Fuel Conservation Strategies:
Cruise Flight

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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.

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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.

POSSIBLE CRUISE SCHEMES

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.

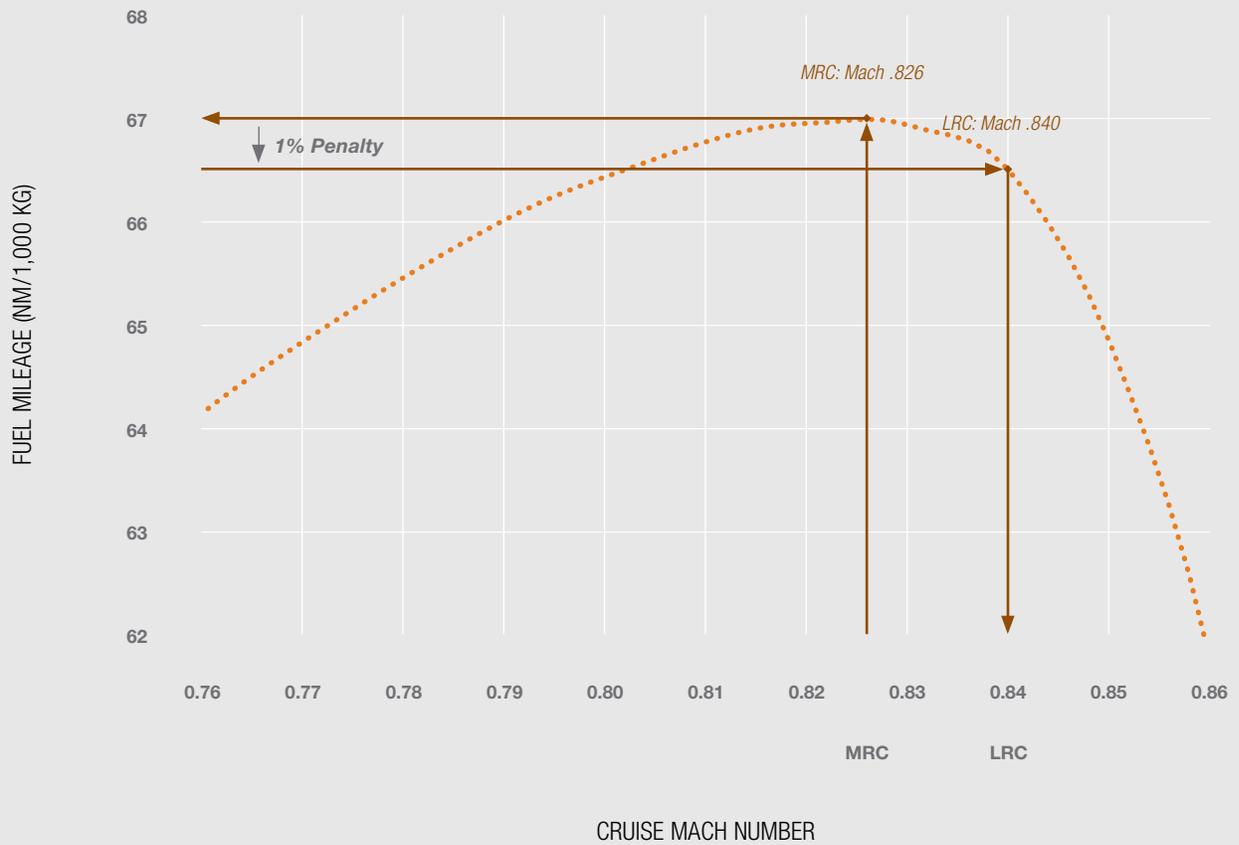$$CI = \frac{\text{Time cost} \sim \$/hr}{\text{Fuel cost} \sim cents/lb}$$

LONG-RANGE CRUISE AND COST INDEX

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.
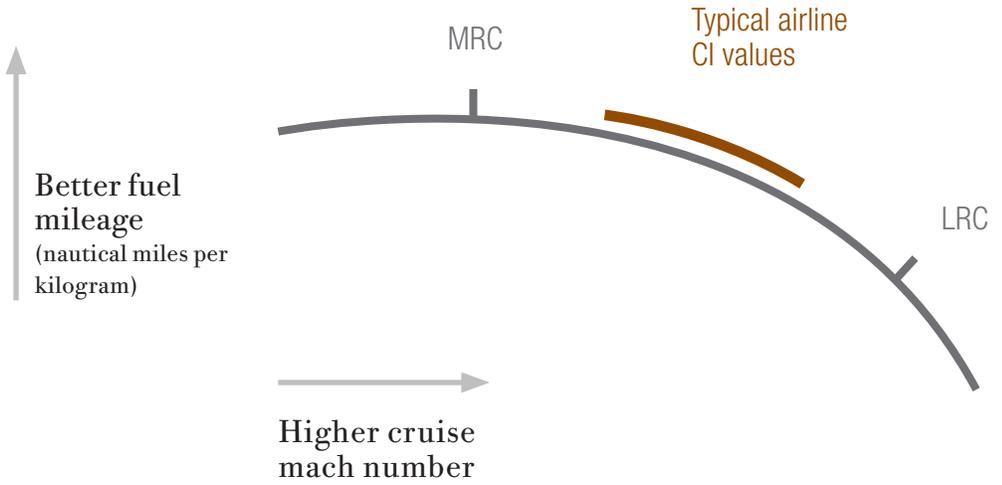
SUMMARY

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. 4

**RELATIONSHIP OF
COST INDEX TO
LRC FOR BOEING
AIRPLANES**
Figure 2

*The LRC-equivalent cost index
varies for different airplane
models and engines.*

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	5 to 25	25
737-3/4/500	0	10 to 30	30
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.