Fuel Conservation Strategies:
Cost Index Explained

Used appropriately, the cost index (CI) feature of the flight management computer (FMC) can help airlines significantly reduce operating costs. However, many operators don't take full advantage of this powerful tool.

by Bill Roberson,
Senior Safety Pilot, Flight Operations

This article is the first in a series exploring fuel conservation strategies.

COST INDEX DEFINED

The CI is the ratio of the time-related cost of an airplane operation and the cost of fuel. The value of the CI reflects the relative effects of fuel cost on overall trip cost as compared to time-related direct operating costs.

In equation form: $\text{CI} = \dfrac{\text{Time cost} \sim \$/\text{hr}}{\text{Fuel cost} \sim \text{cents/lb}}$

The range of allowable cost indices is shown in Figure 1. The flight crew enters the company-calculated CI into the control display unit (CDU) of the FMC. The FMC then uses this number and other performance parameters to calculate economy (ECON) climb, cruise, and descent speeds.

For all models, entering zero for the CI results in maximum range airspeed and minimum trip fuel. This speed schedule ignores the cost of time.

Conversely, if the maximum value for CI is entered, the FMC uses a minimum time speed schedule. This speed schedule calls for maximum flight envelope speeds, and ignores the cost of fuel (see fig. 2).

VARIABLE FUEL PRICES, FUEL TANKERING, AND FUEL HEDGING MAKE THE COST INDEX CALCULATION COMPLICATED.

THE RANGE OF ALLOWABLE COST INDICES FOR GIVEN BOEING AIRPLANES
Figure 1

Airplane Model	737-300 737-400 737-500	737-600 737-700 737-800 737-900	747-400	757	767	777
Cost Index Range	0-200	0-500	0-9999	0-999 or 0-9999	0-999 or 0-9999	0-9999

COMPARING RESULTS FOR COST INDEX VALUES OF ZERO AND MAXIMUM
Figure 2

	CLIMB	CRUISE	DESCENT
Cost Index 0	Minimum Fuel*	Maximum Range	Max L/D
Cost Index Max	VMO/MMO	VMO/MMO	VMO/MMO

*Entering zero for the cost index results in maximum range airspeed and minimum trip fuel.
Entering the maximum value for cost index results in a minimum time speed schedule.*

* Minimum climb contribution to trip fuel; this is different from minimum fuel to cruise altitude.

CALCULATED VALUES FOR A TYPICAL 757 FLIGHT
Figure 3

	CLIMB	CRUISE	DESCENT	ALTITUDE RECOMMENDATIONS
Cost Index 0	290/.778	.778	250	OPT 328, MAX 362, RECMD 310
Cost Index 9999	345/.847	.847	.819/334	OPT 268, MAX 268, RECMD 260
Cost Index 70	312/.794	.794	.80/313	OPT 327, MAX 363, RECMD 310

COST INDEX IMPACT
Figure 4

FLEET	CURRENT COST INDEX	OPTIMUM COST INDEX	TIME IMPACT MINUTES	ANNUAL COST SAVINGS ($000's)
737-400	30	12	+1	US$754 – $771
737-700	45	12	+3	US$1,790 – $1,971
MD-80	40	22	+2	US$319 – $431

In practice, neither of the extreme CI values is used; instead, many operators use values based on their specific cost structure, modified if necessary for individual route requirements. As a result, CI will typically vary among models, and may also vary for individual routes.

Clearly, a low CI should be used when fuel costs are high compared to other operating costs. The FMC calculates coordinated ECON climb (see fig. 5), cruise, and descent speeds (see fig. 6) from the entered CI. To comply with Air Traffic Control requirements, the airspeed used during descent tends to be the most restricted of the three flight phases. The descent may be planned at ECON Mach/Calibrated Air Speed (CAS) (based on the CI) or a manually entered Mach/CAS. Vertical Navigation (VNAV) limits the maximum target speed as follows:

- 737-300/-400/-500/-600/-700/-800/-900: The maximum airspeed is velocity maximum operating/Mach maximum operating (VMO/MMO) (340 CAS/.82 Mach). The FMC-generated speed targets are limited to 330 CAS in descent to provide margins to VMO. The VMO value of 340 CAS may be entered by the pilot to eliminate this margin.
- 747-400: 349 knots (VMO/MMO minus 16 knots) or a pilot-entered speed greater than 354 knots (VMO/MMO minus 11 knots).
- 757: 334 knots (VMO/MMO minus 16 knots) or a pilot-entered speed greater than 339 knots (VMO/MMO minus 11 knots).
- 767: 344 knots (VMO/MMO minus 16 knots) or a pilot-entered speed greater than 349 knots (VMO/MMO minus 11 knots).
- 777: 314 knots (VMO/MMO minus 16 knots) or a pilot-entered speed greater than 319 knots (VMO/MMO minus 11 knots).

FMCs also limit target speeds appropriately for initial buffet and limit thrust.

Figure 3 illustrates the values for a typical 757 flight.

As stated earlier, entering a CI of zero in the FMC and flying that profile would result in a minimum fuel flight and entering a maximum CI in the FMC and flying that profile would result in a minimum time flight. However, in practice, the CI used by an operator for a particular flight falls within these two extremes. Factors affecting the CI include time-related direct operating costs and fuel costs.

TIME COST

The numerator of the CI is often called time-related direct operating cost (minus the cost of fuel). Items such as flight crew wages can have an hourly cost associated with them, or they may be a fixed cost and have no variation with flying time. Engines, auxiliary power units, and airplanes can be leased by the hour or owned, and maintenance costs can be accounted for on airplanes by the hour, by the calendar, or by cycles. As a result, each of these items may have a direct hourly cost or a fixed cost over a calendar period with limited or no correlation to flying time.

In the case of high direct time costs, the airline may choose to use a larger CI to minimize time and thus cost. In the case where most costs are fixed, the CI is potentially very low because the airline is primarily trying to minimize fuel cost. Pilots can easily understand minimizing fuel consumption, but it is more difficult to understand minimizing cost when something other than fuel dominates.

FUEL COST

The cost of fuel is the denominator of the CI ratio. Although this seems straightforward, issues such as highly variable fuel prices among the operating locations, fuel tankering, and fuel hedging can make this calculation complicated.

A recent evaluation at an airline yielded some very interesting results, some of which are summarized in Figure 4. A rigorous study was made of the optimal CI for the 737 and MD-80 fleets for this particular operator. The optimal CI was determined to be 12 for all 737 models, and 22 for the MD-80. The table (see fig. 4) shows the impact on trip time and potential savings over the course of a year of changing the CI for a typical 1,000-mile trip. The potential annual savings to the airline of changing the CI is between US$4 million and $5 million a year with a negligible effect on schedule.

SUMMARY

CI can be an extremely useful way to manage operating costs. Because CI is a function of both fuel and nonfuel costs, it is important to use it appropriately to gain the greatest benefit. Appropriate use varies with each airline, and perhaps for each flight. Boeing Flight Operations Engineering assists airlines' flight operations departments in computing an accurate CI that will enable them to minimize costs on their routes. For more information, please contact FlightOps.Engineering@boeing.com. 4

THE EFFECT OF COST INDEX WHEN CLIMBING TO CRUISE ALTITUDE
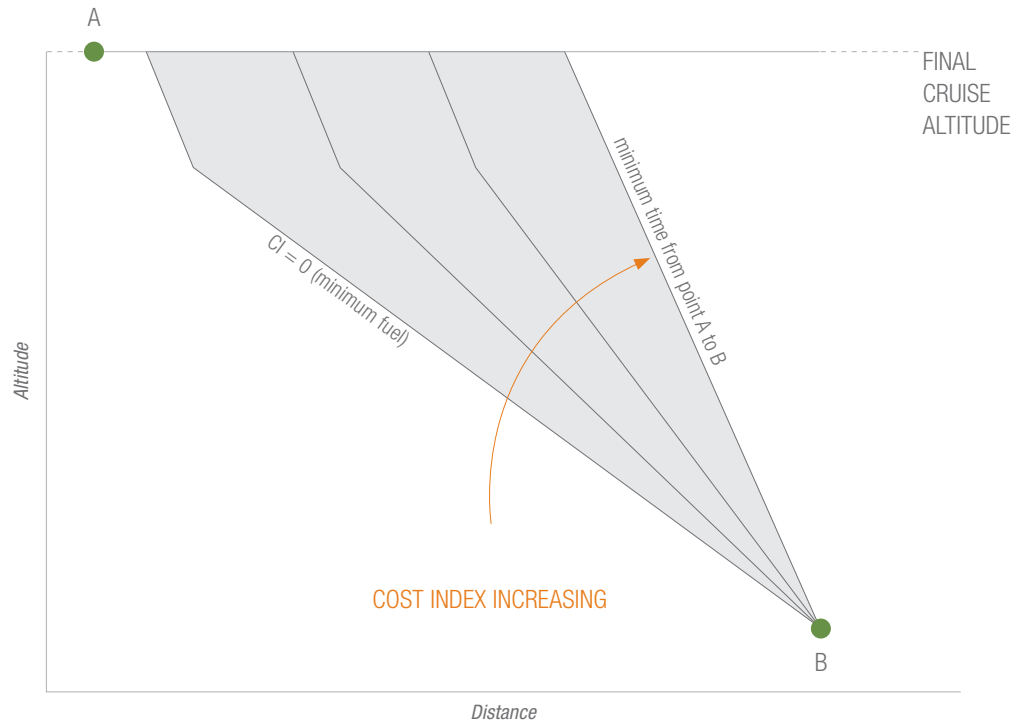*Figure 5*

A cost index of zero minimizes fuel to climb and cruise to a common point in space.
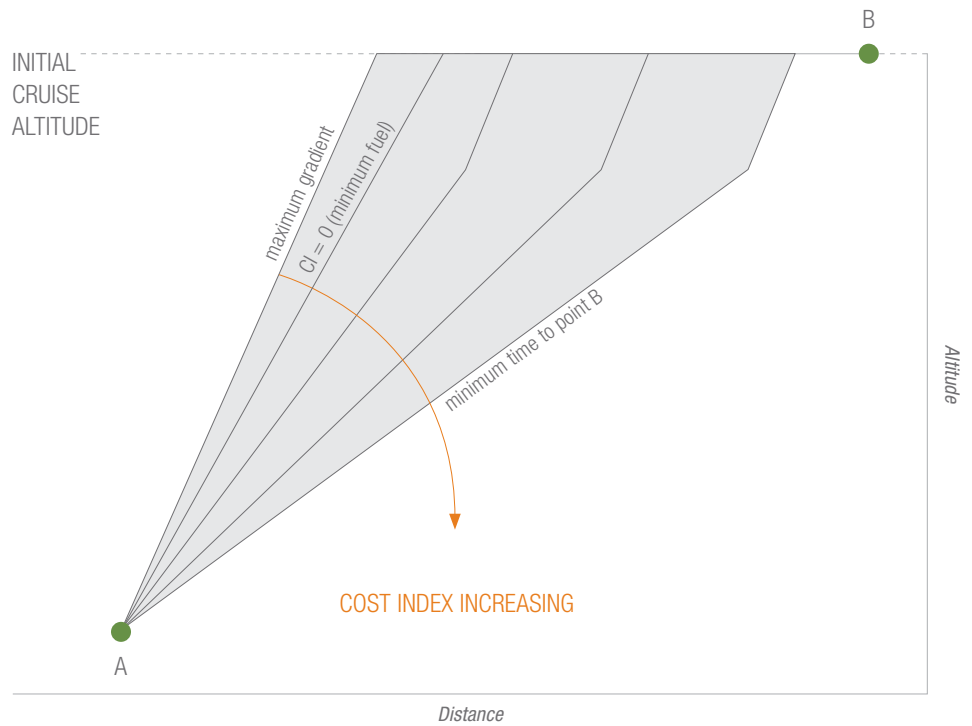
THE EFFECT OF COST INDEX WHEN DESCENDING
Figure 6

A cost index of zero minimizes fuel between a common cruise point and a common end of descent point.

Fuel Conservation Strategies: Cruise Flight

by William Roberson, Senior Safety Pilot, Flight Operations;
Robert Root, Flight Operations Engineering; and
Dell Adams, Flight Operations Engineer

This article is the second in a series exploring fuel conservation strategies.

A good understanding of cruise flight can not only help crews operate efficiently and save their companies money, but can also help them deal with low fuel situations. As an additional benefit, the less fuel consumed, the more environmentally friendly the flight.

This article defines cruise flight, presents various cruise schemes, and outlines the effects of wind on cruise speed calculations. It also discusses the relationship between cruise flight and cost index (CI) which was discussed in the first article in this series, "Fuel Conservation Strategies: Cost Index Explained" in the second-quarter 2007 *AERO*.

Used appropriately, the CI feature of the flight management computer (FMC) can help airlines significantly reduce operating costs. However, many operators don't take full advantage of this powerful tool.

CRUISE FLIGHT DEFINED

Cruise flight is the phase of flight that falls between climb and descent. The largest percentages of trip time and trip fuel are consumed typically in this phase of flight. As an aside, unanticipated low altitude maneuvering, which also impacts trip time and fuel significantly, can often be avoided through appropriate cruise planning.

The variables that affect the total time and fuel burn are speed selection, altitude selection, and, to some degree, center of gravity (CG). This article focuses on speed selection.

A number of high-level objectives may influence speed selection. These objectives, which depend on the perspective of the pilot, dispatcher, performance engineer, or operations planner, can be grouped into five categories:

1. Maximize the distance traveled for a given amount of fuel (i.e., maximum range).
2. Minimize the fuel used for a given distance covered (i.e., minimum trip fuel).
3. Minimize total trip time (i.e., minimum time).
4. Minimize total operating cost for the trip (i.e., minimum cost, or economy [ECON] speed).
5. Maintain the flight schedule.

The first two objectives are essentially the same because in both cases the airplane will be flown to achieve optimum fuel mileage.

Pilots are often forced to deal with shorter-term restraints that may require them to temporarily abandon their cruise strategy one or more times during a flight.

In addition to one of the overall strategic objectives listed above for cruise flight, pilots are often forced to deal with shorter term constraints that may require them to temporarily abandon their cruise strategy one or more times during a flight. These situations may include:

- Flying a fixed speed that is compatible with other traffic on a specified route segment.
- Flying a speed calculated to achieve a required time of arrival (i.e., RTA) at a fix.
- Flying a speed calculated to achieve minimum fuel flow while holding (i.e., maximum endurance).
- When directed to maintain a specific speed by air traffic control.

There are two theoretical speed selections for the cruise phase of flight. The traditional speed is long-range cruise (LRC). LRC speed is interrelated with maximum-range cruise (MRC) speed, which is the speed that will provide the furthest distance traveled for a given amount of fuel burned and the minimum fuel burned for a given cruise distance.

LRC has been historically defined as the speed above MRC that will result in a 1 percent decrease in fuel mileage in terms of nautical miles per kilogram or pound of fuel burned. The classic text, *Aerodynamics for Naval Aviators*, revised in 1965, states: "Most long-range cruise operation is conducted at the flight condition which provides 99 percent of the absolute maximum specific range. The advantage is that 1 percent of range is traded for 3 to 5 percent higher cruise velocity. Since higher cruise speed has a great number of advantages, the small sacrifice of range is a fair bargain." This concept is graphically illustrated in figure 1.

Because fuel is not the only direct cost associated with a flight, a further refinement in the speed for most economical operation is ECON speed, based on the entered CI. This speed, which includes some tradeoffs between trip time and trip fuel, is based on an estimation of the time-related operating expenses that are specific to each airline's operation. CI is defined as the ratio of time-dependent costs to fuel costs.
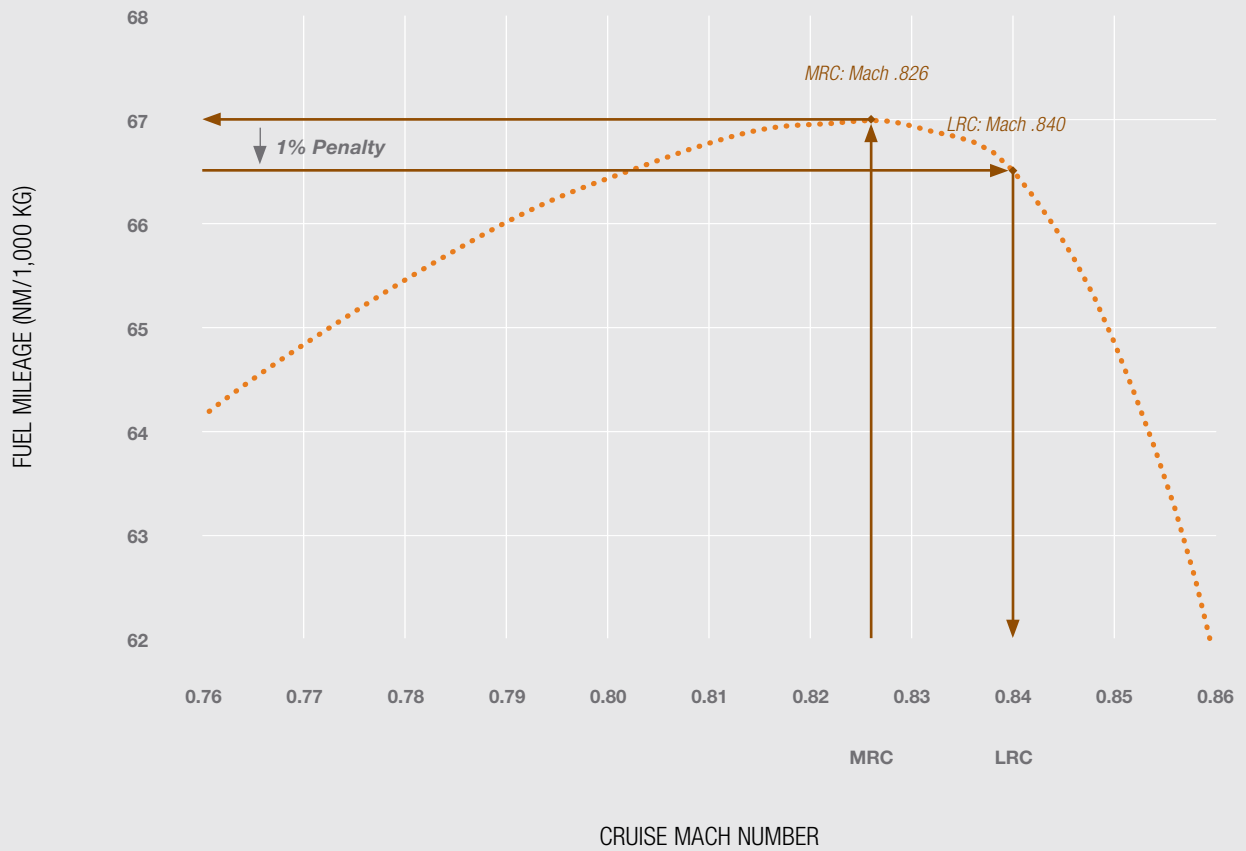
$$CI = \frac{\text{Time cost} \sim \$/hr}{\text{Fuel cost} \sim \text{cents/lb}}$$

The relationship between LRC speed and ECON speed is different for each Boeing airplane model. As stated, LRC is based on a 1 percent penalty on fuel mileage, while the ECON speed uses CI as an input that is based on a more detailed accounting of actual costs. However, it is possible to derive a CI for normal cruise conditions that approximates

*Modern flight management
systems automatically adjust
LRC speed throughout cruise
for weight change due to
fuel burn, as well as changes
in cruise altitude.*

MRC: Mach .826

LRC: Mach .840

1% Penalty

FUEL MILEAGE (NM/1,000 KG)

68

67

66

65

64

63

62

0.76   0.77   0.78   0.79   0.80   0.81   0.82   0.83   0.84   0.85   0.86

MRC   LRC

CRUISE MACH NUMBER

LRC in terms of the cruise speed that results. Figure 2 shows the approximate relationship for Boeing commercial airplanes.

It is very important to note that the LRC speed is almost universally higher than the speed that will result from using the CI selected by most carriers. If faced with a low fuel situation at destination, many pilots will opt to fly LRC speed thinking that it will give them the most miles from their remaining fuel. As shown in figure 2, the best strategy to conserve fuel is to select a very low cost index, with zero providing the maximum range. Any pilot can easily demonstrate this during cruise flight by inputting different CIs into the FMC and comparing with LRC by observing the predicted fuel at destination.

In addition to more accurately optimizing costs, there is one other benefit of flying ECON instead of LRC with most Boeing airplanes. The LRC speed calculated by the FMC is typically not adjusted for winds at cruise altitude but the ECON speed is. As a result, LRC is ideal only for zero wind conditions, while the ECON speed is optimized for all cruise wind conditions.

For example, in the presence of a strong tailwind, the ECON speed will be reduced in order to maximize the advantage gained from the tailwind during the cruise. Conversely, the ECON speed will be increased when flying into a headwind in cruise to minimize the penalty associated with the headwind (see example in fig. 3).

THE RELATIONSHIP BETWEEN
OPERATING COSTS AND COST INDEX

If fuel prices increase relative to other costs, a corresponding reduction in CI will maintain the most economical operation of the airplane. If, however, an airline experiences rising hourly costs, an increase in CI will retain the most economical operation. In either case, the changing CI will result in changes to the cruise speed calculated by the FMC. Even calculating a cost index based on approximate time costs and flying ECON speed can yield significant cost benefits to the airline.

To be used most effectively, CI should be based on a comprehensive evaluation of an operator's specific operating costs. For this reason, flight crews typically receive a recommended CI value from their flight operations department, and it is generally not advisable to deviate from this value unless specific short-term constraints demand it.

SUMMARY

In order for flight crews to achieve optimum cruise operation, it is necessary to first understand the flight's strategic objectives, and then to select the cruise speed that best meets these objectives. It is equally important to recognize that real-world situations may result in the need for deviations from the overriding strategy. Appropriate use varies with each airline, and sometimes even for each flight.
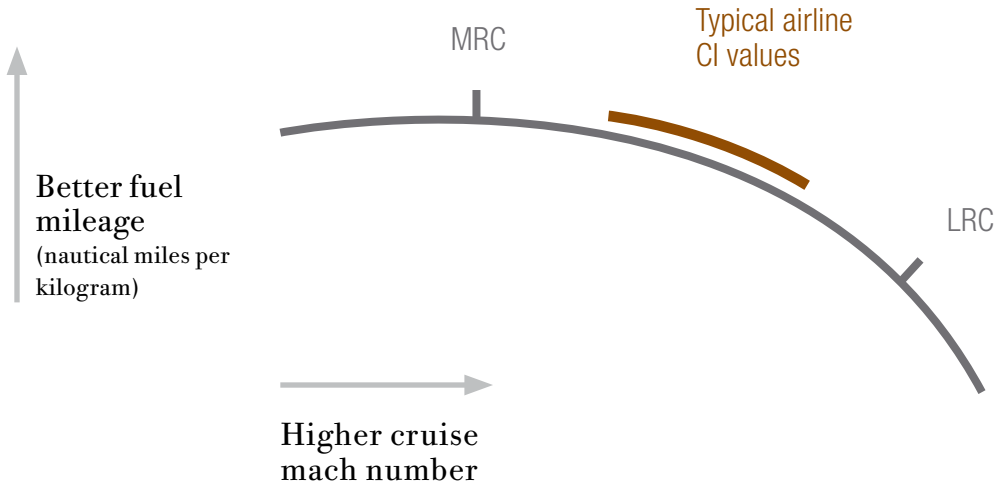
Boeing Flight Operations Engineering assists airlines' flight operations departments in computing an accurate CI that will enable them to minimize costs on their routes. For more information, please contact FlightOps.Engineering@boeing.com.

MRC

Typical airline CI values

Better fuel mileage (nautical miles per kilogram)

LRC

Higher cruise mach number

Entered Cost Index (CI)

AIRPLANE MODEL	MRC	TYPICAL AIRLINE CI VALUES	APPROXIMATE LRC EQUIVALENT
717	0	40 to 60	70
737-3/4/500	0	5 to 25	25
737-6/7/800	0	10 to 30	35
757	0	15 to 50	85
767	0	15 to 55	70
777	0	90 to 150	180
MD-11	0	80 to 120	200
747-400	0	25 to 80	230

ECON Cruise Mach

COST INDEX	100 KT TAILWIND	ZERO WIND	100 KT HEADWIND
0	0.773*	0.773	0.785
80	0.787	0.796	0.803
Max**	0.811	0.811	0.811

*FMC will not slow down below still air CI=0 ECON speed.

**At maximum CI, FMC will fly at envelope limit in all wind conditions.

Fuel Conservation Strategies: Takeoff and Climb

By William Roberson, Senior Safety Pilot, Flight Operations; and
James A. Johns, Flight Operations Engineer, Flight Operations Engineering

This article is the third in a series exploring fuel conservation strategies.

Every takeoff is an opportunity to save fuel. If each takeoff and climb is performed efficiently, an airline can realize significant savings over time. But what constitutes an efficient takeoff? How should a climb be executed for maximum fuel savings? The most efficient flights actually begin long before the airplane is cleared for takeoff.

This article discusses strategies for fuel savings during the takeoff and climb phases of flight. Subsequent articles in this series will deal with the descent, approach, and landing phases of flight, as well as auxiliary-power-unit usage strategies. The first article in this series, "Cost Index Explained," appeared in the second-quarter 2007 *AERO*. It was followed by "Cruise Flight" in the fourth-quarter 2007 issue.

TAKEOFF AND CLIMB FUEL CONSERVATION STRATEGIES

In the past, when the price of jet fuel increased by 20 to 30 cents per U.S. gallon, airlines did not concern themselves with fuel conservation in the takeoff and climb segment of the flight because it represents only 8 to 15 percent of the total time of a medium- to long-range flight.

But times have clearly changed. Jet fuel prices have increased over five times from 1990 to 2008. At this time, fuel is about 40 percent of a typical airline's total operating cost. As a result, airlines are reviewing all phases of flight to determine how fuel burn savings can be gained in each phase and in total.

This article examines the takeoff and climb phase for four types of commercial airplanes to illustrate various takeoff and climb scenarios and how they impact fuel usage. These analyses look at short-range (e.g., 717), medium-range (e.g., 737-800 with winglets), and long-range (e.g., 777-200 Extended Range and 747-400) airplanes.

An important consideration when seeking fuel savings in the takeoff and climb phase of flight is the takeoff flap setting. The lower the flap setting, the lower the drag, resulting in less fuel burned. Figure 1 shows the effect of takeoff flap setting on

fuel burn from brake release to a pressure altitude of 10,000 feet (3,048 meters), assuming an acceleration altitude of 3,000 feet (914 meters) above ground level (AGL). In all cases, however, the flap setting must be appropriate for the situation to ensure airplane safety.

Higher flap setting configurations use more fuel than lower flap configurations. The difference is small, but at today's prices the savings can be substantial — especially for airplanes that fly a high number of cycles each day.

For example, an operator with a small fleet of 717s which flies approximately 10 total cycles per day could save 320 pounds (145 kilograms) of fuel per day by changing its normal takeoff flaps setting from 18 to 5 degrees. With a fuel price of US$3.70 per U.S. gallon, this would be approximately US$175 per day. Assuming each airplane

THE ROLE OF THE FLIGHT CREW IN FUEL CONSERVATION

Every area of an airline has a part to play in reducing the cost of the operation. But the flight crew has the most direct role in cutting the amount of fuel used on any given flight.

The flight crew has opportunities to affect the amount of fuel used in every phase of flight without compromising safety. These phases include planning, ground operations, taxi out, takeoff, climb, cruise, descent, approach, landing, taxi in, and maintenance debrief.

Top fuel conservation strategies for flight crews include:

- Take only the fuel you need.
- Minimize the use of the auxiliary power unit.
- Taxi as efficiently as possible.
- Take off and climb efficiently.
- Fly the airplane with minimal drag.
- Choose routing carefully.
- Strive to maintain optimum altitude.
- Fly the proper cruise speed.
- Descend at the appropriate point.
- Configure in a timely manner.

is flown 350 days per year, the airline could save approximately US$61,000 a year. If an airline makes this change to a fleet of 717 airplanes that averages 200 cycles a day, it could save more than US$1 million per year in fuel costs.

Using these same assumptions on fuel price, the potential fuel savings for an operator of a small fleet of 747-400s whose airplanes average a total of three cycles per day would be approximately 420 U.S. pounds (191 kilograms) of fuel per day, or approximately US$230. During a year, the operator could save approximately US$84,000. These savings are not as dramatic as the short-range transport airplane, but clearly they increase as the fleet size or number of cycles grows.

Operators need to determine whether their fleet size and cycles are such that the savings would make it worthwhile to change procedures and pilot training. Other important factors that determine whether or not it is advisable to change standard takeoff settings include obstacles clearance, runway length, airport noise, and departure procedures.

Another area in the takeoff and climb phase where airlines can reduce fuel burn is in the climb-out and cleanup operation. If the flight crew performs acceleration and flap retraction at a lower altitude than the typical 3,000 feet (914 meters), the fuel burn is reduced because the drag is being reduced earlier in the climb-out phase.

COMPARING THE FUEL USAGE OF TWO STANDARD CLIMB PROFILES

Figure 2 shows two standard climb profiles for each airplane. These simplified profiles are based on the International Civil Aviation Organization (ICAO) Procedures for Air Navigation Services Aircraft Operations (PANS-OPS) Noise Abatement Departure Procedures (NADP) NADP 1 and NADP 2 profiles. Profile 1 is a climb with acceleration and flap retraction beginning at 3,000 feet (914 meters) AGL, which is the noise climb-out procedure for close-in noise monitors. Profile 2 is a climb with acceleration to flap retraction speed beginning at 1,000 feet (305 meters) AGL, which is the noise climb-out procedure for far-out noise monitors. As a general rule, when airplanes fly Profile 2,

IMPACT OF TAKEOFF FLAPS SELECTION ON FUEL BURN
Figure 1

AIRPLANE MODEL	TAKEOFF FLAP SETTING	TAKEOFF GROSS WEIGHT Pounds (kilograms)	FUEL USED Pounds (kilograms)	FUEL DIFFERENTIAL Pounds (kilograms)
717-200	5	113,000 (51,256)	933 (423)	–
	13		950 (431)	17 (8)
	18		965 (438)	32 (15)
737-800 Winglets	5	160,000 (72,575)	1,274 (578)	–
	10		1,291 (586)	17 (8)
	15		1,297 (588)	23 (10)
777-200 Extended Range	5	555,000 (249,476)	3,605 (1,635)	–
	10		3,677 (1,668)	72 (33)
	20		3,730 (1,692)	125 (57)
747-400	10	725,000 (328,855)	5,633 (2,555)	–
	20		5,772 (2,618)	139 (63)
747-400 Freighter	10	790,000 (358,338)	6,389 (2,898)	–
	20		6,539 (2,966)	150 (68)

FUEL-SAVING POTENTIAL OF TWO CLIMB PROFILES
Figure 2

AIRPLANE MODEL	TAKEOFF GROSS WEIGHT Pounds (kilograms)	PROFILE TYPE	TAKEOFF FLAP SETTING	FUEL USED Pounds (kilograms)	FUEL DIFFERENTIAL Pounds (kilograms)
717-200	113,000 (51,256)	1	13	4,025 (1,826)	–
		2		3,880 (1,760)	145 (66)
737-800 Winglets	160,000 (72,575)	1	10	5,234 (2,374)	–
		2		5,086 (2,307)	148 (67)
777-200 Extended Range	555,000 (249,476)	1	15	14,513 (6,583)	–
		2		14,078 (6,386)	435 (197)
747-400	725,000 (328,855)	1	10	21,052 (9,549)	–
		2		20,532 (9,313)	520 (236)
747-400 Freighter	790,000 (358,338)	1	10	23,081 (10,469)	–
		2		22,472 (10,193)	609 (276)

EFFECT OF COMBINING TAKEOFF AND CLIMB STRATEGIES
Figure 3

AIRPLANE MODEL	TAKEOFF GROSS WEIGHT *Pounds (kilograms)*	PROFILE TYPE	TAKEOFF FLAP SETTING	FUEL USED *Pounds (kilograms)*	FUEL DIFFERENTIAL *Pounds (kilograms)*
717-200	113,000 (51,256)	1	18	4,061 (1,842)	–
		2	5	3,859 (1,750)	202 (92)
737-800 Winglets	160,000 (72,575)	1	15	5,273 (2,392)	–
		2	5	5,069 (2,299)	204 (93)
777-200 Extended Range	555,000 (249,476)	1	20	14,710 (6,672)	–
		2	5	14,018 (6,358)	692 (314)
747-400	725,000 (328,855)	1	20	21,419 (9,715)	–
		2	10	20,532 (9,313)	887 (403)
747-400 Freighter	790,000 (358,338)	1	20	23,558 (10,686)	–
		2	10	22,472 (10,193)	1,086 (493)

they use 3 to 4 percent less fuel than when flying Profile 1.

Figure 3 shows the combined effect of using a lower takeoff flap setting and flying Profile 2, compared to using a higher takeoff flap setting and flying Profile 1. Combining a lower takeoff flap setting with Profile 2 saves approximately 4 to 5 percent fuel compared to the higher takeoff flap setting and Profile 1.

Once the flaps are retracted, the crew should accelerate to maximum rate of climb speed. The 737s with flight management computers (FMC) provide this speed directly via the FMC control display unit. All Boeing flight crew training manuals provide guidance for maximum rate of climb speed. It can also be achieved by entering a cost index of zero in the FMC. (See "Cost Index Explained" in the second-quarter 2007 *AERO*.)

OTHER CONSIDERATIONS

From a fuel consumption perspective, a full-thrust takeoff and a full-thrust climb profile offer the most fuel economy for an unrestricted climb. However, from an airline's cost perspective, this must be balanced with engine degradation and time between overhauls, as well as guidance from the engine manufacturer. The airline's engineering department must perform the analysis and provide direction to flight crews to minimize overall cost of operation when using takeoff derates or assumed temperature takeoffs and climbs.

SUMMARY

In a time when airlines are scrutinizing every aspect of flight to locate possible opportunities to save fuel, the takeoff and climb phases of flight should be considered as part of an overall fuel savings effort. The impact of incorporating fuel saving strategies into every phase of the operation can result in considerable cost reductions.

Boeing Flight Operations Engineering assists airlines' flight operations departments in determining appropriate takeoff and climb profiles specific to their airplane models. For more information, please contact FlightOps.Engineering@boeing.com

Decisions on which type of approach to use vary with each airline, and sometimes even for each flight.

Fuel Conservation Strategies: Descent and Approach

The descent and approach phases of flight represent the flight crew's final opportunities to reduce fuel consumption during flight. By carefully planning the airplane's descent and appropriately using drag and high lift devices, the flight crew can ensure a safe landing while saving fuel.

By **William Roberson,** Chief Pilot Research, and
James A. Johns, Flight Operations Engineer, Flight Operations Engineering

This article is the fourth and final in a series exploring fuel conservation strategies. It discusses strategies for saving fuel during the descent and approach phases of flight. The first article in this series, "Cost Index Explained," appeared in the second-quarter 2007 AERO. *It was followed by "Cruise Flight" in the fourth-quarter 2007 issue and "Takeoff and Climb" in the fourth-quarter 2008 issue.*

Fuel conservation is a significant concern of every airline. An airline can choose an approach procedure and flap setting policy that uses the least amount of fuel, but it should also consider the trade-offs involved with using this type of procedure.

In this article, two types of approaches are analyzed: the standard approach and the low-drag or delayed-flaps approach. The cost of a missed approach is also discussed.

THE STANDARD APPROACH

Boeing flight crew training manuals and/or flight crew operating manuals (FCOM) define standard approach profiles for every Boeing model. These profiles include specific flap settings and when to select them during various parts of the approach (see fig. 1).
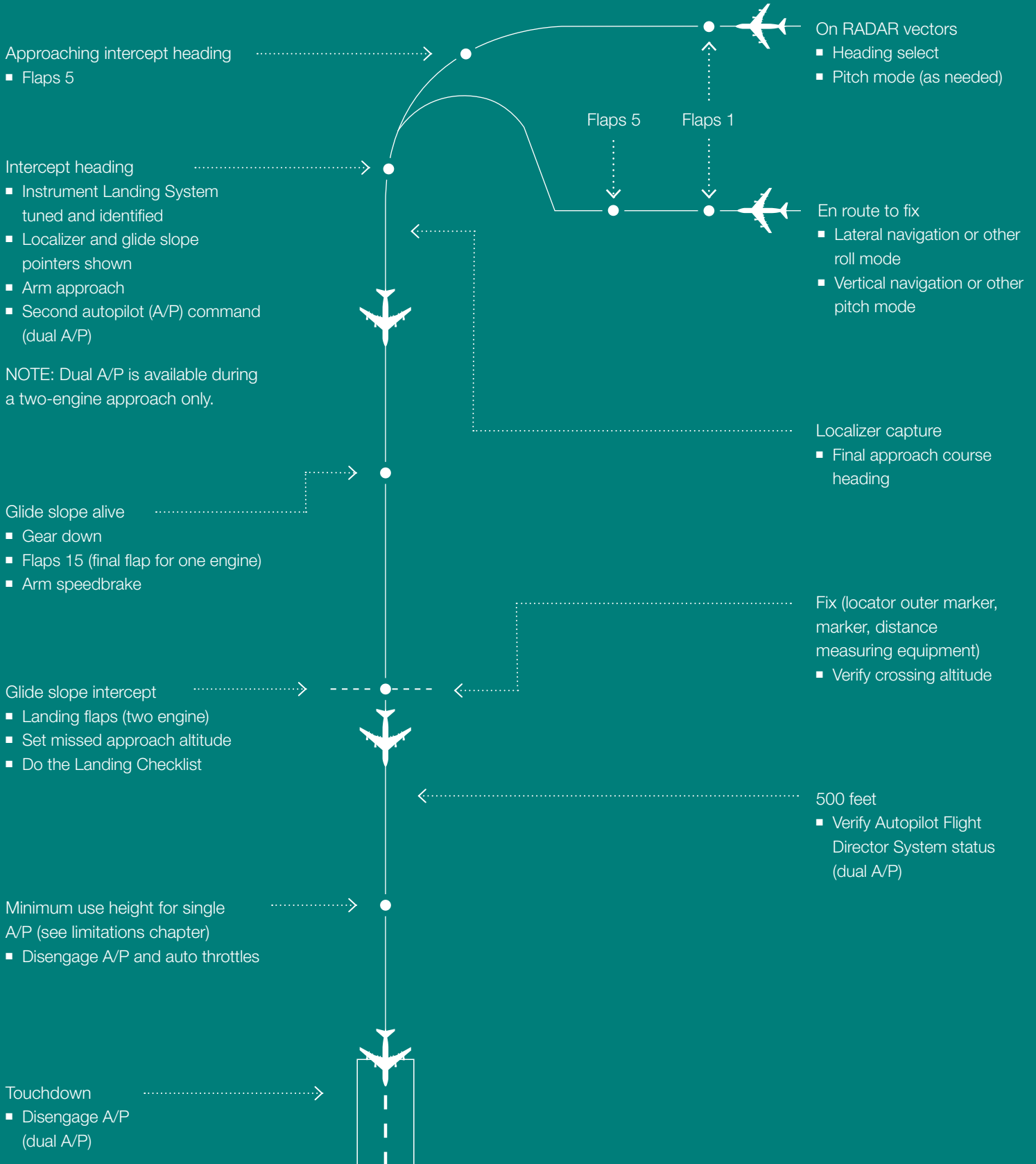
THE LOW-DRAG OR DELAYED-FLAPS APPROACH

If the approach is not being conducted in adverse conditions that would make it difficult to achieve stabilized approach criteria, the final flap selection may be delayed until just prior to 1,000 feet above field elevation (AFE) to conserve fuel and reduce noise and emissions or to accommodate speed requests by air traffic control. This approach is known as a low-drag,

Figure 1: Standard approach profile for 737 models

Boeing flight crew training manuals and/or operating manuals include specific instructions for standard approaches.

Approaching intercept heading
- Flaps 5

Flaps 5   Flaps 1

On RADAR vectors
- Heading select
- Pitch mode (as needed)

Intercept heading
- Instrument Landing System tuned and identified
- Localizer and glide slope pointers shown
- Arm approach
- Second autopilot (A/P) command (dual A/P)

NOTE: Dual A/P is available during a two-engine approach only.

En route to fix
- Lateral navigation or other roll mode
- Vertical navigation or other pitch mode

Localizer capture
- Final approach course heading

Glide slope alive
- Gear down
- Flaps 15 (final flap for one engine)
- Arm speedbrake

Fix (locator outer marker, marker, distance measuring equipment)
- Verify crossing altitude

Glide slope intercept
- Landing flaps (two engine)
- Set missed approach altitude
- Do the Landing Checklist

500 feet
- Verify Autopilot Flight Director System status (dual A/P)

Minimum use height for single A/P (see limitations chapter)
- Disengage A/P and auto throttles

Touchdown
- Disengage A/P (dual A/P)

Figure 2: Fuel savings estimates for delayed-flaps approach procedure

The delayed-flaps approach uses 15 to 380 fewer pounds of fuel than the standard approach with the same flap setting.

AIRPLANE ENGINE	LANDING WEIGHT LBS (KG)	LANDING FLAP (DEG)	PROCEDURE	FUEL BURNED LBS (KG)	FUEL DIFFERENTIAL LBS (KG)
737-800 CFM56-7B24	120,000 (54,431)	30	Standard	230 (104)	
		30	Delayed	213 (97)	17 (8)
		40	Standard	266 (121)	
		40	Delayed	230 (104)	36 (16)
747-400 CF6-80C2B1F	450,000 (20,411)	25	Standard	590 (268)	
		25	Delayed	540 (245)	50 (23)
		30	Standard	610 (277)	
		30	Delayed	230 (104)	380 (172)
767-300 CF6-80C2B4	270,000 (122,469)	25	Standard	400 (181)	
		25	Delayed	370 (168)	30 (14)
		30	Standard	440 (200)	
		30	Delayed	390 (177)	50 (23)
777-200 GE90-94B	450,000 (204,411)	25	Standard	850 (385)	
		25	Delayed	790 (358)	60 (27)
		30	Standard	920 (417)	
		30	Delayed	820 (372)	100 (45)

delayed-flaps, or noise-abatement approach. The actual steps to use vary by airplane model and are described in the FCOM, flight crew training manual, or airline standard operating policy. These are the general steps for the 737, 757, 767, and 777:

- 737: Intercept the glide slope with gear down and flaps 15 at flaps 15 speed. 757/767/777: Intercept the glide slope with gear down and flaps 20 at flaps 20 speed.

  Note: The thrust required to descend on the glide slope may be near idle.

- Approaching 1,000 feet AFE, select landing flaps, reduce the speed to the final approach speed, and then adjust thrust to maintain it.
- Perform the Landing Checklist.

  Note for the 757/767/777: In particularly noise-sensitive areas, use the technique above but delay extending the landing gear until 1,500 feet AFE.

FUEL SAVINGS ASSOCIATED WITH DELAYED-FLAPS APPROACH

Depending on the flap setting and airplane model, the delayed-flaps approach uses 15 to 380 fewer pounds of fuel than the standard approach with the same flap setting (see fig. 2). To repeat, this approach should only be conducted in conditions that do not make it difficult to achieve a stabilized approach criteria.

Figure 3: Additional fuel burn attributed to missed approaches

The fuel burned during one missed approach is equivalent to 2 to 28 times the fuel burn required for a descent and approach.

AIRPLANE/ENGINE	ADDITIONAL FUEL BURN LBS (KG)
737-800 CFM56-7B24	280 (127)
747-400 CF6-80C2B1F	1,400 (635)
767-300 CF6-80C2B4	610 (277)
777-200 GE90-94B	880 (399)

Planning an approach to minimize fuel consumption

Seven key points should be considered when planning an approach and descent to minimize fuel consumption:

1. Plan the descent carefully.

2. Start the descent at the proper point.

3. Fly the most economical speed.

4. Use idle thrust for descents.

5. Avoid flying extended periods at low altitudes.

6. Configure flaps and gear for landing at the optimal time.

7. Use the most appropriate final flaps setting for landing.

THE COST OF A MISSED APPROACH

Although reduced-flap, delayed-flap, or low-drag approach procedures can save an airline significant amounts of fuel over time, if these procedures are inappropriately applied resulting in a missed approach, the subsequent additional fuel burn required for the missed approach and additional flight pattern with nullify all the fuel saving efforts employed on the entire flight. It cannot be overemphasized that the first priority of the crew is to fly the descent and approach safely and to be in a position to land at the appropriate time.

The typical missed-approach procedure is to apply go-around thrust, retract the flaps and gear while climbing to a minimum of 1,500 feet AFE, and accelerate to a minimum of flaps-up maneuvering speed. Depending on the airplane model and landing flap configuration, the fuel burned during one missed approach is equivalent to 2 to 28 times the fuel burn required for a descent and approach (see fig. 3). There will also be the fuel required to fly an additional traffic pattern.

SUMMARY

Flight crews can vary their approach procedures and flap selections to match the flight's strategic objectives, which almost always include fuel conservation, noise abatement, and emissions reduction. Decisions on which type of approach to use vary with each airline, and sometimes even for each flight.

Boeing Flight Operations Engineering assists airlines' flight operations departments in planning low-drag approaches for any airport in the world. For more information, please contact FlightOps. Engineering@boeing.com. 4