

Mathematically Modeling Aircraft Fuel Consumption

by

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GoCal Airlines

April 9, 2009

Lyn Chastin
Los Angeles International Airport
1 World Way
Los Angeles, CA 90045

Professor Canton
Director of Math, Science & Engineering Program
Lambda University
1265 College Drive
Littleton, WA 99056

Dear Professor Canton:

The fuel efficiency team at CoCal Airlines is seeking proposals from interested agencies to provide cost savings strategies for our Boeing 737-400 aircraft. Specifically, we are exploring ways to improve fuel economy for our most popular flight—our Denver-to-LA direct flight. Although we have always prided ourselves as being a “green airline,” we feel more can be done to improve fuel efficiency. We are contacting you because we are familiar with your integrated Math, Science and Engineering programs, and are looking to hire qualified candidates to lead a special charter of our company called the CoCal Green Team. Interested candidates should form a research team (3–4) and present a proposal to Lyn Chastin (CoCal Board Chair).

The proposal should include:

1. Analysis of the fuel consumption which occurs for the “typical” Denver–LA; LA–Denver-direct flight.
2. Identification of areas of potential fuel-savings, along with supporting models which highlight fuel savings.
3. Evidence of effective problem-solving processes and effective team collaboration.

Sincerely,

Lyn Chastin

Los Angeles International

Part I – Describing a “Typical” Flight

The first step in the analysis of fuel consumption is to identify what constitutes a “typical” flight. There are many factors that affect fuel consumption for any given flight. For the purposes of this exercise, it is not reasonable to include all factors in your model of fuel-consumption for a typical flight. In general, mathematical modeling of real world situations requires making assumptions and simplifying situations. Since you are interested in determining how to improve fuel efficiency, you must understand what impacts fuel efficiency. You must begin to organize major impacts and lesser impacts. For the flight that you will be studying, there is a wealth of information regarding flight performance. For example, Appendix A provides information from the Statistical Loads Data (Rustenburgg, Tipps, and Skinn 1998) that were determined for the aircraft you are studying.

Questions

1. Look at the diagram in Appendix B of the stages of a flight and think about how you expect the rate of fuel use of an aircraft to change as it goes through these stages. Sketch a rough graph that illustrates the total fuel use with respect to time throughout the flight. Explain why you chose to make your graph with particular features.
2. Discuss in your group which phases in a typical flight you think might consume a disproportionate amount of fuel and why.
3. How might this information assist you in researching this issue and making recommendations regarding fuel savings?

Part II – A Typical Flight Continued . . .

In the previous section of the case, you reviewed the fuel consumption data for a given aircraft, focusing on which parts of a flight might contribute to greater rates of fuel consumption over the course of a flight. Now you are going to consider the key elements of a typical flight as they relate to fuel use. Remember that one of the goals of this case is for you to investigate how fuel is consumed for a given flight, and then make recommendations regarding how fuel savings might be achieved. Therefore, it is important to understand the underlying assumptions that must be considered when studying fuel consumption for a given flight. Further, it is also important to understand what assumptions must be made in order to simplify this problem so that fuel consumption can be investigated and so that fuel savings recommendations can be made. Several aspects of this problem have already been defined (see the letter from Lyn Chastin to Professor Canton). However, fuel performance for a given flight can be influenced by a great many variables.

Questions

1. What might be some variables that impact fuel performance? Consider anything that might affect fuel use whether or not it can be controlled. Make a brief note of how you think these variables influence the fuel use (increase fuel use or decrease fuel use).
2. Look at the list you generated in Question 1 and consider only those variables that you think an airline or pilot may be able to control on the daily flights between Denver and Los Angeles. Create a refined list of variables that may affect the fuel use of an aircraft on this flight. Justify your responses.
3. What are some assumptions that you will need to make in order to simplify this problem to a degree that you can conceptualize it and make recommendations regarding fuel performance?
4. What variables might you want to hold constant or eliminate? Why?

Part III – Analysis of Fuel Consumption in a Typical Flight

Now that you have considered how different variables may affect fuel consumption, in this part you will find functions that model the fuel consumption based on the specific variables of weight and distance. To do this, you will go through a series of steps: generating functions and then evaluating the robustness of a function (e.g., To what extent does the function describe the phenomena? What does the function describe or not describe? What are the meanings of the functions in terms of fuel use? How can we use the functions to predict fuel consumption?)

Generating functions to estimate fuel consumption

Create function(s) that estimate the fuel used (in pounds) as a function of the range of the flight (in nautical miles (nm)) and functions that estimate the fuel used as a function of the zero fuel weight of the plane. Use the “Block Fuel Estimates” table in Appendix E to create functions for a Zero Fuel Weight (ZFW) of 90,000 lbs. The ZFW is the weight of the plane before fuel is added, but includes the weight of the passengers and cargo. You might find the website <http://www.graphpad.com/curvefit/index.htm> helpful as you choose your model.

Tasks

1. Create functions that estimate the block fuel estimate (in pounds) as a function of distance (in nm). Use the Block Fuel Estimates table to create functions for a ZFW of 90,000 lbs. Clearly show and explain how you determined that your function is the best for this data.
2. Use the Block Fuel Estimates table to create functions for a weight of 115,000 lbs. Clearly show and explain how you determined that your function is the best for this data.

Interpolating values from function(s)

Tasks

3. Use your functions(s) to find a block fuel estimate for a flight with ZFW 115,000 lbs and with a range of 1850 miles. Explain whether your estimate seems reasonable and why.
4. Create functions that estimate block fuel estimates as a function of the ZFW for distances of (a) 500 miles, and (b) 1000 miles.

Part IV – A Closer Look at the Fuel Consumed Throughout a Flight

The previous part allowed you to estimate the total fuel needed to fly from Los Angeles to Denver. However, in order to think about areas of savings, you will need to consider the amount of fuel used during different phases of the flight, such as: takeoff and climb to altitude; cruising at altitude; and descending to land. In this part of the case, you will construct models to help you determine approximate amounts of fuel used during these phases. Keep track of the assumptions you make.

Task

Consider a typical flight from Los Angeles to Denver that carries 160 passengers, flies at 35,000 feet, and has negligible wind. Use the three tables in Appendixes F, G, and H to estimate the fuel used in each of the three phases of flight: ascent, cruise, and descent. Assume that the average weight of a passenger and his or her luggage is 220 lbs. Put your estimations together to determine the total estimated fuel use of the flight. Explain how you determined your estimate.

Part V – Identification of Areas of Potential Fuel Savings

Scenarios / Tasks

1. A member of your team suggests that one possible way to save fuel for a typical flight may be to carry less reserve fuel. What might be the plausibility of this suggestion? Provide a calculation using the functions you generated to evaluate the plausibility. How much fuel might be saved using this strategy?
2. A member of your team suggests one possible way to save fuel for a typical flight is to cruise at a different altitude. Use the functions you have generated and the Cruise Altitude Capability table in Appendix J to evaluate the plausibility of this suggestion. How much fuel might be saved using this strategy?
3. A competitor airline has recently described one way they are saving fuel, which is through the use of “fuel-sipping” (Johnson 2009). This new strategy involves a gradual, gentle, descent rather than a step-wise process that requires the addition of power at each stage to level off, which thus burns more fuel. Using the functions you have generated, evaluate the plausibility of this strategy. How much fuel might be saved for a typical flight?

Part VI – Writing Up and Presenting your Results

With your group, create a report for Lyn Chastin describing what you have found out and describing next steps for CoCal Airlines. In particular, include in your report answers to the questions and tasks for Parts I–V showing all your work and stating any assumptions you made. Clearly show and explain how you arrived at your conclusions, and provide questions you think still need to be answered. Cite any sources you used. Finally, write a summary of your answers and include a description of how you think your assumptions affected your answer. Submit one paper for your group with all your group members' names on it.

References

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<http://www.flightsite.org/flights/denver-colorado-to-los-angeles-california/7548-7275/>
- Johnson, J. (2009). United Airlines test flight cuts fuel use, emissions, *Chicago Tribune*. Retrieved from
<http://www.spokesman.com/stories/2008/nov/16/united-airlines-test-flight-cuts-fuel-use/>
- Rustenburg, J., Skinn, D., & Tipps, D. (1998). *Statistical Loads Data for Boeing 737-400 Aircraft in Commercial Operations* (U. S. D. o. Transportation/FAA, Trans.). Washington, D.C.: University of Dayton Research Institute.

Resources

- Curvefit information.
<http://www.graphpad.com/curvefit/index.htm>



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Appendices

- A: Statistical Loads Data
- B: Stages of Flight (Figure and Table)
- C: Weight Data
- D: Flight Distance Data
- E: Block Fuel Estimates
- F: Time Distance and Fuel to Climb
- G: Enroute Fuel and Time
- H: Time Distance and Fuel to Descend
- I: Continuous Descent Approaches (Figure)
- J: Cruise Altitude Capability

Sources:

Appendices A, B, C, and D are from the following:

Rustenburg, J., Skinn, D., & Tipps, D. (1998). *Statistical Loads Data for Boeing 737-400 Aircraft in Commercial Operations* (U. S. D. o. Transportation/FAA, Trans.). Washington, D.C.: University of Dayton Research Institute. Available online at <http://www.tc.faa.gov/its/worldpac/techrpt/ar98-28.pdf> (last accessed March 19, 2012).

Appendices E, F, G, H, and J are from *Alaska Airlines 737 Performance Handbook* and used with permission.

Appendix I is from Enviro.aero, an initiative "... supported and financed by the commercial aviation industry under the umbrella of the Air Transport Action Group (ATAG). Its purpose is to provide clear information on the many industry measures underway to limit the impact of aviation on the environment." <http://www.enviro.aero/Enviroaeroabout.aspx>, accessed March 28, 2012.

Appendix A— Statistical Loads Data

5.1.2 Altitude Data (p. 19 of report)

Measured operational altitudes and their correlation to flight distance and maximum speed are presented. Figure A-7 [see next page] shows the correlation between the maximum altitude attained in flight and the flight distance flown in percent of flights. **The data show that for short flights of less than 250 nautical miles, the maximum altitude is generally below 30,000 feet with the most flights occurring from 20,000-25,000 feet. For flights from 250-500 nautical miles the altitude may range from 25,000 to 40,000 feet, while for flights above 500 nautical miles the maximum altitude can be considered above 30,000 feet.** Figure A-8 presents the percent of total flight distance spent in various altitude bands as a function of flight distance. The flight distances in figure A-7 reflect the stage lengths, whereas the flight distances in figure A-8 are based on the numerical integration approach mentioned in paragraph 4.4.2. The combined information in figures A-7 and A-8 provide a comprehensive picture of the flight profile distribution. Figures A-9a and A-9b show the coincident altitude at the maximum Mach number and the maximum equivalent airspeed attained in the cruise phase of the flights respectively. Figures A-10a and A-10b show the maximum Mach number or the maximum equivalent airspeed with respect to the design cruise limit regardless of flight phase. In other words, the speed that most closely approached the speed limit in a flight was identified as the maximum speed. As an example, in one flight the maximum speed with respect to the limit might have been attained in the climb phase, while in another flight the maximum speed with respect to the limit speed might have occurred in the cruise phase. The data in figures A-10a and A-10b are fairly evenly distributed between the climb, cruise, and descent phases with only a single occurrence in the departure and approach phases. The design speed limits are also shown in the figures. It should be noted that maximum Mach number and maximum equivalent airspeed do not necessarily occur simultaneously.

Maximum Altitude (1000 Feet)

| Flight Distance (NM) | 11723 Flts | 0-5 | 5-10 | 10-15 | 15-20 | 20-25 | 25-30 | 30-35 | 35-40 | Total |
|----------------------|------------|-------|-------|-------|-------|--------|--------|--------|--------|--------|
| | 0-250 | | 0.051 | 0.563 | 1.638 | 2.602 | 9.068 | 2.269 | 0.392 | 0.136 |
| 250-500 | | | | | 0.017 | 1.689 | 14.911 | 10.663 | 8.249 | 35.528 |
| 500-750 | | | | | | 0.068 | 0.768 | 8.462 | 8.436 | 17.734 |
| 750-1000 | | | | | | 0.06 | 0.478 | 9.733 | 8.317 | 18.587 |
| 1000-1250 | | | | | | 0.034 | 0.094 | 3.062 | 2.32 | 5.511 |
| 1250-1500 | | | | | | | 0.026 | 0.631 | 0.793 | 1.45 |
| 1500-1750 | | | | | | | 0.026 | 1.467 | 1.476 | 2.969 |
| 1750-2000 | | | | | | | 0.026 | 0.887 | 0.384 | 1.297 |
| 2000-2250 | | | | | | | | 0.171 | 0.034 | 0.205 |
| Total | | 0.051 | 0.563 | 1.638 | 2.619 | 10.919 | 18.596 | 35.469 | 30.146 | 100 |

FIGURE A-7. CORRELATION OF MAXIMUM ALTITUDE AND FLIGHT DISTANCE, PERCENT OF FLIGHTS

Total Flight Distance (NM)

| Altitude Band (Feet) | 11723 Flts | 0-250 | 250-500 | 500-750 | 750-1000 | 1000-1250 | 1250-1500 | 1500-1750 | 1750-2000 | 2000-2250 | 2250-2500 |
|----------------------|---------------|-------|---------|---------|----------|-----------|-----------|-----------|-----------|-----------|-----------|
| | 29,500-39,500 | | 0.09 | 20.03 | 51.4 | 64.46 | 70.11 | 76.33 | 80.4 | 81.79 | 81.63 |
| 19,500-29,500 | | 28.14 | 42.66 | 26.6 | 20.27 | 17.95 | 14.44 | 11.6 | 11.32 | 12.54 | 12.17 |
| 9,500-19,500 | | 42.13 | 22.02 | 12.76 | 8.69 | 6.94 | 5.67 | 4.71 | 3.99 | 3.44 | 2.4 |
| 4,500-9,500 | | 16.73 | 8.6 | 5.26 | 3.66 | 2.91 | 2.05 | 2.13 | 1.77 | 1.25 | 0.92 |
| 1,500-4,500 | | 10.31 | 5.24 | 3.09 | 2.18 | 1.6 | 1.19 | 0.93 | 0.93 | 0.89 | 0.71 |
| 500-1,500 | | 2.04 | 1.07 | 0.68 | 0.49 | 0.34 | 0.23 | 0.18 | 0.17 | 0.18 | 0.16 |
| 0-500 | | 0.56 | 0.38 | 0.21 | 0.24 | 0.16 | 0.08 | 0.05 | 0.04 | 0.06 | 0.08 |
| Total | | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

FIGURE A-8. PERCENT OF TOTAL DISTANCE IN ALTITUDE BANDS

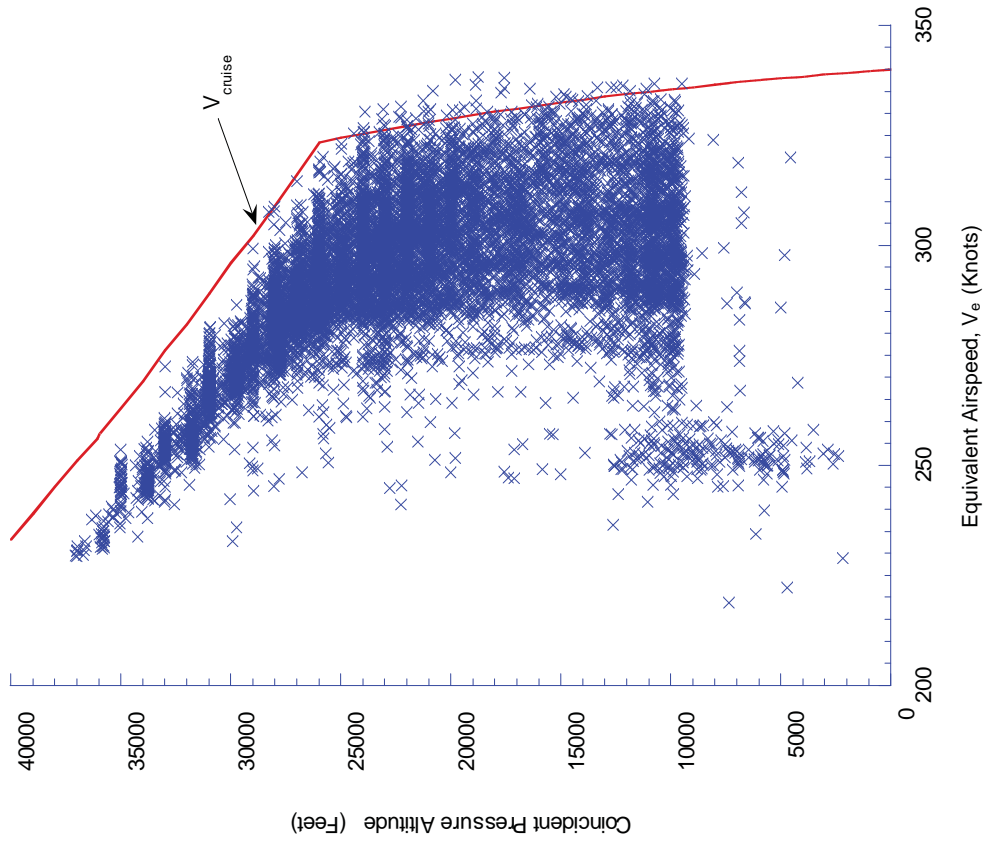


FIGURE A-9b. COINCIDENT ALTITUDE AT MAXIMUM EQUIVALENT AIRSPEED, CRUISE PHASE

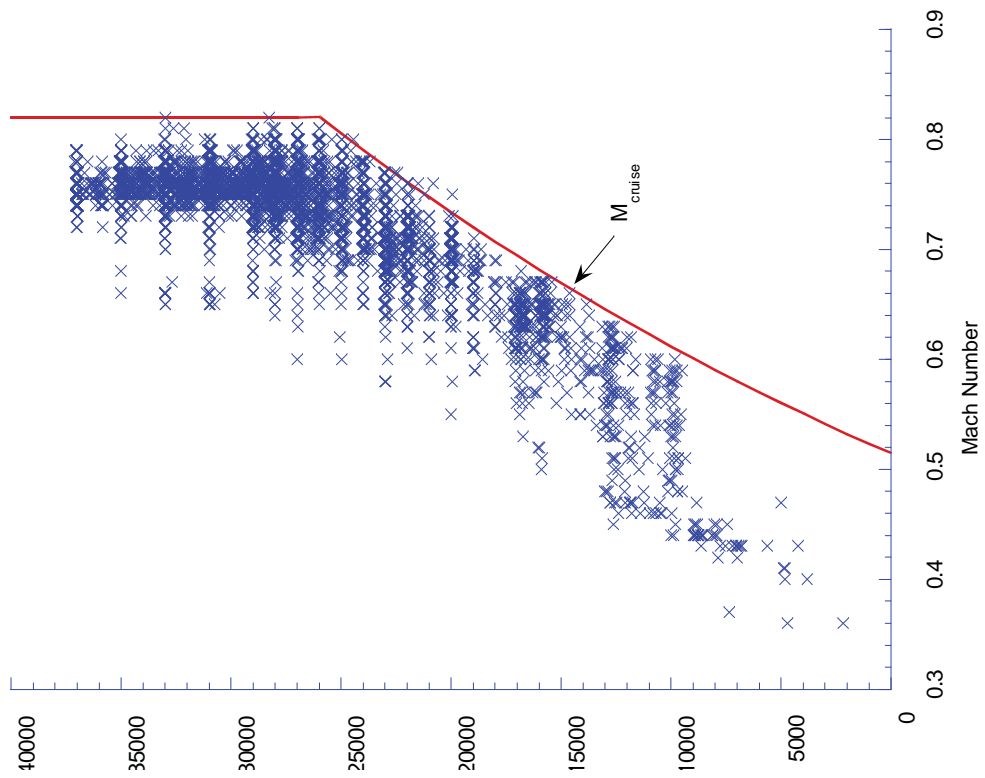


FIGURE A-9a. COINCIDENT ALTITUDE AT MAXIMUM MACH NUMBER, CRUISE PHASE

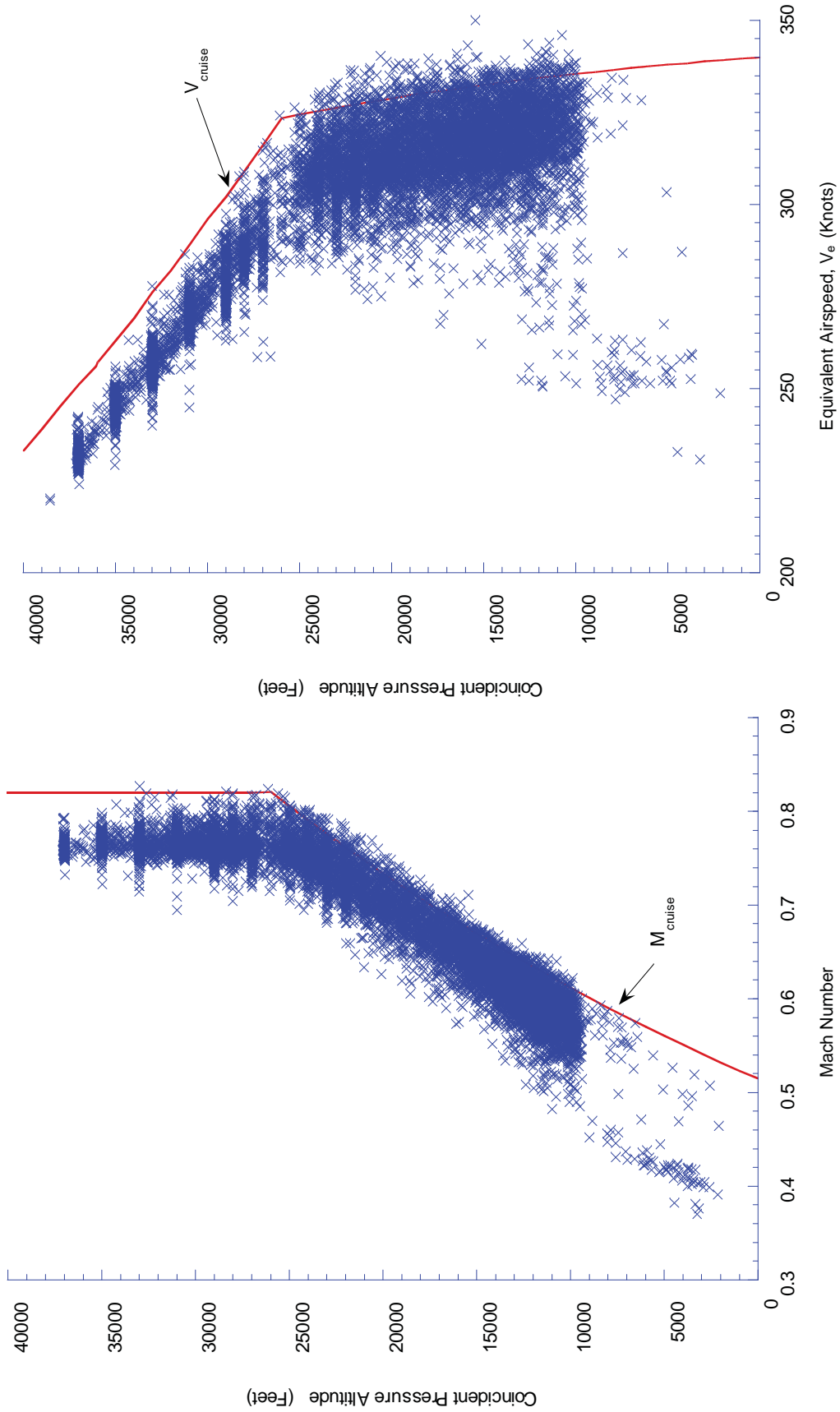


FIGURE A-10a. COINCIDENT ALTITUDE AT MAXIMUM MACH NUMBER, ALL FLIGHT PHASES

FIGURE A-10b. COINCIDENT ALTITUDE AT MAXIMUM EQUIVALENT AIRSPEED, ALL FLIGHT PHASES

Appendix A (continued)



Table: Boeing 737-400 Aircraft Characteristics (p. 1 of report)

| | |
|--------------------|-------------------|
| Max Taxi Weight | 143,000 lb |
| Max Takeoff Weight | 142,500 lb |
| Max Landing Weight | 121,000 lb |
| Zero-Fuel Weight | 113,000 lb |
| Fuel Capacity | 5311 U.S. gallons |

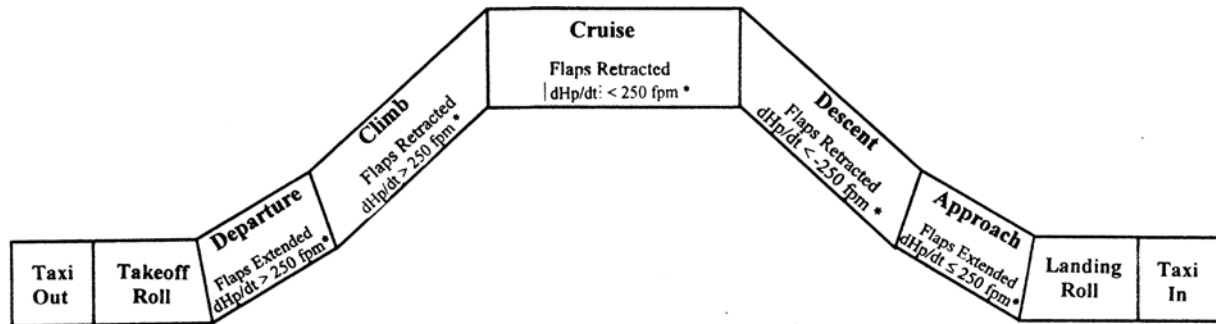


Flight information for LA to Denver (Source: <http://flightsite.org/flights/denver-colorado-to-los-angeles-california/7548-7275/>)

- 831.87 Miles in distance
- 1338.76 Kilometers in distance.
- 722.88 Nautical miles in distance.

Appendix B— Stages of Flight (Figure and Table)

Figure (p. 10 of report)



*Climb rate must be maintained for at least one minute before transition into another phase of flight takes place

Table (p. 10 of report)

| Phase of Flight | Conditions at Start of Phase |
|-----------------|---|
| Taxi Out | Initial condition |
| Takeoff Roll | Acceleration $> 4 \text{ kts/sec}$ for a minimum of 12 seconds |
| Departure | Time at liftoff; flaps extended (squat switch off) |
| Climb | Flaps retracted; rate of climb $\geq 250 \text{ ft/min.}$ for at least 1 minute |
| Cruise | Flaps retracted; rate of climb $\leq 250 \text{ ft/min.}$ for at least 1 minute |
| Descent | Flaps retracted; rate of descent $\leq -250 \text{ ft/min.}$ for at least 1 minute |
| Approach | Flaps extended; rate of descent $< 250 \text{ ft/min.}$ for at least 1 minute |
| Landing Roll | Touchdown; (squat switch on) |
| Taxi In | Magnetic heading change greater than 13.5 degrees after touchdown or deviation from runway centerline greater than 100 feet |

Appendix C— Weight Data

(p. 18)

5.1.1 Weight Data.

Statistical data on operational takeoff gross weights, landing gross weights, and fuel weights are presented in this section. These weights are also correlated to flight distance. The cumulative probabilities of takeoff gross weight, takeoff fuel weight, and landing weight are presented in figures A-1 through A-3 respectively. The correlation between fuel weight at takeoff and the flight distance is presented in figure A-4. A similar correlation for takeoff gross weight and flight distance is shown in figure A-5. The flight distances in figures A-4 and A-5 are based on the great circle distance between departure and arrival points. It is interesting to note that the small difference in the number of flights between figures A-4 and A-5 has an insignificant impact on the flight distance distribution as indicated by a comparison of the numbers in the right end columns of these figures. Figure A-6 provides the correlation between the takeoff gross weight and the landing gross weight. The correlation shows that for most flights with light takeoff weights (less than 100,000 pounds) the landing weight is within 10,000 pounds of the takeoff weight. For the medium takeoff weights from 100,000-130,000 pounds the landing weights are from 10,000-20,000 pounds below takeoff weight. For the heavy weight takeoffs from 130,000-150,000 pounds the landing weights are from 20,000-30,000 pounds below the takeoff weight.

Appendix D—Flight Distance Data

(p. 19)

5.1.3 Flight Distance Data.

Flight distance statistics useful in the generation of flight profiles were derived and are presented here. The cumulative probability of flight distances flown is presented in figure A-11. The great circle distance reflects the ground distance between two points as obtained from the great circle distance calculation, but does not necessarily reflect the actual distance flown. Deviation from direct flight between departure and arrival points resulting from traffic control requirements will increase the actual distance flown by some unknown amount. To a much lesser extent, the climb and descent distances are slightly larger than the level flight distance. Head or tail winds also are unknown contributors. The integrated distance accounts for such variables. The figure provides a graphical presentation of the differences in flight distance obtained by the two approaches.

Appendix E: Block Fuel Estimates

This table provides approximate block fuel requirements for the given range and zero fuel weight using the listed speed and altitude assumptions. These figures are order of magnitude estimates and will differ from the flight plan due to wind, temperature deviation and flight plan fuel flow adjustments. To find approximate block fuel estimate enter table with range in nautical miles and ZFW. Read block fuel estimate.

BLOCK FUEL ESTIMATES

CFM56-7B26

LRC Cruise

Domestic Reserves, 200 nm alternate

Standard Day, Zero Wind

| ZFW (LB) | RANGE (NM) | | | | |
|-------------|------------|-------|-------|-------|-------|
| | 500 | 1000 | 1500 | 2000 | 2500 |
| 90,000 | 13100 | 17600 | 22300 | 27100 | 32000 |
| 95,000 | 13400 | 18100 | 23000 | 27900 | 33000 |
| 100,000 | 13800 | 18600 | 23600 | 28800 | 34000 |
| 105,000 | 14200 | 19200 | 24300 | 29600 | 35100 |
| 110,000 | 14600 | 19800 | 25100 | 30500 | 36300 |
| 115,000 | 15000 | 20300 | 25800 | 31500 | 37400 |
| 120,000 | 15400 | 20900 | 26600 | 32500 | 38700 |
| 125,000 | 15800 | 21500 | 27400 | 33600 | 39900 |
| 130,000 | 16200 | 22200 | 28300 | 34600 | 41100 |
| 136,000 | 16700 | 22800 | 29100 | 35800 | 42400 |

Source: Alaska Airlines Flight Operations Engineering. Training use only.

Appendix F: Time Distance and Fuel to Climb

The enroute climb tables are based on the climb speed schedule shown. Enter table with takeoff gross weight and target pressure altitude. Read climb time, fuel, and distance from brake release. To obtain step climb values, read time/fuel/distance for target altitude then subtract time/fuel/distance for initial altitude.

Temperature Correction Multipliers are provided to account for temperature deviations from ISA. If necessary, multiply the values from the table by the appropriate multiplier.

TIME DISTANCE AND FUEL TO CLIMB

CFM56-7B26; Max Climb Thrust

Speed Schedule 280 KIAS / M0.78

A/C Auto

| PRESSURE ALTITUDE (FT) | | TAKEOFF GROSS WEIGHT (LB) | | | | | | | | |
|------------------------|------|---------------------------|------|------|------|------|------|------|------|------|
| | | 100 | 110 | 120 | 130 | 140 | 150 | 160 | 170 | 180 |
| 41000 | TIME | 14 | 16 | 18 | 21 | 25 | | | | |
| | DIST | 88 | 100 | 114 | 131 | 154 | | | | |
| | FUEL | 2600 | 2900 | 3200 | 3600 | 4100 | | | | |
| 37000 | TIME | 12 | 13 | 15 | 16 | 18 | 20 | 23 | 26 | 32 |
| | DIST | 69 | 77 | 86 | 96 | 108 | 121 | 137 | 158 | 198 |
| | FUEL | 2300 | 2500 | 2800 | 3100 | 3500 | 3800 | 4200 | 4800 | 5600 |
| 35000 | TIME | 11 | 12 | 14 | 15 | 17 | 18 | 20 | 22 | 25 |
| | DIST | 61 | 69 | 77 | 85 | 95 | 106 | 118 | 132 | 150 |
| | FUEL | 2200 | 2400 | 2700 | 3000 | 3300 | 3600 | 3900 | 4300 | 4800 |
| 33000 | TIME | 10 | 11 | 12 | 14 | 15 | 17 | 18 | 20 | 22 |
| | DIST | 55 | 62 | 69 | 76 | 84 | 93 | 103 | 115 | 128 |
| | FUEL | 2100 | 2300 | 2500 | 2800 | 3100 | 3400 | 3700 | 4000 | 4400 |
| 31000 | TIME | 9 | 10 | 11 | 12 | 14 | 15 | 16 | 18 | 20 |
| | DIST | 48 | 54 | 60 | 66 | 73 | 80 | 88 | 98 | 108 |
| | FUEL | 1900 | 2100 | 2400 | 2600 | 2900 | 3100 | 3400 | 3700 | 4000 |
| 29000 | TIME | 8 | 9 | 10 | 11 | 12 | 13 | 15 | 16 | 17 |
| | DIST | 42 | 46 | 51 | 57 | 62 | 69 | 75 | 83 | 91 |
| | FUEL | 1800 | 2000 | 2200 | 2400 | 2600 | 2900 | 3100 | 3400 | 3700 |
| 25000 | TIME | 7 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| | DIST | 31 | 35 | 38 | 42 | 46 | 50 | 55 | 60 | 65 |
| | FUEL | 1500 | 1700 | 1900 | 2100 | 2300 | 2500 | 2700 | 2900 | 3100 |
| 20000 | TIME | 5 | 6 | 6 | 7 | 8 | 8 | 9 | 9 | 10 |
| | DIST | 21 | 24 | 26 | 29 | 31 | 34 | 37 | 40 | 43 |
| | FUEL | 1300 | 1400 | 1500 | 1700 | 1800 | 2000 | 2200 | 2300 | 2500 |
| 16000 | TIME | 4 | 5 | 5 | 6 | 6 | 7 | 7 | 8 | 8 |
| | DIST | 15 | 17 | 19 | 20 | 22 | 24 | 26 | 28 | 31 |
| | FUEL | 1100 | 1200 | 1300 | 1400 | 1500 | 1700 | 1800 | 1900 | 2100 |
| 10000 | TIME | 3 | 3 | 3 | 4 | 4 | 5 | 5 | 5 | 5 |
| | DIST | 8 | 9 | 10 | 11 | 12 | 12 | 14 | 15 | 16 |
| | FUEL | 800 | 800 | 900 | 1000 | 1100 | 1200 | 1300 | 1400 | 1500 |

Source: Alaska Airlines Flight Operations Engineering. Training use only.

Appendix G: Enroute Fuel and Time

CFM56-7B26

Long Range Cruise

Wind Corrected Distance

| AIR DISTANCE (NM) HEADWIND COMPONENT | | | | | Ground Distance (NM) | AIR DISTANCE (NM) TAILWIND COMPONENT | | | | |
|---|------|------|------|------|----------------------------|---|------|------|------|------|
| 100 | 80 | 60 | 40 | 20 | | 20 | 40 | 60 | 80 | 100 |
| 273 | 256 | 239 | 224 | 211 | 200 | 190 | 183 | 175 | 166 | 159 |
| 542 | 507 | 475 | 447 | 422 | 400 | 382 | 366 | 351 | 336 | 323 |
| 811 | 758 | 711 | 670 | 633 | 600 | 574 | 549 | 527 | 506 | 487 |
| 1080 | 1011 | 948 | 893 | 844 | 800 | 765 | 733 | 703 | 675 | 650 |
| 1351 | 1264 | 1185 | 1116 | 1056 | 1000 | 957 | 916 | 879 | 844 | 813 |
| 1623 | 1517 | 1423 | 1340 | 1267 | 1200 | 1148 | 1099 | 1054 | 1013 | 976 |
| 1895 | 1772 | 1661 | 1564 | 1478 | 1400 | 1339 | 1282 | 1230 | 1182 | 1139 |
| 2167 | 2026 | 1899 | 1788 | 1690 | 1600 | 1530 | 1465 | 1405 | 1351 | 1301 |
| 2441 | 2282 | 2138 | 2012 | 1901 | 1800 | 1721 | 1648 | 1581 | 1519 | 1463 |
| 2715 | 2537 | 2377 | 2237 | 2113 | 2000 | 1913 | 1831 | 1756 | 1688 | 1625 |
| 2990 | 2793 | 2616 | 2461 | 2324 | 2200 | 2103 | 2014 | 1931 | 1856 | 1787 |
| 3265 | 3050 | 2855 | 2686 | 2536 | 2400 | 2294 | 2197 | 2106 | 2024 | 1949 |
| 3541 | 3306 | 3095 | 2911 | 2748 | 2600 | 2486 | 2380 | 2282 | 2192 | 2111 |

Reference Fuel and Time

| AIR DIST (NM) | PRESSURE ALTITUDE (FT) | | | | | | | | | |
|---------------------|------------------------|------|-------|------|-------|------|-------|------|-------|------|
| | 29000 | | 31000 | | 33000 | | 3500 | | 37000 | |
| | FUEL | TIME | FUEL | TIME | FUEL | TIME | FUEL | TIME | FUEL | TIME |
| 200 | 1900 | 0:35 | 1700 | 0:34 | 1800 | 0:35 | 1600 | 0:35 | 1500 | 0:34 |
| 400 | 4200 | 1:06 | 4000 | 1:04 | 3900 | 1:03 | 3700 | 1:02 | 3600 | 1:01 |
| 600 | 6500 | 1:37 | 6300 | 1:34 | 6000 | 1:31 | 5800 | 1:29 | 5700 | 1:28 |
| 800 | 8800 | 2:08 | 8500 | 2:04 | 8200 | 2:00 | 7900 | 1:57 | 7700 | 1:55 |
| 1000 | 11100 | 2:39 | 10700 | 2:34 | 10400 | 2:29 | 10000 | 2:25 | 9800 | 2:22 |
| 1200 | 13300 | 3:11 | 12900 | 3:05 | 12500 | 2:58 | 12100 | 2:54 | 11800 | 2:50 |
| 1400 | 15500 | 3:43 | 15100 | 3:36 | 14600 | 3:28 | 14100 | 3:22 | 13800 | 3:17 |
| 1600 | 17700 | 4:15 | 17200 | 4:07 | 16700 | 3:58 | 16200 | 3:51 | 15800 | 3:45 |
| 1800 | 19900 | 4:47 | 19300 | 4:38 | 18700 | 4:28 | 18200 | 4:20 | 17700 | 4:13 |
| 2000 | 22000 | 5:20 | 21400 | 5:09 | 20800 | 4:58 | 20200 | 4:48 | 19700 | 4:41 |
| 2200 | 24200 | 5:52 | 23500 | 5:42 | 22800 | 5:29 | 22100 | 5:18 | 21600 | 5:09 |
| 2400 | 26300 | 6:25 | 25500 | 6:14 | 24800 | 6:00 | 24100 | 5:48 | 23500 | 5:38 |
| 2600 | 28400 | 6:58 | 27600 | 6:46 | 26800 | 6:31 | 26000 | 6:18 | 25300 | 6:06 |

Correction to Reference Fuel

| REFERENCE FUEL REQUIRED | INITIAL WEIGHT (LB) | | | | |
|----------------------------|---------------------|-------|-----|------|------|
| | 90 | 110 | 130 | 150 | 170 |
| 5000 | -600 | -400 | 0 | 400 | 1300 |
| 10000 | -1200 | -800 | 0 | 900 | 2400 |
| 15000 | -1800 | -1100 | 0 | 1400 | 3500 |
| 20000 | -2500 | -1400 | 0 | 1900 | 4600 |
| 25000 | -3200 | -1700 | 0 | 2400 | 5600 |
| 30000 | -3900 | -2000 | 0 | 2800 | 6500 |

Source: Alaska Airlines Flight Operations Engineering. Training use only.

Appendix H: Time Distance and Fuel to Descend

Time, fuel and distance for descent are shown for M0.78/280KIAS descent speed. This data includes the effect of 250 KIAS speed restriction below 10,000 feet, and includes a straight-in approach with flaps down at the outer marker. Each additional minute of flaps down maneuvering consumes approximately 170 lbs of fuel with the gear retracted.

TIME DISTANCE AND FUEL TO DESCEND

CFM56-7B26

Descent Speed M0.78/280 KIAS

Flight Idle Thrust

Straight-In Approach

| PRESSURE ALTITUDE (FT) | DISTANCE (NM) | | | | TIME (MIN) | FUEL (LB) |
|------------------------------|---------------------|--------|--------|--------|---------------|--------------|
| | LANDING WEIGHT (LB) | | | | | |
| | 90000 | 110000 | 130000 | 150000 | | |
| 41000 | 103 | 119 | 132 | 141 | 26 | 750 |
| 39000 | 98 | 113 | 126 | 135 | 26 | 740 |
| 37000 | 93 | 108 | 120 | 129 | 25 | 730 |
| 35000 | 89 | 103 | 115 | 123 | 24 | 720 |
| 33000 | 86 | 99 | 110 | 118 | 23 | 710 |
| 31000 | 81 | 94 | 104 | 112 | 22 | 690 |
| 29000 | 76 | 88 | 97 | 105 | 21 | 680 |
| 27000 | 72 | 82 | 91 | 98 | 20 | 660 |
| 25000 | 67 | 77 | 85 | 91 | 19 | 640 |
| 23000 | 62 | 71 | 79 | 84 | 18 | 620 |
| 21000 | 58 | 66 | 73 | 78 | 17 | 600 |
| 19000 | 53 | 61 | 67 | 71 | 16 | 580 |
| 17000 | 49 | 55 | 61 | 64 | 15 | 550 |
| 15000 | 44 | 50 | 55 | 58 | 14 | 530 |
| 10000 | 31 | 34 | 37 | 38 | 11 | 440 |
| 5000 | 18 | 19 | 20 | 21 | 7 | 330 |
| 1500 | 9 | 9 | 9 | 9 | 4 | 250 |

Source: Alaska Airlines Flight Operations Engineering. Training use only.

Appendix I: Continuous Descent Approaches



“Traditionally, landing aircraft approach a runway by ‘stepping’ down from the cruising level to the ground (blue path). At each step, the pilots have to alter the thrust of the engines to level out the aircraft. New technology means that airlines can work with air traffic control and airports to create a much smoother descent to the runway, cutting out the stepping procedures and cutting fuel use and noise at the same time (green path). In fact, airlines estimate that each continuous descent approach can save 150kg of jet fuel (around 500kgs of CO₂).”

Source: Image and text courtesy of www.enviro.aero, used with permission. Available at <http://www.enviro.aero/Innovation.aspx>.

Appendix J: Cruise Altitude Capability

The optimum altitude where best fuel mileage will be attained and the maximum altitude at which the airplane can be flown using maximum cruise thrust are indicated.

CRUISE ALTITUDE CAPABILITY

CFM56-7B26

LRC, Max Cruise Thrust

Two Engines Operating, Anti-Ice OFF

| WEIGHT (1000 LB) | OPTIMUM ALTITUDE | MAX |
|---------------------|---------------------|-------|
| 90 | 41000 | 41000 |
| 100 | 41000 | 41000 |
| 110 | 41000 | 41000 |
| 120 | 41000 | 41000 |
| 130 | 40000 | 41000 |
| 140 | 38500 | 39900 |
| 150 | 37000 | 38500 |
| 160 | 35700 | 37100 |
| 170 | 34400 | 35900 |
| 180 | 33200 | 34700 |

Source: Alaska Airlines Flight Operations Engineering. Training use only.