Beginner's Guide to **Aviation Efficiency**

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ATAG AIR TRANSPORT ACTION GROUP

www.enviro.aero™

Contents

The importance of aviation

- Aviation provides the only rapid worldwide transportation network, is indispensable for economic development, tourism and facilitates world trade. Air transport improves quality of life in countless ways.
- Air transport moves over 2.2 billion passengers annually.
- The air transport industry generates a total of 32 million jobs globally.
- Aviation's global economic impact (direct, indirect, induced and catalytic) is estimated at $3,560 billion, equivalent to 7.5% of world gross domestic product.
- Aviation is responsibly reducing its environmental impact.
- Air transport's contribution to climate change represents 2% of man-made CO_2 emissions and this could reach 3% by 2050, according to updated figures from the Intergovernmental Panel on Climate Change (IPCC).
- This evolution is based on a growth in aviation CO_2 emissions of 2-3% per year, with an annual traffic growth of 5%.

This publication is for information purposes only. While every effort has been made to ensure the quality and accuracy of information in this publication, it is made available without any warranty of any kind. All currency is in US Dollars. This *Guide* is written in metric units, except where normal aeronautical use requires imperial units (i.e. altitude in feet and distance in nautical miles). A list of sources and references can be obtained at www.enviro.aero/aviationefficiency.

Introduction

Aviation has come a long way. With over two billion people travelling safely around the world every year and some 23,000 aircraft in commercial service, the aviation industry today provides a lifeline to communities, a connector of business and a conduit to the world's great experiences.

We have seen some amazing advances, none more so perhaps than the improvement in fuel efficiency. We can now transport people distances once thought impractical at speeds once believed impossible using relatively small amounts of energy. **But our drive for even greater fuel efficiency is pushing the industry further still.**

In aviation, fuel efficiency correlates directly to the distance an aircraft can fly, the amount of payload it can carry and, importantly, better environmental performance. This *Guide* explores the challenge of pushing efficiency in the aviation sector and some of the ways in which today's industry is meeting that challenge, while ensuring it remains the safest form of transport. It outlines the progress currently being made and looks towards the future. For further details, including a review of the new sources of fuel the industry is exploring, check out **www.enviro.aero**.

The miracle of flight

December 17, 1903. Two brothers, Orville and Wilbur Wright, undertake the first powered, controlled flight which lasted all of 37 metres. Today, as people regularly fly distances exceeding 15 million metres, one can appreciate what a world-changing event that small hop really was.

For most of the twentieth century, aviation pioneers were obsessed with speed – first breaking the sound barrier and then pushing aircraft speeds higher and higher. It was the key to winning the air war and the key to exploring space. In the civil market, faster aircraft could fly higher – above the worst of the weather – and connect the world's continents in ever decreasing times.

Speed isn't everything

It was only in the 1960s that it became clear that the cost of speed had to be measured in more than just dollars. Fast jets may have made intercontinental travel possible for a new generation of passengers, but they were also extremely noisy, especially for those communities living under the airport flight-path. The aviation industry had to re-connect with the society it served and re-think its priorities.

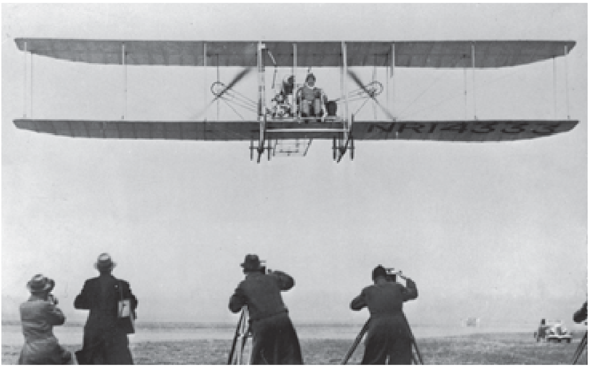
So in the last 40 years a new obsession took hold – efficiency. The aviation leaders of the 1980s and 1990s were those who could push the envelope of efficient aeronautical design to its limit in other ways. Faced with the challenge of delivering more power at lower noise levels, engine designers developed the extraordinary 'high-bypass ratio' engine which, since the 1970s, has delivered a quantum increase in power and a dramatic drop in noise. Thanks to the continued evolution of the high-bypass turbofan, aircraft are now 50% quieter on average today than they were just 10 years ago.

An efficient way to travel long distances

Once up in the air, an aircraft is an incredibly efficient vehicle. A jet aircraft has one unique characteristic that sets it above all other modes of transport – the faster it flies the more efficient it becomes. Up to a speed of 150 kilometres per hour, trains and cars are more energy efficient, but beyond that, it's aircraft all the way.
This is simply because most of the energy needed for high speed travel is used up by friction and air drag, but modern aircraft fly at an altitude where the air is thinner, producing less resistance movement. Aircraft are also much more streamlined than cars and trains.

In fact, from the moment aircraft are designed, engineers are working out how to make them more efficient. Unlike ground vehicles, which don't need to be optimised for efficiency to the same extent as aircraft because they can refuel often, long-distance aircraft must carry all their fuel with them. Fuel is expensive, heavy and takes up a great deal of storage room. Its weight can limit the range of an aircraft and it needs to be stored in tanks which affect the wing size and the payload able to be carried.

1780s



1903

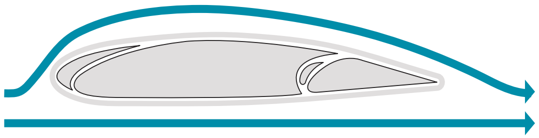
1950s

1969

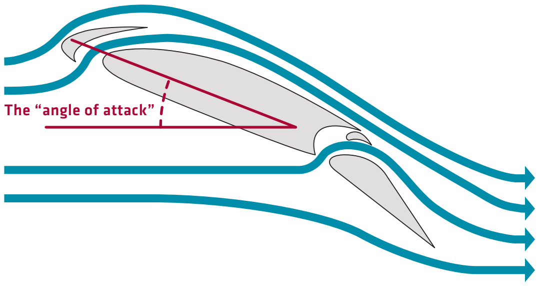
> *“Early pioneers understood the principles of aerodynamics, but the real success of heavier-than-air machines depended upon the availability of lightweight and efficient engines.”*

Wing cross-section

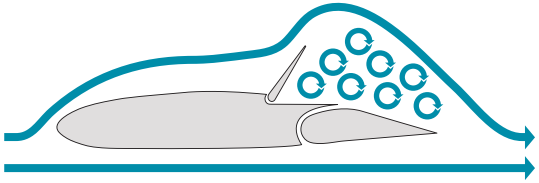
Retracted with zero angle-of-attack (the wing is flat)



Extended with high angle-of-attack (the wing is angled towards the air flow)



Spoilers up reduces lift and provides braking as the aircraft lands



For a passenger in one of today’s new generation aircraft travelling across the Pacific or Atlantic, the rate of fuel consumption is around three litres per 100km – almost exactly the same as a small family car. An aircraft flies further in a day than most cars will drive in a year and at nearly the speed of sound, so exact comparisons with ground-based transport are not meaningful – roads and railways do not offer trans-Oceanic travel alternatives and ships are very slow – but by any measure flying is an extraordinarily efficient way to travel. And it’s about to become even more efficient.

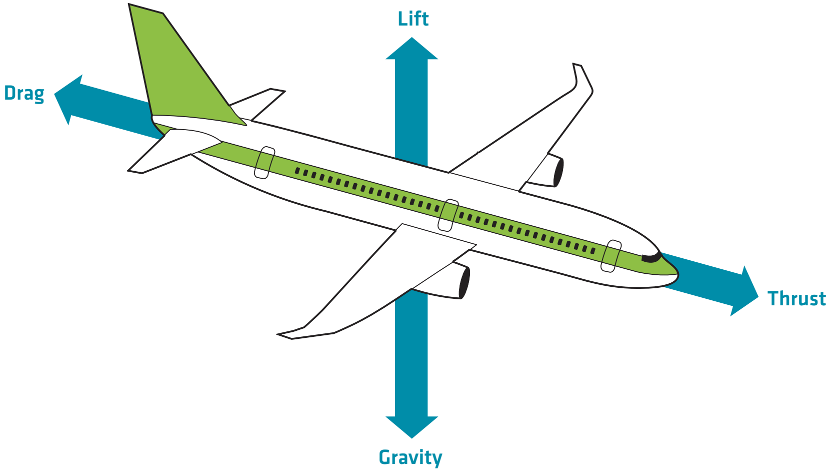
To understand how the industry is conserving fuel, it is important to understand the dynamics of how aircraft fly.

The principles of flight

It still seems miraculous that an aircraft weighing several hundred tonnes can defy the forces of gravity, rise gracefully from an airport runway and climb to a height of 30,000 feet or more to carry hundreds of passengers for thousands of kilometres. But the principles of flight that enable giant aircraft to operate so efficiently also applied to those first human attempts to fly.

Lift is a result of a combination of the wing’s airfoil shape (the shape of a cross-section through the wing) and a positive “angle-of-attack”, in which the front of the wing is tilted slightly higher than the back, relative to the oncoming air. This combination produces lower pressure on the upper surface than the lower surface. The pressure on the lower surface pushes up harder than the pressure on the upper surface pushes down, and the net result is the upward force known as lift.

Forces of flight



Controlling the air

Aircraft wings are equipped with devices that can be extended and retracted to change the shape and size of the wing to allow the aircraft to fly efficiently at high cruise speed and safely at low speed for take-off and landing. These devices enable the wing to produce the same amount of lift (approximately equal to the aircraft's weight) over a wide range of speeds. Ailerons control the direction of the air flow between right and left wings (necessary to change flight direction), while slats and flaps help control the amount of lift. As an aircraft is coming in to land, for example, it is flying more slowly than during other sectors of the flight so needs to extend its slats and flaps (to increase the surface area and change the shape of the wing) to maintain lift.

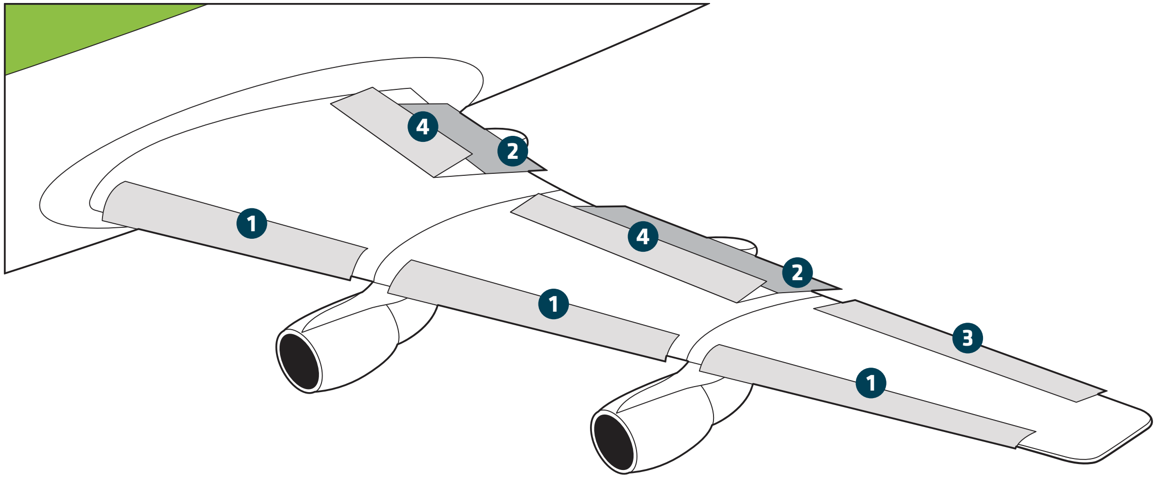
Powering through the air

Sufficient power to achieve speed through the air is another essential factor when considering the principles of flight. Early pioneers understood the principles of aerodynamics, but the real success of heavier-than-air machines depended upon the availability of lightweight and efficient engines. As an aircraft flies, resistance from the air creates a force called 'drag'. Commercial aircraft overcome this resistance using the force of thrust, provided by the engines. Initially, propellers were the only solution but the jet engine has long since revolutionised aircraft design, especially when higher speed is required.

Weight = fuel burn

The amount of fuel that is used in the course of a flight is approximately proportional to the drag of the aircraft. Higher drag means that more fuel must be burnt, so designers devote a lot of attention to shaping the aircraft to reduce its drag. Weight is also important. Adding weight to an aircraft requires a greater lifting force as it moves through the air – which also increases the drag. You will see throughout this *Guide* that drag and weight are two key areas the industry is focused on overcoming to improve efficiency.

Wing devices



- ❶ Slats
- ❷ Flaps
- ❸ Aileron
- ❹ Spoilers

History of fuel efficiency

The aviation industry has come to measure its technical progress in the increasing efficiency of its aircraft and engines. Fuel is one of the highest cost items of an airline operation and oil prices are volatile. Therefore, when an airline decides to buy new equipment, fuel consumption is one of the first things it looks at. There is also a direct link between reduced fuel use and environmental performance – each tonne of fuel saved means approximately 3.15 tonnes fewer CO_2 emissions.

The most direct way for an airline to improve its fuel efficiency is to modernise its fleet with new aircraft incorporating the latest available technology.

Historic trends in improving efficiency levels show that aircraft entering today's fleet are around 80% more fuel efficient than they were in the 1960s. These efficiency levels have been achieved with step changes in design – such as the introduction of turbofan engines with increasingly high bypass ratios (see page 10) – coupled with year-on-year 'incremental' improvements to engine design and operation.

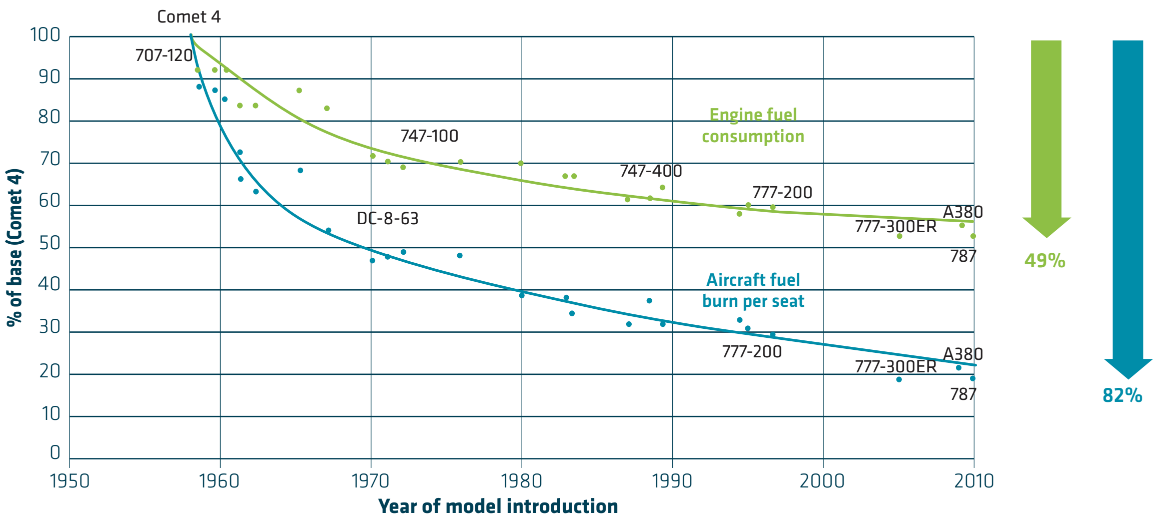
In the mid-1970s, fuel conservation was further enhanced with the development of flight management systems which automatically set the most efficient cruise speed and engine power settings based on fuel and other operational costs involved. More recently, airlines have undertaken a range of operational, maintenance and planning procedures to ensure that their current technology aircraft are flying to their optimal levels of efficiency.

Fuel efficiency in action

The world's most widely used jet aircraft is the Boeing 737. The first commercial version, the Boeing 737-100, took to the skies for the first time in 1967 and could carry 124 passengers over 2,775km with a total payload of 12,701kg. A recent version, the 737-800, can carry 48% more passengers 119% further with a 67% increase in payload, while burning 23% less fuel – or 48% less fuel on a per-seat basis.

The latest generation Airbus A320 is around 40% less expensive – and more fuel-efficient – to operate than the aircraft it replaced. In fact, Airbus spends $265 million per annum on research and development in further improving the efficiency of the A320 family of aircraft. In the coming years, further improvements will be made to narrow body aircraft efficiency in the Boeing and Airbus models, as well as new developments from Bombardier (the CSeries) and Embraer's E-Jet family.

Fuel efficiency gains since the early jet age



Designing aircraft

To the casual observer, commercial aircraft have not really changed all that much since the early days of jet travel. They may be larger or have different names, but ultimately, an aircraft is still a big tube with wings on either side. However, this similarity doesn't do justice to the many factors, some of them subtle, that go into designing aircraft to operate efficiently.

Reducing drag

Drag is the number one enemy of aircraft designers. It is the aerodynamic force that opposes an aircraft's motion through the air and it is generated by every part of the external surface of the aircraft. Aircraft are carefully designed to minimise drag, but because they are so large and fly at such high speeds, drag is still a major factor.

The aircraft designer combats drag by giving the major parts of the aircraft streamlined shapes to which the air flow can remain attached all the way back to a nearly sharp edge at the back of the wings and tail surfaces and a small or sharp closure at the tail of the body.

If aircraft were designed with squared-off or blunt back ends (like those of cars and trucks) the air flowing over the aircraft would leave a wake full of large swirls, which would lead to a large amount of drag. With the drag produced by the shape of the aircraft kept to a minimum by streamlining, much of the remaining drag is as a result of skin friction.

The new generation


Boeing 787


Airbus A350


Bombardier CSeries


Embraer E-jet

> *"A major area of aerodynamic improvements in recent years has come in the design of the wing itself."*

The wing

A major area of aerodynamic improvements in recent years has come in the design of the wing itself. As in all aspects of aircraft architecture, achieving a good wing design requires finding a favourable balance between conflicting factors.

Increasing the wingspan reduces one kind of drag but increases the weight of the required wing structure. Increasing wing thickness reduces structural weight because thinner skins can be used, but increases drag, especially at the high speeds of cruising flight. Increasing wing area makes it possible to take-off and land at lower speeds and thus use shorter runways, but increases skin-friction drag for the rest of the flight. Improvements in airfoils (the cross-sectional shapes of wings) aimed particularly at the high-speed phase of flight, have made it possible to find more favourable balances between span, thickness, area, and weight.

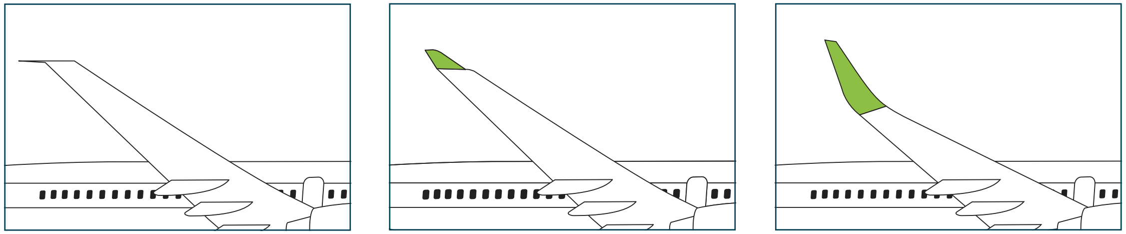
Another area of innovation has been the wingtips. Adding winglets tilted upward at the tips, either to new aircraft or as retrofits to existing models, has delivered 3-5% reductions in fuel burn, depending on the length of the flight and type of aircraft. Winglets reduce induced drag without needing a significant increase in horizontal span. This would be an issue for parking at some airport gates, where no additional room is available for increases in wingspan. An alternative to the winglet is the raked tip, which can produce similar drag reductions. These are used on several new long range aircraft, providing a lighter weight wingtip design.

Different types of wingtip device

No wingtip device

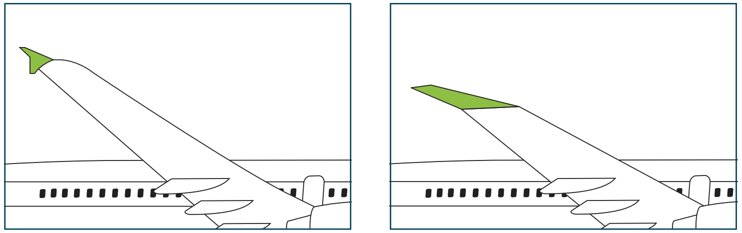
First generation winglet

Blended winglet

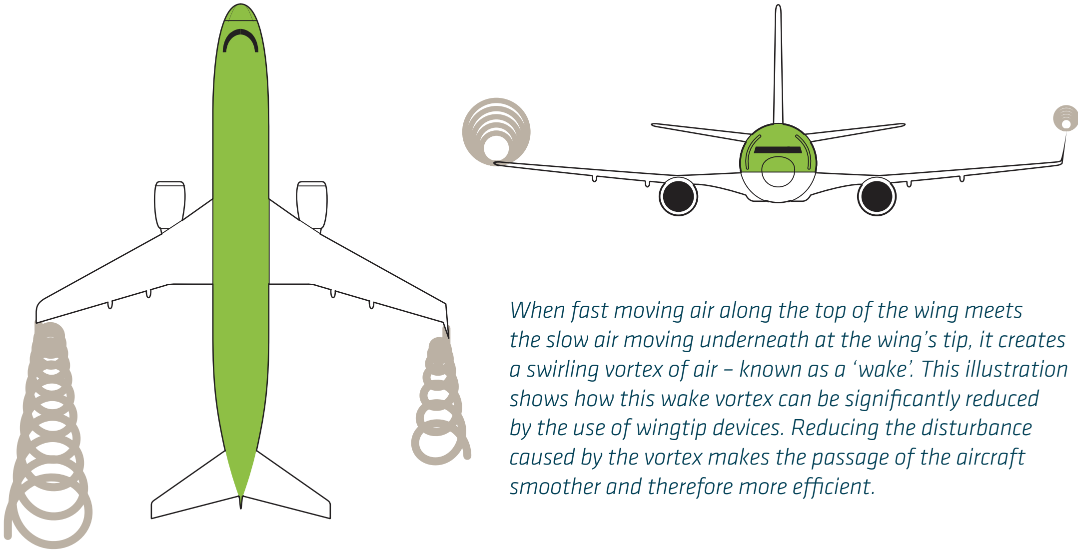


Wingtip fence

Raked wingtip



The efficiency impact of winglets



When fast moving air along the top of the wing meets the slow air moving underneath at the wing's tip, it creates a swirling vortex of air – known as a 'wake'. This illustration shows how this wake vortex can be significantly reduced by the use of wingtip devices. Reducing the disturbance caused by the vortex makes the passage of the aircraft smoother and therefore more efficient.

> “Modern aircraft can be built with materials which precisely match the task they have to perform.”

Systems

Aircraft have complex arrangements of systems with networks of electrical wires, pneumatic cables and air conditioning, among others. While the demands on these systems grow with every new aircraft type – for example, the recent addition of personal seat-back televisions has added hundreds of metres of wiring to an aircraft – there is a growing and contradictory requirement to reduce the weight of these systems while increasing their performance and reliability levels. However, new information technology advances are allowing reduced wiring for in-flight entertainment and even wireless systems are in development.

In older aircraft, the control surfaces such as the flaps and slats on the wings and the rudder and ailerons used to be controlled mechanically from the cockpit through cables or heavy, hydraulically-powered systems. Since the 1980s, these have been replaced with lighter and more powerful electrical systems which are electronically-controlled "fly-by-wire" management systems. Other improvements in the design and weight of the individual motors which control all those surfaces has further reduced the weight of the systems on board an aircraft.

The APU

At the back of an aircraft is a small generator called the auxiliary power unit, or APU. This unit provides power to the aircraft when the main engines are turned off, particularly for lighting, air conditioning and other systems when parked at the airport gate. Instead of continuing to use these fuel-powered units, many airports are installing electrical supplies directly to aircraft to reduce fuel use and carbon emissions.

The advent of personalised in-flight entertainment systems has increased the amount of wiring needed onboard an aircraft.

The auxiliary power unit is used to power the onboard systems when the aircraft is on the ground and the main engines are off.

APU manufacturers have also been working on improving the performance of these small gas turbines. Since the 1960s, the amount of power per kilo of weight delivered by APUs has been increased by a factor of two, and fuel consumption has been reduced by 40%.

In the near term, APUs will continue to be improved incrementally, through better materials, better aerodynamic efficiency, higher thermal efficiencies and with low emissions technologies. Also, APUs are being better integrated within other aircraft systems – such as more electric architectures – to provide further improvements in system weight.

In the long term, aircraft systems manufacturers are researching ways to replace separate power generation/storage systems with new-technology higher-efficiency fuel cells to reduce fuel consumption. In fact, these new fuel cells could reduce carbon emissions by over 6,000 tonnes per aircraft over its operational life. Work on these more efficient technologies is well underway.

Lighter components

Other parts of the aircraft are also going on a diet. Lighter carbon brakes are now available as alternatives to steel brakes; they provide a weight saving of at least 250kg per aircraft. There are also new, lighter and more efficient, technologies available to power and control the braking system. All-electric braking systems, which are lighter and easier to monitor than hydraulic or pneumatic systems, are now entering the market.

Mastering the huge forces involved in slowing down a large aircraft as it lands can provide other benefits to the overall aviation system – such as an automated "brake-to-vacate" system which combines satellite positioning with the on-board airport database and flight-control management system. The pilot selects a runway exit point and the system manages the braking process to ensure the aircraft reaches the chosen exit point at the optimal speed, having factored in runway and weather conditions. This ensures that exactly the right force is applied to the brakes – thereby increasing their operational life as well as minimising runway occupancy time and allows up to 15% more departures to be scheduled.

New materials and structural weight saving

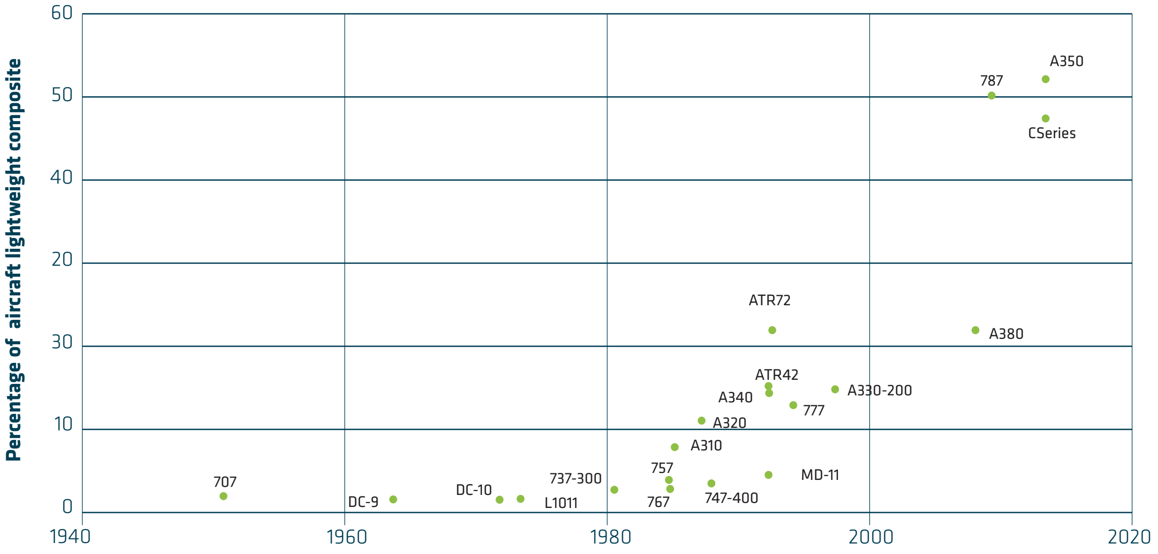
The last few decades have seen a steady rise in the amount of 'composite' materials used in the airframe of aircraft. These have added strength but lowered the overall weight of the aircraft. The use of composites in one new aircraft has generated a weight saving of 20% over traditional aluminium alloys.

A composite material typically consists of relatively strong, stiff fibres in a tough resin matrix. The fibres are set into resin to form sheets which are laid on top of each other, bonded and then heated in a large oven, or "autoclave". The main materials used in aerospace composite structures are carbon- and glass-fibre-reinforced plastic. They have several advantages over traditional aluminium alloys. As carbon composites are, in general, only 60% of the density of aluminium, they provide a much better strength-to-weight ratio than metals: sometimes by as much as 20%. They can also be formed into more complex shapes than their metallic counterparts, reducing the number of fuselage parts and the need for fasteners and joints.

Specially made for the task

The increasing use of composite structures in aircraft is only part of the story. Design engineers now have very detailed data on the different forces and loads on each millimetre of the aircraft's structure. With the availability of new light aluminium alloys, metal-composite materials and different types of composites, the modern aircraft can be built with materials which precisely match the task they have to perform on the aircraft. For example, the kind of material required to resist bird strike impact, in the aircraft nose, is unlikely to be the same material used in the wing, which will have incorporate highly elastic properties to take into account the lift forces on the wing during turbulence and take-off.

Growth in the use of composites in commercial aircraft



Designing engines

Aircraft engines play the most important role in determining an aircraft's fuel efficiency. From the earliest days of simple propellers driven by motors not dissimilar to those used in motor cars, aircraft engines are now some of the most highly-specialised and efficient machines on the planet. There have been a number of significant advances in engine design that have led to such efficiency.

Turboprop engines

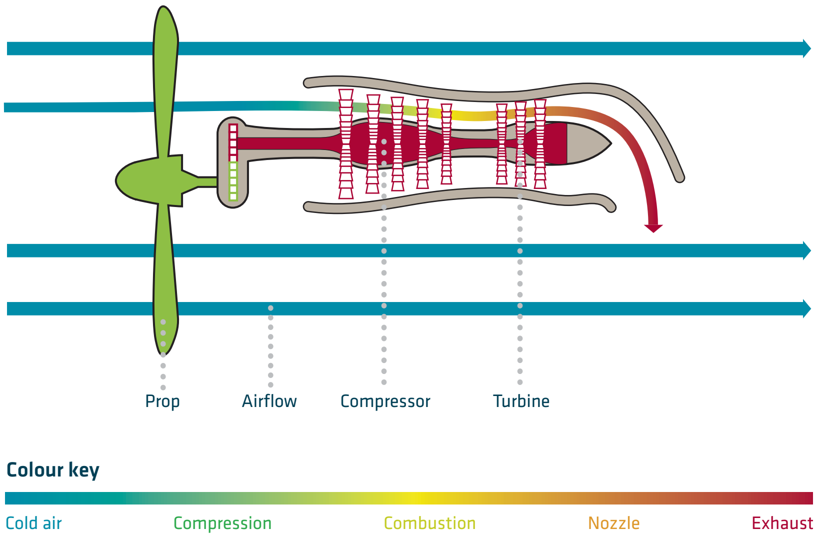
The arrival of the turboprop engine in the early 1940s was a step-change in power, reliability and efficiency over the piston engines then being used on regional aircraft. A turboprop engine is a gas turbine which powers a propeller. Pure turbojets (the type of engine used in early commercial jet aircraft and still used in military jets) may allow you to fly faster but they also use more fuel than a turboprop, making the turboprop a perfect engine for aircraft cruising between 480kph and 650kph (compared to a turbofan-powered jet aircraft which flies at around 800kph).

In recent years there has been a resurgence of interest in the turboprop technology – given their potential economic and environmental performance benefits – especially among regional aircraft developers. A modern turboprop can consume 25-40% less fuel than an equivalent turbofan engine on shorthaul routes.

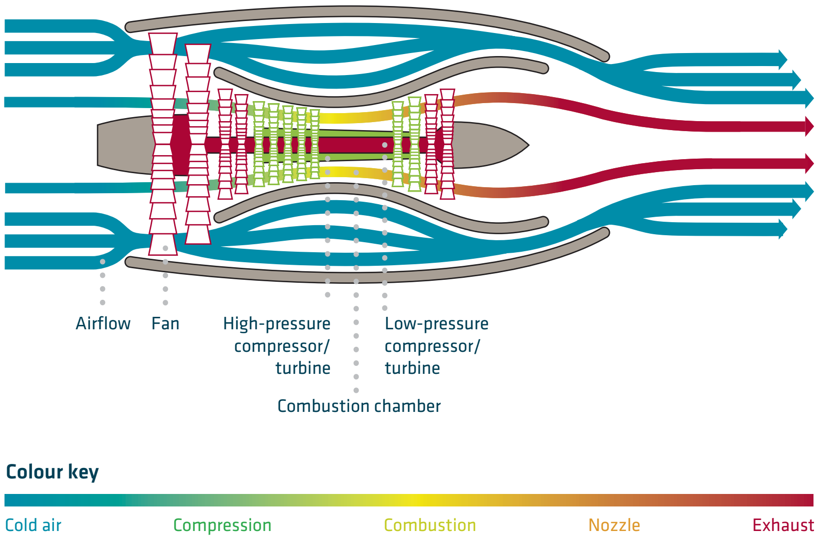
The high bypass ratio turbofan

The appearance of the high bypass ratio turbofan engine in the late 1960s changed the civil aviation industry almost overnight. This new engine design was more than twice as powerful but much quieter and cheaper to operate than the turbojets it replaced. It opened the door to a new generation

How a turboprop works



How a turbofan works



> “There have been a number of significant advances in engine design that have led to such efficiency.”

Turboprop

GE Aviation test a new-generation engine

Rolls-Royce Trent 1000 engine

Carbon-fibre fan blade

of wide-body (two-aisle) aircraft and a step change in engine efficiency which would see a gradual diminishing of aircraft noise “footprints” over the next 40 years.

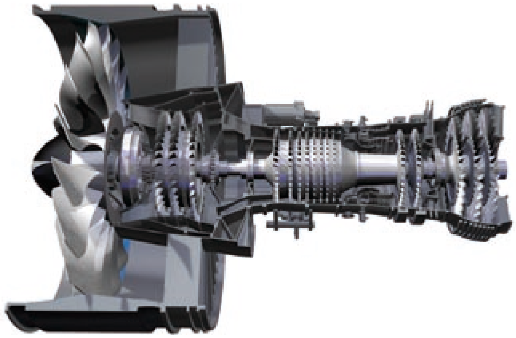
The turbofan incorporates two changes in jet design: it adds a second low-pressure turbine and a large fan mounted in front of the compressor. The fan pulls in large amounts of air into the engine intake, some of which is directed into the hot core of the engine – where it is compressed and then ignited – but most of which bypasses the core where it creates a majority of the engine’s thrust. If there is twice as much cold air bypassing the core as the hot air going through it, the bypass ratio is 2:1. The higher the bypass ratio, generally the better the fuel consumption as more thrust is being generated without burning more fuel. High-bypass ratio turbofans are also much quieter than turbojets, in part because the flow of cold air surrounding the exhaust from the engine core reduces the noise produced by the exhaust gases.

The first commercial high-bypass ratio turbofan engines had around a 5:1 bypass ratio. The latest models are around 11:1. It is also impressive to note that the latest model of engines for wide-body aircraft generate over 115,000 pounds of thrust each – more than the thrust of four engines in the late 1960s, all while using less fuel, producing fewer emissions and with a noise footprint just a fraction of that of the first jet aircraft.

A steady investment in advanced technology has enabled jet engine efficiency to improve at an average of 1% a year – which means engines available in 2020 are likely to be at least 10% more efficient than engines designed today. Engine manufacturers and government researchers are working so that this trend can continue over the next few decades.

To power next-generation aircraft, engine and airframe manufacturers are evaluating and developing several different approaches to achieve or exceed the above improvement trend. There are three new technologies that have received specific attention.

An advanced turbofan



A cutaway of the geared turbofan engine being developed by Pratt & Whitney

CFM International's open-rotor concept engine

Advanced high-bypass turbofans

Manufacturers of narrow-body aircraft engines are currently looking to use ultra-efficient technology that has until now been targeted at long-range aircraft. This includes the use of high-efficiency, high pressure-ratio cores and direct-drive higher bypass-ratio fans using new technology to produce an engine that delivers the low maintenance costs expected for high frequency flights from narrow body aircraft, while managing risk. This engine design, which will be available to enter service by 2016, can provide up to 16% lower fuel consumption compared to current engines and a 75% reduction in the noise footprint. These advances are made possible by breakthroughs in aerodynamics, materials (composites for hot and cold parts), coatings, combustion and cooling technology, as well as improved integration for the entire engine casing with the engine and airframe.

Geared turbofans

Recent technology advances have opened the door for the further development of a technology that has been used in smaller aircraft engines for some time – the geared turbofan. A gear system (much like in a car) allows a geared turbofan engine's fan section to operate at a slow speed and the low-pressure compressor and turbine to operate at much higher speeds – increasing engine efficiency and lowering fuel consumption, gaseous emissions and noise levels. This new type of engine for narrow body commercial aircraft, first entering service in 2013, will offer around a 15-20% improvement in efficiency over the engines they replace. These engines will also reduce noise footprints on the ground. Once introduced into service, new models of the geared turbofan should continue the historical efficiency improvement of 1% per year or more.

Open-rotor

Open-rotor engines are gas turbines driving two high-speed propellers moving in opposite directions to each other. The application of new aerodynamic and material technologies means we could see the return of the propeller-driven engine on larger aircraft, but with higher flight speeds and lower noise levels. This concept was first developed in the early 1980s, but was not pursued due to the relatively low fuel cost of the day. Now with the intense interest in fuel economy and more advanced design techniques, the open-rotor design may have a renaissance. Wind-tunnel tests on prototype models have shown that, thanks to new propeller designs, these engines will offer a 25-30% fuel improvements over current production engines, while meeting noise standards. Further research is underway and flight demonstrations may occur around 2015. By 2020 they could be ready for in-service use on some aircraft.

Operating the aircraft

An aircraft is likely to remain in service for at least 25 years, during which time several new generations of fuel-saving technologies will be developed. Some of these will only be available on new aircraft models but others will be available for retro-fitting on to existing aircraft.

Lighter components

During 25 years of operations, it is likely that an aircraft will benefit from at least two or three complete interior changes, to fit lighter panels, galleys and seats. But there are other important improvement modifications that are possible to an aircraft in service.

A large aircraft can be constructed from over one million parts. When it is time for a major overhaul, a number of weight saving changes are possible, especially components within the large aircraft sub-systems such as light, electrical and fuel systems. Just routinely inspecting aircraft exterior surfaces during regular maintenance checks to identify and correct defects – including chipped paint, scratches and damaged seals – can reduce the annual fuel consumption of an aircraft by 0.5%.

Paint

New aircraft paints will soon be available that will weigh 10-20% less than current paints. New coatings are under development which will be more resistant to chipping and cracking than current coatings and will be lighter, too. When one airline began using a new aircraft paint process which eliminated the typical need for a third coat of paint, it calculated it saved about 136kg of paint per aircraft.

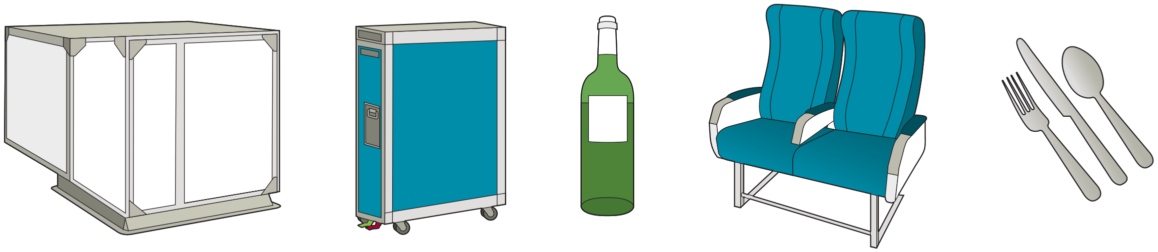
Reducing weight = reducing fuel use

In recent years, aircraft operators as well as manufacturers have been focusing on new ways to reduce the weight of the aircraft they operate. As the measures adopted by one airline show, these range from cutting the weight of crockery to washing the aircraft's engine. A new generation of lightweight but strong carbon-fibre based materials to replace traditional aluminium-alloy materials for interior systems and equipment have greatly reduced the weight carried on board. When one airline introduced a new beverage cart that was 9kg lighter than the previous model it estimated it would save $500,000 in annual fuel costs across the fleet.

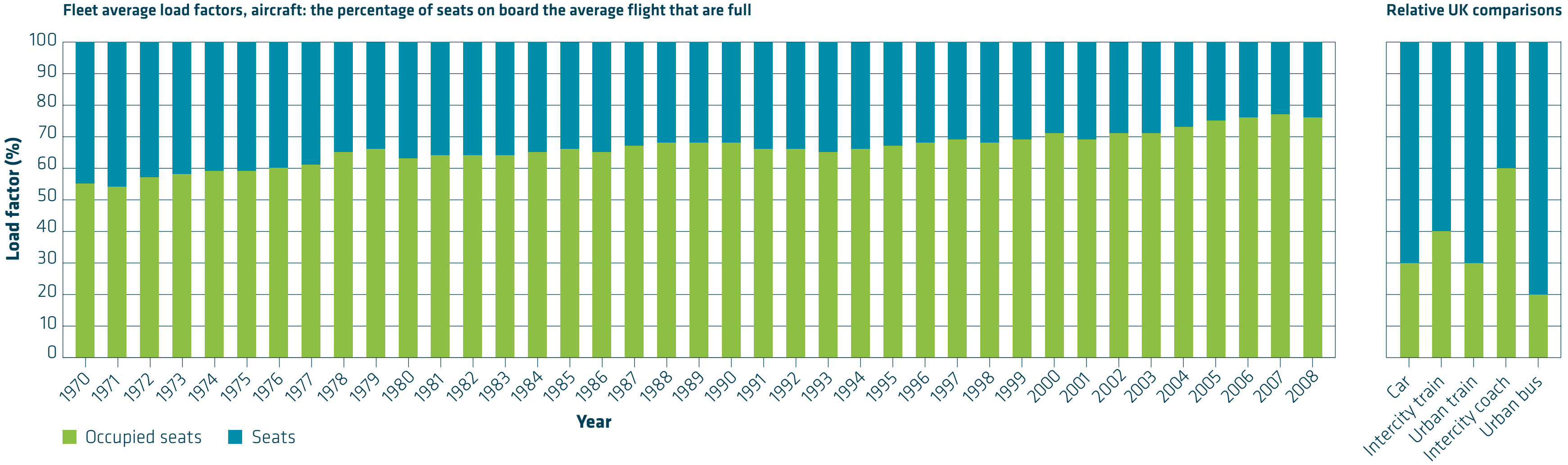
March 2009 saw the launch of a new lightweight economy seat which, at 6kg, is at least 4kg lighter than the average economy seat. By replacing aluminium alloy seats with carbon-fibre seats, one airline has been able to reduce weight carried by 8.8kg per row of seats. Eliminating hot meals on selected flights has allowed some airlines to remove ovens, waste compactors and entire galleys. Magazine racks have disappeared and hard cabin dividers replaced with curtains.

Another successful airline initiative to save weight has been to more closely match the quantity of drinking water with the number of passengers on board, rather than completely filling the water tanks for each flight. One airline was able to cut annual fuel consumption by 0.09% through this measure alone.

Weight saving opportunities on board an aircraft



Load factors over time



Adding weight where it counts

Adding weight can sometimes increase efficiency, too. Many US domestic airlines have added life vests on domestic routes – such as Miami to New York – so they can fly over water where these routes are more efficient.

Fitting 'zonal driers' – electrically powered units, mounted in the space above the ceiling or under the floor – can also help save fuel by reducing moisture trapped in the insulation blankets located between the aircraft outer skin and cabin lining. They typically remove around 200kg of water from each aircraft, which reduces fuel consumption. One airline calculated it will save nearly two million litres of fuel a year across its 42 aircraft by fitting these devices.

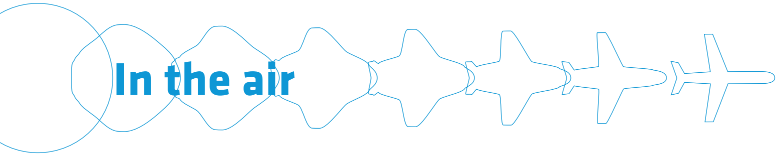
Clean aircraft, clean engines

Washing an aircraft regularly cuts the amount of fuel used as dirt adds to the aircraft's weight and drag. Engine-washing in particular has also been particularly effective at improving aircraft efficiency. For example, one engine-wash service is reported to reduce engine fuel burn by as much as 1.2% and decrease exhaust gas temperature by as much as 15°C, improving performance and increasing the amount of time between engine maintenance.

Optimising operations

Another factor in improving fuel efficiency levels has been the work by airlines to optimise their own network operations, including code-sharing partnerships with other airlines, which allow for greater use of larger aircraft with more passengers. New yield management techniques can also increase the number of passengers per flight and therefore the fuel efficiency of each seat on board. More flexible use of different aircraft in the fleet also allow for better efficiency – for example, the ability for airlines to use smaller twin-engine aircraft in longer operations means that passengers are now able to fly directly between mid-sized cities, rather than having to take extra flights between hubs.

In addition, there have been major improvements in fuel efficiency with the development of highly sophisticated flight-planning and flight-management tools. These allow pilots to exploit prevailing wind conditions, calculate precise fuel loads, set different flight levels and speeds for the aircraft to achieve the most economic performance and determine the exact centre of gravity of the aircraft as it becomes lighter in flight – placing slightly more weight at the back of the aircraft rather than the front can improve fuel consumption rates of the aircraft. In fact, a 28cm adjustment to where the heaviest bags and cargo containers are stowed can save 0.5% of fuel on a flight.



In the air

Every day over 100,000 flights take-off at airports across the world. Some are short hops to nearby destinations, some flights cross the oceans, but all have to fly in the same sky. The following pages explore how the world's air traffic controllers manage to keep aircraft safely separated while allowing thousands of flights to occur and prepare for future growth. It is estimated that up to 8% of all aviation fuel is wasted as a result of the inefficient routes aircraft have to fly. But there is an evolution in the global air navigation industry which is already having a profound impact on the way aircraft are handled in increasing numbers, more safely, efficiently and in more environmentally responsible ways than in the past.

Flight navigation

Until recently, air traffic has been managed by routing aircraft into narrow, pre-determined routes – much like highways in the sky – originally developed to meet the domestic airspace requirements of countries and designed around the location of ground-based navigational aids. This has meant that the shortest route between two airports has only occasionally been an efficient straight line.

Airspace is divided into different control sectors. Before a flight, the pilot files a flight-plan which outlines the planned route for the aircraft. Details of the flight will be agreed with air traffic control – including the altitude at which the aircraft will fly and the time at which it will pass through the various sectors. Controllers will therefore know in advance how much traffic is coming their way before the aircraft actually enters their piece of airspace. In many areas, one controller manages the flight plan data while another monitors the traffic flow on the radar screen, talking to the pilot directly on the radio if route changes or weather issues need to be negotiated. With radar, aircraft are normally separated by five nautical miles (9.2kms) from each other horizontally; without radar, depending on the area of the world, between 30 and 50 nautical miles (55 to 92kms) is the normal minimum separation distance.

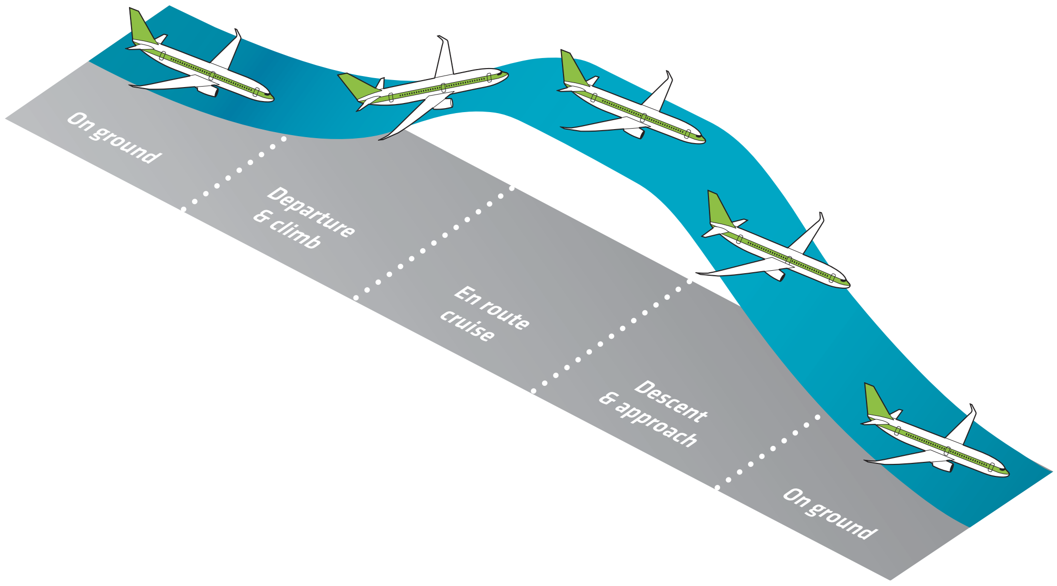
The growth challenge

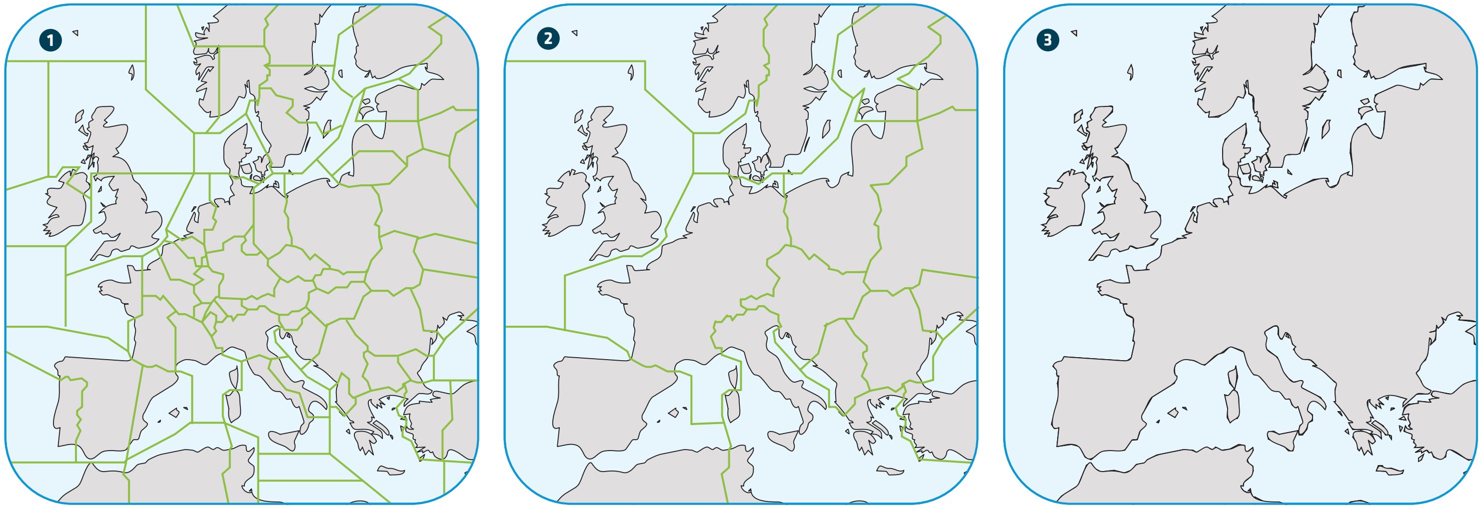
The number of aircraft in service is expected to double in the next 20 years. This growth can only be accommodated safely if the "control" function evolves into an air traffic "management" (ATM) system. This will require re-designing the ATM system around the performance of the flight itself, with controllers managing the optimised use of the airspace rather than taking "hands-on" tactical control of each flight. Once implemented worldwide, the 21st century aircraft that airlines are flying today will fly in a 21st century air navigation system, instead of one that has its origins in the 1940s. This will allow controllers to handle more aircraft at any one time while improving the levels of safety and reducing delays.

Two things will be required to make this possible:

1. The development of new technologies based on automated data-links for communications, navigation and surveillance, which will allow the aircraft to fly within a global framework of information systems, rather than relying on voice communications between

Stages of flight





Today, ① the airspace over Europe is split into around 40 different flight control zones. To reduce this maze of flightpaths to something more manageable and a lot more efficient, the plan is to move in stages. In the coming years, ② the current 36 zones will be amalgamated into 15 larger zones called 'functional airspace blocks', or FABs. These will eventually also merge ③ to become a single European sky.

Indicative schematic only

pilots and air traffic control. In this framework, aircraft will dynamically change their direction and altitude to exploit prevailing weather and traffic conditions.

2. To treat ATM not as a national but as a global operation, with common automated technologies and procedures, many of them based on satellite data-links. A fragmented airspace is an inefficient airspace; each time an aircraft currently crosses a national boundary the workload in the cockpit and the control room rapidly increases. The new ATM system will automate many of the current pilot and controller tasks.

The benefits of moving from a national to an international approach to air traffic control services have been proven for some time. On 24 January 2002, reduced vertical separation minimum (RVSM) was introduced in the airspace of 41 European countries. This meant that between the altitudes of 29,000 feet and 41,000 feet the vertical separation distance between aircraft was reduced from 2,000 feet to 1,000 feet and, as a result, six new flight levels were created. The introduction of RVSM increased the en-route airspace capacity above Europe by 14% overnight. More capacity has resulted in reduced flight delays, better fuel economies for aircraft operators, more operational flexibility for air traffic controllers and, last but not least, considerable environmental benefits from reduced fuel burn.

On certain oceanic routes, flight control computers are automatically plotting their own, most efficient routings with some impressive results. One airline, for example, has been working with Australian air traffic management to save almost 10 million litres of jet fuel and 772 hours of flight time in five years. It does this by exploiting the jet streams and tailwinds in the Indian Ocean.

Next generation air traffic management

The next generation of ATM network-enabled technologies – based on the Single European Sky ATM Research programme (SESAR) in Europe and the Next Generation Air Transportation System (NextGen) programme in the USA – promise to deliver considerably more efficiencies by maturing and implementing ATM technologies and procedures.

The SESAR goals are to triple airspace capacity by 2020 in Europe, halve the costs of providing air navigation services, reduce the environmental impact per flight by 10% over 2005 levels and improve safety by a factor of ten. NextGen is expected to yield significant benefits in terms of delay reduction, fuel savings, additional capacity, improved access, enhanced safety, and reduced environmental impact. The US Federal Aviation Administration estimates that NextGen will reduce delays by 35-40% in 2018 compared with today's systems. And every minute of delay saved also means a reduction in fuel use. SESAR and NextGen will enable air traffic control to evolve further – from air traffic management to air traffic enabling, freeing the aircraft to fly at its most efficient profile possible while achieving new levels of safety in the air and on the ground.

> *While it may be somewhat easy to make a single country's airspace more efficient, these efficiencies also need to be spread across the global airspace.*

Reducing zig-zag in Europe

The challenges to implementing a global ATM system based on performance-based principles are many and complex but not insurmountable. While it may be somewhat easy to make a single country's airspace more efficient, these efficiencies also need to be spread across the global airspace.

The first problem is overcoming the political challenge of sovereignty, by building new airspace sectors to reflect traffic flows, rather than national borders. Europe's airspace, for example is incredibly complex and fragmented. Around 70% of flights are concentrated into just 14% of the available airspace. There are 450 routes which have developed around the twists and turns of national borders; many air routes have to divert around areas set aside for military flights. Each of these flights is flying further, and consuming more fuel, than it really needs to.

By mandating the development of common functional airspace blocs throughout Europe, the Single European Sky programme has taken a major step forward in encouraging national air navigation service providers to develop joint operations with their neighbours.

Not all aircraft operators are airlines. Airlines share airspace with military operators, business and general aviation flyers. The solution to ensuring that all airspace users can access all the world's airspace more safely and efficiently than in the past is to develop new 'flexible use of airspace' concepts. These will increase the capacity of the overall air traffic system by giving civil, military and private aircraft users access to previously restricted airspace, at the time when they need it, and access to a common analysis of the overall traffic situation. By sharing airspace, military can access areas previously reserved for civil flights and commercial aircraft can fly through formerly restricted military airspace; in the past having to avoid these areas has meant lengthy and expensive detours.

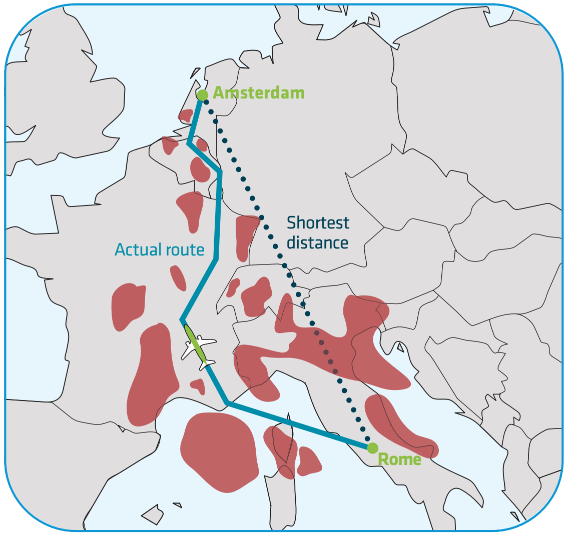
Savings with NextGen in US airspace

Measure	**Units**	**2010**	**2020**	**2030**
Fuel savings	Million tonnes per year	0	5.3	10.8
CO_2 savings	Million tonnes per year	0	16.7	33.9
Net cost saving				
Jet fuel @ $85/b	$ Billions	0	7.1	15.1
Jet fuel @ $165/b		0	11.1	24.3

Savings with SESAR in European airspace

Measure	**Units**	**2010**	**2020**	**2030**
Fuel savings	Million tonnes per year	0.3	3.9	5.6
CO_2 savings	Million tonnes per year	0.8	12.2	17.7
Net cost saving				
Jet fuel @ $85/b	$ Billions	0.5	7.6	10.3
Jet fuel @ $165/b		0.6	10.3	14.3

Example of flying to avoid military airspace and national borders



🟥 Military or temporarily restricted airspace

> *The global air navigation industry is already having a profound impact on the way aircraft are handled in increasing numbers, more safely, efficiently and in more environmentally responsible ways than in the past.*

Preparing for take-off

By tapping into the extraordinarily accurate navigation systems of modern aircraft, air navigation service providers (ANSPs) can design new take-off, cruise and landing procedures and routings which offer some important efficiency improvements.

A number of airports and airlines are trialling the use of so-called 'green departures', allowing pilots to take-off and climb to the optimal cruising altitude in one smooth, continuous ascent. This is in contrast to the traditional method of climbing to the cruising altitude in several steps. By using this new departure method at one airport alone, some 10,000 tonnes of fuel and 32,000 tonnes of carbon dioxide were saved in one year alone.

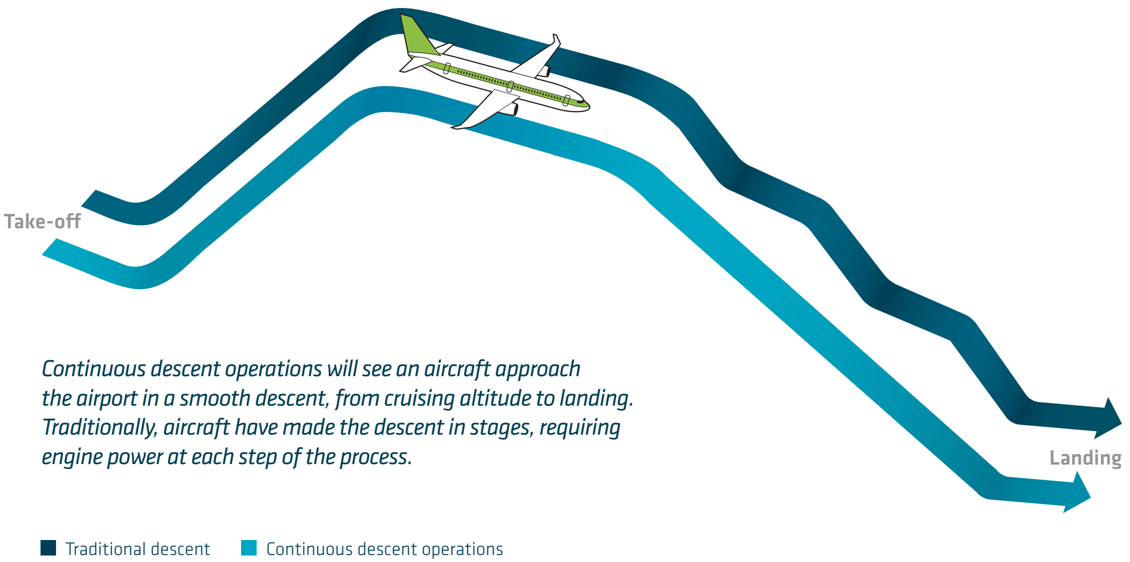
Using satellite-based and on-board precision navigation systems such as "Area Navigation" and "Required Navigation Performance" capabilities allows ANSPs to re-design airspace and procedures so aircraft can fly automatic fuel-saving routes into and out of the busiest airports in the world. These new departure routes have reduced departure delays of more than 2.5 minutes per flight at one airport since their introduction. Annual fuel savings are estimated at $34 million, with cumulative savings of $105 million from 2006 through 2008.

They also open the door to new fuel-saving procedures into airports, especially continuous descent operations (CDO).

Continuous descent operations

In a CDO an aircraft descends towards the airport from its cruising height in a gradual, continuous, approach with minimum thrust – rather than via the conventional series of stepped descents. As there are no "levelling-off" procedures, which require the pilot to increase engine thrust to maintain level flight, less fuel is consumed. In trials, fuel savings of up to 40% during the approach phase have been demonstrated. This equates to between 50 and 150kg of fuel depending on the level at which CDO is commenced and the aircraft type. Up to 150,000 tonnes of fuel a year, or 500,000 tonnes of CO_2, could be saved in Europe alone if CDO approaches were more widely adopted. Not only that, but the noise footprints of CDOs are substantially smaller than the footprints of conventional approach procedures and fuel consumption is about 25-40% lower during the last 45km of the flight.

CDO vs stepped approach



Continuous descent operations will see an aircraft approach the airport in a smooth descent, from cruising altitude to landing. Traditionally, aircraft have made the descent in stages, requiring engine power at each step of the process.

Whole flight projects

By working together with airlines, airports and manufacturers, ANSPs are developing common procedures to ensure aircraft are flying the most efficient route through take-off, cruise and landing. As part of the SESAR programme, 18 aviation groups are working on the Atlantic Interoperability initiative to Reduce Emissions (AIRE) project.

By the beginning of 2010, 1,152 flights had been performed in the AIRE framework. Together, these saved 400 tonnes of CO_2 as a result of new, “greener” ATM procedures. The current trials cover six projects – in Paris (ground movements, green arrivals and departures), Madrid and Stockholm (green approaches and climbs), Portugal and Iceland (oceanic flight optimisation).

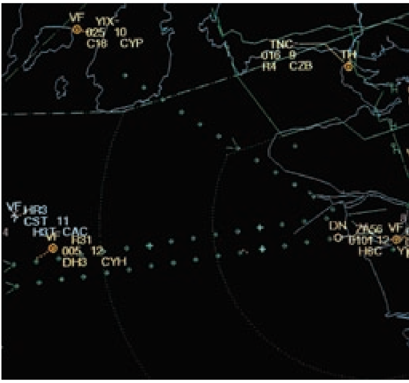
Thanks to these cooperative efforts, the aviation industry is close to being in a position to deliver an “efficiency-perfect flight,” where all the efforts of airlines, airports, ANSPs and manufacturers can be brought together to deliver a flight where the aircraft can be flown in the most fuel-efficient and environmentally responsible way.

The perfect flight

A “perfect flight” scenario is the main objective of the ASPIRE consortium (Asia and South Pacific Initiative to Reduce Emissions). In September 2008, the first ASPIRE flight, from Auckland in New Zealand to San Francisco in the USA took place. This flight was designed to try and do everything possible to reduce fuel use, from the time passengers boarded the flight to the time they disembarked in San Francisco. The result? A reduced flight time of ten minutes and a saving of over 4,500 litres of fuel (with the elimination of more than 13,000kg of carbon emissions). The flight featured the following new procedures:

- **On the ground – fuelling.** Fuelling was completed just 20 minutes before departure so the amount of fuel would be based closer to the actual passenger load. The aircraft was shown to be 800kg lighter than expected so less fuel was required.
- **On the ground – electrical power.** The aircraft used the airport’s electrical power system rather than the more fuel-hungry aircraft auxiliary power unit.
- **In flight** – The aircraft was diverted 100 miles to the east of its original flight plan route to exploit tail-winds.
- **In flight** – On approach into San Francisco International Airport the aircraft flew a continuous descent approach.

Since 2008, new partners have joined the ASPIRE programme and weight-saving procedures have been added. As more of these trial flights take place, the industry is discovering which measures make the biggest difference and eventually will lead to such techniques being used as standard procedure. This will result in very significant savings of carbon emissions.



On the ground

Over 95% of fuel is consumed by an aircraft when it is in the air, but the remainder is used as aircraft taxi from the gate to the runway, from the runway to the gate or while parked at an airport. While this is a comparatively small proportion of overall aviation emissions, there is a lot of work underway to reduce fuel use on the ground.

Single engine taxiing

Airlines have for some years been trialling single-engine taxiing. This is where the aircraft will taxi to or from the runway using only one of the engines to push it forward. By using this technique, one airline saves at least 15 million litres of fuel a year. Another airline has calculated one minute of single-engine taxiing per aircraft movement saves 430,000 litres of fuel annually.

But there are even more efficient methods of moving an aircraft around an airport.

An increasing number of aircraft tugs are available which can be hooked to the nose-wheel of the aircraft and used to tow the aircraft between runway and terminal. Trials are taking place with semi-automated systems to allow the pilot to access robot tugs; developing this into a global solution is complex as airport operations differ widely in size and scope. Aircraft manufacturers are even looking at small electrical motors to drive the nose wheels forward, allowing aircraft to taxi using these and switch on their engines once they reach the runway at the busiest airports.

Fixed electrical ground power

One area at the airport where substantial fuel economies can be made is in cutting the use of aircraft auxiliary power units (APU), which power the aircraft's electrical systems on the ground, when the aircraft's engines are turned off.

A large number of airports are now installing fixed electrical ground power units – these plug the aircraft directly into the mains power so the aircraft does not use fuel while sitting at the airport gate (as illustrated below). Every airport is different, and power can be provided by either ground-based generators or via a frequency converter plugged directly into the mains power supply of the airport, but studies suggest that up to 85% of APU use can be reduced if ground-based electrical power systems are available, cutting the fuel bill, per gate, by $100,000 a year. Decreasing the amount of time the APU is in service also cuts APU maintenance costs. At one mid-sized airport alone, installing these units on 50 gates has resulted in 33,000 tonnes of CO_2 reduced annually.

Fixed electrical ground power and air conditioning

Working together

The biggest efficiency gain on the ground is the reduction in delays and wasted fuel burn as aircraft queue-up for a runway take-off slot, or wait until a terminal gate becomes free. Better coordination between airlines, airports and air traffic management as part of new collaborative decision-making techniques, ensures that airline flight schedules are planned to more closely align with the available runway and airspace capacity. The gains from collaborative decision-making will be substantial. In the United States alone, the cost of burning fuel on the ground as a result of delays to the airline schedule amounted to over $5 billion in 2008 alone.

Airport collaborative decision-making (A-CDM), directly links airports into the air traffic management network and gives users access to a range of operational data allowing them to make their operations more efficient. Successful implementation leads to significant reduction in carbon emissions, which in turn helps airlines save fuel.

The sharing of accurate and timely data between air traffic management and airport operators, airlines, ground handlers and service providers involves investment in new systems and working methods. In one European airport the introduction of A-CDM reduced taxi times by 10%, saving airlines $3.6 million a year in lower fuel bills.

More advanced collaborative decision making will also share information such as passenger flows and baggage information, contributing to an enhanced global picture and a better aviation system for all users and passengers.

Airports are providing efficient on-the-ground services

Aircraft are not the only parts of the air transport system contributing to greenhouse gas emissions. The operations of ground service vehicles, terminal buildings and construction of runways all produce emissions.

However, airports around the world are leading the way in providing energy-efficient infrastructure projects. Terminal buildings are being constructed with sophisticated lighting, heating and cooling control systems to regulate the environment according to the number of passengers expected to use the facility at each hour of the day. Innovative cooling and heating systems are using geothermal, wind turbine, solar or biofuel energy sources. The extensive use of glass provides natural light. Ground service vehicles are increasingly being run on low-carbon fuels or electricity.

Many airport operators are becoming carbon accredited, to ensure the wide range of operations on site are running as efficiently as possible. Airports can be viewed as mini-cities, so collaboration is vital, whether it is through waste recycling programmes within the terminal building or corporate emissions reduction initiatives undertaken between the airport and the airlines, caterers and ground handlers.

Passengers need to play their part too. By far the largest source of on-ground emissions around airports actually comes from passengers driving to the terminal for their flight. A large number of airports are now encouraging passengers to use public transport options to get to the airport and many airports are engaged in developing better intermodal connections with rail and city-based public transport.

> “*Airports around the world are leading the way in providing energy-efficient infrastructure projects.*”

Carbon-neutral growth and the next steps

This *Guide* has looked at all the steps that the aviation industry is taking in its efforts to reduce emissions, particularly the emissions of carbon dioxide which is the most important greenhouse gas. These measures, along with the significant progress being made in developing the benefits of new types of fuel from low-carbon sources, will allow aviation to continue to provide the global economy with the benefits of fast, reliable, safe and efficient connectivity. None of this work is occurring in isolation. In fact, the aviation industry is one of the few sectors that has a globally coordinated approach to reducing its emissions.

The four pillars

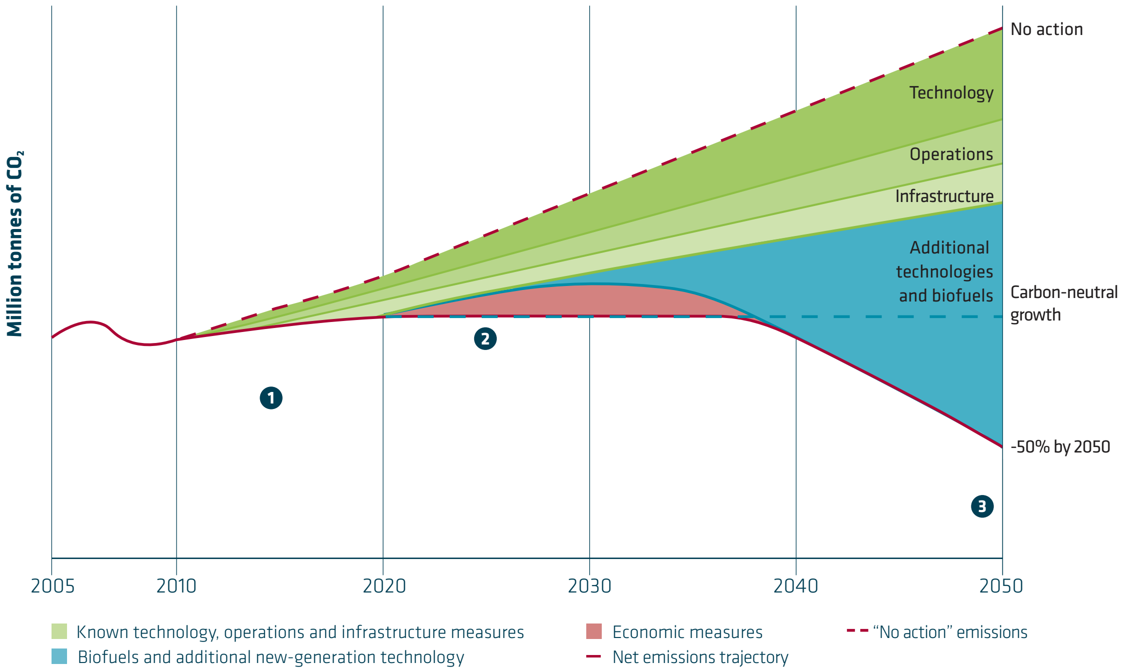
The whole aviation sector signed a declaration in 2008, that committed to what is known as the four pillar strategy for reducing emissions.

Of the four pillars, **technology** has by far the best prospects for reducing aviation emissions. The industry is making great advances in technology, many of which you have seen in this *Guide*. Sustainable aviation biofuels are also part of this pillar, more information on these exciting new fuels can be found in the *Beginner's Guide to Aviation Biofuels* – available on www.enviro.aero/biofuels.

Improved **operational** practices, including reduced auxiliary power unit usage, more efficient flight procedures, and weight reduction measures, could achieve further reductions in CO_2 emissions.

Infrastructure improvements present a major opportunity for CO_2 reductions in the near-term, many of these are described on pages 15-21 of this *Guide*. Full implementation of more efficient air traffic management and airport infrastructure could provide substantial emissions reductions through implementation of measures such as the Single European Sky and the Next Generation Air Traffic Management system (NextGen) in the United States.

Emissions reduction roadmap (schematic, indicative diagram)



While efforts from the first three pillars will go a long way to achieving the goal of carbon-neutral growth from 2020, the aviation sector may need to turn to the fourth pillar – positive **economic measures** – in the medium term to help close the gap.

An industry united

When the world's governments gathered in Kyoto in 1997 to negotiate how the global community would limit climate change, negotiators recognised the difficulties in dealing with aviation emissions. Along with international shipping, the emissions from aviation take place over international waters and are most often not confined to the borders of a single country. With this in mind and the growing need for all parts of the economy to play their role in reducing emissions, the aviation industry has taken the unprecedented step of setting three global commitments for reducing its emissions.

> *The aviation industry has taken the unprecedented step of setting three global commitments for reducing its emissions.*

1 From now until 2020: 1.5% efficiency improvement per year

The industry is using a four-pillar strategy to further increase its fuel efficiency by a further 17% over the coming decade. This is outlined to the left. One of the most important parts of that strategy is the introduction of new technology – the biggest impact of which comes through replacement of older aircraft in the fleet with newer, more efficient ones. This is not cheap. To keep to the 1.5% fleet efficiency improvement target, the world's airlines will need to purchase around 12,000 new aircraft by 2020 at an estimated cost of $1.3 trillion.

2 From 2020: Capping emissions growth from aviation

While emissions will continue to grow until 2020, the aviation sector has agreed to cap its net emissions at the 2020 level. From this point on, any emissions the aviation industry is unable to reduce through operational, technological or infrastructure measures, or by using biofuels, will need to be offset by market based measures.

3 By 2050: halving net emissions based on 2005 levels

After 2020, the industry will start seeing some of the large emission reduction efforts made possible by the advanced technology mentioned in this *Guide*. By this time, sustainable biofuels will be well established and the necessary supply chain will begin to deliver large volumes of low-carbon fuel to the airlines. These two major factors, as well as continuing work on infrastructure and operations efficiency, will allow the industry to aim for the most ambitious goal: to ensure that net carbon emissions from aviation in 2050 will be half of what they were in 2005, or 318.5 million tonnes of carbon, despite the growth in passenger numbers.

Collaboration

The aviation sector has committed to these three ambitious targets and will be using the many projects and possibilities identified in this *Guide* to get there. But the aviation industry can't do it all on its own. Reaching these ambitious targets is contingent on governments playing an important role – particularly in speeding up some vital infrastructure projects such as NextGen and the Single European Sky. Governments need to prioritise research and development through academic institutions into the development of new airframe and engine technologies. Most importantly, they need to make more investment in research and development in sustainable biofuels for aviation. They can also provide incentives for start-up alternative fuel suppliers for aviation.

This *Guide* has presented some of the many ways in which aviation has been working to reduce emissions. Although aviation produces around 2% of the world's man made CO_2 emissions, the industry believes that this is still too much. The aviation industry is committed to the targets it has set and is proud to be one of the only global industries to have such a plan in place. The industry will continue to work with its dedicated United Nations agency, the International Civil Aviation Organization (ICAO), to develop a global plan for reducing emissions with support from the world's governments.

It is clear that efficiency has been a priority for the aviation industry for many years – it is at the heart of the way the industry works. But there is scope for more improvement. The measures outlined throughout this *Guide* need to be rolled out by all airlines, airports, manufacturers and across the world's airspace. It is fair to say that the industry is fully engaged in reducing its emissions. Governments now need to come on board too.

Sustainable biofuels for aviation are:

- Essential: continuing to burn fossil fuels is not sustainable.
- Viable: tests prove that biofuels can be used in flight.
- Sustainable: second-generation biofuels have low impact on land or water used for food crops.
- Cleaner: they have around an 80% reduction in CO_2 lifecycle emissions compared with fossil fuels.
- Practical: second-generation biofuels can be mixed with existing aviation fuel supplies. As more biofuel is produced, we can use more across the industry.
- Coming soon: with certification expected by 2011, biofuels could be used on commercial flights within 3-5 years.

For more details, please see the *Beginner's Guide to Aviation Biofuels* via www.enviro.aero/biofuels.

The next generation

> *The success of first-generation winglet designs has inspired further research into a new generation of devices.*

Aerodynamicists are exploring some radical new aircraft designs for the future. By some measures the most efficient aircraft model is a "blended wing" design where the entire aircraft becomes a lifting device, effectively a flying wing. Super lightweight materials and new systems will be required to implement the concept.

The Very Efficient Large Aircraft project has already researched blended wing concepts which would deliver per-seat fuel consumption improvements of up to 32% over current aircraft designs.

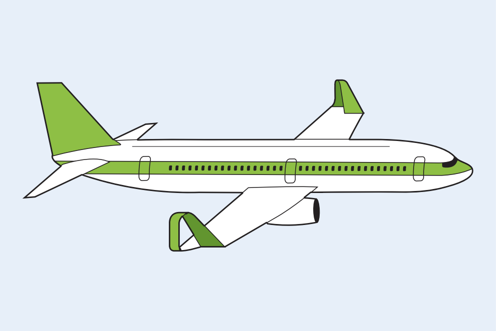
How these aircraft could be designed to fit into current airports and how passengers may react to a windowless journey, however, are subjects for further research.

The success of first-generation winglet designs (see the "designing aircraft" section) has inspired further research into a new generation of devices, including spiroid wing tips which in tests have demonstrated 10% improvements in lift efficiency, fixed multiple winglets (a 15-20% lift to drag improvement) and actively controlled winglets that change shape in flight and could replace conventional control surfaces such as ailerons, elevators and rudders and where the efficiency savings are potentially higher still.

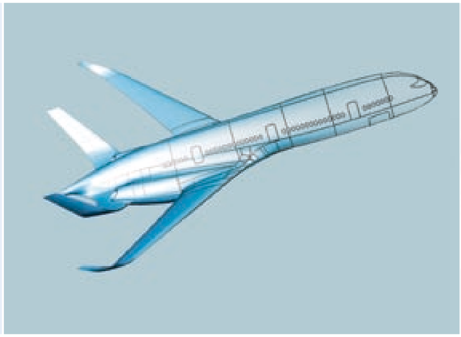
Another European research project is looking at the possibility of a new aircraft model – the Claire Liner – for short to medium range flights which could provide very large reduction in fuel use and noise. It combines various revolutionary concepts including multi-fan embedded engines, 'box wing' configuration and optimised cabin capacity.

Even if these concept aircraft don't eventually fly, research into these designs is producing a lot of the valuable innovation covered in this *Guide*. One thing is very clear – the next 50 years in commercial aviation are going to be just as exciting as the first 50… when we went from the Wright Brothers to intercontinental jet travel.

Claire Liner

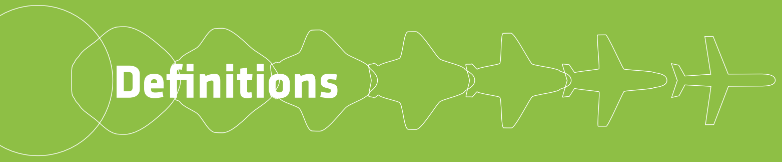


Spiroid winglets



Airbus concept aircraft

Blended wing model aircraft



Definitions

A-CDM: Airport Collaborative Decision Making, where the overall efficiency of an airport is improved by sharing information on aircraft movements between all stakeholders – aircraft operators, airport management, ground-handling and passenger-handling organisations and air traffic management agencies.

ANSPs: Air Navigation Service Providers, organisations responsible for operating air traffic management services throughout the world.

ATC: Air Traffic Control, a service dedicated to keeping aircraft safely apart and clear of potential obstacles in the air and on the ground.

ATM: Air Traffic Management – an evolution of ATC, where the service is responsible not just for aircraft safety but also for reducing delays and providing the most economic and environmentally responsible routings.

Composites: A composite material typically consists of relatively strong, stiff fibres in a tough resin matrix. The most common form of composites used in aviation are carbon fibre reinforced plastics (CFRP).

Cruise: The speed and height at which an aircraft can operate most efficiently. Typically, cruise is referred to as the 'main' part of the flight, after the aircraft has taken off and climbed to this altitude and before it starts to descend towards the destination airport. This part of the flight usually takes place in airspace from around 30,000 to 40,000 feet.

Fixed-wing aircraft: An aircraft with wings fixed to the fuselage – in other words neither a helicopter nor a tilt-wing rotorcraft.

Fuel consumption/fuel burn: The rate at which an aircraft consumes fuel.

High-bypass ratio engine: An engine where most of the air pulled in by the large fan at the front bypasses the hot core and is mixed with exhaust gases at the rear, increasing power but lowering noise levels.

Narrowbody: Aircraft with a single aisle.

Retro-fitting: Adding new equipment to aircraft already in service.

RVSM: Reduced Vertical Separation Minima – reducing the vertical separation distance between aircraft, typically from 2,000 ft to 1,000 ft.

Step-change: The development of a new technology which, from the moment it enters service, can generate a radical improvement in efficiency and/or performance. Jet engines provided a step-change in aircraft performance over piston engines.

Throttle: Similar to an accelerator in a car, the device which regulates engine power.

Widebody: Aircraft with two aisles.

Wingspan: The distance, measured from above, between an aircraft's left and right wing-tips.

Sources for diagrams and a reference version of this document are available at www.enviro.aero/aviationefficiency

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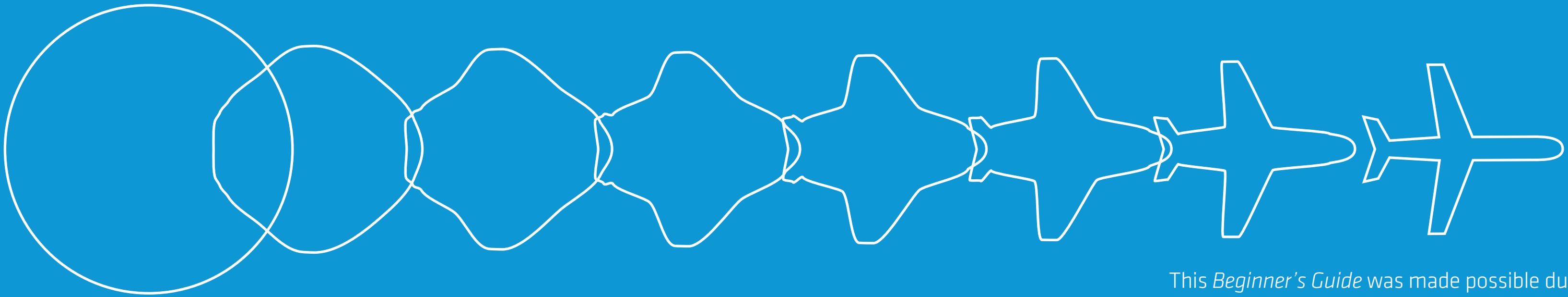

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