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Fuel Conservation

Michael E. Irrgang
Director of Marketing
PROS Strategic Solutions, Inc.

Introduction

Fuel represents one of the most significant items in an airline's operating budget — in fact, it is the single highest direct operating cost for many airlines (competing with crew and maintenance costs). Looking at some typical costs:

- A Boeing 747-400 flying trans-Pacific routes could burn as much as 15 million gallons of fuel per year. At 66¢ per gallon (a typical price in recent years), this single aircraft could burn $10,000,000 in fuel per year!
- At the other extreme, a McDonnell Douglas MD-80 flying short haul with heavy utilization would burn around 5,000,000 gallons per year, for over $3,000,000 per year.

The world's largest airlines typically spend from $1 billion to $2 billion each, per year, for fuel.

These costs obviously become critical whenever an airline needs to reduce expenses. Because of the complexities involved in reducing fuel use, and the myriad factors involved, however, most airlines have great difficulties in this area. A good comprehensive fuel conservation program could probably reduce fuel consumption by 5% (Fuel Conservation, 1990). For many carriers, this exceeds the amount of money they have lost in recent years.

Some Basic Issues

The best way for an airline to save fuel is to modernize its fleet, converting to newer, more fuel-efficient aircraft. The current generation of aircraft, including the B 747-400, B 757, MD-11, A 320, etc., not only have revolutionized flying with their heavily automated systems and two-man cockpits, they have cut the fuel consumption per aircraft seat in half from the previous generation of aircraft, including the DC-10 and B 727. The aircraft manufacturers have done this by increasing significantly the use of lightweight materials in aircraft, thereby reducing their overall weight, and by improving engine efficiency.

However, most airlines cannot afford to modernize their fleets — certainly not after the recent long industry recession. And, regardless of the type of aircraft, the principal ways to reduce fuel costs are always some combination of these general issues:

- Reducing aircraft weight,
- Reducing extra flying, and
- Reducing inefficient and wasteful procedures.

Weight

All aircraft fuel conservation measures ultimately boil down to aircraft weight reduction. The basic issues are:

- For any aircraft type, the heavier the individual aircraft, from any unnecessary weight, the more fuel it burns, and, therefore, the more fuel it must carry.
- The more planned, unneeded flying in a given flight plan, the more fuel that must be carried.
- The more inefficient procedures are common in an airline, the more fuel will be planned to accommodate these procedures.
- It takes burning even more extra fuel to carry all the weight of the extra fuel carried above.

In other words:

- If you can find any way to reduce the weight of the aircraft, you will save fuel.
- The best and easiest way to reduce a large amount of extra weight is to find ways to carry less fuel.

Here are the costs of fuel to carry fuel for two representative aircraft, by length of flight ("Fuel Conservation," 1992).

Table 1 Fuel Costs, two aircraft

Flt. Hours	1	2	3	4	5	6	7	8
B 747-200	3.5	7.1	10.6	13.5	17.6	24.2	30.6	34.3
B 727-200	3.5	8.7	14.0	17.6				

A general rule of thumb often used by many pilots is that you burn 4% of the extra fuel you carry each hour just to carry the fuel ("Fuel Conservation," 1992). This number is higher in newer, more fuel-efficient aircraft, as they are more payload-sensitive.

Most airlines today have programs to find ways to remove unnecessary weight from the cabin, thereby reducing weight. What type of payback can they get from such programs? For any given airline, the benefits are going to vary, based on the use pattern for aircraft; e.g., different airlines will get different savings per unit weight reduction for the same aircraft type. Looking at some typical costs, and taking the aircraft in the original example:

- A Boeing 747-400 flying trans-Pacific routes could save as much as 31 gallons of fuel per year, per pound of weight reduction. At 66¢ per gallon (a typical price in recent years), this single aircraft would save $20 in fuel per pound, per year!
- A McDonnell Douglas MD-80 flying short haul with heavy use could save as much as 45 gallons per year, per pound of weight reduction, for around $30 per pound, per year.
- Additional reductions in other costs associated with having a heavier aircraft (maintenance, especially engine, etc.) can significantly increase these savings.

The airframe manufactures should take note. Based on this example, over a 25-year life of an aircraft, a widebody, such as the 747, could save well over $500 per pound of weight reduction, allowing for inflation; and a narrowbody, over $800 per pound.

Suppose an airline has 50 narrowbodies, and can reduce weight by cutting fuel load by 1,000 pounds across the fleet. Such a conservation program will cut fuel consumption by an order of magnitude of $1,500,000 per year, depending on the airline's route structure and aircraft use profile.

Safety

Weight reduction by reducing fuel carried must never be allowed to compromise safety. The Avianca B 707 disaster in Long Island, in January, 1990, was an example of running out of fuel. Due to an unfortunate combination of circumstances, this aircraft stayed in the air unnecessarily long until it ran out of fuel.

If an airline has effective flight planning, effective flight monitoring, good communications and a System Operations Control Center (SOC), such a situation will never occur. The FAA mandates minimum reserve fuel depending on type of flight (international versus domestic U.S.) and weather conditions (requiring an alternate, versus not requiring one). Most airlines typically plan *significantly more additional* fuel (reserve + alternate + hold fuel) beyond the minimum to fly than the Federal Aviation Regulation (FAR) minimums; often more than twice the amount. Usually, this extra fuel is planned to allow for the variability and unknowns that a flight might encounter.

The more unknowns that can be taken out of the flight plan, making the flight more predictable, the less extra fuel that will be required. And the more efficiency that can be built into the plan, the less fuel will be required for the basic plan. This is how major reductions in fuel carried can be accomplished without compromising safety.

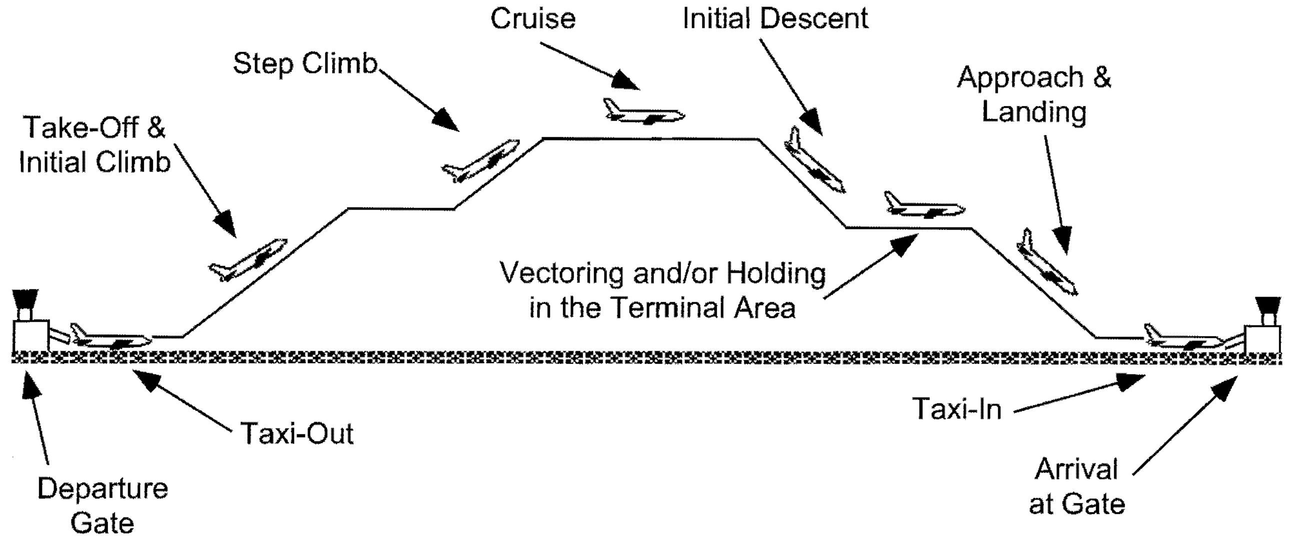
Conservation Philosophy

In order to implement effective fuel conservation, it is first necessary to educate pilots in basic elements of fuel conservation. In general, most pilots view fuel as follows: ("Destination-Specific Ramp Arrival Fuel," 1992).

- There is no such thing as too much fuel.
- Fuel is always measured in pounds (kilos), not in minutes.

In order for pilots to conserve fuel and change their view on the first point, pilots need to be made aware of the costs associated with fuel, and how their actions affect these costs. In these days of airline industry recession,

Figure 1. Stages of a Flight



airline layoffs and bankruptcies, pilots are well aware that their futures are intimately connected with how they can assist their employer in saving money. If they can be taught how to cut fuel use, they will do so.

For pilots to control their fuel use in modern aircraft, such as the A320, MD-87, and the 747-400, it is also necessary to think of fuel in terms of *time*, not *weight*. These new aircraft are far more weight-sensitive to fuel planning, unlike the older aircraft such as DC-10 and B 727. This sensitivity is a natural result of fuel efficiency. If pilots can be educated to think in terms of time, it is easier to control many different fuel burn factors.

Unfortunately, one element working against this approach is the human factors design of the cockpit instruments. While it is completely feasible to have a user interface to piloting of the aircraft that is more oriented toward optimizing fuel, the current interface, even on fully computerized aircraft (also called "fly by wire" and "glass cockpit" aircraft, after the replacement of electromechanical controls and analog instruments with computers), is to still emulate the original analog instrumentation. In other words, the information displayed to the pilots in the cockpit has taken a "lowest common denominator" approach instead of fully using the cockpit computer to orient the pilot toward fuel conservation.

Designing and implementing the policy changes to build new fuel use plans involve considerable analysis, psychology and selling (to pilots and flight dispatchers).

In a study at one major airline (Destination-Specific Ramp Arrival Fuel," 1992), all of the principal elements that came out of interviews with pilots pointed to one key factor. Pilots resist reducing arrival fuel because they have little confidence in their flight plans. The flight planning process is too general, and therefore they assume that they will probably need more fuel.

In order to change pilot attitude and behavior, it is necessary to focus on identifying factors that might produce fuel burn variance *from plan*, and giving pilots enough information that they might be able to judge which of these factors would come into play.

In addition, a key element of any plan should be to focus on the specific variances associated with destination. The following is a discussion of the most predictable variances with the greatest impact.

The Stages of a Flight

Figure 1 depicts the typical stages of a flight.

Let's discuss each of these areas and what an airline can do to conserve fuel.

Prior to Departure

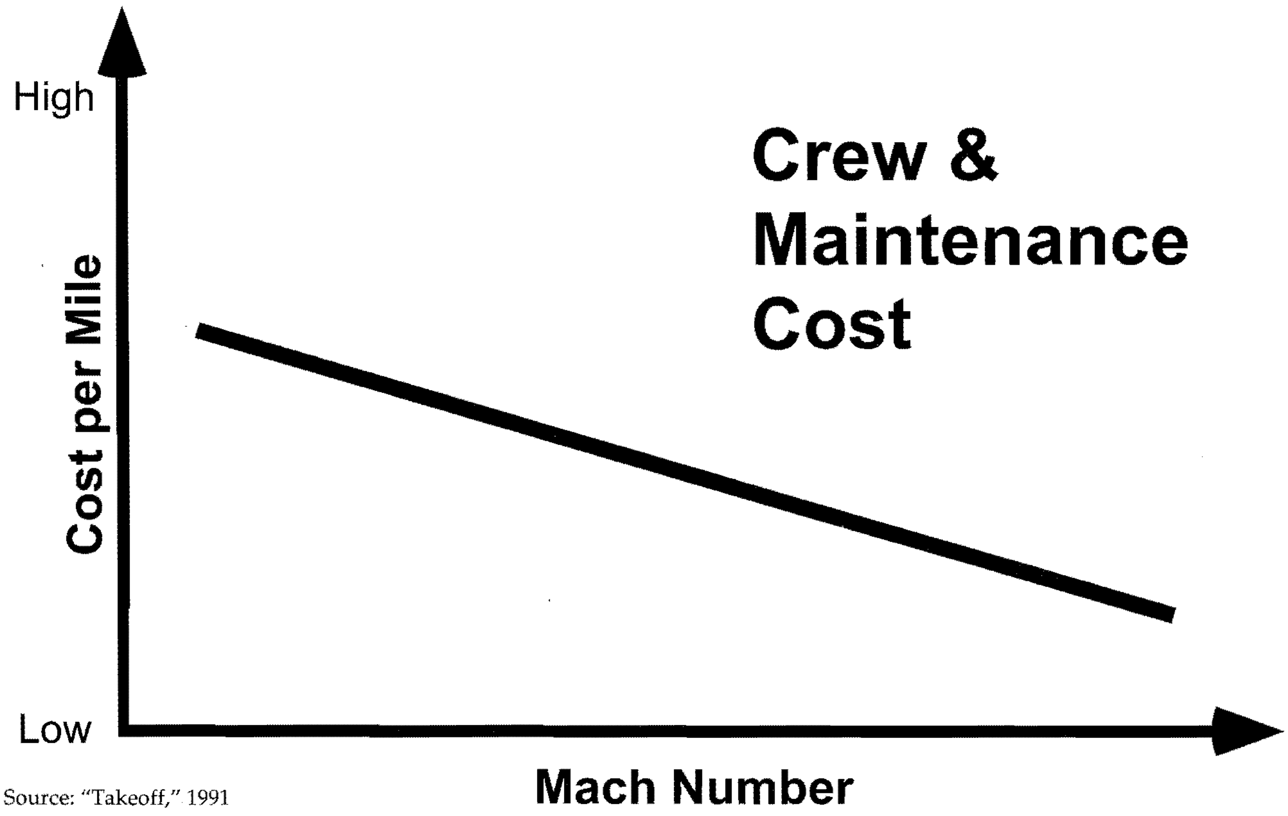
Aircraft are inspected prior to flight by the pilot. At that time, the aircraft should be examined for rough skin, peeling paint, dents and scrapes in the leading edges of the wing, nose and tail. Surface roughness can cause a 1% to 4% drag penalty, depending on location and severity ("Fuel Conservation," 1990).

At the Gate—Using the APU

A major use of fuel at the gate is the auxiliary power unit (APU). All jets since the 1970s have been equipped with these. They are small, internally mounted jet engines used as "donkey engines" to provide power for main engine start, and for air conditioning.

It costs money in wear and tear each time the APU is started. It also costs significant fuel to operate the APU. In the case of long ground times, APU operation should be kept to a minimum, and the aircraft should be cooled

Figure 2. Total Cost Versus Speed



Source: "Takeoff," 1991

from an external source, if available. For very short ground times, the APU should be left running. The exact tradeoff in ground time for these two alternatives will depend on both the aircraft type and the airline.

Table 2
Average APU Fuel Consumption for Aircraft (Lbs/Min.)

Aircraft Type	Full Load Fuel Consumption
727/DC9	41
DC10	71
747-100	137
747-400	129
757	8
A320	38

Source: "Fuel Conservation," 1990.

Taxi

Since taxi can burn considerable fuel, taxi time should be minimized, if possible. Unfortunately, today's method of scheduling hub-and-spoke operations significantly increases average taxi times, as all flights arrive and depart at the same time, creating ground congestion.

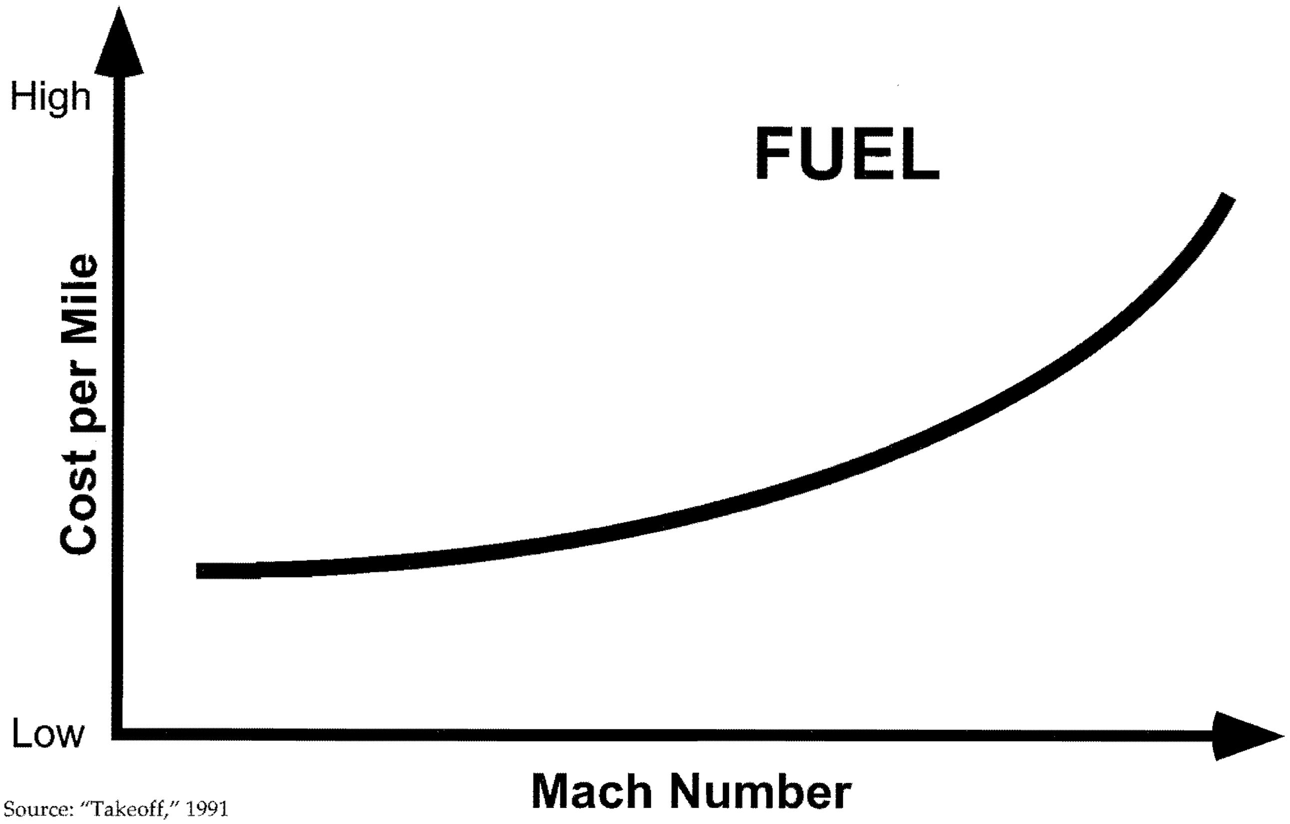
On most aircraft, it is not necessary to use all engines for taxiing. It is possible for a pilot to request departure runways that would minimize taxi time and expedite departure. This may increase the length of route of flight, however. Which is cheaper? Taxi to the nearest departure runway or a runway that would be more directly on course? Every minute of flight saved is equal to three to nine minutes of taxi time, depending on aircraft type. For example, on the B 727 taxiing at 41 pounds/minute, fuel consumption is likely to be more efficient than a turn in flight at over 367 pounds/minute.

Take Off

Cost savings may be achieved by careful selection of runways, avoiding full-power takeoffs, and initiating coordination with ATC to proceed toward destination as soon as possible.

Use of reduced thrust (called derated thrust) has a very positive effect on engine performance, maintenance costs, reliability and fuel efficiency. Most of those benefits relate to extending the life of the engine. Derated/reduced-thrust takeoffs are not more fuel-efficient than full-thrust takeoffs. It is the very significant total cost reduction due to extended engine use that makes derated/reduced thrust economically advantageous.

Figure 3. Specific Range Versus mach Number



Source: "Takeoff," 1991

En Route Climb

Most modern airplanes are equipped with onboard performance computers, called a Flight Management System (FMS) on newer aircraft. These systems provide speed/altitude guidance information tailored to real time weights, winds and temperatures and biased by a cost index (CI) that relates direct operating cost factors. These systems enable the crew to get the best performance from the airplane based on prevailing conditions, providing real-time decision support for minimizing flight cost.

Cruise

The area with the greatest potential for fuel savings is cruise. The major factors affecting fuel consumption are altitude, speed, wind, weight and temperature.

Let's look at operating costs. If we relate the other costs of flying an airplane to speed, we get the graph in Figure 2.

For crew and maintenance costs, cost per mile decreases as speed increases. Now looking at fuel versus speed in Figure 3, we can see that at the speeds at which airliners generally cruise, fuel cost per mile increases as speed increases.

A plot of total cost versus speed is arrived at by combining the two previous curves. Such a curve is shown in Figure 4.

For any given set of conditions (gross weight, altitude), there is a speed at which moving the airplane is done at a minimum cost.

If you go slower than that ideal speed to save fuel, your hourly costs will raise total costs. If you go faster than that speed to save time, your fuel costs will also increase.

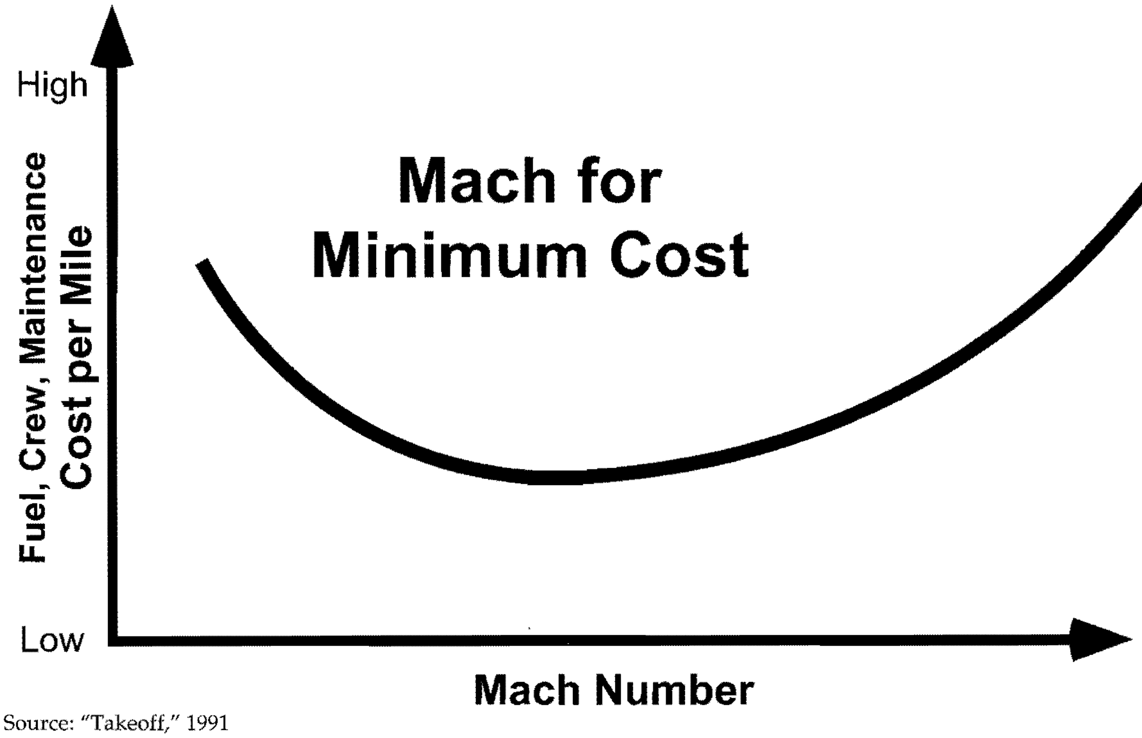
A general rule of thumb is that for each 0.01 increase in Mach number over the optimum cruise Mach, you increase fuel consumption by at least 1% ("Fuel Conservation," 1990, 1992 and " Takeoff," 1991)

The economy cruise-speed target is a Mach value that results in minimum operating cost per mile traveled at the specified cruise altitude. It is calculated based on altitude, air temperature, operating costs and gross weight; then, it is adjusted for current or predicted wind at the top of climb. The optimum altitude is defined as the altitude which yields the most ground miles per pound of fuel for a given Mach. In general, the optimum altitude will continually increase as gross weight is reduced through fuel burn. However, this altitude must be corrected for wind and temperature. As the variables change, so will the minimum cost altitude. It will not remain constant.

During a long flight, the aircraft will, therefore, occasionally be climbing:

- Optimum altitude increases approximately 1,000 feet

Figure 4. Total Cost versus Speed



Source: "Takeoff," 1991

for every hour of flight time.

- Recovery of fuel used in making a 4,000-foot climb can take from one hour (narrowbodies) to nearly three hours (heavy widebodies) if the step was made to near optimum altitude.

On the other hand, the penalties for not making a step climb to a new optimum altitude at the right time increase dramatically as time goes by:

Table 3

Penalties for not Achieving Optimum Altitude, as Time Elapses

Time Past OPT. (hrs.)	0	1	2	3	4
Fuel Penalty	1.5%	3.0%	4.5%	6.5%	8.5%

Source: "Fuel Conservation," 1990.

The estimated penalties for being off-optimum altitude are as follows:

Table 4

Off-Optimum Altitude Penalties

+2,000 feet	2%
-2,000 feet	2%
-4,000 feet	4%
-8,000 feet	12%
-12,000 feet	22%

Source: "Fuel Conservation," 1990.

There is an alternative if an aircraft is unable to operate at optimum altitude, called Long Range Cruise (LRC). If an aircraft is off optimum altitude by 4,000 feet or more, flying LRC can save from one-half of 1% to 3% compared to normal cruise Mach.

The LRC speed is a Mach target which is optimized to provide 99% of the airplane's maximum still air range at the specified cruise altitude. The selection of this point is related to drag, aircraft stability and ease of control ("Fuel Conservation," 1990). For any given gross weight, the speed that will provide the best airplane-specific range is generally the Long Range Cruise (LRC) speed as reflected on a typical specific range versus Mach number graph shown in Figure 5.

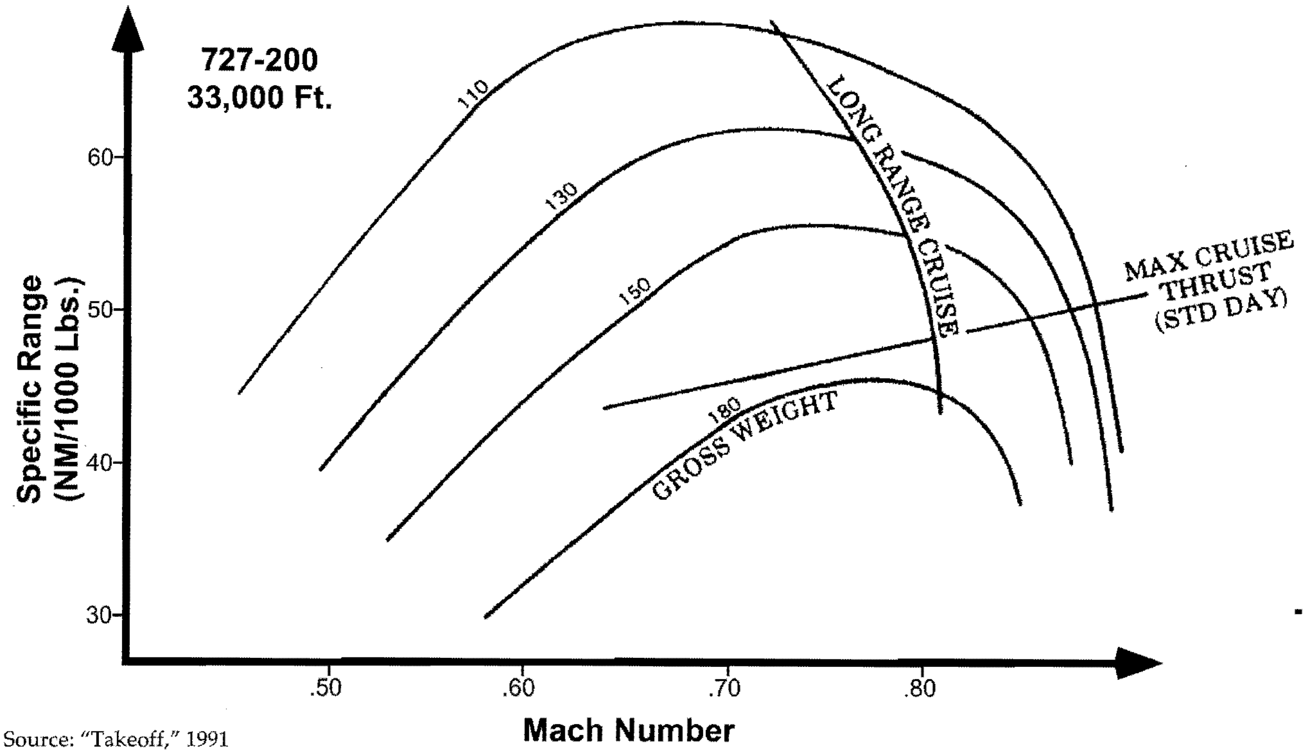
Curves such as this are available for other altitudes, and for each airplane type. The numerical values will obviously be different, but the general shapes of all curves are similar.

Air Traffic Control

Instead of flying the flight plan from radio fix (waypoint) to radio fix on jet airways, it is possible to request more direct routings from ATC, which may save fuel:

- Request direct clearances from ATC when possible, unless the flight plan shows a specific route to adjust for a jet stream or to avoid turbulence.
- A flight may be able to avoid headwinds and turbulence, or take advantage of a tailwind, by obtaining

Figure 5. Specific Range versus Mach Number



Source: "Takeoff," 1991

a different altitude from ATC. A flight might benefit temporarily from a more favorable altitude, even though that altitude does not conform to the direction of flight.

First and foremost, the pilot should talk to the controller. Air traffic controllers' priorities are different from those of pilots. Even so, controllers are often able to accommodate a pilot's request if it is made in a timely manner. The controller's workload and the flow of traffic are, of course, important considerations.

Cabin Management

Reducing the engine bleed air used for air conditioning and pressurization can improve fuel mileage. Full open inlet/exit cooling doors can produce a drag penalty of as high as 2.5% on the B727. Positioning of these inlet/exit cooling doors should be monitored and maintained in a minimum drag configuration, commensurate with air conditioning and pressurization requirements.

Trim

Drag generated by being slightly out of trim can easily cause an increase in fuel burn of 1% and sometimes more. Deviations in trim can and do occur with changes in aircraft speed. It is also necessary to retrim the aircraft periodically, as fuel is burned and the center of gravity (CG) changes.

Descent

There are many techniques for descending an airplane efficiently from cruise altitude to the airport elevation. Flight crews can save (or waste) more fuel in descent than in any other phase of flight. The optimum is to maintain cruise altitude until able to make an idle thrust optimum range descent.

Optimizing the descent requires descent at speeds that result in improved glide ratios. To the extent that ATC allows, the descent should begin at the optimum distance based on these ratios. Every minute of early descent resulting in cruise at a lower altitude consumes fuel unnecessarily: Likewise, any delay in beginning the descent is also inefficient.

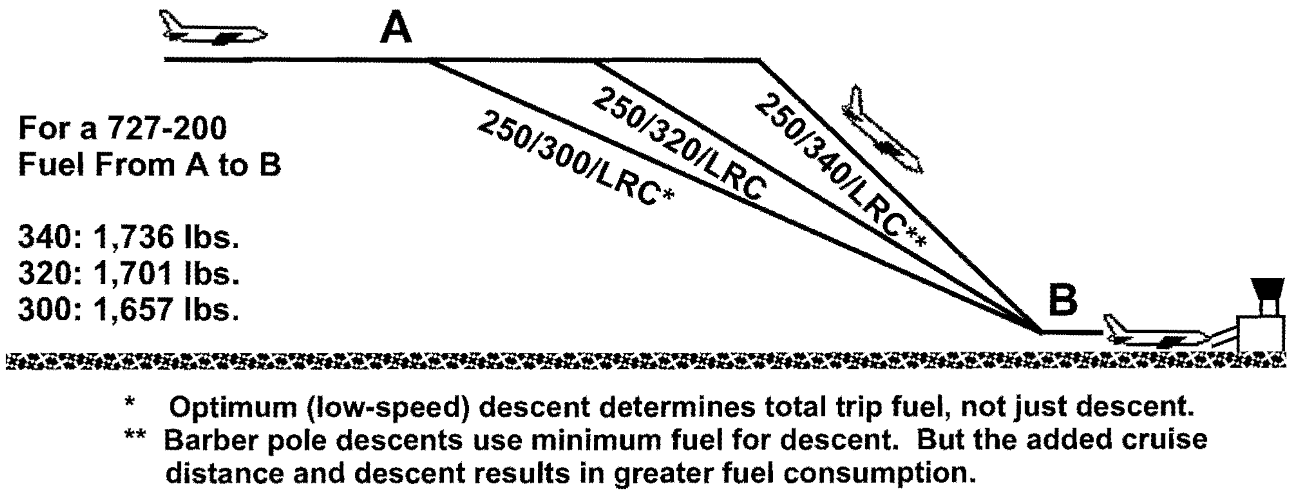
- A B747-200 descending from cruise altitude to 10,000 feet that levels off 10 miles early will cost about 250 extra pounds in fuel burned during low-altitude cruise. The corresponding figures for some other aircraft are: DC-10—211 pounds, B757—83 pounds; B727-200—95 pounds; A320—65 pounds and DC-9/MD-80—70 pounds.

Holding

Holding is obviously a waste of fuel, but pilots have very little control over when and where they may have to hold. Fuel efficiency can, however, be improved when holding is required. Some approaches:

- Request the highest altitude. Stay high as long as possible to minimize fuel flow.
- Request the longest straight flight legs as practicable (to reduce turns which require extra fuel).

Figure 6. Descent



Source: "Fuel Conservation," 1992.

- When informed of an inflight delay, slow down (as slow as holding speed, if necessary) as a more desirable alternative than extended off course vectors. Coordinate the speed reduction with ATC.

Holding prior to landing is very expensive. Carrying hold fuel is expensive whether you hold or not. On the other hand, a diversion is even more expensive. But what is the trade-off? There is no easy answer. It depends on many variables such as prior diversions, weather forecasts, etc. The dispatcher is normally in the best position to determine whether it is practical for a flight to hold or divert. Careful determination of hold fuel prior to the flight will better manage this issue, as discussed below.

Other Issues

There are many additional aerodynamic issues and flight techniques that can have significant effects on the fuel burned during a flight. Proper training and instilling pilots with a fuel conservation philosophy can address these issues.

Fuel Burn Variance

Figure 7 highlights some areas where a flight can experience considerable variance in fuel burn, as time-related overburn factors.

Each of the indicated areas adds distance and time to a flight. Some sample factors of variance for a DC-10 are given

Figure 7. Sources of Fuel-Burn Variances

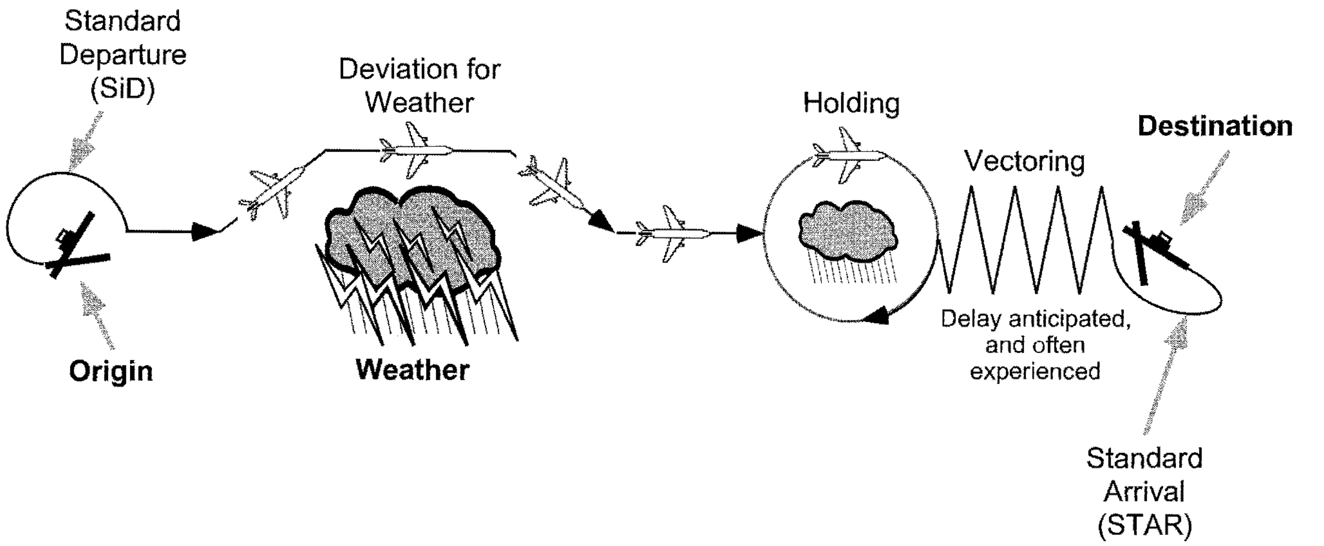
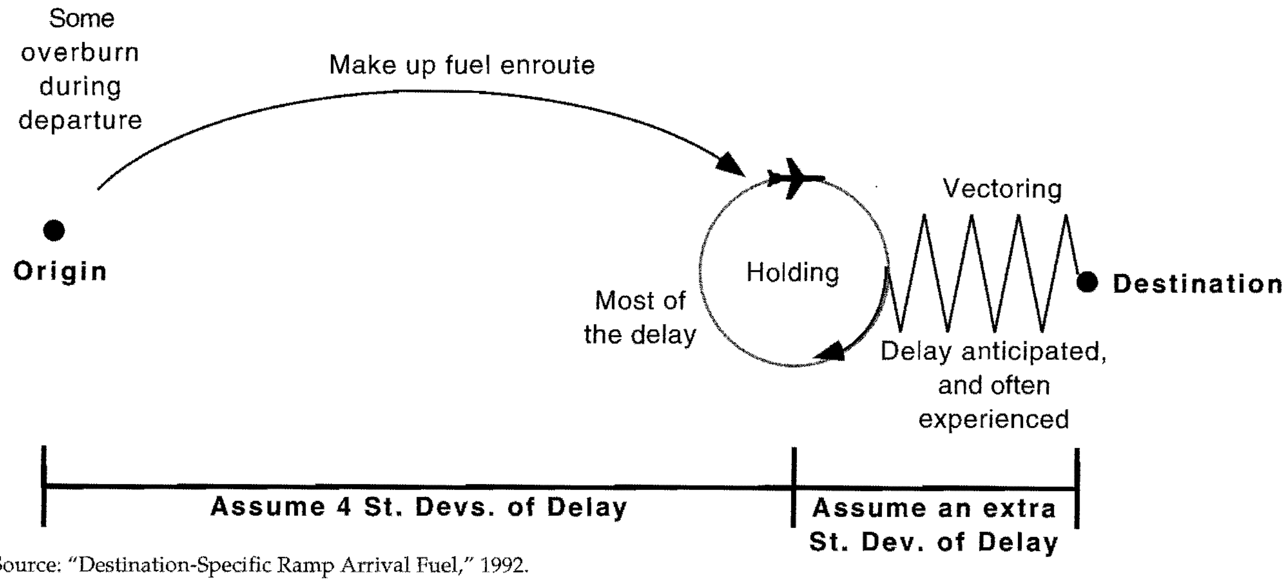


Figure 8. Average Block Times Augmented By Multiple Standard Deviations



Source: "Destination-Specific Ramp Arrival Fuel," 1992.

below. Each one of these would increase burn by 2,500 lbs.:

- Adding 10,000 lbs. of weight to a 4-hour flight
- Cruise 4,000 ft. below normal
- Make a 45-degree deviation for 200 miles around a thunderstorm
- Encounter a 17-knot headwind flying across the United States
- 12 minutes of holding
- Even less extra time vectoring, dependent on number of turns
- Every airport has at least two standard departure routes and standard arrival routes, used in different wind conditions. Flight planning systems usually average them. Flying the longer departure or arrival
- Fly 60 miles toward an alternate

In addition, on any flight, there is a great number of airborne impact factors influencing destination fuel. Some are time-related and some are not.

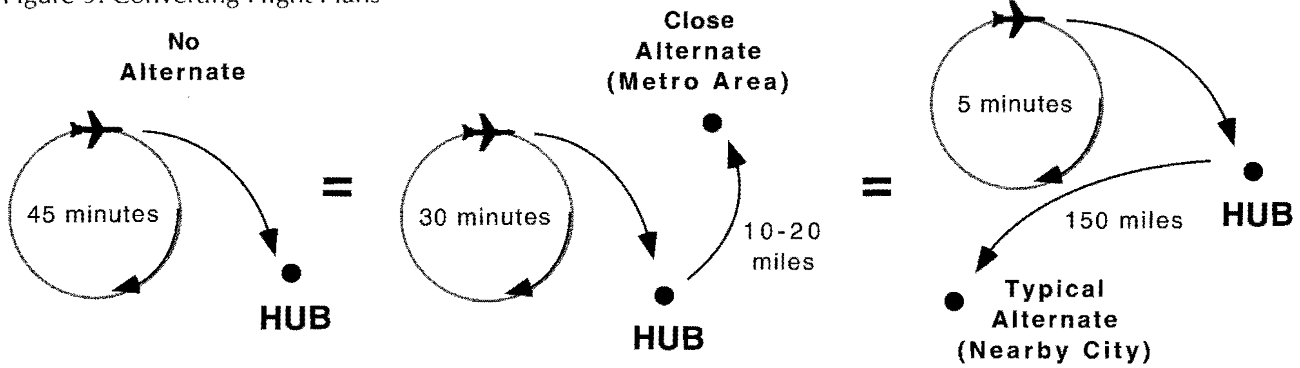
Controlling Fuel Over Destination (FOD): Arrival Fuel

Most airlines plan flights with far too much arrival fuel, usually in the form of one of the following:

- Excess alternate fuel, by using alternate airports farther away than necessary,
- Excess alternate fuel, by using alternate airports when weather conditions do not truly merit them,
- Excess holding fuel, during less-than-perfect weather
- Excess holding fuel, during perfect weather, when hold fuel is really only required for traffic delays.

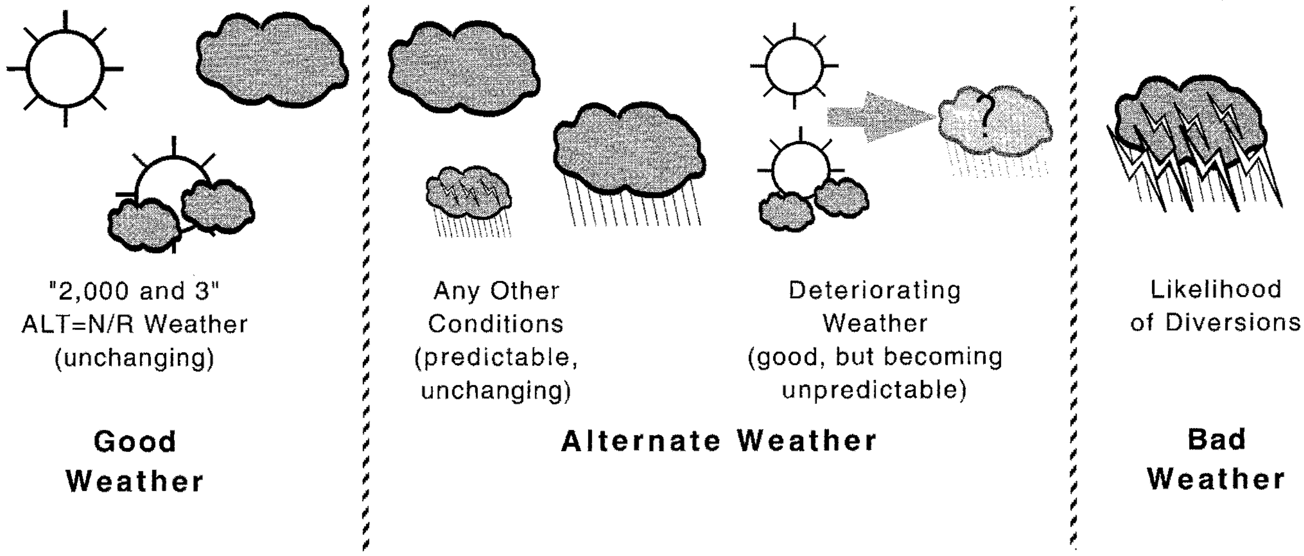
With typical stage lengths, an airline can be wasting 10% of all the excess fuel carried by burning fuel to carry fuel. Why is the fuel so high? To increase pilots' comfort levels with fuel, especially after the Avianca disaster at Long Island. Why is it not easily reduced? Because identifying how much fuel is enough is a complex task, involving psychology, as well as analysis.

Figure 9. Converting Flight Plans



Source: "Destination-Specific Ramp Arrival Fuel," 1992.

Figure 10. Defining The Weather Continuum[27]



Source: "Destination-Specific Ramp Arrival Fuel," 1992.

The arbitrary addition of extra fuel based on unidentified contingencies is wasteful and expensive. Unless the need can be identified, normal reserves should be considered adequate for planning purposes and extra fuel should not be added.

Time-Related Overburn

Many factors cause overburn, irrespective of delays, holding, or the counterbalance of direct routings. Some of these are listed in Figure 7. Flights are usually planned with excess fuel to allow for the potential of these variances. Why is it important to better manage arrival fuel, or FOD?

- To maximize revenue payload capability, including cargo
- Route structure impacts
- Long flights with high load factors
- Minimize fluctuations in payload capability
- Reduces fuel cost to carry fuel
- Maintenance expense reduction
- Fewer maximum power events (reducing engine life)
- Less time at climb power
- Brake wear

The bottom line is that an airline can achieve on the order of magnitude of a reduction in annual fuel costs of 1% for every 1,000 pounds in average FOD reduction (Destination-Specific Ramp Arrival Fuel," 1992).

The Basic Approach

Most airlines keep statistics of average actual block times, and block time variance from plan. The majority of these delays are related to delay at the arrival station. Extensive analysis has shown that to make such an assumption allows accurate predictability of average delay by destination. So an appropriate amount of fuel over and above that to fly the plan would be related to the average delay in block time.

For safety, the average should be augmented by multiple standard deviations. The way a flight is thus defined is illustrated in Figure 8 in a very conservative approach:

As to how this would be applied to planning flights, let us introduce two concepts.

- Converting the actual flight plan as filed with the FAA to the conceptual flight plan with no alternate and hold time, and
- Treating different weather circumstances in a normalized fashion.

The first point is illustrated by Figure 9. All different ways of filing a flight plan can be normalized to a plan with no alternate and hold time. This, in fact, is the way a flight is actually flown in good weather conditions.

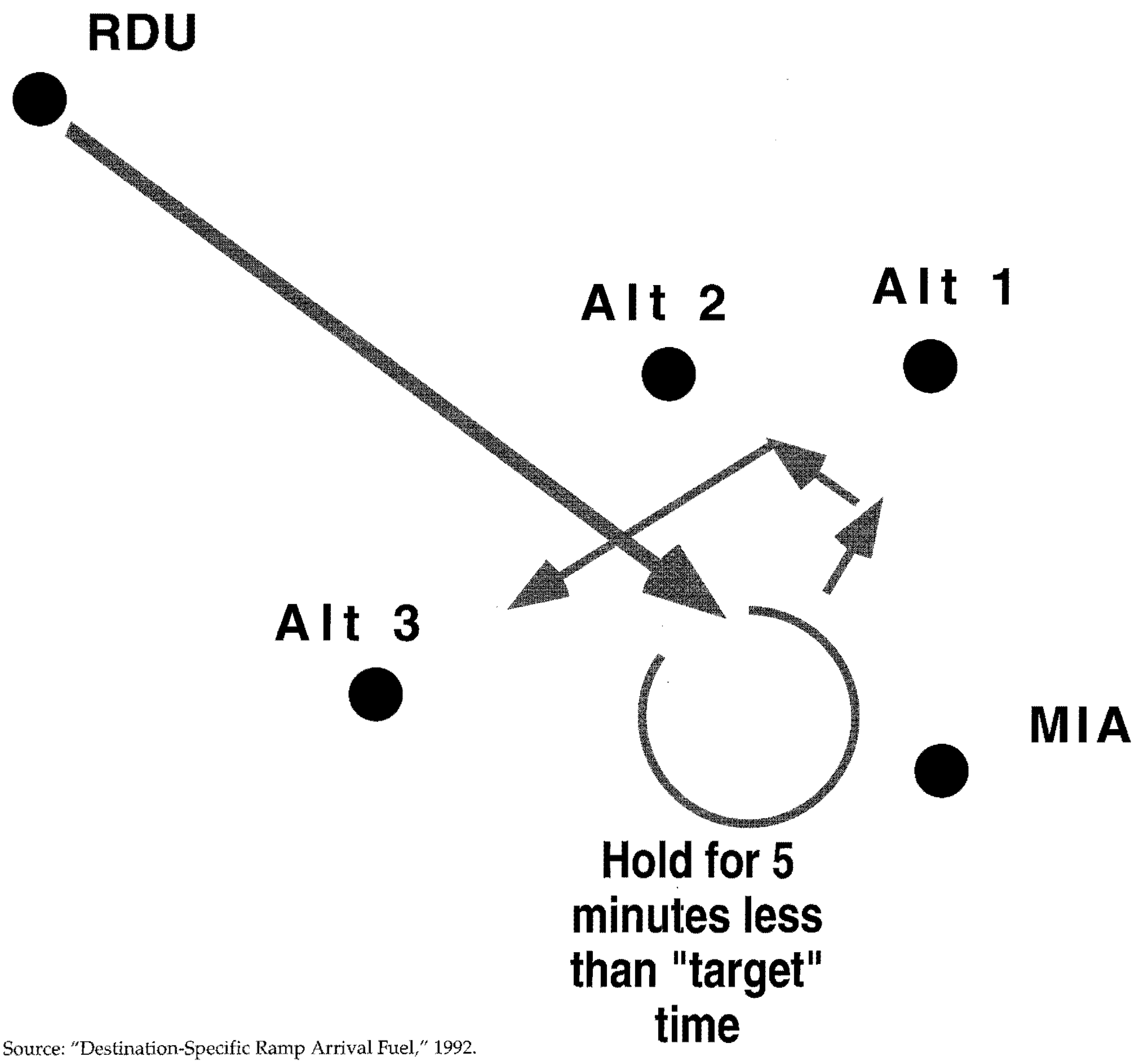
The weather continuum can also be similarly defined in a standard fashion, shown in Figure 10.

Flight plans can be formalized by weather, and the amount of holding time adjusted accordingly. In bad weather, when diversions are possible, flights should still be planned with maximum fuel.

Alternate airport management is the key element in FOD management. Obviously, always plan to protect reserve fuel and plan an alternate whenever required by Federal Aviation Regulation (FAR). Plan a close-in alternate wherever possible, especially at busy airports.

For safety, the approach to bad weather, when diversions are anticipated, should not be changed. Dispatchers feel that they must plan maximum fuel if there is any major chance of thunderstorm. They believe delay statistics, but they want operational flexibility.

Figure 11. Multiple Diversions



Source: "Destination-Specific Ramp Arrival Fuel," 1992.

Example: After holding near limit for a thunderstorm, divert. Destination clears up, but alternate 1 gets bad. Divert ... This is something that is very likely to happen in Florida during the summer, as illustrated in Figure 11.

Fuel Tankering

The preceding is concerned mainly with the disadvantages of carrying extra fuel. Under certain circumstances, however, it is to an airline's advantage to tanker fuel between stations where significant cost or supply differentials exist.

Two good reasons—

1. To save money by taking advantage of cost differentials.
2. To ensure adequate supplies at stations where fuel availability may fall short. Thus, tankering becomes essential to maintaining schedule integrity.

How Advantageous is tankering Fuel to Save Money?

The average B727 trip burns 5% of 1,000 gallons to tanker fuel 550 miles.

Additional Burn . 05 x 1000 = 50 Gallons ("Fuel Conservation," 1992).

—If that fuel costs 66¢ per gallon, the cost of tankering:

66¢ x 50 Gallons = $33

—If the fuel at destination is 10¢ per gallon higher than at departure, we can save:

10¢ x 950 Gallons	=	$95.00
Minus Tanker Cost		$33.00
NET SAVINGS		$62.00

On the other hand, if we carry that 1,000 gallons from the high-cost station to the low-cost station, *unnecessarily*, we would be spending $33 *needlessly*.

As prices vary from station to station, cost differentials will change the combinations of origination destination stations where fuel tankering will be advantageous. This situation is monitored very closely on a day-to-day basis.

A conservative analysis of the actual costs indicates that fuel tankering can save as much as 1% of an airline's annual fuel bill. *Tankering does not conserve fuel, but it can reduce costs and ensure availability.*

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