Aviation Transport

HIGHLIGHTS

■ **TECHNOLOGY STATUS –** This brief highlights notable technologies that are expected to contribute to energy efficiency gains and reduction of greenhouse gas emissions in civil aviation. Aviation travel currently accounts for around one-tenth of transport energy use globally, and is expected to be the fastest-growing transport mode in the future. Aviation kerosene (Jet A-1) is the fuel used in virtually all commercial aviation. Reducing fuel consumption is a key priority for the industry, both to reduce air transport's environmental impact and to keep operating costs down in the face of rising fuel prices. Energy reducing technologies can be broadly grouped into **airframe design** (mainly reducing the weight and aerodynamic drag of aircraft), **engine design** (improving the efficiency of turbofan and turboprop engines), and reducing the **life-cycle emissions from aviation fuel** (particularly through the use of biofuels). Operational measures also have a significant part to play in reducing the impact of the sector.

■ **PERFORMANCE AND COSTS –** Airframe technologies have the potential to lower fuel consumption by up to 20-25% by 2025 if fully implemented in new aircrafts. Energy savings of up to 2-5% could be realised now by retrofit. Engine technology developments have the potential to reduce fuel consumption by 15-20% by 2025. Replacing engines on existing airframes with new, more efficient versions could result in short-term savings of 5-7.5%. As technologies will be incorporated into new aircraft designs, individual costs are not publicly available. However, all technologies offer the potential for fuel cost savings, and fuel costs currently comprise around one third of operating costs. As a consequence, technology costs can be offset against these savings to an extent. A reduced exposure to oil price fluctuations is a further benefit of implementing energy efficiency technologies.

■ **POTENTIAL AND BARRIERS –** The International Air Transport Association (IATA) has set an industry goal of reducing CO_2 emissions from aviation by 50% compared with 2005 levels by the year 2050. In 2010, the International Civil Aviation Organization (ICAO) adopted a resolution on aviation and climate change which included a goal of a global 2% annual improvement in aviation energy efficiency to 2050 (per revenue tonne kilometre performed). An uncertainty over future oil prices provides an initial incentive to increase fuel economy; legislation such as the forthcoming inclusion of aviation in the EU-ETS provides further price signals. However, barriers such as proving the commercial feasibility and safety of novel technologies, the long life cycles of commercial aircraft (around 30 years) and the unproven sustainability of biofuels mean that the timescales and extent to which the environmental impact of aviation can be reduced are far from certain.

TECHNOLOGY STATUS – In 2007, aviation accounted for 11% of global transport energy consumption [1]. The International Energy Agency expects aviation to be the fastest growing transport sector in the future, with passenger-km travelled anticipated to increase by a factor of four between 2005 and 2050 in their baseline scenario [1]. This scenario also projects that aircraft efficiency will improve at a rate of 0.6% per year (or 30% between 2010 and 2050) and that load factors will also increase. The IEA's most ambitious emission reduction scenario (i.e. the BLUE Map) projects a faster rate of improvement of 1% per annum [1].

This briefing note highlights the more notable technologies which are expected to contribute to these efficiency gains along with measures such as alternative fuels, which will contribute to the reduction in greenhouse gas intensity of aviation.

A new aircraft is sourced from two companies: an airframe manufacturer and an engine manufacturer. The two largest airframe manufacturers are Boeing and Airbus, who manufacture a range of short, medium and long haul turbofan-powered aircraft, while ATR and Bombardier manufacture the airframes of short range turboprop aircraft. Airlines also usually have a choice of engine manufacturer. There are two principal types of engine used in commercial aviation: the turbofan and the turboprop. A **turbofan** engine combines a gas turbine core with a ducted fan and is primarily used on executive jets and larger, high altitude passenger aircraft. Major turbofan engine manufacturers include CFM International, Pratt & Whitney, General Electric and Rolls Royce. **Turboprop** engines combine a gas turbine with a propeller and are primarily used on short range, medium altitude executive aircraft, airliners and helicopters. Manufacturers of turboprop engines include Pratt and Whitney and Rolls Royce. Aircraft also make use of **auxiliary power units (APUs)** which are small gas turbines, usually mounted at the rear of airliners. These units supply electricity to operate the electrical, hydraulic and air conditioning systems when the main aircraft engines are switched off and are also used for main engine start up. Turbofans, turboprops and APUs all burn aviation kerosene, known as 'Jet A' in the US and 'Jet A-1' around the rest of the world.

In 2008, aviation fuel was the single largest cost item for the airline industry, representing over 30% of operating costs, up from around 12% of operating costs at the start of the decade [2]. Airlines therefore place a lot of emphasis on reducing aircraft fuel consumption. One of the main goals of airframe and engine

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manufacturers is therefore to reduce aircraft fuel consumption and they achieve this primarily by reducing weight and improving aerodynamic and engine efficiency. Measures to reduce energy consumption and greenhouse gas emissions from aircraft can take the form of conventional airframe and engine improvements, radical innovation, alternative fuels and operational and air traffic management (ATM) improvements.

AIRFRAME TECHNOLOGIES

■ **Increased Use of Composites –** Composite materials are usually stronger and lighter than conventional aerospace materials. Composite materials are virtually free of fatigue stress, a problem that affects aluminium structures and that normally necessitates regular inspection and periodic replacement. However composites do have their weaknesses, including the potential for delamination (where layers of the material split apart under stress), lower damage tolerance and higher costs. The nature of composite materials also makes damage inspection harder than it is for metallic materials. The most common composite material used in primary structural components of aircrafts is an epoxy resin and carbon fibre composite.

In order to maintain high safety levels, the aviation industry has traditionally been very cautious, preferring to utilize materials with well understood characteristics in key structural components. As a result, the use of composites has, until the last decade, mostly been confined to secondary components. However as the industry has gained experience in the use of composites, their application in the primary structural components (wing box, spars, ribs etc.) has been increasing, with both Boeing and Airbus making extensive use of composites in their latest designs with Boeing's 787 made up of 50% composite materials[3].

■ **Winglets -** Winglets are the upturned structures attached to the end of modern aircraft wings. They are designed to increase the wing's effective aspect ratio (the ratio of wingspan to wing chord) as well as to reduce the effect of wing tip vortices which are formed when high pressure air under the wing interacts with low pressure air above. Both of these effects act to reduce lift-induced drag and lower fuel consumption. One type of winglet is the wingtip fence, which extends above and below the wing and is generally smaller than a winglet. This type has been a feature on the Airbus A320 series aircraft. Boeing usually opts for the more conventional winglet, however Airbus is moving towards what it terms 'Sharklets' which are similar to conventional winglets. Winglet kits can be retrofitted to many older aircraft and tend to come as standard on the latest turbofan designs. Being additional structures, winglets will add to the weight of the aircraft, however the aerodynamic benefits lead to an overall saving on all but the shortest routes. The savings from winglets are primarily found during cruise operations so this technology tends not to be applied to turboprops.

■ **Riblets –** Riblets are small ridges which cover an aircraft skin. The riblets energise the boundary layer (the layer of air closest to the aircraft skin) which means that is stays attached for longer, reducing skin friction drag. The technology was first developed by NASA in the 1980s but it didn't catch on as the materials used weren't sufficiently durable. Now that materials technology has developed, the potential for riblets is being reinvestigated [4] and the technology has the potential to be retrofitted to existing aircraft.

■ **Laminar Flow Control –** A laminar (or smooth) flow of air over the surface of an aircraft results in lower drag than a turbulent flow of air. With conventional wing designs, the airflow changes from laminar to turbulent flow as it passes over the wing. Wings can be designed so that the region of laminar airflow is passively extended further back along the wing. Alternatively active systems, which suck the airflow down to the wing surface, extend the laminar flow region backwards along the wing. Laminar flow wing technologies cannot be retrofitted to existing aircraft but laminar flow engine nacelles may become available for retrofit.

■ **Blended Wing Bodies (BWB) –** The blended wing body concept has been in existence since the 1960s and is widely considered to offer the potential for a step-change in aircraft efficiency and noise. The design blends the fuselage into the wing, offering a substantially more efficient design with higher capacity. The design also allows the engines to be mounted on top of the fuselage which will reduce the noise footprint of the aircraft. The design is not without its problems though, as airports will need to be redesigned in order to accommodate the large wingspan. Also the width of the seating layout means that passengers seated at the edge could experience high accelerations in turns and the evacuation of such large numbers of passengers in an emergency could be challenging.

ENGINE TECHNOLOGIES

■ **Incremental Engine Improvements –** A combination of thermodynamic and aerodynamic improvements and weight reduction is expected to lead to reductions in aircraft engine energy consumption in the coming decade. Thermodynamic efficiency can be improved by increasing the engine pressure ratio (the ratio of the pressure at the end of the engine compressor to that at the intake) and increasing the turbine entry temperature, which will require improvements in engine materials and cooling. The most recent aircraft have turbine entry temperatures of about 1800K and pressure ratios of about 40:1. These are likely to rise over the next twenty years to about 2000K and 55:1 - 60:1, respectively. Additional improvements in engine efficiency can also obtained

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through increasing the efficiencies of the individual components, such as the fan, compressor and turbine blades.

■ **Geared Turbofans –** The fan in a conventional turbofan engine is driven by the turbine via a rigid shaft; however this is a sub-optimal design as the turbine works more efficiently at higher rotation speeds and the fan works more efficiently at lower speeds. Introducing a gear train into the system allows each component to work closer to its optimal speed, although there is a penalty in engine weight from the gearbox.

■ **Open Rotor Engines –** Open Rotor engines (also known as propfans) consist of a pair of contra-rotating, multi-bladed propellers driven by a gas turbine core. This type of engine is more efficient because it has a high effective bypass ratio (which increases thrust for a given fuel consumption) and the contra-rotating propellers reduce losses generated by the torsional energy imparted on the air by a single stage fan or propeller. The technology has some barriers which will need to be overcome. The contra-rotating propellers generate interference with each other which, coupled with supersonic blade tip speeds, leads to high engine noise levels. Many airports operate under strict noise regulations so in order to mitigate noise pollution effects, the engine would need to be mounted either on top of the wing or on top of the horizontal stabilizer at the rear of the aircraft. Either solution would necessitate substantial airframe modifications which mean that the development costs of this technology are high.

ALTERNATIVE FUELS

In combination with the technological measures described above, one of the main greenhouse gas mitigation strategies being explored by the global airline industry is the use of alternative fuels, in particular sustainable biofuels. A considerable amount of research and development is underway, with a range of fuels undergoing flight testing [5]. There are two main biofuel production processes being considered by the industry: hydrotreated renewable jet (HRJ) – also known as hydrotreated vegetable oil (HVO) with vegetable oil feedstocks - and biomass-to-liquids (BTL). There is also a range of biological and chemical processes which could be used to produce synthetic, jet range hydrocarbons. Figure 1 summarizes the range of biofuel pathways from feedstock to finished fuel. Unlike the more common biofuels currently being deployed in the road transport sector (e.g. fatty acid methyl ether - FAME, bioethanol etc.), aviation biofuels are expected to be drop-in replacements for aviation kerosene. This is due to the very strict specifications which define aviation fuel and means that aircraft engine modifications will not be required. Further into the future, hydrogen could also contribute to greenhouse gas reductions in aviation.

■ **Hydrotreated Renewable Jet (HRJ) –** Oils from plants such as palm, soy rapeseed, jatropha or camelina or from algae can be converted to aviation fuel through a process which involves treatment of the oil with hydrogen. This process is very similar to that which will be used in the road transport sector and the same plants are expected to be used in the production of HRJ. HRJ has been successfully trialled in tests by several airlines and certification of blends containing up to 50% HRJ is expected soon with small scale commercial production commencing soon after [6].

■ **Biomass-to-liquids (BTL) –** Fischer-Tropsch (FT) synthesis is a process that can be used to produce fuels from mineral sources (such as coal or natural gas) or biomass sources including woody (or lignocellulosic) crops, grasses and municipal solid wastes as well as sugar and starch crops. The biofuel produced is very similar to conventional mineral jet fuel. Aviation fuel blends containing up to 50% BTL have been included in ASTM D7566 (Specification for Aviation Turbine Fuels Containing Synthesized Hydrocarbons) since August 2009 [7]. The underlying technologies are well understood, having been in existence since the 1940s, but the BTL process is currently at the demonstration stage. Commercial BTL plants are expected from around 2012/13 [6]. In 2010, Solena Group signed letters of intent to construct a plant which will convert municipal waste from London into aviation fuel for use by British Airways at Heathrow. It is anticipated that the plant will produce sufficient biofuel to supply 2% of British Airways' annual consumption [6].

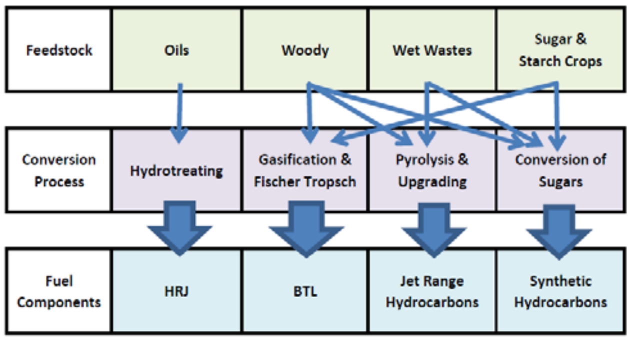

Figure 1 – Biofuel pathways for aviation [6]

■ **Hydrogen -** One potential pathway which could totally decarbonise aviation would be a transition from kerosene to hydrogen fuel. The main option for the deployment of hydrogen in aircraft is as a hydrogen-fuelled turbofan; however fuel cells could theoretically drive a ducted fan engine. The hydrogen would need to be stored in its liquid state in cryogenic storage tanks as compressed hydrogen would require heavy tanks and very large volumes, while hydrogen storage in solid materials still needs significant research to materialise. Cryogenic hydrogen storage suffers from a problem of boil-off which would have to be dealt with, although

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excess hydrogen that evaporates from the tanks could be used to power auxiliary systems. If hydrogen is to make a contribution towards carbon reduction of aviation, then the source of the fuel will need to be low carbon. Even with a zero carbon source of hydrogen, a hydrogen fuelled turbofan would still produce NO_x and water vapour emissions (contrails), with the latter leading to cirrus cloud formation. All of these have an adverse radiative forcing effect [8].

■ **Hybrid Aircraft –** Another option being explored by aircraft manufacturers is the potential for hybrid electric aircraft. The hybrid concept involves coupling an electric motor to a fan turbine, with both being used during the take-off and climb phases and the electric motor powering the cruise phase alone. NASA and Boeing have considered this technology and suggest that it could be viable assuming projected improvements in energy storage technologies materialise [9].

■ **Operational and Air Traffic Management technology –** Significant improvements in fuel consumption can be achieved through operational or ATM strategies which cut fuel use. Increasing load factors (the proportion of filled seats and cargo capacity) and optimum routing are big potential wins for airlines. A continuous descent approach, where the aircraft steadily descends from cruise altitude all the way to the airport will reduce fuel consumption compared with a traditional, stepped approach. On the ground pilots can taxi their aircraft on a single engine or a tug can tow the aircraft out to a taxiway close to the runway before engine start. Simple operational measures such as reducing dead weight (such as the amount of duty free goods carried on the aircraft) are being deployed by many airlines.

PERFORMANCE AND COSTS

The current performance of passenger aircraft in different geographical regions is indicated in Figure 2. It is estimated that the potential cumulative saving in fuel burn from deploying the conventional airframe technologies in new aircraft could be in the region of 20% to 30% by around 2025 and retrofit of measures to existing aircraft could save around 2% to 5% now [10].

New engine technologies are expected to reduce emissions by around 15% to 20% by 2025, while retrofitting new, efficient engines to an existing airframe can save around 5% to 7.5% now [10]. These measures will be incorporated into the standard aircraft designs rather than offered as optional extras so placing a cost on each measure is not possible, however estimates of new aircraft and engine costs are given in Table 1, along with individual savings estimates for each technology. Estimated fuel burn savings for geared turbofans alone (i.e. not including other incremental savings expected from new aircraft

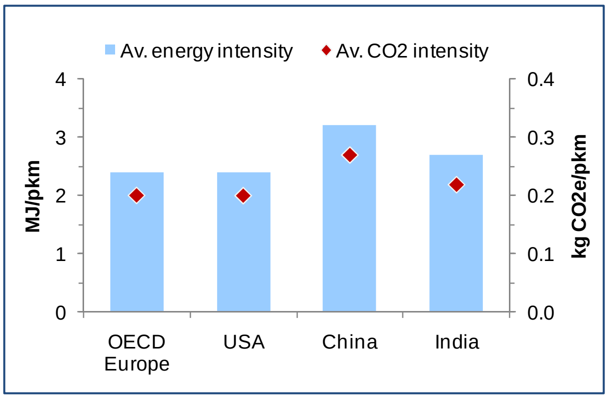

Figure 2 – Energy and CO_2 intensity of aviation [1]

engines) amount to between 8% and 10%, with additional savings in NO_x, noise and maintenance claimed. Open rotor engine configurations are expected to offer savings in the region of 25% - 30% (similar to the fuel consumption of a turboprop) while allowing the aircraft to operate at close to conventional turbofan speeds [10].

Fuel consumption savings of BWB aircraft over conventional designs of up to one third have been estimated however a widespread application of BWB designs could be expected to reduce fuel consumption by around 20%. The earliest date of introduction of BWB aircraft is estimated to be in around 2030 [10].
In total it is estimated that operational and ATM measures could generate abatements of around 10%, while the IEA's BLUE scenarios project 15 - 30% of global aircraft fuel being supplied by sustainable 2nd generation biofuels such as BTL by 2050 [1]. Corresponding savings in greenhouse gas emissions will depend on the performance of the biofuels themselves. For HRJ biofuels the savings are currently estimated to range from around 20 - 50% for conventional vegetable oil feedstocks, from 66 - 89% for newer alternative feedstocks, and up to 98% for algae feedstocks. For BTL biofuels the savings are estimated to be 92 - 95% [8]. However, the impacts of land use change may erode such benefits significantly. Savings estimates for each technology are given in more detail in Table 1.

POTENTIAL AND BARRIERS

■ **Role of Legislation -** The main legislation associated with greenhouse gas reduction in the global aviation industry is the European Union's Emission Trading System (ETS), which in 2012 is expanding to include all commercial aviation that has an origination or destination in the European Union (including non-EU airlines). According to the European Commission, the inclusion of aviation in the ETS is projected to save 183 million tonnes of CO_2 per annum by 2020, a 46% reduction compared with business as usual [11].

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■ Market Potential and Prospects - IATA is targeting improvements in aircraft fleet efficiency of 1.5% per annum to 2020 and achieving carbon-neutral growth after 2020. In the long term IATA has also set the industry a goal of ultimately reducing net CO_2 emission by 50% compared with 2005 levels by 2050 (from 2020). They aim to achieve this through a combination of fleet renewal, engine and airframe technologies, improvements in operations and air traffic infrastructure, biofuels and offsetting [12]. At the UNFCCC COP16 conference in Cancun in December 2010, the global airline industry went further and produced a resolution which included an aspirational goal of annual energy efficiency improvements of 2% up to 2050 (an increase of 0.5% p.a. over previous commitments) and development of a CO_2 standard for aircraft engines by 2013, amongst other measures [13]. Given that the industry is very sensitive to oil price fluctuations, the high oil prices of recent years have added an additional driver to the deployment of energy saving technologies. With long lifetimes, retrofitting of measures such as winglets on existing aircraft is cost-effective in many cases and will become increasingly so as fuel prices rise in the future. These drivers combined mean that the prospect for the deployment of many of the technologies described above looks positive, however barriers still exist.

■ Barriers to Development and Deployment – Some of the measures described above, for example winglets and laminar flow engine nacelles, are incremental improvements that are already being deployed in new or existing aircraft or are undergoing trials with a view to gaining certification. The more radical airframe and engine technologies pose significant design challenges which will mean a major departure from current aircraft designs (for example mounting open rotor engines on top of the wing), or major changes to the layout of airports (in the case of new designs such as blended wing body aircraft). Achieving significant reductions in aircraft energy consumption will also be a relatively slow process because aircraft life cycles are long (around 30 years on average), so it is quite possible that some of the aircraft purchased today will still be flying in 2050. Estimates of when each technology is anticipated to enter into service are given below in Table 1.

One of the most significant barriers to the widespread deployment of alternative fuels in aviation is the issue surrounding biofuel sustainability, in particular as aviation will be competing for limited sustainable fuel supplies against other transport modes (most notably road transport, but also likely with shipping in the future) as well as non-transport demands for energy and biomass (e.g. as bio-alternatives to petrochemical based products, such as chemicals, textiles, plastics, etc.). The sustainable production of hydrogen is also a major barrier to its use as a transport fuel. See IEA Energy Technology Essentials ETE05 (Hydrogen Production & Distribution) for more detail.

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Table 1 – Summary Table: Key Data and Figures for Baseline Civil Aircraft (ranges of the parameters are given in parentheses)

Baseline vehicle: Jet Aircraft		
Metric	**Small Turbofan**	**Large Turbofan**
Energy Input	Aviation Kerosene, Jet A / Jet A-1	
Av. Aircraft Energy Consumption (MJ/km) [a]	181.7 (155 – 185)	361.4 (250 – 500)
Av. Energy Consumption per Available Seat (MJ/seat-km)	1.211 (1.2 – 2.5)	1.205 (1.1 – 1.3)
Number of Seats [b]	150 (90 – 180)	300 (220 – 500)
Annual available seat-km per aircraft [c]	140 x 10^6	830 x 10^6
Average Load Factors [d]	80%	75%
Av. Energy Consumption per Passenger (MJ / passenger-km)	1.51 (1.5 – 2.1)	1.61 (1.5 – 1.8)
Average Aircraft Lifetime, yrs [e]	~30	~30
Capital Cost, overnight [f]	$80 Million ($57 Million - $100 Million)	$240 Million ($150 Million – $375 Million)

a) CORINAIR data for A320 (small turbofan) and a stage length of 500nm (927km), B777-200 (large turbofan) and a stage length of 2500nm (4633km), which are typical /intermediate flight ranges for these types of aircraft. These figures are broadly representative of smaller and larger aircraft, however there can be significant variation between specific makes and models. In addition, these figures will change depending on the flight ranges, with shorter flights having higher average MJ/km due to the greater significance of the landing and take off (LTO) cycle and fuel consumption increasing also for very long flights due to the increased weight of the fuel needed. The average performance of flights within/to a particular region will therefore depend on the mix of aircraft types and flight lengths, and may result in higher or lower figures; b) Average seat numbers from assumptions for a range of aircraft types – note seating numbers can vary quite significantly for the same aircraft type between different airlines due to different configurations (seating pitches, proportions of different seating classes, etc); c) Calculated from ASK data from WEF Global Competitiveness report and split between classes using data from MMU report 2005; d) Single value from IATA for YTD in July 2010; e) Derived from CAEP/5 FESG Retirement curve; f) Derived from Airbus Aircraft 2010 List Prices, www.airbus.com/fileadmin/media_gallery/files/reports_results_reviews/media_object_file_2010-aircraft-list-price.pdf and Boeing Commercial Airplanes Jet Prices , http://www.boeing.com/commercial/prices/.

Table 2 – Energy Savings and Year of Introduction for Aircraft Efficiency Measures [10]

Airframe Measure	**Metric**	**Small Turbofan**	**Large Turbofan**
Composites	Year	2012	2012
	Saving, %	10% - 20%	10% - 20%
Winglets	Year	Now	Now
	Saving, %	1% - 2%	1% - 2%
Riblets	Year	2015 – 2020	2015 – 2020
	Saving, %	1% - 2%	1% - 2%
Laminar Flow Wings	Year	2020	2020
	Saving, %	10% - 20%	10% - 20%
Average New Airframe Potential	Year	By 2025	By 2025
	Saving, %	20% - 30%	20% - 30%
Average Retrofit Airframe Potential	Year	2015 – 2020	2015 – 2020
	Saving, %	2% - 5%	2% - 5%
Engine Measure	**Metric**	**Small Turbofan**	**Large Turbofan**
Pressure Ratio, Materials & Cooling	Year	Now – 2025	Now – 2025
	Saving, %	3% - 5%	3% - 5%
Compressor & Turbine Aerodynamics	Year	Now – 2025	Now – 2025
	Saving, %	3% - 5%	3% - 5%
Geared Turbofans	Year	Now – 2025	
	Saving, %	8% - 10%	
Ultra High Bypass	Year		2013 - 2025
	Saving, %		8% - 10%
Unducted Fans	Year	2015	2015
	Saving, %	15%	15%
Average New Engine Potential	Year	By 2025	By 2025
	Saving, %	15% - 20%	15% - 20%
Average Retrofit Engine Potential	Year	Now	Now
	Saving, %	5% - 7.5%	5% - 7.5%

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