
*THE DIFFERENCE BETWEEN HIGHER AND LOWER FLAP SETTING CONFIGURATIONS MAY SEEM SMALL, BUT AT TODAY'S FUEL PRICES THE SAVINGS CAN BE SUBSTANTIAL.*

# *Fuel Conservation Strategies:* Takeoff and Climb

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*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