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An Economic Model of U.S. Airline Operating Expenses

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Prepared for
NASA Ames Research Center
under Grant NAG-2-1597

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AN ECONOMIC MODEL OF U.S. AIRLINE OPERATING EXPENSES

Franklin D. Harris[1]

University of Maryland

SUMMARY

A new economic model, built upon operating expenses from 67 airlines as reported to the Department of Transportation (DOT) in 1999, has been developed. The model incorporates several expense-estimating equations that capture direct and indirect expenses of both passenger and cargo airlines. The variables and business factors included in the equations allow expenses to be calculated at the flight equipment (i.e., aircraft) reporting level. Total operating expenses for a given airline are then obtained by summation of all aircraft an entity operates followed by summation for all entities operated by the airline.

The model's accuracy is demonstrated by correlation with the DOT Form 41 data from which it was derived. The specific Form 41 accounts, for which expense equations were derived and correlation shown, are as follows:

For Total Aircraft Operating Expenses (direct expenses)

- Flight Crew
- Fuel & Oil
- Insurance
- Rental
- Other Flying Operations
- Airframe Maintenance
- Engine Maintenance
- Depreciation & Amortization

For All Other Operating Expenses (indirect expenses)

- Passenger Service
- Landing Fees
- Rest of All Other (Includes: Aircraft Servicing, Traffic Servicing, Advertising & Promotions, General & Administration, Maintenance & Depreciation of Ground Equipment)
- Transport Related

In 1999, total operating expenses from the 67 airlines included in this study amounted to slightly over $100.5 billion. The economic model reported herein estimates $109.3 billion. As the following table shows, passenger airlines are more accurately modeled than cargo airlines.

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[1]University of Maryland, Department of Aerospace Engineering, College Park, MD 20742.

Service Provided	No. of Airlines	No. of Entities	No. of Airplanes Operated	Predicted Total Operating Expenses	Total Operating Expenses Form 41 Schedule P-1.2 Account # 7199.0	Error (DOT-Pred.) DOT
Passenger	46	75	4,825	$89.898	$90.057	0.2 %
Cargo	21	43	1,138	$19.371	$20.523	5.6 %
Totals	67	118	5,963	$109.269	$110.5805	1.2 %

Finally, a concise summary of the expense-estimating equations, accompanied by explanatory notes, is provided in Appendix 1. The equations include many operational and aircraft variables, which should allow further study of changes airline and aircraft manufacturers might make to lower expenses in the future.

1. INTRODUCTION

The gathering, analyzing, and reporting of airline operating expense data have long played an important part in the evolution of the air transportation business (ref. 1). These data have, of course, been a necessary business tool for each airline as well as being a source for government monitoring of the air transport system (ref. 2). Just as importantly, the operating data have guided aircraft manufacturers in developing each successive generation of civil aircraft (ref. 3). Over the years, the data have also been used to measure the impact of aviation technology in reducing operating expenses (refs. 4, 5).

Periodically, the operating expense data has formed a basis for new and/or revised economic models (refs. 6, 7, 8, 9, and 10). One of the earliest economic models was reported in a 1940 paper by Mentzer and Nourse (ref. 6). Data from DC-3 operations were the basis of their model. Their work led to the Air Transport Association of America (ATA) 1944 publication of how to estimate direct operating costs of airplanes. The ATA model was accepted by the industry and was continually updated to reflect larger piston-powered airliners. In 1967, a last ATA update was made (ref. 7) to account for turbine-powered transport airplanes. Somewhat later, helicopter operating costs were addressed (ref. 8). In 1976, Anderson and Andrastek (ref. 9) published an operating cost model for local service airlines, which provided economic models of both direct and indirect operating costs. Their paper summarized the Douglas Aircraft Co. two-volume study done under contract with NASA (ref. 10). The two-volume Douglas report is particularly unique in that regression-derived cost equations are graphical compared to the data base, so some appreciation of the model's accuracy is gained.[2]

The present report adds to the decades of economic model development work. In this report, a 1999 U.S. Department of Transportation operating-expense data base from 46 passenger and 21 cargo airlines is used to develop several expense-estimating equations that, when added together, yield an airline's Total Operating Expense (TOE). Correlation of the model with the data base from which it is derived is included along with a measure of accuracy. A concise summary of the expense-estimating equations making up this economic model is placed in Appendix 1.

[2]Virtually none of the many economic models surveyed by the author discussed accuracy or showed correlation.

2. FORM 41 DATA BANK

Each United States certificated air carrier (i.e., an airline) is required by law to periodically submit operating and financial information about their operations. Each airline's data are provided to the U.S. Department of Transportation (DOT) on a Form 41.[3] The Form 41 is a collection of some 16 "schedules" on which detailed operational and financial data are placed in a quite orderly manner. However, the number of schedules each airline must submit depends on the airline's grouping, which, in turn, depends on its total operating revenue for a twelve-month period. In 1999, the DOT placed airlines with yearly revenues greater than $1 billion in Group III; those with revenues between $100 million and $1 billion in Group II; and those with revenues below $100 million in Group I. In addition, Form 41s are submitted for each entity the airline has. An entity, by DOT use, is the airline's component that serves either a Domestic, Atlantic, Latin America or Pacific market segment. Thus American Airlines, which serves all four market segments, contributes 4 entities to the data base, but is counted as only 1 at the airline level. On the other hand, Southwest Airlines operates only domestically and is counted as 1 entity and thus 1 airline.

One expeditious digital access to the wealth of Form 41 data shown in Table 1 is provided by Data Base Products, Inc. The DOT provides airline Form 41 data to Data Base Products, who records it on a compact disk (CD) along with helpful software to access the many quarters of traffic and financial information. Their manual (ref. 11) and a CD (ref. 12) are offered for purchase to the public. Schedules A, B-7, B-12, P-1, and P-2 are not included on the CD provided by Data Base Products.

TABLE 1. FORM 41 SCHEDULES

Schedul	**Title**	**Period**
A	Certification	Quarterly
B-1	Balance Sheet	Quarterly
B-12	Statement of Cash Flow	Quarterly
B-43	Inventory of Airframes and Aircraft Engines	Annually
B-7	Airframe and Aircraft Engine Acquisitions and	Quarterly
P-1	Interim Income Statement	Monthly
P-1.2	Statement of Operations	Quarterly
P-2	Notes to RSPA Form 41 Report	Quarterly
P-5.1	Aircraft Operation Expenses (Group I Carriers)	Quarterly
P-5.2	Aircraft Operation Expenses (Group II Carriers)	Quarterly
P-6	Aircraft Operating Expenses by Objective Grouping	Quarterly
P-7	Aircraft Operating Expenses by Functional Grouping	Quarterly
P-10	Employment Statistics by Labor Category	Annually
P-12	Fuel Consumption by Type of Service and Entity	Monthly
T-100	Traffic and Segment (Origin and Destination)	Monthly
T-2	Traffic, Capacity and Operations	Quarterly

[3]A Form 41 bears considerable similarity to the IRS Form 1090 in that there are a variety of schedules that must accompany the primary form.

Familiarity with DOT Form 41 nomenclature and accounting methods of several schedules is nearly a prerequisite to understanding the economic model discussed in this report. This is because the economic model offered in this report contains expense-estimating equations (i.e., more frequently referred to as cost-estimating relationships or CERs) for groups of DOT-defined line-item accounts. Therefore, the detailed data provided by several schedules are shown on Tables 2 through 7; Southwest Airlines operations in 1999 is used as a representative example.

Schedule T-2 (Traffic, Capacity and Operations) shows that in 1999 this airline operated three types of flight equipment (i.e., aircraft models), each a variant of Boeing's 737. The sum of each model's contribution is provided in the column labeled All Equipment Types. Note that the DOT refers to aircraft as flight equipment. Information is provided about both scheduled operations (accounts beginning with "k") and scheduled plus non-scheduled operations (accounts beginning with "z").

TABLE 2. FORM 41, SCHEDULE T-2 FOR SOUTHWEST AIRLINES IN 1999

Account	Traffic, Capacity and Operations	All Eqpt. Types	B-737-5	B-737-3/7	B-737-1/2
k110.0	Enplaned Passengers - Sched. Serv.	65,287,540	0	0	0
k140.0	RPM's - Scheduled Rev. Serv. (000's)	36,483,545	2,624,884	30,396,831	3,461,830
k240.0	Revenue Ton Miles-Sched. Serv. (000's)	3,782,325	269,433	3,155,670	357,222
k280.0	Available Ton Miles-Sch. Serv. (000's)	6,680,292	512,725	5,458,718	708,849
k320.0	ASM's - Scheduled Rev. Serv. (000's)	52,899,775	3,777,889	43,861,841	5,260,045
k410.0	Revenue Aircraft Miles-Sched. Serv.	393,932,502	30,966,307	320,159,428	42,806,767
k510.0	Departures Performed - Sched. Serv.	846,820	78,637	650,843	117,340
v510.0	Revenue Aircraft Dpt. Perf. - Non Sch.	1,875	2	1,848	25
z110.0	Enplaned Passengers - Sch.+NSch. Serv.	65,485,500	0	0	0
z140.0	RPM's - Sch. + NonSch. Serv. (000's)	36,484,892	2,624,952	30,396,831	3,463,109
z240.0	Rev. Ton Miles - Sch.+NSch. Serv. (000's)	3,782,340	269,439	3,155,670	357,231
z247.0	Freight Rev.Ton Miles-Sch.+NSch. (000's)	68,940	3,776	59,234	5,931
z249.0	Mail Rev. Ton Miles - Sch.+NSch. (000's)	65,031	3,170	56,753	5,108
z280.0	Avl. Ton Miles - Sch.+NSch. Serv. (000's)	6,680,500	512,732	5,458,718	709,050
z320.0	ASM's - Sch. + NonSch. Serv. (000's)	52,901,100	3,777,942	43,861,841	5,261,317
z410.0	Rev. Aircraft Miles- Sch.+NSch. Serv.	393,949,689	30,966,753	320,159,428	42,823,508
z510.0	Departures Performed - Sch.+NSch. Serv.	848,240	78,638	652,241	117,361
z610.0	Rev. Airborne Hours	986,448	80,096	792,879	113,473
z620.0	NonRevenue Airborne Hours	3,923	171	3,383	369
z630.0	Block Hours	1,169,845	96,749	936,155	136,941
z650.0	Total Airborne Hours	990,371	80,267	796,262	113,842
z810.0	Aircraft Days - Carrier Equipment	106,256	9,069	83,494	13,693
z820.0	Aircraft Days - Carrier Routes	106,256	9,069	83,494	13,693
z921.0	Gallons of Fuel	929,103,882	73,922,673	736,449,898	118,731,311

The T-2 schedule does not provide enplaned passenger count at the flight equipment level. The data can be approximated, however, by a simple calculation as follows:

$$\text{Enplaned Passengers} = \frac{1000 \times \text{Revenue Passenger Miles}}{\text{Revenue Aircraft Miles}} \times \text{Departures}$$

Schedule P-5.2 (Aircraft Operating Expenses) shows that in 1999 this airline's total aircraft operating expenses (account 7098.9 = TAOE) amounted to $1.813 billion. Total flying operations (account 5199.0 = FO) was $1.138 billion and total flight equipment maintenance (account 5299.0 = Mtn) was $0.484 billion. An accounting peculiarity of Schedule P-5.2 is that non-flight equipment accounts are listed, but they are not included in TAOE account 7098.9. These non-flight equipment accounts are: 7074.1, 7074.2, 7075.8, 7075.9, and 7076.2. Southwest was unusual in this regard because their Schedule 5.2 did not list these non–flight equipment expenses in 1999.

TABLE 3. FORM 41, SCHEDULE P-5.2 FOR SOUTHWEST AIRLINES IN 1999

Account	Aircraft Operating Expenses	All Eqpt. Types	B-737-5	B-737-3/7	B-737-1/2
5123.0	FO- Pilots and Copilots	325,697,000	26,935,000	260,634,000	38,128,000
5128.1	FO- Trainees and Instructors	2,059,000	170,000	1,648,000	241,000
5136.0	FO- Personnel Expenses	32,829,000	2,715,000	26,271,000	3,843,000
5141.0	FO- Prof. & Tech. Fees & Exp.	22,000	1,000	19,000	2,000
5145.1	FO- AC Fuel	490,501,000	40,046,000	393,902,000	56,553,000
5145.2	FO- AC Oil	2,097,000	174,000	1,676,000	247,000
5147.0	FO- AC Rentals	207,292,000	17,184,000	165,776,000	24,332,000
5155.1	FO- Insur. Purch. - General	3,617,000	303,000	2,885,000	429,000
5157.0	FO- Empl. Benefits and Pensions	47,522,000	3,919,000	38,059,000	5,544,000
5168.0	FO- Taxes-Payroll	26,531,000	2,210,000	21,190,000	3,131,000
5199.0	FO- Total Flying Operations (P1)	1,138,167,000	93,657,000	912,060,000	132,450,000
5225.1	Mtn- Maint Airf. Labor	54,115,000	4,470,000	43,321,000	6,324,000
5225.2	Mtn- Maint Eng. Labor	8,180,000	676,000	6,547,000	957,000
5243.1	Mtn- Maint Airf. Outside Rep.	211,236,000	7,700,000	137,358,000	66,178,000
5243.2	Mtn- Maint Eng. Outside Rep.	94,923,000	1,281,000	89,452,000	4,190,000
5246.1	Mtn- Maint Materials - Airframe	33,752,000	2,589,000	14,163,000	17,000,000
5246.2	Mtn- Maint Materials - Engines	1,708,000	80,000	1,225,000	403,000
5272.3	Mtn- Maint Airfrm O/H Deferred	28,952,000	2,377,000	23,214,000	3,361,000
5278.0	Mtn- Total Dir Maint-Flt. Eqpt. (P6)	432,866,000	19,173,000	315,280,000	98,413,000
5279.6	Mtn- Appl. Maint Bur-Flt. Eqpt. (P6)	51,601,000	4,268,000	41,293,000	6,040,000
5299.0	Mtn- Total Flt. Eq. Maint. (Memo)	484,467,000	23,441,000	356,573,000	104,453,000
7073.9	Obs- Net Obsl&Deter.- Exp. Parts	-3,000,000	-261,000	-2,361,000	-378,000
7075.1	Dpr- Depr. Airframes	143,507,000	11,826,000	114,955,000	16,726,000
7075.2	Dpr- Depr. Aircraft Engines	33,730,000	2,783,000	27,009,000	3,938,000
7075.3	Dpr- Depr. Airframe Parts	5,081,000	419,000	4,069,000	593,000
7075.4	Dpr- Depr. Engine Parts	2,246,000	187,000	1,794,000	265,000
7075.5	Dpr- Depr. Other Flt Eqpt.	1,650,000	136,000	1,320,000	194,000
7075.6	Dpr- Total Depr. - Flt. Eqpt. (P3)	186,214,000	15,351,000	149,147,000	21,716,000
7075.8	Dpr- Depr. Hangr. & Eqpt. (9999Only)	466,000	0	0	0
7075.9	Dpr- Depr. Ground Eqpt. (9999Only)	54,373,000	0	0	0
7076.1	Amr- Amort. Cap. Leases Flt. Eqpt.	7,448,000	622,000	5,944,000	882,000
7098.9	Total Aircraft Operating Expenses	1,813,296,000	132,810,000	1,421,363,000	259,123,000

Schedule P-7 provides a summation of each entity's[4] Total Operating Expenses (line 38.0 = TOE) by functional groups. Note that Total Aircraft Operating Expenses (TAOE) detailed on Schedule P-5.2 is carried over to Schedule P-7, Line 2.0. If TAOE is considered as "direct operating costs" (DOC), then Schedule P-7, Lines 5.0 through 37.0, may be considered "indirect operating costs" (IOC) or, as used in this economical model, All Other Operating Expenses (AOOE). Note that Schedule P-7 provides subtotals of AOOE at Lines 8.0, 13.0, 18.0, 23.0, 28.0, 29.0, 33.0, 34.0, and 35.0. Total Operating Expenses thus equals Lines 2.0 + 36.0 + 37.0.

TABLE 4. FORM 41, SCHEDULE P-7 FOR SOUTHWEST AIRLINES IN 1999

Line	P-7 Operating Expenses by Functional Grouping	Total Eqpt. Types
2.0	Aircraft Operating Expenses (P5)	1,813,296,000
5.0	PS- Flight Attendant Expense	218,914,000
6.0	PS- Food Expense	14,771,000
7.0	PS- Other In-Flight Expense	19,895,000
8.0	PS- Total Passenger Service Exp.	253,580,000
10.0	AS- Line Servicing Expense	194,867,000
11.0	AS- Control Expense	17,674,000
12.0	AS- Landing Fees	123,530,000
13.0	AS- Total Aircraft Servicing Exp.	336,071,000
15.0	TS- Directly Assignable- Passenger	279,996,000
16.0	TS- Directly Assignable- Cargo	24,866,000
17.0	TS- Not Directly Assignable	12,000
18.0	TS- Total Traffic Servicing Exp.	304,874,000
20.0	R&S- Directly Assignable- Passenger	426,556,000
21.0	R&S- Directly Assignable- Cargo	498,000
22.0	R&S- Not Directly Assignable	45,319,000
23.0	R&S- Total Reservation. & Sales Exp.	472,373,000
25.0	A&P- Directly Assignable- Passenger	142,170,000
26.0	A&P- Directly Assignable- Cargo	501,000
27.0	A&P- Not Directly Assignable	5,692,000
28.0	A&P- Total Advertising & Prom. Exp.	148,363,000
29.0	G&A- Total General & Admin. Exp.	539,698,000
31.0	GE- Maintenance Ground Property & Equipment	13,601,000
32.0	GE- Depreciation Ground Prop. & Eqpt.	54,375,000
33.0	GE- Total Maint.+Depr. Ground P&E	67,976,000
34.0	Depr. Expense - Maintenance Eqpt.	468,000
35.0	Amortiz. (Other than Flt. Eqpt.)	0
36.0	Total Servicing, Sales & Gen. Op. Exp.	2,123,403,000
37.0	Transport-Related Expenses	17,417,000
38.0	Total Operating Expenses	3,954,116,000

[4]Unlike American, which reports on 4 entities that need to be added together to get the airline total, Southwest only operates domestically; so Southwest is both an entity and an airline. Thus, Southwest's entity total is the airline's total.

TABLE 5. FORM 41, SCHEDULE P-6 FOR SOUTHWEST AIRLINES IN 1999

Line	P-6 Operating Expenses by Objective Grouping	Total Eqpt. Type
3.0	S&W - General Mgmt. Per.	75,562,000
4.0	S&W - Flight Personnel	462,981,000
5.0	S&W - Maintenance Labor	66,520,000
6.0	S&W - Aircraft. & Traffic Handling Per.	365,369,000
7.0	S&W - Other Personnel	59,417,000
8.0	S&W - Total Salaries	1,029,849,000
10.0	Bfts. - Personnel Expense	101,241,000
11.0	Bfts. - Empl. Benefits & Pensions	346,679,000
12.0	Bfts. - Payroll Taxes	75,982,000
13.0	Bfts. - Total Fringe Benefits	523,902,000
14.0	S&B - Total Salaries & Benefits	1,553,751,000
16.0	Mtls. - Aircraft Fuel & Oil	492,599,000
17.0	Mtls. - Maintenance Materials	60,072,000
18.0	Mtls. - Passenger Food	14,775,000
19.0	Mtls. - Other Materials	41,134,000
20.0	Mtls. - Total Materials	608,580,000
22.0	Svcs. - Advertising & Other Promotion	142,671,000
23.0	Svcs. - Communications	34,319,000
24.0	Svcs. - Insurance	15,757,000
25.0	Svcs. - Outside Flight Eqpt. Maint.	325,051,000
26.0	Svcs. - Traffic Commissions - Passenger	175,314,000
27.0	Svcs. - Traffic Commissions - Cargo	12,000
28.0	Svcs. - Other Services	239,848,000
29.0	Svcs. - Total Services	932,972,000
30.0	Landing Fees	123,530,000
31.0	Rentals	318,246,000
32.0	Depreciation	238,054,000
33.0	Amortization	7,448,000
34.0	Other	154,120,000
35.0	Total Transport Related Expenses	17,415,000
36.0	Total Operating Expenses	3,954,116,000

Schedule P-6 (table 5, pg. 8) also provides a summation of each entity's Total Operating Expenses (line 36.0 = TOE), but by objective groups. Salary, wages, and benefits data can be nearly matched against Schedule P-10 (Employment) from Table 6 to derive average, per person yearly expense.

TABLE 6. FORM 41, SCHEDULE P-10 FOR SOUTHWEST AIRLINES IN 1999

Line	P-10 Employment	Total
21.0	Empl. General Mgmt. Per.	1,350
23.0	Empl. Pilots & Copilots	2,962
24.2	Empl. Other Flt Per-Psgr./Gen. Svc. & Adm.	4,983
25.0	Empl. Maintenance Labor	1,063
26.1	Empl. Gen A/C & Traff. Hndl. Per.	3,783
26.2	Empl. Aircraft Control Pers.	135
26.3	Empl. Passenger Hndling Personnel	11,164
28.1	Empl. Trainees & Instructors	10
31.0	Empl. Record Keeping & Stst. Pers.	685
33.0	Empl. Traffic Solicitors	148
99.1	Empl. Other Personnel	1,091
99.0	Empl. Total Weighted Avg. CY Empl.	27,374

Schedule P-1.2 (Statement of Operations) (table 7) introduces a concept this non-accountant author has not encountered before, namely, that revenue will be treated as a negative and expenses will be positive. Thus, this airline's net income in 1999 (account 9899.0) was a negative $474,380,000. Note that Total Operating Expenses (account 7199.0) is now obtained from 8 subtotals, each traceable to a more detailed schedule as noted.

TABLE 7. FORM 41, SCHEDULE P-1.2 FOR SOUTHWEST AIRLINES IN 1999

Account	P-1.2 Statement of Operations	Total	Author Notes
3901.0	Rev.- Passenger	-4,499,360,000	
3901.1	Rev.- Passenger - First Class	-4,499,360,000	
3905.0	Rev.- Mail	-40,728,000	
3906.0	Rev.- Property	-64,488,000	
3906.1	Rev.- Property - Freight	-62,262,000	
3906.2	Rev.- Property - Excess Baggage	-2,226,000	
3907.0	Rev.- Charter	-30,628,000	
3907.1	Rev.- Charter - Passenger	-30,628,000	
3919.0	Rev.- Air Transport Other	-90,506,000	
3919.2	Rev.- Misc. Operating Revenues	-90,506,000	
4898.0	Rev.- Transport Related	-9,938,000	
4999.0	Rev.- Total Operating Revenue	-4,735,648,000	
5100.0	Exp.- Flying Operations	1,138,168,000	P-5.2, Acct. 5199.0
5400.0	Exp.- Maintenance	498,069,000	P-5.2, Acct. 5299.0 + P-7, Line 31.0
5500.0	Exp.- Passenger Service	253,580,000	P-7, Line 8.0
6400.0	Exp.- Aircraft & Traffic Servicing	640,946,000	P-7, Lines 13.0 + 18.0
6700.0	Exp.- Promotion & Sales	620,736,000	P-7, Lines 23.0 + 28.0
6800.0	Exp.- General & Administrative	539,698,000	P-7, Line 29.0
7000.0	Exp.- Depreciation & Amortization	245,503,000	P-5.2, Acct. 5199.0
7100.0	Exp.- Transport Related	17,417,000	P-7, Line 37.0
7199.0	Exp.- Total Operating Expenses	3,954,117,000	
7999.0	Operating Profit or Loss	-781,531,000	
8181.0	Nonop.- Int. on L-T-D & Cap. Leases	53,612,000	
8182.0	Nonop.- Int. Exp. Other	-30,728,000	
8185.0	Nonop.- Foreign. Exch. Gain or Loss	-15,000	
8188.5	Nonop.- Capital G/Losses- Op. Prop.	11,851,000	
8189.0	Nonop.- Other Income & Exp.- Net	-26,801,000	
8199.0	Nonoperating Income & Expense	7,919,000	
8999.0	Income Before Tax	-773,612,000	
9100.0	Income Tax Expense	299,232,000	
9199.0	Income Bf. Disc. Ops. & Other Items	-474,380,000	
9799.0	Income Before Accounting Changes	-474,380,000	
9899.0	Net Income	-474,380,000	

For DOT purposes, airlines are subdivided into entities. An entity, by DOT use, is the airline's component that serves either a Domestic, Atlantic, Latin America, or Pacific market segment. For example, American Airlines, which serves all four market segments, submits four Form 41s, one for each of its entities. Data at the individual aircraft model level within an entity are obtained from Schedules T-2 (traffic) and P-5.1 and P-5.2. The P-5.1 and P-5.2 data are historically referred to as "direct operating costs." However, today's DOT's 1999 nomenclature is "Total Aircraft Operating Expenses" or TAOE. Data historically referred to as "indirect operating costs" come from Schedule P-7, but are not available to the DOT at the individual aircraft model (i.e., flight equipment) level. That is, the indirect operating costs of each aircraft model are summed to the higher, entity level. For lack of a better name, the author refers to the indirect operating costs as “All Other Operating Expenses,” or AOOE. Thus an entity’s Total Operating Expenses = TOE = TAOE + AOOE.

The accounting titles of Form 41 data as used in this report are shown in Figure 1. Only the grouping titled All Other Operating Expenses is unique to the economic model described in this report. All other titles directly parallel DOT nomenclature and account numbers.

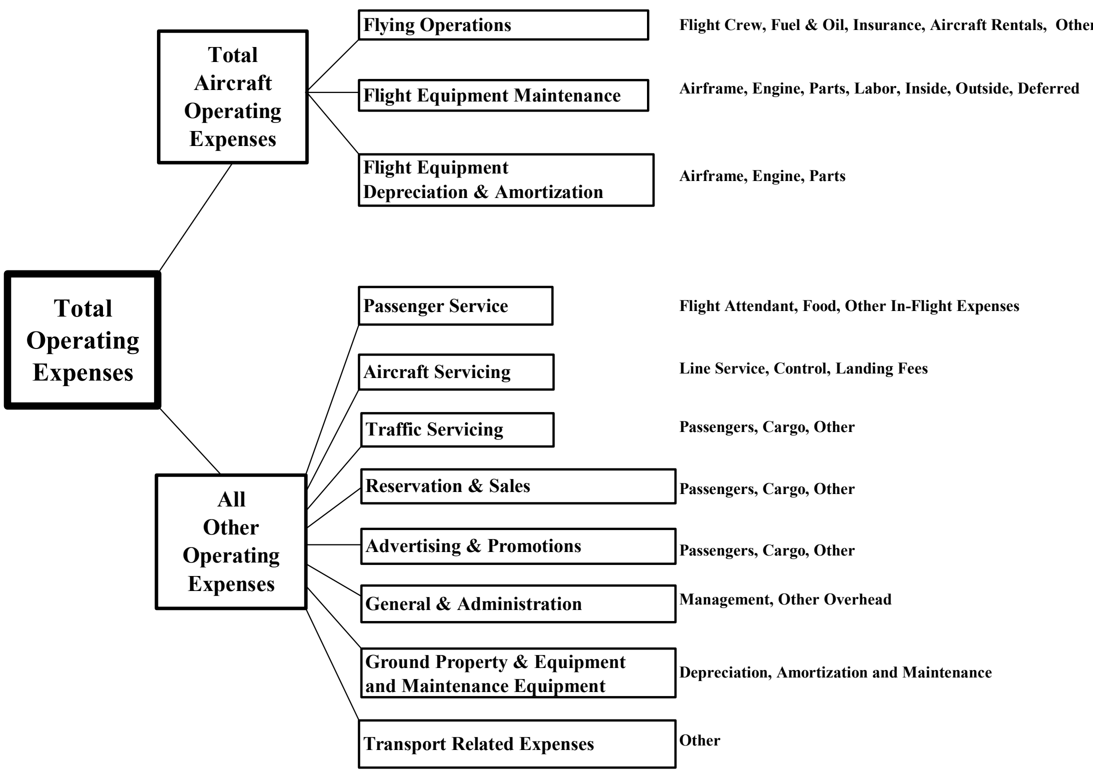

Figure 1. Accounting Tree for Total Operating Expenses.

The first step taken in using the Form 41 data to create the economic model was to transfer Schedules T-2, P-1.2, P-5.1, P-5.2, P-6, P-7, P-0, and B-43 for each airline, entity, and aircraft model from the Data Base Products CD on to individually tabbed spreadsheets in a Microsoft EXCEL workbook. Then a master file spreadsheet some 1420 rows deep by 260 columns wide was constructed, which provided data from 75 passenger entities, 43 cargo entities, and with an additional 11 entities included but having very incomplete data. Next, after a brief review, the T-2, P-5.2, and P-7 schedules were chosen as the base upon which the economic model would be constructed. As a prelude to building a model, several overviews of the airline industry were assessed. The first assessment, shown on Figure 2, examined the relative contribution of Total Aircraft Operating Expenses (TAOE) and All Other Operating Expenses (AOOE) to Total Operating Expenses (TOE). That is, since TOE = TAOE + AOOE, it follows that

$$1 = \frac{\text{TAOE}}{\text{TOE}} + \frac{\text{AOOE}}{\text{TOE}}$$

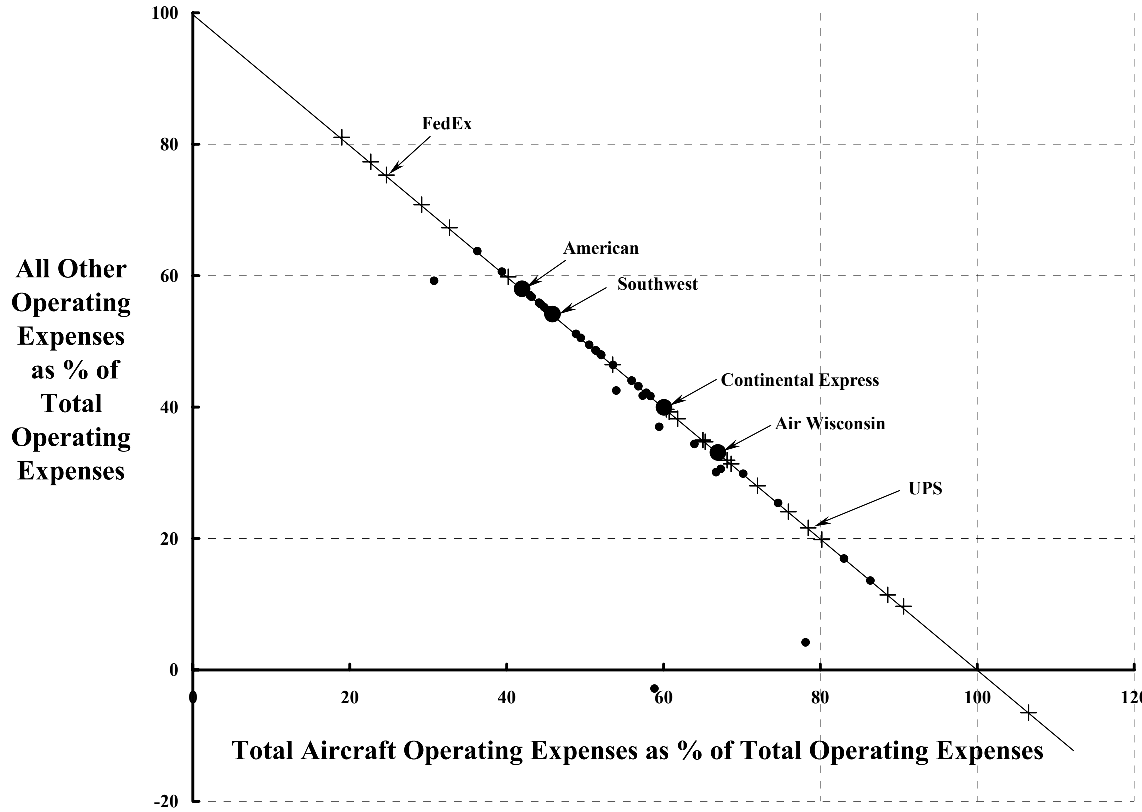

Figure 2. Each Passenger and Cargo Airline was Unique in 1999.

A typical or average ratio of TAOE and AOOE simply did not exist in 1999. For example, two major cargo airlines, FedEx and UPS, were diametrically opposite in distributing their expenses. FedEx accounting charged only 10% of its TOE to TAOE and 90% of its TOE to AOOE, while UPS accounting appears virtually reversed. Similarly, an average of American and Southwest—two large passenger airlines—might be reasonable, but neither was representative of regional passenger airlines such as Continental Express or Air Wisconsin. This assessment showed that the economic model would have to rate or classify each airline in some way to reflect its position relative to an "average" expense-estimating relationship.

Figure 2 also showed that a few smaller entities (i.e., Groups I and II) had data that could not be reconciled. The primary reason for this was that the smaller entities and airlines submitted a Schedule P-5.1 rather than the more complete P-5.2 and, further, they did not submit a Schedule P-7. To include the smaller entities required some approximations that were not adequate in four cases. The second assessment dealt with the Transport Related Expenses account (P-7, Line 38.0 or P-1.2, Account 7100.0). The overwhelming majority of entities accumulated less than 3.5 percent of their Total Operating Expenses in this category; however, several entities used this category to account for nearly all of their expenses. This accounting situation came to light with Figure 3. Including these few airlines in any particular expense-estimating equation would have to be done with care so the equation would not be skewed.

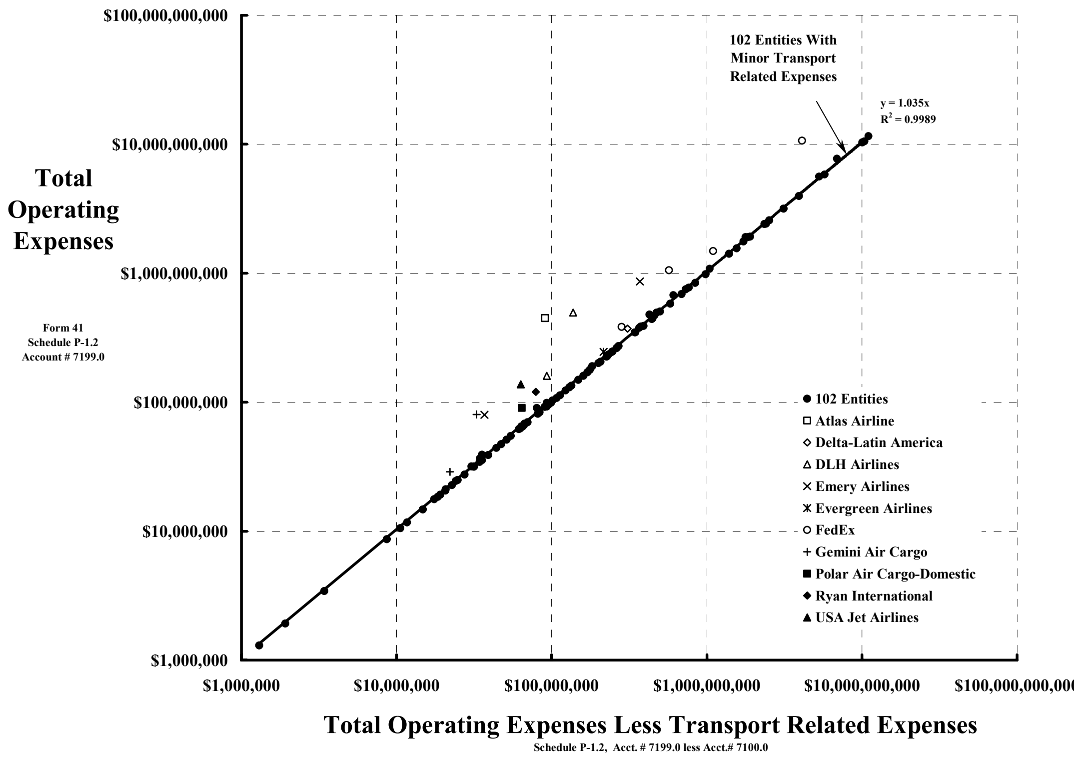

Figure 3. A Few Airlines had Excessive Transport-Related Expenses.

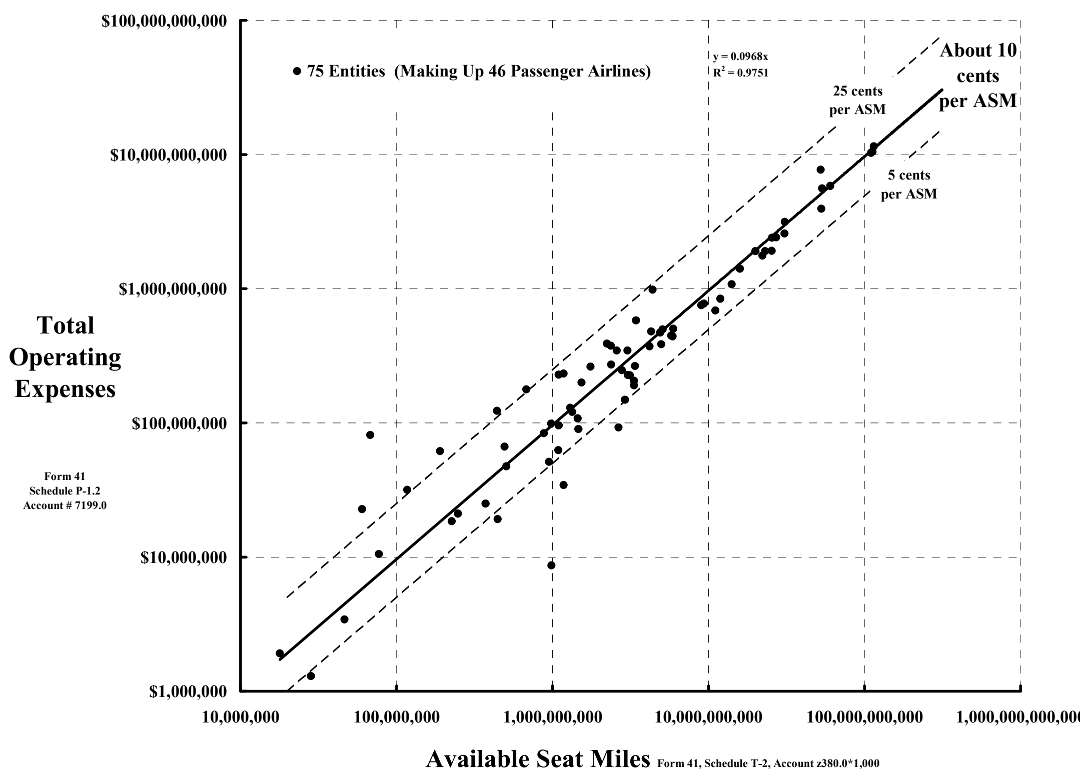

Figure 4. TOE of Passenger Airlines Depend on ASM.

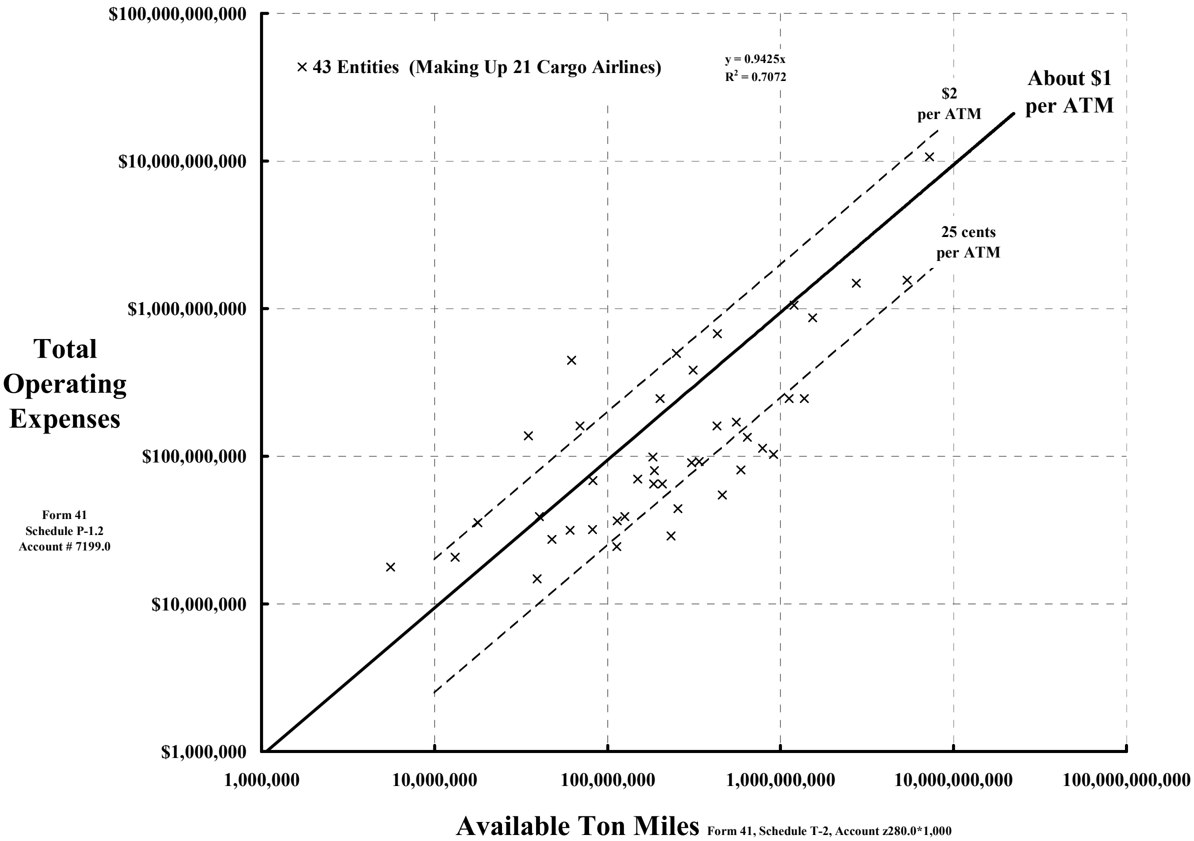

Figure 5. TOE of Cargo Airlines Depend on ATM.

Two additional assessments were made. Both dealt with Total Operating Expenses in relation to available capacity. Figure 4 (on page 13) shows that for the 75 entities making up 46 passenger airlines, Total Operating Expenses amounted to 10 cents per available seat mile (ASM) based on a linear regression average. However, several entities were as low as 5 cents per ASM and several more were at 25 cents per ASM. The cargo entities, as Figure 5 shows, had considerably more scatter in cents per available ton miles (ATM).

Taken together, Figure 4 and Figure 5 strongly suggested that expense-estimating equations would depend on more than one variable.

3. OTHER DATA BANKS

Several expense-estimating equations in this report require an approximate value of capital invested in aircraft. One example is depreciation expense. The DOT Form 41, Schedule B-43, has provisions for entries of

a. Acquired Cost or Capitalized Value
b. Allowance for Depreciation or Amortization
c. Depreciated Cost or Amortized Value
d. Estimated Residual Value
e. Estimated Depreciable Life

Unfortunately, the Data Base Products CD does not have these data available and, in fact, the data appear to be rather difficult to get—readily. As an alternate, three data sets were used to construct a data bank of capital invested in aircraft.

The first step was to use the aircraft identification data that were on the Data Base Products CD. These DOT data matched aircraft to registration number and manufacturer's serial number. To double check this aircraft identification list, the author turned to Jet Information Services, Inc. Their data set filled in several airlines whose data were missing on the DOT list. Armed with a more complete set of aircraft identification data, the author turned to the Airline Price Guide to obtain some estimate of each aircraft's average new price in the year it was bought. The Airline Price Guide describes the aircraft in several columns as

a. Year
b. Type or Model & Series
c. Configuration
d. Engines
e. Serial Numbers (purchased in that year)
f. Average New Prices

By matching serial numbers, the approximate new price of some 7,600 aircraft was added as a new column to the data base. Each aircraft was identified using DOT and Jet Information Services listings as (a) owned by commercial airline—3,630, (b) owned by the government—440, (c) under a commercial operating lease—3,220, or (d) under a commercial capital lease—310. The 67 airlines ultimately used in the edited data base operated slightly under 6,000 aircraft in 1999.

The final aircraft identification data bank was accumulated on a Microsoft EXCEL spreadsheet for use as a ready reference.

4. MODELING TOTAL AIRCRAFT OPERATING EXPENSES

In 1999, the industry experienced $110 billion in Total Operating Expenses (TOE). Expenses charged to Total Aircraft Operating Expenses (TAOE) amounted to $47 billion. These TAOE are predicted with 8 expense-estimating equations addressing the 3 main categories of Schedule P-5.2 as shown in the accounting tree of Figure 1. Flying Operations requires 5 equations, Flight Equipment Maintenance requires 2, and Flight Equipment Depreciation and Amortization requires one. Each equation, including brief comments about their development, is discussed below.

4.1 Flying Operation Expenses (FO)

In 1999, Total Aircraft Operating Expenses of the 67 airlines under study amounted to slightly over $47 billion for the 5,963 airplanes in operation. Flying operation expenses contributed $30.2 billion in expenses to the industry's TAOE. Fifteen sub-accounts were used by the DOT Form 41, Schedule P-5.2, to describe flying operation expenses. These sub-accounts, identified in Figure 6's accounting tree, roll up into five major categories for which expense-estimating equations are described.

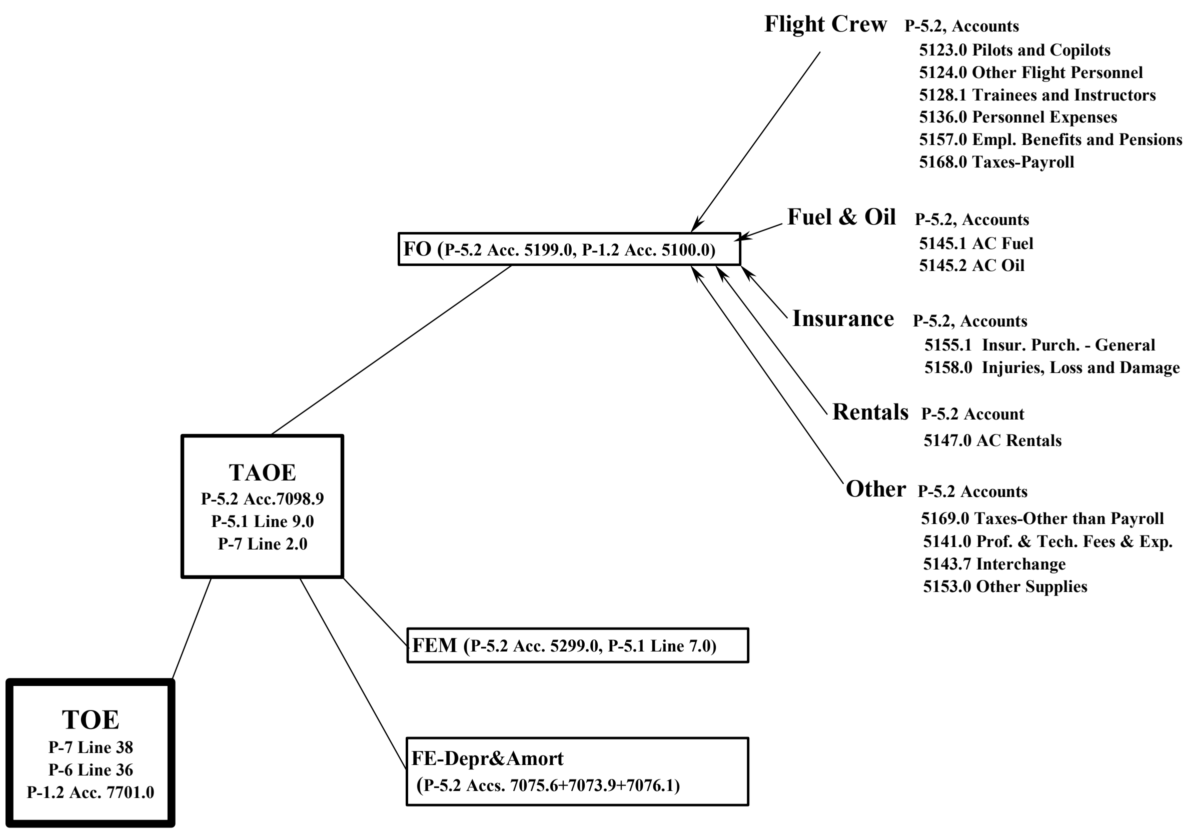

Figure 6. Accounting Tree for Flying Operations.

4.1.1 Flight Crew Expenses

Flight crew expenses are known—at least within the industry—to vary linearly with block hours (BH). To confirm this hint, Figure 7 shows that the linear regression average of 118 entities making up 67 airlines was about \$640 per block hour in 1999. However, the range about this average was from \$150 per block hour to \$1,500 per block hour.

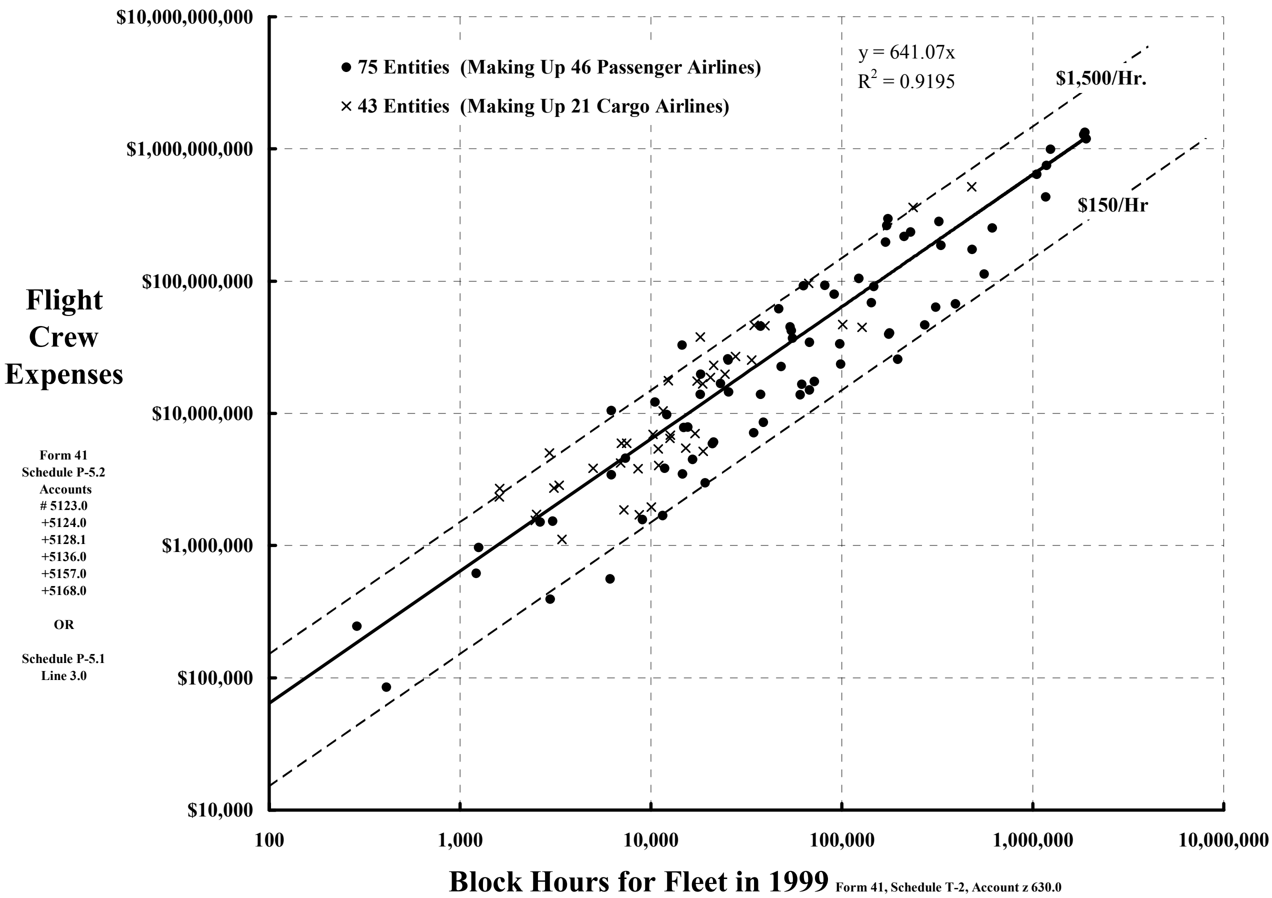

Figure 7. Flight Crew Expenses Appear Linear with Block Hour.

The variation in flight crew expenses per block hour shown in Figure 7 was traced to four factors. A clear dependence on maximum takeoff gross weight was established by regression analysis. This step showed that

$$\text{Flight Crew Expense in 1999} \propto K\left(\text{Max. TOGW}\right)^{N}\left(\text{Block Hours in 1999}\right)$$

with the exponent N falling in the range of 0.35 to 0.45. The constant K became necessary to reflect the differences between (a) regional and major airlines, (b) domestic and 2 crew-member crews, and finally, (c) the Pacific and Atlantic routes and/or 3 crew members required by the older “jumbo” jets. Recognizing these differences led to the refinement that

$$\text{Flight Crew Expenses} \propto K\,(\text{MTOGW})^{0.40}\,(\text{BH})$$

$$\begin{aligned} \text{Where}\quad & K = 2.75 \text{ for Regionals} \\ & K = 5.25 \text{ for Domestic and 2 Crew} \\ & K = 6.50 \text{ for 3 Crew and / or Pacific or Atlantic} \end{aligned}$$

Improving this expense-estimating equation further required introducing an airline factor (AF) so that

$$\text{Flight Crew Expenses} = \text{AF}\left[K\left(\text{MTOGW}\right)^{0.40}\left(\text{BH}\right)\right]$$

This airline factor was found using regression analysis and iterating by assigning numerical values for each airline until near perfect correlation was obtained at the airline level. For example, AF = 0.608 was found for Southwest and a value of AF = 1.063 was found for American. In American Airlines' case, the value of 1.063 was used for each of its four entities. After iterated airline factor values were found, qualitative business scale ratings were selected to group the airlines such that

$$\begin{aligned} &\text{AF} = \text{Very, Very Low} = 0.34 \\ &\text{AF} = \text{Very Low} = 0.44 \\ &\text{AF} = \text{Low} = 0.63 \\ &\text{AF} = \text{Average} = 0.80 \\ &\text{AF} = \text{High} = 1.00 \\ &\text{AF} = \text{Very High} = 1.30 \\ &\text{AF} = \text{Very, Very High} = 1.60 \end{aligned}$$

The resulting expense-estimating equation—with the airline factor approach—yields excellent correlation with the data from which it was derived, as Figure 8 shows. This was, of course, by design at the airline level.

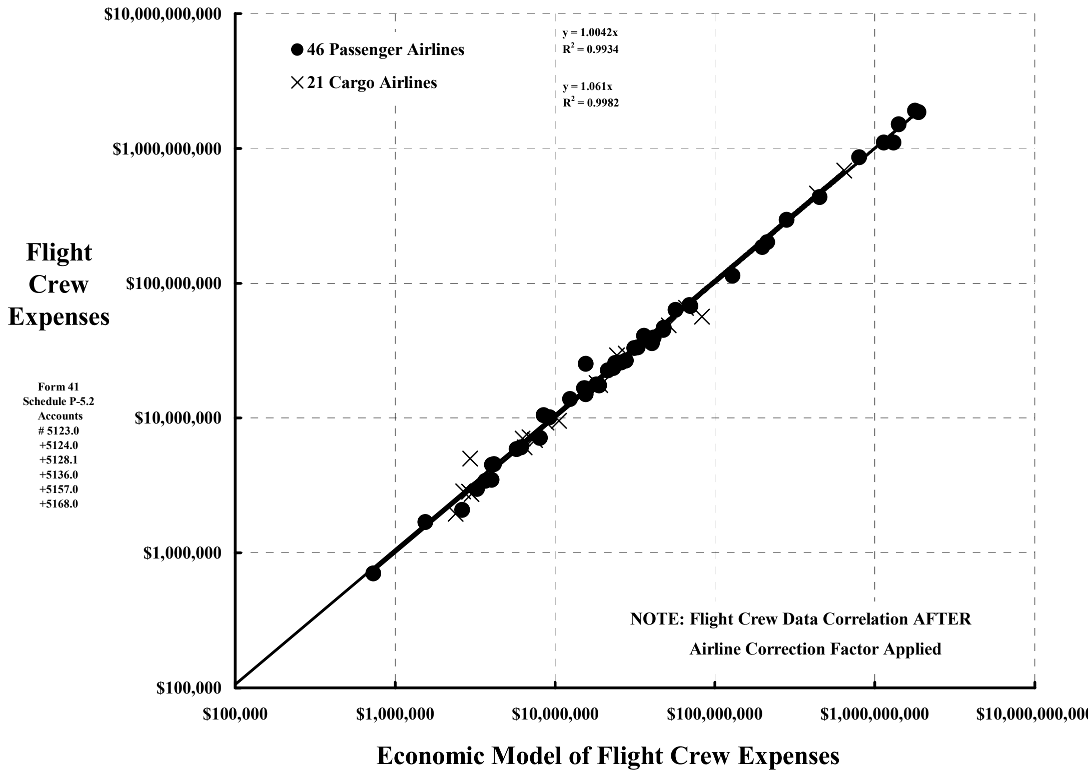

Figure 8. Flight Crew Exp. Correlation at the Airline Level.

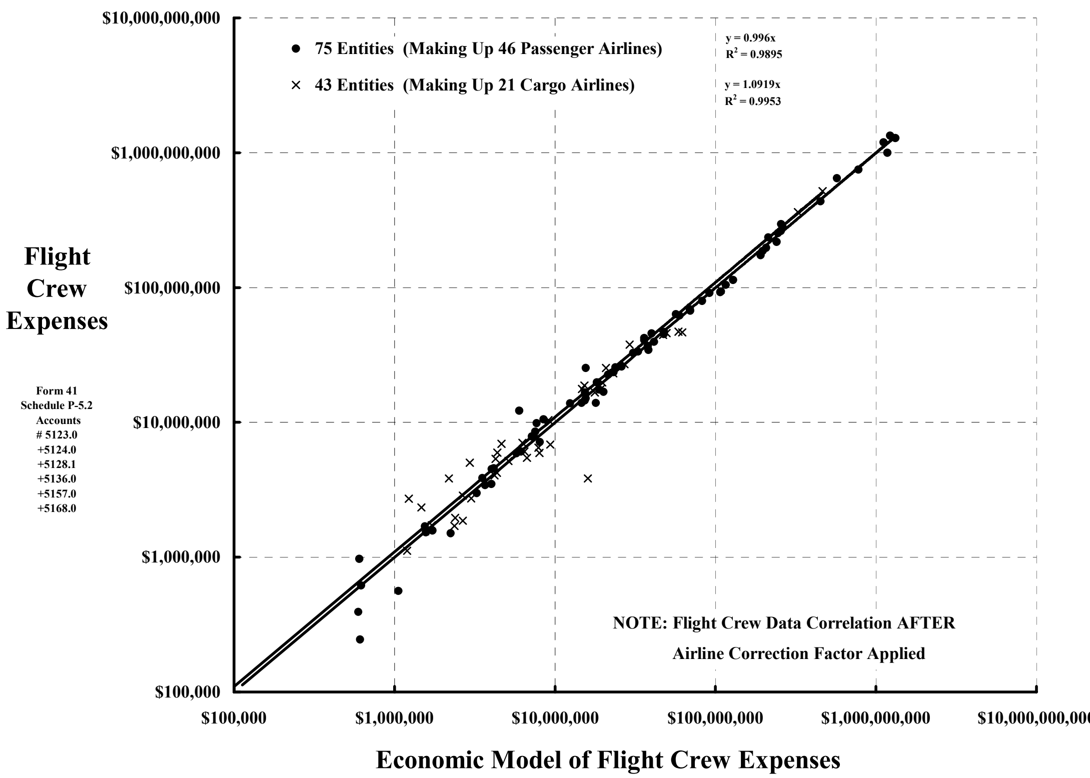

Figure 9. Flight Crew Exp. Correlation at the Entity Level.

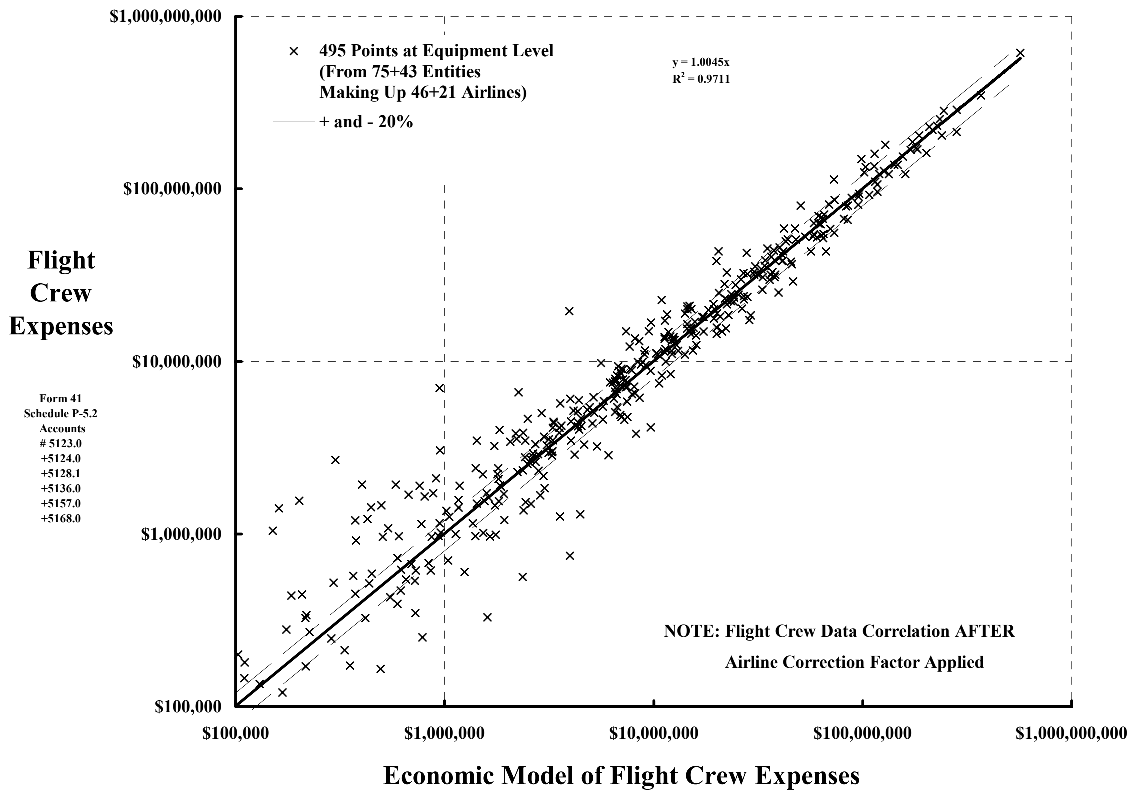

Figure 10. Flight Crew Exp. Correlation at the Flt. Equip. Level.

However, at the entity level (Figure 9) and the flight equipment level (Figure 10), scatter becomes more evident. The correlation of the flight crew expense estimating equation at the entity level begins to show inaccuracy for smaller entities, as Figure 9 shows. While both passenger and cargo entities have a coefficient of determination above 0.98 (i.e., $R^2 > 0.98$), the cargo entities are underpredicted by about 9 percent. At the flight equipment level, Figure 10, the prediction of 495 data points from all airlines has an $R^2 > 0.97$, which was the highest R^2 this author could manage. Perhaps a better measure of correlation accuracy on Figure 10 is the + and – 20% bands. Of the 495 points, 83 points have highly questionable Form 41 reporting.[5] Of the remaining 412 points, 197 fall within the 20 percent error band.

The highest point on Figure 10 comes from American Airlines' domestic entity operating 257 McDonnell Douglas MD-80s. Their reported flight crew expenses for this aircraft model alone were $614.6 million in 1999; the flight crew expense estimating equation predicts $568.3 million, which is an error of some 7.5 percent.

[5] In many cases, for example, the Form 41 data showed no block hours flown by the fleet on Schedule T-2 and yet flight crew expenses were listed on Schedule P-5.1 or P-5.2.

4.1.2 Fuel & Oil Expenses

In 1999, Total Aircraft Operating Expenses of the 67 airlines under study amounted to slightly over $47 billion for the 5,963 airplanes in operation. Fuel and oil expenses contributed $10.2 billion in expenses to the industry's TAOE. Fuel—the primary expense—was sold to the airlines on average at about 51 cents per gallon in 1999. Very few entities reported oil expenses on Schedule P-5.2, Account 5145.2; the inference being that this expense was so small that it could be ignored or, more likely, just lumped in with fuel expenses. From Table 3, Southwest's 1999 Form 41 report showed oil expenses at 0.43 percent of fuel expenses. In contrast, American Airlines' 1999 report showed oil expenses as 0.25 percent of fuel expenses. With oil such a small percentage of fuel-plus-oil expenses, the fuel expense estimating equation reported herein can be assumed to include oil.

Aircraft fuel expenses as a function of revenue aircraft statute miles flown by the 5,943 aircraft fleet in 1999 are shown in Figure 11. While propeller-driven airplanes operated by regional airlines incurred expenses at only $0.50 per mile, larger and older "jumbo" jets operated at $5.00 per mile. Note that on Figure 11 several entities reported fuel expenses well below $0.50 per mile. These airlines used leased aircraft and fuel expense was included in the leasing agreement (i.e., a "wet lease").

The approach to developing a fuel expense estimating equation was to first divide the quantity of fuel used per departure into two parts.[6] The equation assumes that a typical aircraft one-way trip requires fuel while *not in* cruise flight and fuel while *in* cruise flight. The basis for this assumption was obtained by graphing fuel used per departure versus trip length per departure for all Boeing 727s flown in 1999. The graph, Figure 12, showed that even if no trip miles were flown, some fuel would be used during ground, takeoff, climb to cruise altitude, descent, and landing portions of the trip. (The fact that some miles of the trip are covered during these operations was ignored.) Other aircraft studied showed linear trends similar to Figure 12, but with varying slope and intercepts. Thus, the fuel expenses for a given aircraft took the form,

$$\text{Fuel Expense for 1999} = \frac{\text{Fuel Cost}}{\text{Gallon}}\left(\frac{\text{Non-cruise gallons}}{\text{Departure}} + \frac{\text{Cruise gallons}}{\text{Departure}}\right)\text{Departures in 1999}$$

[6]The DOT uses the term departure for a one-way trip.

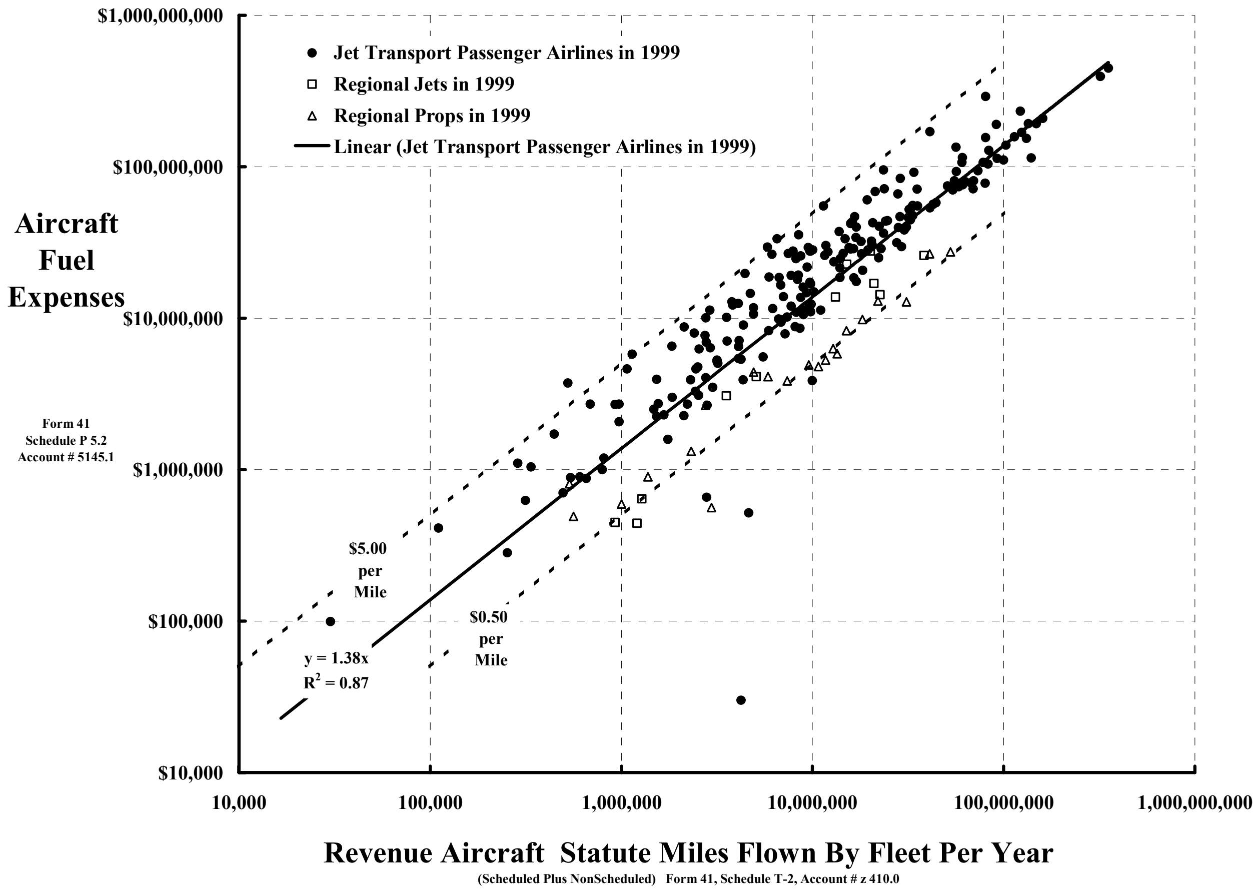

Figure 11. Fuel Expense vs. Miles Flown.

The equation estimating non-cruise gallons was arrived at semi-empirically assuming that acceleration at takeoff was one key parameter. The logic here was that it would take some time to reach cruise speed at altitude. That time (and associated fuel burn) would be reduced if the aircraft design had more acceleration. This acceleration was taken simply as propulsive thrust at takeoff divided by takeoff gross weight (TOGW). Other parameters used were engine-specific fuel consumption (SFC) and engine takeoff thrust (if jet) or brake horsepower (if piston or turboprop).

Reference 13 provides more details on propulsion and aircraft performance. Note that specific fuel consumption is defined differently for turbojet and turbo shaft (or piston) engines. Also, Appendix 3 gives representative values of these parameters as used in this economic model.

$$\frac{\text{Non-cruise Gal.}}{\text{Departure}} = \frac{0.001713\left(\text{SFC}_{\text{jet}} \times \text{Thrust}\right)_{\text{Takeoff}}}{\left(\text{Thrust/TOGW}\right)^2_{\text{Takeoff}}} \quad \left(\text{turbojet/turbofan} - \text{driven airplane}\right)$$

$$\frac{\text{Non-cruise Gal.}}{\text{Departure}} = \frac{0.01113\left(\text{SFC}_{\text{piston}} \times \text{BHP}\right)_{\text{Takeoff}}}{\left(\text{Thrust/TOGW}\right)^2_{\text{Takeoff}}} \quad \left(\text{turboprop} - \text{driven airplane}\right)$$

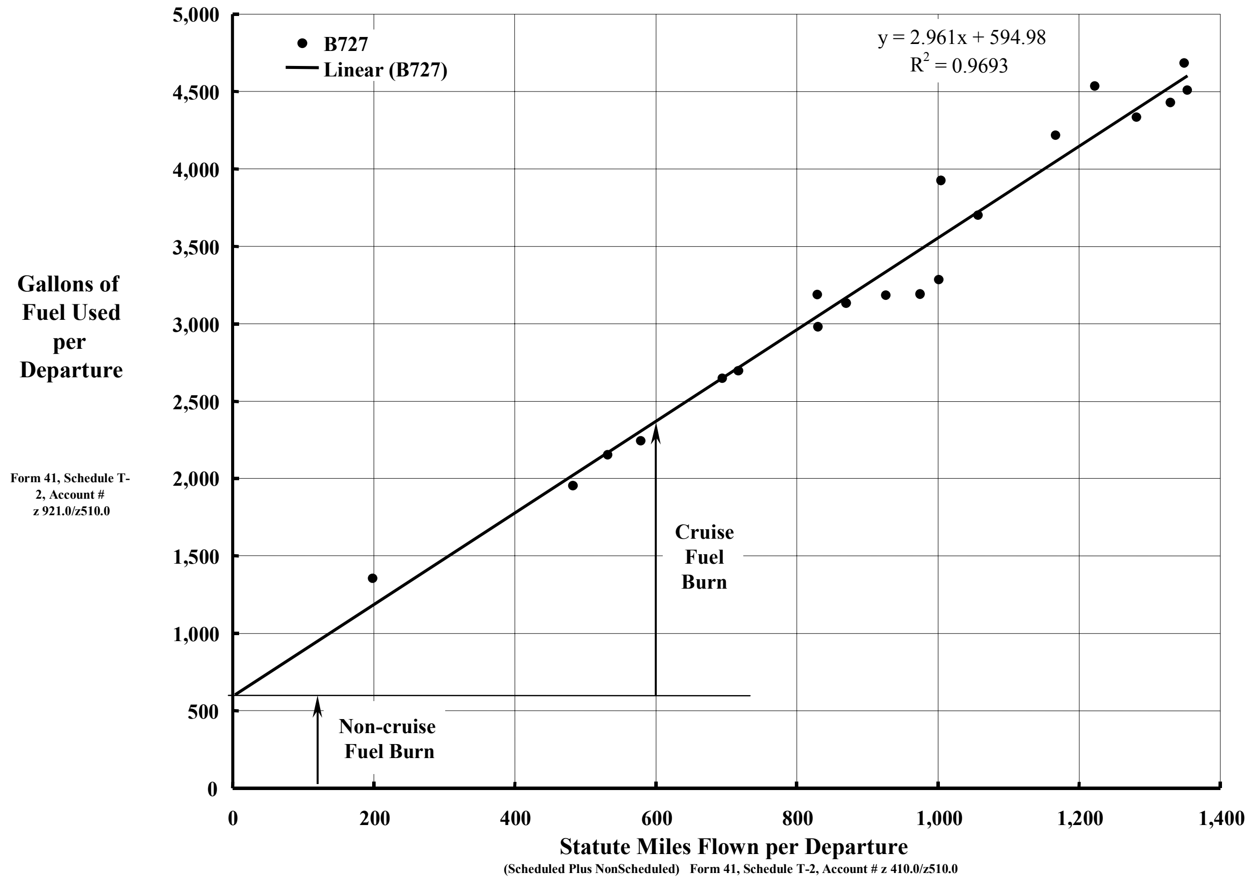

Figure 12. Typical Trip Profile of a U.S. Airliner.

The calculation of fuel burned during cruise was based on the Breguet range equation. This very simple equation only requires knowledge of the trip length (i.e., range), average cruise speed (V), average aircraft lift to drag ratio (L/D), propeller propulsive efficiency (η_p), and average specific fuel consumption in cruise (SFC_{cruise}). (See Appendix 3 for representative values of these parameters.)

$$\text{Cruise Gallons per Departure} = \frac{W_{initial}\left(1 - e^{-K}\right)}{6.5 \ \text{lbs/gal}}$$

$$\text{where } K_{Jet} = \frac{\text{Range} \times SFC_{Cruise}}{\left(V \times L/D\right)_{Average}} \text{ and } K_{Prop} = \frac{\text{Range} \times SFC_{Cruise}}{\left(375 \times \eta_P \times L/D\right)_{Average}}$$

The initial weight at which cruise begins depends, of course, on takeoff gross weight and on the amount of fuel burned during the non-cruise portion of the trip. Since more non-cruise fuel is used on takeoff and climb to altitude, the approximation used in this economic model was

$$\text{Start Cruise at } W_{initial} = \text{Takeoff Gross Weight} - 6.5\,\text{lb/gal}\left(\text{Non-cruise Gallons}\right)$$

Finally, several parameters must be defined and be accompanied by units; note that

a. Passenger TOGW = Operating WE + 225(Avail. Seats)(Load Factor) + 1.5(6.5)(Fuel/Dept.)
b. Cargo TOGW = Operating WE + 2000(Avail. Tons)(Load Factor) + 1.5(6.5)(Fuel/Dept.)
c. Thrust refers to the sum of thrusts from all engines or propellers. Units are pounds.
d. BHP is the sum of brake horsepower from all engines driving propellers. Units are hp
e. SFC is specific fuel consumption in fuel pounds/hour per pounds of thrust for jets or fuel pounds/hour per BHP for engines driving propellers.
f. V is average cruise speed in statute miles per hour (see T-2, z410.0/z650.0).
g. Range is statute miles per departure (see T-2, z410.0/z510.0).
h. The lift to drag ratio (L/D) has no units.

The correlation of fuel used per departure (i.e., per trip) with the preceding, quite simplified model is shown in Figure 13. The takeoff gross weight for nearly every point in Figure 13 includes a 50 percent fuel reserve, which corresponds to the 1.5 factor in the TOGW definition above. See Appendix 1 for additional details.

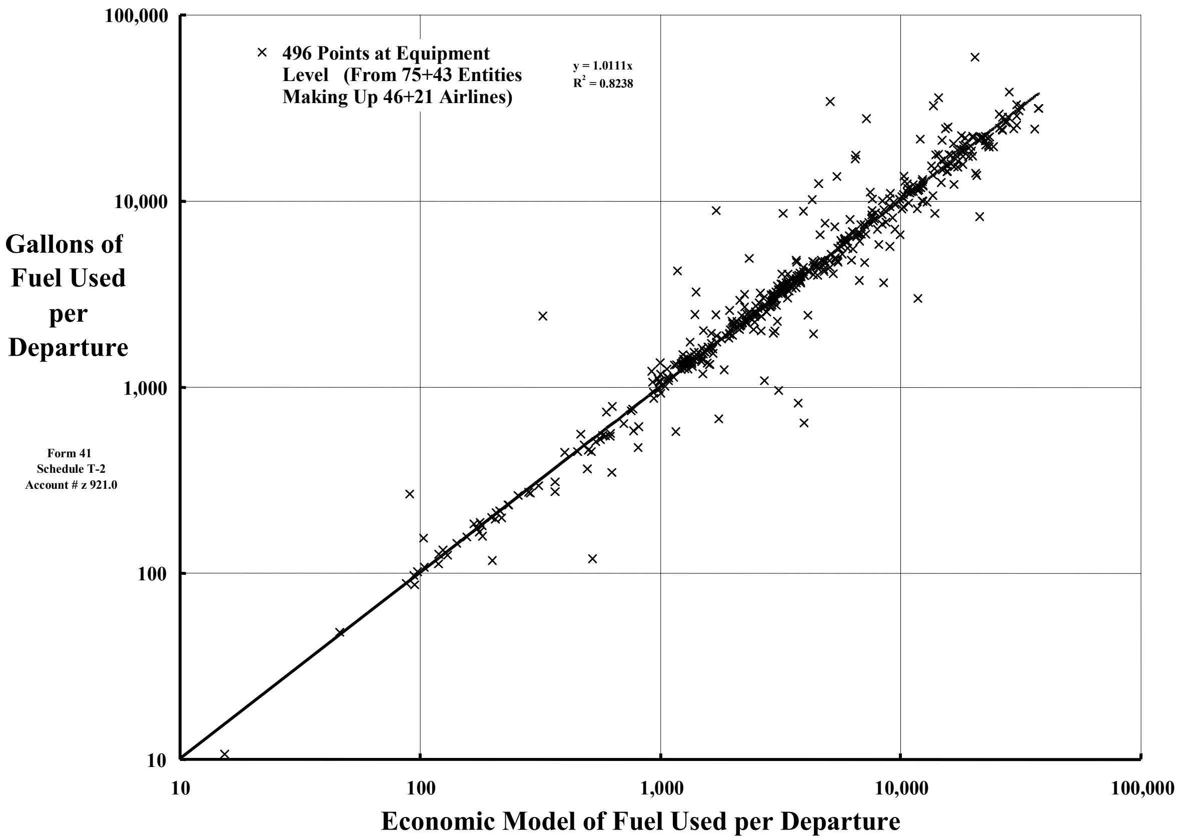

Figure 13. Correlation of Fuel Used per Trip.

A straightforward multiplication of (a) fuel used per departure by (b) the cost of fuel per gallon and then by (3) the number of annual departures performed by the entity's fleet of that model aircraft completes the fuel expense estimating equation. The results for nearly 500 data points are shown in Figure 14.

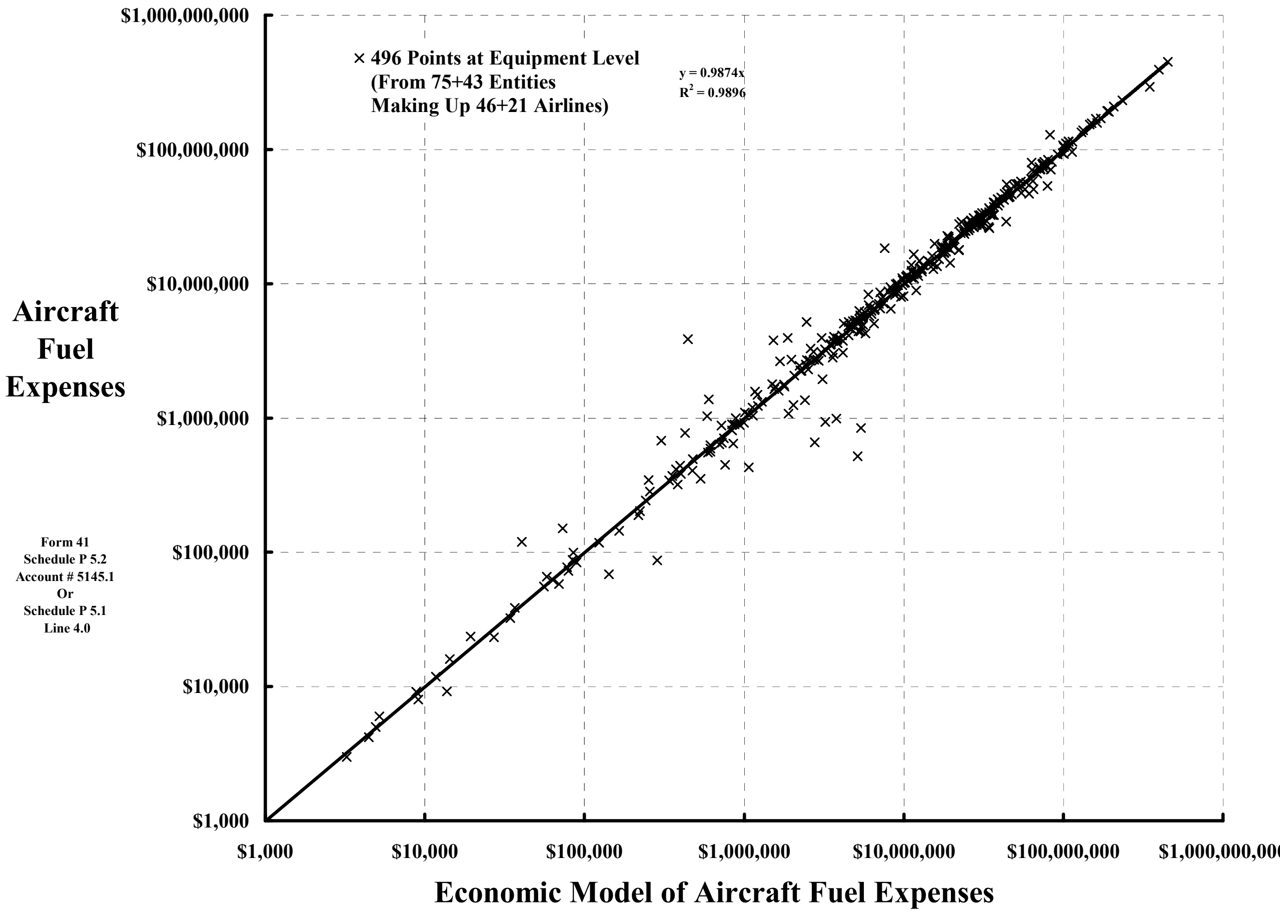

Figure 14. Fuel Expenses Correlation at the Flight Equipment Level.

In closing this fuel expense discussion, it must be pointed out that Reference 7 describes a much more detailed computation of fuel used, which follows a 1967 industry standard flight profile. This flight profile—and any other for that matter—may provide a much more representative estimate of fuel used per departure than the simple profile of this economic model.

4.1.3 Insurance Expenses

In 1999, insurance expenses amounted to slightly over $0.1 billion of TAOE for the 67 airlines under study; about 0.2 percent of the $47 billion in TAOE for the 5,963 airplanes in operation. The DOT, in Schedule P-5.2, Account 5155.1, refers to this insurance category as Insurance Purchase—General. The account covers hull insurance carried on aircraft owned by the entity. (Hull insurance for aircraft rented by an airline was included in rental expenses.) The insurance expense estimating equation uses a single variable—capital invested—as the parameter of note. Capital invested was discussed in Section 3 of this report. From Figure 15

$$\text{Insurance Expense for 1999} = 0.0056\left(\text{Capital Invested}\right)$$

This equation was based on the experience of six major airlines as shown in Figure 15. Note that several smaller entities had expenses considerably higher. In 1999, surprisingly few airlines owned the aircraft they operated.

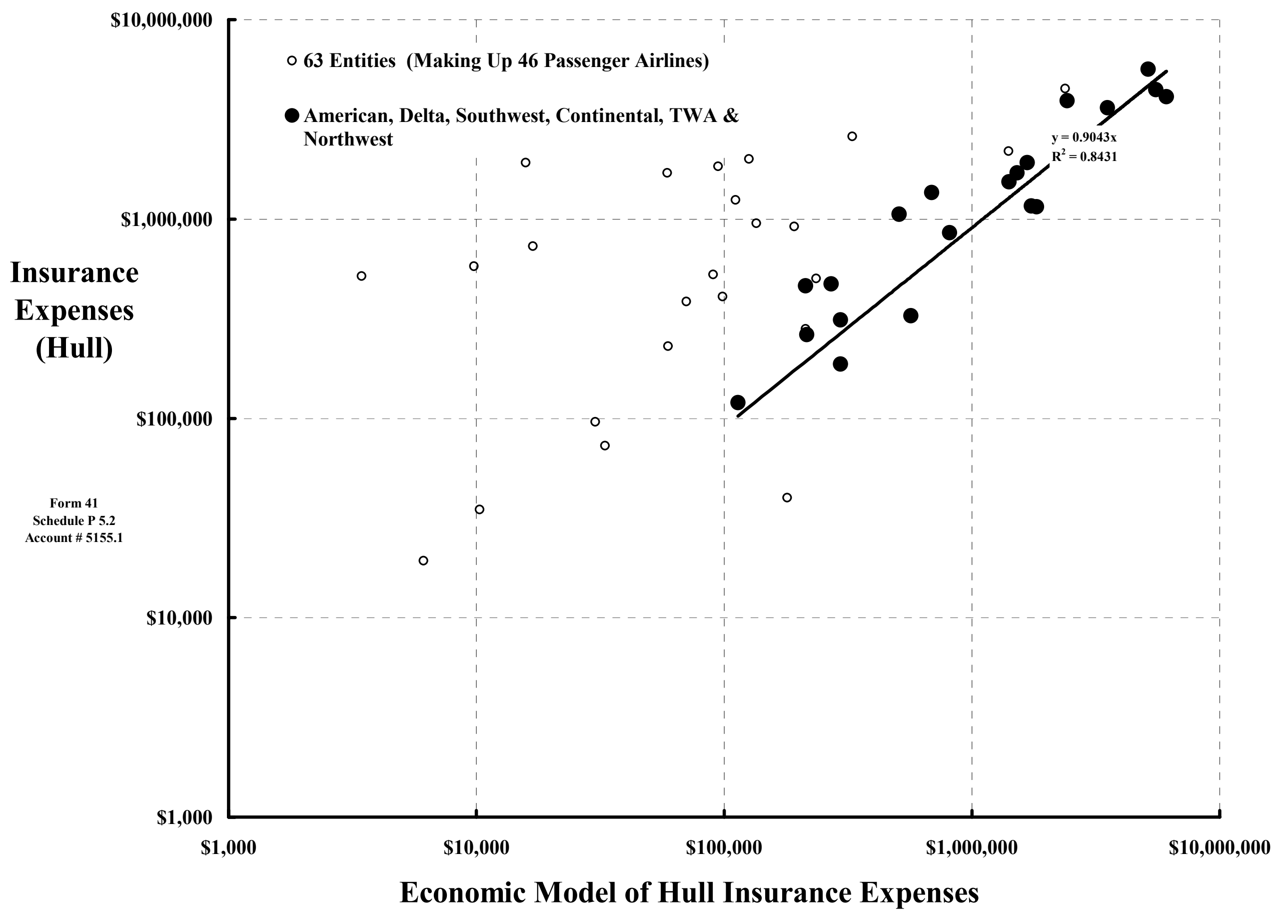

Figure 15. Hull Insurance Expenses Correlation at the Entity Level.

4.1.4 Rental Expenses

In 1999, rental expenses amounted to slightly over $6.5 billion of the TAOE for the 67 airlines under study; about 14 percent of the $47 billion in TAOE for the 5,963 airplanes in operation. As noted in Section 3, of the 5,963 airplanes in operation, over half were leased—not owned—by the airline which operated them.

Somewhat arbitrarily, capital invested in the aircraft owned by the leasing companies was selected as the single, primary variable, so that

$$\text{Rental Expense for 1999} = 0.0835\left(\text{Capital Invested By Leasing Companies}\right)$$

The validity of this selection is shown in Figure 16.

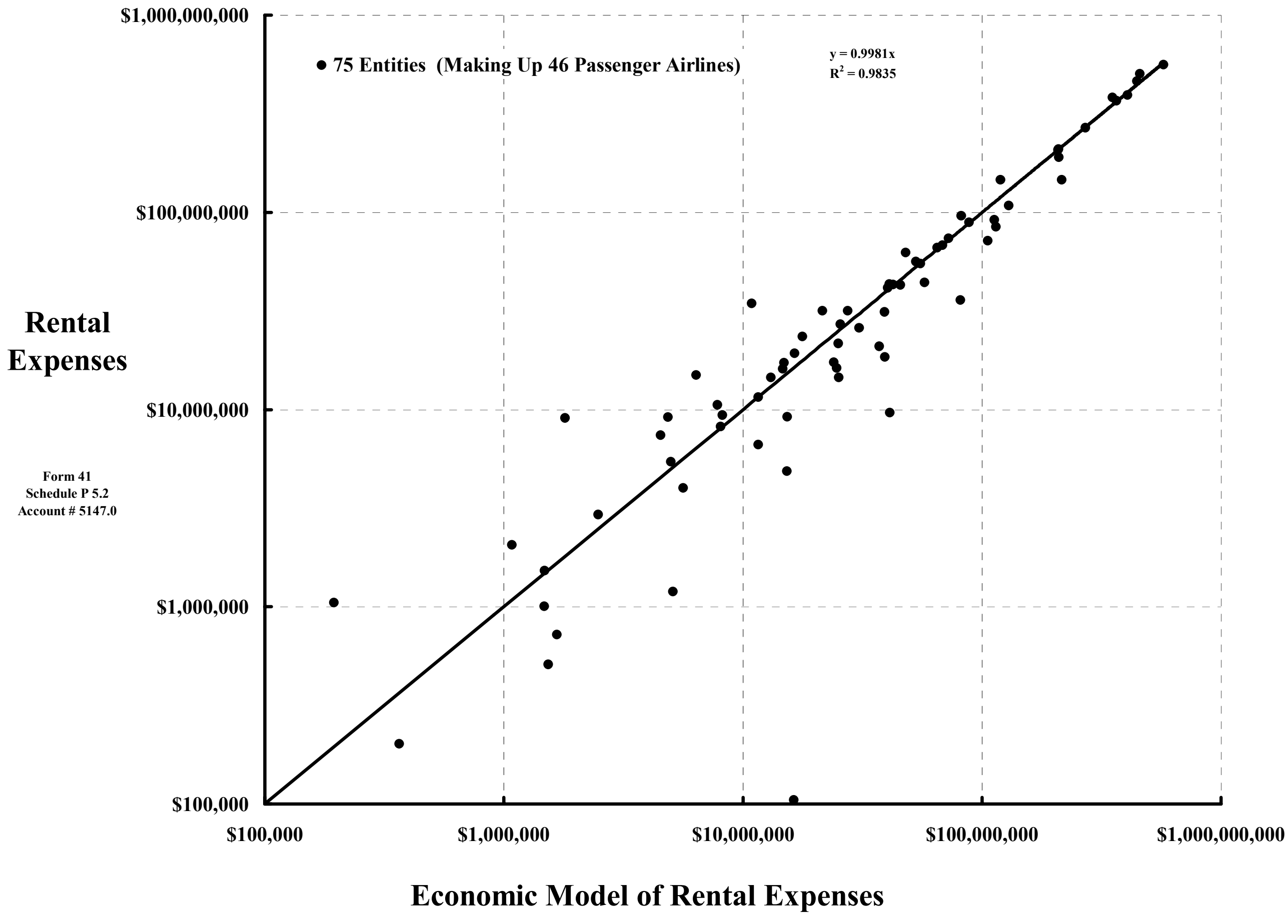

Figure 16. Rental Expenses Correlation at the Entity Level.

4.1.5 Other Flying Operation Expenses

In 1999, other expenses amounted to slightly under \$1.4 billion of the \$47 billion in TAOE for the 67 airlines under study or about 3 percent. The expense equation approximating this category used a percentage of the four other flying operation accounts. That is,

$$\text{Other Expenses in 1999} = 0.04\left(\text{Flight Crew} + \text{Fuel} + \text{Insurance} + \text{Rental}\right)$$

Because these other expenses are relatively small, Figure 17 shows that a simple percentage approach to this miscellaneous expense category is adequate for the economic model offered by this report.

4.1.6 Flying Operation Expenses in Review

Flying operation expenses contributed \$30.2 billion in expenses to the industry's TAOE of \$47 billion in 1999. Flight crew expenses totaled \$11.8 billion, fuel and oil added \$10.2 billion and another \$6.5 billion was contributed by rental expenses. The economic model's correlation with total flying operation expense at the airline level, the entity level, and the flight equipment level is shown in Figure 18, Figure 19 and Figure 20.

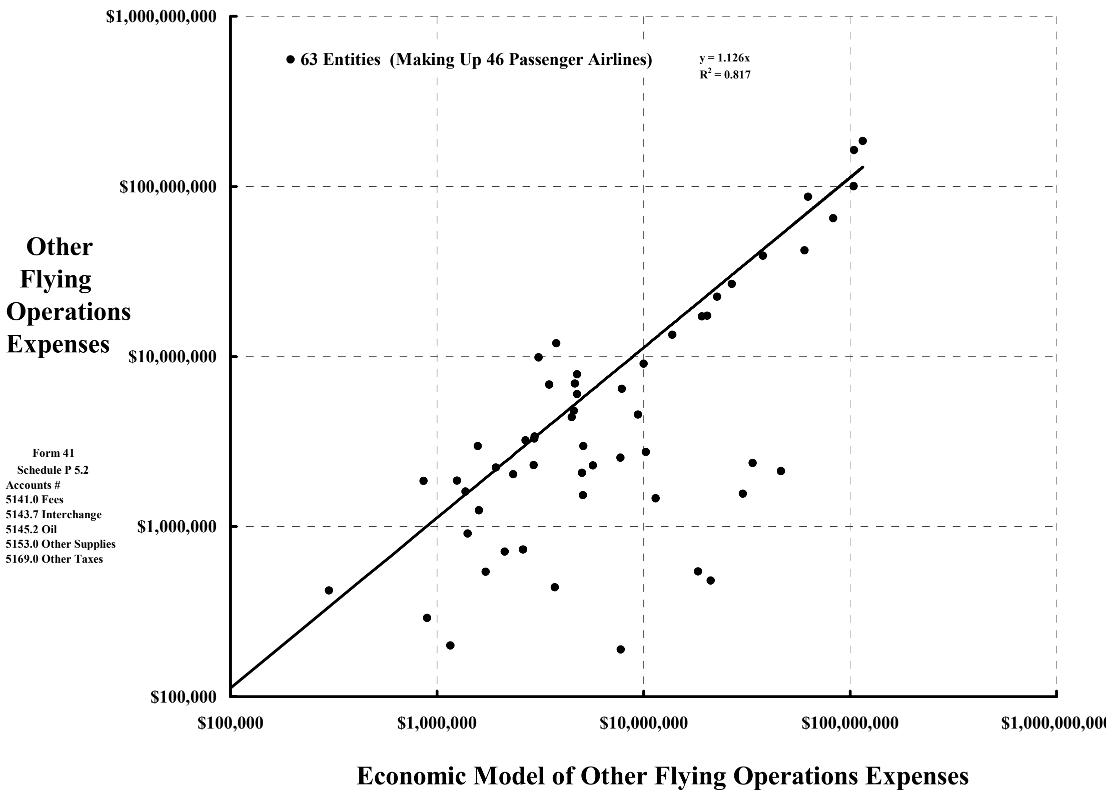

Figure 17. Other Flying Operation Exp. Correlation at Entity Level.

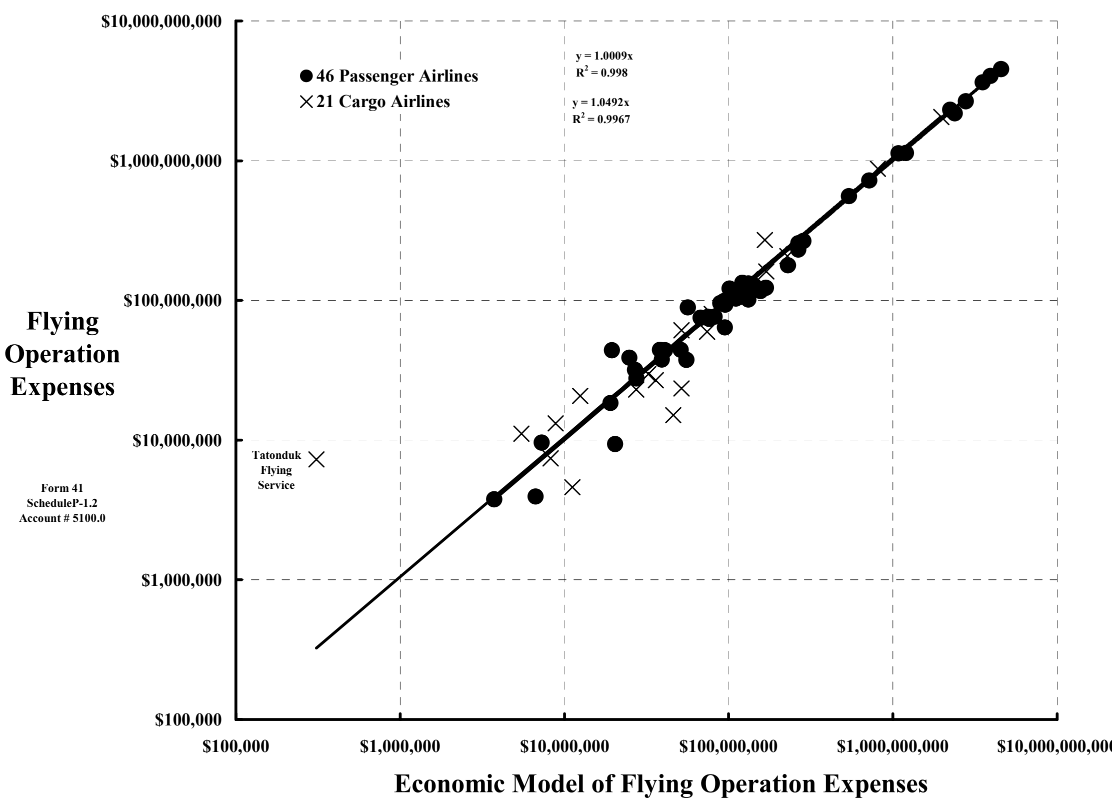

Figure 18. Flying Operations Correlation at the Airline Level.

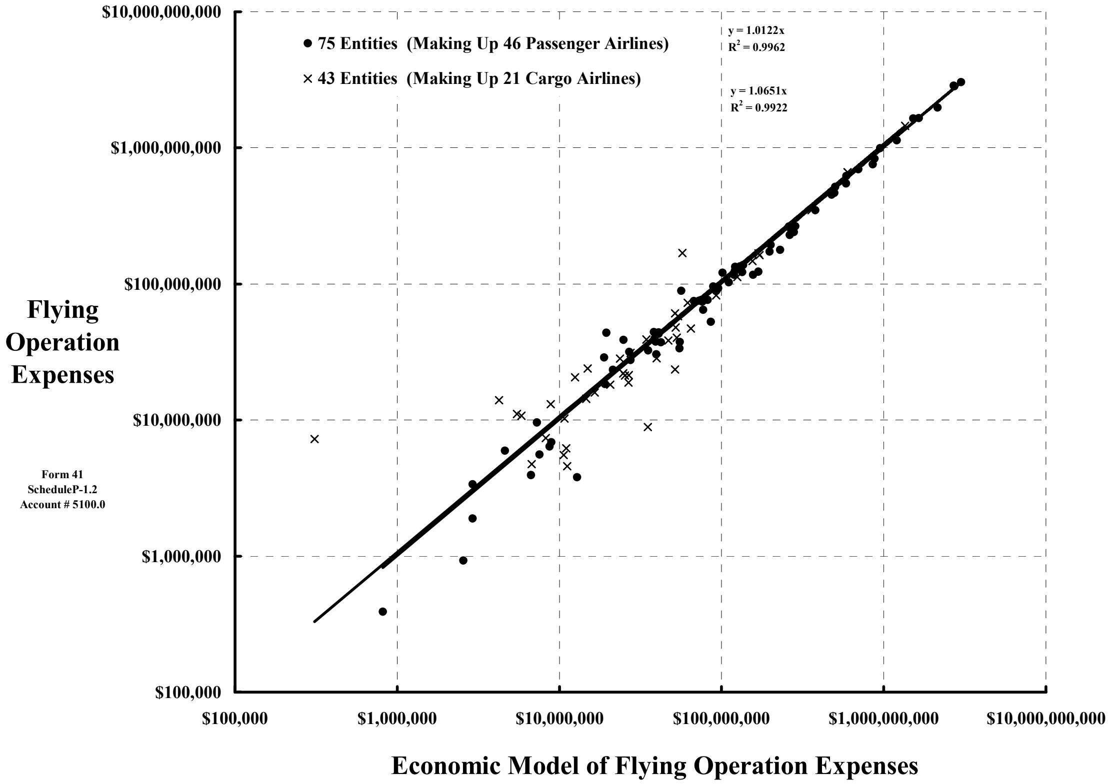

Figure 19. Flying Operations Correlation at the Entity Level.

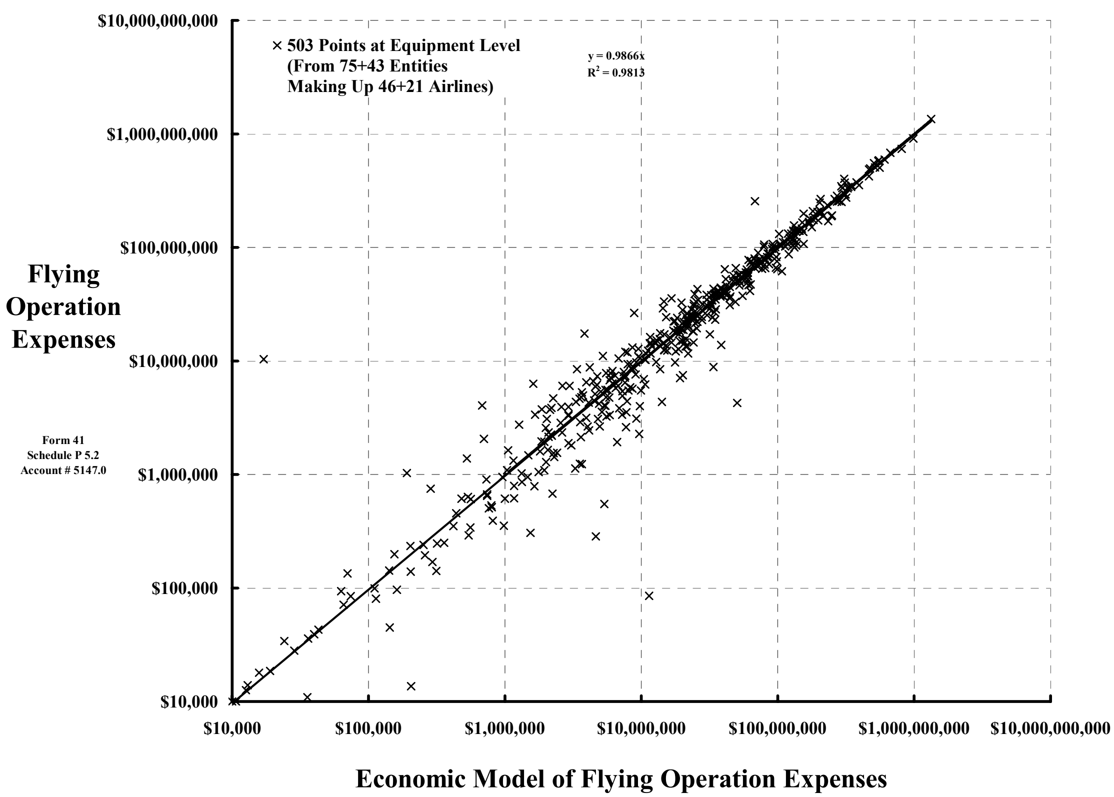

Figure 20. Flying Operations Correlation at the Aircraft Level.

4.2 Flight Equipment Maintenance Expenses (FEM)

In 1999, Total Aircraft Operating Expenses of the 67 airlines under study amounted to slightly over $47 billion for the 5,963 airplanes in operation. Flight equipment maintenance expenses (FEM) contributed slightly over $12.5 billion to this 1999 TAOE. On a per hour flown basis, aircraft maintenance ranged from $250 to $2,500 per airborne hour as Figure 21 shows. Note that cargo aircraft tended to be more expensive to maintain than passenger aircraft.

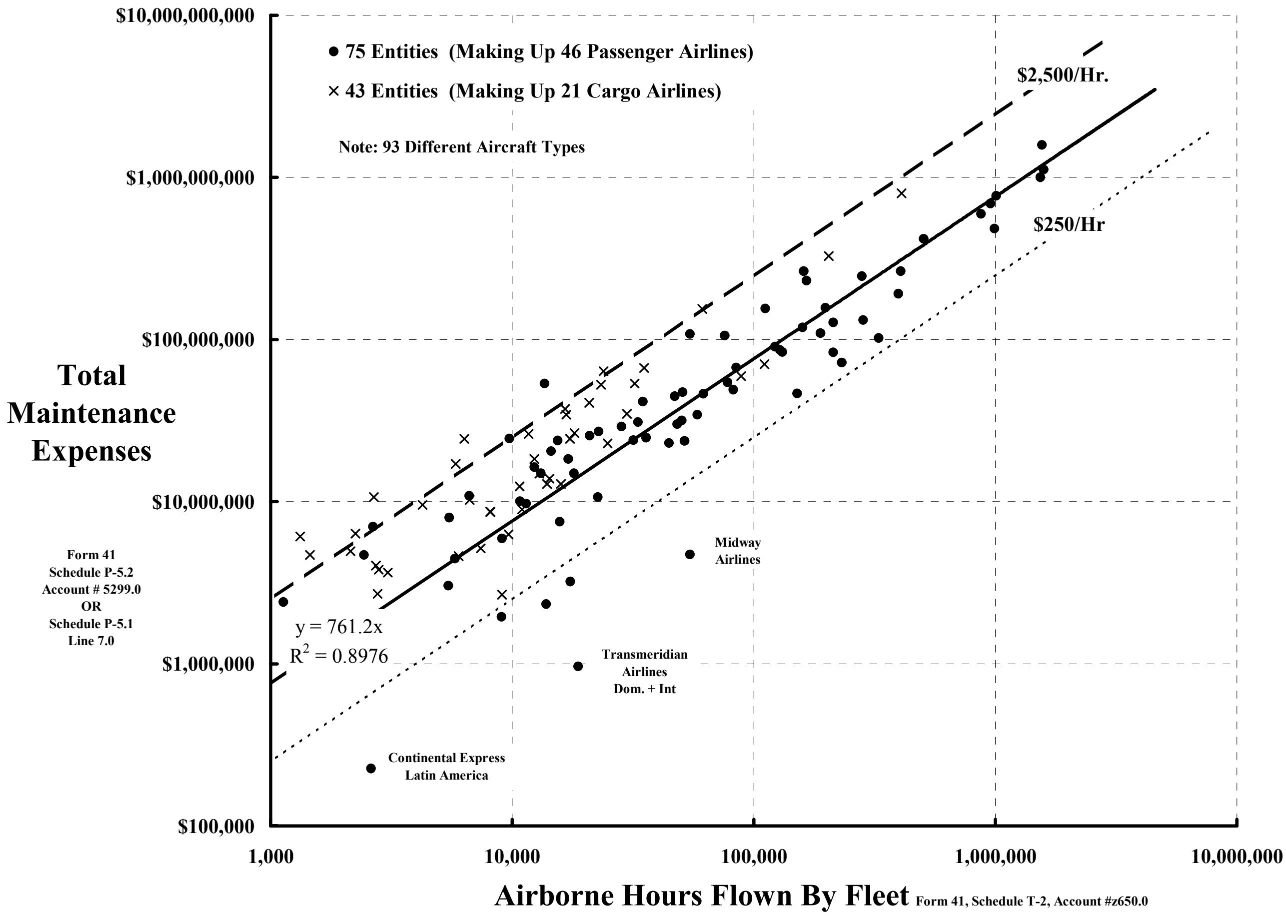

Figure 21. Aircraft Maintenance Expenses vs. Hours Flown.

The FEM accounting tree, Figure 22, shows that the aircraft were divided by Schedule P-5.2 (see Table 3) into airframe and engine categories. Note first that aircraft maintenance includes burdening expenses in the schedule with account 5279.6. For this economic model, burdening expenses were allocated to airframe and engine in proportion to the direct expenses each element incurred. Secondly, many airlines subcontracted maintenance to the "outside." This was, in 1999, true for both the engine and the airframe.

In the several economic models the author reviewed (such as References 3, 7), the modeling approach was to divide maintenance expenses into two parts; namely (a) expenses in proportion to flight hours and (b) expenses in proportion to cycles (i.e., takeoffs and landings). This approach has been considered to most closely approximate the maintenance actions taken by an airline. However, this author found that a classical hours and/or cycles approach was quite insufficient to capture the data reported in 1999 on Schedule P-5.2, Accounts 52xx. The reason the approach failed was traced to the considerable maintenance and repair performed "outside" on both airframe (Acct. 5243.1) and engine (Acct. 5243.2). These two accounts provided no information separating labor from materials. Since this was true for the majority of entities, a classical hours and/or cycles approach was finally abandoned.

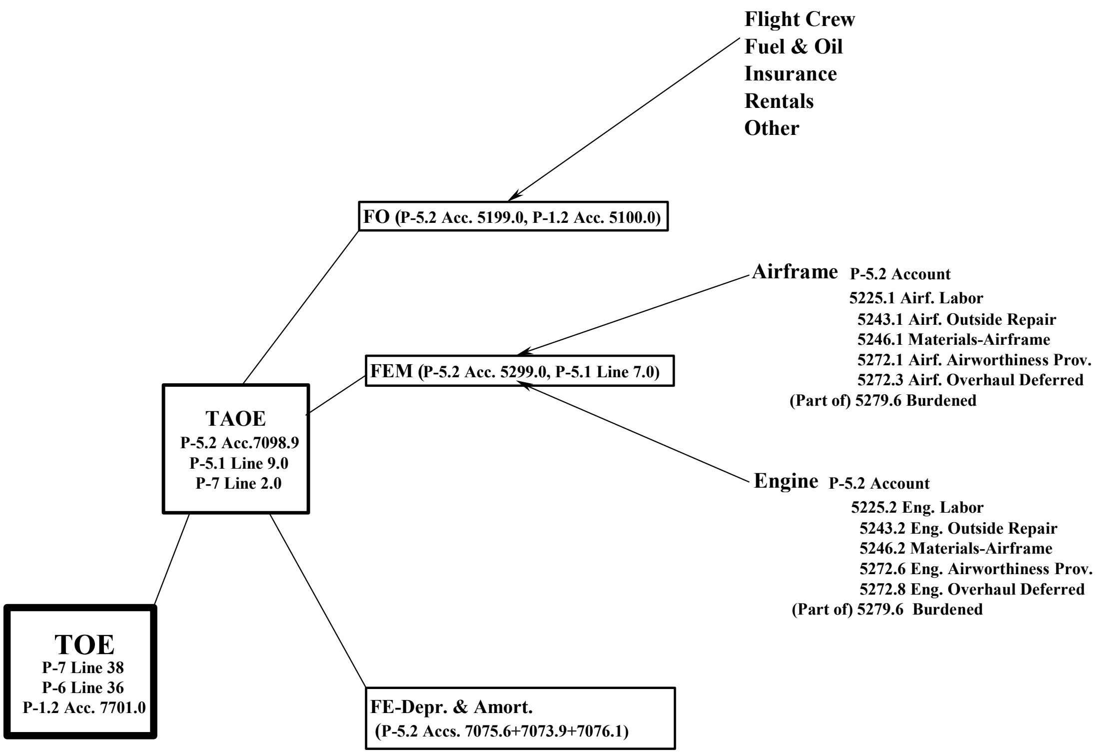

Figure 22. Accounting Tree for Flight Equipment Maintenance.

The expense-estimating equation developed and reported herein was based along the lines of Ref. 10. That is, a regression analysis with the airframe and engine equations in the form

$$\text{Dollars} = K\left[X^A Y^B Z^C\right]$$

After considerable searching, the most likely independent variables (i.e., X, Y, Z, etc.) and their exponents (A, B, C, etc.) emerged. The resulting expense-estimating equation for total airframe maintenance expenses in 1999 emerged as

$$\text{Airframe} = K\left\{(\text{Ref.W})^{0.72118}(\text{FH})^{0.46050}(\text{DP})^{0.32062}(\text{NAC})^{0.20700}\left(1+\frac{\text{Inhouse AF}}{\text{Total AF}}\right)^{-0.43177}\right\}$$

The resulting total engine maintenance equation in 1999 became

$$\text{Engine} = K\left\{(\text{Thrust})^{0.89650}(N_E)^{0.92340}(FH)^{0.15344}(DP)^{0.37535}(NAC)^{0.4429}\left(1+\frac{\text{Outside Eng.}}{\text{Total Eng.}}\right)^{-0.34704}\right\}$$

The definition of variables used in the two preceding equations is

$$\begin{aligned}
\text{Thrust} &\equiv \text{Propulsion Unit's Thrust at Sea Level Standard Day, in pounds} \\
N_E &\equiv \text{Number of Proplusion Units} \\
\text{Ref. W} &\equiv \text{Reference Weight of Aircraft} \\
&= \text{Minimum Operational Weight Empty LESS Engine Dry Weight, in pounds} \\
FH &\equiv \text{Flight Hours Flown by the Fleet in One Year, in hours} \\
DP &\equiv \text{Departures Performed by the Fleet in One Year} \\
NAC &\equiv \text{Number of Aircraft in Fleet for the Year}
\end{aligned}$$

A key independent variable in these two maintenance expense equations was the percentage of work performed “in-house” or “outside” an airline’s organization. The airframe regression analysis showed that the more work performed in-house, the lower the maintenance expenses. In the limit, if 100 percent of the work were performed in-house, then the expenses would be reduced as

$$\left(1+\frac{\text{Inhouse AF}}{\text{Total AF}}\right)^{-0.43177} = (1+1)^{-0.43177} = 2^{-0.43177} = 0.741$$

Thus with all the airframe work done in-house, the ratio would be 1.0 and the factor = 0.741. Alternately, if all airframe maintenance was subcontracted, then the ratio of in-house airframe work to the total airframe work would be 0.0 and this key independent variable would give a factor = 1.0.

The engine maintenance expenses, on the other hand, were found to increase if the work was done in-house. More precisely, expenses would go down if, in the limit, 100 percent of the work was performed outside. The amount of this reduction would be

$$\left(1+\frac{\text{Outside Eng.}}{\text{Total Eng.}}\right)^{-0.34704} = (1+1)^{-0.34704} = 2^{-0.34704} = 0.786$$

Thus, if all the engine maintenance was subcontracted, then the ratio of outside engine work to the total engine work would be 1.0 and this key independent variable would give a factor = 0.786. Alternately, with all the engine work done in-house, the ratio would be 0.0 and the factor = 1.0.

Once the basic equations were established, the constant K was refined to reflect considerations such as passenger service versus cargo service, engine type, aircraft age, and the airlines cost factor. The constant K evolved to

$$K = ST\left[1.73(CF)(MF)(ET)\right]$$

where

ST = Service Type (Passenger = 1.0, Cargo = 1.3252)

ET = Engine Type (Turbofan = 1.0, Turboprop = 1.2644)

MF = Aircraft Model Factor (Earliest = 1.0, Early = 0.7104, Recent = 0.514, Latest = 0.4260, Very Latest = 0.35)

CF = Airline Cost Factor (Very Low = 0.4470, Low = 0.8339, Average = 1.0, High = 1.3019)

The ability of this expense estimating equation to model the total flight equipment maintenance expenses at the highest level—the airline level—is shown in Figure 23. Forty-nine out of 67 airlines correlate to within a plus/minus band of 20 percent.

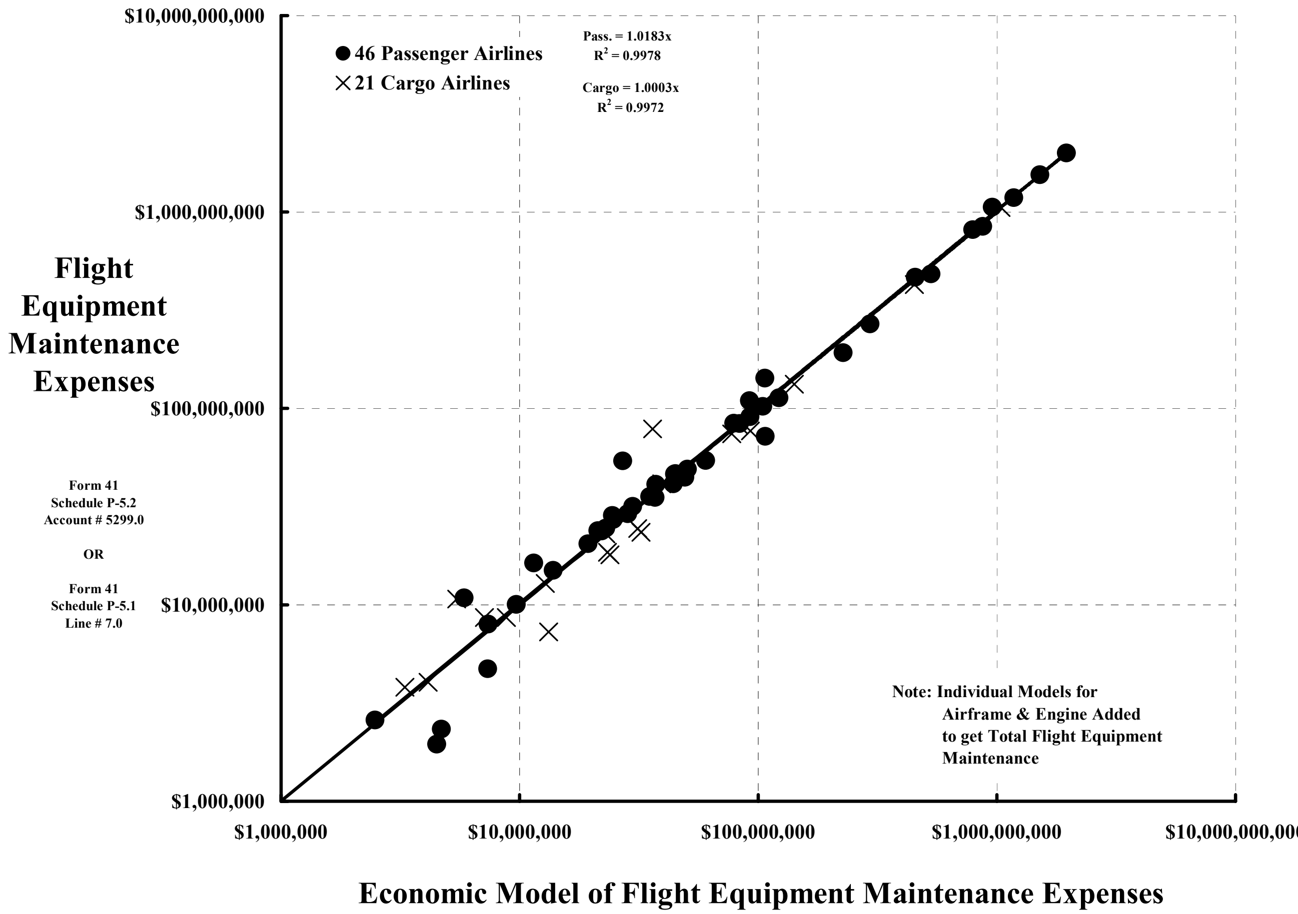

Figure 23. Aircraft Maintenance Expenses Correlation at Airline Level.

When reviewing the economic model at the airline level in Figure 23, the results may be thought to be encouraging. However, the ability of the equations to model the airframe and the engine individually at the flight equipment level, shown with Figure 24 and Figure 25, is much less encouraging. The author found that the closer the individual maintenance accounts were examined, the more the Form 41 was questioned. In some cases it appeared that allocation of expenses rather than actual expenses had been reported. In one airline's report the author found that all aircraft

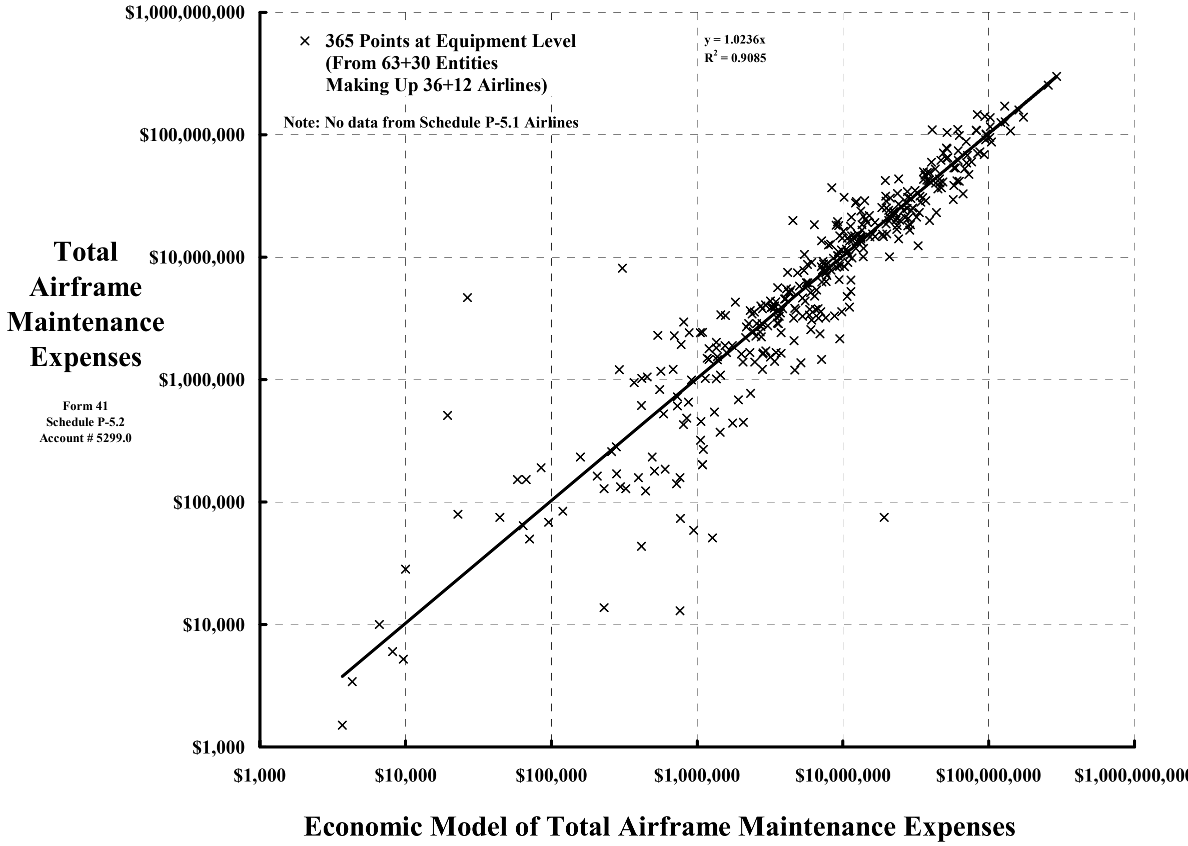

Figure 24. Airframe Maintenance Exp. Correlation at Flt. Equip. Level.

maintenance was book kept in airframe; no engine maintenance expenses at all were recorded.[7] The correlation scatter is somewhat reduced by summing airframe and engine maintenance expenses as shown in Figure 26, and further reduced by moving up to the entity level shown in Figure 27. This is because the errors begin to offset each other. It appears that more accurate estimating of flight equipment maintenance expenses requires the detailed information that airlines (and aircraft manufacturers) must have.

4.3 Flight Equipment Depreciation and Amortization Expenses (FE–Depr. & Amort.)

In 1999, Total Aircraft Operating Expenses of the 67 airlines under study amounted to slightly over $47 billion for the 5,963 airplanes in operation. Flight equipment depreciation and amortization expenses (FE–Depr & Amort) contributed slightly over $4.1 billion to this 1999 TAOE. The accounting tree for this expense category is shown in Figure 28.

[7]A DOT representative explained that repeated calls to that airline had yet to alter their bookkeeping in this area.

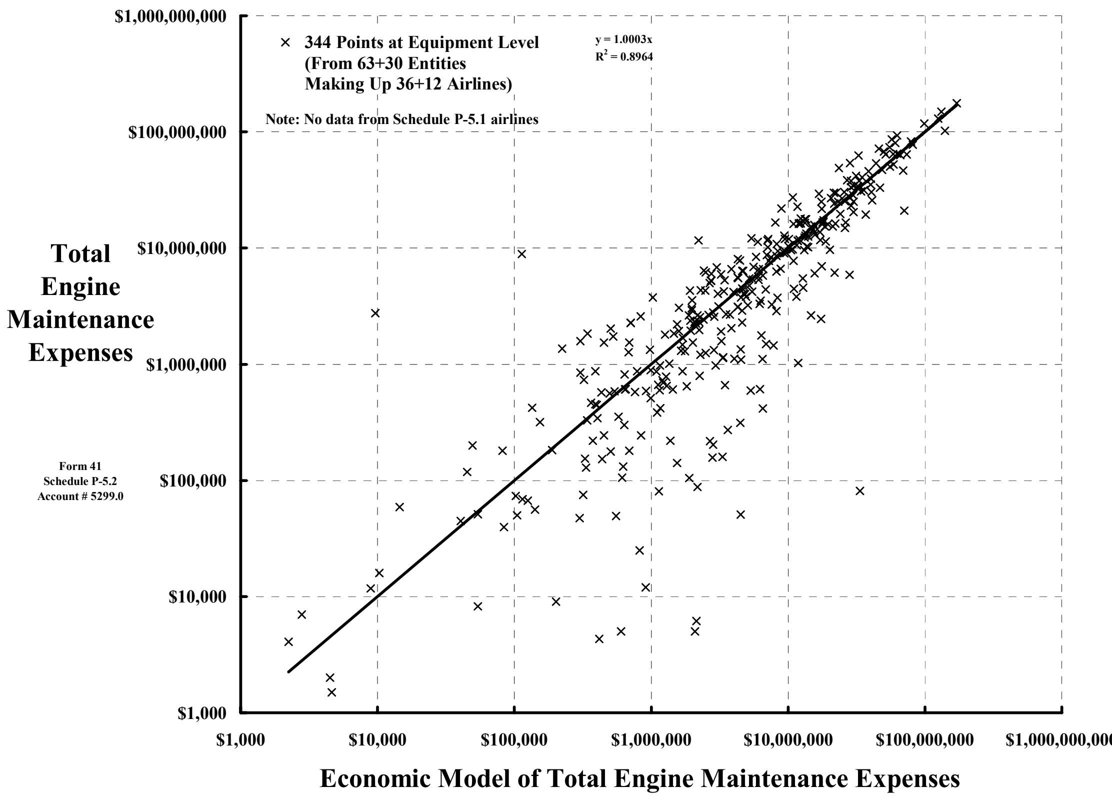

Figure 25. Engine Maintenance Exp. Correlation at Flt. Equip. Level.

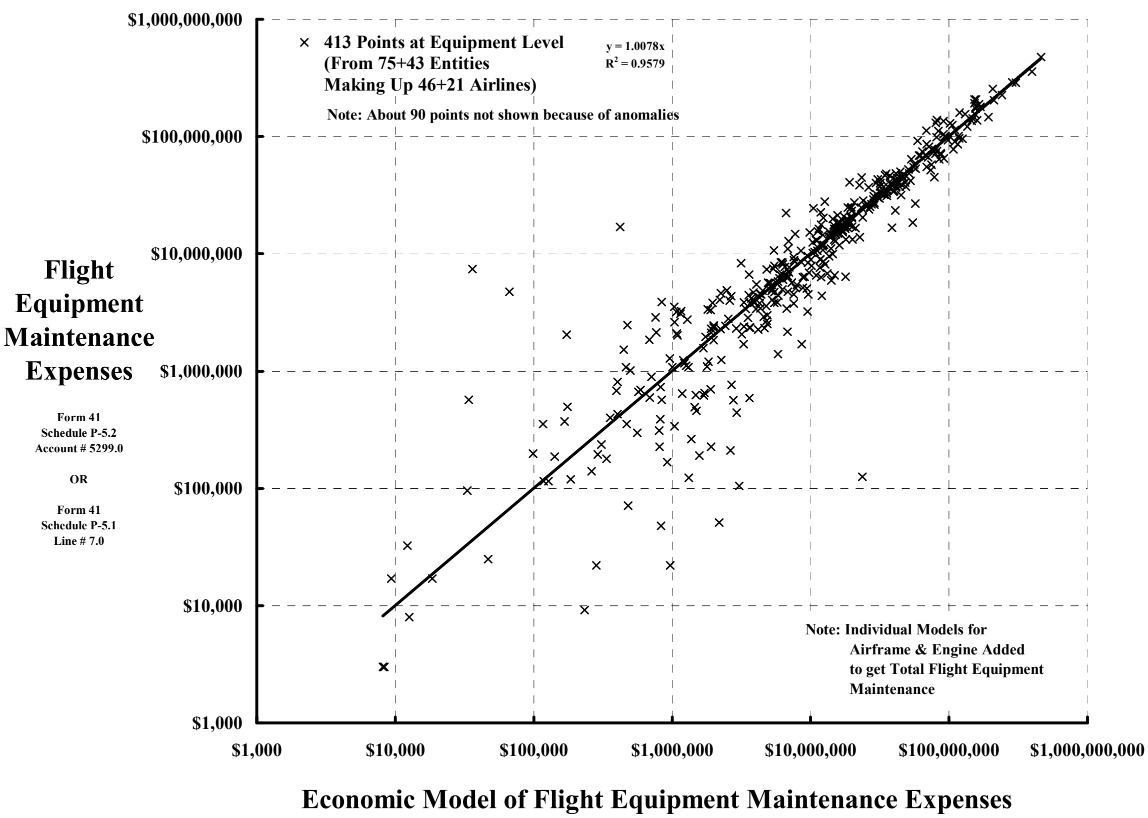

Figure 26. Aircraft Maintenance Exp. Correlation at Flt. Equip. Level.

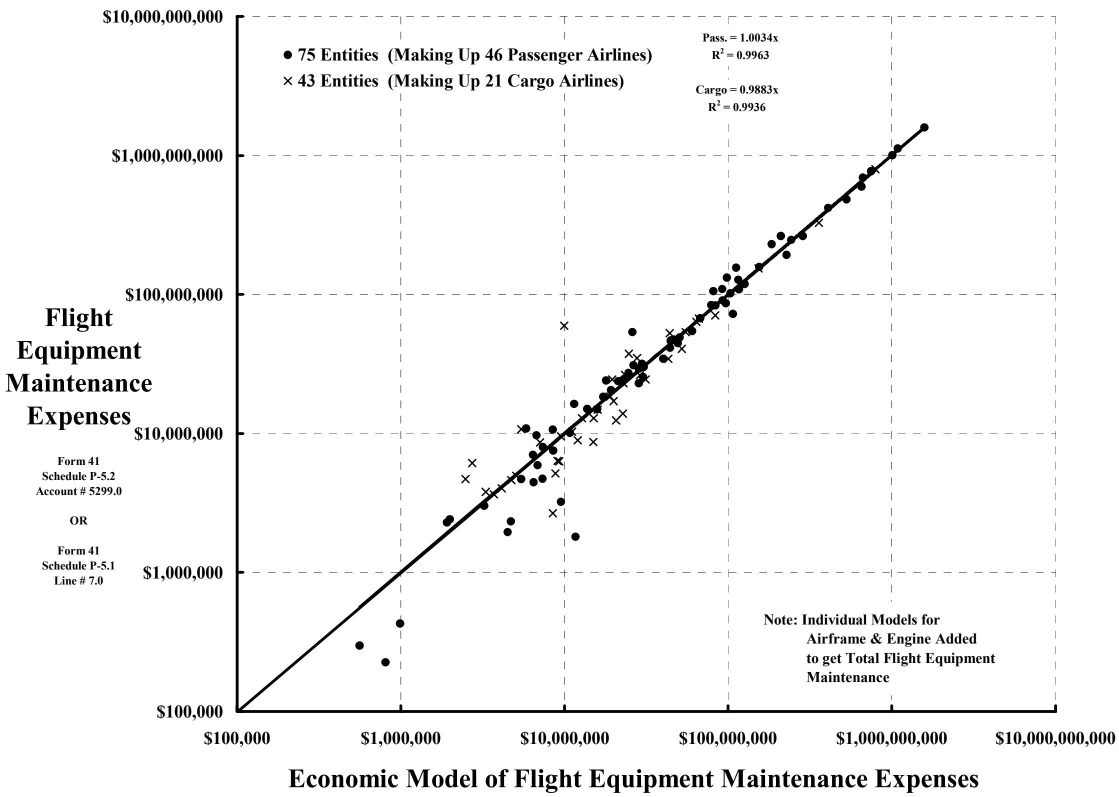

Figure 27. Aircraft Maintenance Exp. Correlation at Entity Level.

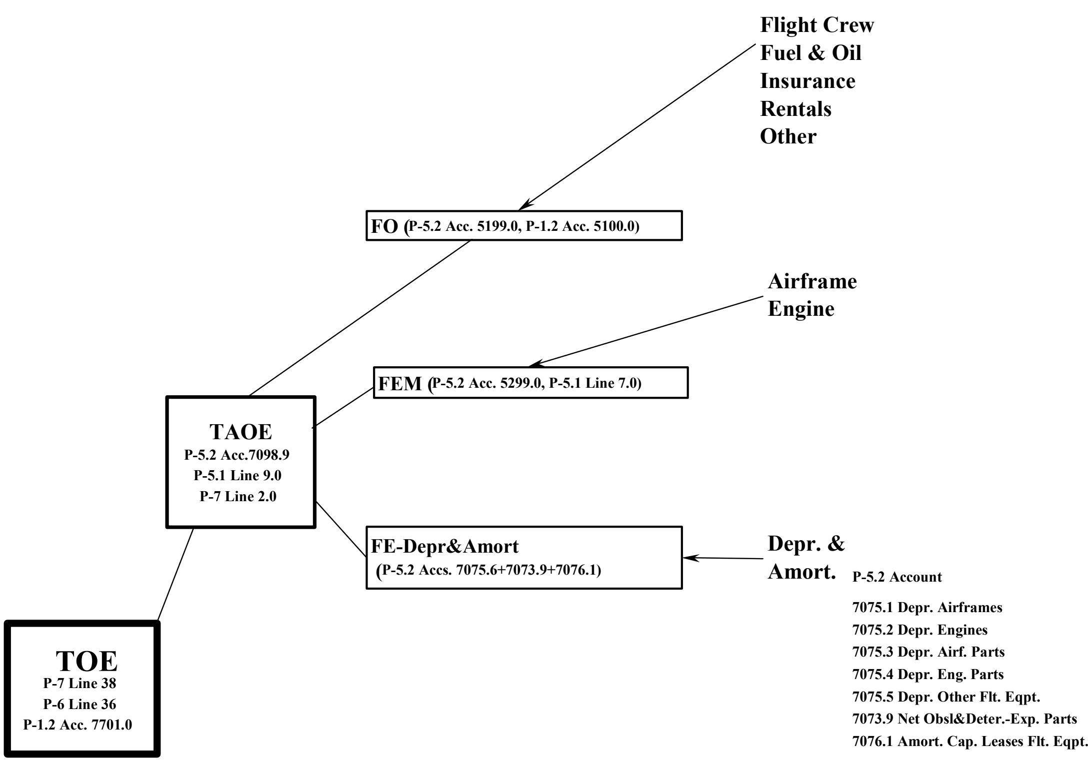

Figure 28. Accounting Tree for Aircraft Depr. & Amort.

A standard expense estimating equation for depreciation/amortization was used. That is,

$$\text{Depr. \& Amort. Expense in 1999} = \text{APP}\frac{(1-\text{RV})}{\text{DP}}$$

$$\text{APP} = \text{Aircraft Purchase Price}$$

$$\text{RV} = \text{Residual Value}$$

$$\text{DP} = \text{Depreciation Period}$$

Using aircraft price from the Section 3 data base, a representative residual value of 0.15 and a depreciation period of 20 years yielded the results shown with Figure 29 and Figure 30. Obviously, using the same residual value and depreciation period for all aircraft and their owners is, at best, a first-order approximation. However, this accounting equation is well known and only requires more accurate input to obtain more accurate estimates of this expense category.

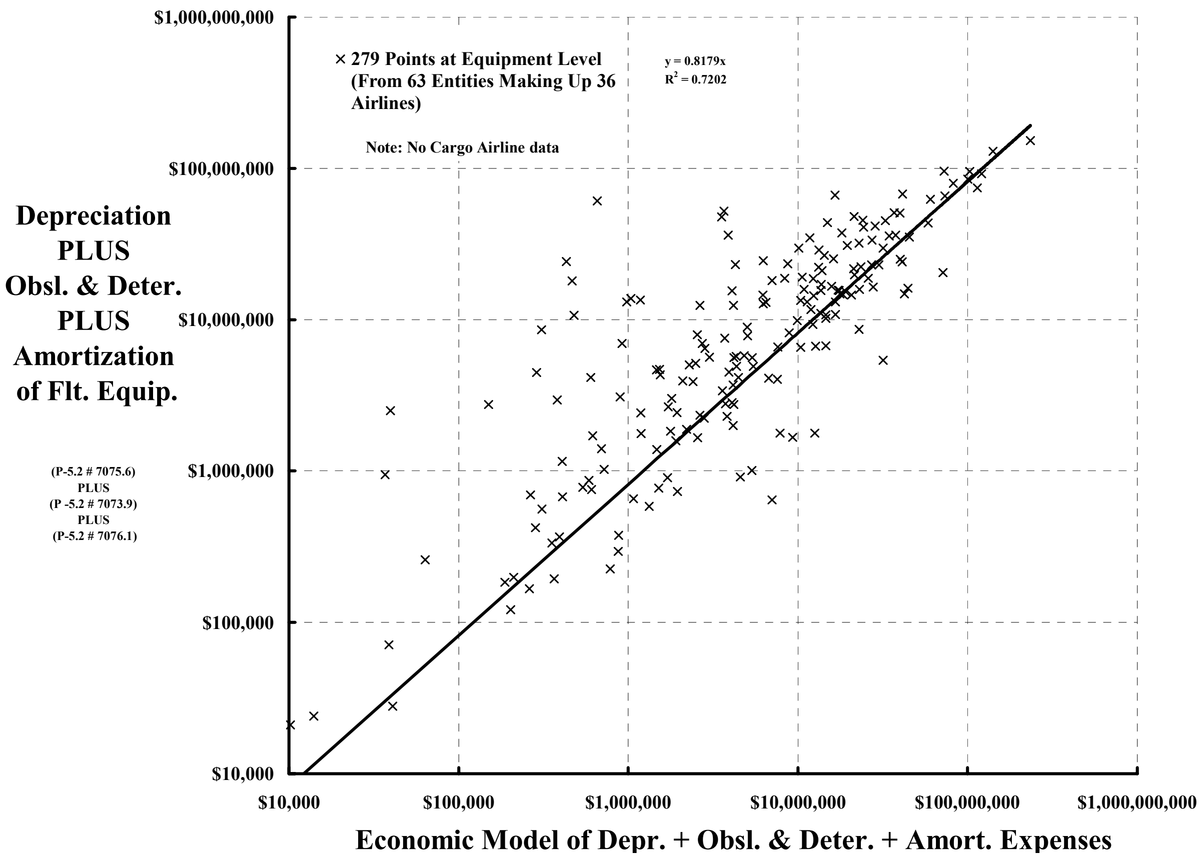

Figure 29. Depr. & Amort. Expenses at the Flight Equipment Level.

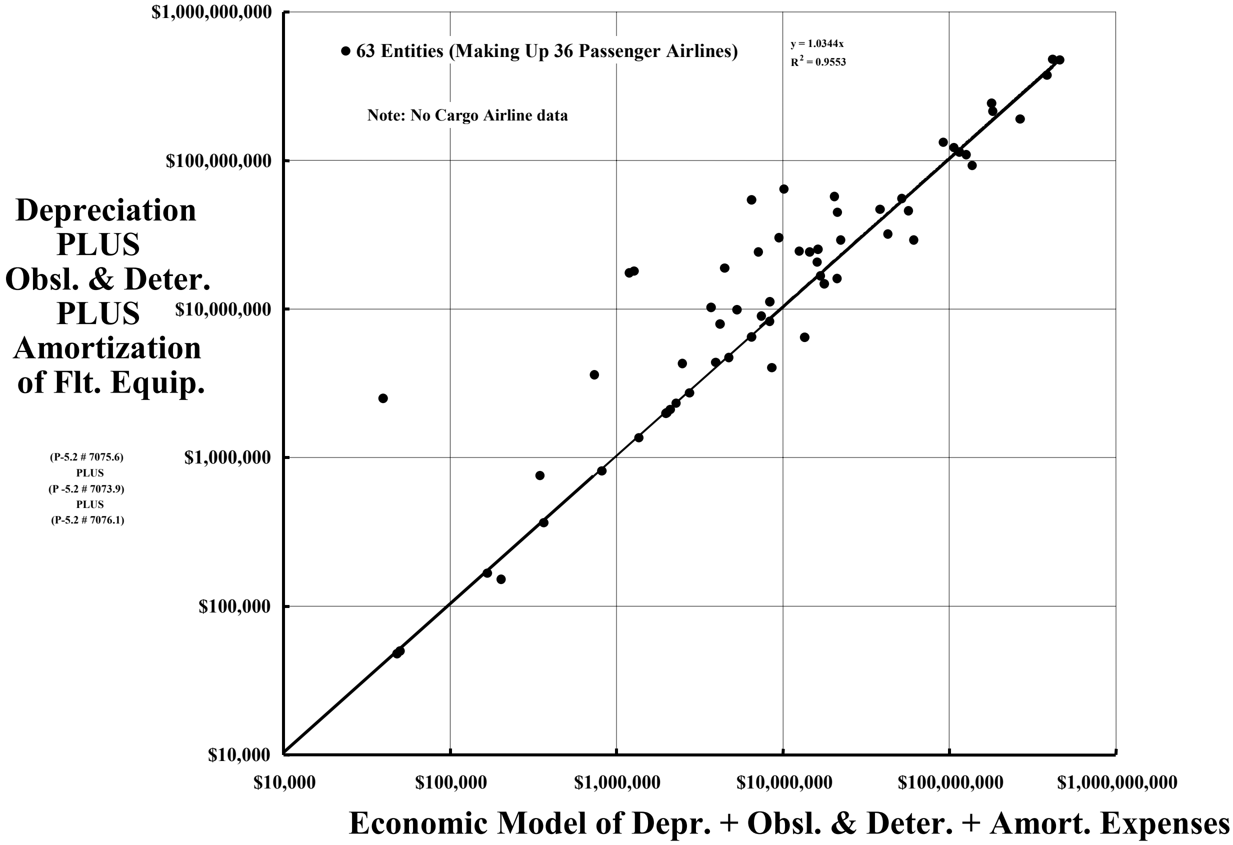

Figure 30. Depr. & Amort. Expenses at the Entity Level.

4.4 Total Aircraft Operating Expenses in Review

In 1999, Total Aircraft Operating Expenses of the 67 airlines under study amounted to slightly over $47 billion for the 5,963 airplanes in operation. Some details about these 1999 expenses are shown in accounting tree form with Figure 31.

When taken as an industry total, the economic model reported herein agrees with the data from which it was derived with sufficient accuracy for many follow on analyses. From Figure 32, the correlation (at the flight equipment level) of estimated expenses with Form 41 reported expenses has a coefficient of determination slightly greater than 0.98 (i.e., $R^2 > 0.98$). At the entity level, Figure 33 shows correlation with $R^2 > 0.996$ for both cargo and passenger entities. Finally, at the airline level, Figure 34, correlation has reached an $R^2 > 0.999$. At the airline level, 35 out of 46 passenger airlines have been modeled to within 20 percent; 15 out of 21 cargo airlines have been modeled to within 20 percent. Note that this economic model's accuracy improves for airlines having more than $100 million in total aircraft operating expenses.

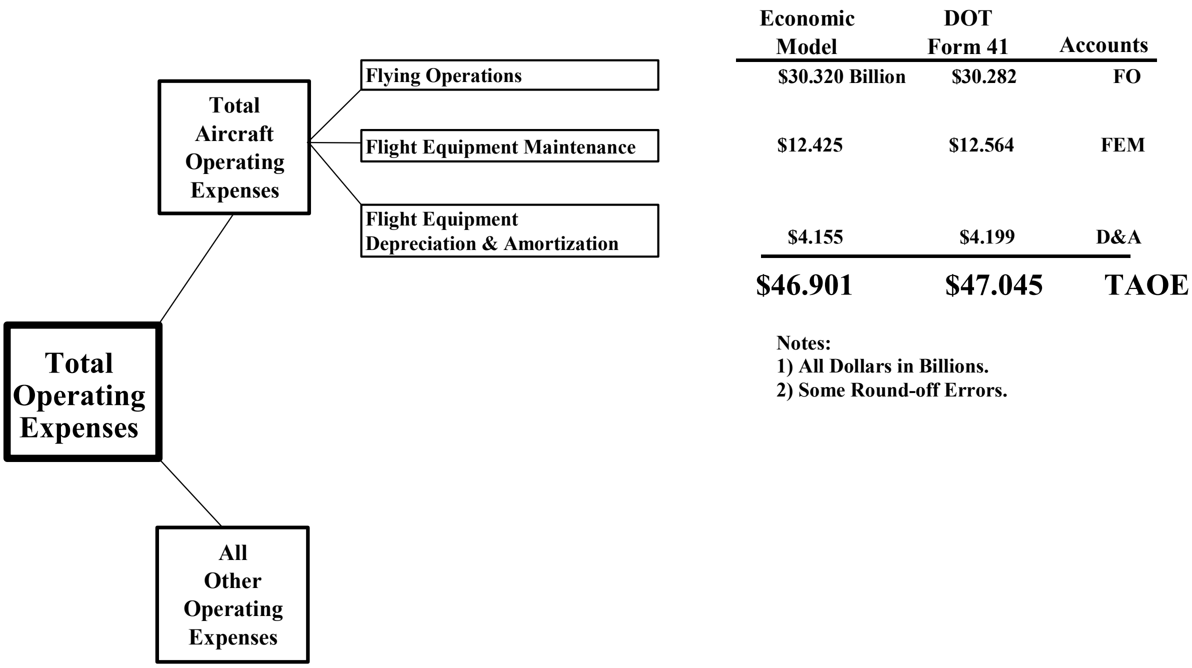

Figure 31. Total Aircraft Operating Expenses (TAOE) by Major Accounts.

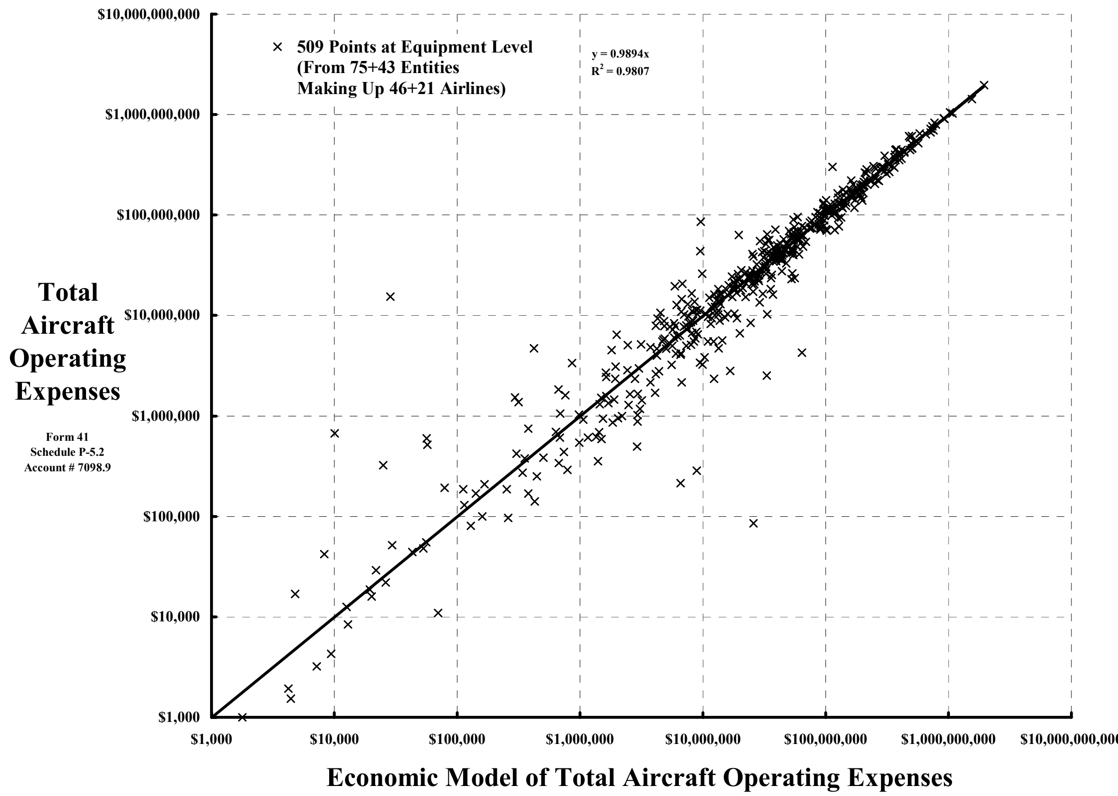

Figure 32. TAOE Correlation at the Flight Equipment Level.

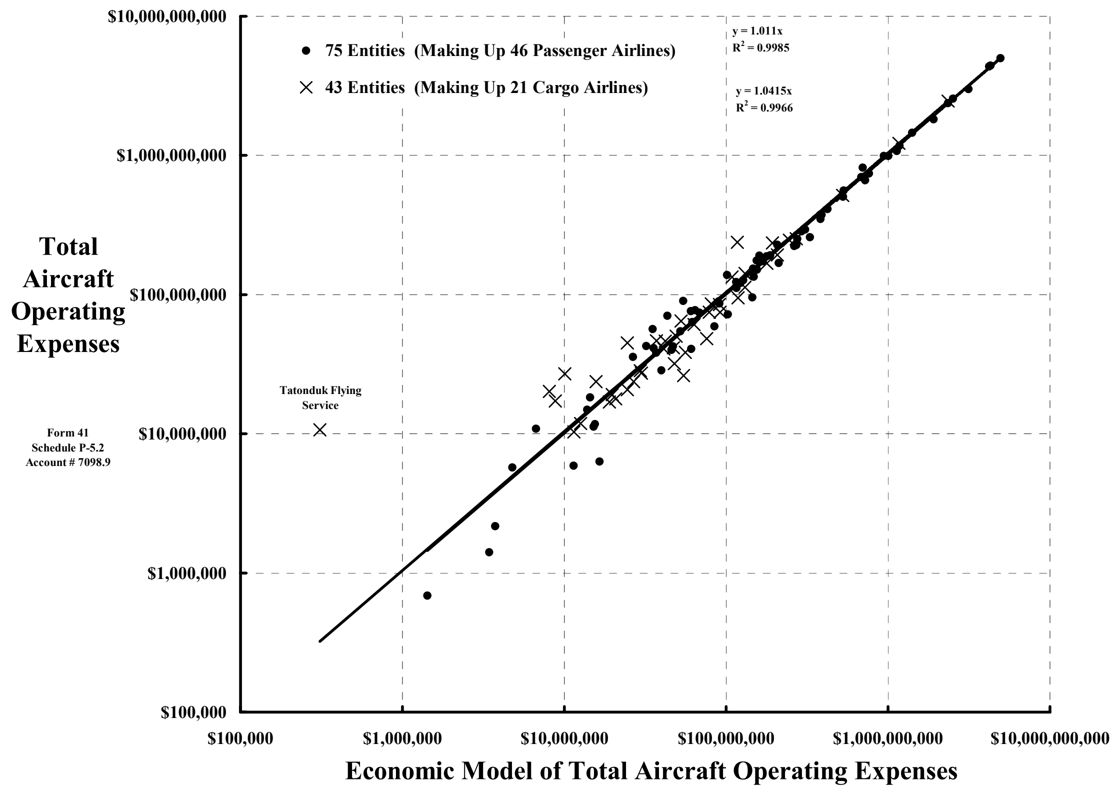

Figure 33. TAOE Correlation at the Entity Level.

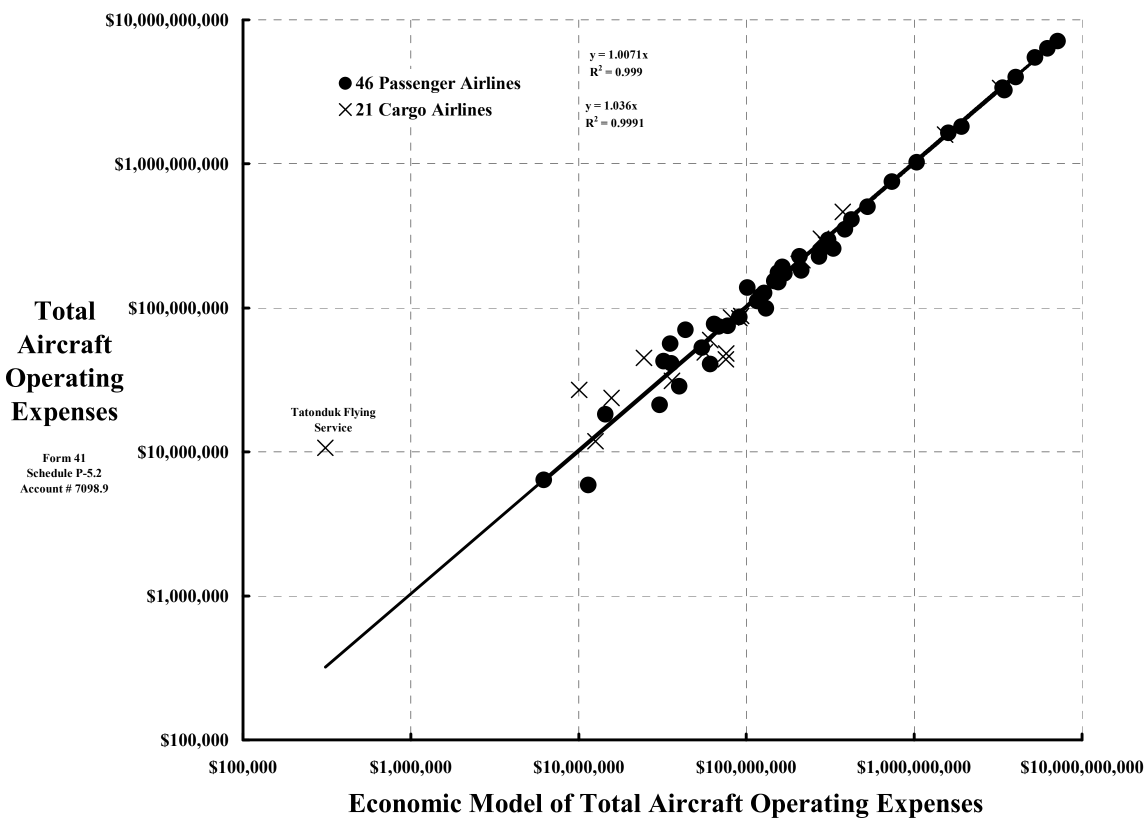

Figure 34. TAOE Correlation at the Airline Level.

5. MODELING ALL OTHER OPERATING EXPENSES

Total operating expenses (TOE) for the 67 airlines under study amounted to $110.580 billion in 1999. The total aircraft operating expenses (TAOE) were $47.045 billion. The difference, $63.535 billion, was contributed by all the other operating expenses. Figure 35 shows an accounting tree for what are frequently referred to as indirect operating costs, but is referred to as All Other Operating Expenses (AOOE) in this economic model. Furthermore, note that in Figure 35 an intermediate account created by the author has been introduced. This intermediate account is referred to as the rest of all other operating expenses (RofAOOE) for lack of a better name. The author created this account (RofAOOE) when it became apparent that individual expense estimating equations for the several sub-accounts showed no better correlation than for the accounts in total. In addition, the author singled out passenger services because this account was passenger airline specific. Landing fees were singled out because significant differences between passenger and cargo airlines appeared as the economic model was being created. However, regardless of the account labeling, the reported expenses for AOOE come primarily from Form 41, Schedule P-7, Lines 5.0 to 38.0, as illustrated on Table 4.[8]

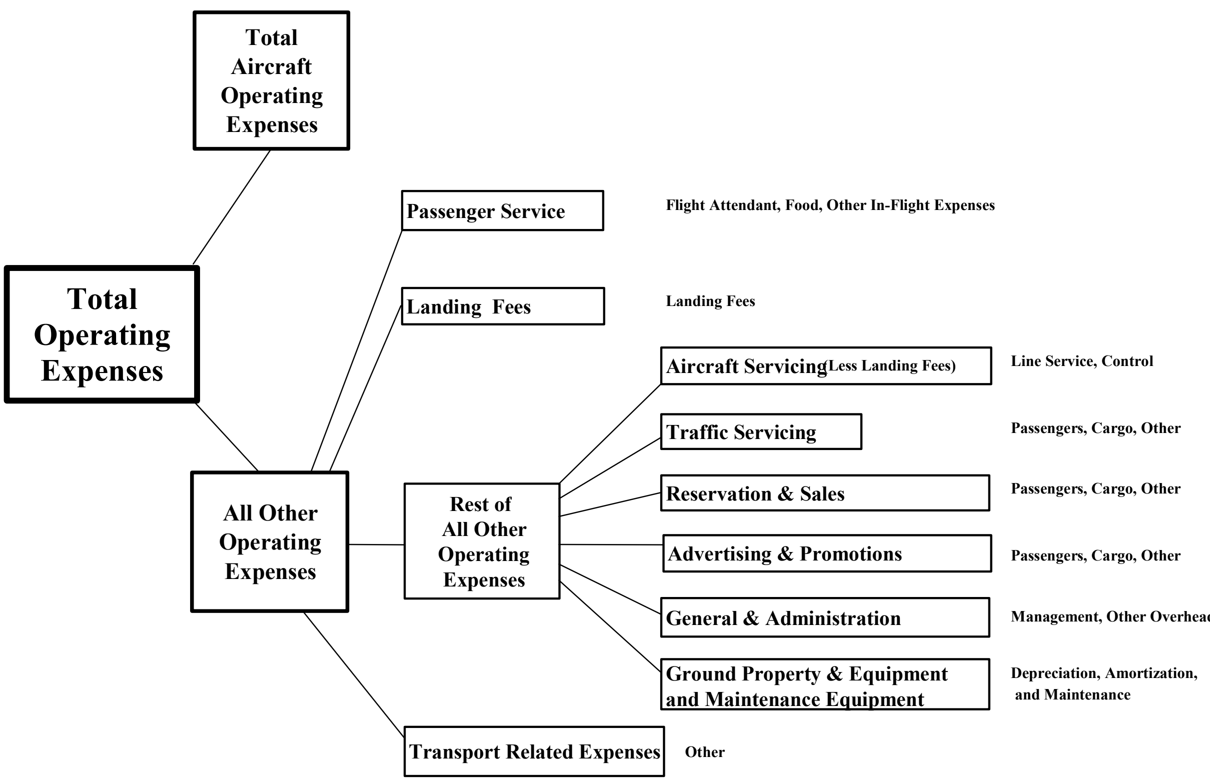

Figure 35. Accounting Tree for All Other Operating Expenses (AOOE).

[8]Figure 35 may be contrasted with Figure 1, which more exactly portrays Schedule P-7.

5.1 Passenger Service Expenses

In 1999, there were 46 passenger airlines (made up of 75 entities) operating 4,825 airplanes. The Schedule T-2 report from these 75 entities showed that they enplaned 646 million passengers. However, only ¾ of these airlines reported passenger service expenses in sufficient detail to include in the economic model data base. But these 63 entities enplaned 640 million of the 646 million passengers. Total passenger expenses for the 63 entities amounted to $9.827 billion or about 20 percent of the $49.978 billion passenger airlines incurred in the category referred to as All Other Operating Expenses (AOOE). Furthermore, while the data suggests that the average enplaned passenger created slightly over $15 in expenses, Figure 36 shows a significant range both below and above this average.

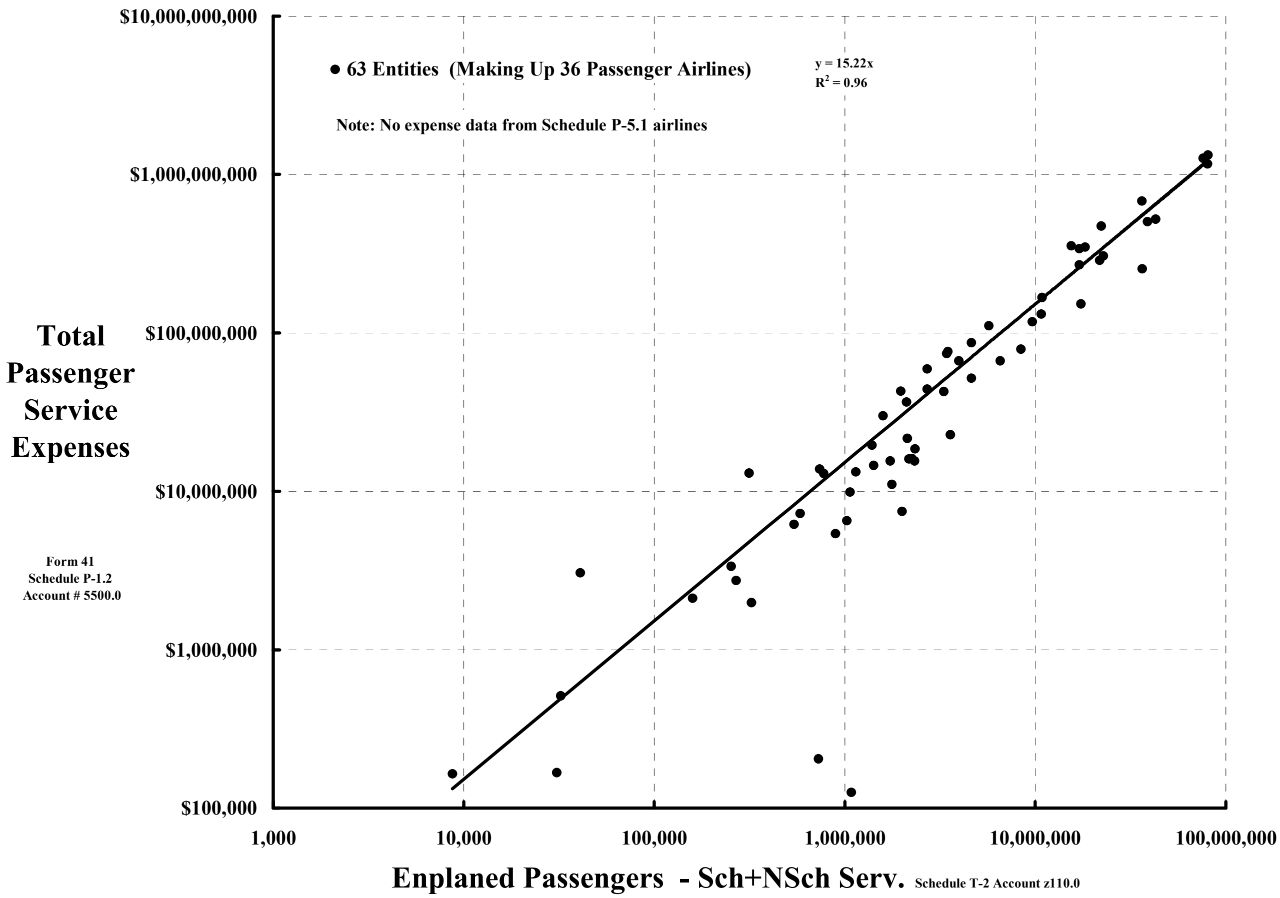

Figure 36. Passenger Service Expenses vs. Enplaned Passengers.

Form 41, Schedule P-7 divides total passenger service expense into 3 accounts, as Table 8 shows. (In addition, total passenger service expense is included on Schedule P-1.2.)

TABLE 8. PASSENGER SERVICE ACCOUNTS.

Line	P-7 Operating Expenses by Functional Grouping
5.0	Flight Attendant Expense
6.0	Food Expense
7.0	Other In-Flight Expense
8.0	Total Passenger Service Expense

A most interesting relationship uncovered as the economic model for passenger service expenses was being developed is shown in Figure 37. Apparently, total passenger service expenses closely followed flight attendant expense, at least in 1999. On this basis, the passenger service expense estimating equation began with

$$\text{Total Passenger Service Expenses in 1999} = 1.6\left(\text{Flight Attendant Expenses}\right)$$

which, of course, then led to the requirement to estimate flight attendant expenses.

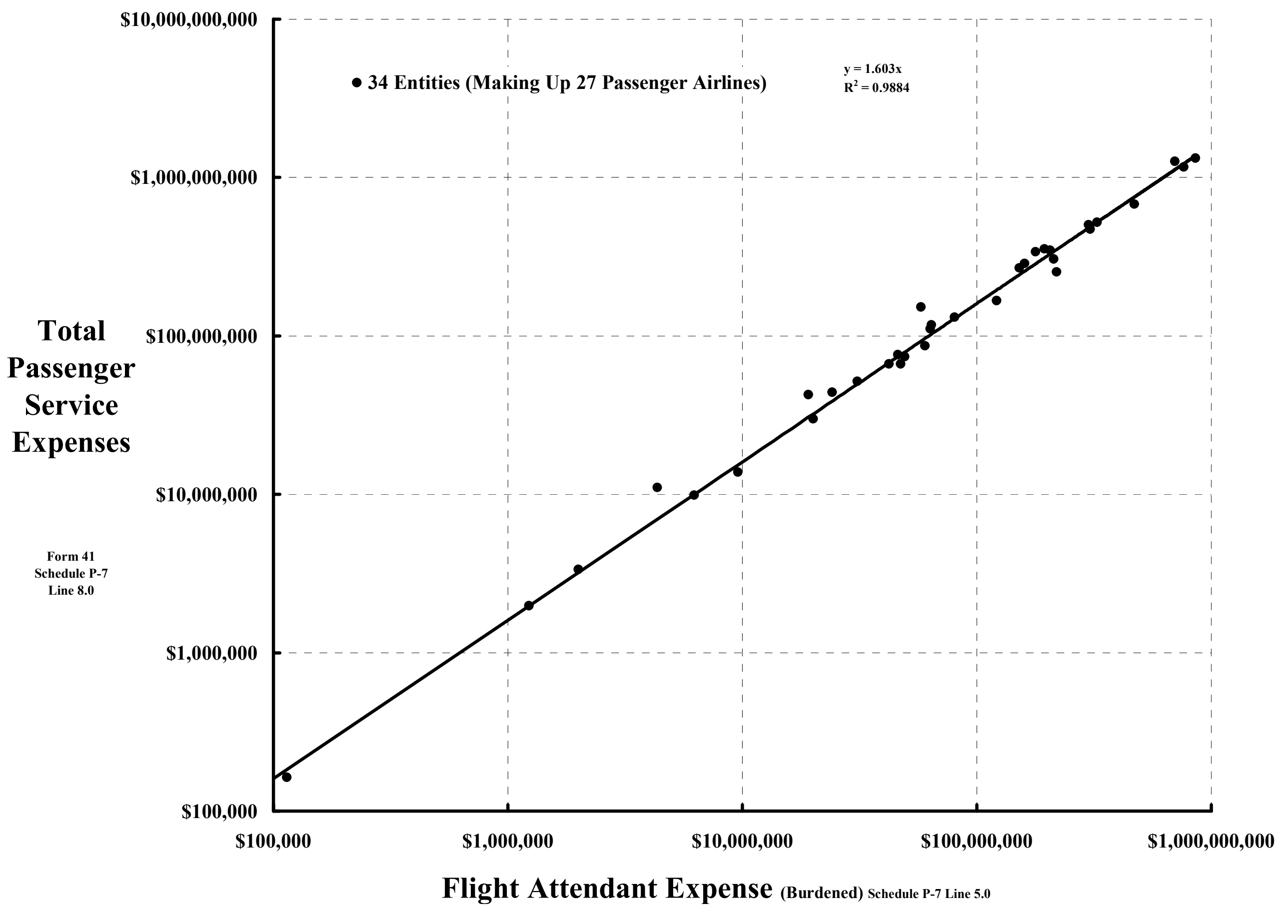

Figure 37. Total Passenger Service Expenses vs. Flight Attendant Expenses.

5.1.1 Flight Attendant Expenses

Flight attendant expenses included salary, layover expenses, overhead, training etc.—in short, all expenses that flight attendants created in 1999. Data from 27 passenger airlines indicated that these employee expenses averaged about $55,500 per attendant in 1999, as Figure 38 shows. A slight variation (less than 10%) in this average was associated with the route flown. Using this relationship led to a total passenger expense equation (for 1999) as

$$\text{Total Passenger Service Expenses in 1999} = 1.6\left(55,500\right)\left(\text{Number of Flight Attendants}\right)$$

which reduced the problem to estimating the number of flight attendants an entity would have.

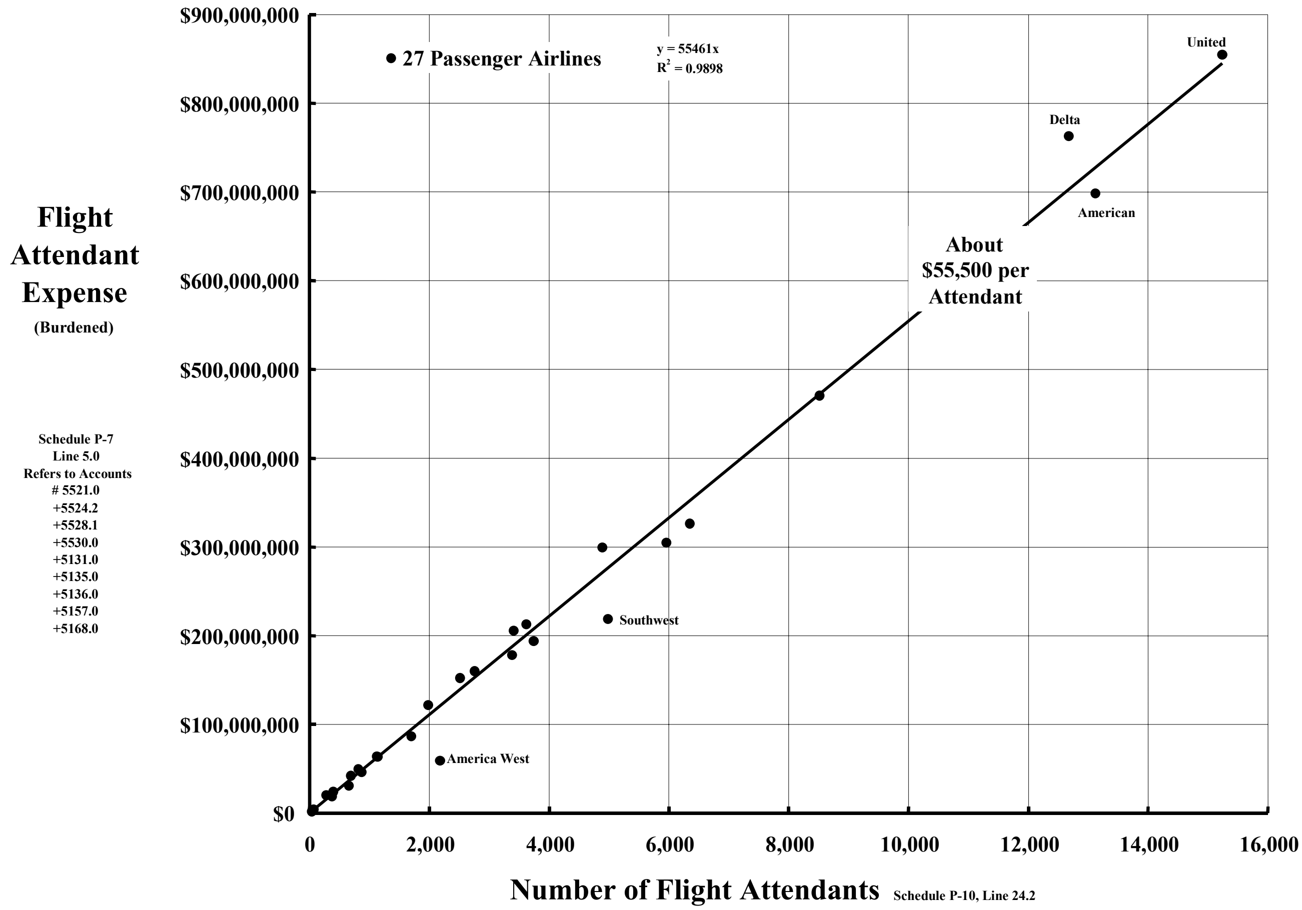

Figure 38. Flight Attendant Expenses vs. Number of Attendants.

5.1.2 Number of Flight Attendants

The number of flight attendants employed by passenger airlines was not at all uniform within the industry in 1999. Two major variables quickly became apparent. The first variable was traced directly to the Federal Aviation Agency requirement[9] that there be at least 1 attendant for each 50 passengers. This introduced parameters of (a) the number of attendants per aircraft, (b) the number of seats that type aircraft had, and (c) the number of that type aircraft the entity was operating. The second variable uncovered was the number of hours an attendant worked during the year. Considerable variation between airlines in annual attendant working hours became quite apparent. While a given aircraft might operate upwards of 3,600 block hours per year in 1999, the average flight attendant crew worked only 1,200 block hours. This meant that three flight attendant crews were employed to operate that aircraft in 1999. In fact, most airlines employed more flight attendant crews than this simple illustration suggests. The estimating equation that captured these variables became

$$\text{No. of Flt. Attendants} = \begin{bmatrix} \left(\dfrac{\text{Aircraft Block Hours per Year}}{\text{Attendant Hours per Year}}\right) \\ \times\left(\dfrac{\text{FAA Req. Attendants}}{\text{No. of Seats}}\right) \\ \times\left(\dfrac{\text{No. of Seats}}{\text{Aircraft}}\right) \\ \times\left(\text{Number of Aircraft}\right) \end{bmatrix} \left(1.3647 + .02351\,\frac{\text{Block Hours}}{\text{Departure}}\right)$$

In the [ ] portion of this equation, the first ratio in this estimating equation accounts for how many hours one aircraft is operating versus the number of hours one attendant is available. The second ratio incorporates FAA regulations. The third ratio speaks to the aircraft configuration (i.e., number of seats). The last term within the [ ]s scales the one aircraft result up to the total number of the given aircraft's type that the entity operates. The term outside the [ ] corrects the result for real life such as vacations, sickness, etc. During development of this equation, number of seats—rather than number of passengers—was used after the correlation including passenger load factor distorted the results.

5.1.3 Passenger Service Expenses in Review

The ability to model passenger service expenses is shown in Figure 39. These results were obtained using each entity's actual attendant hours per year for 1999. Representative additional data is included in Appendix 2.

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[9] See FAR §121.391 Flight attendants.

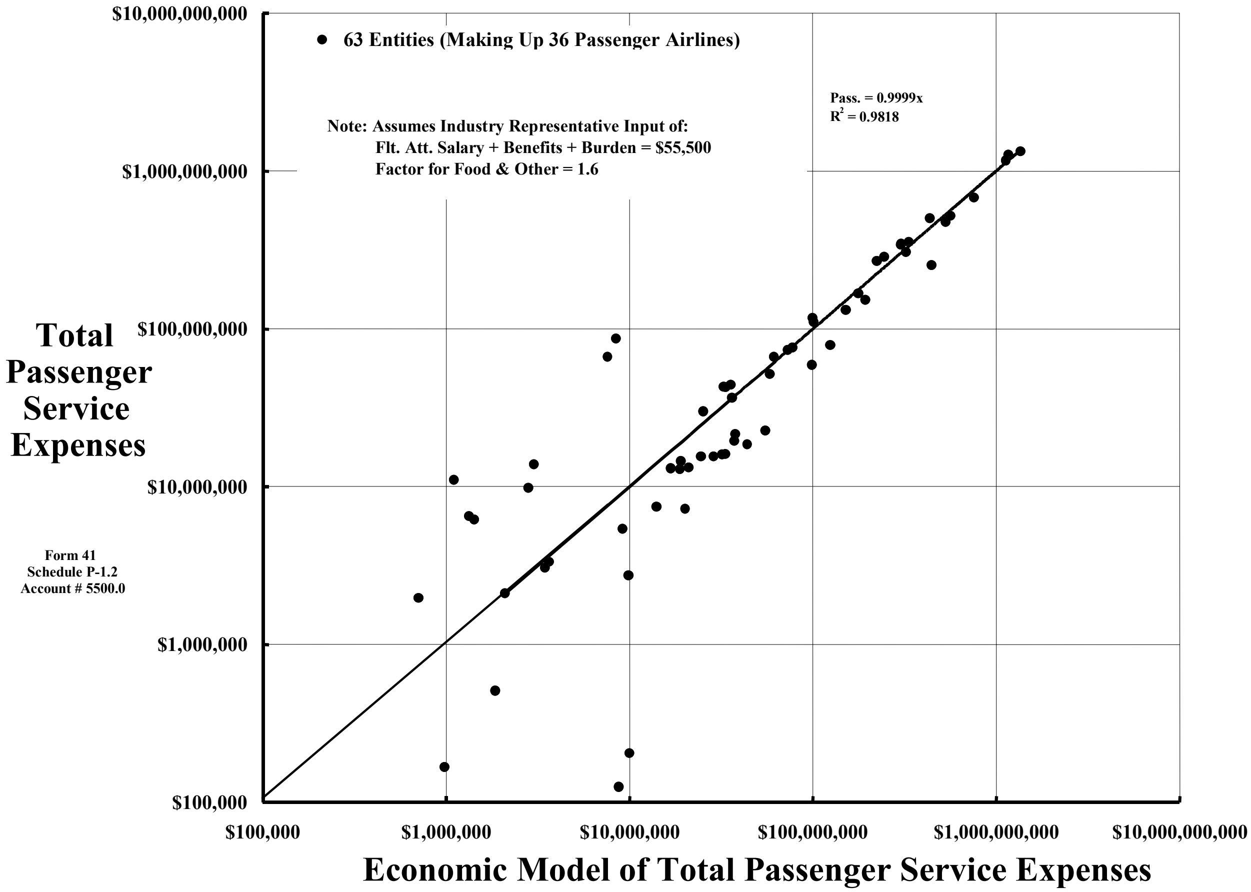


Figure 39. Passenger Service Exp. Correlation at the Entity Level.

5.2 Landing Fees

The 67 airlines under study paid, in 1999, landing fees totaling $2.065 billion. They reported 8,588,836 scheduled departures and 408,533 non-scheduled departures. Given that every departure had a corresponding landing, the average landing fee amounted to about $230. In fact, an average landing fee was hardly representative of the 118 entities under study, as Figure 40 shows.

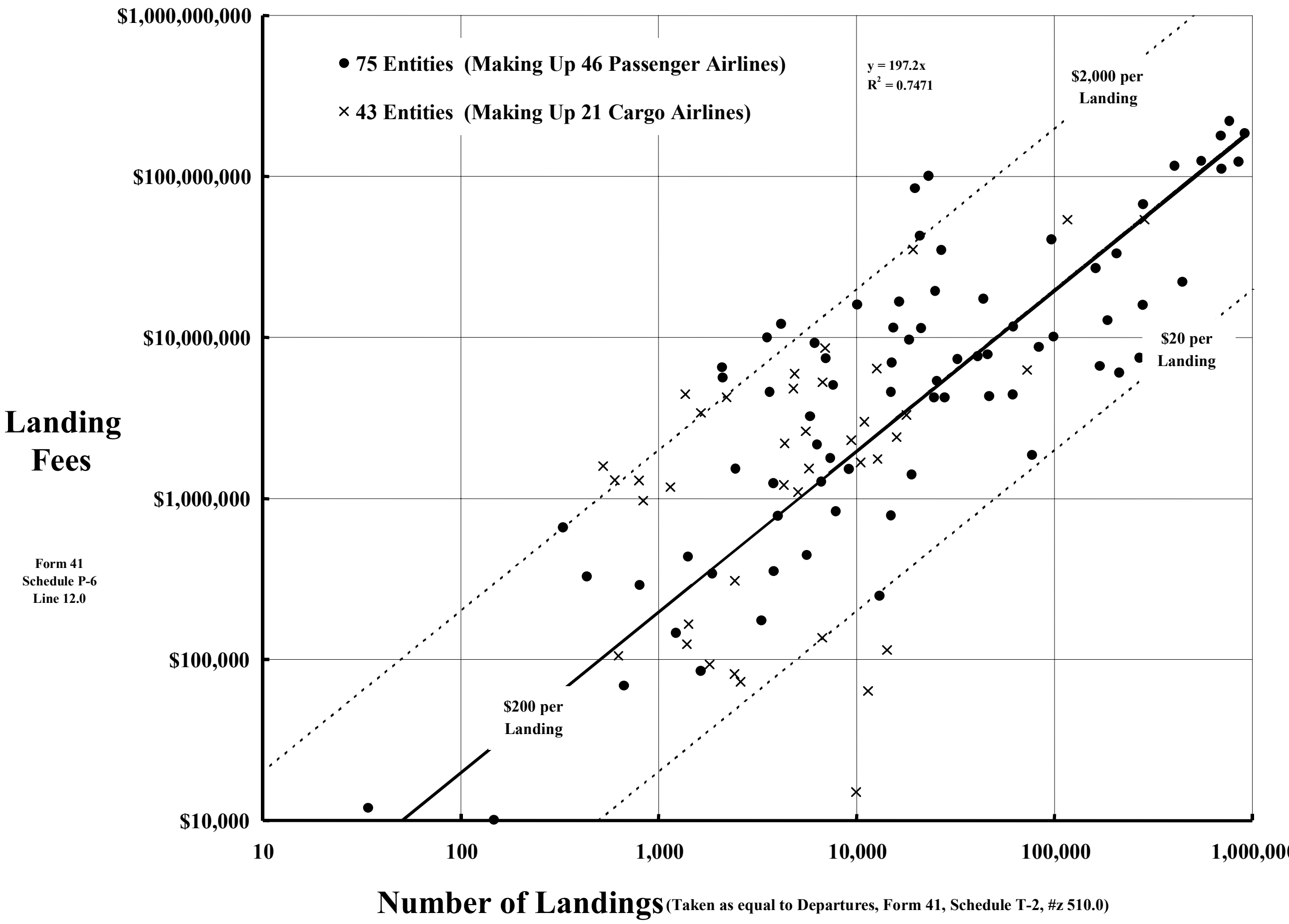


Figure 40. Landing Fees vs. Number of Landings.

The effort to model landing fees was hampered because no details of the many airports and their individual fee structures were readily available. Therefore, a relatively crude approximation was used of the form

$$\text{Landing Fees} = 0.00147(\text{ST})(\text{RF})(\text{MLW})(\text{Departures})$$

$$\text{ST} \equiv \text{Service Type Factor (Passenger} = 1.0\text{, Cargo} = 0.89)$$

$$\text{RF} \equiv \text{Route Factor (Domestic=1.0, Atlantic=2.36, Latin America=1.64, Pacific=4.28)}$$

$$\text{MLW} \equiv \text{Maximum Landing Weight, in pounds}$$

This expense-estimating equation was used at the flight equipment level, and then the results were summed to obtain the total fees an entity paid in 1999. The resulting correlation, while not totally satisfactory for cargo airlines, is shown in Figure 41.

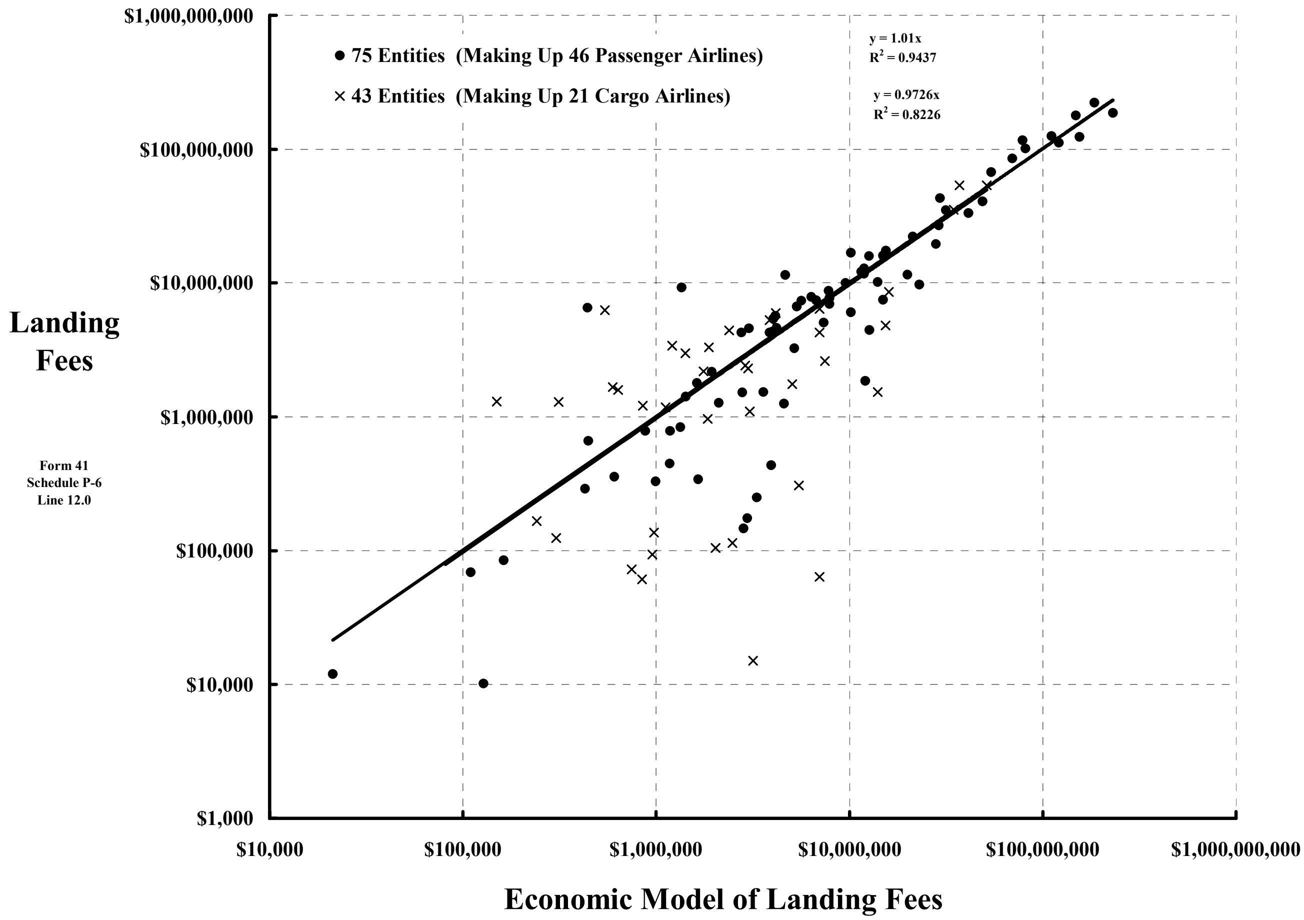


Figure 41. Landing Fees Correlation at the Entity Level.

5.3 Rest of All Other Operating Expenses

As discussed earlier (see Figure 35 and Table 4), the author created an intermediate account about which an expense-estimating equation could be constructed. This intermediate account [referred to as the rest of all other operating expenses (RofAOOE) for lack of a better name] lumped about 80 percent of the all other operating expenses (AOOE) into one category, as Figure 42 shows. The author created this account (RofAOOE) when it became apparent that individual expense-estimating equations for the several sub-accounts became excessively complicated and showed no better correlation than for the accounts in total. The specific accounts included in this intermediate grouping are listed in Table 9 and simply repeat lines from Schedule P-7.

There were several airlines that reported abnormally high transport-related expenses, as pointed out in Figure 3. The entities from those airlines fall far to the right of the diagonal line in Figure 42. The reason these entities are noticeable in Figure 42 is that AOOE includes transport-related expenses, but RofAOOE does not. A further discussion of transport-related expenses is provided in paragraph 5.40 of this report.

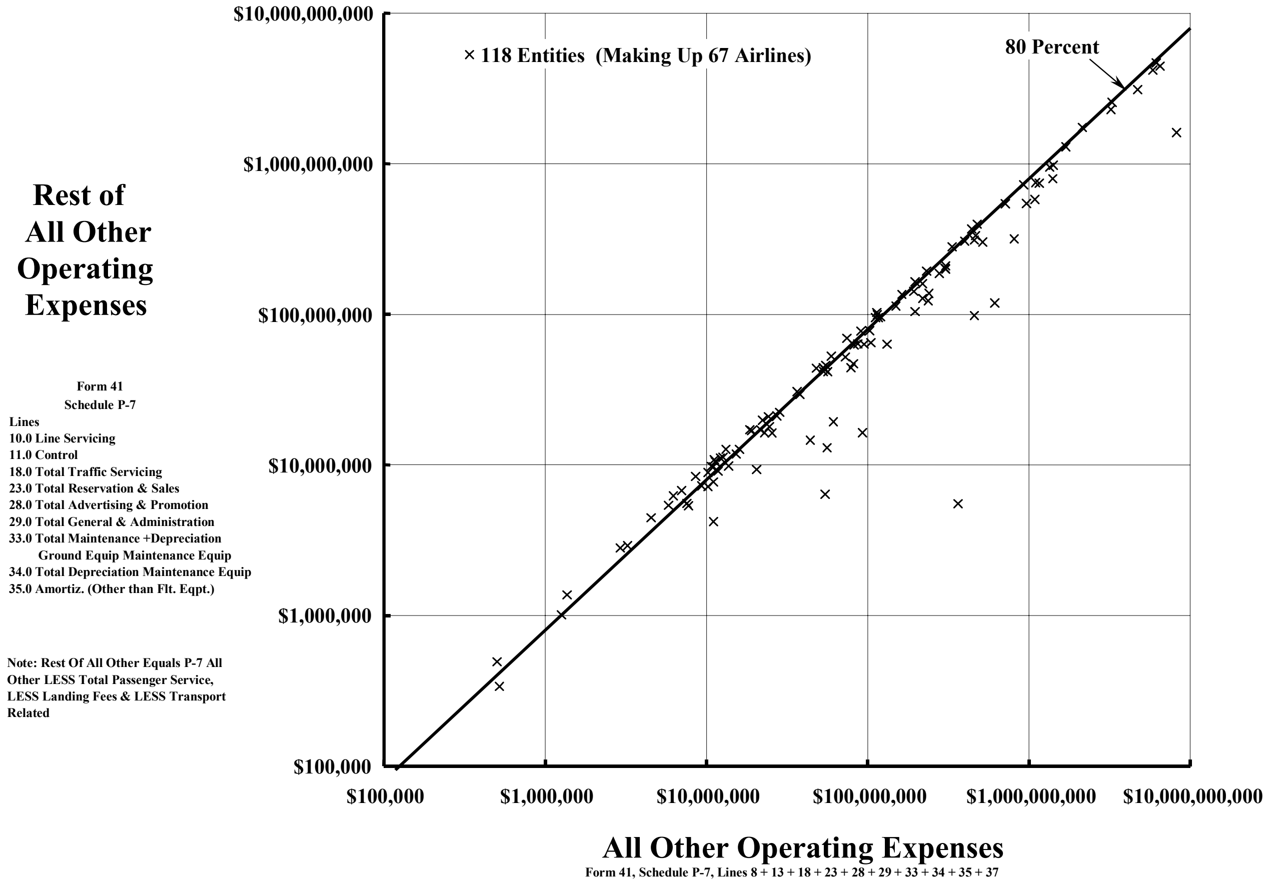


Figure 42. Rest of All Other Operating Expenses vs. AOOE.

TABLE 9. REST OF ALL OTHER OPERATING EXPENSES (ROFAOOE) ACCOUNTS

Line	**P-7 Operating Expenses by Functional Grouping**
10.0	Aircraft Servicing–Line Servicing Expense
11.0	Aircraft Servicing–Control Expense
18.0	Total Traffic Servicing Exp.
23.0	Total Reservation & Sales Exp.
28.0	Total Advertising & Prom. Exp.
29.0	Total General & Admin. Exp.
33.0	Total Maint.+Depr. Ground P&E
34.0	Depr. Expense - Maintenance Eqpt.
35.0	Amort. (other than Flt. Eqpt.)

Note: Line 37.0, Transport Related Expenses, not included in RofAOOE.

The expense-estimating equation for RofAOOE evolved—after considerable searching—into two equations. The major variables in the first equation were quickly found to be (a) number of overhead employees, (b) number of passengers for the year, (c) amount of cargo for the year, and (d) an airline factor. A second equation estimating the number of overhead employees was developed that in itself required a different airline factor.

The first equation gave the RofAOOE expenses in 1999 as

$$\text{Rest of AOOE in 1999} = \text{AF}\left\{\begin{array}{l} 11,604\left(\text{No. Of Overhead Employees}\right) \\ +71,186\left(\text{Passengers}\right) + 161,768\left(\text{Cargo}\right) \end{array}\right\}$$

$$\text{AF} = \text{Airline Factor}\begin{pmatrix} \text{Low} = 0.8,\ \text{Very Low} = 0.6 \\ \text{Average} = 1.0 \\ \text{High} = 1.2,\ \text{Very High} = 1.5 \end{pmatrix}$$

$$\text{Pasengers} = \sum_{n=1}^{N}\left(\frac{\text{Available Seats}}{\text{Aircraft}}\left(\text{Passenger Load Factor}\right)\left(\text{No. of AC}\right)\right)_n$$

$$\text{Cargo} = \sum_{n=1}^{N}\left(\frac{\text{Available Tons}}{\text{Aircraft}}\left(\text{Cargo Load Factor}\right)\left(\text{No. of AC}\right)\right)_n$$

This first equation followed the logic that the overhead employees must (a) obtain and satisfy all the passengers (i.e., reservations) and/or cargo, (b) service all the aircraft, (c) maintain facilities, (d) operate ground equipment, (e) etc.; in short, do all the work not directly related to flying. The measure of this work in one year would be the number of passengers and/or tons of cargo carried. Since an entity might have several different aircraft types with different number of seats or cargo capacity, RofAOOE was assumed to be distributed over all the capacity (i.e., passengers, cargo, and fleet). Therefore, a summation over "N" aircraft was used to gather up an entity's total work load. In 1999, American Airlines, for example, operated its domestic entity using 14 different aircraft ranging from the relatively small Fokker 100 to the "jumbo" MD-11. Thus N = 14 for this example.

The second equation estimated the number of overhead employees as

$$\text{Overhead Employees} = \left(\text{CSF}\right)\left(\text{AF}\right)56.95\left(\text{Number of Aircraft}\right)$$

$$\text{CSF} = \text{Carrier Service Factor}\ \left(\text{Passenger} = 1.0,\ \text{Cargo} = 0.40\right)$$

$$\text{AF} = \text{Airline Factor}\begin{pmatrix} \text{Low} = 0.9, \text{Very Low} = 0.7,\ \text{Very, Very Low} = 0.5 \\ \text{Average} = 1.0 \\ \text{High} = 1.1,\ \text{Very High} = 1.3, \text{Very, Very High} = 1.5 \end{pmatrix}$$

The ability of these two equations to estimate the rest of all other operating expenses is shown in Figure 43. The economic model yielded favorable results for passenger airlines ($R^2 > 0.99$), but left considerable room for improvement for cargo airlines ($R^2 = 0.91$), who reported large expenses in the transport related expenses account.

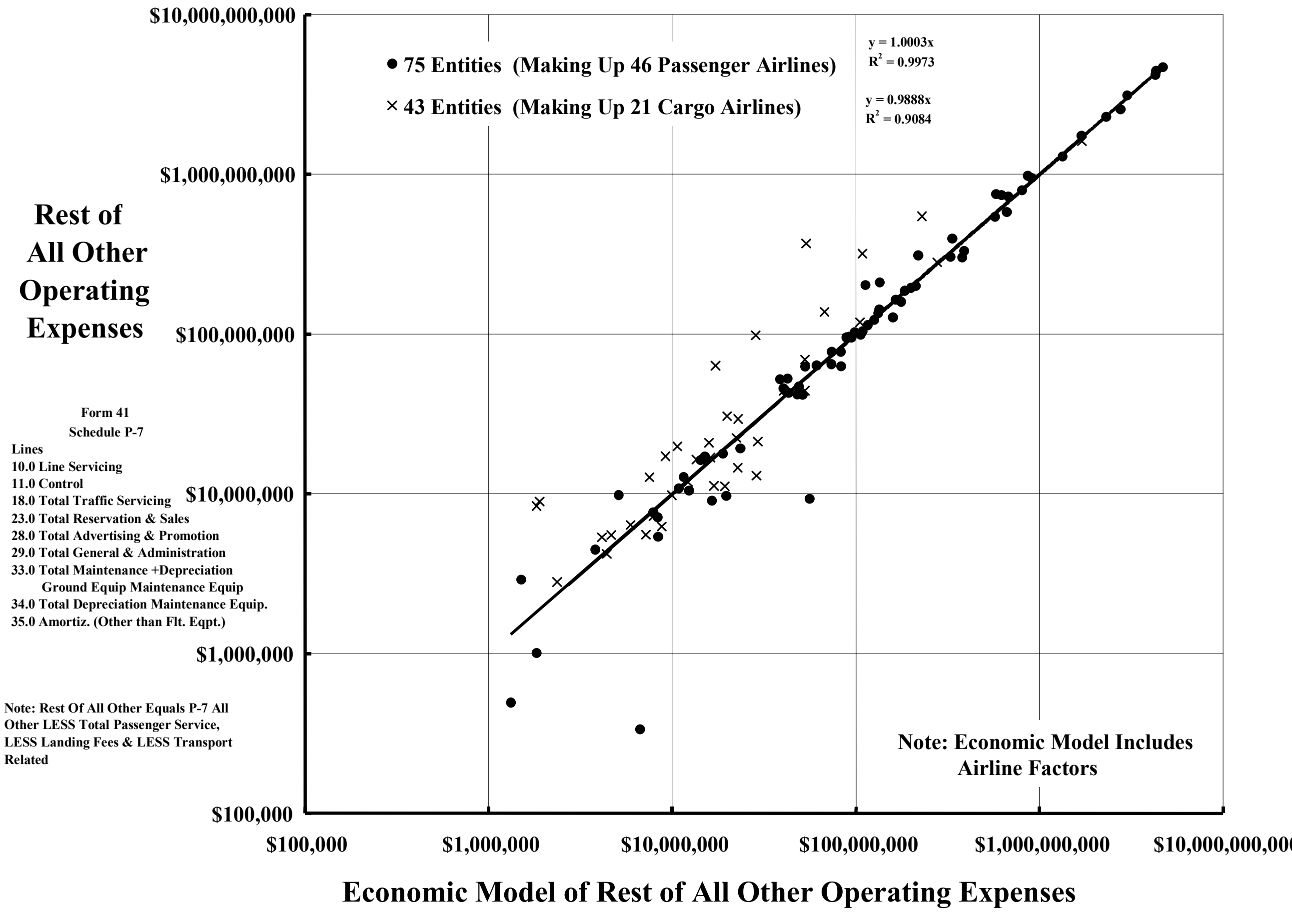


Figure 43. Rest of All Other Expenses Correlation at Entity Level.

5.4 Transport Related Expenses (TRE)

Expenses classified as transport related were—by far, for this investigator—the most difficult category to understand. The account descriptions offered by the DOT were vague at best and offered no hint of variables to incorporate in an economic model. A measure of the situation as it existed in 1999 is illustrated for passenger airlines in Figure 44 and for cargo airlines in Figure 45. The passenger airline situation, Figure 44, hardly merits discussion because all but three airlines reported TREs well below 10 percent of All Other Operating Expenses. On the other hand, nearly ½ of the cargo airlines reported TREs well above 10 percent of AOOE. The author finally gave up thinking he could find an economic model for transport related expenses. Instead, actual 1999 TREs were used in calculating AOOE for the 3 passenger and 10 cargo airlines having TREs above the 10 percent threshold. For all other entities, the expense-estimating equation was

$$\text{Transport Related Expenses in 1999} = 1.035\left(\text{Rest of All Other Operating Expenses}\right)$$

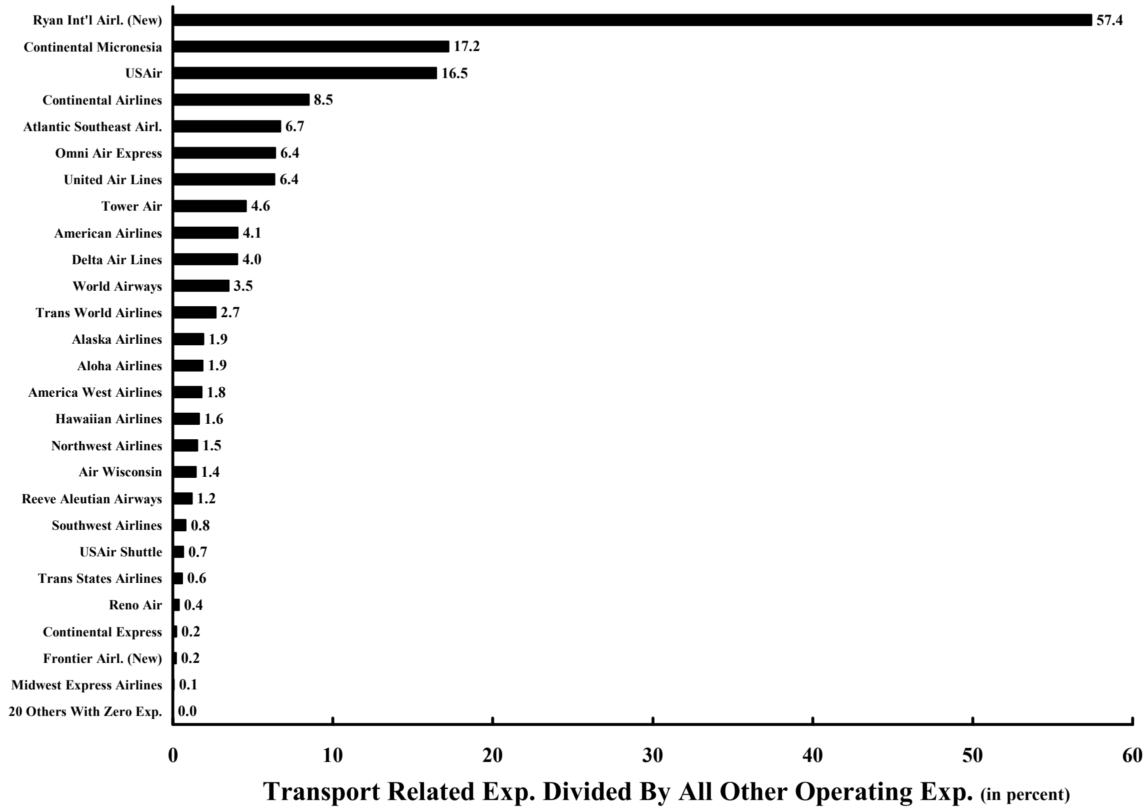


Figure 44. Passenger Airline Transport Related Exp. as Percent of AOOE.

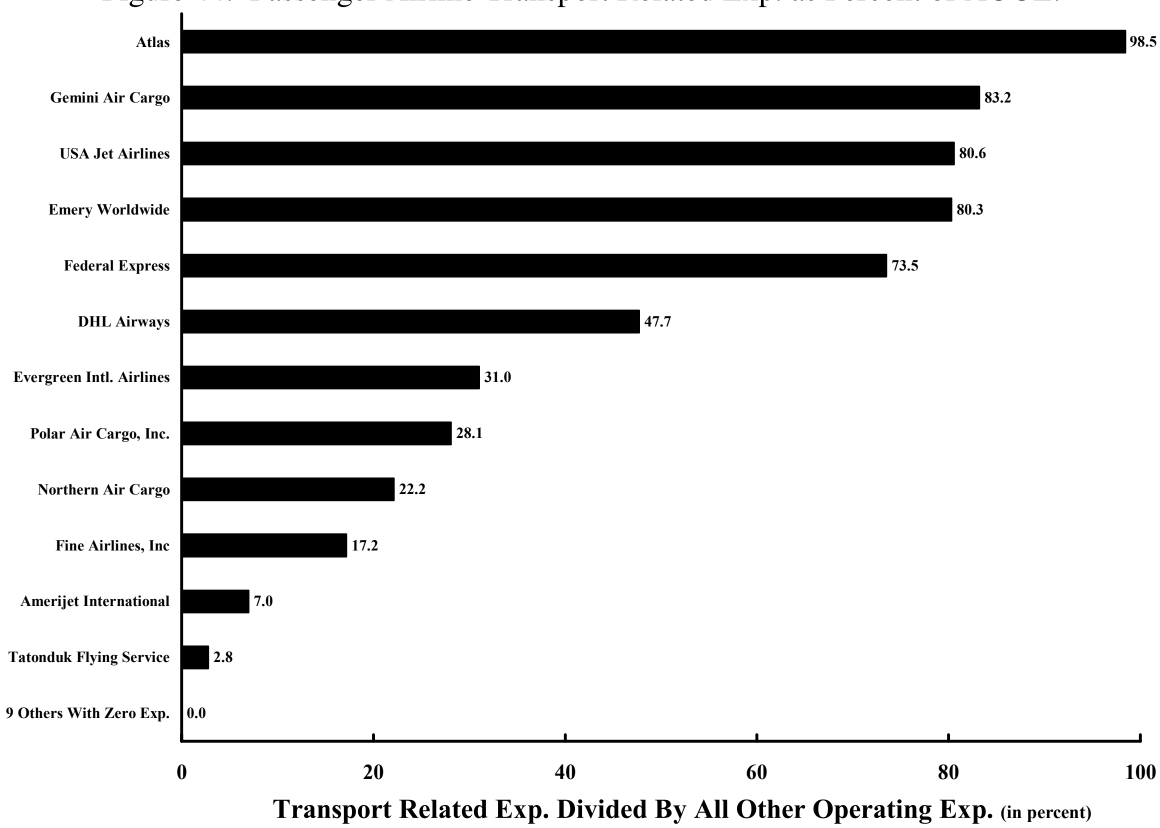
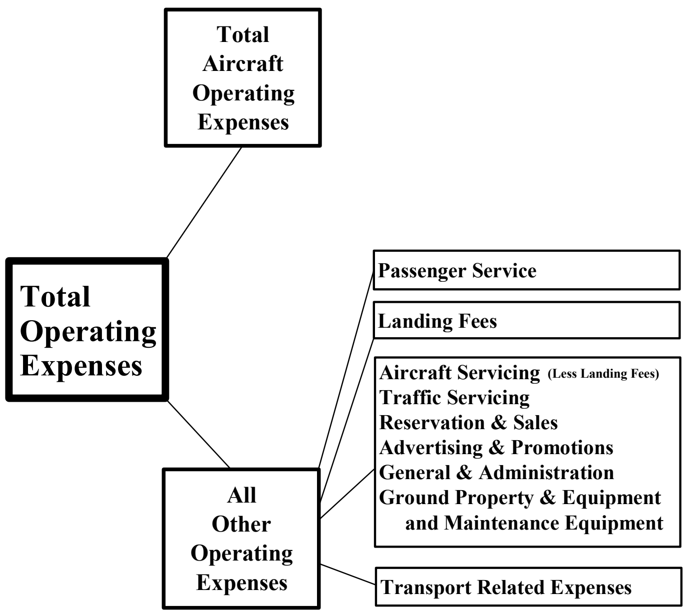


Figure 45. Cargo Airline Transport Related Expenses as Percent of AOOE.

5.5 All Other Operating Expenses in Review

In 1999, All Other Operating Expenses of the 67 airlines under study amounted to slightly over $63 billion for the 5,963 airplanes in operation. Some detail about these 1999 expenses are shown in accounting tree form with Figure 46. Note in passing that the economic model prediction of Total Operating Expenses closely approximates the 1999 Form 41 reported TOE from the 67 airlines.



Economic Model	DOT Form 41	Accounts
$46.901	$47.045	TAOE
$10.055	$9.830	PS
$2.110	$2.066	LF
$38.359	$39.528	Rest of AOOE
$11.882	$11.882	TRE
$62.406	$63.359	AOOE
$109.302	$110.580	TOE

Notes: 1) All Dollars in Billion. 2) Some Round-off Errors. 3) TRE at Form 41 Actuals.

Figure 46. All Other Operating Expenses (AOOE) by Major Accounts.

The ability of the economic model to predict All Other Operating Expenses at the entity level is shown in Figure 47 and, at the airline level, in Figure 48. At both entity and airline levels, the coefficient of determination, R^2, is greater than 0.995. The regression analyses that yielded the expense-estimating equations showed considerable confidence in the variables used. Keep in mind, however, that several airline factors were required to account for large differences in individual airline business practices.

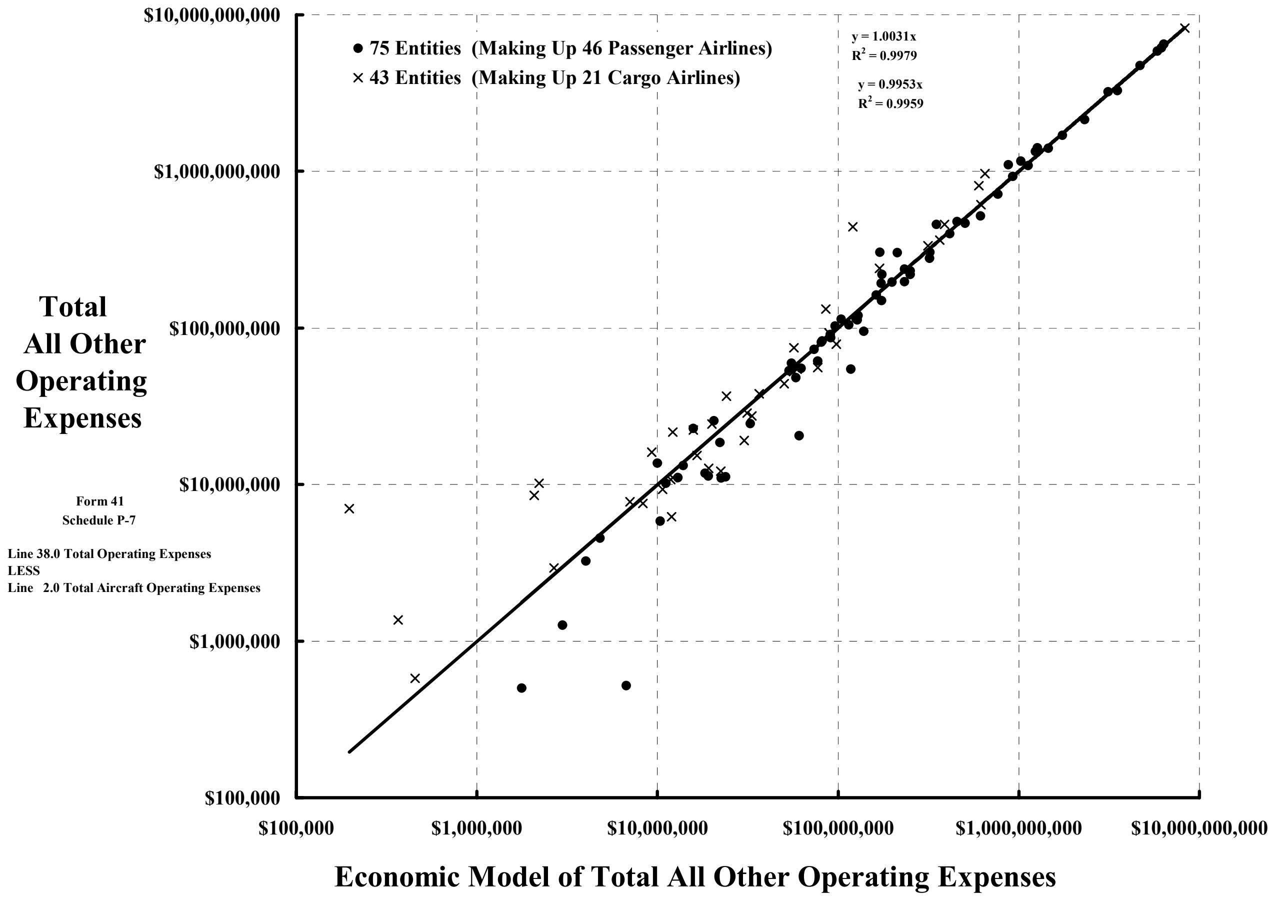


Figure 47. AOOE Correlation at the Entity Level.

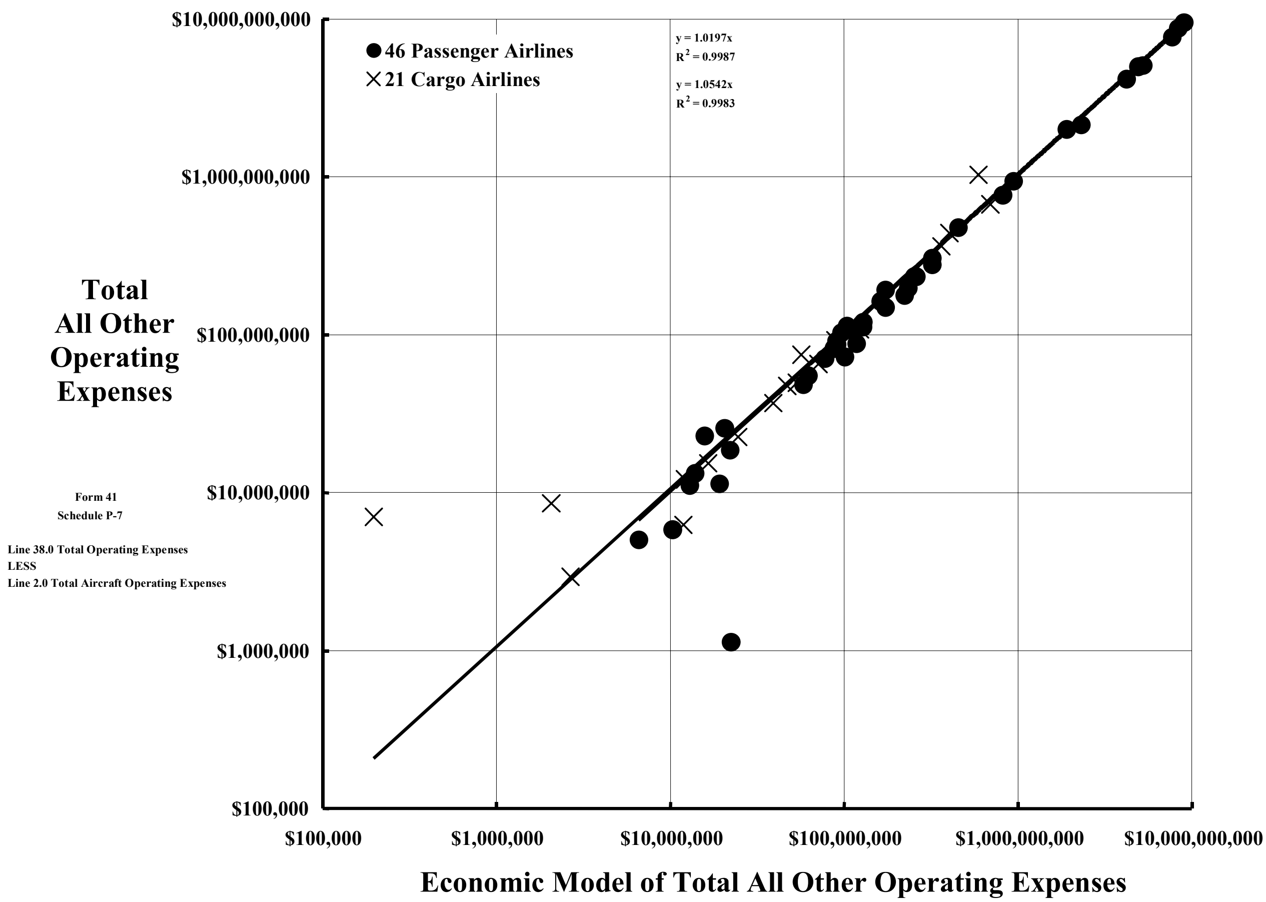


Figure 48. AOOE Correlation at the Airline Level.

6. TOTAL OPERATING EXPENSES IN SUMMARY

Total operating expenses (TOE) is the sum of total aircraft operating expenses (TAOE) and all other operating expenses (AOOE). When summed, total operating expenses from the flight equipment level gives TOE at the entity level. Adding the TOE from as many as four entities gives each airline's TOE. Finally, the sum of TOE from the each airline gives the industry's TOE. Based on a study of 67 airlines expenses in 1999, the industry incurred nearly $111 billion in expenses as Table 10 shows. The economic model of these expenses provided by this report estimates slightly over $109 billion, a correlation error on the order of 1.2 percent. The economic modeling is considerably better for passenger airlines than for cargo airlines, which is also apparent from Table 10.

TABLE 10. TOTAL OPERATING EXPENSES FOR THE AIRLINE INDUSTRY IN 1999

Service Provided	No. of Airlines	No. of Entities	No. of Airplanes Operated	Predicted Total Operating Expenses	Total Operating Expenses Form 41 Schedule P-1.2 Account # 7199.0	Error (DOT-Pred.) DOT
Passenger	46	75	4,825	$89.898 B	$90.057 B	0.2 %
Cargo	21	43	1,138	$19.371 B	$20.523 B	5.6 %
Totals	67	118	5,963	$109.269 B	$110.5805 B	1.2 %

The economic model's correlation with the data from which it was derived is shown in Figure 49. At the airline level, 35 out of 46 passenger airlines are predicted to within a plus/minus error band of 20 percent. The economic model is less accurate for cargo airlines; only 13 out of 21 points fall within the 20 percent error band. Correlation at the entity level, Figure 50, shows that 57 out of 75 passenger entities are predicted to within plus/minus 20 percent, but only 25 out of 43 cargo entities fall within the 20 percent error band.

The Department of Transportation reporting method (Form 41 with several Schedules) requires airlines to submit total aircraft operating and financial data at the flight equipment level. These data are frequently referred to as direct operating costs (DOC). However, indirect operating costs (IOC) need only be reported at the entity level with the current DOT reporting requirements. The economic model reported herein is designed to give IOC (referred to in this economic model as AOOE) at the equipment level should such airline data become available.

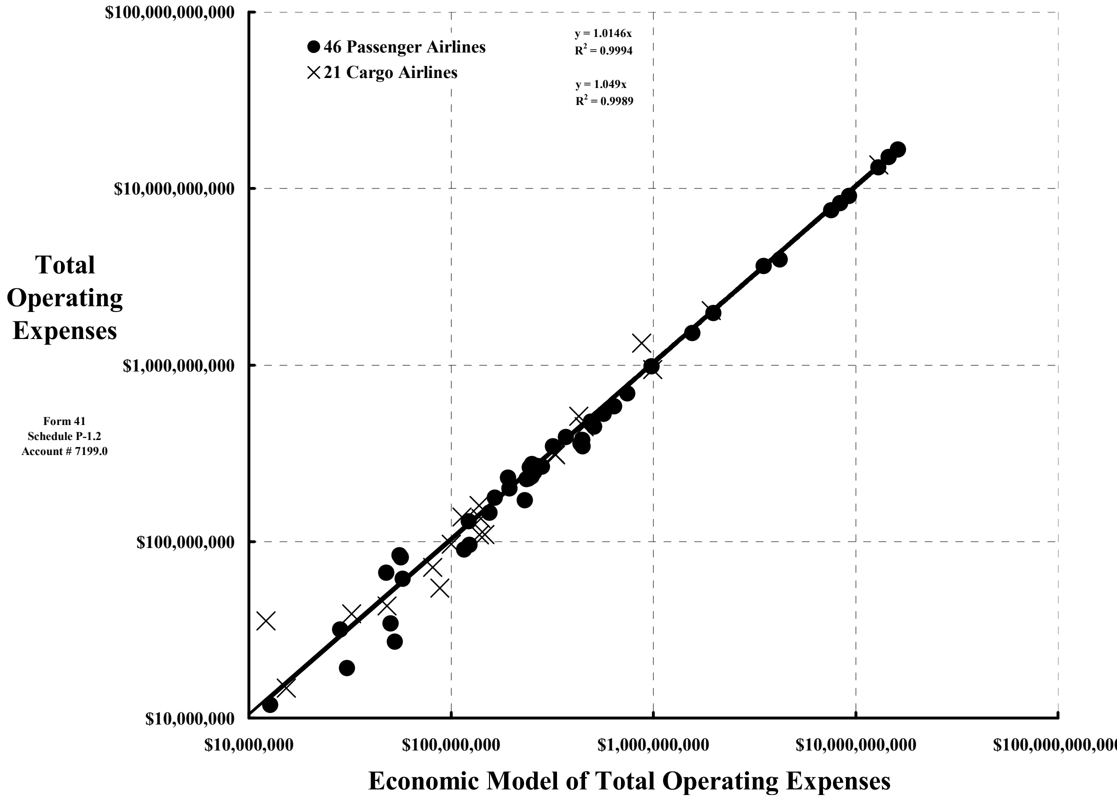


Figure 49. TOE Correlation at the Airline Level.

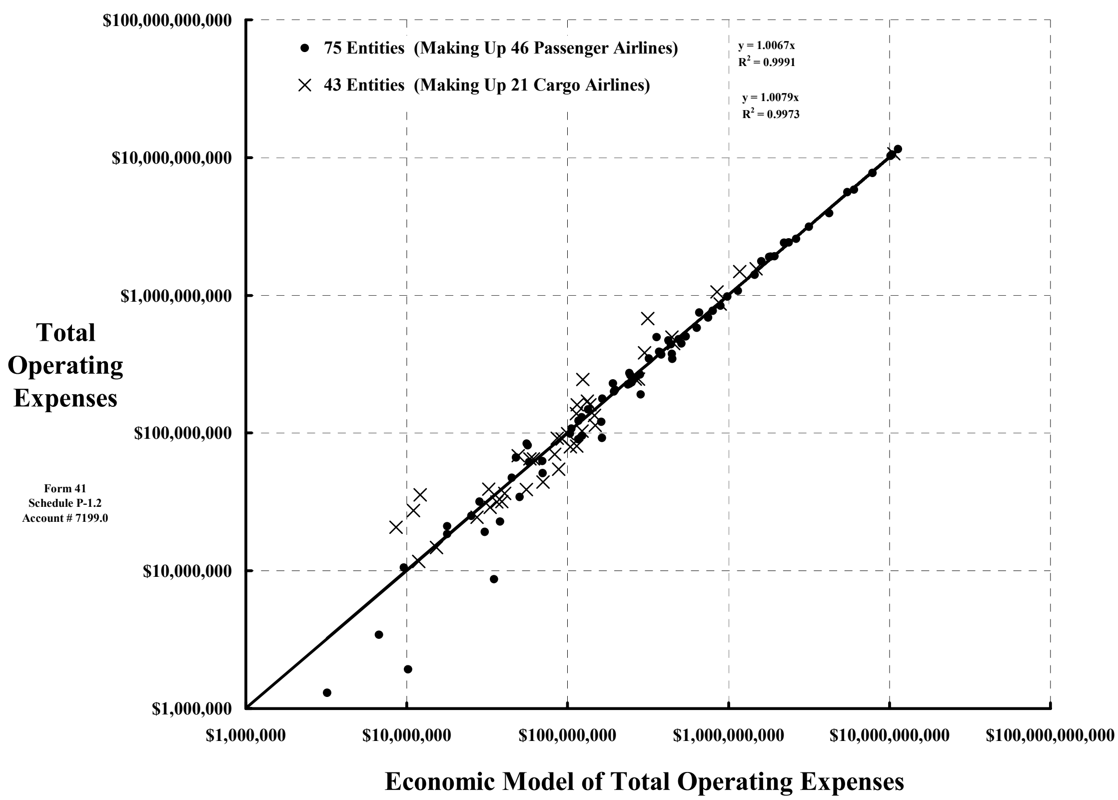


Figure 50. TOE Correlation at the Entity Level.

7. TWO ILLUSTRATIONS

Total operating expenses (TOE) is the sum of total aircraft operating expenses (TAOE) and all other operating expenses (AOOE). Each major account is made up of several sub-accounts, as Figures 1 and 35 show. To illustrate the sub-accounts in greater detail, results of the economic model for two example airline/entities have been included. The first example is Southwest Airlines expenses in 1999. While Southwest operated several aircraft in that year, they only operated domestically. The second example is for the domestic entity of American Airlines.

A detailed comparison of the economic model to Southwest Airlines Form 41 report in 1999 is shown in Table 11. At the Total Operating Expenses level, the model overestimates expenses by slightly over 11 percent. Significant errors—percentage wise—do occur, but only in the small expense accounts. The correlation with American Airlines domestic Form 41, Table 12, shows a slight under-prediction of TOE. The economic model's correlation with the several sub-accounts is considerably better than for Southwest Airlines.

The economic model appears to have one general characteristic, illustrated by Table 11 and Table 12, which is that the smaller the entity and/or airline the greater the error.

TABLE 11. CORRELATION WITH SOUTHWEST AIRLINES IN 1999

Southwest Airlines		Economic Model	DOT Form 41	Error (%) (DOT-Pred.)/DOT
TOE		**$4,405,683,000**	**$3,954,117,000**	**-11.4**
TAOE		**$1,997,209,000**	**$1,813,296,000**	**-10.1**
	Flight Crew	$450,363,000	$434,638,000	-3.6
	Fuel & Oil	$494,727,000	$490,501,000	-0.9
	Insurance	$3,526,000	$3,617,000	2.5
	Rental	$207,699,000	$207,292,000	-0.2
	Other Flying Ops.	$46,239,000	$2,119,000	-2082.2
	Airframe Maintenance	$343,119,000	$374,436,516	8.4
	Engine Maintenance	$185,820,000	$110,030,484	-68.9
	Depr. & Amort.	$265,711,000	$190,662,000	-39.4
AOOE		**$2,408,474,000**	**$2,140,821,000**	**-12.5**
	Passenger Service	$442,490,000	$253,580,000	-74.5
	Landing Fees	$155,178,000	$123,530,000	-25.6
	Rest of All Other	$1,696,116,000	$1,746,294,000	2.9
	Transport Related	$114,689,000	$17,417,000	-558.5

TABLE 12. CORRELATION WITH AMERICAN AIRLINES DOMESTIC IN 1999

American Airlines Domestic		Economic Model	DOT Form 41	Error (%) (DOT-Pred.)/DOT
TOE		**$10,151,651,000**	**$10,307,674,000**	**1.5**
TAOE		**$4,267,732,000**	**$4,434,787,000**	**3.8**
	Flight Crew	$1,224,460,000	$1,336,504,000	8.4
	Fuel & Oil	$977,892,000	$1,001,754,000	2.4
	Insurance	$6,095,000	$4,101,000	-48.6
	Rental	$406,807,000	$393,849,000	-3.3
	Other Flying Ops.	$104,165,000	$100,238,000	-3.9
	Airframe Maintenance	$666,488,000	$653,163,318	-2.0
	Engine Maintenance	$426,776,000	$468,907,682	9.0
	Depr. & Amort.	$458,877,000	$476,270,000	3.7
AOOE		**$5,883,919,000**	**$5,872,887,000**	**-0.2**
	Passenger Service	$1,165,056,000	$1,268,884,000	8.2
	Landing Fees	$148,414,000	$179,216,000	17.2
	Rest of All Other	$4,290,263,000	$4,180,926,000	-2.6
	Transport Related	$280,186,000	$243,861,000	-14.9

8. CONCLUSIONS

A new economic model of U.S. airline Total Operating Expenses (TOE) has been offered. The model, suitable for both passenger and cargo airlines, is made up of several, relatively simple, expense estimating equations. Eight accounts associated with Total Aircraft Operating Expenses (generally referred to as direct operating costs, or DOC) have been modeled. In addition, 4 accounts yielding All Other Operating Expenses (frequently referred to as indirect operating costs, or IOC) have been modeled. The 12 accounts, when added together, yield TOE. The expense-estimating equations apply to the flight equipment (i.e., single aircraft) expense level. Each equation's accuracy is demonstrated by correlation with the account data from which it was derived. Correlation of the individual accounts shows the model to be least accurate at the aircraft level, but with improvement at the higher, entity level and even more accuracy at the airline level. The improving accuracy is because of offsetting errors. Other conclusions are as follows:

1. Based on a study of 67 airlines' expenses in 1999, the industry incurred nearly $111 billion in expenses. The economic model of these expenses estimates slightly over $109 billion, a correlation error on the order of 1.2 percent. The economic modeling is considerable better for passenger airlines (0.2%) than for cargo airlines (5.2%).

2. In 1999, Total Aircraft Operating Expenses incurred by the 67 airlines under study amounted to slightly over $47.045 billion for the 5,963 airplanes in operation. The economic model of these expenses estimates slightly over $46.901 billion, a correlation error well below 1 percent.

3. All Other Operating Expenses incurred by the 67 airlines in 1999 amounted to $63.359 billion. The economic model estimates slightly over $62.406 billion, a correlation error well below 1 percent.

4. Detailed correlation examples, one for Southwest Airlines and the other for American Airlines, illustrate one general characteristic of the model, which is that the smaller the entity and/or airline the greater the error.

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APPENDIX 1

SUMMARY OF EXPENSE ESTIMATING EQUATIONS

This appendix provides a concise summary of the several expense-estimating equations associated with this economic model. Explanatory notes are provided as appropriate or required. Each equation yields the *yearly expenses* of one aircraft at the flight equipment level, not expenses per block hour or per trip or per airborne hour. The expenses are in 1999 dollars. No estimate of inflation or other major changes within the industry is considered.*

Several equations require an assessment of the airline's approach to business, quantified by an airline factor. The airline factor attempts to account for such things as a start-up situation, a charter airline approach, a "lean and mean" philosophy, the average airline, a mature but low-fare airline, or a mature major airline. In some equations, the range of this airline factor is large. However, this reflects the industry as it existed in 1999.

Appendix 3 tabulates representative values for all aircraft parameters required by this economic model.

Any number of comparisons driven by the variables—not by the airline factor—can be made using this economic model. One need only set any given airline factor to average and then proceed.

<u>Flight Crew Expenses (page 17)</u>

$$\text{Flt. Crew Expenses} = \text{AF}\left\{\text{K}\left(\text{MTOGW}\right)^{0.4}\right\}\left(\text{Block Hours}\right)$$

$$\text{K} = 2.75 \text{ for Regionals}$$

$$\text{K} = 5.25 \text{ for Domestic and 2 Crew}$$

$$\text{K} = 6.50 \text{ for 3 Crew and/or International}$$

$$\text{AF} = \text{Airline Factor}\begin{pmatrix}\text{Low} = 0.63\text{, Very Low} = 0.44\text{, Very, Very Low} = 0.34 \\ \text{Average} = 0.80 \\ \text{High} = 1.00\text{, Very High} = 1.30\text{, Very, Very High} = 1.60\end{pmatrix}$$

<u>Fuel & Oil Expenses (page 21)</u>

$$\text{Fuel Expense} = \frac{\text{Fuel Cost}}{\text{Gallon}}\left(\frac{\text{Non-cruise gallons}}{\text{Departure}} + \frac{\text{Cruise gallons}}{\text{Departure}}\right)\text{Departures}$$

*This model does not, for example, attempt to reflect the disruption of September 11, 2001. The model's basis is industry data of 1999 and the model was developed during the period January 2000 through July 2002. The first draft of this report was completed in early September of 2002.

Takeoff gross weight (TOGW) for passenger aircraft assumes one passenger equals 225 pounds. Fuel weight is 6.5 lbs/gal. Fuel load is increased by 50 percent to provide a reserve.

$$\text{TOGW} = \text{Operating WE} + 225(\text{Available Seats})(\text{Load Factor}) + 1.5\left(\frac{6.5\ \text{lbs}}{\text{gal}}\right)\left(\frac{\text{Fuel in lbs}}{\text{Departure}}\right)$$

Cargo aircraft TOGW assumes one ton of cargo equals 2,000 pounds. Fuel weight is 6.5 lbs/gal. Fuel load is increased by 50 percent to provide a reserve.

$$\text{TOGW} = \text{Operating WE} + 2000(\text{Available Tons})(\text{Load Factor}) + 1.5\left(\frac{6.5\ \text{lbs}}{\text{gal}}\right)\left(\frac{\text{Fuel in lbs}}{\text{Departure}}\right)$$

$$\frac{\text{Non-cruise Gal.}}{\text{Departure}} = \frac{0.001713\left(\text{SFC}_{\text{jet}} \times \text{Thrust}\right)_{\text{Takeoff}}}{\left(\text{Thrust/TOGW}\right)^2_{\text{Takeoff}}} \quad (\text{turbojet/turbofan} - \text{driven airplane})$$

$$\frac{\text{Non-cruise Gal.}}{\text{Departure}} = \frac{0.01113\left(\text{SFC}_{\text{piston}} \times \text{BHP}\right)_{\text{Takeoff}}}{\left(\text{Thrust/TOGW}\right)^2_{\text{Takeoff}}} \quad (\text{turboprop} - \text{driven airplane})$$

$$\text{Start Cruise at } W_{\text{initial}} = \text{Takeoff Gross Weight} - 6.5\,\text{lb/gal}(\text{Non-cruise Gallons})$$

$$\frac{\text{Cruise Gallons}}{\text{Departure}} = \frac{W_{\text{initial}}\left(1 - e^{-K}\right)}{6.5\ \text{lbs/gal}}$$

$$\text{where } K_{\text{Jet}} = \frac{\text{Range} \times \text{SFC}_{\text{Cruise}}}{\left(V \times L/D\right)_{\text{Average}}} \text{ and } K_{\text{Prop}} = \frac{\text{Range} \times \text{SFC}_{\text{Cruise}}}{\left(375 \times \eta_P \times L/D\right)_{\text{Average}}}$$

Nomenclature:

a. Thrust refers to the sum of thrusts from all engines or propellers. Units are pounds.
b. BHP is the sum of brake horsepower from all engines driving propellers. Units are hp.
c. SFC is specific fuel consumption in fuel pounds/hour per pounds of thrust for jets or fuel pounds/hour per BHP for engines driving propellers.
d. V is average cruise speed in statute miles per hour. (See T-2, z410.0/z650.0)
e. Range is statute miles per departure (See T-2, z410.0/z510.0)
f. The lift to drag ratio (L/D) has no units.
g. Propeller efficiency (η_P) has no units.
h. Operating Weight Empty. Units are pounds.
i. Fuel cost per gallon in 1999 was \$0.51.

Calculation Notes:

The fuel calculations require iteration because the TOGW depends on the pounds of fuel required by the departure (i.e., trip); but the fuel required depends on the TOGW. Initiate the iteration with the takeoff gross weight at maximum. Then run through the equations and recalculate the TOGW. If the second TOGW is higher than the maximum TOGW, stop the calculation at one iteration and use the calculated fuel. (This result means the 50 percent fuel reserve is too high.) If the second TOGW is lower than the maximum TOGW, proceed to iterate until the calculation converges.

Insurance Expenses (page 25)

$$\text{Insurance Expense} = 0.0056\left(\text{Capital Invested}\right)$$

This insurance covers what is called "hull" insurance for aircraft owned by the airline. Lacking a more appropriate insurance company policy contract, use the aircraft purchase price in the year the aircraft was bought by the airline. The constant, 0.0056, is associated with the industry in 1999.

Rental Expenses (page 26)

$$\text{Rental Expense} = 0.0835\left(\text{Capital Invested By Leasing Company}\right)$$

A leasing company buys an aircraft and then leases or rents the aircraft to an airline. Use the aircraft purchase price in the year the aircraft was bought by the leasing company. The constant, 0.0835, is associated with the industry in 1999. This rental expenses assumes a "dry" lease where the airline pays for the fuel and oil.

Other Flying Operation Expenses (page 27)

$$\text{Other FO Expenses} = 0.04\left(\text{Flight Crew} + \text{Fuel \& Oil} + \text{Insurance} + \text{Rental}\right)$$

Flying Operation Expenses (page 27)

$$\begin{aligned}\text{Flying Operation Expenses} = {} & \text{Flight Crew} \\ & + \text{Fuel \& Oil} \\ & + \text{Insurance} \\ & + \text{Rental} \\ & + \text{Other FO}\end{aligned}$$

Flight Equipment Maintenance Expenses (page 30)

$$\text{Flight Equipment Maintenance Expenses} = \text{Airframe Maint.} + \text{Engine Maint.}$$

$$\text{Airframe} = K\left\{\left(\text{Ref.W}\right)^{0.72118}\left(\text{FH}\right)^{0.46050}\left(\text{DP}\right)^{0.32062}\left(\text{NAC}\right)^{0.20700}\left(1 + \frac{\text{Inhouse AF}}{\text{Total AF}}\right)^{-0.43177}\right\}$$

$$\text{Engine} = K\left\{\left(\text{Thrust}\right)^{0.89650}\left(N_E\right)^{0.92340}\left(\text{FH}\right)^{0.15344}\left(\text{DP}\right)^{0.37535}\left(\text{NAC}\right)^{0.4429}\left(1 + \frac{\text{Outside Eng.}}{\text{Total Eng.}}\right)^{-0.34704}\right\}$$

The constant K depends on 4 considerations as

$$K = \text{ST}\left[1.73\left(\text{CF}\right)\left(\text{MF}\right)\left(\text{ET}\right)\right]$$

where

ST = Service Type (Passenger = 1.0, Cargo = 1.3252)

ET = Engine Type (Turbofan = 1.0, Turboprop = 1.2644)

MF = Aircraft Model Factor (Earliest = 1.0, Early = 0.7104, Recent = 0.514, Latest = 0.4260, Very Latest = 0.35)

CF = Airline Cost Factor (Very Low = 0.4470, Low = 0.8339, Average = 1.0, High = 1.3019)

The constant K introduces an aircraft Model Factor to reflect the aircraft generation and quantify aircraft age. The logic here is that the airlines operated, in 1999, a wide range of aircraft models. However, in the jet engine propelling group, for example, all the aircraft have swept wings. The fundamental type begins with the earliest Boeing 707 class, passes through smaller and larger variations, and ends with the very latest Boeing 777 class. While the takeoff gross weight varies a great deal between classes, the fundamental technology remains. Improvements over the 4 decades have occurred, however, which lowered maintenance expenses. In this light, the earliest swept-wing, jet-propelled model in a given class has been assigned a Model Factor of one. More recent versions have a reduced value Model Factor. The table at the end of this appendix should help in conveying the author's logic.*

The table at the end of this appendix lists, qualitatively, the classification of all aircraft in the industry's fleet in terms like earliest, recent, latest, etc. The numerical values assigned to the qualitative classifications were found by iterations so that the predicted flight equipment expenses correlated with DOT, Form 41, reported data.

Finally, the definitions of variables used in the airframe and engine maintenance equations are

$$
\begin{aligned}
\text{Thrust} &\equiv \text{Propulsion Unit's Thrust at Sea Level Standard Day, in pounds} \\
N_E &\equiv \text{Number of Propulsion Units per Aircraft} \\
\text{Ref. W} &\equiv \text{Reference Weight of Aircraft} \\
&= \text{Minimum Operational Weight Empty LESS Engine Dry Weight, in pounds} \\
\text{FH} &\equiv \text{Flight Hours Flown by the Fleet in One Year, in hours} \\
\text{DP} &\equiv \text{Departures Performed by the Fleet in One Year} \\
\text{NAC} &\equiv \text{Number of Aircraft in Fleet for the Year}
\end{aligned}
$$

*In following this logic, the author would assign the SST, the first in its technology and class, with a Model Factor = 1. Similarly, should a commercial airliner evolve from the military tiltrotor program, it would be "the first" and receive MF = 1. Should models evolve (i.e., introducing a SST-200 after the now flying SST-100) from either of these two unique technologies, that aircraft would advance from MF = 1.0 to early and MF = 0.7104. The assumption is, of course, that improvements, which reduce maintenance expenses, are incorporated in an ongoing process. Thus, maintenance experiences from all preceding aircraft will be addressed in the next aircraft to be produced.

It should be noted that the equations were developed from entities having many more than 1 aircraft in the fleet. The author believes, however, that the two equations are valid for NAC = 1. The reason for this statement is that there is only the slightest evidence of economy of scale. For example, the airframe maintenance could be rewritten as

$$\text{Airframe} = K\left\{(\text{Ref.W})^{0.72118}\left(\frac{\text{FH}}{\text{NAC}}\right)^{0.46050}\left(\frac{\text{DP}}{\text{NAC}}\right)^{0.32062}(\text{NAC})^{0.98812}\left(1+\frac{\text{Inhouse AF}}{\text{Total AF}}\right)^{-0.43177}\right\}$$

and the engine maintenance as

$$\text{Engine} = K\left\{(\text{Thrust})^{0.89650}(N_E)^{0.92340}\left(\frac{\text{FH}}{\text{NAC}}\right)^{0.15344}\left(\frac{\text{DP}}{\text{NAC}}\right)^{0.37535}(\text{NAC})^{0.97169}\left(1+\frac{\text{Outside Eng.}}{\text{Total Eng.}}\right)^{-0.34704}\right\}$$

Written in this form shows that the exponent of NAC in both equations is, for practical purposes, 1.0. This result says that flight equipment maintenance expenses are directly proportional to number of aircraft.

Flight Equipment Depreciation & Amortization Expenses (page 34)

$$\text{Depr. \& Amort. Expense} = \text{APP}\,\frac{(1-\text{RV})}{\text{DP}}$$

$$\begin{aligned}\text{APP} &= \text{Aircraft Purchase Price}\\ \text{RV} &= \text{Residual Value}\\ \text{DP} &= \text{Depreciation Period}\end{aligned}$$

This expense applies to the aircraft owned by the airline. The purchase price is in then year dollars.

Total Aircraft Operating Expenses (page 38)

$$\begin{aligned}\text{Total Aircraft Operating Expenses} &= \text{Flying Operation}\\ &+ \text{Flt. Equip. Maint.}\\ &+ \text{Flt. Equip. Depr. \& Amort.}\end{aligned}$$

Passenger Service Expenses (page 42)

$$\text{Passenger Service Expenses} = 1.6(55{,}500)(\text{Number of Flight Attendants})$$

where

$$\text{No. of Flt. Attendants} = \begin{bmatrix} \left(\dfrac{\text{Aircraft Block Hours per Year}}{\text{Attendant Hours per Year}}\right) \\ \times\left(\dfrac{\text{FAA Req. Attendants}}{\text{No. of Seats}}\right) \\ \times\left(\dfrac{\text{No. of Seats}}{\text{Aircraft}}\right) \\ \times\left(\text{Number of Aircraft}\right) \end{bmatrix} \left(1.3647 + .02351\,\frac{\text{Block Hours}}{\text{Departure}}\right)$$

The factors 1.6 and $55,500 per attendant are representative of the industry in 1999.

<u>Landing Fees (page 46)</u>

$$\text{Landing Fees} = 0.00147(\text{ST})(\text{RF})(\text{MLW})(\text{Departures})$$

$$\begin{aligned} \text{ST} &\equiv \text{ Service Type Factor (Passenger} = 1.0,\ \text{Cargo} = 0.89) \\ \text{RF} &\equiv \text{ Route Factor (Domestic} = 1.0,\ \text{Atlantic} = 2.36,\ \text{Latin America} = 1.64,\ \text{Pacific} = 4.28) \\ \text{MLW} &\equiv \text{ Maximum Landing Weight, in pounds} \end{aligned}$$

<u>Rest of All Other Operating Expenses (page 47)</u>

$$\text{Rest of AOOE in 1999} = \text{AF}\begin{Bmatrix} 11,604(\text{No. of Overhead Employees}) \\ +71,186(\text{Passengers}) + 161,768(\text{Cargo}) \end{Bmatrix}$$

$$\text{AF} = \text{Airline Factor} \begin{pmatrix} \text{Low} = 0.8,\ \text{Very Low} = 0.6 \\ \text{Average} = 1.0 \\ \text{High} = 1.2,\ \text{Very High} = 1.5 \end{pmatrix}$$

$$\text{Passengers} = \sum_{n=1}^{N}\left(\frac{\text{Available Seats}}{\text{Aircraft}}(\text{Passenger Load Factor})(\text{No. of AC})\right)_n$$

$$\text{Cargo} = \sum_{n=1}^{N}\left(\frac{\text{Available Tons}}{\text{Aircraft}}(\text{Cargo Load Factor})(\text{No. of AC})\right)_n$$

Transport Related Expenses (page 51)

$$\text{Transport Related Expenses} = 1.035\left(\text{Rest of All Other Operating Expenses}\right)$$

The factor 1.035 is a reasonable allocation for passenger airlines in 1999. For cargo airlines, such as FedEx and some others, a more representative value would be 1.5 to 2.0, as Figure 45 suggests.

All Other Operating Expenses (page 53)

$$\begin{aligned}\text{All Other Operating Expenses} = {} & \text{Passenger Service} \\ & + \text{Landing Fees} \\ & + \text{Rest of All Other} \\ & + \text{Transport Related}\end{aligned}$$

Total Operating Expenses (page 56)

$$\begin{aligned}\text{Total Operating Expenses} = {} & \text{Total Aircraft Operating Expenses} \\ & + \text{All Other Operating Expenses}\end{aligned}$$

Aircraft Model Factors Used in the Flight Equipment Maintenance Expense Estimating Equation

Aircraft Model	Aircraft Model Factor	Aircraft Model	Aircraft Model Factor	Aircraft Model	Aircraft Model Factor	Aircraft Model	Aircraft Model Factor
A300-600	Earliest	A300-600	Early	CV-640	Early	A320-1/2	Recent
ATR-42	Earliest	A310-2CF	Early	DC-10-1	Early	ATR-72	Recent
ATR-72	Earliest	A319	Early	DC-10-3	Early	B-737-3/7	Recent
B-717-2	Earliest	A320-1/2	Early	DC-10-4	Early	B-737-4	Recent
B-727-2	Earliest	ATR-42	Early	DC-10-4	Early	B-737-5	Recent
B-727-QC	Earliest	ATR-72	Early	DC-10-4	Early	B-757	Recent
B-737-1/2	Earliest	AVRO-RJ85	Early	DC-9-10	Early	B-767-3/ER	Recent
B-737-2C	Earliest	B-707-3C	Early	DC-9-30	Early	DC-9-40	Recent
B-747-1	Earliest	B-727-2	Early	DC-9-40	Early	DC-9-50	Recent
B-747-F	Earliest	B-737-1/2	Early	DC-9-50	Early	FOKR-100	Recent
BAE-146-3	Earliest	B-737-2C	Early	DHC8-100	Early	MD-11	Recent
BAE-ATP	Earliest	B-737-3/7	Early	DO-28	Early	MD-80	Recent
DC-10-1	Earliest	B-737-5	Early	DO-328	Early	MD-87	Recent
DC-10-3	Earliest	B-747-2/3	Early	EMB-110	Early	MD-87	Recent
DC-10-4	Earliest	B-747-2/3	Early	EMB-120	Early	MD-90	Recent
DC-10-F	Earliest	B-747-4	Early	EMB-135	Early	B-737-8	Latest
DC-3	Earliest	B-747-F	Early	EMB-145	Early	B-747-4	Latest
DC-6	Earliest	B-757	Early	F-27	Early	MD-90	Latest
DC-8-50	Earliest	B-767-2/ER	Early	FALCON	Early	RJ-145	Latest
DC-8-50F	Earliest	Bae RJ-100/ER	Early	FOKR-100	Early	B-777	Very Latest
DC-8-61	Earliest	BAE-146-2	Early	JETST-31	Early		
DC-8-62	Earliest	BECH-18	Early	JETST-41	Early		
DC-8-63	Earliest	BECH-C99	Early	L-1011	Early		
DC-8-63F	Earliest	B-l900	Early	L-1011-5	Early		
DC-8-71	Earliest	C-185	Early	L-188A	Early		
DC-8-73	Earliest	C-208	Early	LEAR-25	Early		
DC-8-73F	Earliest	C-401	Early	LEAR-35	Early		
DC-9-10	Earliest	C-402	Early	MD-11	Early		
DC-9-15	Earliest	C-404	Early	MD-80	Early		
DC-9-30	Earliest	C-411	Early	MD-90	Early		
DHC8-100	Earliest	C-421	Early	METRO-II	Early		
EMB-120	Earliest	C-46	Early	METRO-III	Early		
EMB-135	Earliest	CASA-212	Early	MU-2/B	Early		
F-28	Earliest	CES-206/7	Early	PA-30'S	Early		
FOKR-100	Earliest	CV-240	Early				
L-1011	Earliest	CV-580	Early				
L-382E	Earliest	CV-600	Early				
MD-11	Earliest						
SF-340	Earliest						

APPENDIX 2

FLIGHT ATTENDANT SUPPORTING DATA

The tabulated data below give values of flight attendant hours per year for several airlines and their associated entities. Very few entities have attendants working close to what some consider a full year (i.e., 40 hours a week times 50 weeks = 2,000 hours). Because aircraft are operated about 3,600 hours a year, the flight attendant staff must be on the order of 2 to 3 times the number of aircraft that the airline operates.

Airlines	Atlantic	Domestic	Latin America	Pacific
American Airlines	898	991	957	1,071
Alaska Airlines		1,024		
Delta Air Lines	982	1,028	1,273	1,060
America West Airlines		1,496		
Trans World Airlines		1,048		
United Air Lines	1,278	884	1,076	787
USAir		775		
Continental Airlines	1,024	1,394	1,771	
Southwest Airlines		1,191		
Northwest Airlines	1,501	1,102		1,347
Continental Micronesia				1,317
Hawaiian Airlines		1,189		1,250
World Airways	1,094	1,094		
Sun Country Airlines		1,309		1,158
Ryan Int'l Airl. (New)		1,619		
Atlantic Southeast Airl.		1,522		
Horizon Air		1,816		
Continental Express		1,744		
Air Wisconsin		1,138		
USAir Shuttle		860		
Vanguard Air Express		1,205		
Miami Air Int'l		2,055		
Reeve Aleutian Airways		1,257		
Airtran / Frontier (Old)		1,520		
Spirit Air Lines		1,107		
Midwest Express Airlines		1,126		
National Airlines (New)		580		
Average	**1,130**	**1,234**	**1,269**	**1,142**

APPENDIX 3. REPRESENTATIVE AIRCRAFT CHARACTERISTICS

Representative engine and aircraft weight and performance data are required by the several equations in the economic model. One example is the computation of fuel used per departure. The author has gathered the following engine and aircraft characteristics over the years from various sources. Cruise SFC and cruise L/D are, in most cases, estimated by the author and probably will not agree with manufacturers' data. The fact that fuel used per departure is reasonably well predicted with these characteristics, as Figure 13 shows, is perhaps fortuitous.

Aircraft Model	Engine Model	Number of Engines	Eng. Takeoff Power (BHP)	Eng. Takeoff Thrust (lb)	Engine Wgt. (dry)	Max Takeoff Wgt. (lb)	Max Land. Wgt. (lb)	Operating Wgt. Empty (lb)	Reference Engine Thrust NOTE: Turboprop Uses 5 lb/HP	Total Takeoff Thrust (lb)	Takeoff SFC	Cruise SFC	Cruise L/D	L/D Divided by SFC
A300-600	GE CF6-80C2A1	2	0	59,000	9,480	363,765	304,240	198,665	59,000	118,000	0.334	0.450	12.5	27.71
A319	CFM56-5A4	2	0	22,000	4,995	141,095	134,480	88,537	22,000	44,000	0.320	0.600	14.1	23.58
A320-1/2	CFM56-5B4/P	2	0	27,000	5,250	162,040	142,195	92,980	27,000	54,000	0.340	0.600	14.6	24.38
B-727-2	PW JT8D-9	3	0	14,500	3,217	172,000	150,000	99,000	14,500	43,500	0.595	0.790	12.9	16.39
B-737-1/2	PW JT8D-7	2	0	14,000	3,205	115,500	107,000	60,507	14,000	28,000	0.585	0.790	12.9	16.39
B-737-3/7	CFM56-7B24	2	0	24,200	5,257	154,500	129,200	84,100	24,200	48,400	0.360	0.603	13.2	21.87
B-737-4	CFM56-3C1	2	0	23,500	4,301	138,500	121,000	72,700	23,500	47,000	0.390	0.672	13.7	20.34
B-737-5	CFM56-3C1	2	0	23,500	4,301	115,500	110,000	68,240	23,500	47,000	0.390	0.672	12.2	18.20
B-737-8	CFM56-7B27	2	0	27,300	5,257	174,200	146,300	90,710	27,300	54,600	0.380	0.603	14.9	24.66
B-747-1	CF6-50E2	4	0	52,500	8,768	710,000	564,000	375,000	52,500	210,000	0.371	0.499	13.4	26.89
B-747-2/3	CF6-80C2B1	4	0	59,000	9,499	820,000	585,000	390,000	59,000	236,000	0.335	0.450	11.8	26.11
B-747-4	RR RB211-524G	4	0	58,000	9,670	800,000	574,000	400,700	58,000	232,000	0.574	0.570	13.9	24.40
B-757	PW 2037	2	0	38,250	7,300	220,000	210,000	128,730	38,250	76,500	0.335	0.563	14.1	25.13
B-767-2/ER	PW 4052	2	0	52,200	9,213	345,000	278,000	185,800	52,200	104,400	0.351	0.540	15.3	28.42
B-767-3/ER	PW 4060	2	0	60,000	9,213	400,000	320,000	199,600	60,000	120,000	0.354	0.537	14.9	27.69
B-777	GE90-76B	2	0	76,400	16,664	515,000	445,000	306,500	76,400	152,800	0.389	0.520	17.0	32.74
DC-10-1	GE CF6-6D	3	0	40,000	7,505	430,000	363,500	231,779	40,000	120,000	0.354	0.631	14.0	22.16
DC-10-3	GE CF6-50A	3	0	49,000	8,225	555,000	403,000	263,087	49,000	147,000	0.389	0.654	15.6	23.83

Aircraft Model	Engine Model	Number of Engines	Eng. Takeoff Power (BHP)	Eng. Takeoff Thrust (lb)	Engine Wgt. (dry)	Max Takeoff Wgt. (lb)	Max Land. Wgt. (lb)	Operating Wgt. Empty (lb)	Reference Engine Thrust NOTE: Turboprop Uses 5 lb/HP	Total Takeoff Thrust (lb)	Takeoff SFC	Cruise SFC	Cruise L/D	L/D Divided by SFC
DC-10-4	JT9D-59A	3	0	53,000	9,075	572,000	403,000	271,062	53,000	159,000	0.595	0.624	14.6	23.44
DC-9-10	PW JT8D-1	2	0	14,000	3,155	77,700	74,000	45,300	14,000	28,000	0.585	0.785	10.6	13.44
DC-9-30	PW JT8D-7	2	0	14,000	3,205	103,000	93,400	56,200	14,000	28,000	0.585	0.790	12.0	15.18
DC-9-40	PW JT8D-11	2	0	15,000	3,389	121,000	110,000	58,670	15,000	30,000	0.620	0.807	12.7	15.75
FOKR-100	RR Tray Mk 620-15	2	0	13,850	3,099	95,000	88,000	53,738	13,850	27,700	0.300	0.690	10.6	15.29
L-1011	RR RB.211-22B	3	0	42,000	9,200	430,000	358,000	240,400	42,000	126,000	0.370	0.640	13.4	20.98
L-1011-5	RR RB.211-22B	3	0	42,000	9,200	430,000	358,000	240,400	42,000	126,000	0.370	0.640	13.4	20.98
MD-11	PW 4460	3	0	60,000	9,420	602,500	430,000	288,880	60,000	180,000	0.485	0.450	13.2	29.31
MD-80	PW JT8D-209	2	0	18,500	4,410	140,000	128,000	79,757	18,500	37,000	0.468	0.724	13.1	18.09
MD-90	IAE V2525-D5	2	0	25,000	5,224	156,000	142,000	88,000	25,000	50,000	0.370	0.575	11.7	20.35
EMB-145	AE3007A	2	0	7,240	1,581	45,415	41,226	25,772	7,240	14,480	0.330	0.700	8.0	11.43
ATR-42	PW 120	2	1,800	0	921	34,725	34,171	21,986	9,000	18,000	0.390	0.650	9.6	14.76
ATR-72	PW 124B	2	2,160	0	1,060	47,400	47,068	27,558	10,800	21,600	0.468	0.550	9.6	17.44
AVRO-RJ85	Allied Signal LF 507	4	0	7,000	1,385	97,000	85,000	53,100	7,000	28,000	0.406	0.800	10.0	12.50
A310-2CF	GE CF6-80A3	2	0	50,000	8,720	313,053	267,859	176,683	50,000	100,000	0.357	0.525	12.5	23.75
B-707-3C	PW JT3D-3B	4	0	18,000	4,260	333,600	247,000	146,400	18,000	72,000	0.535	0.790	12.5	15.82
B-717-2	BMW/Rolls BR715	2	0	18,500	4,597	114,000	102,000	89,000	18,500	37,000	0.370	0.790	12.0	15.18
B-727-QC	PW JT8D-7B	3	0	14,000	3,155	169,000	142,500	89,000	14,000	42,000	0.585	0.790	12.5	15.82
B-747-F	GE CF6-50E2	4	0	52,500	8,768	820,000	580,000	391,000	52,500	210,000	0.371	0.499	13.4	26.89
BAE-146-3	ALF 502R-7	4	0	7,500	1,283	97,500	84,500	54,752	7,500	30,000	0.405	0.800	12.0	15.00
BAE-ATP	PW 126A	2	2,795	0	1,060	52,200	51,000	31,400	13,975	27,950	0.461	0.710	12.0	16.90
BECH-18	PW R-985AN-14B	2	450	0	668	8,750	8,750	6,600	2,250	4,500	0.500	0.600	7.5	12.50
BECH-C99	PT6A-36	2	750	0	331	11,300	11,300	6,494	3,750	7,500	0.590	0.720	7.3	10.07
B-l900	PT6A-65B	2	1,137	0	481	16,600	16,100	8,700	5,685	11,370	0.506	0.800	6.5	8.13
C-185	Cont. IO-540-D	1	300	0	459	3,350	3,350	1,696	1,500	1,500	0.500	0.700	6.0	8.57

Aircraft Model	Engine Model	Number of Engines	Eng. Takeoff Power (BHP)	Eng. Takeoff Thrust (lb)	Engine Wgt. (dry)	Max Takeoff Wgt. (lb)	Max Land. Wgt. (lb)	Operating Wgt. Empty (lb)	Reference Engine Thrust NOTE: Turboprop Uses 5 lb/HP	Total Takeoff Thrust (lb)	Takeoff SFC	Cruise SFC	Cruise L/D	L/D Divided by SFC
C-208B	PW PT6A-114	1	675	0	345	8,750	8,500	4,550	3,375	3,375	0.640	0.700	5.5	7.86
C-401/402	Cont. TSIO-520-VB (TC)	2	325	0	560	6,850	6,850	4,077	1,625	3,250	0.550	0.700	6.0	8.57
C-46	PW R-2800-51	2	2,000	0	2,330	50,000	43,000	29,483	10,000	20,000	0.700	0.700	6.5	9.29
CASA-212	TPE 331-5-251C	2	750	0	360	16,975	16,424	8,333	3,750	7,500	0.626	0.800	6.0	7.50
CES-206	Cont. IO-520-A	1	285	0	471	3,300	3,300	1,705	1,425	1,425	0.550	0.700	6.0	8.57
CV-240	PW R-2800-CA18	2	2,400	0	2,350	41,790	39,800	27,600	12,000	24,000	0.540	0.807	6.0	7.43
CV-580	ALLISON 501-D13	2	3,460	0	1,756	54,600	52,000	30,275	17,300	34,600	0.552	0.807	8.5	10.53
CV-600	RR Dart Rda.10	2	2,750	0	1,366	46,200	44,000	28,380	13,750	27,500	0.556	0.807	8.5	10.53
CV-640	RR Dart Rda.11	2	2,750	0	1,366	55,000	52,500	30,275	13,750	27,500	0.556	0.807	8.5	10.53
DC-3	Wright Cyclone R 1820	2	1,475	0	1,398	25,200	24,400	16,480	7,375	14,750	0.500	0.800	14.0	17.50
DC-6	PW R-2800-CA15	4	2,400	0	2,350	97,200	88,200	51,495	12,000	48,000	0.500	0.800	14.0	17.50
DC-6A	PW R-2800-CB17	4	2,500	0	2,390	107,000	88,200	54,148	12,500	50,000	0.500	0.800	14.0	17.50
DC-6B	PW R-2800-CB18	4	2,500	0	2,390	107,000	88,200	54,148	12,500	50,000	0.500	0.800	14.0	17.50
DC-8-50	PW JT3D-3	4	0	18,000	4,170	325,000	217,000	132,325	18,000	72,000	0.535	0.800	14.3	17.81
DC-8-50F	PW JT3D-4	4	0	18,000	4,170	325,000	217,000	132,325	18,000	72,000	0.535	0.800	14.3	17.81
DC-8-61	PW JT3D-3B	4	0	18,000	4,260	325,000	258,000	148,897	18,000	72,000	0.535	0.800	14.3	17.81
DC-8-62	PW JT3D-3B	4	0	18,000	4,260	335,000	258,000	141,903	18,000	72,000	0.535	0.800	14.3	17.81
DC-8-63	PW JT3D-7	4	0	19,000	4,260	350,000	245,000	153,749	19,000	76,000	0.560	0.800	14.3	17.81
DC-8-63F	PW JT3D-8	4	0	19,000	4,260	355,000	258,000	140,000	19,000	76,000	0.560	0.800	14.3	17.81
DC-8-71	CFM56-2-1C	4	0	24,000	4,635	325,000	240,000	162,700	24,000	96,000	0.370	0.651	14.3	21.89
DC-8-73	CFM56-2-1C	4	0	24,000	4,635	350,000	245,000	165,600	24,000	96,000	0.370	0.651	14.3	21.89
DC-8-73F	CFM56-2-1C	4	0	24,000	4,635	355,000	275,000	140,000	24,000	96,000	0.370	0.651	14.3	21.89
DC-9-15	PW JT8D-1	2	0	14,000	3,155	90,700	81,700	50,800	14,000	28,000	0.585	0.750	9.5	12.67
DC-9-50	PW JT8D-15	2	0	15,500	3,309	121,000	110,000	65,000	15,500	31,000	0.630	0.611	10.5	17.18
DHC8-100	PW 120A	2	2,000	0	933	34,500	33,900	22,100	10,000	20,000	0.485	0.550	9.8	17.73

Aircraft Model	Engine Model	Number of Engines	Eng. Takeoff Power (BHP)	Eng. Takeoff Thrust (lb)	Engine Wgt. (dry)	Max Takeoff Wgt. (lb)	Max Land. Wgt. (lb)	Operating Wgt. Empty (lb)	Reference Engine Thrust NOTE: Turboprop Uses 5 lb/HP	Total Takeoff Thrust (lb)	Takeoff SFC	Cruise SFC	Cruise L/D	L/D Divided by SFC
DO-28	TPE331-5-252D	2	715	0	360	14,110	13,448	8,243	3,575	7,150	0.548	0.800	8.0	10.00
DO-328	PW 119A	2	2,288	0	921	27,557	27,006	20,492	11,440	22,880	0.479	0.611	11.3	18.49
EMB-110	PWC PT6A - 34	2	750	0	311	13,000	12,570	7,751	3,750	7,500	0.595	0.611	11.6	18.99
F-27	RR DART Rda.7	2	2,050	0	1,235	19,730	18,600	10,606	10,250	20,500	0.578	0.611	9.0	14.73
F-28	RR Spey Mk 555-15H	2	0	9,900	2,222	73,000	66,500	38,269	9,900	19,800	0.560	0.700	10.5	15.00
FALCON 10	G-AiResearch TFE731-2	2	0	3,500	725	18,740	17,640	10,760	3,500	7,000	0.490	0.815	10.0	12.27
EMB-120	PW 118	2	1,800	0	921	25,353	24,802	15,163	9,000	18,000	0.516	0.611	8.2	13.42
EMB-135	AE 3007A	2	0	7,040	1,581	44,092	40,785	24,544	7,040	14,080	0.330	0.700	9.6	13.70
JETST-31	TPE331-10	2	1,020	0	385	15,212	14,550	9,570	5,100	10,200	0.550	0.800	8.0	10.00
JETST-41	TPE331-14GR/HR	2	1,759	0	633	24,000	23,300	14,114	8,795	17,590	0.502	0.800	8.7	10.81
L-188A	ALLISON 501-D13	4	3,750	0	1,756	116,000	95,650	57,300	18,750	75,000	0.540	0.807	7.5	9.29
L-382E	T56A-7A	4	4,050	0	1,833	154,324	130,000	77,680	20,250	81,000	0.528	0.650	14.0	21.54
LEAR-25	GE CJ610-6	2	0	2,950	392	15,000	13,300	7,683	2,950	5,900	0.980	0.960	10.0	10.42
LEAR-35	AiResearch TFE 731-2	2	0	3,500	725	17,000	14,300	9,110	3,500	7,000	0.490	0.815	10.0	12.27
MD-87	JT8D-217C	2	0	18,500	4,533	140,000	128,000	79,606	18,500	37,000	0.500	0.807	11.5	14.25
METRO-II	Garrett TPE331-10UA-511G	2	900	0	380	12,500	12,500	7,800	4,500	9,000	0.571	0.600	10.0	16.67
METRO-III	Garrett TPE331-11U-601G	2	1,000	0	400	14,500	14,000	8,737	5,000	10,000	0.530	0.600	10.8	17.92
MU-2/B	AiResearch TPE 731-25B	2	715	0	335	10,802	10,262	6,563	3,575	7,150	0.590	0.700	9.0	12.86
PA-30'S	LYCOMING IO-320-B	2	160	0	285	3,725	3,725	2,238	800	1,600	0.530	0.600	10.5	17.50
PA-32	LYCOMING IO-540-KIA5	1	300	0	470	3,400	3,400	1,713	1,500	1,500	0.530	0.600	10.5	17.50
RJ-100/ER	Allied Signal LF 507	4	0	7,000	1,385	101,500	88,500	55,100	7,000	28,000	0.406	0.800	12.0	15.00
RJ-145	AE3007A	2	0	7,580	1,581	45,415	41,226	25,772	7,580	15,160	0.330	0.700	8.0	11.43
SF-340	GE CT7-5A2	2	1,630	0	432	27,275	26,500	17,415	8,150	16,300	0.474	0.800	9.5	11.88

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14. ABSTRACT
This report presents a new economic model of operating expenses for 67 airlines. The model is based on data that the airlines reported to the United States Department of Transportation in 1999. The model incorporates expense-estimating equations that capture direct and indirect expenses of both passenger and cargo airlines. The variables and business factors included in the equations are detailed enough to calculate expenses at the flight equipment reporting level. Total operating expenses for a given airline are then obtained by summation over all aircraft operated by the airline. The model's accuracy is demonstrated by correlation with the DOT Form 41 data from which it was derived. Passenger airlines are more accurately modeled than cargo airlines. An appendix presents a concise summary of the expense estimating equations with explanatory notes. The equations include many operational and aircraft variables, which accommodate any changes that airline and aircraft manufacturers might make to lower expenses in the future. In 1999, total operating expenses of the 67 airlines included in this study amounted to slightly over $100.5 billion. The economic model reported herein estimates $109.3 billion.

15. SUBJECT TERMS
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