The two categories of fuel burn reducing applications are those that achieve in-flight savings, and those that identify operating techniques following the processing and analysis of QAR data. New aerodynamic modifications are becoming available to provide further reductions.

Systems & techniques to reduce fuel consumption

Despite the steady decline in crude oil and jet fuel prices over the past 12-15 months, airlines can still achieve savings in fuel consumption and the related cost through a variety of operational efficiency measures.

Airline departments and flightcrews can use several fuel consumption monitoring and saving applications. Reductions in trip fuel burn can exceed 5% when all possible fuel-saving measures that can be used are implemented simultaneously.

A further 5-6%, and possibly more, can be achieved by modifications that are under development for aircraft that aid a reduction in induced drag during cruise.

Fuel savings

Fuel consumption clearly depends on aircraft type and vintage, average route length, and number of operations or flight cycles (FCs) per year. An example of a narrowbody is a 737-800 that will burn 1,200-1,300 US gallons (USG) on a 540-585nm route with a flight/block time of 95-103 minutes. At typical rates of utilisation of 1,800-1,900FC per year, this is equal to annual fuel consumption of 2.3 million USG. A fleet of 20 aircraft will, therefore, consume about 46 million USG per year, while a fleet of 200 operated by a large US carrier, for example, would consume 460 million or almost 0.5 billion USG per year. A 1% reduction in fuel burn would be equal to 23,000USG per aircraft per year, equal to 460,000USG and 4.6 million for fleets of 20 and 200 aircraft.

At current fuel prices of 105-115 cents per USG, this is equal to an annual saving of $24,000-26,000 per aircraft. A medium-sized fleet of 20 aircraft would have an annual lower cost of $0.5 million, while a large US major fleet would save $5 million. Clearly a carrier, such as Southwest Airlines, could save more than $15 million a year for its fleet of 681 aircraft, through a reduction in fuel burn of just 1%.

It has already been demonstrated, however, that the magnitude of these savings can be up to 5%. Fuel burn savings could then double again if the new drag-reduction modifications that are being developed are implemented.

Jet fuel prices of 105-115 cents per USG in January 2016 are the lowest since 2003. Average crude oil prices of $30-35 per barrel in January 2016 have declined from highs of $110 per barrel in mid-2014. This generated a fuel price of about $2.85 per USG. A 1% saving in fuel burn at these prices would therefore generate an annual saving of $65,000 per aircraft, and so $1.3 million for a fleet of 20, and $13 million for a fleet of 200.

While the industry is now enjoying low fuel prices, the future is unpredictable. Oil prices may increase again, especially over the medium to long term.

Moreover, fuel burn reductions of 1% will generate significant savings for the variety of types operated by airlines. An A320 and A321 will consume 2.0 to 2.4 million USG per year on average route lengths and at typical rates of utilisation. A 757-200 will consume about 3.1 million USG per year on the same basis.

Each year a 767-300ER will consume up to 8.5 million USG, the A330-200 up to 8.5-9.5 million USG, the 787-8/-9 up to 7.6-9.3 million USG, a 777-300ER up to 13.3-13.6 million USG, a 747-400 up to 16.1-17.0 million USG, and an A380 up to 21 million USG. This is when all are operated at typical rates of utilisation.

At current fuel prices, the financial savings possible from larger reductions in fuel burn of up to 5% are, therefore, clearly in the order of $125,000 annually for a 737-800, and more than $1 million per year for an A380.

Fuel burn variables

Realising a 5% saving in fuel consumption is achieved through two main methods: implementation of long-term operating practices following the analysis of post-flight operations data; and optimisation of flights and associated flight plans using real-time operational data. Both need a feed of data, data analysis tools, and appropriate software systems to implement optimisation methods and monitor effectiveness.

Fuel burn and consumption are determined by several dozen variables in each phase of flight. Fuel burn can be reduced by targeting each variable.

Some of the main variables and phases of flight that affect fuel burn and achieve the largest reductions are: profile of the climb phase; altitude and speed of the cruise phase; and profile of the descent phase. Appreciable savings can also be made during the on-ground and taxi phases, and the landing phase.

Variables in the take-off, climb-out and climb phases include take-off flap setting, engine power setting, and airspeed and rate of climb. Reduced take-off flap will mean lower drag and so a lower climb rate and faster acceleration, and result in lower fuel burn.

As an example of flight phase, a fuel burn reduction of up to 1% can be realised by optimising cruise speed and altitude vertical profile components of the cruise phase. This is achieved by using an application to re-calculate the flight plan by using real-time wind strength and direction data and so identify the optimum altitude and cruise Mach number, and implement any changes to the original flight plan. This is considering air traffic control (ATC) limitations on altitudes, separation requirements, and cruise speeds.

Alternations to the flight plan's lateral profile will deliver fuel burn savings if

Even though jet fuel prices are at their lowest level for 13 years, a 1% or 2% reduction in fuel consumption is easily achievable. This will generate savings of $25,000-50,000 for a single 737-800s and similar-sized aircraft, and up to $230,000-460,000 for an A380.

changes to forecast wind and weather en-route are used to optimise the lateral track. Shorter tracks may also become available by missing out some waypoints. It is possible to save 1-2% of cruise fuel burn with these two combined techniques.

Optimisation of vertical and lateral profiles of the flight in the cruise can be done simultaneously, thereby generating a combined saving of 2-3%.

Techniques to optimise various phases of flight in real time require the constant feed of weather and wind data. These data are then used to re-optimise the flight plan using applications hosted on an electronic flight bag (EFB). There are individual applications to optimise the climb phase, and lateral and vertical profiles of the cruise phase. These can all be hosted on the EFB, and each used when appropriate. Changes to the flight plan can then be input to the FMS/FMC.

The original flight plan is loaded electronically onto the EFB in the pre-flight phase. It is then loaded manually by the crew from the EFB into the multifunction control display unit (MCDU) of the flight management system/computer (FMS/FMC), or transferred electronically from the EFB to the FMS/FMC via an aircraft interface device (AID).

In-flight savings

Boeing

Boeing has a suite of fuel efficiency applications. These are grouped into the three categories of pre-flight solutions, flight solutions, and post-flight solutions.

Pre-flight solutions include the flight planning system Jetplan, a flight planning system that includes weather (Wx) and notices to airmen (NOTAMs) information. It also includes a tail assignment application.

Airlines use the flight solutions and post-flight solutions to optimise and reduce fuel consumption.

Flight solutions include on-board decision support tools to allow flight crews to optimise flights as they progress. These include EFB applications, such as the on-board performance tool (OPT), that is used to perform flight plan optimisation calculations in-flight using real-time wind updates and re-planning lateral profiles to achieve more direct routes.

The group of products also includes the Flightdeck Fuel Advisor, which is in development and is a real-time fuel efficiency application. “The Flightdeck Fuel Advisor application provides a gauge to tell a driver how to efficiently drive a car,” says Ian Britchford, director of post-flight solutions at Jeppesen Boeing. “In the case of an aircraft, it will make recommendations to the flightcrew on how to achieve optimised vertical and lateral profiles. The system will take data that include wind speed and direction, temperature, airspeed and ground speed, altitude, position, and other information and pass this to the EFB tablet.”

Honeywell

Like Boeing, Honeywell has applications, both for the real-time and long-term reduction of fuel burn.

Honeywell has three products linked to the real-time improvement of fuel consumption. “The first of these is an FMS datalink service that provides real-time wind and temperature forecast data to the FMS on the aircraft during flight,” says Jason Wissink, technical sales director of aerospace services at Honeywell. “Most FMSs/FMCs on aircraft are manufactured by Honeywell, and the flight plans generated prior to departure are loaded on to them, often by ACARS link. Airlines send their flight plans to our data centre, and we then send them back the latest forecast wind and temperature data via ACARS. This information can be loaded electronically into the FMS. As the forecast wind and temperature data get updated, it is sent to the aircraft via ACARS. It is then used in the FMS/FMC to optimise altitude and flight level (FL) during cruise in terms of recommending steps in FL. It also optimises the descent profile by identifying optimum top of descent (ToD) and descent trajectory. The forecast data, however, are only updated once every six hours. Implications are that new information may only get sent to the aircraft once during a long-haul flight. While the cruise phase may not be re-optimised during a short-haul flight, the forecast data may be updated before ToD to optimise the descent phase. Long-haul flights, therefore, benefit from an improved cruise phase, while short-haul flights benefit from an optimised ToD point and descent trajectory.”

Wissink explains that the main issue is that the FMS does not have the capacity to hold detailed wind and temperature information for several FLs at each waypoint in the flight plan. A long-haul flight may have up to 100 waypoints. Only limited and simplified wind and temperature data can be loaded into the FMS when using a conventional system of loading a flight plan. The Honeywell service, therefore, allows detailed wind and temperature data to be loaded for waypoints for segments of the flights. “Detailed data can be loaded into the FMS every two or three hours,” says Wissink. “Having detailed updates en route allows the FL profile to be re-optimised by the FMS as the flight progresses.”

Honeywell’s second real-time service is being launched and entering service.

One of Boeing's applications for in-flight savings is the Flightdeck Fuel Advisor. This provides a gauge or dashboard parameters and make recommendations to the flightcrew on how to realise the easiest savings.

"IT is an application hosted on iOS and Windows tablets. It is a vertical profile optimisation application that recommends step climbs and new FLs for the cruise phase, and also a ToD and descent trajectory," says Wissink. "This is basically the same as the system for the FMS, but this product allows these re-optimised cruise and descent profiles to be displayed graphically on the EFB screen."

Before departure, the flight plan and Wx data are loaded through a WiFi or cellular connection to the EFB. New and updated information is then uploaded en route through any available in-flight connectivity link that the EFB can use. "Even if it is not possible to get live Wx updates, the vertical profile can still be optimised in the same way the FMS does. This is because more accurate weights are known for the aircraft at and after departure compared to when the flight plan was generated two or three hours before departure," explains Wissink. "FL profile and step climbs are, therefore, optimised because the original and optimised plans are presented graphically on the screen. The flight becomes optimised because actual weights, Wx and temperature are all known. The performance of the aircraft is also monitored in real time. This product is basically an EFB version of the optimising product used on the FMS, and has a graphical display."

Honeywell's third product is a Wx application for the EFB, and it entered service in April 2015. "The application displays graphical Wx information and data across the whole the route. The application can be hosted on a iOS or Windows-based tablet," explains Wissink. "The Wx data is provided by various suppliers and aggregated by the Honeywell data centre. The Wx data on the EFB can be updated in flight, and the process can be automated to update the information every 30 minutes. This is actual real time Wx data, and is different to the forecast data that gets updated every six hours. The information can, therefore, be used to optimise the lateral and vertical profiles of the flight, although the majority of airlines are expected to use it to make lateral profile changes. The system uses large volumes of data, and so conventional ACARS links are too limited to provide good quality graphical information. An I.P. external connectivity system is really required. This can be either with a Satcom or air-to-ground connection."

PACE

PACE has an application named Pacelab Flight Profile Optimiser (FPO), and it uses real-time operational data for flightcrews to optimise the flight in real-time. "Pacelab FPO is an EFB application that constantly calculates the most cost-efficient airspeed and altitude, based on the airline-specific cost index," explains Oliver Spaeth, director of sales for aircraft performance products and solutions at PACE. "The system focusses on optimising the vertical profile of the climb, cruise and descent phases, but will also consider changes to the lateral profile in flight plan updates."

"Pacelab FPO works by first loading the flight plan into the system," continues Spaeth. "Using the XML-based ARINC 633 format, a global standard for exchanging data between different IT systems, the application is able to process OFPs from any flight planning system."

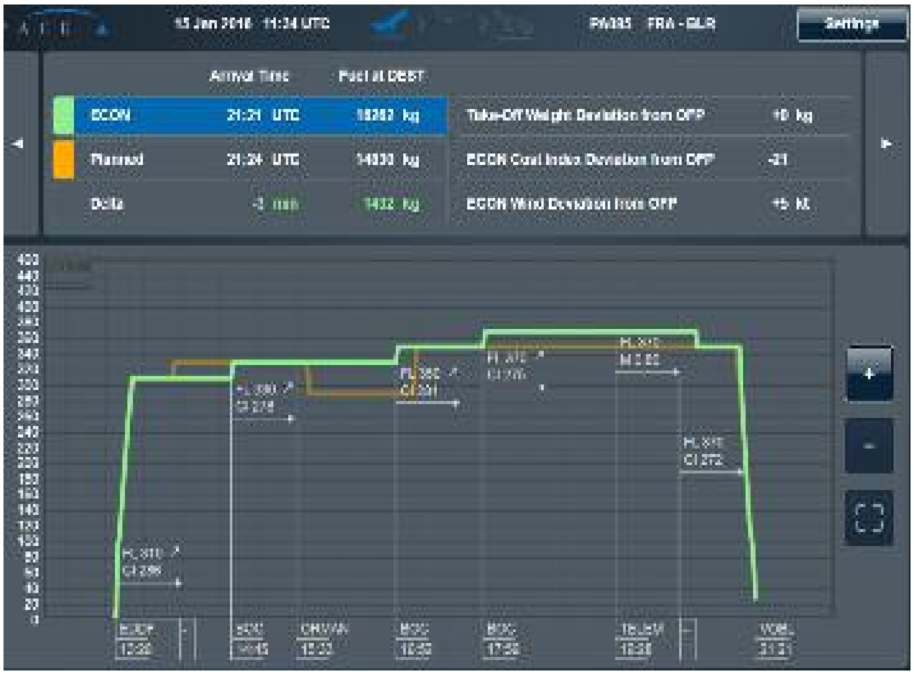
Typical methods of loading the flightplan electronically into the EFB during turnaround would be to send it via a WiFi or cellular wireless groundlink. The aircraft would need to be equipped with a terminal wireless lan unit (TWLU), such as a wireless groundlink (WGL) provided by Teledyne Controls.

"Optimisation starts with taking basic information from the flight plan, which includes the aircraft's zero fuel weight (ZFW), fuel loaded, and cruise CoG," says Spaeth. "This can be revised prior to take-off when more precise information becomes available. Examples are the final passenger and cargo weight or fuel uplift, which is available when the actual off-block weight is known.

"Once airborne, the FMS delivers basic advice, but it will only give the crew the optimum altitude for the current position and is not concerned with the total trip cost," continues Spaeth. "Pacelab FPO, on the other hand, takes a holistic view and optimises speeds and altitudes so as to complete the flight at the lowest possible cost. Overall, you can achieve an average saving of 1% in trip fuel by optimising the vertical profile, particularly for regional jets, and savings can sometimes be several times higher. Given the large impact of fuel cost on airline profits, this translates into a 5-10% increase in earnings per flight, depending on the profitability of the individual airline."

Precise data is essential, so Pacelab FPO makes the best use of real-time operational data, such as actual aircraft weights, actual position, actual speed, actual CoG, and remaining distance read from the ARINC 429/717 buses; live weather such as en-route winds that can be regularly updated during flight; and, uniquely, manufacturer's first principles performance data, which is the most accurate performance data available.

The user interface shows the original trajectory of the flight plan as an amber line, and the suggested optimum trajectory as a bright green line *(see chart, page 31)*. Pacelab FPO thus gives flight crews instant visual feedback on the available savings potential. Pacelab FPO



The Pacelab Flight Profile Optimiser (FPO) specialises in optimising the vertical profile of a flight's cruise phase. The application constantly calculates the optimum altitude and speed, and illustrates this as a bright green line. This is superimposed over an amber line which represents the original flight plan.

also helps to manage on-time performance and minimise delay cost. "When the aircraft is late, it is also possible to use the scheduled arrival time as a constraint and calculate the most cost-efficient trajectory for those conditions," explains Spaeth. Other constraints are taken into account automatically. An example is on a transatlantic operation where altitude and speed changes are not permitted during the part of the track in which the aircraft is out of radar range. Alternatively, the user can put in constraints to be applied to specific portions of the flight; user-defined constraints typically reflect ATC instructions on speed and/or flight level.

"Essentially, Pacelab FPO gives flightcrews a better awareness of the economic impact of their on-board actions, which informs the decision-making process on board. It helps to explore ways of minimising trip cost and provides support for negotiations with ATC, which is much more amenable to flight crew requests than some would expect," says Spaeth. "Our customers' flight operations departments report that they are given the freedom to optimise both speeds and altitudes by ATC the majority of the time."

Sabre

Sabre has a flight planning system called Sabre AirCentre Flight Plan Manager. The solution helps airlines to produce optimum lowest cost flight plans that are compliant with industry and company regulations. "The optimisation functionality ensurer optimised, lowest cost flight plans through 4-D route analysis, dynamic cost indexing and delay cost management," says Zoran Savic, principal solution manager at Sabre. "As the heart of our approach to integrated flight planning, Flight Plan Manager fully automates the end-to-end flight planning process with integrated data support services. In the next step, closer to departure, airlines can achieve more accurate flight planning results and fuel savings through flight parameter changes and recalculation using a mobile flight planning solution, called eFlightManager. There is, therefore, a ReCalc module on the EFB software, allowing pilots to change parameters, such as weight, runway, SID/STAR or alternates and recalculate the flight plan prior to departure.

"During the flight, actual values, such as fuel on board, altitude, or times are recorded. They are then automatically compared with planned values by the system," continues Savic. "Results of the comparison are used to fine-tune future flight plans."

Sabre also has a flight tracking application called Flight Explorer, used by flight operations departments to track flights on the ground at airports and in the air during flight. Flight Explorer is integrated with the flight planning system, so that a trajectory of the planned flight can be plotted on the map shown on Explorer. Flight Explorer visualises global real-time flight tracking information and offers extensive weather options, displaying current and forecasted worldwide Wx with radar and satellite overlays, international graphical METARs, AIRMETs, SIGMETs, lightning, turbulence and volcanic ash advisories.

SafetyLine

OptiClimb from SafetyLine is an application that targets the climb phase of the flight to gain a large saving in fuel burn. "The system's customers include Transavia as a launch carrier, and a number of them are following in Europe and South America," says Eric Boucher, chief operating officer at SafetyLine. "The system first uses big data techniques to analyse quick access recorder (QAR) data. OptiClimb is applied during the climb phase of the flight. We have targeted this phase because it provides the biggest reduction in fuel burn when the optimisation of all phases of a flight are considered. This also has to be considered against the fact that about 60% of all global flights are with narrowbodies, and about 80% are regional or short-haul operations. They, therefore, have short cruise phases, while the climb phase accounts for a relatively high portion of total flight time. This of course means that a large percentage of flights have a large portion of the flight with engines operating at climb power, and most fuel is consumed in this phase of the flight. Optimising the climb can save up to 10% of the fuel burn during this phase.

"A conventional flight plan will calculate a single climb speed and rate of climb to the first cruise altitude," says Boucher. "OptiClimb calculates climb speeds for two or three segments of the climb. It usually calculates two speed changes, and so splits the climb into three segments."

For the first step of optimising the climb phase, SafetyLine analyses a large quantity of QAR data from 100-200 flights for each aircraft in the user's fleet. These data are used to establish the fuel burn and consumption characteristics of each aircraft, and how these change with a large number of variables.

For the next stage OptiClimb uses statistical techniques to establish a model to achieve optimal climb performance for the aircraft. Two to three hours before departure, a flight plan is computed to provide the flight's main characteristics, including: Wx, aircraft used, weights, planned altitude and route.

OptiClimb, used on the EFB, then uses an algorithm to optimise the climb segment of the flight plan and so provide modified instructions for the climb phase. This calculation takes five minutes, and gives three different indicated airspeeds (IAS) to be used up to three different altitudes. The data can be put into the FMS/FMC to modify the flight plan.

Climb profile is calculated for each

Lufthansa and Lufthansa Cityline both utilise the Pacelab FPO. They report that they are given the freedom by ATC to optimise both altitudes and speed in most areas of airspace except near major airports.

flight. "This is because the Wx, temperature and all other operating conditions are continuously changing," explains Boucher. "OptiClimb computes in relation to the cost index (C.I.) used by the airline. The C.I. is a ratio between the aircraft's fuel consumption and the time-related operating costs. The C.I. selected by the airline depends on strategy. C.I. Min means the aircraft will go slower and achieve the lowest fuel burn possible. So Opticlimb takes into account the airline's strategy. If the climb is optimised by splitting it into three phases, it is estimated that a 737-300 could save up to 150 kg (330lbs/50USG) per trip."

Software instructions are sent to the EFB, and illustrates the flight plan and profile, with the vertical scale denoting the altitude, and the horizontal scale the tracked distance. A regular climb profile and an optimised climb are indicated by the two different coloured lines.

The final step of the OptiClimb system uses QAR data post-flight to see if climb instructions were followed, and calculate the fuel saving achieved. This can only be done if the aircraft's fuel burn characteristics are already established.

OptiClimb is relatively new, having been in operation for six months. "It has been trialled by Transavia with its 737-800s," says Boucher. "The results so far are that average fuel consumption in the climb phase has declined from 1,086Kg (2,390lbs/357USG) to 981 kg (2,158lbs/323USG), a saving of 105 kg (55USG) or 10% of climb fuel. About 60% of flights followed the Opticlimb profile during the trial, but now that this is completed we expect it to increase to 80%. On this basis, Transavia could save about 170 tonnes (57,000USG) of fuel per aircraft per year. At current prices, this is equal to $58,000 per aircraft per year, on the basis that 90% of flights will use the system, and equal to an annual saving of $1.5 million for the airline's fleet of 26 aircraft.

"When we introduce OptiClimb at a new airline, we have to go through identification and experimentation phases," continues Boucher. "It takes about three months before the system can be fully implemented and possible savings are established. Now that we have developed systems for the climb phase, we will start looking at other phases of the flight to generate further savings, in particular the cruise."

Opticlimb can be run in parallel with other fuel and flight optimisation solutions, such as PACE, on the EFB.

Long-term reductions

In addition to the techniques for optimising flight paths and flight plans in real time, it is also possible to implement operational practices to achieve fuel burn savings over the long term.

There are several categories of these techniques. The first is a technique to achieve reductions in aircraft weight, by reducing the aircraft's operating empty weight (OEW) or aircraft prepared for service (APS) weight. As a rough guide, the effect of additional weight, the aircraft's landing weight being used as the basis, on fuel burn is 40Kg (13USG) of additional fuel burn for every 1,000Kg (329USG) landing weight (AUW). A ratio of 4% can, therefore, be used as a simple guide, but the actual ratio depends on flight time and several aircraft characteristics.

It has been proven that reductions in OEW/APS by 100Kg or a few hundred Kg can reduce fuel burn by about 4Kg for each flight. When multiplied over all flights within a fleet, substantial savings can clearly be made on an annual basis.

Reductions in OEW/APS can be achieved through several measures. The first is to use lighter materials in the aircraft cabin. Many new-generation in-flight entertainment (IFE) systems, for example, are wireless or use pre-loaded tablets for passengers, so they weigh less than legacy IFE systems. New-generation seats and furnishings are made with lighter materials.

Further reductions in OEW/APS can be achieved by reducing the amount of potable water loaded. This can only be done if the risk of running out of potable water during the flight is minimised, requiring accurate monitoring of the amount of water consumed and quantity remaining at the end of each flight. Statistical techniques can then be used to determine the amount of water that should be loaded, rather than just filling all tanks on every flight.

Other weight reduction techniques include reducing the amount of in-flight catering and other passenger service items. There is also the issue of the crew, their bags and equipment.

Aircraft centre of gravity (CG) also affects drag and, therefore, fuel burn. CG optimisation can be achieved through optimised loading using applications.

While there are techniques that can be used to optimise several phases of each flight in real time, there are long-term techniques that can be applied to flight planning.

The first issue of flight planning is that most airlines use the main flight planning systems at the pre-flight stage. These systems include Jeppesen's Jetplan system, Lufthansa Systems's LIDO, and Sabre's Flight Plan Manager system. First, in many cases one or a limited number of plans are generated, but these are usually not sufficient to get the most optimal plan and profile for each flight phase. Second, all the systems use detailed algorithms to calculate flight plans, and these work with a number of assumptions for each aircraft type, including characteristics

Transavia has has trialled the OptiClimb system for six months. It has been able to reduce climb fuel by about 10% during the trial period. On the basis that the airline uses the system on 80-90% of flights, these reductions are equal to a saving of about $60,000 per aircraft per year.

relating to the engines and the aircraft type's aerodynamic efficiency. Detailed analysis reveals, however, that aircraft do not burn the amount of fuel predicted by the flightplan. This is often because assumptions about the weight and physical status of each aircraft, and the engines' maintenance status, are not as assumed in the flight planning system. It is possible to get a fuel burn profile for each aircraft in a fleet via post-flight analysis. Factors adversely affecting fuel burn, such as skin repairs, can be identified, including identifying optimal lateral paths and tracks for each route in an airline's network, optimising speed in relation to other time-related aircraft operating costs, analysing and identifying optimal take-off power and climb profiles from each utilised airport for each fleet type, and identifying optimal descent profiles for each route and aircraft type.

In addition to the main phases of each flight, different elements of fuel can be added to the basic trip fuel, some of which are a legal necessity and have a legal minimum. These include contingency fuel for en-route issues that may arise, holding fuel to cater for ATC delays at the arrival airport, diversion fuel to an alternate, and discretionary fuel that a flightcrew may add to the total fuel upload before departure.

Post-flight analysis can reveal that in many cases, an airline may be using little added contingency fuel. Analysis may also reveal routes where large volumes of contingency fuel are not being used, or times of the year when consumption of contingency fuel is relatively low.

Similar analysis will reveal the amount of holding fuel being used on each route, and how the quantity varies with time of year, and day of the week. This will allow holding fuel to be reduced without compromising safety.

Diversion fuel can also be reduced by a similar post-flight analysis, and by subsequently identifying more suitable and closer alternate airports.

Post-flight analysis shows that most or all of the additional discretionary fuel loaded onto a flight by flightcrews is not actually used, so it is additional weight that is carried unnecessarily, and increases fuel burn.

There are also the techniques of engine at taxiing, and using a ground power unit (GPU) instead of the aircraft's auxiliary power unit (APU) during turnaround to reduce fuel consumption.

Post-flight data analysis to effect these changes comes from processing and analysing QAR data, which relate to a large number of flight and operational parameters.

Other data sources include aircraft health monitoring (AHM) and engine health monitoring (EHM) data; filed flight plan; loadsheet; crew schedules and rosters; actual departure, take-off, landing and arrival times; and flight log.

Up to 1,000 flight and operational parameters will be recorded and monitored, including AHM, EHM and flight operations quality assurance (FOQA) data.

Most QAR, AHM and EHM data are downloaded from the aircraft post-flight.

It is mandatory for airlines to download several parameters of QAR data to maintain a safety management system (SMS). Downloading is done manually in the case of older aircraft.

A small number need to be transmitted in real time from the flightdeck to alert to in-flight problems, such as engine vibration and engine temperature surges.

Most parameters are used for long-term analysis, and do not need to be downloaded in real time. They include a large number of fuel-consumption-related parameters, such as fuel flow to each engine. It is estimated that modern aircraft types generate 5.5 to 8 megabytes (MB) per hour of data. The data are stored in a QAR on older aircraft types, and the data can be downloaded manually using magneto-optical disks.

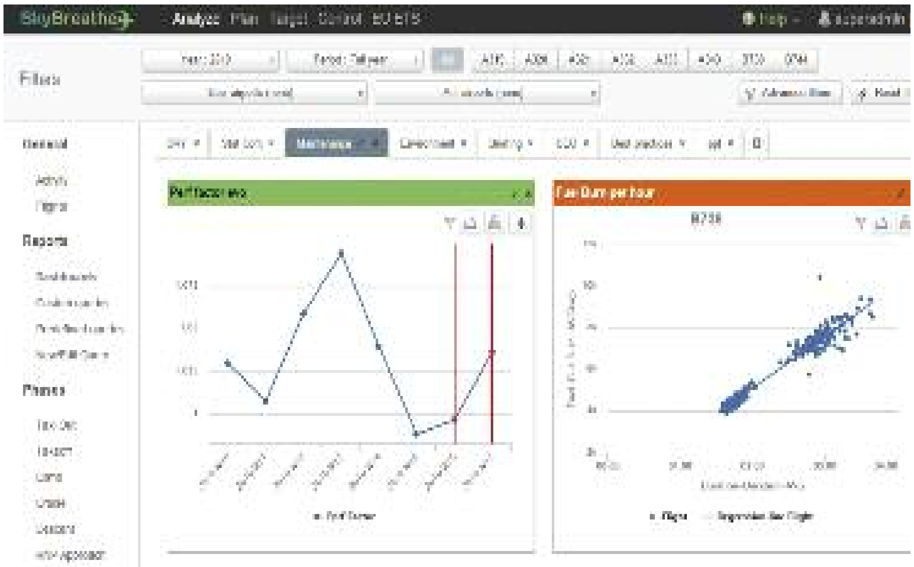
More modern aircraft types have an integrated modular avionics (IMA) system, in which a single box performs all avionic functions, including the QAR and a server.

The large volumes of data can be downloaded from the QAR more economically using on-ground data transmission systems via the wireless channels of WiFi and cellular on-ground connectivity. Several hundred MB of data will be downloaded each month.

These data will then be transferred to systems in airline departments for processing and analysis, including the mandatory SMS. Fuel consumption monitoring and reduction applications will also use some of the QAR data.

Icelandair is one user of SkyBreathe. "There is a huge QAR data set, and the metadata that results from analysis provides an insight into what the data tell you," says Einar Ingvi Andresson, flight data analyst at Icelandair. "Our idea is to achieve the lowest total costs, but we have focussed on fuel efficiency. When the data is used in a proper way the results can be staggering, so full use of the data should be achieved. One important issue is to correctly establish the correct calculation of the C.I.

"The two main operating techniques to reduce fuel burn are EOTI and continuous descent approach (CDA). "There are actually not many secrets in how to achieve fuel efficiency, and you just have to apply yourself," says Andresson. "Pilot compliance is essential.



OpenAirlines's SkyBreathe application analyses QAR and flight operations data to identify main operating techniques to achieve the easiest reductions in fuel burn. The system then identifies where progress has been made in reducing fuel burn.

Pilots must use the best fuel-saving practices, but operational reality means that it is not always possible to use these techniques all the time. We have been using SkyBreathe for about 18 months now, which is long enough to get results. You eventually get to the point when you reach diminishing returns, but you have to continue to monitor fuel burn and all QAR data to maintain the gains."

Long-term applications

Boeing

Boeing's Post-Flight suite of products includes four main applications: Fuel Dashboard, Fuel Optimiser, Fuel Finance Manager, and the Emissions reporter. The first three applications can be used to reduce fuel consumption.

"The Fuel Dashboard is a key performance indicator (KPI) tool, and identifies fuel saving and efficiency measures by analysing QAR data to analyse what operational procedures can be used to achieve reductions in fuel burn. These include procedures, such as single engine taxi, and optimised climb and descent profiles," says Britchford. "It is not just QAR data that is analysed, but crew, financial, ACARS messages, flight plans and loadsheets that all provide data and information sources. The large number of data sources means that the data can be accurately validated to provide good quality decisions. The QAR data will use actual performance data, such as the fuel flow of each engine during taxi, to measure savings. The use of accurate QAR data means potential savings are not based on vague assumptions. The data are then further analysed once these operational procedures have been used to determine what percentage of flights have used them, and calculate the fuel burn savings that have been generated as a result."

The data are presented in an intuitive interface, and used by the airline's fuel efficiency manager to consider all possible fuel-saving initiatives. The Dashboard advises which practices will give the biggest savings. "Airlines can get to the position where most of the possible savings have been reached, but achieving all possible efficiency gains is difficult," says Britchford. "It is also possible to use the system to compare the fuel burn efficiency of a new type versus existing fleets. An airline must continuously use the Dashboard to monitor fuel consumption, since it will increase again if it is not monitored. Analysis of the potential savings for 15 customers revealed a range of 1.4% to 7.0%, and an average of 4.3%. Most airlines save one third to a half of this using the Dashboard, and so achieve fuel burn savings that average 2.2%."

The Fuel Optimiser is used together with the Jeppesen flight planning system. "This flight-planning system makes it possible to run several flight plans for a flight to get the optimal plan," says Britchford. "That is, we can alter several aspects, such as climb profile, lateral track, altitude, cruise speed, and several other parameters to pick the best plan. The savings generated from each change can be analysed."

Fuel Optimiser features algorithms to further optimise flight plans, leading to more reductions in fuel consumption. This is done by targeting the biggest opportunities for reduction. The optimal plan is compared to the actual plan to reveal differences. The analysis reveals how good weather predictions were, and how closely the plan was followed.

This is done post-flight, so that it identifies the targets for each route and provides suggestions for optimising flight plans on each route with each aircraft type in the future. The system is used to improve choice of alternate airports with particular Wx conditions, and provides suggestions for changing a route's lateral profile. Fuel Optimiser takes into consideration real ATC constraints and other factors so that realistic recommendations are made. It is calculated that Fuel Optimiser will be able to identify a further 1-2% saving in fuel burn when comparing the original plan to the optimal plan.

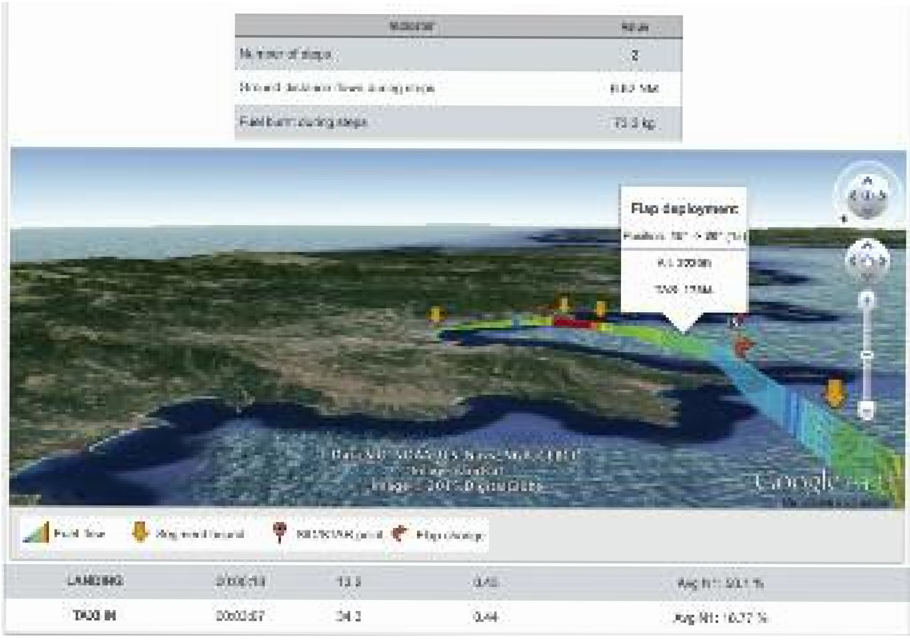
Fuel Finance Manager is an application to manage all financial aspects related to purchasing fuel. It does not, however, optimise fuel burn through operational practices or by making adjustments to flight plans. "Fuel Finance Manager gives airlines an accurate cost allocation of all fuel bought for each fleet and at every airport where it uploads fuel onto its aircraft," explains Britchford. "The system works by analysing every invoice for fuel uploads, and reconciling them with fuel upload reports made by crews in flight logs. This can save about 0.5% in the amount of fuel paid for, since there are often mistakes made in upload sheets. The large number of invoices clearly made it impossible for an airline to reconcile every invoice with every fuel upload, but Fuel Finance Manager now makes it possible to do so.

"Fuel Finance Manager also allows an airline's fuel manager to accurately monitor and attribute a fuel cost for every flight," says Britchford. "The application not only takes the fuel uploaded for the flight as fuel consumed, but also uses QAR data to use the fuel onboard prior to fuel upload and after landing to calculate fuel consumed on each flight.

"The airline can also use the application to accurately forecast future fuel spend for several months ahead," continues Britchford. "This is because fuel on each route will depend on seasonal variations in the weather, passenger demand and loads. A SIM file of the airline's future flying schedule will then be used to generate a forecast of fuel consumption. Adjustments to this forecast can also be made as forecast load factors change. The system can also compare the price paid for fuel with each supplier at each airport it operates to."

Leading Edge

Leading Edge takes the view that optimising flights in real time is difficult, especially because ATC would often not



One operational technique used to reduce fuel consumption is CDA. This can save about 30Kg or 11USG per flight for a narrowbody, and more for larger aircraft types.

allow pilots to adjust the vertical and lateral profiles of flight plans. CGX Aero has developed an application for Leading Edge to save fuel by analysing post-flight data and recommending long-term practices for airlines to follow.

"We approach the airline as a whole and work with the application developed by CGX Aero and use pre-flight, in-flight and post-flight data. The pre-flight data are mainly from the flight plan, and also include other information, such as fuel on board. The in-flight data is not analysed during flight, however, but post-flight with all the other data. The in-flight data are captured from the actual flight," says Stef Denuwelaere, chief executive officer at Leading Edge. "The application analyses all the QAR and flight planning data post-flight, and ultimately provides an analysis of the different ways to generate fuel savings. An example of where some of the easiest savings can be made concern the amount of discretionary fuel loaded. Analysis of actual fuel on board on departure and arrival will indicate when it is useful to carry extra fuel, and more importantly when it is not. The application analyses on which days and seasons of the year the discretionary fuel is actually used.

"Another main factor that our system works on is the cost of carrying additional weight," continues Denuwelaere. "The 'cost of weight factor' is calculated using a different algorithm to the one used by the IATA value. We calculate a number that determines the amount of additional fuel burned for carrying each unit of additional weight. This is an important value, since there are some airlines that carry as much as an additional 500Kg (1,100lbs/165USG) of weight on each short-haul flight." Weight can be fuel, water, equipment, duty-free and customer service items.

The CGX Aero application has a large number of filters to analyse the easiest or biggest opportunities to save fuel. "We tend to create a sense of urgency just by implementing a company-wide fuel efficiency project," adds Denuwelaere. "Pilots, flight dispatchers, and ground handlers become fuel-aware in daily operations. The main areas that customers have targeted for reducing fuel consumption starts with using a GPU instead of the APU. Other big targets are discretionary fuel, cost of weight, reduced engine taxi, and applying fuel efficient procedures in flight."

OpenAirlines

OpenAirlines has developed an application called SkyBreathe, and works by identifying operational techniques to achieve the easiest and biggest fuel savings. The application is used by more than 15 airlines, including Atlas Air, Polar Air, Icelandair, Transavia, Royal Air Maroc, Enter Air and Onurair.

"Among the main operational techniques that SkyBreathe identifies are: reduced acceleration and climb rate, idle reverse thrust at landing, and engine out during taxi-in after landing," says Alexandre Feray, chief executive officer at OpenAirlines. "Transavia has found this from its use of our application, and the airline has been using it since 2010. The system identifies where the most progress in reducing fuel burn can be made, by analysing the fuel-saving techniques prescribed by IATA. An example is the use of idle reverser thrust at landing. The FMS/FMC calculates the aircraft's stopping distance at landing. The use of carbon brakes on most aircraft types means there is little difference in the stopping distance between the use of reverse thrust and idle thrust. Before using SkyBreathe in 2010, only 44% of pilots at Transavia used idle reverse thrust. By 2012 the use of idle reverse thrust had more than doubled to 93%. This practice alone saves the airline about $15,000 per year and per aircraft for its fleet of 34 737-700/-800s."

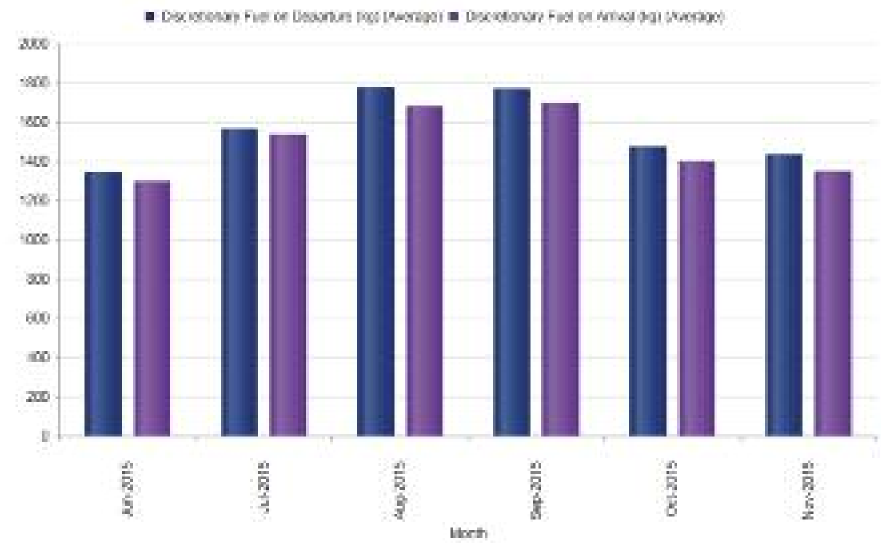
SkyBreathe analyses flight data records, so it can determined which crews applied the best practices, and if the practices could have been followed when they were not. The system then computes what the saving would have been if the practice had been used, and what the saving was when the practice was used.

"IATA's fuel-saving practices identify 30-40 operating techniques, and are a good reference for airlines," says Feray. "Saving fuel not only involves pilots, but also flight operations, dispatch, maintenance, and ground operations. Maintenance plays a role in terms of keeping the aircraft clean and using techniques, such as engine wash, to maintain engine performance. Ground operations is responsible for ensuring that a GPU is used instead of the aircraft's APU. Besides engine-out during taxi, the other main techniques identified are optimising the flight profile and using alternate flap settings."

Feray makes the point that in the case of dispatchers, the process of flight planning starts three hours prior to departure. Dispatchers have to make estimates of weights and use company strategies for contingencies. This can be the international standard of 5%, but an airline's regulatory authority will approve a lower ratio if the airline can provide post-flight statistics to demonstrate that there is no risk. "Flight planning requires human knowledge of items, such as the taxi time at each airport at different seasons and days of the week, so the dispatch process cannot be left entirely to the flight-planning system.

"The flight operations department uses a high degree of automation, but there are still many pilot decisions that affect fuel burn," continues Feray. "For example, an engine cannot be shut down immediately after landing for engine-out taxi in (EOTI), because it is too hot, and the engine has to idle for three minutes to cool before it can be shut down. The engine also has to run for two minutes before take-off, which has to be taken into consideration when calculating possible fuel burn savings from engine-out when taxiing out."

There is also the use of lower flap



An example of identifying a fuel saving technique is an analysis of the quantity of discretionary fuel at departure and at arrival. Having a large amount of arrival will indicate that excessive weight is frequently carried, leading to higher than necessary fuel burn.

settings. Aircraft configuration with respect to flap settings, speed, engine power setting and flight profiles are calculated using the FMS/FMS for both take-off and landing. "Calculating the use of lower flap settings for take-off and landing is, therefore, safe in the absence of obstacles," says Feray. "Clearly a lower flap setting will affect the aircraft's climb profile and rate of airspeed acceleration, and these two factors will affect the aircraft's fuel consumption. The standard departure procedure has to be taken into account. Some airports allow acceleration to altitudes of just 800 feet, rather than 3,000 feet. The aircraft will thus be using take-off configuration (engine power and flaps) for a shorter period of time, and so this will save fuel burn as the aircraft achieves a lower drag profile quicker.

"Another main technique for saving fuel is the use of CDA, which is used from the top of descent to the landing approach, so that there are no steps during the descent, each of which requires an increase in engine power to maintain an altitude, and so increases fuel burn rate," adds Feray. "Saving per landing can be about 30Kg (10USG) for a narrowbody and much more for a widebody. Contrary to standard belief, CDA does not just depend on ATC but also on company culture. By benchmarking two of its customers on a voluntary basis, OpenAirlines found that at the same airport, using the same arrival procedure and operating the same aircraft type, one airline could use the technique of CDA 80% of the time, while the other only achieved it in 10% of operations."

Rolls-Royce

Rolls-Royce includes EHM and AHM as part of a portfolio of support products. This also includes analysis of airframe and engine data from the QAR to identify operational techniques to achieve long-term savings. "Common techniques include: CDA; engine-out taxi; weight optimisation; optimising flight profiles in-flight with respect to winds, lateral routes, altitudes and speeds; reduced flap and climb performance; several weight-saving initiatives; and the amount of discretionary fuel, holding fuel, and contingency fuel used," says Wayne Beardsley, fuel management solution consultant at Rolls-Royce. "The problem is that flight-planning systems do not know what actually happens during the flight, so the plan is based on a lot of assumptions. Some fuel saving applications are based on real-time and in-flight support to achieve optimisation.

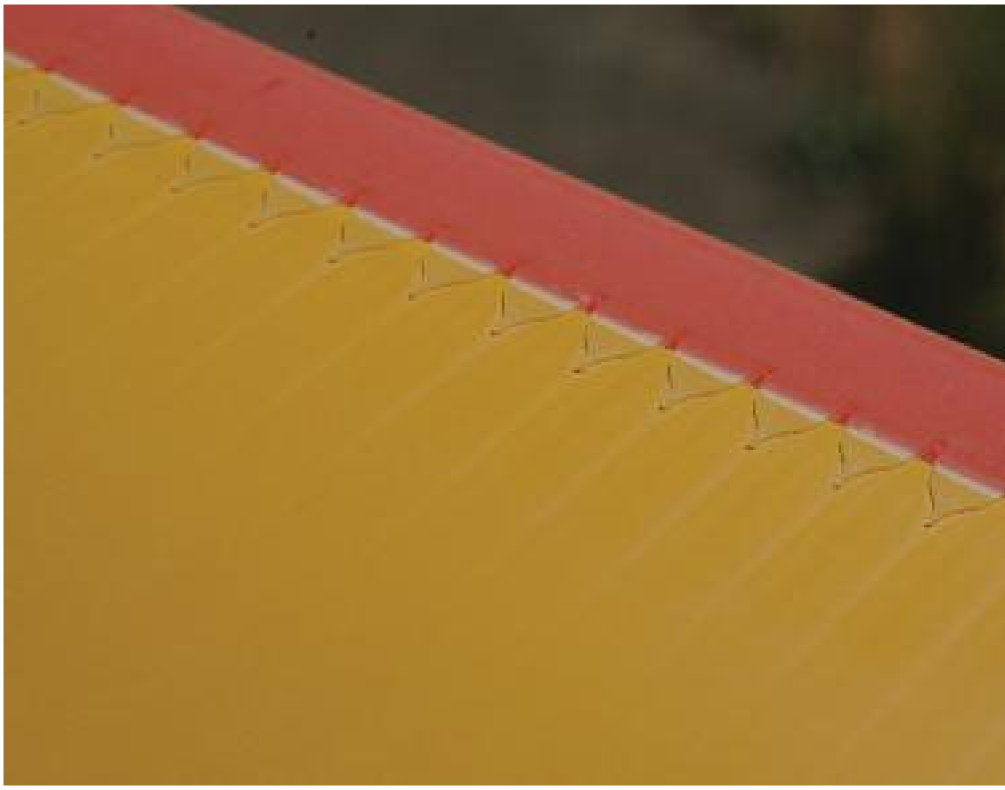
"The Rolls-Royce system is based on post-flight analysis of QAR and operational data, and it analyses the differences between planned and actual fuel burn, and finds areas to achieve long-term savings," continues Beardsley. "The system also monitors how much these fuel saving practices and techniques are being followed by the pilots and other staff. To achieve a significant saving in fuel consumption over the long term, a lot of process behaviour change is required from pilots, flight planners and dispatchers, and airline scheduling departments. The focus is on the efficiency of an airline's overall operation. An airline's other costs and factors, therefore, have to be taken into account. It is sometimes better to go faster and burn slightly more fuel to save other time-related costs, such as maintenance, and avoid expensive delays and late arrivals."

An example of a cost-saving technique is the use of engine power de-rate during climb. "This results in a lower climb rate and so slightly longer time to the same altitude, which may consume a little more fuel in the climb phase but results in a shorter cruise phase and burn. Rolls-Royce has the experience to recommend the best practice to preserve engine maintenance condition, prolong engine on-wing and save engine maintenance costs," explains Beardsley. "If this is sustained over a long-term then the power-by-the-hour rate paid for engine maintenance may be reduced. This cost saving needs to be considered against the increase in fuel consumption, and the overall saving will depend on fuel prices."

An airline and fuel-saving application vendor has to be aware of initiatives that have already been launched, and so more effectively identify opportunities to realise more savings. The post-flight analysis of QAR data will provide the detail needed to identify these opportunities. Rolls-Royce's focus is to have a partnership with airlines, and aims to cooperate with all departments to maximise savings.

"The Rolls-Royce system requires a minimum of 50 parameters to make the required analysis, although the more parameters, the more detailed the analysis," says Beardsley. "There are also several other data sources, including the flight-planning system, engineering departments, flight-tracking systems, Wx information, and loadsheets. Our first task is to integrate all the data and information. Examples of the parameters we follow are flight number, departure and arrival times, actual route, altitude, and speeds flown. All the data are split into the different flight phases and segments. This means that hundreds of parameters can be followed and processed, including loadsheet information on potable water and catering loaded. Simple calculations can be performed so that planned and actual times, performance and other factors can be compared. Examples are the time taken for taxi, time used in holding, and other critical points in the flight.

"Airlines want to track the percentage of flights that use the engine-out taxi and other techniques. Ultimately they want to present the information on certain dashboards that apply to each user group. There are many comparisons that can be made," says Beardsley. "An example is a chart that is generated to show the amount of discretionary fuel that is loaded on the flight at departure, and the amount remaining on arrival. The difference indicates how much discretionary fuel was unused, and, therefore, loaded unnecessarily. This is clearly shown by two different coloured bars on the chart for each flight, giving



The Conformal Vortex Generator (CVG) has been developed by Edge Aerodynamix. It is an inexpensive modification that is an elastomeric, adhesive-backed film applied to the upper surface of the wing. This reduces the boundary layer thickness, and improves airflow over the wing. This has been shown to generate an initial fuel burn reduction during the cruise phase by 4-6%.

the user a visual cue on utilisation."

A line may or may not be superimposed over the chart to indicate the difference between planned and actual flight time. This indicates if the flights were late or early, which may explain why discretionary fuel was or was not used. Ultimately, the chart is intended to show if the discretionary fuel was actually required.

"While the system can illustrate the savings made from initiatives that have been put in place, it can also highlight practices that are not yet being used and the possible savings these would generate," says Beardsley. "There are enough data to calculate what fuel would be saved using each of these initiatives."

The Rolls-Royce system has an overall dashboard that illustrates all the initiatives that the airline user has introduced. The dashboard tracks achieved versus targeted savings.

Drag reduction systems

Among the various applications available, US R&D company Edge Aerodynamix has developed an aerodynamic modification, which is the first Conformal Vortex Generator (CVG). This will achieve a reduction in viscous and profile drag. It has been demonstrated in testing that this system can achieve fuel burn savings of at least 5% in cruise conditions, with the initial application applied to part of the wing. The system is based on mitigating the problem of disturbances to the airflow over a surface.

"One of the main problems apparent in the boundary layer is the lack of smoothness. This is due to lines of rivets, gaps between the wing skin, spoilers, and the flap sections," says Sander de Moor, fuel efficiency manager at Etihad Airways. "This lack of smoothness spoils and interrupts the laminar flow of air close to the wing surface."

"An additional problem is that even when a wing has a smooth surface all the way from the leading to the trailing edge, there is a shockwave that develops about two-thirds of the way down the chord of the wing," continues de Moor. "This is caused by the air that has accelerated to a supersonic speed over the first part of the chord, then decelerates to less than a supersonic speed. This shockwave occurs above certain speeds, and depends on the wing's design. The shockwave induces drag. The position of the shockwave down the chord is brought forward by the wing surface-spoiler gap on the top surface of the wing. It is actually visible from the aircraft's windows during the cruise phase. It occurs at speeds of about Mach 0.70 and above for thick wings.

"Aircraft manufacturers have tried to solve this problem by placing rows of vertical vortex generators on the wing's top surface. These were intended to improve the boundary layer flow, but these devices in fact created more drag, and so increased fuel burn," adds DeMoor.

Edge Aerodynamix has introduced CVG, which is a simple and inexpensive modification that implements flow control device to reduce in drag from the slat step condition. CVG is a length of elastomeric, adhesive-backed film applied to the upper surface of the wing behind the slat. The pattern of the film reduces the boundary layer thickness and so improves the flow over the wing surface. The film is placed aft of the wing surface-slat step near the leading edge of the wing (additional layers may be placed at the wing surface-spoiler gap, which is just aft of the top surface of the spoilers in later versions). Applying the film is a quick and simple process. The wing surface needs to be cleaned before installation and only 4 man-hours are needed to equip each 737.

"The main benefits are improvements in aircraft performance, but there is also less buffeting during landing when using full flap because there is improved airflow over each of the flap sections," explains de Moor. "The main benefit overall is that the 737 Classic series, on which the film was first tested, had a 6.1% reduction in fuel burn in the cruise phase when operating at Mach 0.78. The benefit is smaller at a lower speed."

A single strip of film at the leading edge of the wing on the test 737 Classic aircraft generated an improvement of 4-6%, dependent on operating Mach number cruise speed. This product is due to receive its STC in the first quarter of 2016, and will be commercially available early in the second quarter.

Edge Aerodynamix provides the tape free of charge to airlines. In return, Edge Aerodynamix requires the airline to repay a percentage of its established savings. The savings will be based on customer equipment back-to-back comparison testing. The test takes two flights of approximately one hour each, with an hour in between to configure the aircraft. This test gives the customer exact figures in a controlled manner. Upgraded designs will be offered to existing users preferentially as certified, but are globally offered on production availability.

The next project for Edge Aerodynamix is to extend the STC to include the A320, 757, 767 and 777 families of aircraft. The 747 designs are slightly different, but are also of great interest to Edge Aerodynamix, since testing on high-speed test aircraft will provide useful data that can be incorporated in that aircraft's design. AC