100 Ways to Reduce Fuel Burn
A guide for BAE Systems Regional Aircraft Operators
100 Ways to Reduce Fuel Burn - Preface

This publication is intended for Operators of the Avro RJ, BAe 146, ATP, Jetstream 31/32 and 41 series of aircraft to help manage fuel burn cost. Reducing fuel burn should be of significant interest due to fuel prices increasing to unprecedented levels and the introduction of new government legislations around the world, additionally a reduction in fuel burn will reduce the emissions into the environment. The guidance set out does not address any other aspect of the total cost of the operation of these aircraft.

This publication has been written recognising that we have both large and small fleet Operators, and both experienced and new Operators to the types.

This publication has been compiled to advise ways in which fuel burn can be minimised throughout the entire operation of the aircraft. As such this will necessitate a committed team ranging across all disciplines; from flight planners to pilots to ground engineers. Accordingly, the aim of this document is to draw the Operators’ attention to areas where fuel conscious operating procedures or maintenance may bring fuel savings.

These suggestions do not override the limitations and procedures in the Flight, Operations, Maintenance and Repair manuals.

With fuel burn contributing 27% of the Direct Operating Cost (DOC) of an aircraft the main potential benefits of considered fuel management are a reduction in this operational cost and the mitigation of any negative effects upon the environment.

Although many of the suggestions contained within this guide may already be practiced, we suggest that each Operator considers these individually to determine if they can offer further benefits.

Equally, any suggestions from Operators would be very welcome for any future updates of this brochure.

“Large savings can result from the accumulation of many smaller fuel saving actions and policies.”

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1 International Civil Aviation Organisation (Global Average), (2001).
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Visit www.enviro.aero for everything you need to know about aviation and the environment.
Introduction

With the uncertainty associated with fuel costs, the introduction of new government policies on emissions around the world and the ever-increasing value of public image in the modern marketplace it is of more importance now, than ever, that we do all we can to reduce the quantity of fuel we burn.

There is now general acceptance worldwide that global warming is a reality and action needs to be taken to prevent permanent damage to the environment. The aviation industry seems to have been tarred by a somewhat unfair image in this regard, actually only contributing in the region of 2% to the worldwide CO₂ emissions. Although small, action must be taken. From this it is clear to see not only the economic significance of reducing fuel burn but also in combating this negative consumer image.

In June 2009 the International Air Transport Association (IATA) laid out its environmental vision to mitigate greenhouse gas emissions from aviation. These are:

- A cap on aviation CO₂ emissions from 2020 (carbon-neutral growth).
- An average improvement in fuel efficiency of 1.5% per year from 2009 to 2020.
- A reduction in CO₂ emissions of 50% by 2050, relative to 2005 levels.

These have been endorsed by the aviation community through the joint industry submission to the International Civil Aviation Organisation (ICAO) in September 2009. These collective targets serve as a pioneering example to be followed - no other industry has made such commitments on a global scale.

Environmental responsibility is nothing new to the aviation industry. Well before the Kyoto Protocol the industry was working hard to reduce emissions. Over the past forty years our industry has improved fuel efficiency by 70% - with a 16% reduction between 2001 and 2008. It is forecast that such progress will continue into the future, but this cannot happen without hard work and focus across the entire aviation sector.

With this in mind, BAE Systems have compiled this publication to advise ways in which you, the Airlines, can reduce fuel burn throughout the entire operation of the aircraft. Not only reducing the operating costs but also supporting our ongoing commitment in reducing global CO₂ emissions.

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“We all know the 100 ways to save fuel”

Do we really?

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This publication lists these 100 ways to save fuel in a logical order. Starting with
the pre-flight planning and preparation, through the entirety of the flight and ending
with the post-flight operations and maintenance.

Firstly however, there are various parameters which fall outside of these categories
and must be addressed at the outset.

**General thoughts**

**You can’t control what you can’t measure:**

1. **Track weight, fuel use and efficiency over time**

   In order to understand and verify the benefits of any fuel saving measures one must
   have a reliable means of recording fuel consumption in place. This should be unique
to each aircraft as there is no such thing as an identical pair. This would allow
simple trend-lines to be plotted and any discrepancies identified for further
investigation.

2. **Use of statistical contingency fuel**

   By tracking the fuel use and efficiency an Airline will be able to satisfy the authorities’
requirements enabling the use of statistical contingency fuel. This means loading the
correct amount of fuel on an aircraft by aircraft basis specific to a certain route.
Using the statistics provided through flight measurements one will be able to reduce
the weight of contingency fuel carried in accordance with paragraph (iv) see below. It
has been employed by a number of Airlines, resulting in significant fuel savings. It
has been stated to be worth over $10 million to British Airways5.

3. **Measure success against set targets**

   Simply put, you cannot go somewhere if you do not know where you want to go. The
power of goals is that they direct focus. Setting a long-term target with a series of
readily achievable intermediary goals will drive the required change.

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5 Workshop on Aviation Operational Measures for Fuel and Emissions Reductions, Air Carrier Efficiencies, British Airways, (21/09/06).
Teamwork:

It takes an entire team to succeed

It is of the upmost importance to recognise the conservative, safety orientated culture which exists and to build upon this through the use of accurate validated data, recurrent training and further education. Regular feedback to your employees showing trends and highlighting successes and failures will serve to greatly substantiate any operational changes. A necessity exists to establish a culture of efficient operations and to drive for trust, cohesion and transparency. This should not be limited to pilots and any changes should not merely be enforced from upper management. Working from the bottom-up across all disciplines is essential.

Utilise the experience and knowledge within

Ask staff for their ideas on the best ways to save fuel - you may be surprised! Consider setting up a dedicated committee, maintaining two-way communication and adopting an open door policy. Encourage and reward the ideas and initiative shown by staff - programmes driven by staff are more likely to succeed. Who knows better about unnecessary galley items than your Flight Attendants?

Standard Operating Procedures:

Publish clear and concise procedures

Any changes to SOPs must be communicated in an effective manner. These should be established for all phases of aircraft operation from ground crews to pilots giving clear instruction and reasoning where appropriate.

As with all other aspects of reducing the fuel burn of your fleet, the standard operating procedures must be open to suggestions and adaptation. Furthermore, it is essential that any revisions are implemented in a gradual manner to ease integration with established procedures and that every report or suggestion from crews is responded to and feedback provided.
Pre-flight

The initial, and arguably most important, aspect of aircraft operation is the pre-flight stage. This consists of route-planning, airframe preparation and loading. Careful consideration of all possibilities at this stage could facilitate significant fuel burn reductions.

Flight plan of route: The first stage of pre-flight planning is to assess the routes, distances and airways available. Every effort should be made to take the shortest route possible, although this may be counteracted by airways costs.

7

Make sure you have the latest software and data

When planning a flight it is essential that the most up to date versions of any software and data are available, thus facilitating the generation of the most effective, valid route. For example one must have the latest airways data in order to capitalise on (and observe) the most up to date airways.

8

Invest in flight plan optimisation software

Flight planning route assessment can be achieved with the aid of computerised flight planning software or through other service providers. Additionally the adverse effect of last minute ATC route restrictions may be mitigated by the judicious use of computer aided flight planning. An example of such savings can be found with Air Transat who adopted the flight optimisation software of Flugwerkzeuge (f:wz); saving 0.76% fuel in 2004. Further to this, the development of an in-house solution taking into account all costs, such as crew wages and overflight charges etc. can be developed. According to IATA, “Cost Index optimisation of planned speeds will yield savings from 2 to 3% and in some cases as much as 10% when a flight is restricted to a low altitude or in unusually strong winds.”

9

Use the latest, best possible, most accurate data

Ideally, these route plans should then be optimised for the conditions of the day, taking into account the actual planned take-off mass, last-minute winds, temperature, icing conditions and turbulence. Ideally, plans should be done by tail number - some aircraft are better than others.
10 Stored flight plan review

In the cruise the single greatest influence on fuel, distance and time will be routing. This should be optimised at the flight planning stage. Where possible every stored (repetitive) flight plan should be held in archive and these should be evaluated the day before the flight. This would seek to determine the most optimal route adhering to the rules of the governing body (e.g. EUROCONTROL). This will be based on the latest airways, military airspace, and predicted winds and weather. These are based on non-direct legs and requests for the most direct routing should be made in-flight by the pilot (item 48).

Future development may see more direct or free routing incorporated at the flight planning stage; this will facilitate maximum fuel savings achievable by routings.

11 Request to take-off and land on the most convenient runways

If the option is available, seek to land off straight in approaches and take-off with minimum taxi time heading in the direction of flight. An example would be an Airline coming from the South always seeking to land on runway 31 at Prestwick, and on departure to the South, take-off on runway 13. Clearly this may not be possible due to wind direction and/or other traffic. If this is frequently unavailable, a pilot may eat into the contingency fuel and will be likely to uplift extra fuel. A survey of pilots should be considered; this would allow statistical determination of where you are likely or less likely to be granted use of preferred runways, allowing for a more appropriate loading of fuel on certain routes.

12 Consider the best cruising speed for optimum SAR

Specific Air Range (SAR) in nautical miles per kilogram of fuel is given as curves in the Cruise Control chapters of the 146/RJ FCOM Volume 2, Chapter 4, Topic 4, and could be provided for the Jetstreams and ATP. To obtain the maximum range or best fuel economy you would cruise at the speed for maximum specific air range. A typical plot of these curves is shown opposite; this can be used to determine the speed for optimum SAR. While this theoretically is the peak value of each weight, altitude and temperature curve; the industry standard is to seek the speed which gives 99% of the peak SAR on the fast side. At a given altitude and temperature, a line can be drawn on the curves as shown to give the optimum speed schedule for decreasing weight.

From the SAR curve the Long Range Cruise (LRC), Intermediate Cruise (IC) and the High Speed Cruise (HSC) speeds can be compared with the speed for best SAR.

Remember that it should not be assumed that either LRC or IC will equate to best SAR - this will depend on actual weight and altitude. For example, in the plot shown opposite, it is clear that an Intermediate Cruise speed of 250 knots would be appropriate for a weight of 42,000kg, whereas the Long Range Cruise speed would be appropriate for 36,000kg. However, to reduce speed below the LRC speed might be too slow from the flight time perspective. Therefore, the Intelligent Fuel Calculator (IFC) follows the 99% optimum SAR line down to LRC speed which we then maintain as the weight continues to decrease.

Additionally, when planning flights at high weights above FL310, one must pay careful attention to the Buffet Boundary lines that are added to the graphs.

It is clear that many Operators’ schedules have not planned for this and thus constant Mach cruise is commonplace - slowing down to optimum SAR speed whenever ahead of schedule should be as standard and adapting future revisions to timetabling to incorporate optimal SAR speed cruise could be considered alongside other operational factors such as number of legs, flight crew hours etc.

Above: a typical curves plot for determining the speed for optimum SAR.
Flight level optimisation

The best flight level where the aircraft performs most efficiently must now be decided. As a basic rule, the aircraft should cruise as high as possible. The maximum and typical flight levels of the aircraft can be observed in the table below. The flight levels shown are governed by the Mod status of the aircraft, Reduced Vertical Separation Minima (RVSM) airspace, and top of climb capability - particularly on hot days.

<table>
<thead>
<tr>
<th>Type</th>
<th>Maximum FL</th>
<th>Commonly Flown FL</th>
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<tr>
<td>146</td>
<td>280, 300, 310</td>
<td>260/270</td>
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<tr>
<td>RJ</td>
<td>310, 330, 350</td>
<td>310/320</td>
</tr>
<tr>
<td>ATP</td>
<td>250</td>
<td>160/170</td>
</tr>
<tr>
<td>J31/J32</td>
<td>250</td>
<td>160/170 (in Europe)</td>
</tr>
<tr>
<td>J41</td>
<td>250</td>
<td>160/170 (in USA)</td>
</tr>
</tbody>
</table>

Where most 146 aircraft are restricted from entry into RVSM airspace, the RJ should seek to fly in this airspace. One Operator has reported a 300 - 400kg of fuel savings through utilisation of RVSM flying on their two hour sectors.

It has been observed over the years that the European turboprop Operators are much more likely to seek to cruise at higher flight levels than their US counterparts for whatever reason. Indeed some pilots might as well have been flying an unpressurised Beech 18!

Use ‘Wind Effects Tables’

This flight level may have to be modified to take advantage of favourable winds at higher or lower levels. This can be done through the use of the Wind Effects Tables (WETs) generated by BAE Systems. These Wind Effects Tables allow a comparison to be made between fuel burn and time for a given wind speed over various cruising altitudes.

These tables pre-suppose that the aircraft should cruise as high as possible. However, the tables show the benefits in fuel burn of flying at lower flight levels where winds might be less penalising. The tables can be used to assess such penalising headwinds and capitalise on beneficial tailwinds. Tables are presently available for the 146/RJ.

Avoid unnecessary manoeuvres

Pilots anecdotally have been observed flying their regional aircraft too aggressively. This results in increased fuel burn in addition to faster system degradation and maintenance issues. For example, an Airline suffering from larger than expected fuel burn found that pilots were performing overly tight turns on departure as opposed to those required. Smooth operation is always recommended and wherever a doubt exists or an opportunity is found, established patterns should be challenged.
**Fuel Reserves**

The standard requirement for fuel policy is provided in EU-OPS 1.255 for EASA Operators and FAR 121.639-645 for FAR Operators. The EU-OPS fuel policy is reprinted opposite and is represented by the diagram below. Note that EU-OPS 1.255 only provides a basic requirement on fuel policy. For additional information, Appendix 1 of EU-OPS 1.255 should be considered.

To reduce fuel burn, Operators must seek to minimise non-essential fuel. In order to do this each Pilot Log must be accurate and fuel planning should be made by tail number - don’t use the worst aircraft in the fleet to determine the load for all.

(A) **Taxy fuel**: This takes into account the local conditions at the departure aerodrome and APU consumption. This is an area where a large overload can occur frequently, consider basing this value on statistics as a number of Operators have, yielding significant savings.

(B) **Trip Fuel**: The fuel which is required to reach the destination.

(C) **Reserve fuel**: An appropriate amount of reserve fuel must be carried so as to ensure a safe flight. Extra reserves are extra weight which means unnecessary fuel burn. The amount required depends on the regulatory requirements, the choice of airport, company policies, discretionary fuel etc.

(C) 1. **Contingency fuel**: This is generally a function of trip fuel and is normally 5%. It is intended to cover errors in navigation, weather predictions or other unforeseen circumstances. One method of reducing this is through the use of Re-dispatch which will be discussed in (item 18) of the guide. Another means of reducing this is through the use of Statistical Contingency Fuel as described in item 2 of the guide.

(D) **Alternate fuel**: At the planning stage of the flight the Operator should decide on the diversion alternate airport and the fuel required diverting from the destination airport. It should be noted that the fuel amount required on the day may change due to winds and other weather factors.

(E) **Extra fuel**: Also known as ‘Discretionary’ fuel. If an Operator routinely includes a small amount of extra fuel in its fuel policy - this should be reviewed.

**EU-OPS 1.255 – Fuel Policy**

(i) For A to A Flights - An operator shall specify the minimum fuel contents at which a flight must end. This minimum, final reserve, fuel must not be less than the amount needed to fly for a period of 45 minutes.

(ii) For A to B Flights - An operator shall ensure that the pre-flight calculation of usable fuel required for a flight includes:

(A) Taxy fuel - Fuel consumed before take-off, if significant; and

(B) Trip fuel - Fuel to reach the destination; and

(C) Reserve fuel -
   1. Contingency fuel - Fuel that is not less than 5% of the planned trip fuel or, in the event of in-flight re-planning, 5% of the trip fuel for the remainder of the flight; and
   2. Final reserve fuel - Fuel to fly for an additional period of 45 minutes (piston engines) or 30 minutes (turbine engines); and

(D) Alternate fuel - Fuel to reach the destination alternate via the destination, if a destination alternate is required; and

(E) Extra fuel - Fuel that the commander may require in addition to that required under subparagraphs (A) - (D) above.

Fuel policy is a crucial area at the pre-flight planning stage and should be carefully investigated by Airlines on a regular basis. If extra care is taken and aircraft consistently land with the predicted fuel on board pilots will have faith in dispatch and be less inclined to load additional fuel. We must start to load the ‘right amount of fuel’ for each sector and nothing in any policy should limit the Commander from uplifting as much fuel as is required.
17 Make a considered choice of alternate airports

Operators may wish to reconsider their choice of alternate airport for certain routes. There are numerous factors which must be considered; if it is too close it may suffer from the same weather or other problems as the destination aerodrome, however being too far away will incur fuel and time penalties.

An example of the type of saving possible can be found in recent work by the Oxford Aviation Academy. In recent simulator “flying” of the Airbus A320 on two identical short sectors between Gothenburg (GOT) and Copenhagen (CPH), changing the alternate from Gothenburg to Malmö allowed the aircraft to carry 450kg less fuel.

18 Use an en-route alternate and re-dispatch?

As previously highlighted, one method of reducing Contingency fuel is by the use of Re-dispatch (Re-planning). This will involve the selection of one or two suitable en-route alternate airfields. As each of these points is reached, the remaining fuel would be reassessed against that required to complete the flight with final reserve and alternate fuel.

Using this technique the contingency fuel at departure could be loaded as 5% of the distance from the last en-route alternate to destination rather than 5% of the entire sector distance (EU-OPS 1.255 Para (C) 1, as shown opposite.)

This technique might allow a reduction in departure fuel of 100 to 250 kg. For particularly long flights where passengers might be offloaded to carry the fuel required, this might allow one or two more passengers to be carried. The use of Re-dispatch (Re-planning) can be an effective method of reducing fuel load, but it normally must only be used for Public Transport flights with the approval of the National Authority.

Below: the use of Re-dispatch.

19 Discretionary fuel

In reducing the all up weight of our aircraft, one of the most powerful measures which can be employed is to minimise the landing fuel weight. In order to achieve this, Airlines must seek to demonstrate accuracy of their flight plans and consequently win over the confidence and support of their pilots. This could be done through the measurement of landing fuel and demonstration of verifying data as described in (item 1) of this guide. Once again raising awareness and continued education are crucial.

Another consideration would be to seek explanation whenever a pilot requests discretionary fuel. As always there should be a no blame culture and nothing in the procedures which limits fuel uplift or compromises safety.
Think about tankering

Fuel tankering is the practice of carrying more fuel than required for a particular sector in order to reduce the quantity of fuel uplifted at the destination airport for the return or next sector. The Operator should assess the advantages of tankering and decide if it will be beneficial to their route. All things being equal, fuel should not be tankered, as carrying the extra weight will result in additional fuel burn, and revenue payload should not be sacrificed to tanker fuel. The main reasons to tanker fuel are:

- No, or limited amount of, fuel available at destination.
- Fuel price differential.
- Shorter turnaround time.
- Unreliable airport service.
- Fuel quality at destination airport.

Fuel savings can be realised through careful planning to minimise tankering. It is important to balance the potential economic advantage of fuel tankering against the disadvantages. When tankering, it is important to consider:

- The increased take-off mass may limit climb performance, and the final cruise flight level to less than the optimum altitude.
- The higher mass will have an adverse effect on brake and tyre wear whilst taxiing, and higher than normal thrust settings may be required to meet ATC climb requirements.
- Revenue payload loss.
- In the event of tailwinds or ATC direct routings, the aircraft mass at the arrival destination may be in excess of the maximum or regulated landing mass. In this case excess fuel may have to be burned off prior to landing.

Do not round up

It should become company policy not to round up until the last stage of any calculations. The compounded effect of rounding at every intermediary stage can result in inaccurate numbers and carrying unnecessary fuel.

Managing non-revenue flying

Limiting the amount of non-revenue flying to the absolute minimum should be attempted – whether training, ferry, positioning, verification, testing, development or any other type of non-revenue flying.

Operators should seek to do everything possible when on the ground, construct logical test schedules (can various tasks be combined?) and try to couple it with some form or other of revenue flying where possible. An example of this would be an Airline flying positioning flights with freight onboard.
Preparation of Airframe: The second stage of pre-flight planning is the preparation of the airframe, ensuring non-essential weight is minimised and the aircraft is configured to the best possible standard to perform its mission.

Reduce operational empty weight

An increase of weight on the aircraft will increase the lift and thrust required for operation, increasing the drag and fuel flow, thus the fuel burn. This effect can be approximated as follows:

\[
\text{Additional Fuel Flow} \approx 5\% \times \text{Additional Weight} \times \text{Hours Flown}
\]

For example; 100kg of additional weight would result in around 5kg of additional fuel flow per flight hour. Therefore it is important that any excess weight on the aircraft is closely monitored so as to avoid any unnecessary increase in fuel burn. Some examples of sources of excess weight are excess fuel and build-ups of old paint which are discussed elsewhere.

An area of particular interest in recent years is the reduction of the operational empty weight of the aircraft. There are innumerable measures to be explored and the ongoing theme of this publication is of particular relevance here: large savings can be realised through the accumulation of numerous smaller savings. Some areas which can be investigated in order to reduce the OEW are:

- Unnecessary commissary stores such as in-flight magazines, blankets, pillows, catering packs etc. (It is suggested that regular reviews of catering and cabin services requirements for particular sectors are carried out.)
- Redundant galleys, catering trolleys or in-flight entertainment.
- Unnecessary safety equipment, tools and strappage.
- Are you landing with a large amount of potable water remaining?
- Fully remove aircraft modifications when not in use.
- Lighter weight tyres, carpets, seats, fire extinguishers, etc.
- Make use of summer vs. winter passenger weights.

Regular re-weighing should be performed and well documented. You will be amazed at the large savings which can be achieved through the careful consideration of every detail. Finally, ask your employees and be innovative: it all adds up!

As a practical example of the above, BAE Systems were engaged in a fleet re-weighing exercise on BAe 146s. The preparation of the aircraft saw a pallet filled with over 200kg of paper. Investigation revealed the current month’s feeder Airline magazine, the current month’s major Airline magazine, the last month’s magazines in the seat-back pockets, bundles of spare magazines in overhead bins, and an excessive number of aircraft manuals carried in the cockpit.

Reduce weight without compromising on passenger comfort or safety

Instrument calibration

It is essential to maintain accurate instrument calibration. For example; flying just 5 knots below the 99% SAR speed can increase fuel burn by 1\%\(^{10}\).

\(^{10}\) For an Avro RJ85, cruising at FL 290 at a weight of 32,000kg.
25 Ensure correct rigging of particular items

Close attention to the alignment of doors, access panels and fairings is required to ensure that into and out of wind steps and gaps are minimised. The important areas to check are:
- Nose and main landing gear doors.
- All external doors.
- Wing-to-fuselage fairings and seals.
- Flight control surfaces.
- Flaps, flap track shutters and flap tab hinge cover fairings.
- Engine intake and nacelle fit.
- Edge sealant.

Correct rigging of the aircraft flaps and flight controls, including the roll and lift spoilers and airbrake will minimise drag. The rigging of the lift and roll spoilers should be regularly checked to ensure that they stow correctly during flight and the roll spoilers do not initiate early. If the surfaces are not correctly rigged or the trailing edge seals are not correctly adjusted it can result in vibration and additional drag. Lifting of the roll spoilers during flight may require an aileron input in order to trim the aircraft, again increasing drag. With the autopilot engaged the flight control trim inputs should be monitored.

Such considerations should be made of the Jetstreams and ATP where appropriate.

26 Configuration Deviation List

The Configuration Deviation List in the Aircraft Flight Manual contains a list of engine or airframe items which may be allowed to be missing prior to flight. Whilst operations with items removed (within the AFM limitations) may well be permitted, performance and fuel burn may be adversely affected. For example, a missing aileron hinge cover on a 146/RJ could result in an increase of 4,000kg or more in fuel burn per aircraft per year. The period of operation without these external items should therefore be minimised.

27 Loading:

The final stage of pre-flight planning is the loading of the aircraft. A little bit of thought and care here can result in reduced fuel burn and a reduction of unnecessary maintenance of the airframe.

Quick and efficient loading and preparation

It is important that SOPs and schedules are followed and allow for a smooth and logical preparation and dispatch of the aircraft. One must seek to minimise any unnecessary time on the ground; this is fuel burned for no air miles when sitting powered up.

Key to achieving such a schedule is the careful planning of all the aircraft in the fleet and co-ordination of different departments’ activities.

Maximising the load factor

A further extension to this scheduling optimisation would be flight distribution to maximise the passenger load factor on every flight. Usually defined as passenger-kilometres flown as a percentage of seat-kilometres available; it is clear to see the economic significance of this.

Another means of achieving this is to fill the aircraft with freight where available or to change the aircraft type put on certain routes.
**Weight and balance**

When loading the aircraft make sure to do it in an even manner. Maintaining control over the aircraft’s centre of gravity will have the effect of reducing the trim drag and hence fuel burned. For a conventional aircraft, an aft CG position will produce less drag as described below:

As a result of the smaller moment arm between Lift\(_{wing}\) and Weight\(_{aft\,CG}\), less trim drag will be produced. This is due to a reduction in the aerodynamic downforce required by the horizontal tail necessary to achieve longitudinal trim. There are obviously limits to the fore and aft loading of an airplane to retain a minimum stability in flight and these must be adhered to. Depending on the aircraft type, drag created by loading an aircraft to the maximum forward Centre of Gravity can increase drag by up to 3% compared to loading the aircraft to the most rearward CG where drag can be reduced by approximately 1.5% of nominal drag\(^7\). Therefore properly managing the CG can have a significant effect on fuel efficiency.

It should also be noted that considered, well managed loading procedures will serve the further benefit of reduced maintenance due to impacts of luggage etc. with the doors and fuselage.

**Quality of fuel**

The final item to be considered at the pre-flight stage of operation is to ensure the fuel being loaded is of the necessary and documented quality. The Airline should seek to have a policy in place to frequently check the standard of the uplifted fuel at various locations. This should cover aspects such as:

- Volume.
- Temperature correction and evaporation losses.
- Contamination.
- Octane rating.
- Water content.

Regular audits of the fuel records, meter calibrations and tolerance quality measurements should be carried out.

An important issue to highlight is that of accumulation of water in the fuel tanks; this can cause flow restrictions due to ice build up in-flight as well as corrosion. For the 146/RJ the Maintenance Review Board Report calls for the fuel tank water drains to be checked every 50 flights, however, this is supported by a note to highlight the requirement that this frequency must be adjusted to meet local fuel storage and supply conditions as necessary.

One Operator has reported a loss of around two tonnes of fuel per week across their fleet in draining the tanks of water. This serves to highlight the importance of carefully following the correct procedures. These can be found in the AMM - Chapter 12-10-28.CAA publication CAP 748, Chapter 4 - Detection and Prevention of Fuel Contamination, which gives excellent guidance on fuel storage, testing and delivery to aircraft.
Flight

This section covers all phases of the flight: from start-up to taxy-in. Although some of the suggestions contained herein may seem like common sense, please consider every point with equal merit when making an informed evaluation.

Minimise Auxiliary Power Unit use

While always keeping the comfort of passengers in mind, efficient APU management can yield significant savings. The use of the APU should be minimised whenever possible by the use of ground equipment for electrical power and, where economically available, cabin conditioning. Further still, is the use of gate provided fixed power and air which is becoming more prevalent and should be embraced and encouraged by all Operators. This is about 30 to 50 times cheaper than use of the APU. The flight crew should always be aware of ground or fixed power availability at every destination. Not only does the APU consume a large amount of fuel and cause pollution; it also incurs a high maintenance cost.

Where the APU must be used on the ground, savings can be made by minimising the loads either by not using air conditioning, or, if some conditioning is necessary by using only a single pack. Where procedures and performance allow, engine air bleed as opposed to APU can be used for take-off and landing.

Electrical use during ground support activities is primarily used for supporting aircraft pre-flight, post-flight, loading, servicing, cleaning and maintenance as well as for lighting, heating and cooling. Although it is often more convenient to use the APU it is generally much more cost effective to use a GPU for electrical power supply and an Air Conditioning truck for the conditioning element. However, it should be noted that if an APU is being used for air conditioning it can concurrently drive the electrical generator for a modest additional cost in fuel consumption.

Additionally, for short turnarounds of about 40 minutes or less, shutting down the APU may not be the best course of action because of the increased fuel burn and wear associated with a start-up. So it may be more economical to keep the APU running for the short turnarounds.

Initial:

Some basic suggestions must first be reaffirmed which are often overlooked and should perhaps be mandated within a revised set of SOPs.
This awareness of power consumed by the aircraft should not merely be limited to time on the ground. Important attention should be paid to the usage at all times. An area to consider is the unnecessary use of cabin lighting during daylight hours. Through minimising this avoidable power consumption a fuel saving can be realised.

### Start-up and Push-back:

#### 33 Start engines as late as possible

It should always be the target to start the engines as late as possible with respect to the specific requirements of the airfield and performance. Where possible, only start one engine at the gate and the rest on the taxi-way or push-back. This will serve to reduce fuel consumption and pollution.

To minimise departure delays and ramp congestion, engine start-up and push-back procedures should be streamlined and well documented. In order to lessen ground hazard and power requirements when moving off, the aircraft should be positioned in the initial taxi-out direction.

#### 34 Absorb delays at the gate

Coordination with the Air Traffic Control departure schedule is essential. If a departure slot time would result in a long hold time and if gate occupancy permits, consider delaying the push-back and absorbing some of the delay at the gate with the engines off.

This also applies if it is foreseen that holding will be required at the destination. There should be a large emphasis placed on maintaining continual close communication at this stage.

<table>
<thead>
<tr>
<th>APU Fuel Burn</th>
<th>Lb per hour</th>
<th>Kg per hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zero Load</td>
<td>178</td>
<td>81</td>
</tr>
<tr>
<td>105 Amps Load</td>
<td>209</td>
<td>95</td>
</tr>
</tbody>
</table>

The table above shows the fuel consumption of the APU for zero load and 105 amps load at sea-level ISA conditions with a single Environmental Control System (ECS) pack in fresh mode for the Avro RJ11.

Most aircraft spend considerably longer on the ground than in the air. During these times electrical equipment may be inadvertently left switched on. By careful management of servicing and maintenance schedules it may be possible to save hours of additional power usage.

32 Consider shutting off cabin and instrument lighting during daylight hours and galley power when not in use

This awareness of power consumed by the aircraft should not merely be limited to time on the ground. Important attention should be paid to the usage at all times. An area to consider is the unnecessary use of cabin lighting during daylight hours. Through minimising this avoidable power consumption a fuel saving can be realised.

Taken from the Avro RJ FCOM Volume 1.
35

Use ground power start when available

Ground power should be used in preference to the APU for engine start for a number of reasons; these include:
- Maintenance costs of the APU.
- Increased fuel burn with the APU.
- Environmental emissions and noise considerations.
- Conformance to local airfield regulations.
- Avoidance of ingesting de-icing fluid during winter operations.

Additionally, if the APU has to be used for engine start, consider shutting it down as soon as possible. On the BAE 146 it may, of course, be necessary to keep the APU running for take-off unless an ‘Engine Air OFF take-off’ is to be used. On the Avro RJ series of aircraft ‘Engine Air ON take-offs’ are permitted therefore the APU may be shut-down after engine start.

On the other hand, however, a major European fleet operator advises that it is not economically attractive to operate the APU for any length of time less than 30 minutes. Therefore it is worthwhile to think twice before starting the APU, and instead rely wholly on ground power units.

If a ground power start is utilised another consideration on the 146/RJ is the use of an unpressurised take-off to avoid starting the APU. The packs can also be switched off prior to landing to save APU life and fuel. If operating unpressurised ensure that one engine bleed (normally number 4) is selected.

36

Taxy-out:

Is there a case for one engine off taxi on 146/RJ?

BAE Systems recommend all engine taxy-out on both the ATP and Jetstream series of aircraft.

The BAE 146 and Avro RJ however, have the benefit of four engines and thus the case for an engine-off taxy-out can be made.

The 146/RJ generally tend to have too much thrust on taxi and as such an engine-off taxy-out would present no power limitation and would save on excessive braking. This is of course one way in which to save on fuel burn, however the relatively small benefit may very well be negated by the associated problems.

Before embarking on an engine-off taxy-out11 one must consider:
- Start reliability and reduced fire protection from ground personnel when starting additional engine(s).
- Engine thermal stabilisation times (on cold days the engines may not have time to reach the minimum operating temperatures before take-off).
- Excessive thrust may be required for aircraft break-away.
- Out-of-sequence checklist usage will be required.
- Systems redundancy is diminished.
- At high ambient temperatures electrical loads may become limiting.
- Taxy conditions such as; runway slope, tight turns, aircraft weight, visibility.

As such, BAE Systems do not recommend an engine-off taxy-out on the BAE 146 or Avro RJ aircraft.

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11 If the inboard engines are serviceable they must be running when the aircraft is taxied. If the APU generator is available, both outboard engines may be shut down. If the APU generator is not available, only one outboard engine may be shut-down. In either case only one main generator is available during the taxy.
100 Ways to Reduce Fuel Burn

If however, as an Airline, you decide to accept such limitations and adopt this as a fuel saving measure; a thorough analysis of all parameters must be undertaken. Airlines must ensure that SOPs are well established for engine-off taxy-out, and comprehensibly documented, communicated and trained throughout your piloting community.

37 Use minimum braking and thrust

A clear and obvious method of reducing the cost associated with the taxy is to minimise the use of braking and thrust. The 146/RJ tends to have enough thrust at idle to start the aircraft moving, however at high weights on, when facing uphill, a slight amount of additional thrust may be required. This should be applied in a controlled manner as necessary, nothing more.

When taxying with all four engines at idle, the aircraft tends to accelerate when taxying, to control this one should avoid riding on the brakes. It is better to allow the aircraft to accelerate to the highest speed dictated by the prevailing conditions and then use around 500 psi to decelerate the aircraft to a low speed. This technique preserves brake life and generally results in lower brake temperatures. On the turboprops the minimum power required should be used and the speed controlled so as to minimise the need for brakes.

38 Take the shortest possible route

Whenever possible, within other operational factors and local conditions, attempt to take the shortest route possible to your departure runway, thus minimising taxy-time. This will require coordination with local timetabling and ATC.

39 Make intersection take-offs if possible

A useful technique to minimise unnecessary taxy time and extra brake usage is to perform intersection take-offs. ATC would probably not offer an expeditious take-off, the crew could request an intersection take-off when a benefit could be realised. Where possible reduced power take-offs should be used (item 41), thus if an intersection take-off does not allow for this the full length should be used instead.

In order to perform an intersection take-off RTOW data must be available for the new runway length. In order to maintain a suitable margin of safety an intersection take-off should not be performed in low visibility or on a contaminated runway.

Always ask ATC - You don’t get if you don’t ask!
100 Ways to Reduce Fuel Burn

Reduced thrust take-off preferred on 146/RJ and Jetstreams where possible and AFM certified

In any situation where the actual take-off weight is less than the maximum limiting take-off weight, a reduced thrust (or FLEX) take-off is recommended\(^3\). Compared to full thrust, the use of reduced thrust will not necessarily reduce fuel consumption during take-off. However, it will preserve engine life and reduce the rate at which specific fuel consumption deteriorates as the engine ages. It has been estimated that a 1% reduction from full take-off thrust will result in a 10% saving in engine life\(^7\).

The procedure for calculating this can be found for the 146/RJ in AFM 5.1 Section 6: PERFORMANCE. Equivalently, for the Jetstream 31/32/41 aircraft this is available in the form of an AFM Appendix or Supplement if certificated. This has not been certificated for the ATP.

Shown opposite is a part-example of a N1 Full Flex Table generated by BAE Systems for BAe 146 and Avro RJ aircraft, which can be procured from the Flight Operations Support department.

It should also be noted that for the turboprop aircraft a reduced power take-off is only permitted if the continued availability of the static take-off torque has been confirmed before, or during, the first take-off of the day. Equivalently, for the 146/RJ the AFM states that a reduced power take-off may only be performed if the availability of the rated thrust is periodically checked to ensure that take-offs are not made with excessive engine deterioration. Some Airlines perform this on the first flight of the day whereas others do it over a larger time period. This is solely a SOP driven procedure.

\(^{13}\) Within tailwind, crosswind and other safety constraints. Reference should be made for the 146/RJ in AFM 5.1 Section 2: LIMITATIONS or to the appropriate Appendix or Supplement of certificated turboprop aircraft.
Depart in direction of flight

Departing in the direction of the flight course whenever possible will save on fuel costs. At low-density airports, there may be a choice of departure runways. Additionally, whenever it could be of benefit a request to ATC should be made as standard. It is difficult to establish an exact comparison between the fuel costs of taxying against time in the air.

Fuel consumption when taxying on all engines in the Avro RJ is 15kg/min as compared to around 75kg/min in the climb. With a view to this it could be said that it might be worthwhile to taxy for a longer time thus reducing time in the air. For example, a flight departing in a direction 180 degrees from the intended flight course may need to travel an extra 15 miles in the air and in such a case a saving could be made on the ground. One must also keep in mind additional delays and time expenses which might be incurred.

Retract flaps and undercarriage as soon as possible

Speed and flap management on departure will greatly impact fuel consumption in addition to flight time. Once in the air, the flaps and slats should be retracted as soon as possible within the constraints of aircraft limitations, obstacle clearance and safety.

Although these devices increase lift, they also increase drag and therefore increase the fuel consumption.

Minimise manoeuvring with flaps and gear down

It is of clear benefit to reduce the amount of manoeuvring required before retraction of the flaps and undercarriage. Careful consideration of the departure procedures should be performed and the best, most fuel efficient, techniques established and documented.

If runway length permits perform a rolling take-off

The Flight Manual take-off performance is based upon standing starts with maximum thrust. Although a standing start takes less time to achieve the required take of speed relative to a rolling take-off, when conditions permit a rolling start is normally the preferred procedure. This will save fuel and increase engine efficiency due to the aircraft not requiring full power under braking at the start of the take-off run. It will have the further benefit of increased passenger comfort.
Climb:

46

After take-off turn on-course as soon as possible

Where it has not been possible to depart in the direction of your destination, turn as soon as possible, in accordance with the aircraft and local procedures (e.g. SIDs), to minimise the distance travelled away from the intended direction.

47

Accelerate to the most economical climb speed in a timely manner

A further situation which can lead to an increase in unnecessary fuel burn is delay of acceleration to the most economical climb speed. This should be performed as soon as operationally possible when flap retraction is complete and the aircraft has turned in the direction of the flight.

Cruise:

48

Always ask for direct routing

As stated in (item 10) of this guide, the single biggest influence on fuel, distance and time in the cruise is routing. This still may not have been optimised by pre-flight planning, and therefore in-flight requests for direct or expedited routings from ATC should be considered. If Company procedures allow, consider flying off-airways if this results in a more direct routing. For example, large savings can be made through using non-active military airspace at the weekends. Additionally, when the aircraft is suitably equipped and the flight crew approved, full use of the most direct (P)RNAV routings will pay dividends.

It has been reported by EUROCONTROL for the year 2008 that the average route extension per flight in Europe was 48.8km, with an estimated number of flights around 10.1 million. This gives an overall additional distance flown of 493 million km.

It is important to understand that the Great Circle distance is not always the shortest air distance when winds and weather are considered. In addition to this there are many other factors which need to be considered such as; departure and landing runways, airways restrictions, NOTAMs, restricted areas and overflight charges, etc.

Clearly some indirect routes are unavoidable but equally air traffic control and Operators alike must seek to reduce this ‘unnecessary’ fuel burn.

With direct routing the flight plan fuel will already be on board hence the weight of any extra would be carried and the benefit would be that it would not be burned.

Example

Hamburg (HAM) → Toulouse (TLS)

Flight on airways vs. “Direct routing” 97.8 km extra distance.
Maintain optimum flight level

Flying the most efficient vertical profile offers great potential savings. Whilst this is done in the pre-flight planning, it is important that this is adhered to. Also, if the actual aircraft weight differs significantly from that planned or there is significant wind and weather changes en-route re-evaluation may be necessary. This can be easily done through the use of an Electronic Flight Bag (EFB).

Furthermore, if an aircraft has to deviate from the planned flight level for a significant amount of time then a re-assessment of the optimal cruising speed at this altitude should occur.

A final note should be made with respect to the short flights which are commonplace on BAE Systems aircraft. Research suggests the most efficient vertical profile for these short sectors is generally to continue climbing until intercepting the descent profile. However, this is not always practical. Total air distance should be considered when evaluating the optimum altitude on short flights, including the departure and arrival runways and procedures.

Use of the FCOM Vol.2 SAR curves or the ‘Intelligent Fuel Calculator’ to fly at optimum SAR speed

As described in (item 12) located in the ‘Flight Plan of Route’ section of this guide, it is essential to fly at the optimal cruising speed.

On the BAe 146/Avro RJ this speed is that for optimum Specific Air Range as given in tables in the FCOM. This is a function of altitude, weight and temperature. A program has been developed by BAE Systems which can be used by dispatch or in the cockpit environment (through the use of an EFB) to interpolate these tables and provide the optimal cruising speed depending on the current circumstance of the aircraft. This is called the ‘Intelligent Fuel Calculator’ and can be procured from the Flight Operations Support department. The table below depicts the calculated fuel savings which can be made by operating at 99% SAR speed.

<table>
<thead>
<tr>
<th>Range (nm)</th>
<th>400</th>
<th>600</th>
<th>800</th>
<th>1,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instead of Long Range</td>
<td>$20,000</td>
<td>$35,000</td>
<td>$55,000</td>
<td>$70,000</td>
</tr>
<tr>
<td>Instead of High Speed</td>
<td>$40,000</td>
<td>$75,000</td>
<td>$115,000</td>
<td>$145,000</td>
</tr>
</tbody>
</table>

BAE Systems could make available SAR curves and an “Intelligent Fuel Calculator” for any of the turboprop aircraft if requested.

Use of the ‘Wind Effects Tables’

In the cruise aim to fly as high as possible. However, the flight level may have to be adapted to take advantage of favourable winds at different altitudes. This can be done through the use of the Wind Effects Tables (WETs) generated by BAE Systems Regional Aircraft.

These Wind Effects Tables allow a comparison to be made between fuel burn and time for a given wind speed over various cruising altitudes. This should be performed using the latest, most up-to-date wind data and can yield significant savings if this practice is effectively integrated into the en-route standard operating procedures. Again, this could be easily included in an EFB solution.
Step climb on longer flights to maintain optimum altitude

Of course, on some long distance routes it may not be possible to reach the optimal cruising altitude initially due to the weight of the extra fuel on board. In this case a step climb may be a powerful tool in the reduction of fuel burn. The optimum altitude is generally a function of aircraft weight; increasing as the aircraft gets lighter, with the ideal flight profile being that of a continual cruise climb. However, due to air traffic restrictions, at least for now, a stepped cruise is the best option.

This method of flight must be very carefully considered on longer flights, with an early ascent above optimum preferred to delaying the climb, as in this case the penalty is always decreasing. From the FCOM tables for the BAe 146/Avro RJ it can be shown in general that every 1,000ft altitude increase is worth 1% reduced fuel burn.

An example of such a saving on a flight between Madagascar and South Africa can be observed below. This clearly shows the benefit in climbing to higher flight levels as soon as the aircraft is capable.

Adjust 99% SAR speed as aircraft gets lighter

As the aircraft burns fuel in flight and reduces in weight the flight speed should be reduced in accordance with the optimal 99% SAR speed as defined in (items 12 and 50). This serves to maintain the optimal speed for fuel efficiency. This can easily be performed in flight through the use of the “Intelligent Fuel Calculator.”

It should be highlighted that such a procedure must take into account the scheduling which is in place.

Fly straight and level using correct trim procedures

Any out-of-trim condition will result in additional drag and thus unnecessary extra fuel burn. In cruise the aircraft may require flight control trim input to maintain balanced straight and level flight.

In the BAe 146 and Avro RJ series aircraft an out-of-trim condition, especially in the directional sense, can cause a roll spoiler to open when compensating for an imbalance. This condition will dramatically increase the drag of the airframe; as such the roll spoiler indicators should be checked in non-turning flight to ensure that they are correctly stowed.

If it is suspected that a directional out-of-trim condition exists, check the aircraft trim as follows:

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52 For an RJ85 at maximum structural take-off weight in ISA conditions.
Maintain symmetrical synchronised engine thrust (N1).
Dis connect the autopilot.
Assess the trim condition and make small adjustments as necessary.
Check the slip balls. If they disagree, first establish wings level flight using the ailerons, and then trim the rudder until the aircraft is in straight, non-yawing flight as indicated by reference to a compass reference system. Check and note the status of the roll spoilers, in correctly trimmed straight flight they should be stowed.

Of course, roll spoilers are not present on the turboprop aircraft however maintaining correctly trimmed flight is of equal importance. BAE Systems has experience of flying a fleet of around 20 Jetstream 32 aircraft when an Operator was complaining about increased fuel burn. Upon investigation it was found that torque split was the reasoning behind this. Thus emphasising the significance of the first bullet-point above.

Any unusual circumstance with respect to the aircraft trim should be reported to company maintenance for timely attention.

Do not use unnecessary anti-ice

It is essential that the anti-icing systems on the aircraft are used in conjunction with the guidelines provided within the flight manuals. Unnecessary use of such systems is a prime source of preventable fuel burn. For example, the cruise fuel flow on the Avro RJ increases 6-7% with full ANTI-ICE systems selected ON.

Further guidance can be found in the BAE Systems 'Think Ice!' brochure.

Judicial use of air conditioning

Fuel savings can be achieved through judicial control of aircraft air conditioning. When demand is low it is worth considering switching one pack off. Additionally, operation in RECIRC mode uses 40% less fresh air direct from engines and therefore less fuel.

Remember also that leaks in the bleed system or Environmental Control System (ECS) ducting will increase demand on Engine/APU.

Maintain a balanced fuel load

Careful control of the fuel load on the aircraft should be maintained. Ensuring an aft Centre of Gravity and a lateral fuel balance will negate the necessity to carry trim drag in-flight.

As such fuel burn in each engine should be monitored and accurate, symmetric loading on the ground should be mandated.

Auto-throttle use on the BAe 146/Avro RJ

Where equipped, the Auto-throttle reduces pilot workload and aids accurate speed holding. However, in areas of moderate turbulence or wind/temperature shear, the Auto-throttle will tend to become over-active as it attempts to hold an accurate speed. This will result in an increase in overall fuel consumption. In this case, if the company procedures allow, it is advisable to disconnect the Auto-throttle and accept small variations of speed.

This has recently become a SOP for one operator for whom, on a long route, it makes the difference between arriving at the destination or diverting.
At Hold Speed given in Operations Manuals

For reduced fuel consumption holding should be conducted at the recommended hold speed. This is the speed for optimal fuel flow whilst maintaining a safe margin from stall or other potential problems. Holding speeds can be found in the Aircraft Flight, Flight Crew or Manufacturer’s Operating Manuals and are typically; 150 - 160kts for the turboprop aircraft and dependant on weight, 180 - 200kts flaps up and 140 - 160kts flaps 18° for the jets. An example of a holding fuel flow table, flaps up, all engines for the BAE 146/Avro RJ can be seen below:

We have been advised that some Airlines choose to hold around 10kts faster than these speeds as an added margin ensuring that they are observed in situations of high pilot workload.

Hold at highest possible altitude

Clearly demonstrated in the above table is the necessity for agreement with ATC to allow the aircraft to hold at as high an altitude as possible. For example; holding at a weight of 33,000kg at 10,000ft requires 6% less fuel than holding at 1,500ft at the same weight. Holds can also be planned to take place at the end of the cruise, before any diversion, rather than post-diversion at low altitude.

Early recognition of potential holding delay helps to plan so as to minimise penalty

As previously stated in (item 34), one should maintain close communication before departure with your company dispatch office to determine whether a delay at the destination airfield is expected or not. This communication should be maintained throughout the entire flight and previous experience, knowledge of slot times, gate constraints, local curfews, expected traffic and weather should be utilised to better plan for holding. Data presented by National Air Traffic Services in 2009 further compounds the need for careful planning and optimisation of any holding procedures:

Periods of peak delays over the course of a day can be statistically identified. Where possible, flights could be re-timed to arrive outside of such peak times.
**62. Attempt to absorb delays linearly when possible by slowing down**

One technique to be used when holding at destination is expected, is to absorb the delay en-route by requesting ATC for permission to slow down in the cruise. This will result in a decrease in fuel flow and an increase in cruise time, thus reducing the required hold duration. This has the effect of a reduced fuel penalty incurred from the delay.

An example of this linear holding technique is given below:

**Example**

ATC informs 15 minutes before reaching a fix that 10 mins holding is expected.

**Typical Hold**
- 15 minutes at cruise

**Linear Hold**
- Cruise at holding speed
- 2.5 mins Hold for remaining time

- **= 901kg of fuel**
  - (634kg + 267kg)

- **= 667kg of fuel**
  - (600kg + 67kg)

This picture shows a comparison based on reducing from high speed cruise to cruise at the holding speed, both at nominally 24,000ft.

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**Descent and Approach:**

**63. Request the most convenient routing and runway**

Once arrival information has been received, consider negotiating with ATC for the most direct routing to the final approach. If the main runway in use will result in an extended taxi to the gate, consider requesting a more appropriate runway, bearing in mind any extra flight time taken to reach the final approach.

**64. Stay as high as possible for as long as possible**

As has previously been described throughout this guide, the fuel consumption at higher flight levels is less than that at lower altitudes. Thus, staying higher for as long as possible will ensure the optimal fuel burn. It is important that the trade-off between early and late descent is understood. A late descent poses the problem of additional energy to be dissipated through increased drag (i.e. the requirement for airbrakes to slow down).

Conversely, initiating the descent too early may result in extended flight at the more uneconomic lower altitudes thus consuming more fuel. If one is to err, it is better to be early as this still allows for recovery of the optimum profile.

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*For an Avro RJ85, flying in ISA conditions at 24,000ft at 40,000kg in High Speed Cruise.*
65 Utilise a Continuous Descent Approach whenever possible

The stair-stepped approaches in use today begin many miles from the airport and require substantial time flying at the undesirable lower altitudes. Aircraft descend in steps and require more thrust each time they level off.

With a Continuous Descent Approach (CDA), the aircraft will remain at its optimum flight level until it is relatively close to the destination airfield. At that point the thrust is reduced and the aircraft will descend continuously avoiding any level segments of flight prior to intercepting the landing glidepath.

Benefits include significant reductions in noise, fuel burn and emissions, and shorter flights. It has been shown that on average a saving of 40kg of fuel and 2 minutes of flight time per flight can be expected\textsuperscript{24}. The use of a CDA should become the preferred SOP for Airlines and ATC alike.

66 Be stabilised in the final approach

BAE Systems recommend stabilised approaches as illustrated in the FCOM (Volume 3, Part 1) for the 146/RJ and MOM Flight Guides for the turboprops. These approaches offer the safest arrival and a baseline in determining fuel burn.

67 Do not transition to landing configuration too early

In adhering to the stabilised approach, keep the aircraft as clean as possible for as long as possible. Flaps and slats are designed to provide additional lift at slower speeds however a consequence of their deployment is a significant additional drag on the airframe. It should be noted that ATC might not always be aware of the clean manoeuvring speed of your aircraft - often a word to them will save an unnecessarily early flap extension.

Another point is that an early extension of the undercarriage should be avoided, always following procedures and observing flight manual or ATC limitations. Landing configuration fuel flow is approximately 150\% of that of the clean aircraft\textsuperscript{25}.

68 Auxiliary Power Unit use

If the APU is required for the approach and landing, it should be started as late as possible within the constraints of crew workload. On the Bae 146, it may be possible to conduct an ENG AIR OFF approach and landing. For the Avro RJ, consideration should be given to an approach and landing with the Engine Air Conditioning bleeds ON. Then, if required, the APU can be started after landing.

For the turboprops it may be that Freon air-conditioning units are fitted, particularly in warmer climates. Their use will ultimately add to fuel burn.

\textsuperscript{25} Aviation Operational Measures for Fuel and Emissions Reduction Workshop, Fuel Conservation: Operational Procedures for Environmental Performance, Rob Root, Boeing, (22/05/2002).
Try for no part-power descents

A properly planned and executed descent offers a tremendous opportunity for fuel savings. The ideal is an uninterrupted descent from cruising altitude without the use of thrust or speed brakes until reaching the final approach stabilisation altitude.

In the descent the use of minimum scheduled thrust (N2) consistent with cabin conditioning, engine and/or airframe anti-ice is essential. Whenever possible a descent with engines at the minimum power required should be the target.

A recent change to the 146/RJ AFM has sought to assist in such a procedure:

This revision allows better control of engine power and airspeed, possibly reducing use of the airbrakes in the descent, and hence increased fuel burn from the resulting extra drag.

Landing:

Reduced flap landings

Wherever possible, one should attempt to land with a reduced flap setting in order to minimise drag, thus fuel burn 26. This is a function of the Modification standard and AFM certification of the aircraft, see opposite.

When conditions are appropriate, landing at less than full flap has some definite advantages. A reduced flap landing will suffer from less drag than its higher counterpart, hence reducing fuel burn, and chemical and noise emissions. When considering a reduced flap landing one must consider the landing weight, runway length, conditions, exit point, occupancy time, wind and weather (especially any tail-wind component) and brake cooling periods for short turnarounds.

The flight manuals must be consulted for safety limitations and procedures for reduced flap landings per specific aircraft type. For example, on the 146/RJ the landing distance available must be reduced by 30% for landing with flap 24°, whereas on the Jetstream 41 the landing distance required must be increased by 10% for a 15° flap landing.

26 On the 146/RJ, landing with flaps at positions other than 33° should be avoided if either anti-skid or lift spoilers are inoperative.
Idle or reverse thrust on props?

The use of reverse on the turboprop aircraft should be minimised. This will lead to a reduction in fuel consumption, fuel and noise emissions, a saving in engine life and a reduction in the likelihood of foreign object damage (FOD) and the potential for stall and engine re-ingestion. This will also serve to reduce the cool down requirement before shutting down engines for an engine-out taxy.

Although no such system is in place on the 146/RJ, one should make full use of all the aerodynamic retardation and lift spoiler devices which are fitted and serviceable.

Where is your turn-off?

The location of the turn-off is a vital consideration and should in the pilots mind from the approach stage. A cost analysis should be performed to determine the optimal usage of braking, aerodynamic retardation and lift spoiler devices, in addition to reverse thrust on the turboprops.

One may find benefit in utilising the entire runway available or in decelerating harder to allow for a sooner turn-off. When evaluating such a choice, the conditions of the day; including aircraft configuration and available systems, weather, contamination and gate availability, to name but a few, must be considered. Once again the safety of the aircraft should never be compromised.

Taxy-in:

On fewer engines with minimum braking

A final method of fuel burn reduction in the Flight stage of operation is the use of an engine-out taxy-in.

The 146/RJ series of aircraft consume approximately 15kg/min of fuel when taxying on all four engines. So where a long taxy-in is unavoidable consideration should be given to shutting down engines 1 and 4 so long as the APU is serviceable and running (Engines 2 and 3 power the hydraulic systems, shutting down 1 and 4 requires the APU to be running to provide air and electrical power). A taxy-in with two engines shut down will save approximately 5kg/min in fuel.

On the Jetstreams and ATP aircraft there is potential for taxy-in with one engine off, however this offers a very small benefit versus the potential problems and as such is not recommended.

One should always keep thrust and steering requirements in mind and observe the minimum time at idle thrust as stated by the engine manufacturer before shutting down engines.

Taxying on two engines on the 146/RJ is not recommended in conditions of low visibility, at night, or where ramp and traffic conditions require a high level of exterior monitoring by both crew members. Once again the necessity for clear SOPs and thorough training of such procedures should be emphasised.

On a 146/RJ a taxy-in with two engines shut down will save approximately 5kg/min in fuel.
Post-flight

The next aspect is the post-flight stage of operation. This consists of aircraft turnaround and maintenance of both the airframe and all aircraft systems. A rigorous approach to this will allow a further fuel burn reduction to be realised. It has been estimated that a fuel saving of 1-2% can be expected from improved maintenance.

Turnaround:

Some basic suggestions must first be reaffirmed which are often overlooked and should perhaps be mandated within a revised set of SOPs.

74 Plug into ground power/heating/pre-conditioned air as soon as possible

As discussed in (item 31), it is essential that use of fixed or ground unit power is prioritised over the aircraft’s engines or APU. The Airline should have already arranged for the services to be in place and if not currently available, a petition to the airport should be submitted. Such technique should be employed as a SOP if not already enforced.

75 Keep aircraft in the lowest power requirement configuration

In order to minimise the power consumed when on the ground it is important to configure the aircraft to its lowest power requirement configuration. Some examples of measures which can be implemented to achieve this when on the ground are; turning off the in-flight entertainment system, environmental control, and unnecessary electrical lighting and closing blinds in order to maintain cabin temperature. Every measure should only be made within reason, with constant consideration of passenger safety and comfort.

The ideas given are only the tip of the iceberg and as suggested in (item 5), ask your staff for their input. Many kilograms of unnecessary fuel burn can be saved on every flight.

76 Minimise time on the ground

The time spent idle on the ground should be minimised. Flight schedule timetables should be thoroughly planned out in order to maximise the time flying of the aircraft. This timetabling should include standardised times for disembarking, cleaning, refuelling and reloading specific to season and route. In addition to this, there must be contingency plans in place and a dynamic, adaptive viewpoint taken in order to best accommodate any unforeseen difficulties, such as ATC delays.
Consider leaving APU running

Ground power is always preferred over engines or APU, however, for short turnarounds of about 40 minutes or less, when the APU is operative, shutting it down may not be advised because to start it up will both burn more fuel and incur added wear decreasing its life. Therefore, it may be more economical to keep the APU running for short turnarounds, in adherence to the restrictions of the airfield in question.

Ensure that any unnecessary electrical equipment is switched off

Highlighted in (item 31) is the fact that aircraft spend considerably longer on the ground than in the air. On such occasions it should be ensured that unnecessary electrical equipment is switched off. This can be controlled through rigorous servicing and maintenance drills, effectively communicated to all team members concerned.

Tow between maintenance facility and gate if possible

Whenever there is service availability and it is of suitable convenience it should be sought to tow the aircraft between the maintenance facility and the gate, this will not only save on fuel burn but also on preventable life deterioration.

Investigate potential aircraft modifications

As has been stated throughout this document, a great amount of performance limitations are governed by the Mod status of the aircraft. Some parameters which can be exploited through investment in modifications are; the maximum flight level at which the aircraft can be operated, the use of reduced flap landings and drag reduction modifications.

Examples might be RVSM certification for the Avro RJ, 24° flap landing for the 146/RJ, and the Jetstream 32 Enhanced Performance mods. For J31 and J32 consideration could be given to removal of the baggage pod, particularly for executive aircraft.

As with every suggestion in this publication, Operators must weigh up the return on investment which could be achieved through any potential Modifications.

It has been estimated that a fuel saving of 1-2% can be expected from improved maintenance.
**Airframe Maintenance:** With respect to maintenance of the airframe, particular attention should be paid to the highlighted areas on the following diagram (specific to the BAe 146 but equally relevant to the other types).

### Door seals

Missing or leaking door seals will place greater demands on engine air bleed leading to a fuel penalty. Additionally, overboard leakage of cabin pressurisation can disrupt the external airflow leading to further fuel penalties.

To reduce this cost the seals on all pressurised doors should be checked periodically for conformity and repaired or replaced as necessary. Leaking seals also create noise which can be annoying to passengers.

### Mismatched surfaces

A large increase in drag, hence fuel burn, can be experienced through a misalignment of surfaces. Such as; steps between panels, around windows, doors, control surfaces and access panels. Further surface misalignment can occur from external patches, the number and size of which will have an adverse effect on fuel burn. It is recommended that into-wind edges are radiused and out-of-wind steps are chamfered to reduce the resulting drag.

### Internal airflow

Another area which should merit careful attention is the condition of aerodynamic seals. Leaks from higher to lower pressure areas due to poorly fitted or damaged seals are a common cause of increased airframe drag.
Surface roughness
Damage (dents) or repairs which change the shape or roughen the surface will have the effect of reducing aircraft performance. When using sealant, to fill gaps or bond surfaces, care should be taken to avoid excessive build-up and edges should be carefully smoothed.

Regular re-weighing
An aircraft will accumulate weight throughout its life-cycle, mainly through moisture and dirt. To monitor this, a regular aircraft re-weighing schedule should be planned and upheld. One fundamental principle of this publication is to highlight the tremendous negative effect that unnecessary extra aircraft weight has on fuel burn.

Regular re-weighing will serve to reveal subtle increases of OEW which can then be remedied on a per aircraft basis.

Heating of aircraft periodically to remove collected water
A source of not only excess weight but safety and structural concern is the build up of ice within the airframe and fuel tanks. It should be ensured that the drain traps are working correctly and emptied regularly, and that fuel tank sumping is periodically and thoroughly performed.

An example of this is the accumulation of water (ice) and dirt under the freight bay floors where keel drains have become blocked. One Operator reported an accumulation of 4 inches of water, this weighed nearly 800kg.

Paint
Aircraft paint not only helps prevent corrosion and ensures a smooth finish but it also helps to provide a unique identity for your airline. The provided smooth finish is essential in minimising the drag of the airframe; however, one must be careful when maintaining this.

When repainting, any old paint must first be removed. For example, one layer of redundant paint on a BAe 146 could cost up to 2,000kg in excess fuel burn per aircraft per year.

Wash the aircraft regularly
Where permitted by airfield policy, regular washing of the airframe may help reduce airframe drag as well as presenting a better corporate image for passengers. It will also demonstrate to customers and employees alike; a commitment to maintaining the aircraft, to cost reduction, and to the environment.

In addition to this external cleaning, regular thorough and comprehensive cleaning of the interior should be practised.
89 Engine: Dirt accumulation, increased tip clearances, seal leakage and aerofoil erosion

The Specific Fuel Consumption (SFC) of the engines will deteriorate between overhauls. The degree of this deterioration will depend on the number of engine hours, the procedures used (e.g. full or FLEX take-off), operating conditions and the duty cycle. SFC deterioration rate is approximately 0.45% per 1000 hours (cycles). At overhaul the engine SFC will be improved depending on the amount of reworking carried out; this should be carefully analysed and the optimal economic compromise sought. It should be noted that the SFC will not necessarily be returned to the “as new” standard.

There are further simple procedures which can be carried out to maintain a better SFC between shop visits.

An accumulation of dirt and rub debris will cause performance losses that increase with the amount of contamination. Periodic engine water wash serves to retain performance and can readily be accomplished on wing.

The resulting improvement in performance varies depending on the degree and type of gas path contamination. The part of the engine gas path which is most accessible on-wing and has a significant impact on fuel consumption is the fan. Fan blade leading edge erosion, deterioration of the fan rub strip and damage to the fan blades, rub strip, or low pressure compressor inlet are easily detected by visual inspection. On a 146/RJ a 1% loss of compressor bleed air will increase fuel rate for thrust by 1.3%. This increase equates to around 50,000kg of additional fuel burn per year.\footnote{Assuming a fuel consumption of 2,000kg per block hour and utilisation of 2,000 hours per annum.}

Reference should be made to the appropriate Engine Manuals when carrying out such a procedure. For example, the 146/RJ Honeywell Engine Manual - Chapter 72-00-00, Special Procedures 03.

90 Identifying engine sources of engine performance loss

As stated in (item 1) of this guide, engine trend monitoring should be carefully maintained. Such a system would very quickly highlight any abnormal loss in engine performance. This can be caused by either the engine itself or other airframe factors.

Close reference should be made to the Aircraft Maintenance Manuals whenever such an investigation is conducted. These contain a wealth of guidance to assist in locating the problem. In terms of engine sources of loss this advice can be found in the 146/RJ AMM - Chapter 71-00-00, page block 501.

91 Identifying airframe sources of engine performance loss

The source of engine performance loss may also be related to the airframe itself. Once again reference should be made to the appropriate AMM for advice on locating this. Some common areas of interest for the 146/RJ aircraft are described in the following AMM locations:

- Environmental Control System: Ch 21-09-11.
- De-icing System: Ch 30-11-17.
- Engine Bleed System: Ch 36-11-00.
Careful operation reduces deterioration

Whether on the ground or in the air, all Operators must seek to ensure smooth and controlled operation of their aircraft. Ensuring smooth throttle movements and avoiding unnecessary or overly sharp manoeuvres will provide a great benefit in terms of engine performance retention. In addition to this, engine run-up should be avoided near any surface with loose or flaking material or frozen contaminants.

An example of this can be found on the Jetstream 41 aircraft where a significant increase in impeller wear has been recognised in conjunction with hard manoeuvring.

Ground running procedures

The practices which maintenance crews use when operating engines during ground runs can have a very large impact on performance retention. One of the most detrimental practices is the use of rapid throttle movements. The most damaging throttle movements are those that reduce the engine from prolonged high power to speeds near idle, hold there for insufficient time to allow for adequate cool-down and then return once again to a high power setting.

Calculations and engine experience demonstrates that on some engines such a throttle sequence with only two minute cool-down at idle can result in a significant rub between the High Pressure Turbine (HPT) blade and shroud of such a magnitude as to cause a change of 12°C in EGT at take-off and a reduction of 0.5% in cruise SFC.

Regular instrument accuracy and calibration checks

Instruments that read low can lead to excess fuel consumption, especially if power setting is adjusted for target True Air Speed/Mach. Cross checking and calibration of key instruments should be included in routine maintenance.

The tolerance of the fuel gauge system should be checked periodically to ensure that the gauges neither under- nor over-read. It is also important to check pitot and static lines regularly for cleanliness and integrity. The AMM gives guidance as to the maximum allowable errors between pitot/static and other performance instrument systems.

Whenever instrument error is suspected or detected it should be reported immediately in as much detail as possible.

Other:

A final method which is becoming more and more prevalent is the use of simulator flying to test and train new fuel saving techniques.

Use of simulators for training, testing and validation

One fantastic way for Airlines to experiment and develop a new set of fuel efficient Standard Operating Procedures is through the use of simulator “flying.” An example of such benefits can be found in (item 17) of this guide.

The use of a simulator will allow a cost-effective means of undertaking a large, required, step towards a more efficient future. This can be used to compare various suggestions and techniques so as to establish the most effective means of fuel saving, whilst maintaining safety and allowing for identical conditions to be set.

An additional measure which has been adopted by many is the inclusion of a fuel efficient section into recurrent training. This serves to instill a fuel-conscious mindset and to quantify its importance to the crew. There are also a number of training courses promoting such a mentality available.
As you can see, there are numerous measures which we, at present, can and should take in order to reduce our fuel burn. However, any changes enforced must be subject to continual development and adaptation based on collaboration across the entire aviation sector. In order to meet the targets laid out by IATA3 in 2009, monumental steps are occurring almost daily within our industry, and these must be followed. Some of these projected future ideas which should be kept in mind are listed below.

- European Union Emissions Trading Scheme
- Air Traffic Control enhancement
  - Single European Sky ATM Research.
  - Collaborative Decision Making.
  - Microwave Landing System.
  - Lobby ATC establishments with your ideas!
- Weather forecast improvements
- Airport infrastructure and ground unit development
- Bio-fuels

...Ways to Reduce Fuel Burn
Summary of actions

BAE Systems Regional Aircraft recognises that many of the suggestions contained within this guide may already be practiced, however we recommend that each Operator considers every item in turn to determine if they can offer further benefits.

Below is a summary of the main points from this guide:

- Minimise take-off weight.
- Carry the correct amount of fuel.
- Use the lowest flap settings.
- Target optimum altitude and wind-corrected SAR speed.
- Aim for the most direct routing.
- Minimise APU/engine use on the ground.
- Use of correct trim procedures.
- Do not descend too early.
- Cross-check instruments.
- Thorough and careful maintenance.

If you have any advice or opinions with respect to this guide please do not hesitate to contact us (details can be found on the back cover). We very much appreciate your input.
Appendix Glossary

(P)RNAV  Precision Area Navigation
AFM  Aircraft Flight Manual
APU  Auxiliary Power Unit
ATC  Air Traffic Control
ATOW  Actual Take-off Weight
ATP  Advanced Turboprop
CDA  Continuous Descent Approach
CEAS  Council of European Aerospace Societies
CG  Centre of Gravity
DOC  Direct Operating Cost
EASA  European Aviation Safety Agency
ECS  Environmental Control System
EFB  Electronic Flight Bag
EGT  Exhaust Gas Temperature
FAR  Federal Aviation Regulations
FCOM  Flight Crew Operating Manual
FL  Flight Level
FOD  Foreign Object Damage
GPU  Ground Power Unit
HPT  High Pressure Turbine
HSC  High Speed Cruise
IATA  International Air Transport Association
IC  Intermediate Cruise
ICAO  International Civil Aviation Organisation
IFC  Intelligent Fuel Calculator
IPPC  Intergovernmental Panel on Climate Change
ISA  International Standard Atmosphere
LRC  Long Range Cruise
NOTAM  Notice to Airmen
OEW  Operational Empty Weight
RJ  Regional Jet
RTOW  Regulated Take-off Weight
RVSM  Reduced Vertical Separation Minima
SAR  Specific Air Range
SiDs  Standard Instrument Departure routes
SFC  Specific Fuel Consumption
SOPs  Standard Operating Procedures
TGT  Turbine Gas Temperature
WETs  Wind Effects Tables