NASA Technical Memorandum 110240

Uncertainties that Flight Crews and Dispatchers Must Consider When Calculating the Fuel Needed for a Flight

Anna C. Trujillo
Langley Research Center, Hampton, Virginia

May 1996

National Aeronautics and
Space Administration
Langley Research Center
Hampton, Virginia 23681-0001

Uncertainties that Flight Crews and Dispatchers Must Consider When Calculating the Fuel Needed for a Flight

Abstract

In 1993, fuel accounted for approximately 15% of an airline's expenses. Fuel consumption increases as fuel reserves increase because of the added weight to the aircraft. Calculating fuel reserves is a function of Federal Aviation Regulations, airline company policy, and factors that impact or are impacted by fuel usage enroute. This research studied how pilots and dispatchers determined the fuel needed for a flight and identified areas where improvements in methods may yield measurable fuel savings by (1) listing the uncertainties that contribute to adding contingency fuel, (2) obtaining pilots' and dispatchers' perspective on how often each uncertainty occurred, and (3) obtaining pilots' and dispatchers' perspective on the fuel used for each occurrence. This study found that for the majority of the time, pilots felt that dispatchers included enough fuel. As for the uncertainties that flight crews and dispatchers account for, air traffic control accounts for a 28% and weather uncertainties account for 58%. If improvements can be made in these two areas, a great potential exists to decrease the reserve required, and therefore fuel usage without jeopardizing safety.

Introduction

Fuel costs are a major aircraft expenditure (ref. 1, 2, 3). In 1993, fuel accounted for approximately 15% of an airline's expenses (ref. 4, 5, 6). Thus, the most dramatic changes in decreasing the cost of flight normally are a result of more fuel efficient procedures and equipment. This typically encompasses: efficient aircraft resulting partially from improved airline maintenance and flight preparation; efficient aircraft operations resulting partially from improved airline loading, taxi, and flight procedures; efficient air traffic control (ATC) procedures; and improved equipment and facilities (ref. 7, 8). Fortunately, the procedures for saving fuel that were relatively easy to implement have already been done, such as using simulators to train pilots, gate holds, and area navigation and direct routing (ref. 8). These increases in efficiency have resulted in an increase of nautical air miles per 1000 lbs (pounds) of fuel from 32.9 in 1975 to 44.0 in 1992 for domestic flights, a 34% increase (ref. 6, 9). Since the implementation of more fuel efficient procedures, the consensus on the areas with the greatest possibilities for additional fuel savings are improving aircraft (ref. 7) and ATC procedures (ref. 8, 10).

Another way to affect fuel-related costs entails fuel management before and during flight. One part of fuel management is concerned with everything that contributes to adding fuel for reserves, from Federal Aviation Regulations (FARs) and airline company policy to factors that impact or are impacted by fuel usage enroute, which include anticipated delays in the system (e.g., weather and ATC), sensor tolerances (e.g., fuel flow and fuel quantity), and the captain's and dispatcher's experience on a certain aircraft and route. Flight crews must carry enough fuel to be within FAR guidelines, and to maintain safety and passenger comfort. But, some dispatchers and flight crews request additional fuel over that required by the FARs, company policy, and the particular characteristics of the flight such as the time of day, time of year, and originating and destination airports (ref. 11). Considering even a modest penalty to carry this unused fuel [approximately 4% per hour per pound of unused fuel (ref. 12)], decreasing the average reserve on landing without compromising safety may result in significant savings to the airline industry. Therefore, this study examined how pilots and dispatchers determined the fuel needed for a flight and identified areas where improvements in methods may yield measurable fuel savings.

Fuel Requirement Calculation

The determination of how much fuel a flight needs involves three phases, although they may not be explicit in the fuel calculation process. The first phase calculates the fuel needed to satisfy the FARs, which sets the minimum legal amount of fuel needed for the flight. Basically, the FARs require enough fuel to arrive at the destination airport, then to divert to an alternate airport if available, and finally additional fuel for further flying.

The FAR fuel requirements for turbine domestic air carriers are essentially divided into over-land (within the 48 contiguous United States and the District of Columbia) and over-water (outside the 48 contiguous United States and the District of Columbia). The FARs relating to the fuel needed for a flight are stated below (ref. 13).

121.639 FUEL SUPPLY: ALL OPERATIONS: DOMESTIC AIR CARRIERS. No person may dispatch or takeoff an airplane unless it has enough fuel —

(a) To fly to the airport to which it is dispatched;
(b) Thereafter, to fly to and land at the most distant alternate airport (where required) for the airport to which dispatched; and
(c) Thereafter, to fly for 45 minutes at normal cruising fuel consumption.

121.645 FUEL SUPPLY: TURBINE-ENGINE POWERED AIRPLANES, OTHER THAN TURBO PROPELLER: FLAG AND SUPPLEMENTAL AIR

CARRIERS AND COMMERCIAL OPERATORS.

(a) Any flag air carrier operations with the 48 contiguous United States and the District of Columbia may use the fuel requirements of §121.639.

(b) For any flag air carrier, supplemental air carrier, or commercial operator operation outside the 48 contiguous United States and the District of Columbia, unless authorized by the Administrator in the operations specifications, no person may release for flight or take off a turbine-engine powered airplane (other than a turbo-propeller powered airplane), unless, considering wind and other weather conditions expected, it has enough fuel —
  (1) To fly to and land at the airport to which it is released;
  (2) After that, 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 was released;
  (3) After that, to fly to and land at the most distant alternate airport specified in the flight release, if and alternate is required; and
  (4) After that, to fly for 30 minutes at holding speed at 1,500 feet above the alternate airport (or the destination airport if no alternate is required) under standard temperature conditions.

(c) No person may release a turbine-engine-powered airplane (other than a turbo-propeller airplane) to an airport for which an alternate is not specified under §121.621(a)(2) or 121.623(b) unless it has enough fuel, considering wind and other weather conditions expected, to fly to that airport and thereafter to fly for at least two hours at normal cruising fuel consumption.

121.647 FACTORS FOR COMPUTING FUEL REQUIRED.

Each person computing fuel required for the purposes of this subpart shall consider the following:
(a) Wind and other weather conditions forecast.
(b) Anticipated traffic delays.
(c) One instrument approach and possible missed approach at destination.
(d) Any other conditions that may delay landing the aircraft.

For the purposes of this section, required fuel is in addition to unusable fuel.

Next, dispatchers apply airline policy and the particular characteristics of the flight to add fuel to the FAR minimums. This normally includes fuel to taxi, to execute a go-around, and to cover fuel indicator error (ref. 14). The total from these three values should be the minimum amount of fuel a flight should land with if no go-around was executed (ref. 14). The amount of fuel determined from this step plus the fuel needed to satisfy the FARs could be considered the airline minimum fuel needed for the flight.

Next, the captain, at his discretion, may add additional fuel to the dispatcher's recommendation. This added fuel is based on the captain's experience on a certain route and aircraft, in addition to his comfort level. This step is probably the least understood in the process.

All of these steps consider the fuel needed for possible contingencies such as arrival delays and inflight weather changes. These contingencies are uncertainties in the system which pilots and dispatchers must realistically account for in their calculations of the fuel needed for a particular flight.

Objectives

This investigation had three objectives. The objectives were to (1) list the uncertainties that contribute to adding contingency fuel, (2) obtain the pilots' perspective on how often each uncertainty occurred and the fuel used for each occurrence, and (3) obtain the dispatchers' perspective on how often each uncertainty occurred and the fuel used for each occurrence.

Experimental Variables

The primary independent variables were each of the events, or uncertainties, that contributed to contingency fuel. The analysis considered, within each event, the current position of the respondent (captain, first officer, or dispatcher) and the type of primary route he managed (over-land or over-water).

Experiment Design

Subjects

Pilots

Eighteen active line pilots from four airlines returned the survey, for a return rate of approximately 64%. They had an average of 19 years of commercial flying experience, with a range of six to 31 years. Eleven were current captains and seven were first officers. An equal split occurred between pilots that flew primarily over-land routes and pilots that flew primarily over-water routes.

Dispatchers

Nine dispatchers from three airlines returned the survey, for a return rate of approximately 45%. They had an average of 11 years of dispatching experience, with a range of five to 18 years. Six dealt with primarily over-land routes, while the remaining three dealt primarily with over-water routes.

Test Design

Each uncertainty was treated separately, as were the survey responses. The study of the responses was a 3x2, position by route, analysis of variance (ANOVA). Position was either captain, first officer, or dispatcher and route was either over-land or over-water.

Dependent Measures

The dependent measures consisted of the respondents' answers to the survey and their revisions to the uncertainties that affected the fuel carried. The subjects' estimates of the frequency of occurrence of an uncertainty and the fuel used for each occurrence comprised the majority of the revisions.

Procedure

First, two recently retired airline pilots, with 35 years and 29 years of airline experience, enumerated the uncertainties dispatchers and pilots need to consider when calculating the fuel needed for a flight. This generated a list of 59 unplanned occurrences. These occurrences were due to: 19 weather uncertainties, seven route uncertainties, 10 ATC uncertainties, 10 airport uncertainties, and 13 aircraft systems uncertainties. (See table 1.) Each unplanned occurrence is not necessarily independent from all others. For instance, a weather disturbance in one area of the country may affect the whole ATC system, requiring a route change on a flight that is nowhere near the initial weather disturbance. Also included in the table were the estimated frequency a crew might encounter a particular uncertainty in a year and the estimated fuel used for each occurrence of a particular uncertainty.

This table and a short survey were then sent to current airline pilots (see appendix A) and dispatchers (see appendix B). They were instructed to complete the survey and to modify the table where they saw fit, especially for the values of the estimated frequency and the estimated fuel used.

Data Analysis

Before the data were analyzed, the scale ratings were normalized to the same scale of how often, never to always, the flight crew added additional fuel to the dispatcher's original calculation. Also, three of the over-land dispatchers estimated the frequency of an event occurring per dispatcher rather than per flight crew. For over-land routes, a dispatcher will handle about 35 flights per day and a pilot will fly about 4 days a week, 2 flights a day (ref. 15). Thus, a correction factor of $\frac{4\ \text{days/week} * 2\ \text{flights/day}}{35\ \text{flights/day} * 7\ \text{days/week}}$ was included for those three over-land dispatchers that estimated the frequency of an event occurring per dispatcher.

The response data were analyzed using SPSS® statistical software (ref. 16). An ANOVA was run separately on each of the 59 unplanned occurrences and the survey responses. This analysis used position and route as the independent factors. Significance was at $p \leq 0.05$, where p is the probability of a Type II error.

Results and Discussion

Survey Responses

The majority of the time (approximately 67%), pilots felt that dispatchers included enough fuel. Pilots only requested additional fuel about once every 79 flights (one outlier data point omitted).

For most of the survey questions, a significant difference occurred between route types. The additional fuel added, the amount of fuel flight crews plan to land with, and the actual amount of fuel they land with were greater for over-water routes than for over-land routes. (See table 2.) The ratio of the amount of fuel flight crews plan to land with for over-water flights to over-land flights is 2.3. For domestic flights, the FARs require reserve fuel of

$$\frac{\text{lbs}}{\text{hr}}\left(t_{\text{dom\_alt}} + 45\ \text{min} * \frac{\text{hr}}{60\ \text{min}}\right) \text{ pounds of fuel} \tag{1}$$

where hr=hours, min=minutes, and $t_{\text{dom\_alt}}$=flight time (in hours) to domestic alternate airport. For international flights with a redispatch point and an alternate airport, the FARs require reserve fuel of

$$\frac{\text{lbs}}{\text{hr}}\left(0.10t_{\text{intl\_flt}} + t_{\text{intl\_alt}} + 30\ \text{min} * \frac{\text{lbs}}{\text{hr}}\text{hold} * \frac{\text{hr}}{60\ \text{min}}\right) \text{ pounds of fuel} \tag{2}$$

where $t_{\text{intl\_flt}}$=international flight time (in hours) from redispatch point, $t_{\text{intl\_alt}}$=flight time (in hours) to international alternate airport, and $\frac{\text{lbs}}{\text{hr}}\text{hold}$=fuel flow for a hold at 15,000 ft. Assuming the following average values, $t_{\text{dom\_alt}}$=20 min, $t_{\text{intl\_flt}}$=2.25 hrs, $t_{\text{intl\_alt}}$=35 min, and $\frac{\text{lbs}}{\text{hr}}\frac{\text{hold}}{\text{cruise}} = 0.85$ (ref. 15), the ratio of (2) to (1) is 1.1.

Essentially, flight crews are landing with twice as much fuel for over-water flights than required by the FARs. This may be due to several reasons. First, flight crews may not fully understand the redispatch rules pertaining to the FARs. For example, 10% of the total flight time is from the redispatch point and not the originating airport of the flight. Second, flight crews just may not feel comfortable traveling long distances over-water with what they perceive as unsafe amounts of contingency fuel. Third, the long-term prediction that dispatchers and pilots must rely on, especially regarding weather and ATC, may not be perceived as reliable. But, as seen in table 2, flight crews regularly land with most of the fuel they planned to land with.

Frequency and Amount Table Responses

Table 1 indicates the average frequency an unplanned event occurs and the amount of fuel it requires. As an example of the fuel used for these uncertainties, a Boeing 757 type of aircraft would use approximately 274,284 lbs of reserve fuel each year (ref. 17). (See table 3.) As seen in table 4, which lists the uncertainties by the amount of fuel a Boeing 757 type of aircraft would consume in a year by descending order, weather and ATC dominate essentially the first half of the list. Not unexpectedly, ATC accounts for a significant portion (28%) of fuel needed to cover uncertainties in the system. (See fig. 1.) In fact, it has been estimated that "the industrywide cost of ATC's inefficiencies ... [are] more than $5 billion a year" (p. 58, ref. 18).

This is one of the driving reasons for the free flight initiative the FAA is studying and beginning to implement in a limited manner. Free flight is defined as "a safe and efficient flight operating capability under IFR in which the operators have the freedom to select their path and speed in real time. Air traffic restrictions are imposed only to ensure separation, to prevent exceeding airport capacity, and to prevent unauthorized flight through special use airspace. Even those restrictions are to be limited in extent and duration and only to address an immediate ATC concern" (p. 15, ref. 19).

Currently, within the FAA, two programs are hinting at the savings free flight may bring, (1) the National Route Program (NRP) and (2) Future Air Navigation System (FANS). NRP has been estimated to save Northwest Airlines approximately 15 million lbs of fuel with an average of 300 lbs per segment (p. 48, ref. 20) and the Air Transport Association (ATA) has estimated that it will save its members $40 million a year (p. 48, ref. 20). As for FANS, United Airlines has estimated "fuel savings of $2,500 per leg in Pacific operations, ..., not including additional revenue from carrying more cargo and less fuel" (p. 49, ref. 20).

The major contributor, though, is weather uncertainties, which account for 58%. Research in this area by C. Scanlon has indicated that substantial fuel savings may be obtained by providing flight crews real-time graphical weather information (ref. 21). He found that flight crews with real-time graphical weather information "flew 5% shorter enroute segments and burned 5% less fuel" (ref. 21, p. 90). Since airline pilots deviate around adverse weather once every 12.8 flights, "an airline could save ... 0.4% of all enroute distance flown and fuel used during domestic enroute flight operations" (ref. 21, p. 90). As an example of weather optimized routes, "American Airlines has already demonstrated annual savings of $2.2 million through a collaborative 'negotiated wind routes' program with the FAA" (p. 34, ref. 22).

Respondents' Comments

Table 5 shows the contingency factors pilots and dispatchers consider the most often. Again, weather is the greatest consideration when pilots factor in the uses of contingency fuel, especially related to thunderstorms, winds -- including clear air turbulence (CAT) and windshear, and visibility. Route and ATC uncertainties were difficult to differentiate from the comments; but again, ATC-related factors constituted the second greatest concern. ATC-related reasons primarily concerned traffic-related problems on takeoff and landing due to congested airspace, and ATC changes to the planned route, again due to overcrowding problems. Rockwell Collins has estimated that enroute losses and cruise inefficiencies have resulted in approximately $174 million in losses in 1993(p. 48, ref. 20). Pilots also mentioned airport uncertainties quite often, especially taxiing problems due to weather and heavy traffic volume. Rockwell Collins has estimated a loss of approximately $108 million in 1993 due to gate and taxi delays (p. 48, ref. 20).

Conclusions

Eighteen line pilots and nine dispatchers completed a short survey and corrected entries on a table listing reasons why contingency fuel is needed, how often the uncertainty occurs, and how much fuel it uses per occurrence per flight crew. Analysis of the survey data indicated that these users allocate total fuel differently for over-land and over-water routes. For example, flight crews are landing with twice as much fuel for over-water flights than required by the FARs. This excess may be due to flight crews not fully understanding the redispatch rules pertaining to the FARs, flight crews may not feel comfortable traveling long distances over-water with what they perceive as unsafe amounts of contingency fuel, and the long-term predictions that dispatchers and flight crews must rely upon may not be perceived as reliable.

The respondents also indicated that weather and ATC related contingencies use the most reserve fuel. These two categories account for approximately 86% of the reserve fuel used in a year. The weather related reasons for using contingency fuel included: thunderstorms; winds, including CAT and windshear; and visibility. The ATC related reasons included: traffic-related problems on takeoff and landing, and ATC changing the planned route. If improvements can be made in these two areas, such as NRP and FANS leading towards free flight, and presenting flight crews with real-time graphical weather in the cockpit, a great potential exists to safely decrease fuel usage.

References

1. U.S. Department of Transportation: *Aircraft Operating Cost and Performance Report (for Aircraft Over 60 Seats), for Calendar Years 1983 and 1984.* U.S. Dept. of Transportation, Sept. 1985.
2. Van Bodegraven, G.: "AIAA 90-3224 Commercial Aircraft DOC Methods," *AIAA/AHS/ASEE Aircraft Design, Systems and Operations Conference.* AIAA, Sept. 1990.
3. Hardaker, William T.: "Fuel -- A System Problem of Major Proportions," *24th Annual Air Traffic Control Association Fall Conference Proceedings.* Oct 1979.
4. Air Carrier Financial Statistics Table 1--RSPA: "Table 6.11 — Operating Expenses of Domestic Operations, All Services Large Certificated Air Carriers, Major National And Large Regional Groups, 1984-1993," *gopher://gopher.bts.gov:70/11/stat-tables/aviationhb/tables/chap06/tab6-15/tab6-15.* U.S. Department of Transportation, 1993
5. Council of Economic Advisors, Economic Report of the President, February 1994, Tables B-59, 60: "Table 103. Average Retail Price of Transportation Fuel," *gopher://gopher.bts.gov:70/59/tables/table-66/t-66.* U.S. Department of Transportation, 1993.
6. CAB - Handbook of Airline Statistics, 1977; CAB - Fuel Cost and Consumption, Twelve Months Ended December 31, 1984, and earlier editions; U.S. DOT/RSPA, Data Administration Division, DAI-20: "Table 86. Fuel Consumption by Certificated Air Carriers," *gopher://gopher.bts.gov:70/59/tables/table-72/t-72.* U.S. Department of Tranportation, 1993.
7. Barber, D. and Morrall, J.C.: "Fuel Conservation and Economy Constraints," *AGARD Air Traffic Control in Face of Users' Demand and Economic Constraints.* AGARD, 1983.
8. Covey, R.R.; Mascetti, G.J.; Roessler, W.U.; Bowles, R.L.: "Past and Potential Near Term Fuel Savings in Commercial Aviation Through Modified Operational Strategies," *SAE International Air Transportation Meeting.* SAE, May 1980.
9. "Table 5. Vehicle-Miles," *gopher://gopher.bts.gov:70/59/nts/1995/tables/table-005/t005.* U.S. Department of Transportation, 1993.
10. Grundy. P.M.: "Fuel Conservation — the Airline - ATC," *The Controller vol. 21, no. 2.* International Federation of Air Traffic Controllers' Association, Switzerland, May 1982.
11. Schooley, Brooks: "Flight Preperation and Planning," *DOE Symposium on Commercial Aviation Energy Conservation Strategies.* 1981.
12. Correspondance with Dave Simmon, UAL Pilot, Ret. 1995
13. "Federal Aviation Regulations — Part 121 Certifications and Operations: Domestic, Flag, and Supplemental Air Carriers and Commercial Operators of Large Aircraft," *Jeppesen Airway Manual Services.* Jeppesen Sanderson, Nov. 1992.

14. *767 Flight Manual - Handbook, Revision #72.* United Airlines SFOEG - New Aircraft and Operational Engineering. Oct. 1986.
15. Correspondance with Richard Gifford, UAL Pilot, Ret. 1995
16. Norušis, Marija J.: *SPSS® for Windows™: Base System User's Guide, Release 6.0.* SPSS Inc., 1993.
17. *757/767 Flight Manual - Handbook, Revision #38.* SFOEG - Operational Engineering. Nov. 1991.
18. Sweetman, Bill: "Accelerating the ATC Revolution," *Air Transport World vol. 32, no. 5.* May 1995.
19. Speck, Lane: "Free Flight," *Proceedings of the Air Tranportation Management Workshop.* NASA CP-10151, Jan. 1995.
20. McGee, William J.: "Getting There Faster and Cheaper: The National Route Program," *Air Transport World, vol. 32, no. 9.* Sep. 1995.
21. Scanlon, Charles H.: "Cockpit Graphical Weather Information Shown to Enhance Efficiency, Safety, and Situation Awareness," *Safe Application of Technology In Corporate Aviaiton - Proceedings of the 39th annual Corporate Aviation Safety Seminar (CASS).* Flight Safety Foundation, April 13-15, 1994.
22. Nordwall, Bruce D.: "Road Map Leads FAA to 'Free Flight'," *Aviation Week and Space Technology, vol. 143, no. 19.* Nov. 6, 1995.

Table 1 - Reasons for Reserve Fuel

Reason For Reserve Fuel (unplanned occurances)	**Frequency (per crew)**	**Fuel Used (per occurrence)**
Weather Uncertainty		
1. **Ramp conditions** causing unplanned departure delays.	16.25 per yr	15.09 min idle fuel
2. **Ramp conditions** causing unplanned arrival delays.	9.55 per yr	15.09 min idle fuel
3. **Deicing** causing unplanned departure delays.	6.83 per yr	18.93 min idle fuel
4. **Runway conditions** causing unplanned departure delays.	5.31 per yr	15.71 min idle fuel
5. **Runway conditions** causing unplanned arrival delays.	5.49 per yr	16.79 min hold fuel
6. **Thunderstorms** causing unplanned departure delays.	12.19 per yr	21.25 min idle fuel
7. **Thunderstorms** causing unplanned enroute detours.	15.57 per yr	6.52 min cruise fuel
8. **Thunderstorms** causing unplanned arrival delays.	Land Water Capt 3.33 2.67 F/O 6.00 13.00 Disp 40.67 2.00 Note: per yr	18.84 min hold fuel
9. **Surface wind** changes causing unplanned departure runway changes and delays.	3.09 per yr	22.32 min idle fuel
10. **Surface wind** changes causing unplanned arrival runway changes and delays.	6.82 per yr	4.80 min cruise fuel
11. **Winds** at cruise altitude more unfavorable than planned.	16.10 per yr	18.36 min cruise fuel
12. **Turbulence (CAT)** causing a change in the flight plan.	Land Water Capt 1.58 0.27 F/O 0.93 6.02 Disp 0.61 0.69	3.07% cruise fuel during period

	Note: per yr	
13. **Temperature** at altitude above forecast.	1.20 per yr	1.00% cruise fuel during period
14. **Volcanic dust** or **high ozone** causing enroute detours.	0.56 per yr	11.07 min cruise fuel
15. **Actual** or **forecast ceiling** and **visibility** at destination deteriorating while enroute requiring an alternate.	5.26 per yr	30.36 min cruise fuel
16. **Actual** or **forecast ceiling** and **visibility** at alternate deteriorating while enroute requiring an additional alternate.	0.84 per yr	16.07 min cruise fuel
17. **Ceiling** and **visibility** at destination worsening causing unplanned arrival delays.	6.67 per yr	22.32 min hold fuel
18. **Ceiling** and **visibility** at destination below crew's minimums causing unplanned holding or diversions.	3.48 per yr	33.04 min holding/cruise fuel
19. **Unforecast restrictions to visibility** or **windshear** at the destination causing delays, holding, go-arounds, or diversions.	5.75 per yr	14.29 min hold fuel
Route Uncertainty		
20. **Cruise altitude**, **IAS/Mach**, or **route** is non-optimal.	19.02 per yr	3.46% cruise fuel during period
21. **ATC** requiring a change of route, altitude, or speed.	35.39 per yr	1.68% cruise fuel
22. **Mach** increase to make up unplanned loss of time in accordance with company policy.	13.55 per yr	3.43% cruise fuel during period
23. **Traffic/military** causing unplanned route change.	0.78 per yr	3.14 min cruise fuel
24. **Restricted area** causing unplanned route change.	2.77 per yr	4.64 min cruise fuel
25. **Priority traffic** causing unplanned delay.	10.34 per yr	6.07 min hold fuel
26. **Terrorist activity** causing unplanned diversion.	0.01 per yr	30.64 min cruise fuel

ATC Uncertainty		
27. **Traffic** delays on departure incurred unexpectedly while taxiing.	16.39 per yr	5.07 min idle fuel
28. **Traffic** delays on arrival due to unplanned high volume.	7.85 per yr	15.18 min hold fuel
29. **Takeoff direction** opposite to planned route of flight.	22.49 per yr	3.29 min cruise fuel
30. **Departure vectors** are not optimum.	22.60 per yr	2.36 min cruise fuel
31. **Climb out speeds** are not optimum due to traffic separation.	32.95 per yr	3.21% climb fuel
32. **Early descent** required unexpectedly.	34.09 per yr	38.75% descent fuel
33. **Descent speeds** are not optimum due to unplanned traffic.	32.16 per yr	9.82% descent fuel
34. **Delaying vectors** are given during approach unexpectedly.	22.21 per yr	2.71 min cruise fuel
35. **Hold** is required unexpectedly.	7.98 per yr	11.68 min hold fuel
36. **Runway changes** required at destination unexpectedly.	5.85 per yr	5.00 min cruise fuel
Airport Uncertainty		
37. **Curfew** is in effect unexpectedly.	0.05 per yr	12.86 min hold fuel
38. **Runway closure** occurs unexpectedly.	0.76 per yr	12.14 min cruise fuel
39. **Airport closure** occurs unexpectedly.	0.18 per yr	30.89 min cruise fuel
40. **Aircraft instruments** or **ground facilities** fail unexpectedly.	0.18 per yr	29.64 min cruise fuel
41. **Aircraft on active runway** causing a go-around unexpectedly.	0.38 per yr	18.89 min approach fuel
42. **Trucks** or **equipment on active runway** causing a go-around unexpectedly.	0.02 per yr	10.89 min approach fuel
43. **Ground delays** due to unplanned large volume of traffic.	6.21 per yr	9.36 min idle fuel
44. **Gate** is occupied unexpectedly.	18.37 per yr	10.98 min idle fuel
45. **Union slow-down** or **work stoppage** occurs unexpectedly.	0.07 per yr	10.74 min hold fuel

46. **Operational creeping delays** occur unexpectedly.	7.86 per yr	10.19 min idle fuel
Aircraft Systems Uncertainty		
47. **Aircraft weight** listed incorrectly unexpectedly. (This is affected by **fuel density** and affects **CG)**	5.01 per yr	4.04% / hr for weight error of ~2,000#
48. **Actual fuel at departure** is less than planned.	0.97 per yr	385.00 lbs of fuel
49. **Aircraft variances** are larger than expected.	5.30 per yr	1804.20 lbs of fuel
50. **Fuel gage error** is larger than expected.	1.37 per yr	0.50% tank capacity
51. **Unusable fuel** causes an unplanned reduction of the perceived reserve fuel.	0.10 per yr	15.00 min cruise fuel
52. **Trapped fuel** causes an unplanned reduction of the perceived reserve fuel.	0.02 per yr	7.50 min cruise fuel
53. **Fuel leak** occurs unexpectedly.	0.05 per yr	10.50% increase in cruise fuel
54. **Evaporation** occurs unexpectedly.	0.01 per yr	0.50% increase in cruise fuel
55. **Inflight irregularities** occur unexpectedly.	0.68 per yr	25.00% increase in cruise fuel
56. **Drag-sensitive** irregularity occurs unexpectedly.	0.05 per yr	3.00% cruise fuel flow
57. **Off-optimum altitude** or **speed** caused by an irregularity occurs unexpectedly.	0.56 per yr	22.79% increase in cruise fuel
58. **Time-sensitive** irregularity occurs unexpectedly.	0.48 per yr	20.00 min hold fuel
59. **Airport-sensitive** irregularity occurs unexpectedly.	0.49 per yr	30.00 min cruise fuel

Table 2 - Survey Results

Question	Average	Standard Deviation
Fuel is added ...	1 every 79 flights	154
The amount of fuel added is ...	over-land 2050 lbs over-water 3571 lbs	721 lbs 1427 lbs
The amount of fuel that is planned for landing is ...	over-land 8018 lbs over-water 18556 lbs	3250 lbs 9732 lbs
The amount of fuel on landing is ...	over-land 8300 lbs over-water 18417 lbs	2792 lbs 7842 lbs

Table 3 - Fuel Required by a Boeing 757 in a Year to Cover Uncertainties

Reason For Reserve Fuel (unplanned occurances)	**lbs of Fuel Used per Year (for B757)**
Weather Uncertainty	
1. **Ramp conditions** causing unplanned departure delays.	8582
2. **Ramp conditions** causing unplanned arrival delays.	5044
3. **Deicing** causing unplanned departure delays.	4525
4. **Runway conditions** causing unplanned departure delays.	2920
5. **Runway conditions** causing unplanned arrival delays.	7989
6. **Thunderstorms** causing unplanned departure delays.	9066
7. **Thunderstorms** causing unplanned enroute detours.	10945
8. **Thunderstorms** causing unplanned arrival delays.	19936
9. **Surface wind** changes causing unplanned departure runway changes and delays.	2414
10. **Surface wind** changes causing unplanned arrival runway changes and delays.	3529
11. **Winds** at cruise altitude more unfavorable than planned.	31870
12. **Turbulence (CAT)** causing a change in the flight plan.	1726
13. **Temperature** at altitude above forecast.	26
14. **Volcanic dust** or **high ozone** causing enroute detours.	668
15. **Actual** or **forecast ceiling** and **visibility** at destination deteriorating while enroute requiring an alternate.	17218
16. **Actual** or **forecast ceiling** and **visibility** at alternate deteriorating while enroute requiring an additional alternate.	1455
17. **Ceiling** and **visibility** at destination worsening causing unplanned arrival delays.	12902

18. **Ceiling** and **visibility** at destination below crew's minimums causing unplanned holding or diversions.	11181
19. **Unforecast restrictions to visibility** or **windshear** at the destination causing delays, holding, go-arounds, or diversions.	7121
Weather Uncertainty Sub-Total	**159117**
Route Uncertainty	
20. **Cruise altitude, IAS/Mach**, or **route** is non-optimal.	1419
21. **ATC** requiring a change of route, altitude, or speed.	1282
22. **Mach** increase to make up unplanned loss of time in accordance with company policy.	1002
23. **Traffic/military** causing unplanned route change.	264
24. **Restricted area** causing unplanned route change.	1386
25. **Priority traffic** causing unplanned delay.	5440
26. **Terrorist activity** causing unplanned diversion.	33
Route Uncertainty Sub-Total	**10826**
ATC Uncertainty	
27. **Traffic** delays on departure incurred unexpectedly while taxiing.	2908
28. **Traffic** delays on arrival due to unplanned high volume.	10327
29. **Takeoff direction** opposite to planned route of flight.	7978
30. **Departure vectors** are not optimum.	5750
31. **Climb out speeds** are not optimum due to traffic separation.	2281
32. **Early descent** required unexpectedly.	22897
33. **Descent speeds** are not optimum due to unplanned traffic.	5474
34. **Delaying vectors** are given during approach unexpectedly.	6489

35. **Hold** is required unexpectedly.	8078
36. **Runway changes** required at destination unexpectedly.	3154
ATC Uncertainty Sub-Total	**75336**
Airport Uncertainty	
37. **Curfew** is in effect unexpectedly.	56
38. **Runway closure** occurs unexpectedly.	995
39. **Airport closure** occurs unexpectedly.	599
40. **Aircraft instruments** or **ground facilities** fail unexpectedly.	575
41. **Aircraft on active runway** causing a go-around unexpectedly.	622
42. **Trucks** or **equipment on active runway** causing a go-around unexpectedly.	19
43. **Ground delays** due to unplanned large volume of traffic.	2031
44. **Gate** is occupied unexpectedly.	7060
45. **Union slow-down** or **work stoppage** occurs unexpectedly.	65
46. **Operational creeping delays** occur unexpectedly.	2803
Airport Uncertainty Sub-Total	**14825**
Aircraft Systems Uncertainty	
47. **Aircraft weight** listed incorrectly unexpectedly. (This is affected by **fuel density** and affects **CG)**	436
48. **Actual fuel at departure** is less than planned.	373
49. **Aircraft variances** are larger than expected.	9562
50. **Fuel gage error** is larger than expected.	548
51. **Unusable fuel** causes an unplanned reduction of the perceived reserve fuel.	162
52. **Trapped fuel** causes an unplanned reduction of the perceived reserve fuel.	16

53. **Fuel leak** occurs unexpectedly.	11
54. **Evaporation** occurs unexpectedly.	11
55. **Inflight irregularities** occur unexpectedly.	366
56. **Drag-sensitive** irregularity occurs unexpectedly.	3
57. **Off-optimum altitude** or **speed** caused by an irregularity occurs unexpectedly.	275
58. **Time-sensitive** irregularity occurs unexpectedly.	832
59. **Airport-sensitive** irregularity occurs unexpectedly.	1585
Aircraft Systems Uncertainty Sub-Total	**14180**
Total Fuel	**274284**

Note: Idle fuel = 35 lbs/min

Hold fuel = 5200 lbs/hr

Cruise fuel = 6469 lbs/hr (for 39000 ft at 180,000 lbs)

Disturbances last for 20 min

from ref. 19

Table 4 - Fuel Required by a Boeing 757 in a Year to Cover Uncertainties

Reason For Reserve Fuel (unplanned occurances)	Uncertainty Category	lbs of Fuel Used per Year (for B757)
1. 11 - **Winds** at cruise altitude more unfavorable than planned.	weather	31870
2. 32 - **Early descent** required unexpectedly.	ATC	22897
3. 8 - **Thunderstorms** causing unplanned arrival delays.	weather	19936
4. 15 - **Actual** or **forecast ceiling** and **visibility** at destination deteriorating while enroute requiring an alternate.	weather	17218
5. 17 - **Ceiling** and **visibility** at destination worsening causing unplanned arrival delays.	weather	12902
6. 18 - **Ceiling** and **visibility** at destination below crew's minimums causing unplanned holding or diversions.	weather	11181
7. 7 - **Thunderstorms** causing unplanned enroute detours.	weather	10945
8. 28 - **Traffic** delays on arrival due to unplanned high volume.	ATC	10327
9. 49 - **Aircraft variances** are larger than expected.	aircraft systems	9562
10. 6 - **Thunderstorms** causing unplanned departure delays.	weather	9066
11. 1 - **Ramp conditions** causing unplanned departure delays.	weather	8582
12. 35 - **Hold** is required unexpectedly.	ATC	8078
13. 5 - **Runway conditions** causing unplanned arrival delays.	weather	7989
14. 29 - **Takeoff direction** opposite to planned route of flight.	ATC	7978
15. 19 - **Unforecast restrictions to visibility** or **windshear** at the destination causing delays, holding, go-arounds, or diversions.	weather	7121

16. **44 - Gate** is occupied unexpectedly.	airport	7060
17. **34 - Delaying vectors** are given during approach unexpectedly.	ATC	6489
18. **30 - Departure vectors** are not optimum.	ATC	5750
19. **33 - Descent speeds** are not optimum due to unplanned traffic.	ATC	5474
20. **25 - Priority traffic** causing unplanned delay.	route	5440
21. **2 - Ramp conditions** causing unplanned arrival delays.	weather	5044
22. **3 - Deicing** causing unplanned departure delays.	weather	4525
23. **10 - Surface wind** changes causing unplanned arrival runway changes and delays.	weather	3529
24. **36 - Runway changes** required at destination unexpectedly.	ATC	3154
25. **4 - Runway conditions** causing unplanned departure delays.	weather	2920
26. **27 - Traffic** delays on departure incurred unexpectedly while taxiing.	ATC	2908
27. **46 - Operational creeping delays** occur unexpectedly.	airport	2803
28. **9 - Surface wind** changes causing unplanned departure runway changes and delays.	weather	2414
29. **31 - Climb out speeds** are not optimum due to traffic separation.	ATC	2281
30. **43 - Ground delays** due to unplanned large volume of traffic.	airport	2031
31. **12 - Turbulence (CAT)** causing a change in the flight plan.	weather	1726
32. **59 - Airport-sensitive** irregularity occurs unexpectedly.	aircraft systems	1585
33. **16 - Actual** or **forecast ceiling** and **visibility** at alternate deteriorating while enroute requiring an additional alternate.	weather	1455
34. **20 - Cruise altitude, IAS/Mach**, or **route** is non-optimal.	route	1419
35. **24 - Restricted area** causing unplanned route change.	route	1386

36. **21 - ATC** requiring a change of route, altitude, or speed.	route	1282
37. **22 - Mach** increase to make up unplanned loss of time in accordance with company policy.	route	1002
38. **38 - Runway closure** occurs unexpectedly.	airport	995
39. **58 - Time-sensitive** irregularity occurs unexpectedly.	aircraft systems	832
40. **14 - Volcanic dust** or **high ozone** causing enroute detours.	weather	668
41. **41 - Aircraft on active runway** causing a go-around unexpectedly.	airport	622
42. **39 - Airport closure** occurs unexpectedly.	airport	599
43. **40 - Aircraft instruments** or **ground facilities** fail unexpectedly.	airport	575
44. **50 - Fuel gage error** is larger than expected.	aircraft systems	548
45. **47 - Aircraft weight** listed incorrectly unexpectedly. (This is affected by **fuel density** and affects **CG)**	aircraft systems	436
46. **48 - Actual fuel at departure** is less than planned.	aircraft systems	373
47. **55 - Inflight irregularities** occur unexpectedly.	aircraft systems	366
48. **57 - Off-optimum altitude** or **speed** caused by an irregularity occurs unexpectedly.	aircraft systems	275
49. **23 - Traffic/military** causing unplanned route change.	route	264
50. **51 - Unusable fuel** causes an unplanned reduction of the perceived reserve fuel.	aircraft systems	162
51. **45 - Union slow-down** or **work stoppage** occurs unexpectedly.	airport	65
52. **37 - Curfew** is in effect unexpectedly.	airport	56
53. **26 - Terrorist activity** causing unplanned diversion.	route	33
54. **13 - Temperature** at altitude above forecast.	weather	26

55. **42 - Trucks** or **equipment on active runway** causing a go-around unexpectedly.	airport	19
56. **52 - Trapped fuel** causes an unplanned reduction of the perceived reserve fuel.	aircraft systems	16
57. **53 - Fuel leak** occurs unexpectedly.	aircraft systems	11
58. **54 - Evaporation** occurs unexpectedly.	aircraft systems	11
59. **56 - Drag-sensitive** irregularity occurs unexpectedly.	aircraft systems	3
	Total	**274284**

Table 5 - Contingency Factors from Comments

Uncertainty Category	Pilots	Dispatchers	Total
Weather	28	13	41
Route	3	3	6
ATC	12	13	25
Airport	17	4	21
Aircraft Systems	4	3	7

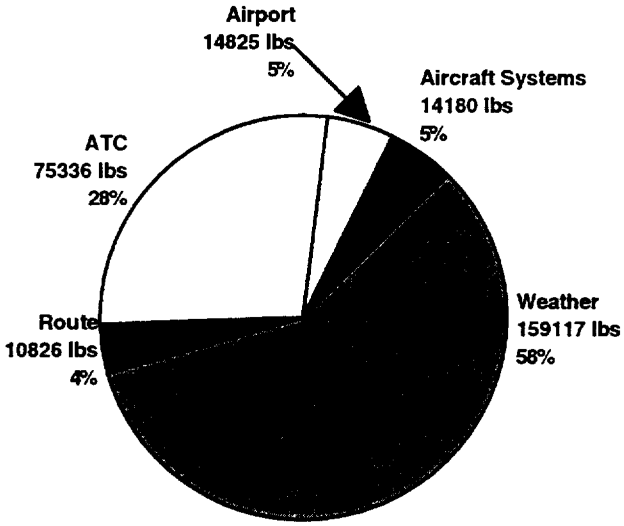

Figure 1 - Contribution of Each Uncertainty Category

Appendix A - Contingency Fuel Survey for Pilots

1. How long have you been piloting commercial aircraft? ____________________ years

2. What aircraft are you currently flying? ______________________________

3. What is your position on this aircraft? ☐ Captain ☐ First Officer

4. What route or routes do you fly the most? ______________________________
____
____
____

5. Dispatchers add-in enough contingency fuel. Never |____|____|____|____| Always

   a. How often do you need to add fuel? Once every ____________ flights

   b. How much fuel do you usually need to add? ______________________________ lbs

6. If a flight goes exactly as planned (i.e., no delays and flight plan followed completely), how much fuel do you plan to land with? ______________________________ lbs

7. On average, how much fuel do you land with? ______________________________ lbs

8. What contingency factors do you primarily consider when calculating the fuel needed for a flight?

9. Briefly describe how you determine whether a dispatcher's calculations for the fuel required for a flight are accurate.

For further comments, use the back
of this page or a separate sheet

Appendix B - Contingency Fuel Survey for Dispatchers

1. How long have you been a dispatcher? ____________________ years

2. What aircraft do you handle the most? ____________________
____
____
____

3. What route or routes do you handle the most? ____________________
____
____
____

4. Pilots add additional fuel to the dispatcher's calculation. |___|___|___|___|
Never Always

a. How often do pilots add fuel (i) for over land flights? Once every__________ flights
(ii) for over water flights? Once every__________ flights

b. How much fuel do pilots usually add (i) for over land flights? __________ lbs
(ii) for over water flights? __________ lbs

5. If a flight goes exactly as planned (i.e., no delays and flight plan followed completely), how much fuel should flights land with (a) for over land routes? __________ lbs
(b) for over water routes? __________ lbs

6. On average, how much fuel do flights land with
(a) for over land routes? ____________________ lbs
(b) for over water routes? ____________________ lbs

7. What contingency factors do you primarily consider when calculating the fuel needed for a flight?

8. Briefly describe how you determine the fuel needed for a flight.

For further comments, use the back
of this page or a separate sheet

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY ***(Leave blank)***

2. REPORT DATE
May 1996

3. REPORT TYPE AND DATES COVERED
Technical Memorandum

4. TITLE AND SUBTITLE
Uncertainties that Flight Crews and Dispatchers Must Consider When Calculating the Fuel Needed for a Flight

5. FUNDING NUMBERS
505-64-53-01

6. AUTHOR(S)
Anna C. Trujillo

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
NASA Langley Research Center
Hampton, VA 23681-0001

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Washington, DC 20546-0001

10. SPONSORING / MONITORING AGENCY REPORT NUMBER
NASA TM-110240

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Unclassified - Unlimited
Subject Category 03

12b. DISTRIBUTION CODE

13. ABSTRACT ***(Maximum 200 words)***

In 1993, fuel accounted for approximately 15% of an airline's expenses. Fuel consumption increases as fuel reserves increase because of the added weight to the aircraft. Calculating fuel reserves is a function of Federal Aviation Regulations, airline company policy, and factors that impact or are impacted by fuel usage enroute. This research studied how pilots and dispatchers determined the fuel needed for a flight and identified areas where improvements in methods may yield measurable fuel savings by (1) listing the uncertainties that contribute to adding contingency fuel, (2) obtaining the pilots' and dispatchers' perspective on how often each uncertainty occurred, and (3) obtaining pilots' and dispatchers' perspective on the fuel used for each occurrence. This study found that for the majority of the time, pilots felt that dispatchers included enough fuel. As for the uncertainties that flight crews and dispatchers account for, air traffic control accounts for 28% and weather uncertainties account for 58%. If improvements can be made in these two areas, a great potential exists to decrease the reserve required, and therefore, fuel usage without jeopardizing safety.

14. SUBJECT TERMS
fuel, fuel consumption, fuel reserves, contingency fuel, uncertainties

15. NUMBER OF PAGES
29

16. PRICE CODE
A03

17. SECURITY CLASSIFICATION OF REPORT
Unclassified

18. SECURITY CLASSIFICATION OF THIS PAGE
Unclassified

19. SECURITY CLASSIFICATION OF ABSTRACT
Unclassified

20. LIMITATION OF ABSTRACT