Aircraft Fuel Savings in Jet Streams by Maximising Features of Flight Mechanics and Navigation

Ronald C. C. Houghton

(*Department of Aeronautical Engineering, University of Sydney, Australia*)

Performance enhancement and cost reduction are driving forces in today's airline industry. In a world of cost pressures and escalating charges, research was conducted into better use of jet streams as a means of reducing costs. When operating on international airline routes, specific features of flight mechanics were adapted and tailored to fit a B747-200 aircraft, major emphasis being placed on intercepting, or avoiding where necessary, the high energy jet stream winds of the global weather system, adjusting flight profiles and modifying route structures. Operations were conducted both into wind and down wind, over a period of five years. Techniques employed show fuel may be saved regardless of the wind being a tailwind or headwind. Both fuel and time have a significant bearing on airline direct operating costs: savings of more than 1·1 percent being made on fuel and 0·786 percent on time. Limitations on using the techniques to gain maximum benefit are related to the high volume of aircraft blocking all major airways, and better quality, real time weather forecasts. The discussion looks at ways of improving the use of jet streams, as the world's airline traffic continues to grow. Forecasting upper winds, particularly in oceanic areas, needs to improve if airlines are to derive maximum benefits from these winds. There is need for further study utilising other aircraft types to ascertain what savings can result. Initial results were encouraging, using a Tristar L1011 aircraft.

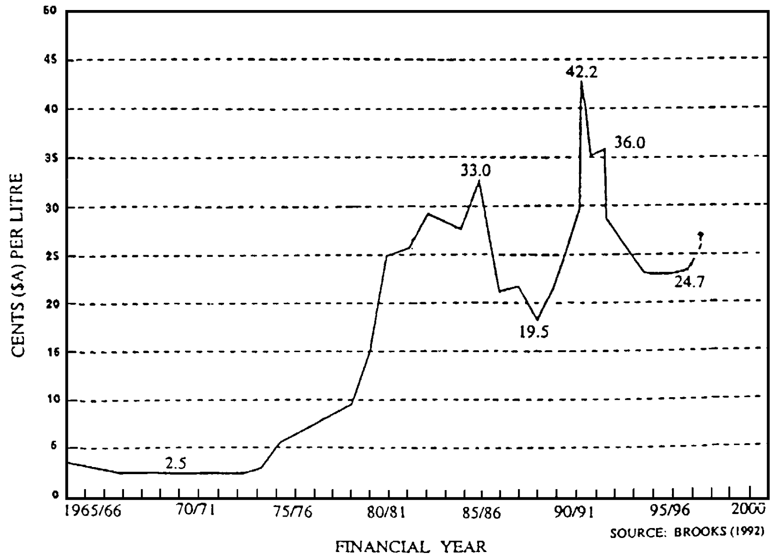
1. INTRODUCTION. In the highly competitive arena of international airline operations, cost reduction and performance enhancement have become pre-emptory to survival for most airlines. Cost of acquisition coupled with high running costs have squeezed the margins between operating revenues and operating expenses (including taxes and interest), to just a few percent. During the period 1984–1991, shown in Table 1, the year 1988 was considered as a 'good' year, yet the margin was a mere 2·63 percent. Other years show constant slim margins, with the years 1990 and 1991, going into heavy deficit. This narrowness of margins underscores the critical balance between profit and insolvency in airline management, where costs must be under constant scrutiny and review. It is imperative that every avenue that offers a reduction in costs be fully exploited.

Escalation of fuel prices, as a consequence of Arab oil embargoes in the 1970s and 1980s, then again in the early 1990s, increased direct operating costs (DOC) of many international airlines, to 55 percent. Today 20–25 percent of DOC is still attributed to fuel price, where, for each 1 cent (US) increase in jet fuel price, the airline industry will suffer a reduction in profits of $(US) 300 million, (Butterworth-Hayes, 1997). With constant volatility shown in the spot oil

Table 1. Iata financial results (us$ billions)

Financial year	1984	1985	1986	1987	1988	1989	1990	1991
Operating revenues	39·5	40·7	45·2	53·8	60·9	70·7	91·0	91·7
Operating expenses (inc. interest & tax)	38·7	40·5	45·5	52·9	59·3	70·4	93·7	95·7
Profit/loss (−)	0·8	0·2	−0·3	0·9	1·6	0·3	−2·7	−4·0
Margin as % of operating revenues	2·03	0·49	−0·66	1·67	2·63	0·43	−2·97	−4·36

Source: Compiled from IATA Annual Reports.



SOURCE: BROOKS (1992)

Fig. 1. Qantas average aviation fuel price 1965–1996

markets of Europe, North America and Middle East, it takes just a few cents rise for this figure to increase to over a billion dollars. Figure 1 charts the average cost of aviation turbine fuel from 1965 to 1996 for one international airline, specifically Qantas. These figures embrace basic fuel costs plus varying taxes from more than 30 different countries. Given there is a broad level of excise raised on aviation fuel by many nations, Qantas figures represent a reasonably accurate estimate of global fuel costs, for any particular period selected.

Constantly changing fuel prices are reflected almost immediately in DOC, and it is these costs that have a major effect on an airline's balance sheet. Some small differences in operating costs are noted, varying from airline to airline. These differences tend to occur, where there is a fleet mix, percentage of aircraft owned outright or leased, together with their age, salary scale of crews and fuel purchasing power of larger airlines. Fuel prices, a major contributor to DOC, are also driven by political instability and the capricious nature of Middle East politics. DOC closely track fuel costs and show dramatically the volatile effects of price changes. Figure 2, extracted from industry sources, plots the cost of fuel as a percentage of direct operating costs, and when correlated with Fig. 1, it illustrates how political events of the Middle East influence costs from the moment of extraction, through to the end user.

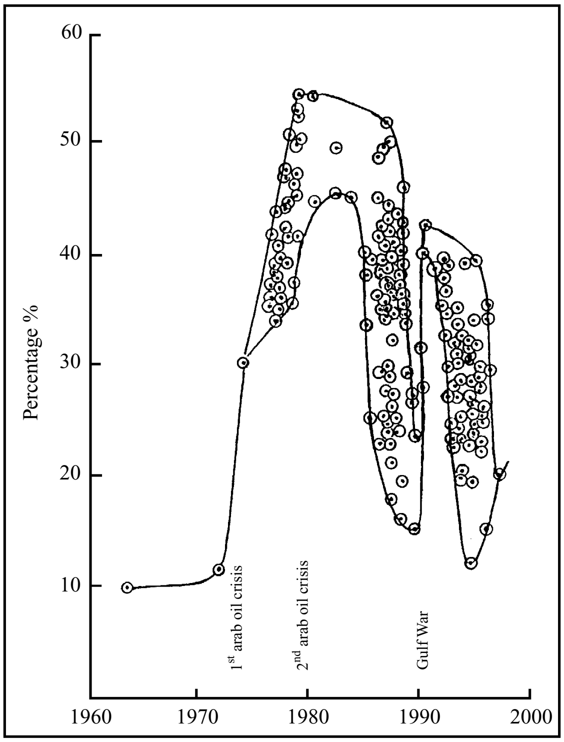
In an attempt to alleviate the impact of erratic fuel pricing, the aircraft industry put in place a series of fuel-saving policies and procedures. These measures covered a broad range of operations from refined aircraft designs, drag reduction programmes, improved engine specific fuel consumption (SFC, given in lb/hr/lb), and more efficient flight management and handling techniques.

Aircraft manufacturers reacted to the oil price challenge by producing aircraft, such as the B767 and A320, that were aerodynamically superior to earlier generations of jet aircraft. Engine manufacturers also appreciated the seriousness of high fuel prices and responded with engines that reduced SFC, by as much as 40·3 percent (Norris 1992). A typical example is the early model B737, fitted with JT8D9–11 engines giving a SFC of 0·6–0·62. On later models, B737-400, -500, -600, fitted with CMF56-3C1 engines, gave a SFC of 0·37. Reductions of SFC were also made with the higher thrust engines, similar to those fitted to B747 aircraft, where a 11·35 percent improvement was gained from the initial RB211-524B2 to the later -524H model. With larger commercial fan engines coming into use, such as the Trent, GE 90, and P & W 4000 series, the trend to produce engines with a lower SFC has continued, with SFC of approximately 0·31–0·33.

Flight operations departments, equally concerned with fuel prices, circularised crews with fuel-saving techniques. These included such items as the necessity always to strive for inflight performance optimisation, e.g. on correct speed at correct altitude, also allow sufficient time and attention for precise trimming procedures. Further savings also accrue from overall aircraft weight reduction, demonstrated by the carriage of less contingency fuel. On the negative side, minimal attention was directed towards better use of jet stream winds embedded in the general global circulation system of the upper atmosphere.

It was these winds, with their vast kinetic energy, that were targeted to reduce costs in both fuel and time. Experiments were conducted using a B747-200 aircraft during the course of regular public transport operations. Both the static air temperature gauge and INS were used as prime indicators, with cloud form, turbulence, altitude and seasonal location as secondary indicators. It was found, using these winds and giving greater attention to inflight procedures such as identifying the core, that substantial savings could be made. Equally when flying into wind, techniques were developed to avoid or lessen the effects of strong headwinds; again fuel savings were made (Houghton, 1997).

2. NAVIGATION. Flying downwind, using a jet stream to shorten sector times, is not new to aerial navigation. In the 1950s, Pan Am meteorologists, Serebreny (1955), with Reynolds & Chandler (1958), developed procedures on propeller driven aircraft, using pressure pattern 'D' values combined with static air temperature to detect high winds. Their procedures required use of a radio altimeter, which restricted the techniques to over-water flights. This was further compounded by the aircraft's inability to reach jet core levels. Though judged



Source: Industry Journals

Fig. 2. Plot of high and low fuel costs as a percentage of direct operating costs

successful at the time, the efforts of early researchers would be considered imprecise compared to aircraft and instrumentation available today.

The introduction of jet aircraft capable of high altitude flight brought the jet stream core within their ambit, and the introduction of accurate navigation sensors allowed actual wind speed and direction to be read directly off the INS, over both terrain and oceanic regions. At the same time, any trend in SAT (static air temperature), either vertically or horizontally could be monitored. There are many flights that proceed downwind in a jet stream, yet few make full use of the wind resource available. Perhaps this is a result of there being no published works on utilising jet streams by high altitude aircraft; all previous works pertained to propeller aircraft. Placing an aircraft in a jet stream is one thing, finding the core has to be the objective.

To take advantage of jet stream winds, a paramount prerequisite is for crews to be adequately briefed on key recognition features, some of which may not be present at any given time. Descriptions given in the literature, mostly from ground based observations, can be difficult to correlate with actual conditions experienced in flight. Determination of the core may require some gentle manoeuvring (5° bank) within the limits of the airways width. This is a procedure many crews are reluctant to use, as the INS will require, in part, to be re-programmed. Dissemination of specific jet stream information is generally required as an aid to identifying some characteristics and finer details in flight.

This particularly applies to cloud types and recognition features, where cloud appearances take on different forms and shapes, when viewed at altitude.

On air routes from Europe to the Far East and on to the US West Coast, the predominant jet stream is the sub tropic jet (STJ). Core temperatures found were $-50{\cdot}0 \pm 2{\cdot}0$ °C. When climbing into a jet stream, using a vertical temperature gradient of ≈ 2 °C/1,000 ft will give an indication within 1,000 feet of the core height. During winter, the STJ consistently maintains an altitude close to 38–40,000 ft and at this height is placed about 5,000 ft below the tropopause. Seasonal location is another indicator; during winter the STJ establishes itself in a quasi-stationary position between 25° and 30° north.

When approaching or leaving a jet stream there is a characteristic gentle ripple or light bumpiness type of turbulence generally found when the wind speed is passing through the range of 55–65 knots. On a number of occasions when approaching from the equatorial side, when the ripples occurred, an estimate of the distance to the core was made, using the cosine of the closing angle with ground speed. It was found the core was located 320–350 nm to the north. When climbing into a jet stream, as the wind velocity reached 55–65 kt range, the identifying ripples were found to be some 10–15,000 ft below the core; that is, the layer of maximum wind was identified to be approximately within a 5,000 ft layer.

Much has been made of jet stream clouds as a key indicator to track the main stream. However there are many occasions when clouds are not present. Should clouds be visible, as high cirrus or cirrostratus, they are characterised by a series of long filamentous threads, composed of ice crystals, arranged roughly in parallel streaks trailing tufted heads. When viewed from above and looking downwind, these tufted heads lean towards the warm air, with the tail trailing across the direction of the main stream at an angle of approximately 30–45°. Should clouds be present, they are generally located ≈ 150 nm on the equatorial side of the layer of maximum wind. No cloud was found above core level. From this comes the tenet that should the aircraft be located above jet cirrus cloud, it is above and south of the jet stream core. If seeking to utilise higher speed winds, a descent will be required, or if attempting to avoid headwinds, a climb (if aircraft weight permits) will reduce the adverse wind component.

When proceeding downwind and unable to fly in the core, a move to the equatorial side of the airway, where the distance between the isotachs is greater, will allow the flight to benefit from sustained high velocities. Conversely if flying up wind, a move to the polar side, where the isotachs tend to be bunched, will mean lower velocities on the nose. Usually most airways have a width of ± 10 nm, with some ± 20 nm. Should it be needed, these distances allow a manoeuvring corridor of some 20–40 nm.

3. FLIGHT MECHANICS. During flight, normal cruise procedures followed minimum cost cruise (MCC), M0·84 techniques, until reaching a jet stream. At heavy weights when flying into a headwind, the speed was marginally increased above M0·84 to long range cruise or M0·845, whichever was the lesser. At flight level 350, this gave an increase of 5 kt to true airspeed (TAS). When flying downwind, the speed was marginally reduced towards M0·835 or slightly below

this figure if the attitude was less than 2·5° nose up. Utilising this cruise technique gave a reduction of 4 kt with commensurate reduction in fuel burn, when maintained for 3 or 4 hours in a jet stream. Rationale for adjusting the speed is related to the L/D ratio, an important efficiency factor of aircraft performance. Maximum range for a jet aircraft occurs when the aircraft is flying at a velocity so that $C_L^{\frac{1}{2}}/C_D$ is maximum. This relationship is illustrated in Fig. 3 and shows how the maximum range velocity decreases for a tailwind and increases for a headwind.

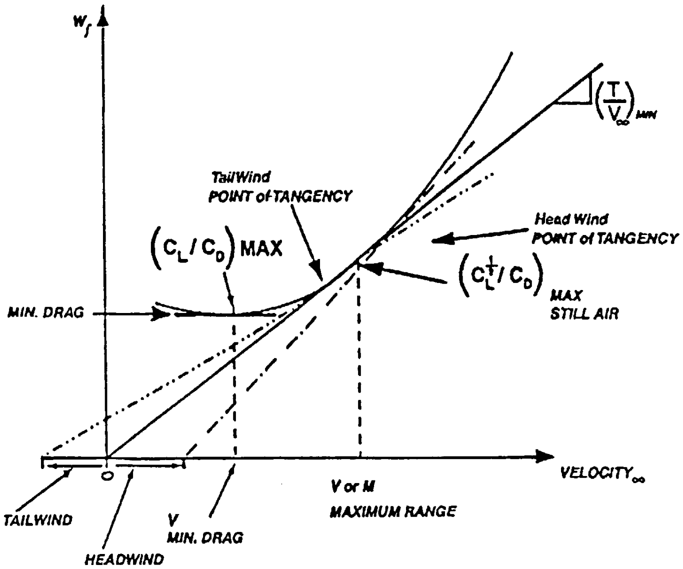
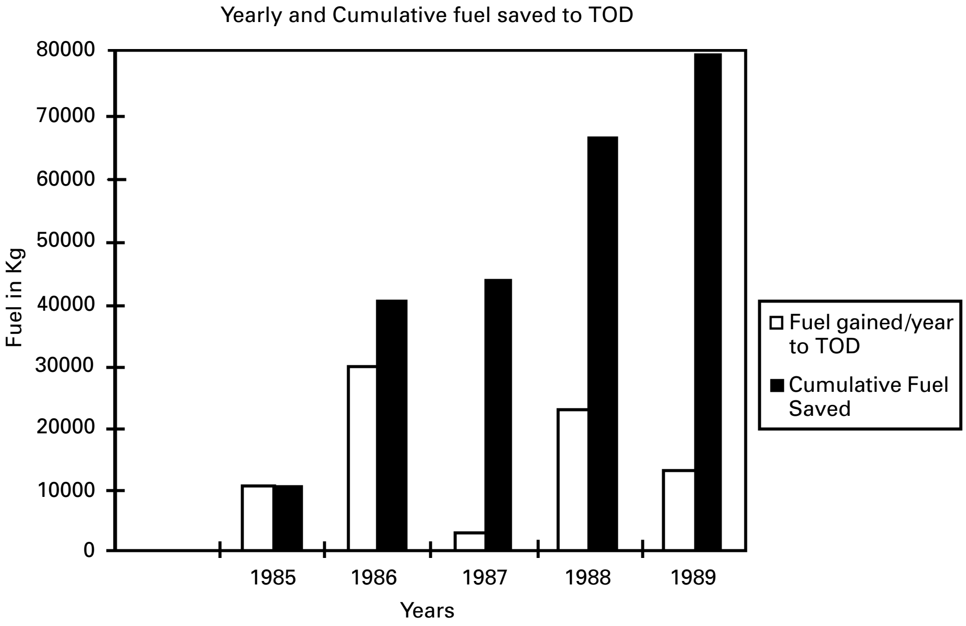


Fig. 3. Velocity vs Fuel Required Curve, schematically showing maximum range and illustrating how the point of origin increases in headwinds and decreases in tailwinds

4. RESULTS. Over a period of 5 years, operating in both headwind and tailwind conditions, savings of more than 1·1 percent were made on fuel and 0·785 percent on time. Figures 4 and 5 graph each year, together with cumulative results.

5. DISCUSSION. When adjusting speed schedules, it is emphasised that only small increments of 3 or 4 knots are required. When spread over a long sector of 10 or more hours, these small numbers become significant. Airway width poses a restraint; however, manoeuvring within the limits yields benefits. Restraint on altitude selection due to conflicting traffic is a major problem that becomes worse each year as more aircraft are registered. Introduction of lower lateral and vertical standards will ease the situation for a number of years; however, the problem will occur again in 5–10 years at the current rate of aircraft production. A 'free flight' policy will possibly have problems with most aircraft endeavouring to intercept a jet stream simultaneously. This is the situation across the North Pacific, where the STJ is constantly saturated with aircraft from Asia to Honolulu and the west coast of the US. Many flights are



DATA

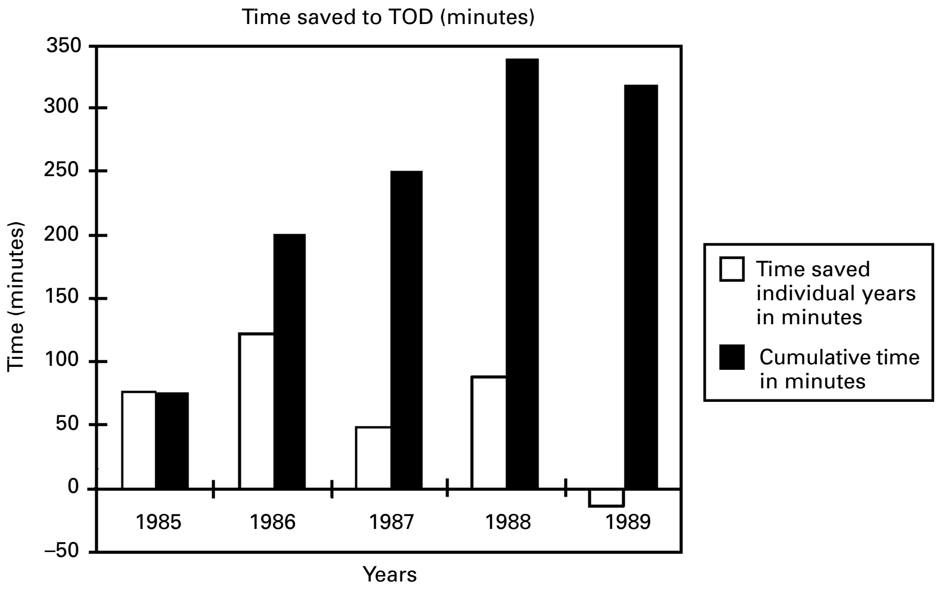
Year	Fuel gained/year to TOD in Kg	Cumulative Fuel Saved in Kg	Fuel Price Cents/US Gallon	Total Savings $US
1985	10805	10805	109	3939
1986	29810	40615	125	12452
1987	3175	43790	83	884
1988	22795	66585	87	6640
1989	12935	79520	76	3275
Refer Fig 1 for fuel prices				$27.189 57

Fig. 4. Fuel saved to top of descent

forced to cruise some 6–8,000 ft off their optimum. Free flight should give most flights optimum altitude, but away from the jet stream wind maxima.

Another area of concern is the quality of international forecasting of jet streams, notably over oceanic and sparsely populated areas. Lack of reporting stations with radiosondes will also continue to be an ongoing problem. Numerical forecasting of jet streams across the Middle East and Indo-Pakistan region has been less than satisfactory particularly in winter months.

The techniques suggested in this paper were passed to five L1011 Tristar captains, operating from the Persian Gulf to Europe. All five reported gains in both fuel and time; however, collection and recording of data were not sufficiently rigorous to be considered as acceptable for this study. As such, they are regarded as positive indicators only with potential for further study. Other aircraft should also be trialled in the interest of saving fuel.



DATA

Year	Time saved individual years in minutes	Cumulative time in minutes	Cumulative Total Savings – $US
1985	77	77	21816
1986	123	200	56666
1987	49	249	70549
1988	88	337	95482
1989	−19	318	90099
Totals	318	318	$90.099

Fig. 5. Time saved to top of descent

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KEY WORDS

1. Air Navigation. 2. Meteorology. 3. Commercial. 4. Nav. Practice.