NATIONAL CENTER FOR CASE STUDY TEACHING IN SCIENCE

Mathematically Modeling Aircraft Fuel Consumption

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CoCal Airlines

April 9, 2009

Lyn Chastin
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1 World Way
Los Angeles, CA 90045

Professor Canton
Director of Math, Science & Engineering Program
Lambda University
1265 College Drive
Littletown, 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

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

Flightsite.org. (2011). Retrieved 2/10/2011, from Flightsite.org. 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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Photo in title block of a Boeing 737-400 was digitally altered from a public domain image in Wikimedia Commons, http://commons.wikimedia.org/wiki/File:Klm.b737-400.ph-btf.arp.jpg.

Appendices

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.

Apendix 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	16.719
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

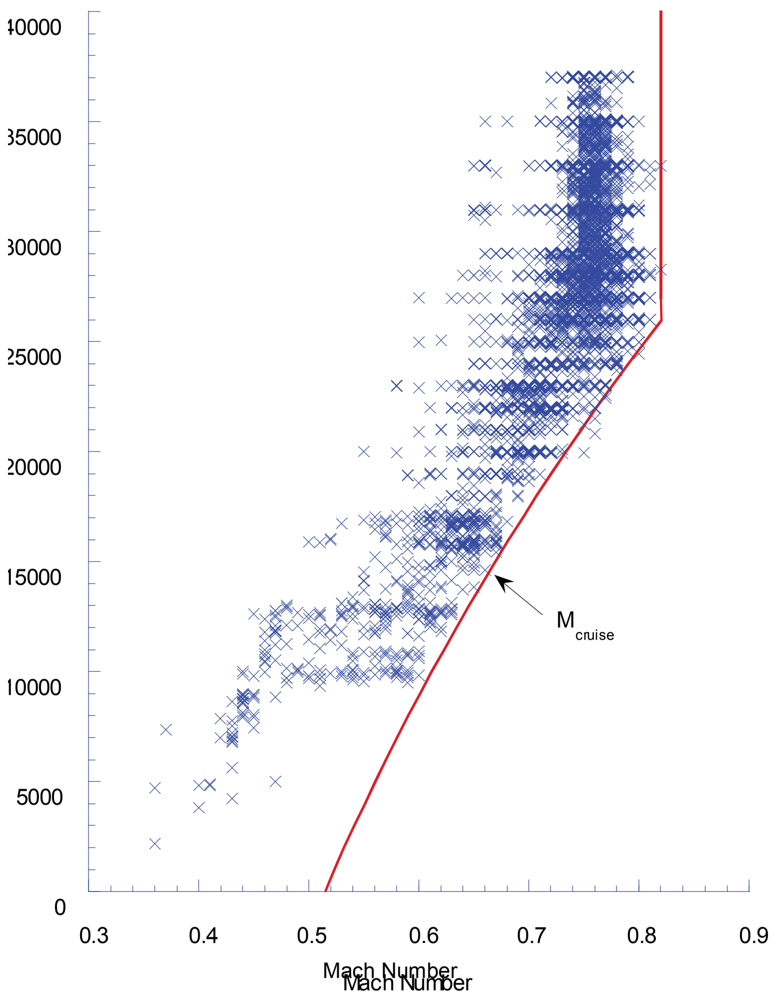
FIGURE A-7. CORRELATION OF MAXIMUM ALTITUDE AND FLIGHT DISTANCE, PERCENT OF FLIGHTS

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	83.56
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



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

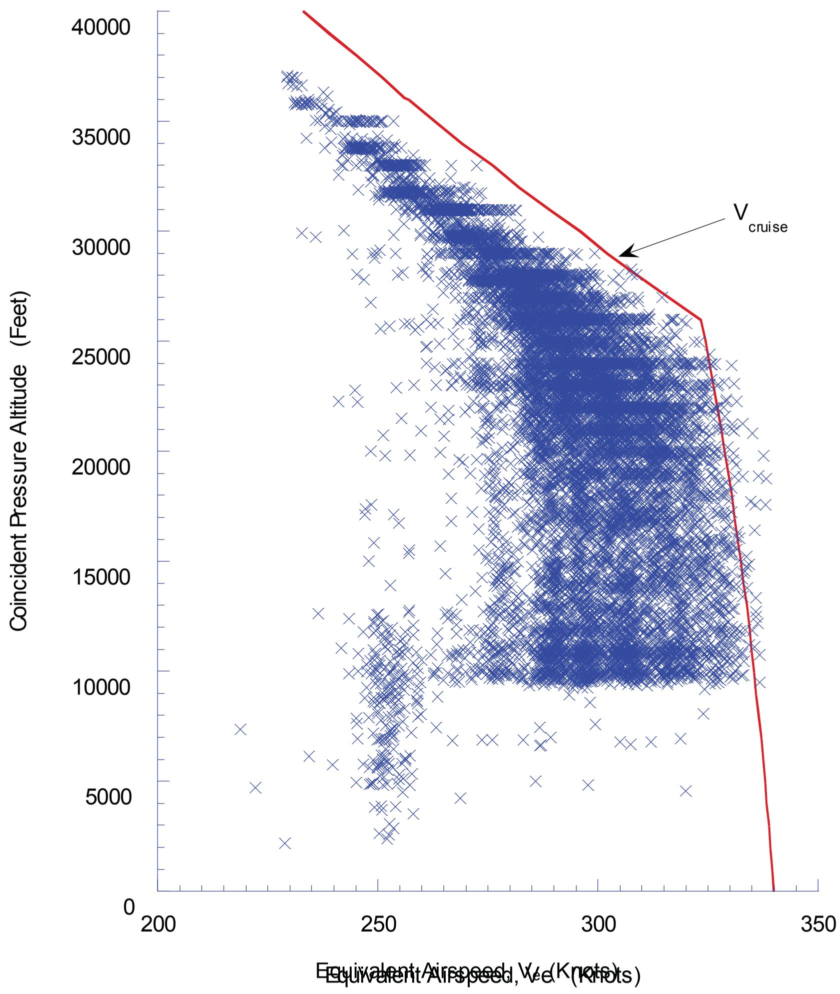


FIGURE A-9b. COINCIDENT ALTITUDE AT MAXIMUM EQUIVALENT AIRSPEED, CRUISE PHASE

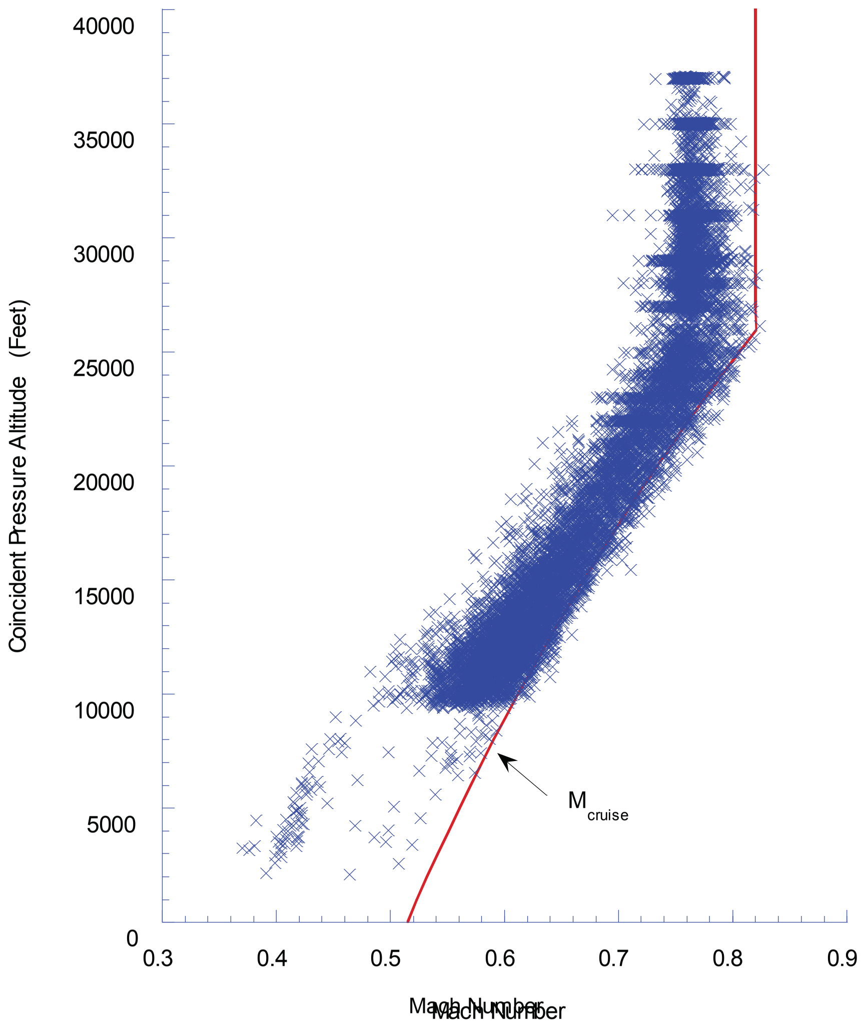


FIGURE A-10a. COINCIDENT ALTITUDE AT MAXIMUM MACH NUMBER, ALL FLIGHT PHASES

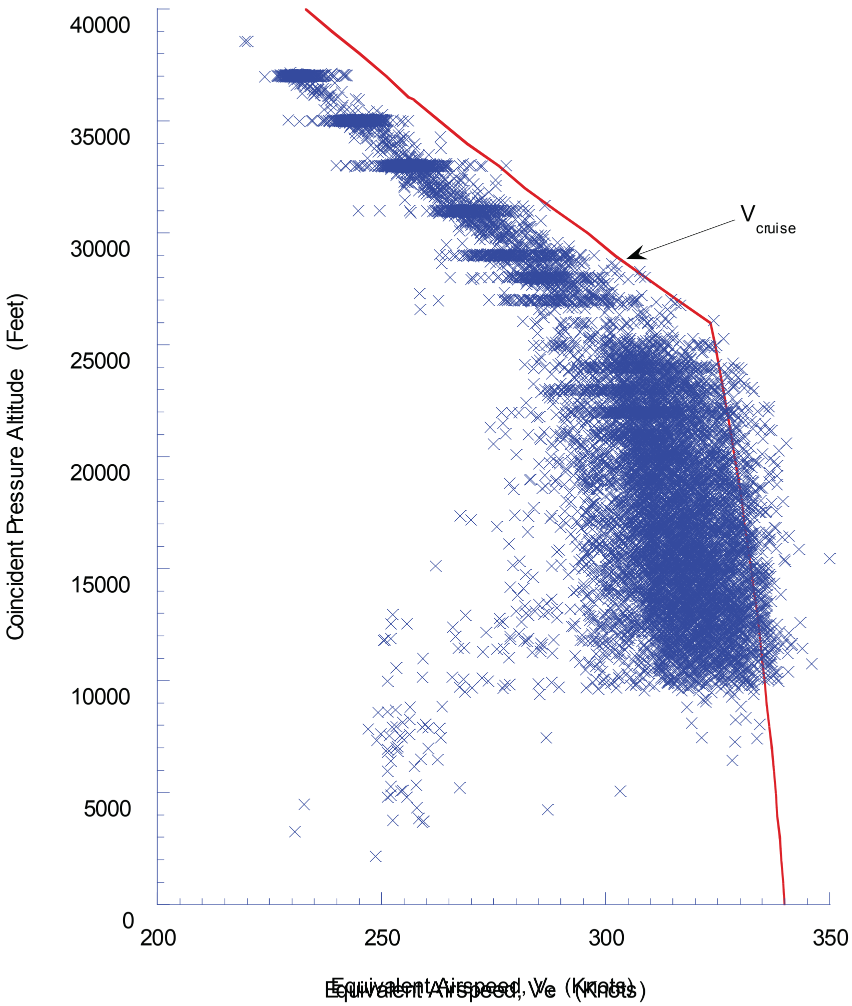


FIGURE A-10b. COINCIDENT ALTITUDE AT MAXIMUM EQUIVALENT AIRSPEED, ALL FLIGHT PHASES

Appendix A (continued)

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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

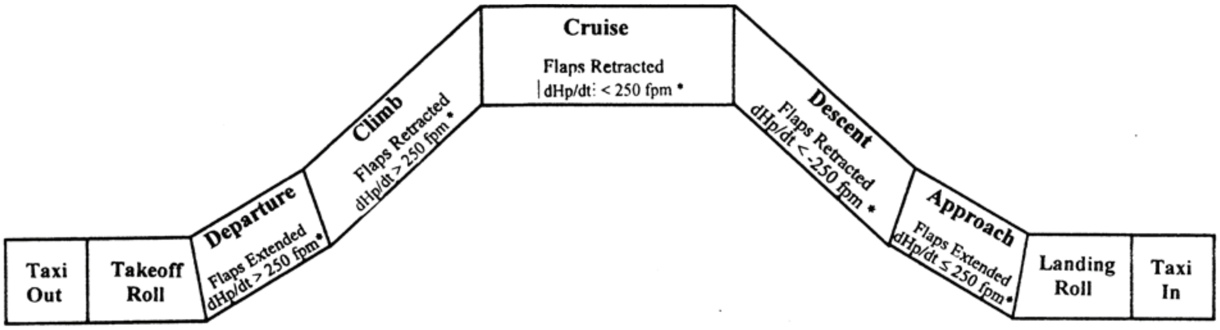
❧

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 kts/sec for a minimum of 12 seconds
Departure	Time at liftoff; flaps extended (squat switch off)
Climb	Flaps retracted; rate of climb ≥ 250 ft/min. for at least 1 minute
Cruise	Flaps retracted; rate of climb ≤ 250 ft/min. for at least 1 minute
Descent	Flaps retracted; rate of descent ≤ -250 ft/min. for at least 1minute
Approach	Flaps extended; rate of descent < 250 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

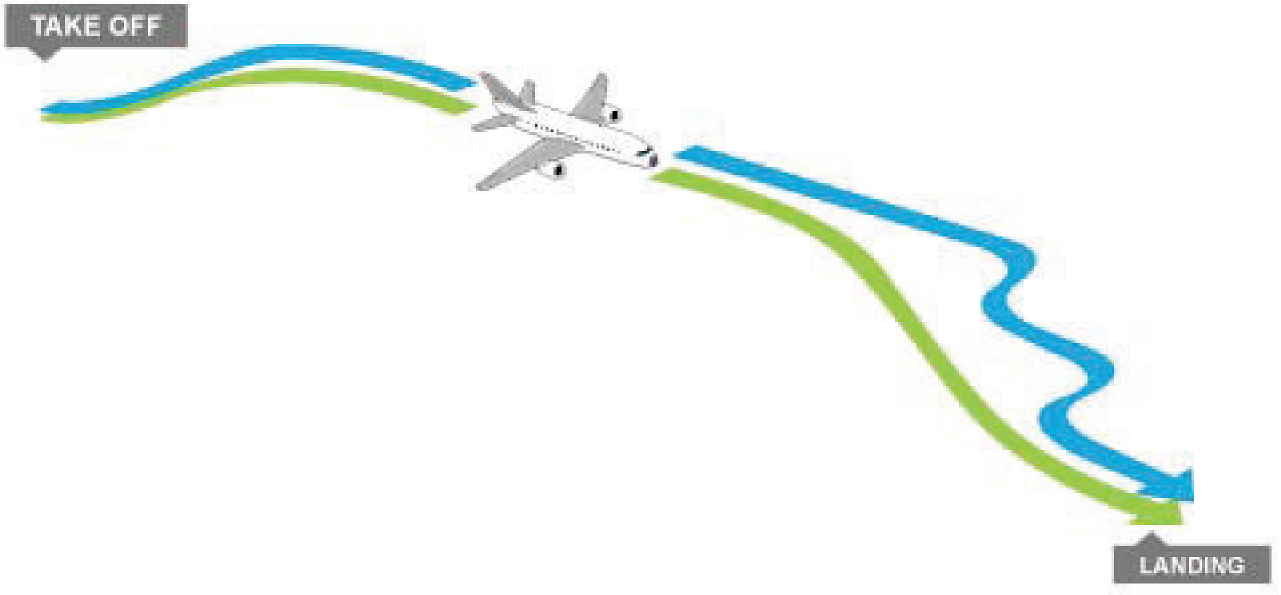
Time, fuel and distance for descent are shown for M0.78/280KIAS descent speed. This data includes the effect of 250 KIAS speed restriction below 10,000 feet, and includes a straight-in approach with flaps down at the outer marker. Each additional minute of flaps down maneuvering consumes approximately 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) LANDING WEIGHT (LB)				TIME (MIN)	FUEL (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 CO_2)."

Source: Image and text courtesy of www.enviro.aero, used with permission. Avaliable 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.