The industry's consumption of fuel has risen more than 40% since 1995, and is forecast to double over the next 20 years. What fuel saving technologies are available to minimise the rise in fuel used by air transport, and what are the prospects of alternative fuels?

Fuel: how can we reduce consumption?

For more than 20 years after the oil crises of the late 1970s and early 1980s, the price of oil and jet fuel was no longer such a concern for airlines, yet it has risen by a factor of three to four times since 2001. Not only does this have immediate consequences for airline profitability and implications for fleet planning, but it also highlights how the industry will cope if high fuel prices are sustained or continue to rise.

Oil & jet fuel prices

The air transport industry and global economy enjoyed cheap crude oil up to 2002. The International Air Transport Association's (IATA) historical data shows that the price of crude oil was at a low of $17 per barrel in 1995, rising gradually to $24-25 in 2001-2002.

The industry has been plagued ever since by increasing fuel prices. Crude oil reached an all-time high of $100 per barrel briefly in December 2007, before falling to $88-92 by February 2008.

Supply is also tight. Economic growth in China and India has created unprecedented demand, while Venezuelan and Nigerian oil is absent from the market. There is political uncertainty in parts of the Middle East, and refining capacity suffered from under-investment in years when crude prices were low.

There is little prospect of supply increasing to the point where it will allow the price of crude to fall even to medium levels of $40-60 per barrel.

The price-elasticity of crude oil is high, making it a commodity whose price is sensitive to small changes in supply.

The direct relationship between crude oil prices and the unit cost of jet fuel is simple: the additional cost of refining (or the 'crack spread') gives a total cost per barrel. There are 42 US Gallons (USG) of jet fuel per barrel of oil, so the total cost per barrel divided by 42 provides the cost per USG of jet fuel.

IATA data shows that in 1995 the refining cost was $5 per barrel. This total of $22 per barrel for refined crude oil equalled a jet fuel price of 53 cents per USG *(see table, page 41)*. At this level, aircraft fuel accounted for a low percentage of total airline costs compared to the fuel crises of 1973 and 1979.

A long-term unit fuel cost of 50-70 cents per USG put little pressure on airlines to renew their fleets with more fuel-efficient aircraft. It also gave little incentive for aircraft and engine manufacturers to develop more fuel-efficient designs. In the late 1980s Pratt & Whitney (PW) and General Electric (GE) developed and tested open-rotor, contra-rotating ultra-high-bypass engines on the MD-80 and 727. The saving in fuel expenditure these engines offered at the prevailing fuel prices was not enough to offset the noise emissions and high maintenance costs resulting from their complex gearing systems.

The price of crude oil has climbed steadily since 2002. The unit cost rose by $10 per barrel from 2003 to 2004, and then by a further $15 to $55 from 2004 to 2005. Crude oil prices rose continuously through to late 2007, when they temporarily reached $100 per barrel.

The refining cost of crude oil also rose from $5 per barrel in 1995 to $17 in 2007, making the total cost of a barrel up to $117, and equal to a jet fuel price of $2.78 per USG. IATA shows that average prices in 2007 were $73 per barrel and the refining cost was $17, equating to $2.14 per USG for the cost of jet fuel *(see table, page 41)*.

Industry fuel consumption

The importance of fuel prices depends on the total amount of fuel consumed by the industry, and its annual cost relative to all other costs and to revenues.

Fuel consumption rises as traffic growth and airline capacity continues, although not proportionately. While passenger numbers and freight volumes have always risen with economic growth, the rise in traffic has been accommodated by higher load factors and an increase in capacity. Capacity has therefore increased at a lower rate than passenger numbers and freight volumes. Driven by airlines' need to improve unit revenues, this factor has contributed to a steady fall in the fuel consumed per passenger over time.

The other major factor in lower fuel consumption per passenger, however, is the constant improvement in the fuel efficiency of new generation aircraft.

Fleet development

While new generation aircraft have lower fuel burns per seat compared to the previous generation, the improvement in the overall efficiency of fuel used per passenger is slow. This is because aircraft remain in operation for 25-30 years and the percentage of the fleet accounted for by older and latest generations of aircraft changes slowly. The most recent Boeing market forecast predicts that 11,500 aircraft of the current fleet of 16,250 will retire or be converted to freighter over the next 20 years. This is equal to 800 per year, leaving only 5,000 of the current fleet in operation by 2027. Another 26,000-28,000 new aircraft are forecast to be delivered over 20 years, at average delivery rates of 1,300-1,400 per year. There will therefore be a net increase in

AIRLINE INDUSTRY FINANCIAL PERFORMANCE & FUEL CONSUMPTION

Year	1995	2001	2004	2007	2027*
Airline revenues-$ million	267,000	307,500	378,800	490,400	N/A
Passengers-millions	1,304	1,640	1,888	2,243	5,400
Airline expenses-$ million	253,500	319,300	375,500	474,000	N/A
Fuel expense-$ million	28,970	42,950	61,210	135,433	N/A
Fuel used-USG millions	46,718	59,245	61,763	66,810	121,000
Crude oil-$/barrel	17.2	24.7	38.3	73.0	N/A
Refining cost-$/barrel	5.0	5.8	11.4	17.0	N/A
Fuel unit price-$ per USG	0.53	0.73	1.18	2.14	N/A
Fuel use per passenger-USG	35.9	36.1	32.7	29.8	22.5
Non-fuel expenses-$ million	224,500	276,400	314,300	338,600	N/A
Operating profit-$ million	13,500	-11,820	3,260	16,344	N/A

Source: IATA
**** Aircraft Commerce estimate***

the fleet of 16,500 aircraft over 20 years.

IATA says that in 1995 the industry consumed 46.72 billion USG of jet fuel, and transported 1.3 billion passengers. Average fuel consumption per passenger was 36 USG *(see table, this page)*.

In 2004 1.89 billion passengers were carried, an increase of 45% over 1995. The industry also consumed 61.76 billion USG, an increase of 32.2%, and equal to 32.7 USG per passenger. The lower rate of fuel consumption achieved by 2004 is mainly due to the global fleet changing to younger and more fuel-efficient types.

By 2007 passenger traffic had increased by another 19% to 2.24 billion, and fuel consumption by another 8% to 66.81 billion USG. Fuel consumption per passenger therefore fell to 29.8 USG *(see table, this page)*.

The amount of fuel consumed by the industry is not rising as fast as traffic volumes because of the improved fuel efficiency of aircraft as the fleet gradually modernises. The rate of fuel-efficiency improvement was acceptable when crude oil cost $20-30 per barrel, and jet fuel was 65-85 cents per USG.

Annual fuel cost

The industry's annual fuel bill is rising faster than consumption, however, because of higher crude prices. This will force airlines to accelerate their fleet modernisation programmes, and retire older aircraft earlier than planned. High oil and fuel prices will also stimulate airframe and engine manufacturers to produce more fuel-efficient designs.

In 1995, the industry's consumption of 46.7 billion USG was equal to a cost of $29 billion when the average fuel price was 53 cents *(see table, this page)*. At the time, industry-wide revenue totalled $267 billion, with total expense of $253 billion and an operating profit of $13.5 billion. The industry had an operating margin of 5.1%, and the cost of fuel accounted for 11.4% of all airline costs.

The industry still enjoyed relatively low fuel costs in 2001, when consumption was 59 billion USG, unit cost was 73 cents and fuel expenditure was $43 billion *(see table, this page)*. This was 13.4% of total annual costs. This was the first year since 1995 that the industry made an operating loss, with 9/11 impacting passenger numbers and revenues, particularly in the US.

By 2007, unit fuel prices had reached more than $2 per USG, and the industry's annual fuel cost had reached $135 billion *(see table, this page)*, equal to 28% of total costs.

The industry has learned to cope with higher fuel costs since 2001. While crude and fuel prices steadily climbed from 2001 to 2007, and passenger numbers grew by almost 37%, airlines managed to control and improve non-fuel costs, which increased at a lower rate of 22.5%. The improvement in cost efficiency is reflected by an operating loss margin of 3.8% in 2001 compared to a positive margin of 3.3% in 2007.

The improvement in non-fuel costs illustrates the increased importance of fuel as an airline cost, and the need to find new techniques, aircraft and engine products to reduce fuel consumption.

Not only has the industry grown by 72% in terms of passenger numbers since 1995, at an annual compound growth rate of 4.5%, but it is also forecast by IATA and several major aerospace manufacturers to continue growing at a similar annual compound rate over the next 20 years. Passenger numbers could therefore increase by a factor of 2.6 to almost 5.4 billion by 2027 *(see table, this page)*.

Fuel consumed has increased by 43% since 1995, indicating that fuel consumption grew at an average of 3% per year over the same period. This rate is lower than passenger growth rates, and is due to constant fleet modernisation. If this rate of fuel consumption growth is maintained over the next 20 years, the industry will consume 80% more fuel in 2027 than in 2007, or 121 billion USG *(see table, this page)*. Fuel consumption per passenger will have fallen from 30USG per passenger in 2007 to 22.5USG per passenger by 2027.

The reduction in fuel consumption per passenger is a positive result of fleet modernisation, but it is only possible if new aircraft and engines with superior fuel efficiency continue to be developed.

Fuel saving technology

Completely new aircraft and engine types are only developed by airframe manufacturers once every 20 to 25 years. This means that airlines can only realise gains in fuel burn efficiency once in every new aircraft generation. Winglets and

ANNUAL FUEL SAVINGS FROM WINGLETS & FUEL SAVING DEVICES

Aircraft type	System provider	Trip nm	% fuel saving	Block fuel USG	Fuel saved USG	FC per year	Fuel saved per year	Fuel price $/USG	$ saving per year
737-300	Aviation Partners	550	2.3-2.5	1,400	35	2,000	70,000	2.80	196,000
737-500	Aviation Partners	550	2.3-2.5	1,300	32	2,000	64,000	2.80	179,000
737-700	Aviation Partners	1,000	3.0	1,700	51	1,050	53,500	2.80	150,000
737-800	Aviation Partners	1,000	3.0	2,100	63	1,050	66,000	2.80	185,000
737-900	Aviation Partners	1,000	3.0	2,350	71	1,050	74,000	2.80	207,000
757-200	Aviation Partners	1,000	3.0	2,800	84	1,050	88,000	2.80	247,000
767-300ER	Aviation Partners	2,000	4.0	6,350	255	800	203,000	2.80	569,000

other fuel saving devices, however, can be installed on many aircraft types mid-life to improve their fuel efficiency prior to fleet renewal.

Examples of widely-used jet aircraft types that have winglets and other fuel saving devices installed are: the 737-300/-400/-500; 737NG; 757-200; and 767-300/ER. Winglets are also being developed or considered for the 767-200ER, 777 and 747-400.

Airbus is researching and developing winglets for the A320 family.

Aviation Partners Boeing (APB) is the biggest supplier of winglet systems for Boeing aircraft. These can be retrofitted, and need a short downtime to install. They do not increase the aircraft's maintenance requirements, result in only minor changes to its flight management computer, and have supplemental additions to its flight and technical manuals. The blended winglets achieve a fuel burn saving by reducing the wing tip vortex drag.

APB first developed winglets for the 737-300, and has now modified more than 60 aircraft. The estimated fuel burn saving is 2.3-2.5% for typical short-haul trip lengths. The fuel burned on a typical mission of 550nm is 1,350-1,400USG. A saving of 2.3-2.5% therefore translates into a fuel burn reduction of 32-35USG. This is equal to a saving of $85-98 at current fuel prices of $2.5-2.8 per USG, and a saving of up to $196,000 per year *(see table, this page)* for an aircraft generating 2,000 flight cycles (FC).

APB has also had blended winglets certified for the 737-500, 737-700, 737-800, 737-900 and 757-200. It is also developing blended winglets for the 757-300, 767-300ER and 777-200ER.

Winglets on the 737NG reduce block fuel burn by 3.0% for a 1,000nm mission. Fuel burns for the -700,-800 and -900 are 1,700-2,400USG, so the aircraft can save 50USG to 70USG per trip, and 55,000USG to 75,000USG per year. This generates savings of $150,000-207,000 per aircraft per year *(see table, this page)*.

The 767-300ER is used on a variety of missions, but block fuel reduction with the winglets is 4% for a 2,000nm mission and 5% on a 4,000nm mission. The fuel saved on missions of these lengths is 255USG and 650USG, making annual savings of $569,000 and $916,000 at current fuel prices *(see table, this page)*.

The trip fuel savings, annual rates of utilisation, annual fuel burn reductions, and annual fuel cost savings for most of these aircraft types are summarised *(see table, this page)*.

Engine developments

Developments in new engine technologies are the main driving force in new aircraft types. New aircraft will only generally be widely accepted if they offer reductions in fuel- and maintenance-related cash direct operating costs of 15-20%. These improvements mainly come from new engine technology, which is driving new aircraft projects.

The only new aircraft being developed are the 787, 747-8 and A350 family. These will all be powered by the General Electric (GE) GEnx, while the 787 will also be powered by the Rolls-Royce (RR) Trent 1000.

Airbus and Boeing have yet to reveal replacements for the A320 and 737NG families. While some engine manufacturers are developing thrust classes close to what A320 and 737NG replacements would require, there are no firm or clear developments that could allow for new airframes to be developed.

PW Geared Turbofan

The latest development for engines in the small jet and narrowbody class is the Pratt & Whitney (PW) Geared Turbofan (GTF) demonstrator engine. The GTF is being developed in two thrust classes: 14,000-20,000lbs thrust for 75- to 95-seat aircraft; and up to 30,000lbs thrust for 100- to 220-seat aircraft. This second thrust range will be sufficient for aircraft of up to 220 seats, since their high gross weight will not be as high as current generation aircraft's. The GTF's second thrust class could therefore potentially be used to power the A320 and 737NG replacements. The GTF has demonstrated thrusts of up to 40,000lbs. "There is actually no reason why the GTF could not be developed for widebody aircraft when the replacements are developed for the 787 and A350," says Robert Saia, vice president of next generation product family at Pratt & Whitney.

The GTF is a conventional two-spool turbofan engine with a gearing system between the fan and the low pressure compressor (LPC). This allows the fan to turn at a different and slower speed than the LPC. Since the LPC is not limited by the fan's speed, the LPC can turn faster, increasing the compression ratio.

A slower turning fan of a wider diameter will provide the same thrust as a conventional turbofan, but the geared fan engine will have a higher bypass ratio and achieve a higher propulsive efficiency. It will therefore achieve lower specific fuel consumption (sfc) and fuel burn. At 30,000lbs thrust the GTF will have a fan diameter of 75-80 inches, compared to 68.3 inches for the CFM56-5B series. It will also have lower noise emissions.

The low pressure turbine will also be able to turn faster because of the gearing system. The turbine can therefore be smaller compared to direct drive engines, thereby saving weight and making the engine more efficient overall. PW estimates that the GTF will be 14-15% more efficient than current generation engines in a similar thrust class.

The possible drawbacks of the gearing system are increased complexity and so higher maintenance costs, as well as installation problems because of the wide fan diameter and engine nacelle.

"We have invested heavily in the GTF technology over the past three or four years, so we are ready for an aircraft entry-into-service date of 2012-2013," says Saia. "The actual service-entry date for many new narrowbody types is likely to be 2015-2020. We have spent a lot of time developing the technology so that the engine's capabilities are known.

"The aim of the GTF programme was to reduce engine-related operating costs by 20%, through improvements in fuel and maintenance. Our target fuel reduction is 12% compared with the A320 and 737NG families," says Saia. "We have also set a maintenance cost reduction target of 40%, so that the GTF will save 12-15% in engine operating costs overall.

"The GTF will also have lower carbon- and nitrogen-related emissions. The lower CO_2 is directly related to lower fuel burn. The lower NOx emissions will be due to the engine's advanced TALON combustor," says Saia. "The engine will therefore have several environmental benefits. Its lower noise emissions will lead to lower landing fees and could see higher aircraft utilisation in some cases."

Saia predicts the GTF will have 12-14% lower fuel burn and be three to five decibels (dB) quieter than the CFM56-5B. "This will take the GTF to minus 20 dB lower than Stage IV levels," says Saia. "The other main issue is maintenance cost. The GTF will have fewer airfoils than a current generation engine. Airfoil repair and replacement is expensive and accounts for a high portion of maintenance costs. We expect the GTF to improve the mature removal intervals of current generation engines, which are only 60% of the first interval. We aim for the GTF to have mature intervals that are 85% of the first interval, which will be achieved by running the engine cooler. This is possible because the fan gearing system allows the core engine to run slower than a conventional turbofan."

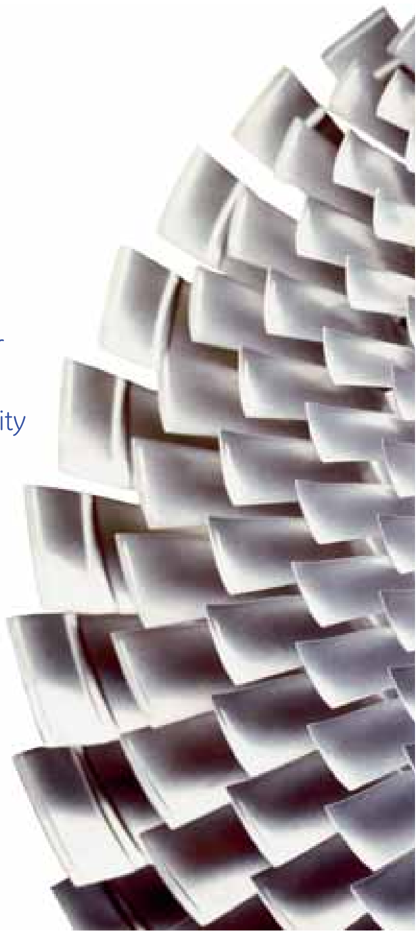
GEnx

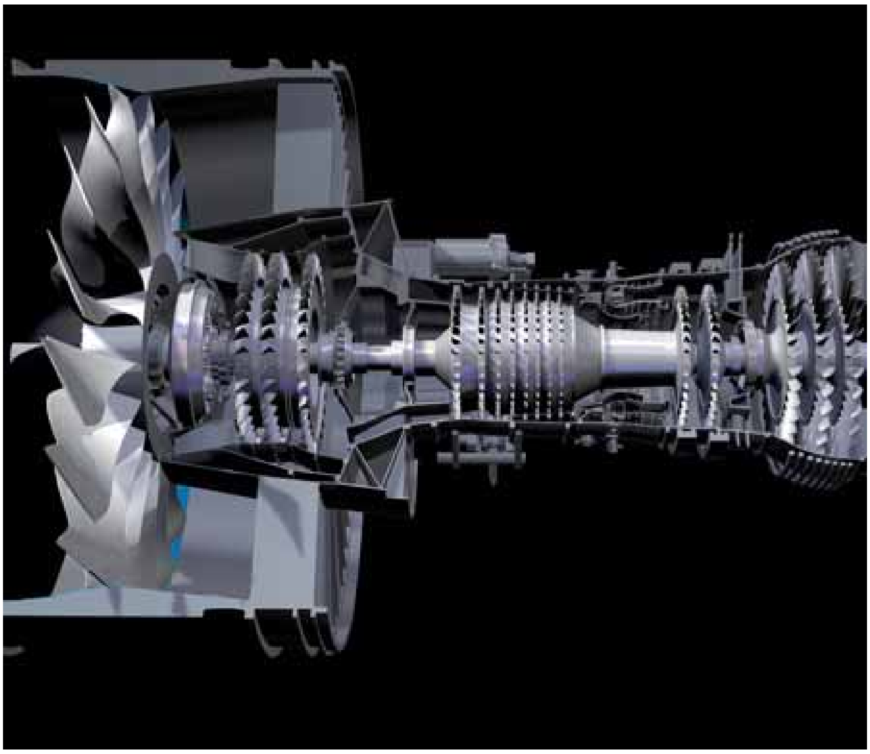
General Electric (GE) is developing the GEnx as an engine family to replace the CF6-80C2 and -80E1 that power a range of widebodies from the A310-300 to the A330. The GEnx will be rated at 54,000-74,000lbs thrust, although it could reach 87,000lbs thrust. "The GEnx is being developed for the 747-8, 787-8/-9 and A350-800/-900," says Melvyn Heard, marketing manager at GE Aviation. "The 747-8 requires engines in the 67,000lbs thrust range, while the 787-8 and -9 require 54,000-74,000lbs. The A350-800 and -900 have a higher requirement of 78,000-87,000lbs thrust. The largest A350-1000 model needs 93,000-95,000lbs thrust, although the GEnx would conflict with the GE90 here.

"The industry wants 15-20% lower fuel consumption and engine maintenance costs, but it has become harder to get efficiency gains," continues Heard. "Boeing wanted the 787 to have 15-20% lower fuel burn than the 767 family with CF6-80C2 engines, without compromising maintenance cost. We chose to develop a conventional two-shaft turbofan and to optimise the design and efficiency of all major modules to meet the design objectives. We wanted to avoid using expensive materials and having shorter removal intervals, but we did want similar or better reliability."

The GEnx has 15.4% lower sfc than the CF6-80C2, and as a consequence the 787 will have 20% lower fuel burn per seat than the 767. A 767-300ER, for example, will burn 13,000USG on a 4,000nm trip, equal to 60USG per passenger. The similar-sized 787-8 would therefore be expected to burn 10,400USG, with a saving of 2,600USG. At an annual utilisation of 4,500 flight hours (FH) and 500 FC, the fuel saved is 1.3 million USG per aircraft.

At current fuel prices of $2.8 per USG the lower trip fuel burn is equal to $6,700 or $740 per FH less than the 767-300ER. The annual saving is $3.4 million. Moreover, the saving of $740 per FH is more than the 767-300ER's line, base and component maintenance costs per FH when operated on long-haul missions *(see 767 family maintenance*





Pratt & Whitney's GTF is being developed in two thrust classes. The GTF is a conventional two-spool engine with a geared fan mechanism that allows the engine to achieve a high bypass ratio, and higher compression ratio in its core which increases efficiency. Pratt & Whitney estimates the GTF will be 14-15% more fuel efficient than current generation engines.

analysis & budget, Aircraft Commerce, June/July 2006, page 23).

Heard explains how GE has optimised the conventional two-shaft turbofan engine. The fan module uses composites in both the blades and casing, saving several thousand lbs of weight per aircraft. Heard says that composites will contribute to lower maintenance costs, since they are enough to contain a fan blade failure and the module is not prone to corrosion, thereby removing the need for kevlar. The GEnx's fan uses 18 swept, wide chord blades versus the 36 used by the CF6-80C2. The GEnx's fan therefore incurs less drag, which contributes to efficiency, and it will have a fan diameter of 111 inches, which compares to 123 and 128 inches of the two GE90 models and 93 inches of the CF6-80C2. The GEnx will have a bypass ratio of 9.5:1, contributing to its lower fuel burn and noise emissions versus the CF6-80C2.

The high pressure compressor (HPC) has been designed to have a pressure ratio of 23:1, versus the -80C2's 16:1. The higher pressure of the air and fuel mixture allows more energy to be extracted by the turbine. The HPC will also have 10 stages compared to the -80C2's 14, reducing the number of parts and weight. The new technique of making a blisk from a single piece of metal is also expected to increase time on-wing, since the absence of dovetails means there will be less wear.

The GEnx will also use a twin annular premixing swirler (TAPS) combustor, which will lead to the efficient mixing of air and fuel for a leaner mixture. Heard claims this will result in up to 50% lower NOx emissions.

The GEnx has also been designed with a two-stage high pressure turbine (HPT) for fuel efficiency. "The HPT is the heart of an engine's maintenance costs, since its high temperatures obviously cause degradation of turbine materials, which drives removal intervals," says Heard. "Cooling technology is therefore important. Components also need to be repairable. The better the cooling, the higher the burn temperature can be and so the more efficient the fuel burning process. The GEnx has a cooling circuit at the tip shelf, so there is cooling around the top of the blade.

The LPT has seven stages, and uses a new material called titanium aluminide to reduce weight and allow another turbine stage to increase energy extraction and efficiency without adding weight.

CFMI's strategy

CFM International has yet to select a design strategy for a family of engines to replace the CFM56. It has three choices, with each one being optimised for a different fuel price scenario.

Stephane Garson, general manager product marketing at CFMI, explains that its Tech56 programme is used to develop modifications and upgrades that can optimise the current CFM56 models. An example is the 3-D aero upgrade package for the CFM56-5B series.

In the longer term CFMI uses its LEAP 56 programme to develop long-term improvements in engine design.

CFMI appreciates the conflicts it faces when selecting its next design philosophy. The first conflict is between fuel burn and maintenance cost: a high combustor temperature and two-stage turbine improve fuel burn efficiency, but reduce removal intervals and increase maintenance cost.

Garson says the CFM56's design is optimised to get the best balance between fuel burn and maintenance cost. Projects like Tech56 have improved this balance. CFMI now has to choose whether to develop a new conventional two-shaft turbofan, a counter-rotating double-fan engine, or an open-rotor ultra-high-bypass engine. Technologies that are derived via its Tech 56 and LEAP56 programmes can be used in these engines. Each of these has design conflicts, and the best choice will depend on the fuel price and the relative importance of fuel efficiency compared to maintenance costs.

"If the market requires engines just to be more environmentally friendly then a conventional turbofan design can be used, and new technologies are all that is required to reduce CO_2 and NOx emissions," says Garson. "This can be achieved by using a TAPS combustor which reduces both CO_2 and NOx, for example, despite high temperatures. This is a product of the LEAP56 programme. This will maintain a balanced engine design. There are still constraints, however, when trying to reduce NOx and CO_2 emissions. High combustion chamber temperatures improve fuel burn efficiency and lower CO_2 emissions, but they also increase NOx emissions.

"The highest bypass ratio a conventional turbofan is likely to reach is 10-15:1," continues Garson. "Once the fan is increased further to obtain higher bypass ratios than this, the fan gets too heavy and installation problems arise that outweigh the benefits of a higher bypass ratio. The objective of LEAP 56 is to push the design of conventional turbofans further. If a conventional turbofan is improved and optimised, then by 2015 an engine could be achieved with 17% lower CO_2, NOx emissions 60% below CAEP VI standards, and noise emissions that are 30 dB lower.

"Pushing for changes in fuel burn efficiency and large reductions in noise emissions would lead to the selection of the contra-rotating two-fan design," continues Garson. "This would be a conventional ducted turbofan, but with two fans that counter-rotate to achieve a

The GEnx is a conventional two-shaft turbofan that has been optimised to achieve lower specific fuel consumption and maintenance costs than current generation engines. Areas of improvement include the fan, HPC, combustor, HPT and LPT.

higher bypass ratio. The drawback is that it would be heavier and more complex because of the second fan and the gearing system. The additional weight would offset some of the fuel efficiency benefits, and the gearing system would increase maintenance costs. Another challenge would be an additional main bearing for the second fan. This design would most likely be selected in the event of sustained high fuel prices and the need to reduce noise. A TAPS combustor could also be used to reduce CO2 and NOx emissions.

"In the event of higher oil and fuel prices an open-rotor, ultra-high-bypass engine would be required," says Garson. "This would have two counter-rotating unducted fans, an extremely high bypass ratio of 35:1, and the rotors would have a diameter of 145-170 inches, compared to the 158-inch width of a 757 fuselage. Besides the obvious installation problems, the engine would be extremely complex due to a gearing system for the two rotors. The engine would also have higher noise emissions than a ducted fan engine, although it could have a composite duct. Such an engine could be in service by 2018, have 27% lower CO2 and 60% lower NOx emissions, and be 25 dB quieter than current generation engines."

Garson explains the design choice ultimately depends on Airbus and Boeing, which will determine what operating cost, operating performance, and emissions criteria they will aim to provide, and if and when to launch a new generation of aircraft.

Alternative fuels

Many projects are under way to find alternative fuels to jet A-1 kerosene. The reasons for this include reducing CO2 emissions, although the industry says that it is only responsible for 3-4% of the global total. This will change with continued traffic growth, and the industry is obliged to try to reduce CO2 emissions as part of its commitment to the Kyoto agreement.

The industry has an interest in using alternative fuels so that it can be less dependent on kerosene. It also has to consider sustainability, and the possibility that high oil and fuel prices may continue or increase further.

Francis Couillard, general manager of environmental affairs at Snecma, explains that aircraft fuel must meet stringent requirements. It must be stable at a wide range of temperatures, since aircraft experience ambient temperatures ranging from minus 50 degrees centigrade to plus 50 degrees. Conventional jet fuel also has materials added to lubricate the aircraft's fuel system. Viscosity, spray capacity, the coking of fuel nozzles when burning, freezing at altitude, and the heating or calorific value of the fuel, as well as its density, all have to be considered. Jet aircraft have been designed to use kerosene, and their weights and fuel tank capacities have been based on its physical characteristics, heating value and density.

"There are three categories of alternative fuels: biofuels; synthetic fuels; and third generation fuels," explains Couillard. "Biofuels are derived from a variety of crops, such as oilseed rape, sunflower oil and maize. There are several biofuels, including bio-ethanol, fatty acid methyl esther (FAME), and ethyl tertio butyl esther (ETBE). Bio-ethanol does not have the same heating capacity as kerosene. While FAME has a similar heating value to kerosene, and could reduce CO2 emissions by 70%, it has low thermal stability problems within the range of temperatures that aircraft operate. It is only really possible to use FAME as a blend with kerosene to maintain thermal stability."

Second generation or synthetic fuels are manufactured from coal, methane gas or biomass. These are obtained by the Fisher Tropsch process, where carbon monoxide and hydrogen are combined to form liquid hydrocarbons. "These fuels can meet the physical specifications and heating value of jet A-1, although they may require additives to have the same lubricating qualities of kerosene," explains Couillard. "This would be a promising solution if the production of such fuels is sustainable. Fuels from coal or gas have similar CO2 emissions to kerosene, but they have alternative supplies which may make them politically and economically attractive. Biomass fuel, however, has an environmental benefit because it offers a net CO2 reduction. The complete well-to-wing analysis of CO2 emissions of each fuel must be analysed."

Third generation fuels, such as liquid hydrogen and liquid methane, are only a possibility on a longer-term basis. Couillard explains that liquid hydrogen, for example, has a lower heating value than kerosene and aircraft would need fuel tanks four times their current size to maintain range performance. There are also potential safety problems with storing such fuels

There are several industry initiatives to test and evaluate the three generations of alternative fuels. CFMI tested a CFM56-7B engine with a first generation fuel in 2007. The DREAM programme is expected to test a blended biomass fuel in the second half of 2010. Meanwhile, the CALIN and ALFA-BIRD programmes are researching the use of third generation fuels. Overall, any fuel must meet the same specifications as A-1, so it will be several years before a suitable alternative is found, which is available in commercial quantities and in airport locations worldwide. AC