in an increased maintenance burden.

The RBS, which turns on automatically, can be installed on wing and can be retrofitted because the hardware is all external.

The system consists of a valve that opens after the engine shuts down. Cooling air is then blown into the flow path through the existing engine bleed duct system, preventing residual heat from pushing the fuel nozzle temperature above the coke-formation threshold. The system shuts down automatically after a specified amount of time.

Q The entire industry – including CFM – was bedevilled with supply-chain and output challenges when the industry began to recover in 2022. Are these now receding?

A There are obviously still challenges, but we are making progress.

We have increased LEAP production this year by 40-45% compared with 2022, putting us on pace to deliver about 1,600 engines by year-end. We plan to further increase production next year and in 2025.

In the meantime, we are working very closely with our top 25 key suppliers, deploying engineers and lean resources to help with processes and improve output.

Q Moving onto the aftermarket, Safran has highlighted the important contribution of CFM aftermarket revenue. What recent services have been provided to customers, including the Open MRO network?

A We currently have more than 6,000 LEAP engines in service and a very healthy backlog of more than 10,000 engines, so the infrastructure to support a fleet that size has to be robust. From our experience with the CFM56 fleet, we know that operators like to have a choice of where to overhaul their engines. There are more than 40 shops globally that can provide MRO services for these engines.

CFM International

That is the model we used as the basis for how we are going to support the LEAP engine and we have been working to build an open global network. We believe that an open, competitive MRO ecosystem reduces maintenance costs over the engine life-cycle.

The internal CFM network, which supports customers who sign CFM services contracts, currently includes eight GE and Safran shops around the world, but we are further expanding our internal capability.

In 2022, we announced a new shop that will open in Hyderabad, India, in 2025, with a capacity of 250 to 300 engine shop visits a year. In addition, capability is expanding with a new 8,500sq m shop opening in Brussels in 2024; fan blade repair capacity has been added to Commercy, France, along with adding capability to shops in Poland and Malaysia.

To give operators more choice, CFM has signed CFM Branded Service Agreements (CBSAs) with five of the top third-party MRO providers: Air France/KLM, Delta TechOps, Lufthansa Technik, Standard Aero and ST Engineering. CBSAs receive the highest level of CFM support and training and access to proprietary overhaul and repair technology. Ultimately, we expect to have a total of six to eight CBSA providers.

To provide additional third-part capacity, Central European Engine Services (CEES), MTU Zhuhai, SR Technics, Sichuan Services Aero-engine Maintenance Company (SSAMC) and TAP Maintenance & Engineering are all licensed LEAP repair shops.

Finally, both GE and Safran have also signed offload agreements with six companies around the world, including Sanad, headquartered in Abu Dhabi, and XEOS, a joint venture between GE Aerospace Poland and Lufthansa Technik.

As part of our sustainability strategy, we have engineered 300 new repairs for the LEAP engine that prevents us from systematically replacing the used parts with new ones.

92% asset availability

LEADERS AREN'T BORN. THEY'RE ENGINEERED.

cfm

LEAP

LEAP turns heads in the boardroom.

LEAP-powered aircraft are achieving the highest days flown ratio* for their thrust class. That means fewer spare aircraft and more flights, which helps profitability climb. Another reason to say **LEAP. By example.**

*Compared to 83% for competition, per third-party data.

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