ANA
All Nippon Airways

Fuel Conservation—Reserve Fuel Optimization

Article **3**

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Introduction

The total amount of fuel carried aboard an airplane is determined by the distance the airplane is to fly, requirements for reserve fuel to meet unexpected situations, and considerations of safety and economics. Excess fuel on board reduces payload and increases fuel burn.

ICAO Annex 6 stipulates that "...the airplane carries sufficient fuel and oil to ensure that it can safely complete the flight. In addition, a reserve shall be carried to provide for contingencies." Regulations in each country specify the amount of fuel to be carried, and airlines base their fuel policy on those national regulations. Up until 2000, Japanese operators established their fuel policy to satisfy Japanese civil aeronautics law and FAR fuel requirements. Japanese civil aeronautics law specifies only a 45-min reserve of cruise fuel and no contingency fuel for all flights. Airline operators thought that this amount of fuel was insufficient to cover deviations from the flight plan for long-range flights. Therefore, Japanese operators adopted the FAR fuel requirement for international flights: 30-min reserve of holding fuel plus fuel for 10% of the total time required to fly from the airport of departure to the destination airport.

In 1999, Japanese authorities and Japanese major airlines discussed the total amount of reserve fuel to be carried on domestic and international flights. They gathered actual flight data and the fuel requirements established in other countries and then, in 2000, established Japanese fuel requirements.

This article is presented as part of the 2005 Boeing Performance and Flight Operations Engineering Conference, providing continuing support for safe and efficient flight operations.

This paper discusses how ANA succeeded in changing our rules and, in the process, reducing the amount of reserve fuel and keeping the same level of safety.

This presentation consists of the following parts:

a. Comparison of Fuel Requirements Before 2000
b. Fuel Carried by Japanese Airlines in 1999
c. Difference in Planned Fuel Burn and Actual Fuel Burn
d. Amount of Reserve Fuel to Be Carried
e. Our Current Fuel Policy

Comparison of Fuel Requirements Before 2000

The requirements specifying how much fuel an airplane should carry differ and depend on the requirements under which the airlines in each country operate (fig. 1).

Requirement	Fuel
	Burn off Fuel
Japan	Completing the flight to the first place of intended landing
ICAO	To fly and execute an approach, and missed approach, at the aerodrome to which the flight is planned
FAR	Complete the flight to the first airport of intended landing
JAR	Trip fuel, which should include: a. Fuel for takeoff and climb from aerodrome elevation to initial cruising level, taking into account the expected departure routing; b. Fuel from top of climb to top of descent, including any climb/descent; c. Fuel from top of descent to the point where the approach is initiated, taking into account the expected arrival procedure; and d. Fuel for approach and landing at the destination aerodrome.
	Alternate Fuel
Japan	To fly to the alternate aerodrome of intended landing
ICAO	To fly to the alternate aerodrome specified in the operational and ATS flight plans
FAR	To fly to and land at the most distant alternate airport
JAR	Alternate fuel, which should be sufficient for: a. A missed approach from the applicable MDA/DH at the destination aerodrome to missed approach altitude, taking into account the complete missed approach procedure; b. A climb from missed approach altitude to cruising level; c. The cruise from top of climb to top of descent; d. Descent from top of descent to the point where the approach is initiated, taking into account the expected arrival procedure; and e. Executing an approach and landing at the destination alternate aerodrome selected in accordance with JAR-OPS 1.295. f. If, in accordance with JAR-OPS 1.295(d), two destination alternates are required, alternate fuel should be sufficient to proceed to the alternate which requires the greater amount of alternate fuel.

Figure 1. Fuel requirements for interim flight restrictions with alternate destination–1999

Requirement	Fuel
	Reserve Fuel
Japan	To fly for 45 minutes of flight at cruising speed
ICAO	To fly for 30 minutes at holding speed at 1500 ft above the alternate aerodrome
FAR	For domestic operations: To fly for 45 minutes at normal cruising fuel consumption For international operations: To fly for 30 minutes at holding speed at 1500 ft above the alternate airport
JAR	To fly for 30 minutes at holding speed at 1500 ft above aerodrome elevation in standard condition
	Burn off Fuel
Japan	No requirements
ICAO	To have an additional amount of fuel sufficient to provide for the increased consumption on the occurrence of any of the potential contingencies specified by the operator to the satisfaction of the State of Operator
FAR	For domestic operations: No requirement For international operations: To fly for a period of 10 percent of the total time required to fly from the airport of departure to, and land at, the airport to which it is released
JAR	Contingency fuel, which should be the higher of (a) or (b) below: a. Either: 1. 5% of the planned trip fuel 2. Not less than 3% of planned trip fuel provided that an en-route alternate is available, or 3. An amount of fuel sufficient for 20 minutes flying time based upon the planned trip fuel consumption provided that the operator has established a fuel consumption monitoring program for individual aeroplanes and used valid data determined by means of such a program for fuel calculation; or 4. An amount of fuel of not less than that which would be required to fly 15 minutes at holding speed at 1500 ft above the destination aerodrome in standard conditions, when an operator has established a program, approved by the Authority, to monitor the fuel consumption on each individual route/aeroplane combination and uses this Data for a statistical analysis to calculate contingency fuel for that route/aeroplane combinations; or b. An amount to fly for 5 minutes at holding speed at 1500 ft above the destination aerodrome in Standard Conditions.

Figure 1. Fuel requirements for interim flight restrictions with alternate destination–1999 (continued)

The requirement for burnoff (trip) fuel and alternate fuel is almost identical in the various regulations, but the requirement for reserve and contingency fuel differs. The background of reserve and contingency fuel for each country is discussed in the following paragraphs.

Japanese Requirement Before 2000

The Japanese requirement for reserve fuel was established considering Japanese domestic operations for which the range is less than 1,300 nmi. The requirement basically follows previous FAR domestic rules. The Japanese requirement for reserve fuel was based on 45 min of cruise fuel, but there was no requirement for or description of contingency fuel. Airlines flying long-range routes adopted the FAR requirement, which is 30 min of holding fuel plus fuel for 10% of the flight time to a destination airport; the requirement for this amount of fuel is in addition to the Japanese requirement. The extra fuel was added because the Japanese requirement was not enough to cover the discrepancy between the flight plan and actual fuel consumption.

ICAO Requirement

The ICAO policy states that an airplane is "... to have an additional amount of fuel sufficient to provide for the increased consumption," but the ICAO policy does not specify a concrete requirement.

FAR Requirement

The requirement for reserve and contingency fuel differs between domestic operations and international operations. For domestic operations, the requirement is 45 min of cruise fuel as reserve fuel and no contingency fuel. For international operations, the requirement is 30 min of holding fuel plus fuel for 10% of the flight time to the destination airport.

The FAR requirement was established many years ago, and the 10% of flight time contingency was based on the following:

a. High fuel consumption of turbojets.
b. Lack of a navigation system that was sufficiently accurate for long-range flights.
c. Impossibility of accurately forecasting weather conditions at destination and alternate airports for long-range flights.

JAR Requirement

The purpose of contingency fuel is explained as follows:

"At the planning stage, not all factors which could have an influence on the fuel consumption to the destination aerodrome can be foreseen. Therefore, contingency fuel is carried to compensate for items such as:

a. Deviations of an individual aeroplane from the expected fuel consumption data;
b. Deviations from forecast meteorological conditions; and
c. Deviations from planned routings and/or cruising levels."

The JAR requirement for contingency fuel does not specify a fixed quantity because

a. Before the current requirement was specified in JAA countries, each country had its own requirement. There had been no accidents associated with the quantity of fuel on board the airplane in over 15 years. Each requirement was as reasonable as the JAR requirement. Therefore, each airline could select contingency fuel requirements in concert with JAR requirements as long as the airlines maintained a sufficient level of safety.

b. The quantity of contingency fuel can be determined based on the percentage of trip fuel rather than the percentage of flight time.
c. The minimum quantity for contingency fuel can be specified in the JAR requirement and the maximum quantity can be referenced.

Fuel Carried by Japanese Airlines in 1999

In 1999, ANA investigated the fuel policy and actual onboard fuel of Japanese airlines. The following material summarizes the results of our investigation.

The fuel policy of each Japanese airline was almost the same, and each airline established a requirement for extra fuel that was other than the national requirement. Extra fuel is the fuel that the captain and flight dispatcher consider necessary to ensure safety and reach total flight efficiency. Extra fuel is loaded for air traffic control, en route weather conditions and conditions at the destination and alternate airports, or other reasons.

The quantity of extra fuel and the reasons why a quantity is selected are shown in Figures 2 and 3.

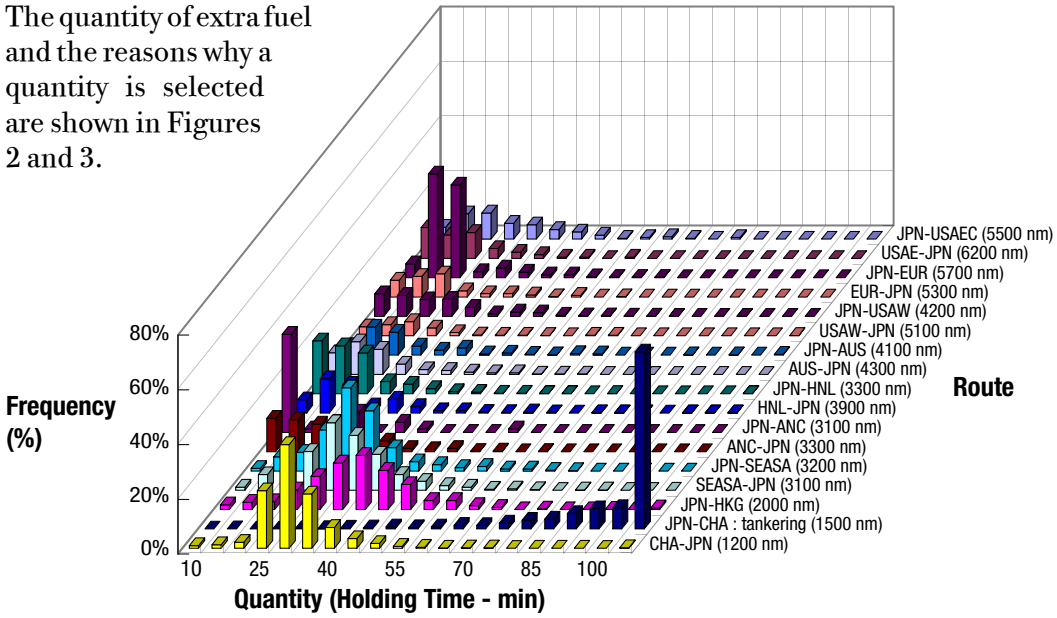


Figure 2. Extra fuel– route and quantity

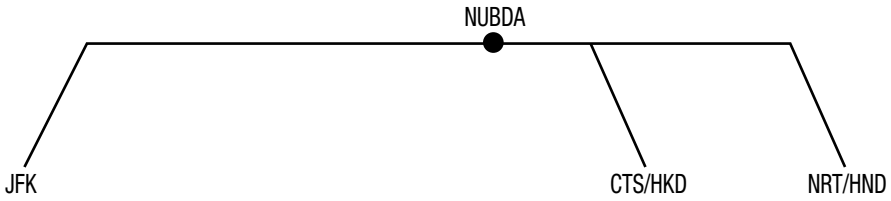
Reason	Route	Frequency, %	Quantity (hold time), min	Note
Difference of altitude from plan	SHA ⇒ JPN	100%	30 min	Altitude restriction at AKARA corridor
	JPN ⇒ HKG China ⇒ JPN JPN ⇔ SE ASA	100%	30 min	Airway congestion
	JPN ⇒ EUR	85%	15 min	Restricted initial altitude to specific point
Difference of route from plan	JPN ⇒ HNL JPN ⇒ ANC	50%	10 to 15 min	Considering alternate route
Holding at destination	USA ⇒ JPN EUR ⇒ JPN AUS ⇒ JPN	20 - 30%	10 to 15 min	Weather forecast at NRT early morning
	JPN ⇒ USA JPN ⇒ AUS	20 - 30%	10 to 15 min	Weather forecast at SFO, ect.
Tankering	JPN ⇒ China	100%	Over 100 min	

Figure 3. Extra fuel– route and reason

We define contingency fuel as the fuel that compensates for the error of fuel burn even when the airplane is flying according to the flight plan. Extra fuel is the fuel that compensates for the difference in fuel burn when a deviation from the planned route is expected.

Reclear or redispatch operations are generally executed during long-range flights. As the accuracy of flight planning has improved, whether contingency fuel is needed is based on the destination airport. Reclear operations are operations for which, at preflight, the operational flight plan may be to a suitable airport as the first destination instead of to the scheduled destination. Thereafter, during flight, the operational flight plan may be changed to the scheduled destination using the remaining fuel at the point known as "reclear fix." At reclear fix, it becomes possible to substantially decrease contingency fuel with a reclear operation.

Following is a comparison of a normal plan and a reclear plan (fig. 4).



Condition	747-400, JFK to NRT
Original destination/alternate	CTS/HKD
Final destination/alternate	NRT/HND
Reclear point	NUBDA

Fuel criteria	Normal plan, lb	Reclear plan, lb
Taxi fuel	2,500	2,500
Burnoff fuel	306,800	303,200 (-3,600)
Alternate fuel	9,100	9,100
Contingency fuel	23,700	6,900 (min cont)
Holding	8,200	8,200
Extra	0	10,000
Reserve total (ref)	41,000 (ref.)	34,200 (-6,800)
Takeoff fuel	347,800 (ref.)	337,400 (-10,400)
Ranp fuel	350,300	339,900
(Contingency + extra)/burnoff fuel	7.7%	5.6%
Δ Burnoff fuel	(ref)	-3,600 lb/-1.2%

Figure 4. Comparison of normal plan and reclear plan—747-400 JFK-NRT

Difference in Fuel Burn and Fuel Plan

We investigated actual fuel burn during 1999 in order to establish a reasonable quantity as standard contingency fuel. We compared the actual fuel burn with the planned fuel burn. The result of this comparison is discussed in the following paragraphs.

International Flight

We investigated the difference in planned and actual fuel burn for each route.

We calculated burnoff fuel from block-out to block-in in the flight plan as follows:

Planned fuel burn = taxi fuel + burnoff fuel (trip fuel)

Actual fuel burn is calculated as follows from our flight operations database:

Actual fuel burn = onboard fuel (ramp fuel) – remaining fuel

We compared the actual fuel burned with the planned fuel burned in the following equation and then displayed the difference as a percentage to eliminate the influence of aircraft size, fuel consumption rate, and aircraft deterioration:

Fuel burn difference = [(actual fuel burn – plan burnoff fuel)/(plan burnoff fuel)] x 100

Figures 5 through 8 detail the differences in fuel burn for each route.

Route	Number of data	Average, %	Standard deviation, %	Reference chart
JPN - USA	664	-0.91%	0.89%	Figure 6
USA - JPN	558	+0.17%	1.13%	
JPN - EUR	874	-0.56%	1.24%	Figure 7
EUR - JPN	723	-1.30%	1.44%	
JPN - SE ASA	1272	-1.23%	2.42%	Figure 8
SE ASA - JPN	957	-2.03%	2.61%	

Figure 5. Deviation of planned fuel burn from actual fuel burn

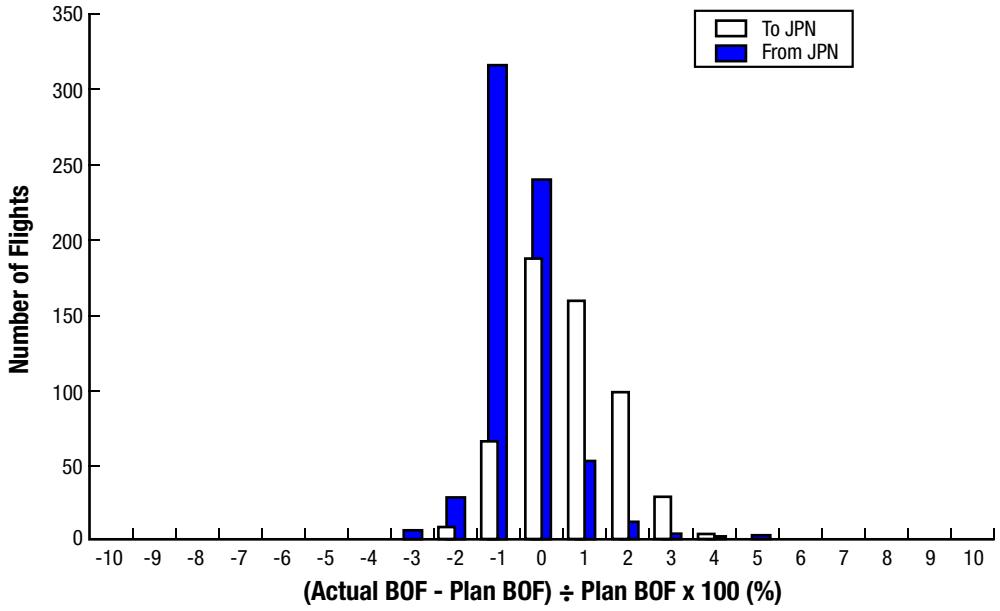


Figure 6. Distribution of fuel burn: Japan to the United States

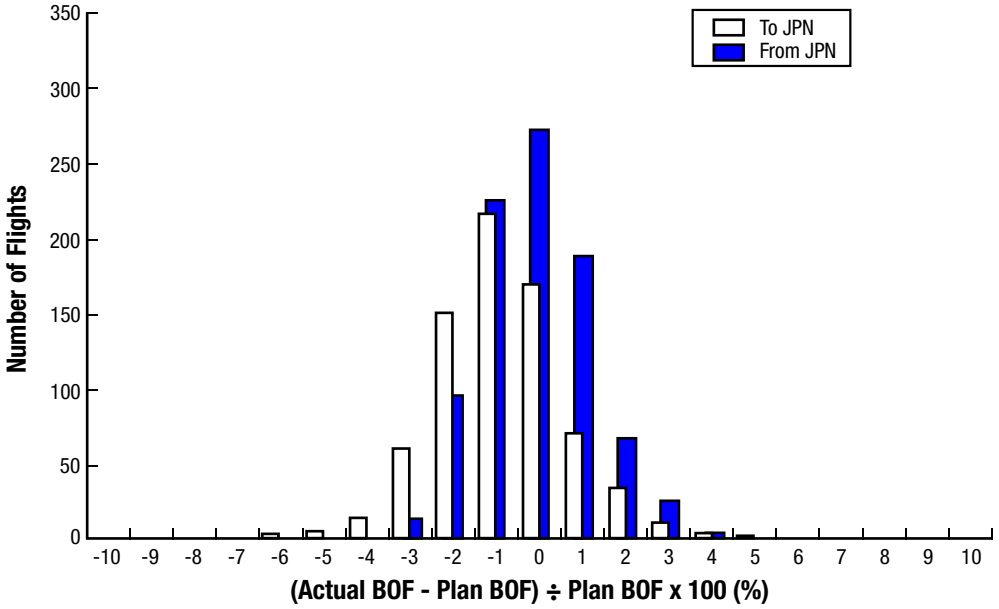


Figure 7. Distribution of fuel burn: Japan to Europe

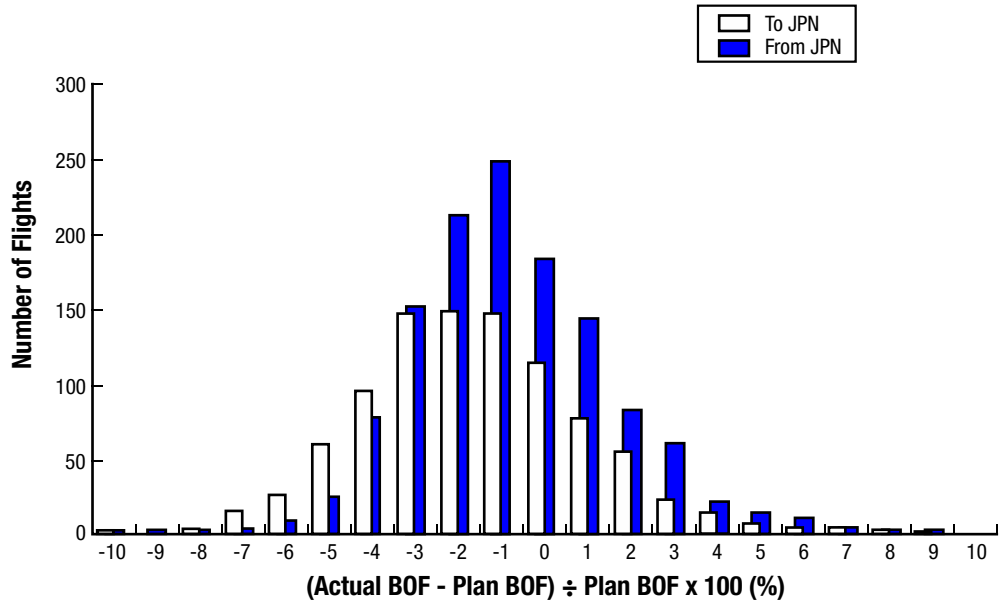


Figure 8. Distribution of fuel burn: Japan to Southeast Asia

For long-range flights, such as U.S. or European routes, the total deviation is less than that for mid- or short-range flights, such as Southeast Asian routes, because the amount of burnoff fuel (BOF) is large.

Domestic Flight

The distribution of fuel burn for domestic flights is shown in Figure 9 in the same units as international flights. This chart is based on 3 months of data or about 36,000 flights.

The average flight time of domestic flights is approximately 1 hr. Because the value in %BOF is a large number, the difference in fuel burn is shown as holding time (fig. 10).

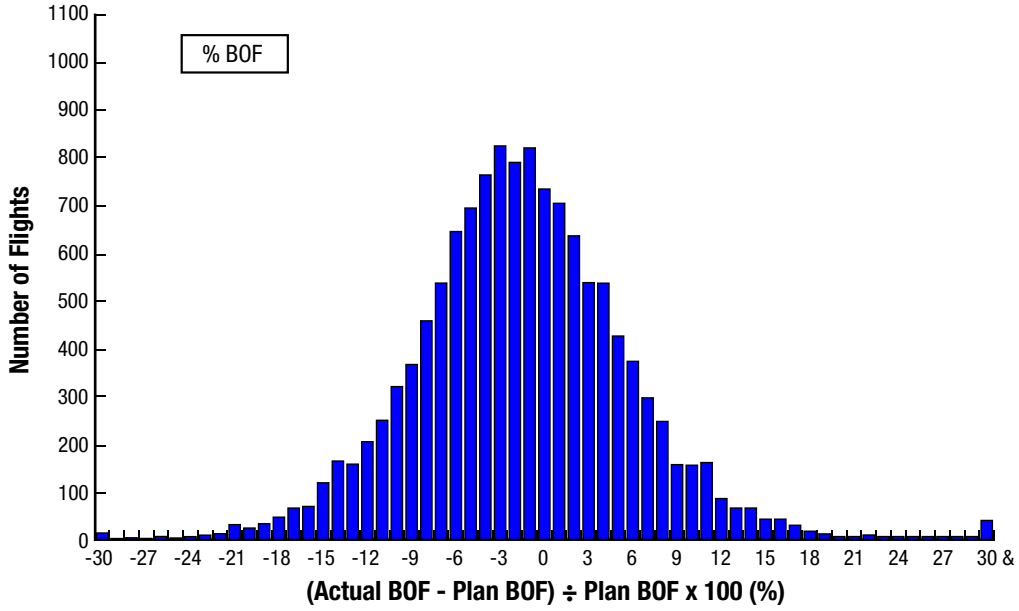


Figure 9. Distribution of fuel burn: Japan domestic flight—%BOB

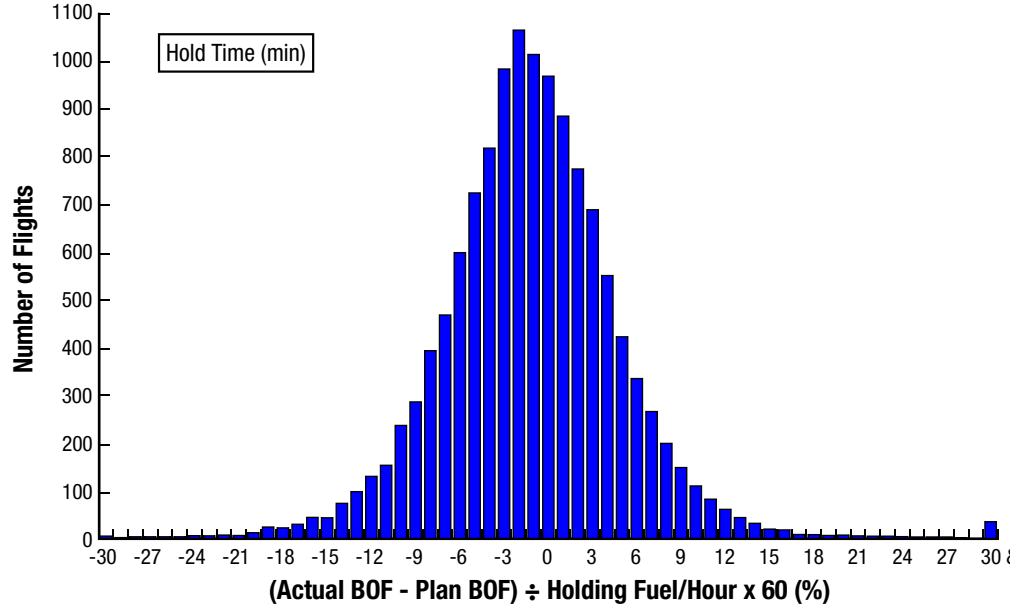


Figure 10. Distribution of fuel burn: Japan domestic flight—holding time

Amount of Reserve Fuel to Be Carried

We now discuss the framework and appropriate quantity of contingency fuel based on analysis of past operational results.

Figure 11 shows the relation between the difference in planned and actual fuel burn and air distance. In Figure 11, we exclude routes when the route and altitude deviate from the plan or when holding can always be expected at a destination airport on a specific route. For such routes, we load additional fuel as extra fuel at planning.

The following information is shown in Figure 11:

a. When the air distance is longer, the difference between actual fuel burn and planned fuel burn expressed in %BOF is less.
b. If the air distance is over 3,000 nmi, Δ%BOF is less than fuel of 5%BOF contingency; most of the reserve fuel remains in the airplane at landing.
c. If the air distance is less than 1,500 nmi, Δ%BOF exceeds 5% BOF and is less than a 15-min hold. This means most of reserve fuel remains at landing.

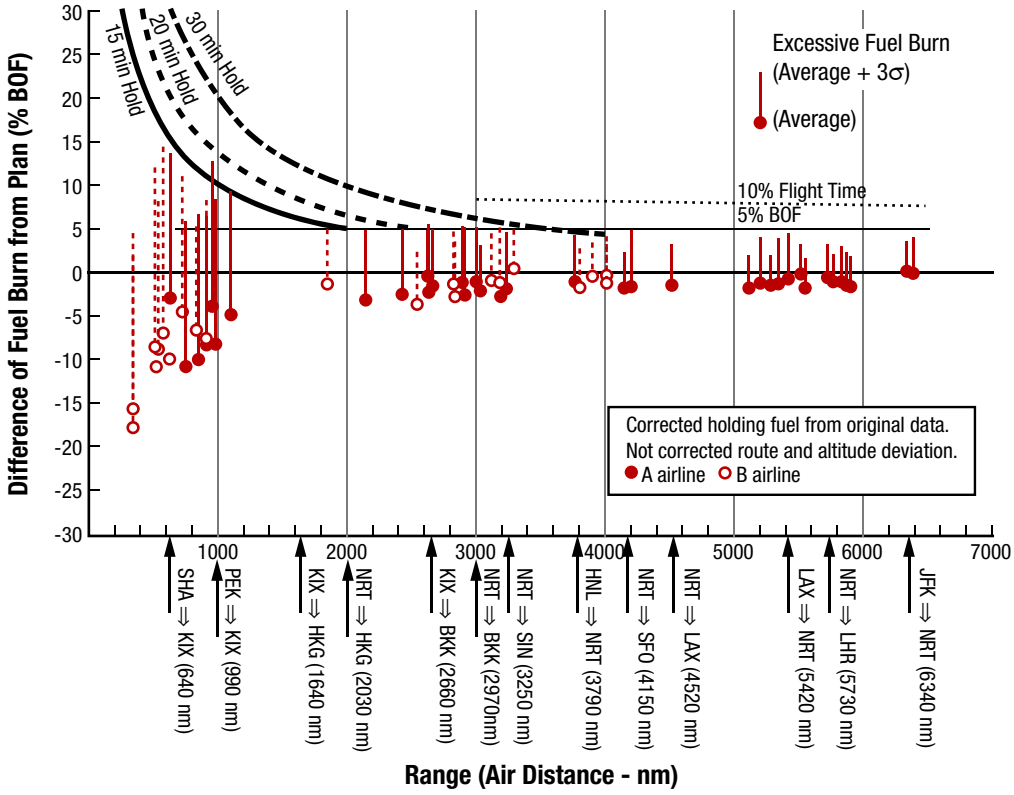


Figure 11. Difference between planned and actual fuel burn

Notes:
= average value of %BOF and its scatter
= average value
Top of bar = three times its standard deviation plus average for one route
Minus value = actual fuel burn is less than planned fuel burn

Framework of Contingency Fuel

We investigated the difference between actual fuel burn and planned fuel burn based on actual operational data, and we found that these factors cause this difference:

a. Error in weather forecast, altitude, or aircraft performance when the airplane is flying according to the flight plan.
b. Inability to fly according to the flight plan because of traffic, weather, or other reasons.

Fuel differences resulting from the reasons listed in item a depend on the air distance, and it is possible to apply the standard that depends on air distance. Fuel differences resulting from the reasons listed in item b tend to happen on specific routes and airports, and the amount of fuel differs by route, airport, operations hours, and weather conditions. Therefore, a fixed standard is difficult to set.

ANA concluded that the difference between actual and planned fuel burn is contingency fuel and planned contingency fuel.

Contingency fuel is related to the information in item a, and planned contingency fuel is related to the information in item b.

Rational Standard of Contingency Fuel

The quantity of additional fuel to cover the following situations is believed to be a rational estimate of contingency fuel.

Higher of a or b:

a. Either 1 or 2
    1. Ten percent of flight time from departure airport to destination airport.
    2. Five percent of burnoff fuel from departure airport to destination airport.
       When adapting 2, the operator establishes the following program:
        (a) Monitoring fuel consumption on each airplane and reflecting this performance in the flight planning
        (b) Monitoring route and airport characteristics and determining whether additional fuel is required
b. Fifteen-minute holding or equivalent.

Our Current Fuel Policy

In 2000, the Japanese fuel requirement was changed based on the investigation discussed in the preceding paragraphs. Our current fuel policy is as follows:

Item	Policy until 1999	Policy after 2000
Contingency	10% flight time	5% burnoff fuel
Reserve	30-min hold	30-min hold
Planned contingency fuel (PCF)	None	If required

We are monitoring route and airport characteristics and are adjusting the quantity of additional fuel, as required, based on operational data collected over the past year. The following is an example of PCF.

Route	Aircraft	PCF [LB]	Note
JPN to EUR	747-400	1500	Restriction of initial altitude, long taxi
JPN to LAX		3000	Airport congestion
Other EUR/ USA	ALL	0	

Conclusion

Japanese authorities and Japanese major airlines devoted 27 persons over period of 8 months and ANA was able to justify reducing reserve fuel requirements on long range flights by average of 2.5% of the total fuel on board. That could be translated into a saving of 1.0% of fuel burn on every flight.