N73-31985

An Analysis of Airline Costs

Lecture Notes for MIT Courses

16.73 Airline Management and Marketing

Robert W. Simpson

Flight Transportation Laboratory, MIT

NASA-MIT Summer Workshop on Air Transportation

Waterville Valley, New Hampshire

July 1972

73

1.0 Introduction

Unlike most forms of public transportation, there is a good body of data describing the costs of providing air transportation services for U.S. domestic airlines. The source of this data is monthly and quarterly reports by US carriers to the CAB using the Uniform System of Accounts and Reports (Form 41). The existence of this data has made it possible for the air transport industry to study the costs of providing service and to introduce new, lower cost methods and equipment in a rational manner.

Historically, costs have been divided into two main categories : Direct Operating Costs, those directly associated with a transport aircraft's operation; and Indirect Operating Costs which are those not directly associated with an aircraft, but rather with an airline and its ground operations.

There are several formula for estimating direct operating costs. A common standard for turbine transports is the ATA 67 formula used by manufacturers to compare transport aircraft (Reference 3).

There is no standard formula for indirect operating costs although they represent roughly one half of the total operating cost and cannot be ignored in any study of air transportation systems. They must be constructed by the analyst for the airline system he is studying using whatever data is available. For new forms of air transportation this is a major difficulty.

The system of accounts used by air carriers to submit their costs to the CAB does not recognize the existence of direct and indirect groupings. It has its own classification scheme which we shall now briefly describe.

U.S. airlines are required to submit to the CAB on a quarterly basis their operating expenses, among other financial statistics, in accordance with the economic regulations of the CAB Uniform

System of Accounts and Reports (Form 41). The accounting provisions are different for route vs. supplemental carriers. Within the route carriers, domestic trunks and locals (Group III) are again distinguished from third level carriers (Groups I and II).

Each cost item in Form 41 is given a four-digit account number. The first two digits designate more general classifications. They are referred to as the functional classification. The last two digits are more detailed breakdowns. They are referred to as the objective classifications. A fifth digit, appended as a decimal, has been assigned for internal control by the CAB. It subdivides the objective classifications.

We include in here, for reference purposes, brief excerpts of the official definitions of the Functional classifications. Full descriptions of the Functional and Objective classifications can be found in Reference 4.

5100 Flying Operations

This function shall include expenses incurred directly in the in-flight operation of aircraft and expenses attaching to the holding of aircraft and aircraft operational personnel in readiness for assignment to an in-flight status.

5200 Direct Maintenance

This function shall include the costs of labor, materials and outside services consumed directly in periodic maintenance operations and the maintenance and repair of property and equipment of all types and classes, regardless of the location at which incurred.

5300 Maintenance Burden.

This function shall include all overhead or general expenses used directly in the activities involved in periodic maintenance operations and the maintenance and repair of property and equipment of all types and classes, including the cost of direct labor, materials and outside services used in the maintenance and repair of property and equipment.

5500 Passenger Service.

This function shall include all expenses chargeable directly to activities contributing to the comfort, safety and convenience of passengers while in flight and when flights are interrupted.

6100 Aircraft Servicing.

This function shall include the compensation of ground personnel and other expenses incurred on the ground incident to the protection and control of the in-flight movement of aircraft; scheduling or preparing aircraft operational crews for flight assignment; landing and parking aircraft; visual inspection, routine checking, servicing and fueling of aircraft; and other expenses incurred on the ground incident to readying for arrival and take-off aircraft.

6200 Traffic Servicing.

This function shall include the compensation of ground personnel and other expenses incurred on the ground incident to handling traffic of all types and classed on the ground subsequent to the issuance of documents establishing the air carrier's responsibility to provide air transportation. Expenses attributable to the operation of airport traffic offices shall also be included in this subfunction; expenses attributable to reservations centers shall be excluded. It shall include expenses incurred in both enplaning and deplaning traffic as well as expenses incurred in preparation for enplanement and all expenses subsequent to deplanement.

6300 Servicing Administration.

This function shall include expenses of a general nature incurred in performing supervisory or administrative activities relating solely and in common to functions 6100 Aircraft Servicing and 6200 Traffic Servicing.

6500 Reservations and Sales.

This function shall include expenses incident to direct sales solicitation, documenting sales, controlling and arranging or confirming aircraft space sold, and in developing tariffs and schedules for publication. It shall also include expenses attributable to the operation of city traffic offices.

6600 Advertising and Publicity.

This function shall include expenses incurred in creating public preference for the air carrier and its services; stimulating development of the air transport market; and promoting the air carrier or developing air transportation generally.

6800 General and Administrative.

This function shall include expenses of a general corporate nature and expenses incurred in performing activities which contribute to more than a single operating function such as general financial accounting activities and other general operational administration which are not directly applicable to a particular function.

7000 Depreciation and Amortization.

This function shall include all charges to expense to record losses suffered through current exhaustion of the serviceability of property and equipment due to wear and tear from use and the action of time and the elements, which are not replaced by current repairs, as well as losses in serviceability occasioned by obsolescence, supersession, discoveries, change in popular demand or action by public authority. It shall also include charges for the amortization of capitalized developmental and preoperating costs, and other intangible assets applicable to the performance of air transportation.

2.0 The Art of Cost Estimation

Before we describe in greater detail a classification system for airline costs, it is necessary to make a few observations on the nature of cost estimation. It is very much dependent upon the judgement of the cost analyst who must correctly apply the available data according to a given purpose or objective. To be correct, the cost analyst must understand the operations of the airline, and how the activities of the airline are measured, as well as how the costs are incurred and recorded.

The data source is usually a cost accounting process. This provides data on the cumulated expenses in various categories over a time period like a quarter, or year, and must be correlated by the analyst with cumulated measures of airline activity which he deems to be causing this expense. Different analysts will correlate a given cost with different measures of activity, or the same analyst may even use different activity measures in analyzing costs for different purposes.

2.1 Cost Functions

Here we shall attempt to provide an analytical framework for cost estimation to show some of its difficulties. We shall introduce the abstract concept of a cost function.

Cost functions attempt to relate the cost of some operation to the various component activities related to the operation. We may denote a cost function as $C_i(\bar{x},t)$

where C_i is the cost function for operation i, (dollars)

t is time variable

x is a vector of activity variables $(x_1, x_2, x_3, .. x_n)$

Thus a cost function provides a time history of the cost of operation i as a function of the activities which are deemed to cause it. We rarely know with any confidence such an analytical expression for any cost function.

Typical measures of activity for airline operations are listed below:

P - passengers originated (or enplaned)

D - aircraft departures

RH - revenue aircraft block hours

RM - revenue aircraft miles

RPM - revenue passenger miles

ASM - available seat miles

RTM - revenue ton miles

ATM - available ton miles

R - revenue dollars

These are cumulative measures for the airline system over some time period similar to the cumulated expense and one expects that any cost function would be montonic if expressed in terms of these measures (i.e. the cumulated cost never decreases as the cumulative measures of activity increase.)

However, analysts commonly use ratios to "average" these cumulative measures, as an index of activity levels. Some of the common ratios are listed below:

$\bar{P} = \frac{P}{D}$ = average passengers per departure

$\bar{D} = \frac{RM}{D}$ = average aircraft stage length, or hop length

$\bar{d} = \frac{RPM}{P}$ = average passenger trip length (or hop length).

$\bar{T}_b = \frac{RH}{D}$ = average aircraft block time

$\bar{r} = \frac{R}{P}$ = average ticket price per passenger

$\overline{LF} = \frac{RPM}{ASM}$ = average passenger load factor

$\overline{LF} = \frac{RTM}{ATM}$ = Average overall ton-mile load factor

Cost functions will generally be "joint" functions of the activity variables, i.e. more than one variable is causing the expense in a certain category. Analysts generally find it necessary to represent the cost as a "separable" function, or to ignore the "jointness" and represent the costs as a function of a single activity variable. Thus, our general cost function is separated into components,

$$C_i(x_1,x_2) = C_i^1(x_1) + C_i^2(x_2)$$

where commonly only one component is said to exist.

The art of cost estimation occurs precisely at this point. The cost analyst must choose the form of the cost function he believes to exist. Having done so, he returns to the "science" of econometrics to use linear or non-linear multiple regression techniques to determine the coefficients and parameter which give a "best fit", or "best correlation" between the observed cost data, and the observed activity data. The analyst postulates cause and effect, and a circumstance of a good correlation does not verify his postulate, although this is often hopefully stated by inexperienced analysts. A result of good correlation is necessary, but not sufficient to verify this postulate.

2.2 Marginal and Unit Costs

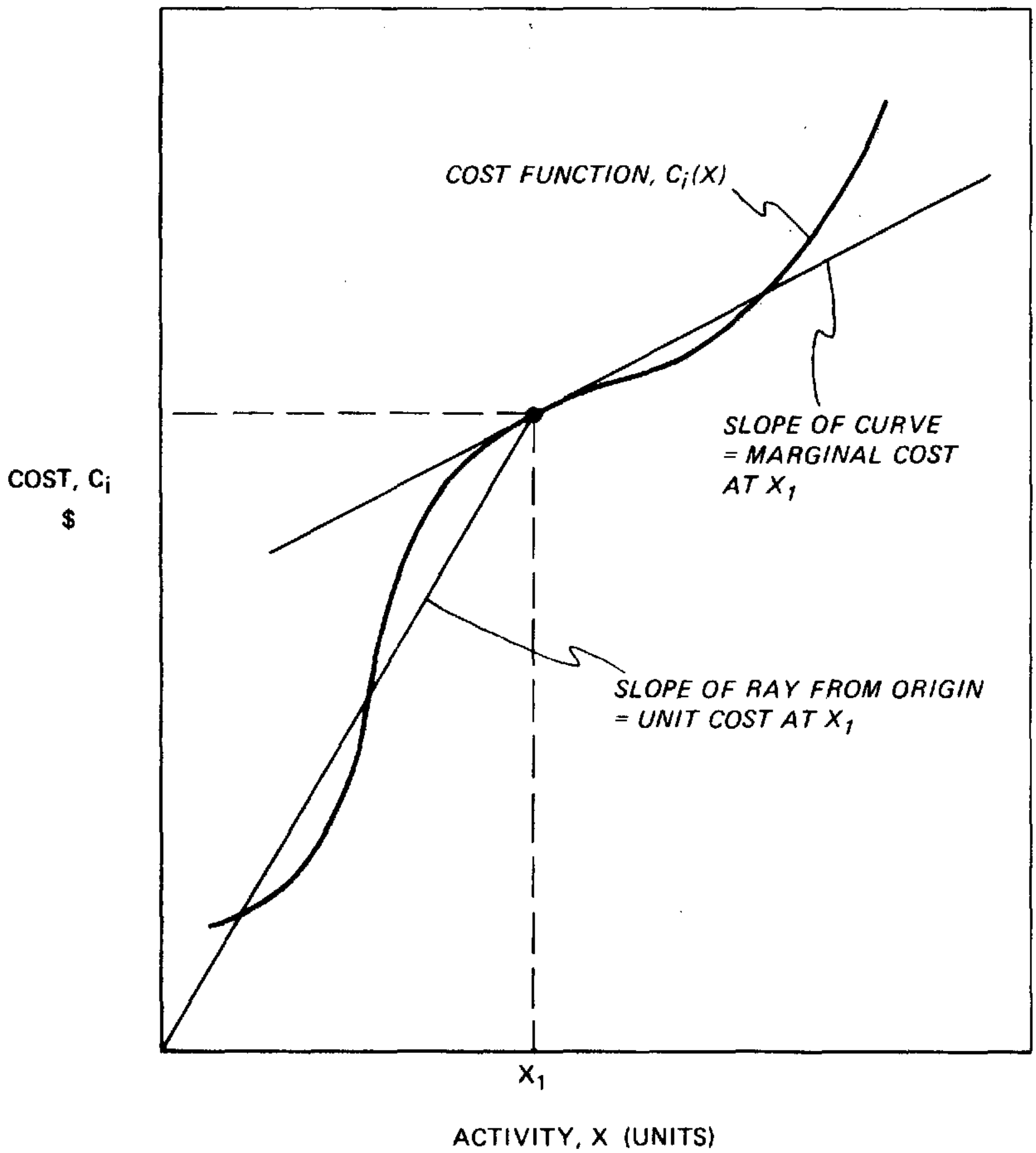
If we assume that we have a single component cost function, we can plot it against its activity variable as shown by figure 1. In this case, we may take the ratio of the cost to its activity at any point to form a "unit cost". Its value corresponds to the slope of the line from the origin to the cost curve as shown in figure 1, and obviously varies as the scale of operations changes, i.e. the unit cost is a function of x.

$$\text{Unit Cost} = c(x) = \frac{C(x)}{x}$$

There is another cost corresponding to the actual slope of the cost curve at any point. This is called the "marginal cost" and is also a function of the activity variable x.

$$\text{Marginal Cost} = c'(x) = \frac{\partial C(x)}{\partial x}$$

Figure 1 A SINGLE COMPONENT COST FUNCTION

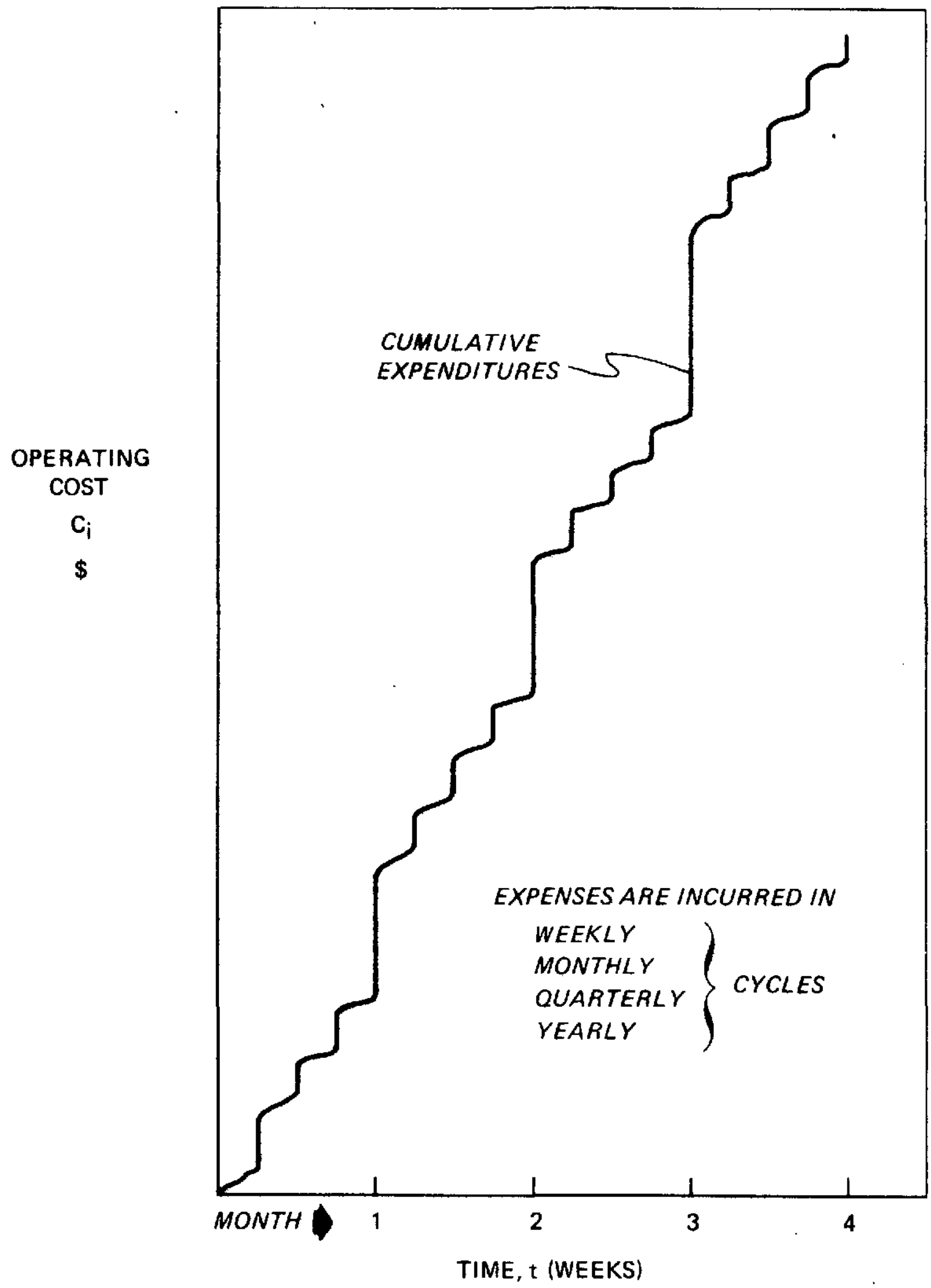


In general marginal costs do not equal unit costs.

The marginal costs also exist for a general cost function, and if known, would tell us the rate of change of cost as any activity variable is changed. If the general cost function is separable, then unit costs can exist for each component of the cost function. Notice that the unit costs represent an "average cost per unit", and thus are sometimes called average costs. We shall avoid that usage here, and refer to them as unit costs.

In a similar manner, costs may be plotted against time as shown in figure 2. The unit cost becomes the "long term" cost, while "short term" rates of expense may be determined by taking the slopes over shorter periods of time. Given a time frame for a cost analysis, the analyst regards short term costs as "variable" costs, and long term costs as "fixed" costs. The distinction of variable and fixed costs may also apply to other activity measures used in a given cost analysis, where only a certain portion of the costs are considered to be variable. Yet another cost concept is the distinction made between "sunk" and "recoverable" costs, where a large expense or investment made at some point in time is classified as to whether or not it could be recovered in some fashion.

Figure 2 VARIATION OF COST OVER TIME



3.0 Categorization of Airline Costs

We shall follow the categories of costs developed in reference 1, where:

a) Direct Operating Costs are designated Flight Operating Costs

b) Indirect Operating Costs are divided into two categories;

1) Ground Operating Costs

2) System Operating Costs

c) System Non-operating Costs are also identified.

Table 1 shows the major categories of this new cost structure. Instead of just direct and indirect categories, there are now four major categories. Table 2 gives a detailed breakdown of the operating cost categories showing a percentage of total operating costs for US domestic trunk airlines for each category and sub-category. Table 2 also indicates the time frame for the expense and some arbitrary allocations of the cost. A brief explanation of this cost categorization is given below:

a) Flight Operating Costs

These are usually known as direct operating costs, and are defined here to coincide with the definition used in reference 2, so that document can be used as a source of data. There is one exception where rental and flight insurance costs listed under Direct Flying Operations are transferred to a category called Flight Equipment Ownership. Flight Operating Costs are usually allocated against the flying hours of the airline fleet. Note that cabin crew expenses and interest costs of debt associated with aircraft ownership are not included, even though they are major cost items. On the other hand, a maintenance burden is included covering general administrative and overhead expenses for the airline maintenance shops.

b) Ground Operating Costs

This is a new group of costs which might be called direct ground operating costs. These costs are incurred at the station in handling passengers and aircraft, and are directly incurred

Table 1

<u>A Breakdown of Airline Expenses</u>

A. Flight Operating Costs - (FC)
- A.1 Direct Flying Operations
- A.2 Flight Maintenance
- A.3 Flight Equipment Ownership

B. Ground Operating Costs - (GC)
- B.1 Reservations and Sales
- B.2 Traffic Servicing
- B.3 Aircraft Servicing

C. System Operating Costs - (SC)
- C.1 System Promotional Costs
- C.2 Svstem Administrative Costs
- C.3 Ground Maintenance
- C.4 Ground Equipment Ownership

D. Total Operating Costs - (TOC) = Sum of A + B + C

E. System Non-Operating Costs - (SNC)
- E.1 Interest and Debt Expense
- E.2 Taxes

TABLE 2 - BREAKDOWN OF AIRLINE OPERATING COSTS

A = Allocation Frame x = Expenditure Frame	Allocation Transform	% TOC (1970)	Time Frame for Expenditure $/ Pax.	$/ Dep.	$/ Hr.	$/ Mo.	$/ Yr.	$/ Rev.
A. FLIGHT OPERATING COSTS		55.7			A			
1. Direct Flying Operations		26.5			A			
Flt. Crew	Hrs./Mo.	13.5			A ←	x		
Fuel, Oil		13.0			x			
Other		-			A			
2. Flight Maintenance		15.5			A			
Direct Airframe + Other	Hrs./Dep.	4.6		x →	A, x			
Direct Engines	Hrs./Dep.	4.4		x →	A, x			
Burden	Hrs./Year	6.5			A ←		x	
3. Flight Equipment Ownership		13.6			A			
Depreciation Airframe + Other	Hrs./Year	8.2			A ←		x	
Depreciation Engines		1.7			A ←		x	
Obsolescence & Deterioration		0.4			A ←		x	
Flt. Equipment Rental		3.2			A ←		x	
Flt. Insurance		0.4			A ←		x	
B. GROUND OPERATING COSTS		23.8	A	A				
1. Reservations & Sales		8.3	A					
Personnel	Pax./Mo.	3.2	A ←			x		
Commissions	$(\text{Rev./Pax.})^{-1}$	3.9	A ←					x
Other		1.2	A					
2. Traffic Servicing		8.2	A					
Personnel	Pax./Mo.	5.5	A ←			x		
Rentals	Pax./Year	0.7	A ←				x	
Other		1.1	A					
3. Aircraft Servicing		7.3		A				
Personnel	Dep./Mo.	4.0		A ←		x		
Landing Fees		2.0		x				
Other		1.2		A				
C. SYSTEM OPERATING COSTS		20.3						A
1. Promotional Costs		12.6						A
Passenger Flight Service	Rev./Pax. Rev./Mo.	10.2	x →			x →		A
Advertising & Publicity		2.4						x
2. Administrative Costs	Rev./Mo.	4.3				x →		A
3. Ground Maintenance		1.5						A
4. Ground Equipment Ownership	Rev./Year	1.9					x →	A

in providing the complete transportation service. They are best allocated against passengers enplaned, and aircraft departures although other allocations may be useful. Station administative costs are not listed here, but included as a system administrative expense later.

c) System Operating Costs

These costs are the old indirect operating costs remaining after ground operating costs are removed. They are not directly associated wtih supplying the transportation service, and are more of the nature of a system overhead expense. For example, Promotional costs are those spent to increase system revenues, and includes the onboard passenger service expenses of food and cabin crew. Administrative expenses are those of a general management of corporate nature for the complete airline system (except maintenance administration). The maintenance and ownership of ground property and equipment are minor categories included for completeness. System Operating costs may be allocated in an overhead manner against dollars of revenue.

d) Total Operating Costs

The sum of the above costs is called total operating cost.

e) System Non-Operating Costs

This is a new group of costs not normally considered by the old DOC-IOC breakdown. They are not associated with the operations of the compnay, but rather with its corporate existence. The interest expenses associated with corporate debt are substantial, and since most of the airline debt can be associated with new flight equipment, can be related to Flight Equipment Ownership for some analysis purposes. The taxation expenses are associated with corporate profit declaration, and is difficult to separate from the corporation.

The following sections will describe these cost categories in more detail.

4.0 Flight Operating Costs - FC

This grouping of costs is more generally known as "Direct Operating Costs". We shall use the basic definitions of the CAB source document (reference 2) with some minor rearrangements as described previously. These costs are long term, average costs for operating an aircraft. For shorter term operations, various categories of the costs should be dropped. For example, ownership costs, and maintenance burden costs are commonly deleted since they are long term costs spread over several years.

As indicated by Table 2, Flight Operating Costs are roughly 55% of total operating costs.

4.1 Flight Operating Costs per Block Hour, FC_{HR}

The basic cost measure for transport aircraft is the flight operating cost per block hour, FC_{HR}. It is a constant, independent of trip distance for a given aircraft and airline, and therefore provides a simple, useful description for comparing different aircraft in airline service

Another simple measure which is not widely used, but which is useful for comparing aircraft of different capacity is the flight operating cost per seat-hour, FC_{SHR}

$$FC_{SHR} = \frac{FC_{HR}}{Sa}$$

where Sa = available seats

A set of typical values of these measures for US transport aircraft is given in Table 3. Notice that FC_{SHR} varies between 4 to 6 \$/seat hour for both jet and turboprop transports, and that the helicopter costs are much higher.

A more detailed breakdown of these hourly costs is shown in Table 4 for the Boeing 727-100 in domestic service in 1969. The total cost

TABLE 3

Operating Costs Per Hour, Costs Per Seat Hour 1969

Aircraft Type A) Domestic Trunks	Fleet Size	Cost/Hr. ($)	Seats[1]	Cost/Seat Hr. ($)	Average Stage (miles)
B707-100	17	810.59	128	6.33	884
B707-100B	91	774.87	128	6.05	1156
B720	45.1	701.02	120.7	5.85	827
B720B	65.7	669.98	116	5.76	721
DC8-20	43.7	728.60	132.8	5.48	1180
DC8-50	43.3	691.00	134.5	5.14	936
DC8-61	35.5	754.76	196.2	3.85	1033
B727-100	275	564.46	95.6	5.90	508
B727-200	144.2	684.55	125.3	5.45	517
DC-9-30	132.4	439.63	89.3	4.93	298
DC-9-10	67.4	444.59	68.4	6.55	296
BAC-111-400	25.9	554.70	64	8.65	214
Electra	40	526.85	82.7	6.37	187
B-737	86.3	457.56	96.2	4.75	231
B) Local Service					
DC-9-30	50.7	396.64	96.5	4.10	230
CV-580	103.3	256.7	50.7	5.07	118
FH-227	47.1	227.26	44.6	5.09	109
C) Helicopters					
S-61	8	340.7	23.5	14.50	18
V-107 (1968)	4.3	575.3	24.6	23.60	13
C) STOL					
DHC-5 Twin Otter (Est.)		100.00	19	5.25	-

[1] Seats are averaged over aircraft miles performed in 1969.

Table 4

Flight Operating Costs per Block Hour for Boeing 727-100[1]

1.	Direct Flying Operations	- 283.63		
	-Flt. Crew		144.91	144.91
	-Fuel Oil		138.72	138.72
2.	Flight Maintenance	- 158.45		
	-Direct Airframe & Other		48.85	48.85
	-Direct Engine		43.00	43.00
	-Burden		66.30	
3.	Flight Equipment Ownership	- 122.15		
	-Depreciation Airframe & Other		69.77	
	-Depreciation Engines		14.46	
	-Obsolescence and Deterioration		1.78	
	-Flight Equipment Rental		26.75	
	-Flight Insurance		9.39	
4.	Long-Term Average Costs		564.46	
5.	Short-Term Average Costs (less Burden, Ownership Costs)			375.48

[1]Yearly average for Domestic Operations, 1969, 274 Aircraft in service from CAB Operating Cost and Performance Report, August 1970.

of 564 \$/hour is distributed roughly equally between crew, fuel, maintenance, and ownership. Thus, the sub-category, "Direct Operatio made up of fuel and crew accounts for roughly 50%, while the other two sub-categories are each 25%. If maintenance burden, and ownership costs are dropped, a short term or monthly operating cost of 375 \$/hour is obtained. A breakdown of hourly costs for the first six months of 1971 is given in Table 5 for various types of current transports and individual airlines. The costs vary quite widely. For the Boeing 727, they range from 593 to 856 \$/block hour with an average of 665 \$/block hour for this period. This range is due to factors such as wage rates, fuel cost variations, varying maintenance programs, and varying depreciation scheduled. The variation is significant enough to invalidate the use of any standard formula such as the ATA67 DOC formula when studying the operations of a particular airline system, or for return on investment calculations.

In recent years there has been a marked rate of increase of Flight Operating costs due to inflationary factors. Reference 5 is a good source of the trends in operating cost for jet transport aircraft in domestic service. Table 6 is extracted from it to show the effects of inflation on the flight operating costs for the Boeing 727. With this rate of growth in costs, it is necessary to also specify the year in studying the operations of the industry, or a given airline system.

The hourly operating cost FC_{HR} for a transport aircraft must be related to its hourly productivity, P_{HR} as measured in available seat miles per hour, or available ton miles per hour. A plot of FC_{HR} against available ton miles per hour is shown in figure 3 for aircraft in domestic trunk and local airline service for the year 1968. The flattening of the trend curve indicates a relative improvement in flight operating costs as productivity increases.

If we divide the hourly operating costs by the productivity measured in available ton-miles per hour, we obtain a value of DOC, direct operating cost in terms of dollars per available ton mile. A

TABLE 5

First Six Months of 1971

(Dollars per Block Hr.)	Total Block Hours	DIRECT EXPENSES Flying Operations	Direct Maint.	Deprec. & Rentals	Total	Maint. Burden	Total Aircraft Expense
Boeing 727							
United	214,550	356	76	137	569	82	651
Eastern	186,238	349	99	120	568	74	642
American[1]	157,712	349	98	134	581	106	687
TransWorld	101,153	353	80	165	598	102	700
National	61,419	310	97	130	537	56	593
Braniff	59,041	329	103	125	557	40	597
Northwestern	58,529	340	68	230	638	34	672
Continental	38,523	345	106	101	552	72	624
Northeast	34,010	347	115	178	640	86	726
Pan American	29,225	392	123	196	711	131	842
Western	9,159	346	95	203	644	37	681
Alaska	8,527	428	162	196	786	42	828
Airlift	5,194	376	154	179	709	42	751
Frontier	5,058	361	168	179	708	61	769
Allegheny	3,355	457	64	264	785	71	856
727 Average	971,693	349	93	144	586	79	665
Douglas DC-9							
Delta	143,573	235	55	102	392	49	441
Eastern	132,576	270	74	108	452	55	507
Allegheny	46,901	271	71	107	449	43	492
Air West	31,307	278	100	123	501	27	528
Continental	30,427	221	89	94	404	62	466
Southern	24,950	236	94	111	441	26	467
Ozark	24,344	241	95	132	468	27	495
TransWorld	22,610	291	80	143	514	91	605
Texas Int'l.	22,410	236	92	115	443	29	472
North Central	21,403	254	75	113	442	44	486
Northeast	19,071	263	92	120	475	71	546
Hawaiian	8,515	305	116	211	632	59	691
Caribair	3,529	418	150	237	805	56	861
DC-9 Average	531,616	255	76	113	444	49	493
Boeing 737							
United	72,953	339	62	116	517	72	589
Western	40,688	264	110	105	479	43	522
Piedmont	17,820	254	78	95	427	39	466
Frontier	15,558	251	124	148	523	47	570
Aloha	4,593	300	120	189	609	77	686
Wien Consl.	3,635	401	114	190	705	74	779
737 Average	155,247	301	86	118	505	58	563
BAC 111							
American	21,068	269	81	216	566	91	657
Mohawk	13,632	250	76	94	420	52	472
Braniff	13,588	211	90	86	387	40	427
111 Average	48,288	247	82	145	474	66	540

Table 5 (continued)

(Dollars per Block Hr.)	Total Block Hours	DIRECT EXPENSES Flying Operations	Direct Maint.	Deprec. & Rentals	Total	Maint. Burden	Total Aircraft Expense
Boeing 747							
Pan American	37,862	818	156	647	1621	164	1785
TransWorld	29,917	634	239	510	1383	134	1517
American	21,254	698	294	695	1687	132	1819
United	16,052	838	218	600	1656	180	1836
Northwest	15,566	724	131	519	1374	71	1445
Delta	7,312	880	165	493	1538	197	1735
Continental	6,103	803	421	377	1601	72	1673
Eastern	4,319	768	536	1995	3299	51	3350
National	3,420	810	256	561	1627	148	1775
Braniff	1,760	1051	312	687	2050	48	2098
747 Average	143,565	758	226	626	1610	137	1747
Douglas DC-8							
United	177,331	462	88	204	754	96	850
Delta	77,463	420	102	176	698	110	808
Eastern	54,238	488	158	230	876	112	988
National	36,425	410	122	106	638	67	705
Flying Tiger	31,725	538	134	229	901	82	983
Seaboard	19,169	477	126	214	817	45	862
Braniff	13,461	490	97	270	857	38	895
Airlift	8,562	551	159	387	1097	43	1140
American[1]	6,133	517	131	318	966	61	1027
Pan American	3,596	741	311	31	1083	14	1097
DC-8 Average	428,103	465	112	202	779	91	870
Boeing 707							
TransWorld	196,514	434	89	170	693	97	790
Pan American[1]	170,538	480	99	194	773	124	897
American	167,564	434	83	184	701	99	800
Northwest[1]	46,417	450	84	242	776	51	827
Continental	22,417	463	142	173	778	109	887
Braniff	17,830	449	137	162	748	58	806
Western	10,056	540	121	162	823	47	870
Alaska	645	415	144	159	718	28	746
Airlift	210	260	236	223	719	72	791
707 Average	632,191	451	94	185	730	100	830
Boeing 720							
Western	47,147	391	139	179	709	55	764
United	41,331	428	73	153	654	85	739
Continental	13,056	338	136	130	604	104	708
Pan American	10,238	420	112	192	724	126	850
American	9,850	392	126	387	905	169	1074
Northwest	9,011	379	80	341	800	47	847
Braniff	8,530	392	204	77	673	116	789
720 Average	139,163	398	116	187	701	85	786
Convair 880							
TransWorld	31,882	413	132	190	735	143	878
Delta	29,361	381	135	48	564	143	707
880 Average	61,183	398	134	121	653	143	796

[1]Data for Trans Caribbean included with American.

plot of this value is shown in figure 4, and clearly demonstrates the superiority of the more productive aircraft in terms of unit costs.

4.2 Flight Operating Costs per Trip

The hourly cost, FC_{HR} is a basic and convenient cost measure for transport aircraft. A more precise formulation for analytic purposes is provided by the trip cost measures; FC_{AT}, flight operating cost per aircraft trip, and FC_{ST}, flight operating cost per seat trip.

Flight Cost per aircraft trip, FC_{AT} always turns out to be a linear function of distance, d.

$$FC_{AT} = c_1 + c_2 \cdot d$$

so that knowledge of the two coefficients c_1 and c_2 is sufficient to accurately describe the cost performance of any transport aircraft. Because the variation of fuel costs is not proportional to block time, and since fuel costs may vary with the particular climb-cruise schedule used for a given aircraft, it is not possible to simply multiply the hourly costs by the block time to obtain a precise measure of trip costs.

For purposes of determining minimum cost flight plans, where varying climb-cruise profiles and schedules may be used, it is sometimes useful to represent trip costs in the following form:

$$FC_{AT} = \text{Time Costs} + \text{Fuel Costs}$$

where the time costs are computed using a short term hourly cost for crew, maintenance, and perhaps ownership, and fuel costs are computed for a given mission profile.

It is useful to also define the trip costs per available seat FC_{ST}. Since Sa, the available seats is not constant after design range, this cost measure will have a linear form up to design range, and a non-linear variation after design range. The traditional DOC curves can be derived from FC_{ST} by dividing by the trip distance. The variation

Figure 3 FLIGHT OPERATING COST PER HOUR VERSUS HOURLY PRODUCTIVITY

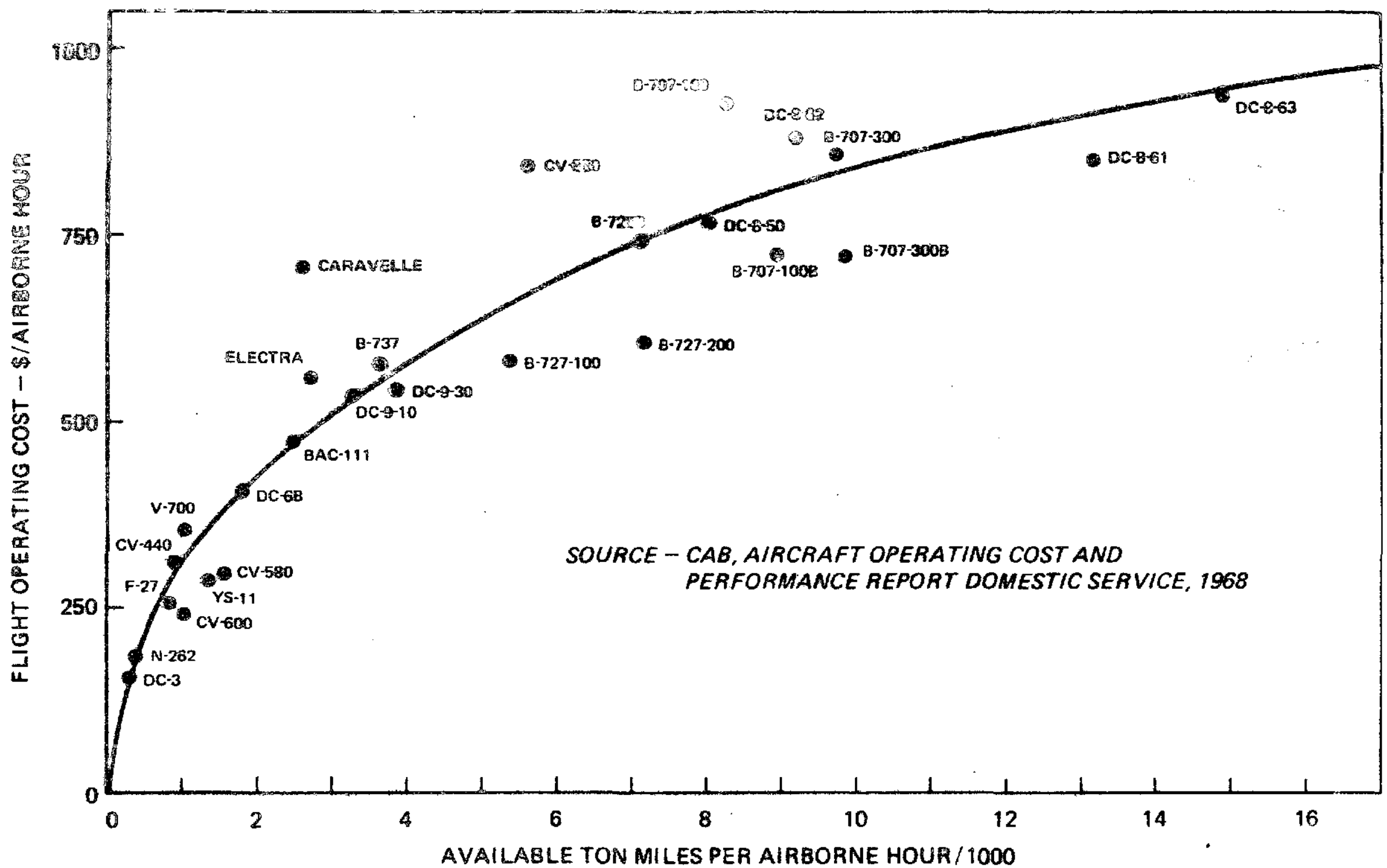
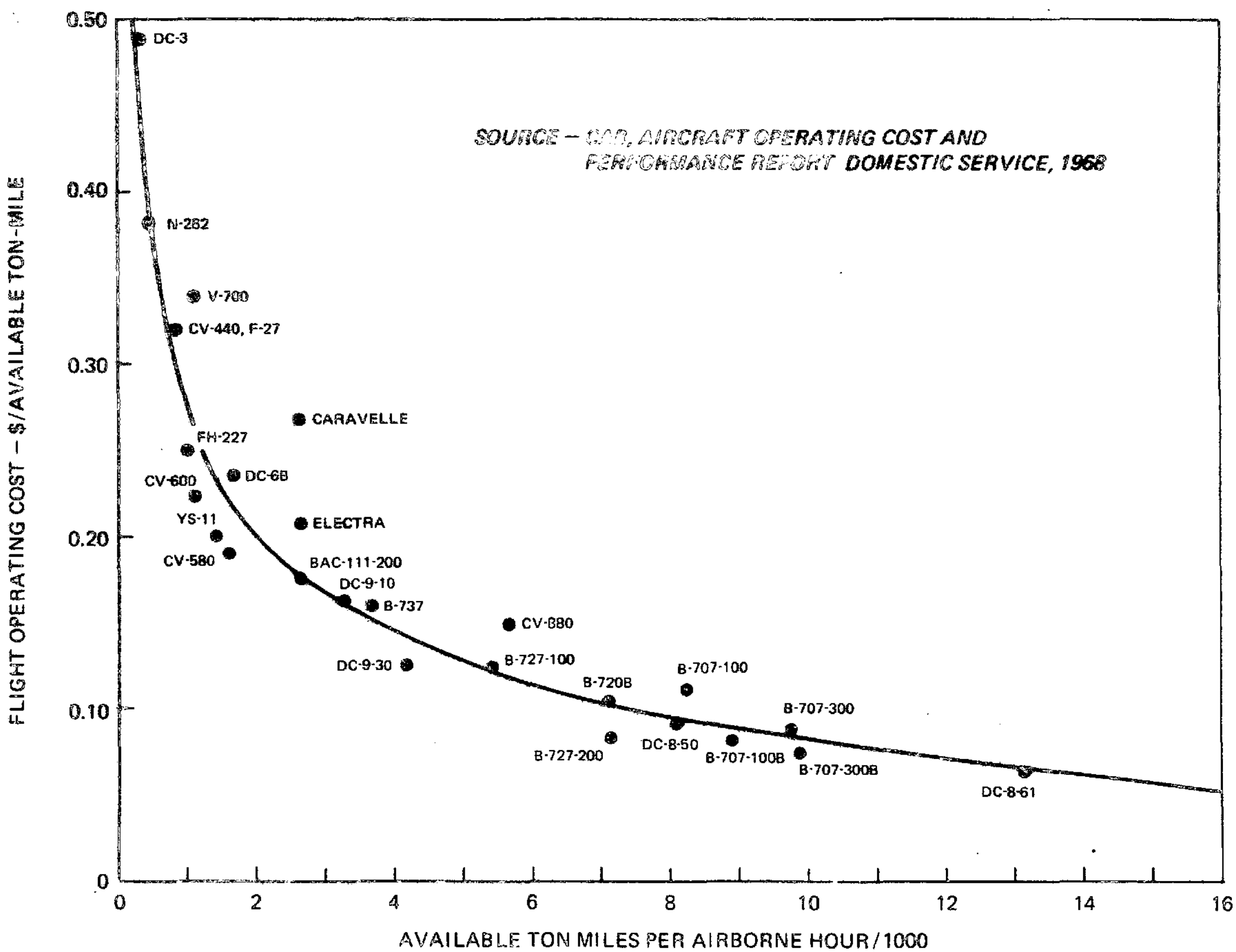


Figure 4 FLIGHT OPERATING COSTS PER AVAILABLE TON MILE VERSUS HOURLY PRODUCTIVITY



97

Table 6

Trends in Flight Operating Cost per Block Hour, B-727 Domestic

Year	Flying Operations		Maintenance $	Ownership $	Total FC_{HR} $
	Crew	Fuel			
1964	108	121	121	161	512
1965	121	129	147	139	539
1966	128	127	171	138	566
1967	123	130	159	121	535
1968	133	132	152	121	539
1969	140	141	143	130	556
1970	160	146	168	147	622

of these cost curves with trip distance is shown in Figure 5 for the B727 in domestic service in 1969. Notice the strong variation in the unit costs measure, DOC, before it flattens out around full design range.

4.3 Average Flight Costs

Suppose we have an aircraft operating over a given set of trips (or hops, or stages) within an airline system. We want to compute measures of average flight operating costs over this set of trips.

If there are N trips with n(x) trips at a particular distance, x, then we may denote a probability density function, $f(x) = \frac{n(x)}{N}$ to describe the distribution of trip distances within the set of trips.

The average trip distance, $\bar{d}$, is given by

$$\bar{d} = \int_0^{\infty} x \cdot f(x) \cdot dx$$

where $$1.0 = \int_0^{\infty} f(x) \cdot dx$$

Now, the flight operating costs per trip can be expressed as a linear function of trip distance, x

$$FC_{AT} = c_1 + c_2 \cdot x$$

The average flight cost per trip, $\overline{FC}_{AT}$, becomes

$$\overline{FC}_{AT} = \int_0^{\infty} (c_1 + c_2 x) \cdot f(x) \cdot dx$$

$$= c_1 + c_2 \cdot \bar{d}$$

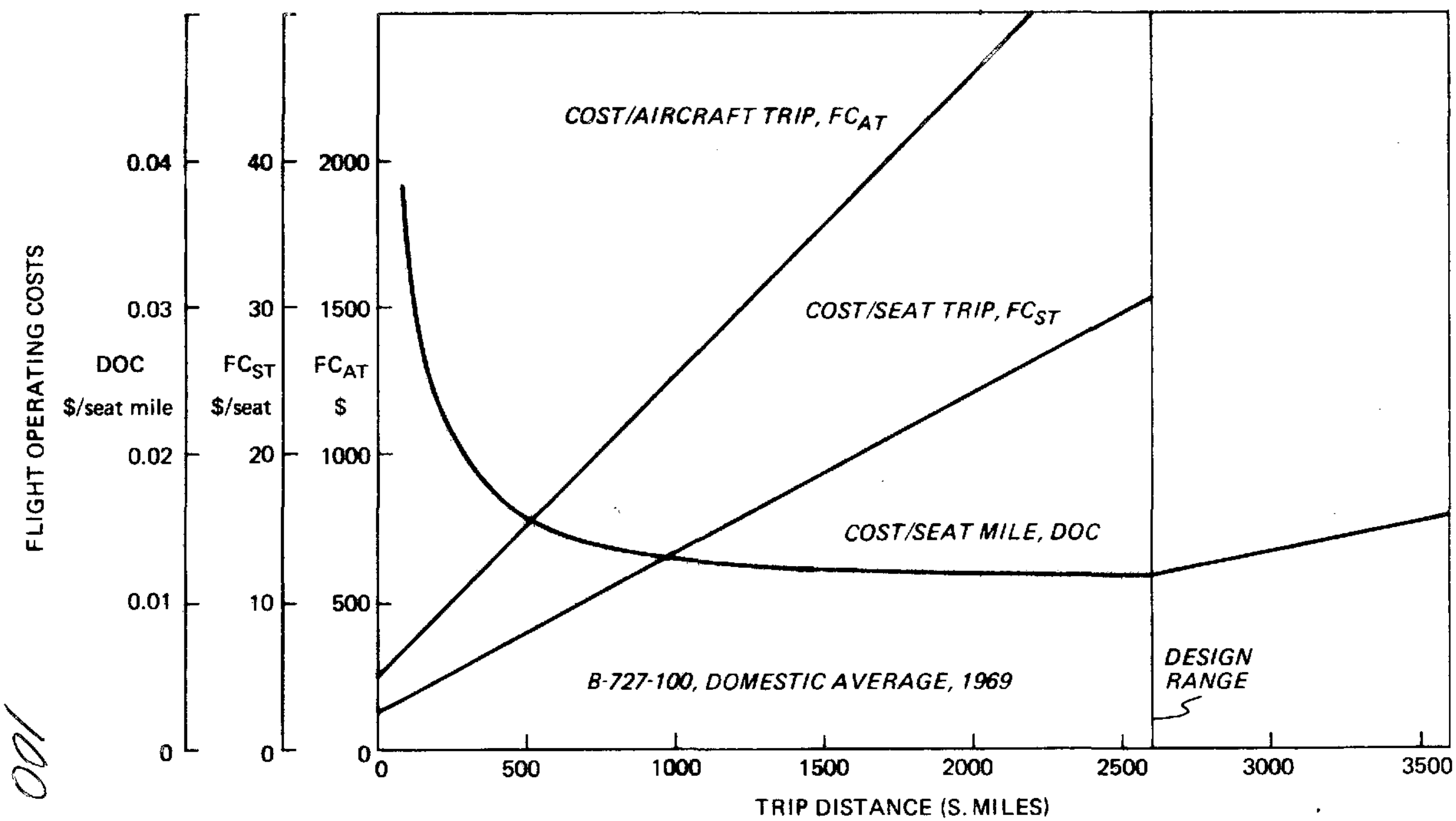
i.e., the average flight cost per trip is exactly the flight cost at the average trip distance.

Now, the total flight operating cost over the set of trips, FC is given by:

$$FC = N \, \overline{FC}_{AT}$$

and the total mileage of the set of trips, M;

Figure 5 VARIATION OF FLIGHT OPERATING COSTS WITH TRIP DISTANCE



100

$$M = N \cdot \overline{d}$$

so that the average flight operating cost per seat mile (if we assume that S seats are available on all trips) becomes:

$$DOC_{AV} = \frac{FC}{M} = \frac{N \cdot \overline{FC}_{AT}}{N \cdot \overline{d} \cdot S} = \frac{c_1 + c_2 \cdot \overline{d}}{\overline{d} \cdot S}$$

$$= \frac{1}{S} \left[\frac{c_1}{\overline{d}} + c_2 \right]$$

$$= DOC\ (\overline{d})$$

i.e., the average direct operating cost over the set of trips is exactly the direct operating cost at the average distance.

These two properties are a result of the linear form of trip costs with trip distance.

Notice, however, that if we average DOC values over a set of trips, we do not get the value of DOC_{AV} since $DOC(x)$ is non-linear in x;

$$\overline{DOC} = \frac{1}{S} \int_0^{\infty} \left[\frac{c_1}{x} + c_2 \right] \cdot f(x) \cdot dx$$

so $$\overline{DOC} \neq DOC(\overline{d}) \neq DOC_{AV}$$

The value $\overline{DOC}$ is a useless quantity, and it is a mistake to compute it. The useful quantity is $DOC(\overline{d})$, the direct operating cost at the average trip distance.

5.0 Ground Operating Costs

This group of operating costs are incurred on the ground in preparation and termination of the trip. They are zero-distance, or "terminal" costs as opposed to "line-haul" costs, although it may be argued that there is more preparation for a longer haul trip.

As indicated by Table 2, Grand Operating Costs are roughly 25% of total operating costs, broken down into roughly equal categories of 8% each for reservations and sales, traffic servicing, and aircraft servicing. A particular airline would use its own costs over the system, or perhaps for each station in its system. Notice that these costs are relatively independent of the type of aircraft

5.1 Measures of Airline Activity

Statistics on measures of activity for domestic airlines for the last quarter of 1970 are given in Table 7. Some selected activity indices are also presented.

While more detailed cost allocations may often be made using various appropriate measures of airline activity, here we shall allocat ground operating costs against passengers originated, and aircraft departures performed for the complete domestic industry. There may be significant variation from these unit costs for a particular airline or station.

5.2 Ground Operating Costs per Passenger, GC_p

For reservations and sales, the unit cost for the last quarter of 1970 is 4.96 \$/passenger originated. For traffic servicing, it is 4.80 \$/passenger originated. The total is defined as ground operating cost per passenger,

$$GC_p = 9.76 \text{ \$/passenger}$$

5.3 Ground Operating Costs per Aircraft Departure, GC_D

The costs per aircraft departure cover the arrival of the plane (and its landing fees), its servicing, and its start up and departure. Dividing the costs reported for the last quarter of 1970 by the number departures gives a unit cost value

$$GC_D = 178.30 \text{ \$/aircraft departure}$$

TABLE 7. ACTIVITY MEASURES, DOMESTIC AIRLINE INDUSTRY

(last quarter, 1970)

Activity Measures

RPM = 22.76×10^9 revenue passenger miles

P = 29.0×10^6 revenue passenger originated

RTM = 2.97×10^9 revenue ton miles

RH = 0.993×10^6 revenue aircraft block hours

D = 0.720×10^6 revenue aircraft departures

R = 1.50×10^9 revenue dollars

Indices of Activity

$\bar{d}$ = 784 (s. miles) - average passenger trip length

$\bar{p}$ = 40.3 (passengers) - average passengers per departure

$\bar{r}$ = 51.7 (dollars) - average ticket price

$\bar{T}_b$ = 1.37 (hours) - average block hours per departure

$\bar{R}$ = 2083 (dollars) - average aircraft revenue per departure

6.0 System Operating Costs

This group of costs is a system wide set of costs of an overhead nature. It is rougly 20% of total operating costs as may be seen from Table 2. Promotional costs are roughly one half of this group, with the remainder split equally between general and administrative and the costs of owning and maintaining ground equipment.

While these costs may be allocated against a variety of airline activity measures, here we shall simply allocate against the revenue dollar as an overhead costs. Again, note that these costs are independent of the types of aircraft used in the airline system.

6.1 System Operating Costs, SC

Using the data for the domestic industry for the last quarter of 1970 once again, we obtain the following costs in terms of dollars per dollar of revenue:

Promotional Costs -	
Passenger Service	- 0.112
Advertising	- 0.025
TOTAL	0.137
General and Administrative	- 0.043
Ground Equipment	
Maintenance	- 0.015
Ownership	- 0.019
TOTAL	0.034

Combining these expenses, we form an overall system cost SC,

$$SC = 0.220 \qquad \$/\text{revenue dollar}$$

7.0 Trip Costs

We now combine the Flight Operating Costs and the Ground Costs and the Ground Costs per aircraft departure to form a cost per aircraft trip, TC_{AT};

$$TC_{AT} = FC_{AT} + GC_{D}$$

Also, we shall define the trip costs per available seat;

$$TC_{ST} = FC_{ST} + \frac{GC_{D}}{S_a}$$

$$= FC_{ST} + GC_{ST}$$

where GC_{ST} = ground operating costs per seat departure.

These trip cost measures combine the aircraft related costs; Flight Operating Costs, and Aircraft Servicing costs. The trip cost per available seat, TC_{ST}, is useful for comparison with fares or yields in a later section.

For example, if we use the industry averages for 1970 for a Boeing 727-100;

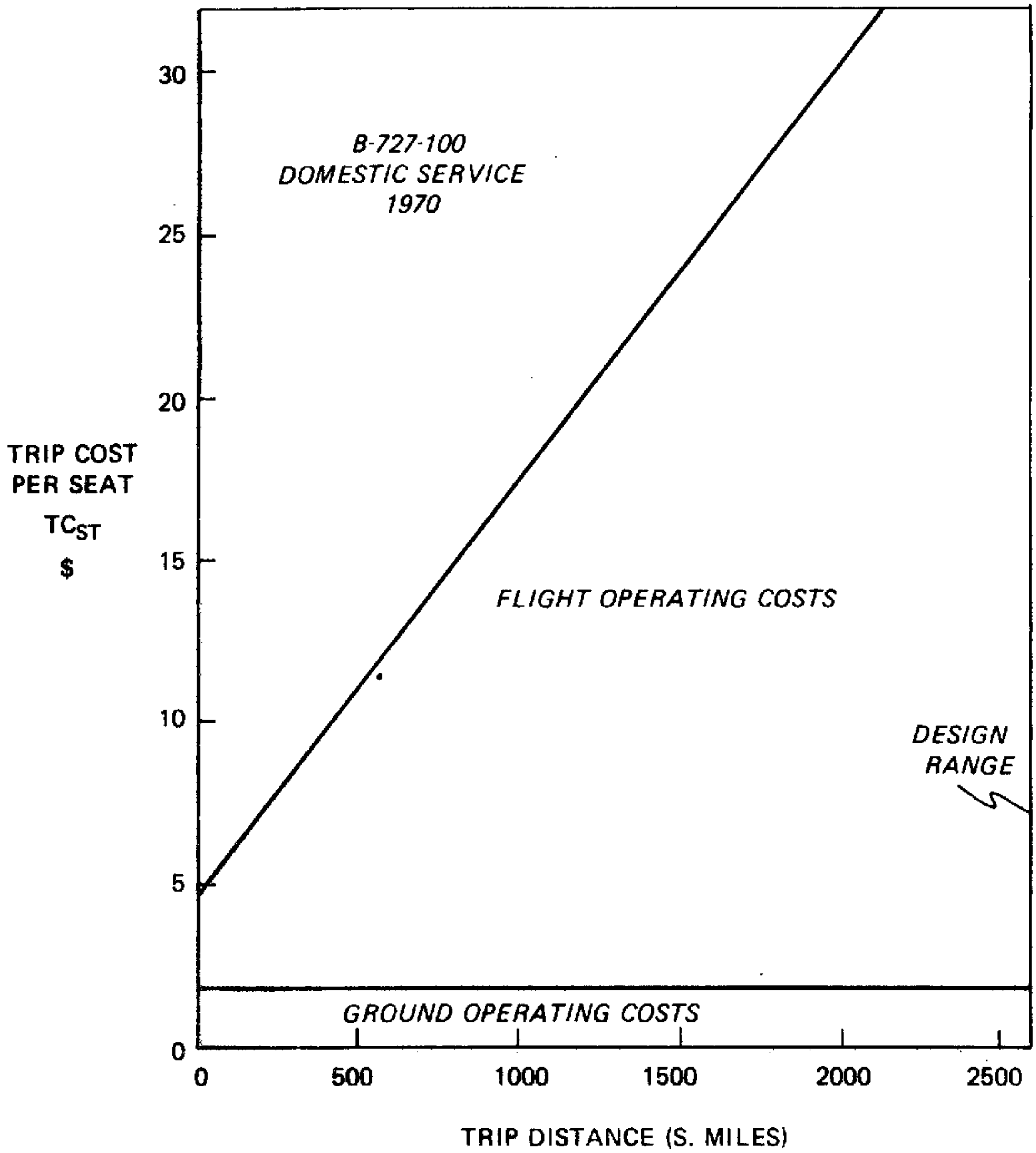
$FC_{ST} = 2.85 + .0121d$ $/seat trip

$GC_{ST} = \frac{178.30}{96} = 1.86$ $/seat departure

Therefore, $TC_{ST} = 4.71 + .0121d$

The variation of trip costs with distance is shown by figure 6. Notice that the ground operating costs are small compared to flight operating costs, and that the cost levels seem very low, e.g. the cost per seat for a 1000 mile trip is only $16.80.

Figure 6 VARIATION OF TRIP COST/SEAT WITH TRIP DISTANCE



8.0 Fares, Yields, and Net Yields

We shall now turn our attention to the variation of airline trip income per passenger with trip distance.

8.1 Domestic Airline Fare Structure, F

Unlike other forms of common carrier passenger transportation (except perhaps taxis) the domestic airline fare structure has a zero distance charge as airlines have attempted to recover the cost of these ground operations. Over the past twenty years, thus zero distance intercept has grown from zero to 9 dollars with a recent CAB examiner's recommendation that it be raised still further to 12 dollars.

In 1967, a CAB regression of coach fares versus trip distance found an extremely good fit for the following formula:

Coach Fares, $F_c = 6.40 + .057d$ dollars

In 1969, at the insistence of the CAB on basing fares on airport to airport distances, the following formula was adopted for coach fares as part of a general industry fare increase:

$$F_p = 9.00 + .060\ d_1 + .056\ d_2 + .052\ d_3 + .050\ d_4 + .048\ d_5$$

where

$$0 \leq d_1 \leq 500 \text{ s.miles}$$

$$501 \leq d_1 + d_2 \leq 1000$$

$$1001 \leq d_1 + d_2 + d_3 \leq 1500$$

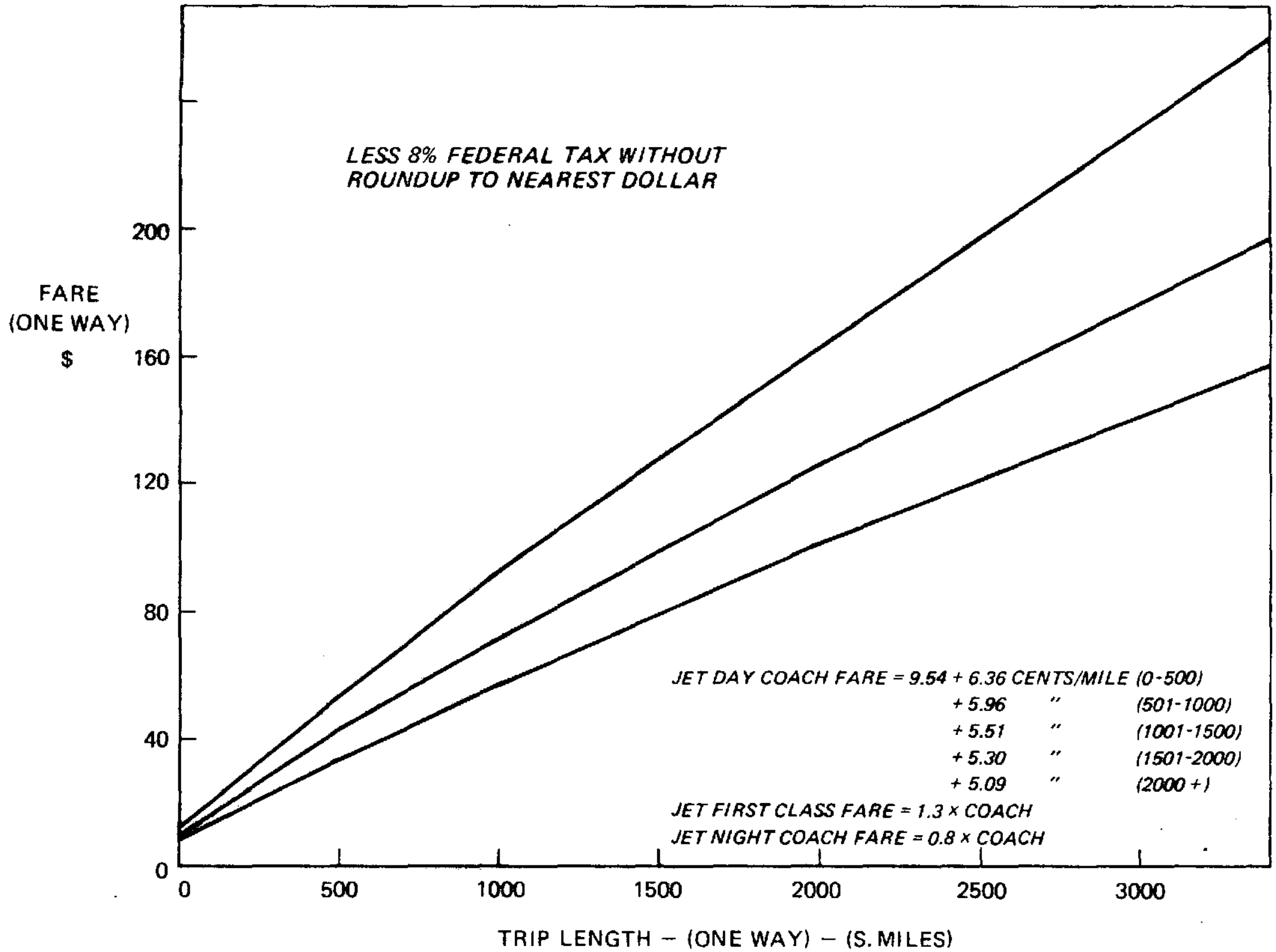
$$1501 \leq d_1 + d_2 + d_3 + d_4 \leq 2000$$

$$2001 \leq d_1 + d_2 + d_3 + d_4 + d_5$$

As part of this decision, first class fares, F_f were to be 1.25 times the coach fares. There was an 8% government tax applied, and then fares were rounded up to the nearest dollar.

In 1971, a further general increase of 6% in coach fares was allowed, with first class being set at 1.3 times coach fare, and night coach

Figure 7 CURRENT FARE FORMULAE, US DOMESTIC FARES, 1971-72



108

fares at 0.8 times coach fare. The round up rule was retained. Figure 7 shows the current fare formulae versus distance for the basic fares before the 8% tax and rounding up to the nearest dollar. The domestic fare investigation has ended and a further change is expected before the end of 1972.

8.2 Yield per Passenger, Y_p

While the fare structure seems to determine airline revenues very explicitly, the actual airline revenue for a given city pair is the result of the traffic which moves at a mix of regular fares (coach, first class, night coach), and a variety of discount fares (½ fare student, military standby, Family Plan, excursion fares, etc). A value for yield on a route is obtained by the airline by dividing the actual revenues from the route by the number of tickets sold, i.e. yield is the average ticket price (exclusive of tax).

Thus, the yield values need not fit an explicit distance formula like the fares, and indeed may vary over month of the year for a given route. However, there is generally a good linear variation with trip distance. We shall represent this by a yield formula,

$$Y_p = y_1 + y_2 \cdot d$$

The value of Y_p generally has been below the level for standard coach fares in recent years, where a great number of travellers have begun to use the discount fares. It may be as much as 15% below coach in tourist markets.

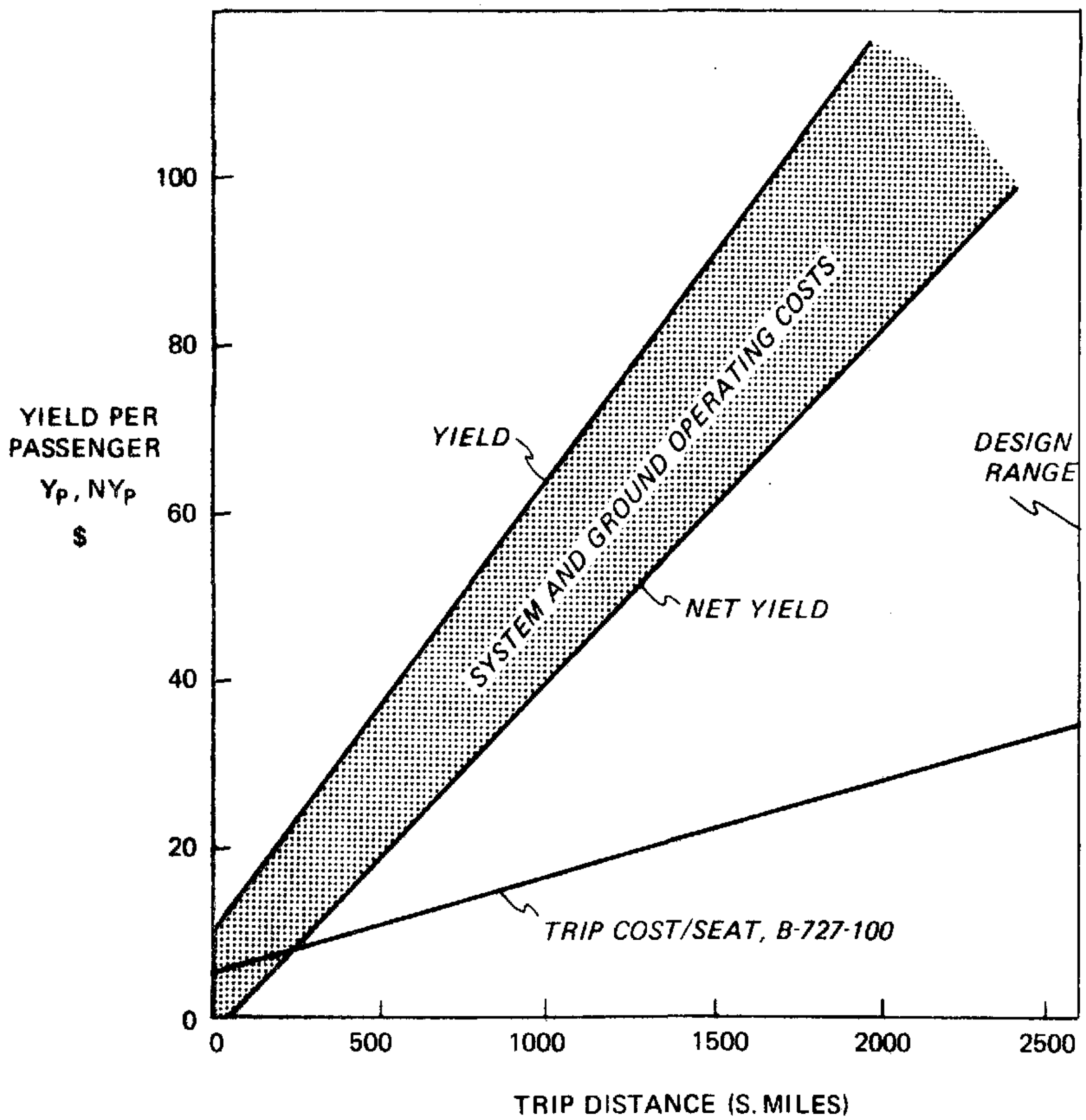
Thus, as well as forecasting the number of travellers in a given market, an estimate must be made of the breakdown of traffic moving at different fares to forecast the yield, and the future expected airline revenue.

8.3 Net Yield, NY_p

We shall define net yield here by combining the yield with the ground operating costs per passenger and the system operating costs per dollar of revenue:

$$NY_p = (1 - SC) \cdot Y_p - GC_p$$

Figure 8 YIELDS AND COSTS VERSUS TRIP DISTANCE



Since the system costs, SC, have been treated as an overhead cost, they further decrease the yield values before we subtract off the cost per passenger for reservations and sales, and traffic servicing. The value of net yield then represents a net income per passenger to be compared with the trip cost per seat from the flight and ground operations of the aircraft.

For example, if we assume a yield formula for 1970,

$Y_p = 9.00 + .055\ d$

with $SC = 0.23$

and $GC_p = 9.76$ \$/passenger.

Then, net yield per passenger becomes

$NY_p = -2.63 + .0423\ D$ dollars/passenger

Notice the negative value of net yield per passenger for distances less than 60 miles! Ground operating costs are higher than the zero distance intercept of the assumed yield formula (or the coach fare formula)

The relationship of yield, and net yield per passenger to trip cost per seat is shown against trip distance in figure 8. Notice that net yield per passenger and trip cost per seat cross around 250 miles, and that there is a large excess of net yield over trip costs as trip distance approaches full design range.

///

9.0 Trip Income and Breakeven Load Factor

We are now in a position to compare the net yield per passenger and trip cost per seat to determine income per aircraft trip, income per seat trip, and the breakeven load or load factor for an aircraft trip.

9.1 Income per Aircraft Trip

If the number of passengers on a given aircraft trip is denoted by P_{AT}, then the income per aircraft trip, I_{AT} is given by;

$$I_{AT} = NY_p \cdot P_{AT} - TC_{AT}$$

If the number of passengers required to breakeven is denoted by P_{ATB}, then when $I_{AT} = 0$,

$$P_{ATB} = \frac{TC_{AT}}{NY_p}$$

9.2 Breakeven Load Factor

If we denote the load factor, LF, as the ratio of passenger load to S, seats available at less than design range.

$$LF = \frac{P_{AT}}{S}$$

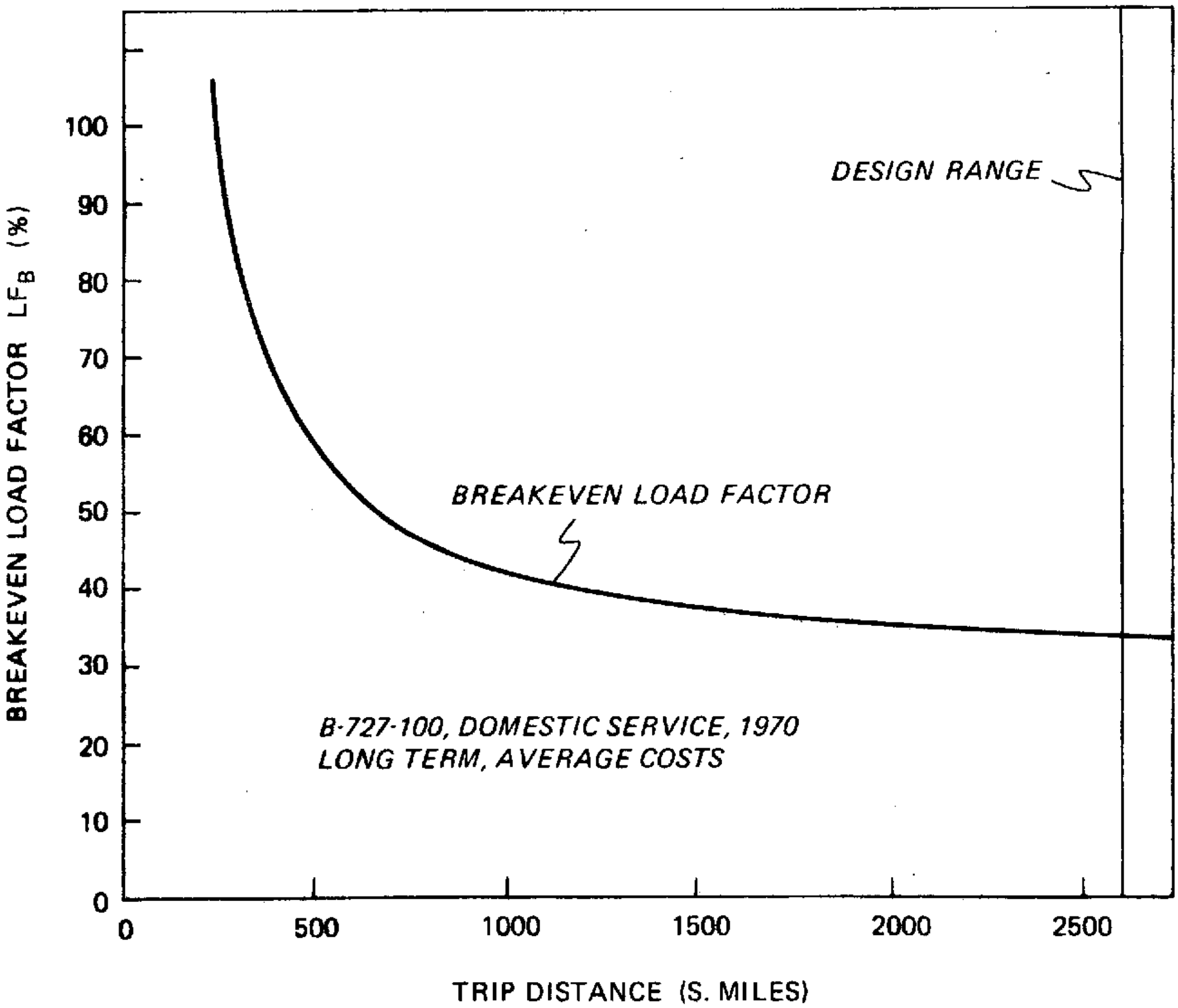
Then the breakeven load factor, LF_B

$$LF_B = \frac{P_{ATB}}{S} = \frac{TC_{ST}}{NY_p}$$

i.e. the breakeven load factor equals the ratio of trip cost per seat to net yield per passenger.

A plot of breakeven load factors for the B-727-100 in domestic service in 1970 is shown in figure 9. Because of the crossover of net yield per passenger and trip cost per seat, there usually is a large variation in LF_B with trip distance. It is over 100% at distances less than 250 miles, and reduces to 35% or less at long ranges. Notice that since we have defined load factor based on total seats, it does not break upwards after design range.

Figure 9 VARIATION OF BREAKEVEN LOAD FACTOR WITH TRIP DISTANCE



Because the variation of net yield and trip cost are linear with distance, the average breakeven load factor for a set of trips is the breakeven load factor at the average trip distance. Thus, for the B-727-100 in domestic service in 1970, the average stage distance was 500 miles where the breakeven load factor was 58%.

9.3 Income Per Seat Trip

We can also define the income per seat trip, I_{ST} as a very simple function of the actual load factor and breakeven load factor;

$$I_{ST} = \frac{I_{AT}}{S} = \frac{1}{S}(NY_p \cdot P_{AT} - TC_{AT})$$

$$= NY_p \cdot \frac{P_{AT}}{S} - TC_{ST}$$

$$= NY_p \cdot LF - NY_p \cdot LF_B$$

$$= NY_p(LF - LF_B)$$

Therefore, the income per seat trip is some fraction of the net yield per passenger, where the fraction is the difference between actual and breakeven load factor. This fraction shows the leverage of every point in achieved average load factor in increasing the airline trip income.

References

1. A Structure for Airline Operating Costs, FTL Technical Memo 71-9, Y.P. Chan, R.W. Simpson.
2. Aircraft Operating Costs and Performance Report, Bureau of Accounts and Statistics, CAB, Washington, D.C.
3. Standard Method of Estimating Comparative Direct Operating Costs for Turbine Powered Transport Airplanes - ATA, December 1967.
4. Uniform System of Accounts and Reports for Certified Air Carriers, US Civil Aeronautics Board
5. Domestic Jet Trends, First Edition, CAB, April 1972.
6. Direct Exhibits of Bureau of Economics, Phase 9, Fare Structure, Domestic Passenger Fare Investigation, November 1970, CAB.