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An Economic Model for Evaluating High-Speed Aircraft Designs

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Nomenclature

	description	dimension
c	number of preproduction aircraft	
Caf	Cost airframe	$
Cakm	Direct operating cost per km	$/km
CASEI	Comp. Airc. seatkm econ. index	
CD	Cost of development	M$=1e6$
CDaf	Development cost airframe	$/M$/G$
CDe	Development cost of engines	$/M$/G$
Ce	Engine price	$
Ct	Total cost of aircraft	M$=1e6$
Da	Depreciation period	years
Dac	Aircraft price deflator (SIC 3721)	1972=1.00
De	Deflator (SIC 3728)	1972=1.00
Df	Deflator fuel	1972=1.00
Dl	Deflator labor (CPI)	1972=1.00
DOC	Direct operating cost '67 ATA def.	$/km
g	acceleration due to gravity: 9.8	m/s2
IOC	Indirect operating cost	$/km
IR	Insurance rate	
lf	loadfactor: n/seats	
maf	Airframe mass	1000*kg
meng	Engine mass = sew*TTo/g	1000*kg
mf	Mass fuel = mftrip + mfres	1000*kg
mfres	Reserve fuel	1000*kg
mftrip	blockfuel trip	1000*kg
moe	operational empty mass = maf+ne*meng	1000*kg
mp	payload mass	1000*kg
mto	maximum takeoff mass=moe+mp+mf	1000*kg
n	#pass.	
nb	break even production units	
ne	number of engines	
R	Range	km
seats	Number of seats available in layout	
sew	Tto/(g*meng*ne)	
tb	blocktime	h
tbref	Ref. blocktime= R/800	h

TET	Turbine entry temperature	K
tf	flight time	h
tl	lost time	h
Tto	Total Takeoff thrust	kN
U	Annual utilization	h
V	cruise speed/1000	Mm/h
Vb	Block speed	km/h
σX	Standard deviation	
ε^2	square of error	

Summary

In this paper we will introduce a Class I method for determining whether further development of a new aircraft design is desirable from all viewpoints.

For the manufacturer the model gives an estimate of the total cost of research and development from the preliminary design to the first production aircraft. Using Wright's law of production we will derive the average cost per aircraft produced for a given break-even number.

The model will also provide the airline with a good estimate of the direct and indirect operating costs.

From the viewpoint of the passenger the model proposes a tradeoff between ticket price and cruise speed.

Finally all of these viewpoints are combined in a Comparative Aircraft Seat-kilometer Economic Index.

Introduction

Before the development of a new transport aircraft design begins, a number of questions need to be answered. The airframe manufacturer needs to know whether he can break even on his initial investment quickly. The airline will only order this new aircraft if the design will help it to expand its market, reduce its costs and increase its revenues. The traveller wants a low ticket price and high comfort. Society as a whole wants this new piece of technology to stimulate the economy while safeguarding the environment.

Since all of these views conflict, we can only evaluate a new design by comparing it with present transports, keeping in mind that the lifespan of a new design can be more than a quarter of a century.

Methodology

a. All costs and revenues are related to the 1972 value.

The economic model presented in this paper uses four deflators to relate 1972 prices and cost of labor to those of today.

Definition of a deflator:
D(year=X) = [Price for year=X]/[Price in 1972].

Tables 1 list the following quantities:

1. The SIC 3721 deflator (Dac) for the airframes industry.
2. The SIC 3724 deflator (De) is used for engine & engine parts.
3. The Consumer Price index (DI) will be used to deflate labor costs. This is by no means an accuate deflator for all labor involved. Maintenance workers, pilots, all have different deflators, but I found that the CPI was a reasonable deflator for all wages.
4. The fuel price deflator (Df).

b. The theory of opportunity cost of capital.

The opportunity cost is the benefit lost by choosing one alternative over another (ref. 8).

Though not mentioned in classical accounting theory, this is one of the cornerstones of engineering economic analysis. If a transatlantic business traveller chooses to travel by B747 instead of Concorde, he will lose 4 hrs. of time when he could be productive abroad. This 4 hrs. represents a certain amount of money which is his opportunity cost. This opportunity cost should therefore be added to his B747 ticket price before comparing it to that for the Concorde.

c. Inherent model error.

Every statistical method has its inherent errors associated with it. In the text we indicate where such errors may occur. For example, the standard deviation in the cost of airframe development was 16%, which introduces a 6% error in the direct operating cost.

Note that all the equations in this paper are purely statistical and cannot be used for the economic analysis of the further development of existing aircraft. For instance, when weight is added to the airframe to simplify maintenance the model predicts an increase in maintenance costs.

The underlying assumption in this model is therefore that all designers of aircraft use the same tradeoffs between component weight and cost.

d. Simplicity as a goal

In previous publications (ref. 13), it has already been proven theoretically that the D.O.C's could be determined by only six variables for a given range.

In the final introduction of CASEI (the Comparative Aircraft Seat-km Economic Index) we will use eight variables. Reduction of variables allows us to evaluate the results more rapidly and also aids us in the validation of the model.

e. Definitions

Given the data available for the empirical analysis it was not always possible to relate the most appropriate variables. For example, because the airframe weight is usually not published while the operational empty weight is, we defined airframe weight as operational empty weight minus dry engine weight. Of course this results in a slight overestimate of the airframe weight, but this is not a problem in the analysis since the error is of the same magnitude and sign for all configurations.

The manufacturer's viewpoint

For the airframe manufacturer the decision whether to continue the research and development of a proposed transport aircraft design will be based on a number of considerations as outlined below.

First, does the manufacturer have the necessary human resources and manufacturing infrastructure to develop and produce the aircraft in the quantities and time schedule required?

Second, is there a market for an aircraft with this payload-range capability? If the aircraft has similar operational characteristics to an existing aircraft which is up for replacement than it is certain that a market exists.

Now we have to make some estimates of the cost of the proposed design in order to decide whether we have the financial resources to carry out the research and development of this new aircraft. This development cost depends on many considerations:

a) Aircraft size expressed in empty weight
Assuming that all aircraft are designed with a comparable degree of sophistication regardless of size it is clear that the aircraft cost of development increases linearly with size.

b) Technology risk, Fig.1 (ref.12)
As Mach number increases, more expensive materials must be used and expensive systems make up an larger fraction of the empty weight which increases the airframe cost per unit weight.

c) Organizational experience and Environmental influence
From Fig. 2 it can be easily determined that experienced manufacturers need less money to develop and produce new aircraft. Experience may reduce or increase the cost of development by as much as 20%. In addition politics and other environmental factors could increase the cost of production.

In an empirical study the author has related the size of 15 different aircraft configurations with the published research and development cost (Table 2 and Fig. 2). Given the suggested relations between Mach number and technology risk in ref. 12, the author has tried to quantify the impact of Mach number on the cost of development (Table 3b), and has come up with the following relation:

$CDaf = Dac^{*}\ 6.2e6\ {}^{*}maf;$ ($)

for supersonic configurations factor by $0.82^{*}V^{2}$.

Standard deviation of method $\sigma(CDaf) = 0.17$.

Most of the aircraft in the table are high-subsonic transports in which the airframe manufacturer could choose an existing power plant. The cost of development is therefore related to the weight of the airframe. For most supersonic configurations there was no power plant available, and the published cost of research and development included money for the power plant. However it can be shown that this did not introduce a significant error for the four engined supersonic configurations.

For completeness' sake Table 3a shows the research and development cost of some engine programs. In our model however, we will consider the engines to be a subsystem just like the avionics, which will be bought on the free market at a fixed price.

We now have an estimate of the manufacturer's research and development cost. Next we have to decide on where to fix our break-even point. Ref. 2 provides sales figures for some success-ful aircraft programs. For small and executive transport aircraft a break-even number of 250 seems appropriate, while for big and medium sized passenger transports the number is closer to 500.

To obtain the sales price per airframe we now we use Wright's 80% learning curve (ref. 9,10):

$Caf = nb^{-0.322} * CDaf / c$ ($)

The constant c here is related to the number of aircraft in the prototype program. The best results were obtained by taking the constant equal to 4.

Table 4 gives the predicted price of the airframe for a break-even number of 400 and four pre-production aircraft. If we do not include Concorde's price the standard deviation is only 16%. [Note: Concorde's pricetag reflects a break-even number of 2000!]

Fig. 3 (ref. 4) shows the learning curve as it was observed with actual aircraft (note the log-log scale).

There exists a link between the gradient of the learning curve and the initial cost of development. It was found that aircraft that were rushed through the research and development phase, such as the DC10, had learning curves with less steep gradients than the 80% suggested here. Therefore we found that the prediction of the unit airframe price was better than could be expected. (An analogous conclusion can be reached for "over-developed" aircraft)

Table 3b shows the price of engines related to maximum thrust. As suggested in ref. 6, it is possible to come up with a dollar amount per kN. In addition the author found a relation between the specific engine weight and the cost.

This relation is depicted in Fig. 4. It is clear that the cost per kN of thrust will increase if we have to decrease the engine weight.

$$Ce = Dec * 24000 * e^{-7*sew}\ Tto \quad (\$) \qquad 0.1 < sew < 0.25$$

$$\sigma(Ce) = 0.10 \text{ (Table 4b)}$$

Whether the subsystem is available or not will depend on the economic analysis of the subsystem manufacturer. It is important to realize that the subsystem manufacturer can also sell his product to others and can produce in higher number (aircraft usually have 2 or more engines) and therefore break even more easily.

The total cost of the aircraft can be found by adding the airframe and the engine price:

$$Ct = Caf + ne * Ce \qquad (\$)$$

The airlines viewpoint

Since we now have a price tag on the aircraft, the airline has the option of buying it. Its decision will be based on the expected profit that can be made on an existing airline operation. It is obvious that when this profit is increased or when the airline can offer a reduced ticket price at the same profit level, the airline can expand. This expansion is either at the cost of its competitors or because the interest in travel has grown.

Before the airline makes a cost comparison it should first evaluate how the aircraft fits in with the current fleet in terms of maintainability, passenger comfort, interior arrangement, handling and turnaround time. Also environmental factors such as domestic air policies, expected traffic demand, capacity and frequency, financing and domestic traffic infrastructure play a role (ref. 11).

It is beyond the scope of this paper to go into all of these factors but a few are directly related to the aircraft design and should therefore be mentioned.

The cruise speed is an important criterion since it influences the number of flights per day on a given route. Airlines greatly favor even numbers of flights a day since this enables them to perform the aircraft's nightly maintenance in its home port each day. Therefore Mach 2 is a good cruise number for the transatlantic range.

We also have to make a note on operational flexibility. The new aircraft should be as good as the plane that it replaces in terms of turnaround time, maintenance and takeoff field performance in order to use this method. Is the interior arrangement of the aircraft as flexible as that of its competitors? In ref.11 Van Ameyden points out that the interchangeability of the A310 containers with the B 747's and the DC-10's made KLM Royal Dutch Airlines choose the A310 over the B767.

In1967 the Air Transport Association of America published a standard method to estimate the direct operating cost of aircraft (ref. 3). Today this method is not used anymore to obtain actual direct operating cost, but it can still be used to make comparative and parametric studies (refs. 6,13).

Since 1967, the airframe manufacturers have been updating this method to reflect new technologies. These studies were not available to the public. However in 1978 American Airlines and NASA (refs. 14,15) put out a new study that reflected the added experience in aircraft operation since 1967.

One of the suggestions in the new method, the introduction of "aircraft relating operating expenses" instead of the DOC, was not followed as far as we can tell. Since some of the items in the new definition have a large variance for different operations in different nations (*e.g.* fuel servicing fees and training costs), we have decided to keep the original definition for the direct operating cost, but has used the relations in refs. 2, 6, 15 and16 for the actual equations.

To enable us to compare configurations all costs and profits are expressed per seat km.

Profit = ticket revenue - (IOC + DOC)

where:

a) IOC= indirect operating cost, which will mainly depend on the operator's type of organization and policy. This cost includes maintenance of buildings, serving of flight operations and administration and sales. Over the years the value of IOC has been between 45 and 50%. In 1985 the average IOC of the world scheduled airlines was 3.5 $-ct/pass.km .

b) DOC=direct operating cost, which includes the cost of flying, airplane maintenance and depreciation (see this chapter).

c) Ticket revenue depends on the load factor (averaging around 65% of the maximum capacity) and the pricing policies of the airline. In 1985 the average revenue per passenger was 5.7 ct/km, which makes commercial air travel the least expensive form of transportation.

In the following statistical formulae we have used the data published in ref. 18. The operating costs of 618 aircraft of 15 different types are presented in Table 6. Where possible the standard deviation of the equation is given.

We can now define:

$$Vb = R/(tloss + tflight)$$

$\sigma(Vb)=7\%$

where:

Vb	block speed	(km/h)
tloss	0.3 (average)	(h)
tflight	R/(1000*V*0.9)+0.3*V	(h)
R	Range	(km)

The cost of a flight crew, including training and employee benefits, per block hour can be expressed as follows: (fig. 5)

$$Cakm1 = Dl^{*}(5.66^{*}mto^{0.7})/Vb \qquad (\$/km)$$

$\sigma(Cakm1)=23\%$

where:

mto	takeoff mass in 1000*kg

The cost of fuel can be found in Table 2 so we can now calculate the fuel cost including 2% non-revenue flying as follows:

$$Cakm2 = Df \cdot 1.02^{*}(mftrip^{*}40+ne^{*}tb^{*}0.145)/R \qquad (\$/km)$$

$\sigma(Cakm2)<1\%$

where:

cost oil	0.145 cts/h per engine
cost fl	40$/1000kg (1972)
mftrip	block fuel JP4, (1000kg)

From an empirical investigation of the annual utilization of 618 aircraft the following relation between block time and utilization can be found for tb>1: (fig. 5)

$$U = 2650 + 2100^{*}(1 - \exp(-tb/2+0.5)) \qquad (h)$$

$\sigma(U)=15\%$

We can now calculate the cost of insurance and depreciation based on the aircraft price:

Insurance:

$Cakm3 = IR * (Caf+ne*Ce)/(U*Vb)$ ($/km)
where:
IR insurance rate proposed 1% by ref 15.

Depreciation:

$Cakm4 = 0.9*(1.04*Caf+ne*Ce*1.3)/(Da*U*Vb)$ ($/km)
$\sigma(Cakm4)=16\%$ (sample=81 aircraft, table 5)

A depreciation to 10% of the original value in Da=14 years is assumed. 4% of the airframe value is needed for spares while 30% of the engine value is needed for spares.

In the published data of ref. 18 a large discrepancy can be observed by the above depreciation and the value found in our estimate. It must be noted that in ref. 18 the depreciation is made on the basis of the original purchase price and not the present purchase price.

We can synchronize both methods by correcting the depreciation of the airframe each year with the airframe deflator.

Based on the original ATA'67, refs. 15 & 16 and the data in table 10 a new model for estimating maintenance cost was made. The model is correct for aircraft five years after their introduction and four years after purchase. The original formulae in ref. 15 and 16 have been compacted by reasonable assumptions and variable estimates as presented in ref. 6:

Airframe labor costs:
number of labor hours per airframe per flight cycle:
$AFCL=(2.14+0.0079mto+0.0046*seats)\sqrt{V}$ (h)
number of labor hours per airframe per flight hour:
$AFHL=(3.08+0.032*maf+0.0041*seats)\sqrt{V}$ (h)

$Cakm5 = DI * 4.82*(AFCL/R + AFHL/Vb)$ ($/km)

Engine labor costs:

mean time between repairs:

$mtbr=3604*tb^{0.28}*e^{-0.000324*TET}$ (h)

number of labor hours per engine per flight hour:

EL=0.143 + (1452 + 530*meng)/mtbr (h)

Cakm6= Dl* 4.82*ne* EL/Vb ($/km)

Airframe parts costs:

materials costs per airframe per flight clycle:

AFCM=(7.23+0.096mto+0.020seats) (h)

materials costs per airframe per flight hour:

AFHM=(6.51+0.028mto+0.025seats) (h)

The above costs AFCM and AFHM must be factored by $0.82v^2$ for supersonic aircraft.

Cakm7=Dac • (AFHM/Vb + AFCM/R) ($/km)

Engine parts costs:

Cakm8 =ne*(Dec*0.626+0.045*Ce/mtbr)/Vb ($/km)

Maintenance burden, indirect maintenance costs such as supervision, inventory management:

Cakm9=1.4*(Cakm5+Cakm6) ($/km)

Total σ(Maintenance)=36%

As is clearly made visible in table 6, a large variation in maintenance costs exists. New aircraft like the B757 and the B767 have much lower maintenance costs than predicted, while some more unusual and older aircraft like the BAE111 have higher maintenance cost. On average the model will present a 24% higher maintenance costs because so many aircraft are new and have much lower cost than aircraft that are 5 years or older.

An estimate of the direct operating cost per seat km can now be obtained by the following equation:

$$DOC=\sum_{i=1}^{i=9}(Cakmi)/(loadfactor*seats) \qquad (\$/pass.km)$$

where:

loadfactor=0.66 average for most airlines (in 1984)

In table 5 the influence of deflators in the model is shown, by the calculation of some historic DOC's. As you may observe, the deflators as presented in this model work well.

The public's viewpoint

In his decision to travel, the passenger has to weigh the benefits of making the trip and the cost including the loss in income during the trip.

How much can the airline ask for a decrease in trip duration? In view of the definition of opportunity cost of capital in ref. 8 we must relate the value of the increase in comfort to the decrease in trip time. Every hour not spent in the aircraft is an hour somebody can work and make money, this is especially true for business travellers.

There is another consideration to keep in mind. People have a preferred travelling time close to 4-6h/day (ref. 14). This means that a faster means of transport will make more people travel over a certain range. A economically competitive Mach 2 transport is therefore expected to make the pacific route as popular as the transatlantic route and this in its turn as popular as the East-West Coast route. And this is what transport is all about.

One piece of data does seem to prove this point. In table 8 one can observe an 80% growth in domestic American travel between '75 and 1980 (traveltime within 6h/day), while international travel only grew 55%.

It is now clear that the opportunity cost of capital is different for different passengers, but I propose an average of \$3.59/h. This reflects the average earnings in 1972.

If we assume a reference blockspeed of 800 km/h for current air transportation, we can propose the following relationship for added income through an increase in ticket price per passenger.

$$\Delta rev=DI^{*}\ ((tbref-tb)^{*}3.59)/R$$

According to this equation, the maximum ticket price increase as a result of an infinite increase in blockspeed is going to be no more than Dl*0.5 cts/km, which represents no more than 13% of the average ticket price.

It is not only the passenger who has to make a decision, society has to make a decision as well.

In terms of the protection of the environment the public, through the federal airworthiness regulations made a clear statement in the seventies and the aircraft manufacturers are obliged to conform to these regulations.

But if we are going to introduce new technology that is not yet covered by existing regulations we should always ask ourselves what the risk and cost of cancellation of new technology because of anticipated new regulations is and add this to the original cost of development.
It is not hard to predict that while there are no regulations regarding the maximum allowed ozone-depletion by jet engines today, the introduction of hundreds of SST's would certainly trigger such regulations.

Apart from this society has to make a political decision on the initial investment. Investments in aerospace typically break even after a 15 year period and are therefore uninteresting for private investors, so society as a whole (politics) has to step in.

As Mr. Flax points out in ref. 7, and as you yourself may conclude from table 1b, the cost of developing an aircraft becomes an ever larger fraction of the GNP. Today we are almost always speaking in terms of Billions of dollars. Apart from the economic impact study society must therefore always ask the question whether society can afford the risk of failure.

CASEI, an economic decision criterion

In recent years people have compared new aircraft designs with existing aircraft by plotting the direct operating costs of aircraft configurations.

In fig. 7 (ref. 11) one can see the improvement of direct operating cost in time, while fig. 8 represents the growth of world air traffic. Both of them clearly demonstrate the impact of new technology on travel.

The first segment of the curve in fig. 7 represents a break-through in aircraft construction. The DC-3 airliner introduced the monocoque structure which is still applied today.

The second segment of the curve shows the impact of the turbine engine which boosted the average cruise speed to double the value and therefore reduced the DOC by half.

But in this paper we have shown that there does exist an opportunity cost or gain related to increase in blockspeed.

We therefore define the Comparative aircraft seatkm economic index as follows:

$$CASEI = DOC - \Delta rev$$

It is of course crucial that aircraft should be compared on an equal basis. Preferably the aircraft should have approximately the same operational flexibility (*e.g.* takeoff field length) and payload-range capability. This is especially important when we compare short haul aircraft (fig. 9), since the DOC is primarily determined by range.

If our new aircraft is to be successful with a reasonable certainty the CASEI should be at least 20% lower than the aircraft it replaces,this in view of the inherent model errors.

Conclusion

The method presented in this paper gives a new way to look at the introduction of a new airliner using only eight variables at the harmonic range:

moe,mto,mp,Tto,ne,Tet,sew,V,R
or alternatively:
maf,mf,meng,Tet,Tto,mp,V,R,ne

and 4 Deflators to take into account economic change:
DI,Dac,De,Df

We have been able to predict the total investment in R&D in the new aircraft, and using Wright's law of production we predicted the average airframe cost within a 16% standard deviation for 81 aircraft sold in the last three years.

Using the old Direct and Indirect Operating Cost definition of the ATA'67 method and the compacted American Airlines and NASA airline operating cost methods, as well as an extensive empirical analysis of the direct operating costs of 618 american airliners, the author was able to estimate the direct operating cost of new designs within a 15% standard deviation.

To evaluate the design as a whole the passengers opportunity cost of time was used to model the expected increased revenues through the increase in blockspeed. Though this influence is only in the order of five percent for a 100% increase in blockspeed, such blockspeed increases are expected to increase the market as a whole.

To get accurate results with this method one should always compare your design's CASEI with competitor aircraft's CASEIs for similar ranges and payloads and loadfactors.

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Table 1: Economic deflators

year	Dac	De	Dl	Df
1960	0.783	0.783	0.708	* *
1970	0.943	0.937	0.928	* *
1971	0.982	0.973	0.968	0.967
1972	1.000	1.000	1.000	1.000
1973	1.033	1.038	1.062	1.094
1974	1.078	1.195	1.179	2.092
1975	1.160	1.401	1.287	2.508
1976	1.275	1.534	1.361	2.720
1977	1.400	1.594	1.449	3.110
1978	1.583	1.737	1.559	3.371
1979	1.778	1.907	1.735	4.944
1980	1.998	2.135	1.970	7.703
1981	2.215	2.368	2.174	8.922
1982	2.500	2.506	2.307	8.418
1983	2.740	2.712	2.381	7.620
1984	3.050	2.972	2.483	6.910
1985	3.200	3.098	* *	* *
1986	3.353	3.226	* *	* *

Source: ref. 12

TABLE 2: COST OF AIRFRAME DEVELOPMENT

type	moe	maf	CD M$	V	year	Dac	project	airframe
							---1000$/kg-----	
concorde	78.700		1400	2.179	66	.796	22.348	
sst	130.131		4500	2.867	66	.796	43.443	
dc10	111.086	97.12	420	.925	71	.970		4.458
f111	25.072	21.27	560	2.500	66	.796	28.060	
b747	159.664	140.00	600	.978	66	.796		5.384
dc-8	69.220	57.29	300	.965	66	.796		6.578
dc-9	25.104	21.62	100	.927	66	.796		5.810
vwf614		10.50	80	.743	71	.970		7.855
f28	16.620	14.27	75	.843	71	.970		5.419
c141a	67.186	59.71	280	.910	71	.970		4.834
a300b	79.382	69.08	450	.917	71	.970		6.716
c5a	169.643	151.01	950	.919	71	.970		6.485
b1 (-'79)	87.090		2776	2.335	72	1	31.875	
shuttle(-'82)	68.040		8390	28.325	72	1	123.310	
mercure	28.677	23.48	190	.900	71	.970		8.343

$\sigma(CD)=0.1$

MODELLED INFLUENCE OF SPEED ON AIRFRAME DEVELOPMENT COST

V	factor model	K$/kg
1.1<	1	6.200
1.200	1.181	7.321
1.600	2.099	13.015
2	3.280	20.336
2.400	4.723	29.284
2.800	6.429	39.859
3	7.380	45.756
28	19.921	123.509

TABLE 3A: COST OF DEVELOPMENT OF ENGINES

type	Tto	meng	cost M$	year	De	M$/kN	ε^2
j58	21		40	66	.80	2.38	.00
rr-103	95	1400	125	66	.80	1.65	.07
ge-cf6	178	3679	280	66	.80	1.98	.01
tf34	41	661	96	72	1	2.34	.00
GE-propfan	111		1200	85	3.80	2.84	.07
					mean	2.24	
					σX		.20

TABLE 3B: PRICE OF ENGINES

						Cost predicted M$	ε^2
tf-33	80	1969	.35	71	.97	.34	.00
tf-41	64	1353	.30	71	.97	.35	.03
rr-103	97	1400	.95	71	.97	.85	.01
tf-30	93	1900	.60	71	.97	.53	.01
jt-9d	197	3900	1.10	71	.97	1.18	.01
rb-211	187	4171	1	71	.97	.94	.00
ge-4	320	6400	1.80	71	.97	1.89	.00
					σX		.10

TABLE 4: PRICE OF AIRCRAFT

type	year	1)	price	De	Dac	moe	Tto	predicted	ε^2
Concorde	1975	4	47	1.160	1.410	78.200	784	78.399	.446
B737-300	1985	2	30.400	3.610	3.200	31.500	178	23.897	.046
DC-9	1985	4	24.400	3.610	3.200	26.600	129	20.031	.032
B737-200	1984	1	18.500	3.436	3.050	27.574	138	19.816	.005
B737-300	1984	13	26.062	3.436	3.050	31.500	178	22.772	.016
B767-200	1984	10	48.160	3.436	3.050	79.900	426	57.592	.038
MD-80	1984	17	25.847	3.436	3.050	36.200	166	25.914	.000
B757	1983	4	46	3.073	2.740	57.200	356	37.314	.036
B747-300	1983	6	93.050	3.073	2.740	176.900	832	113.821	.050
MD-80	1983	17	24.435	3.073	2.740	36.200	166	23.267	.002
B737-200	1983	3	19.333	3.073	2.740	27.574	138	17.791	.006
Total		81						σX	.260
								σX (3)	.160

1)Number of aircraft used to average price
2)Assumptions: sew=0.2/ nb=400 /c=4
3)Excluding Concorde

source: ref.5 & ref. 2 :export/import bank authorizations of loans in support of exports of commericial jet aircraft

TABLE 5: HISTORIC OPERATING COSTST

type	year	n	R(Mm)	DOC	DOCe	ε
F-28-6000	1973	79	1.20	.61	.64	.05
L-1011	1970	268	6.80	.44	.46	.05
Concorde	1976	108	6.23	2.25	2.31	.03
B747	1970	374	6	.42	.45	.07
B707	1970	149	6	.50	.55	.10

TABLE 6: AIRCRAFT OPERATING COST IN 1984

							-----------OPERATING COSTS (5)---------				
type	mfuel/ blockh.	U	Vflight	Vb	tfl	tb	crew (2)	fuel (3)	airframe (4)	engine (4)	burden (4)
B747	9.33	3674.40	813.05	735.77	4.52	4.99	738.54	2719.58	255.88	226.52	395.71
--->(1)		4464.94					855.35		249	315	232
B747SP	9.02	4442.47	853.30	814.66	5.21	5.45	853.66	2629.09	93.52	110.02	224.42
		4523.42					758.77		181	261	186
A300B4	5.15	3239.58	729.33	632.73	4.44	5.12	602.93	1501.01	107.20	212.90	166.08
		4482.35					483.31		177	201	158
B767-200	3.74	3813.29	735.77	635.95	5.18	6.00	480.96	1089.18	79.37	28.76	126.75
		4577.29					436.12		164	178	149
BAE146-2	1.84	3200.60	540.96	462.07	5.92	6.93	149	536.14	71.56	70.29	121.10
		4641.54					174.01		128	101	131
MD80	2.62	3804.98	692.30	595.70	5.50	6.39	376.76	763.61	54.18	29.85	46.98
		4607.98					255.90		131	71	114
B737-200	2.33	3552.69	610.19	495.88	5.82	7.16	264.29	679.05	109.70	64.68	76.77
		4653.70					229.05		147	73.70	123
F28	1.75	2725.06	566.72	452.41	4.81	6.02	165.59	509.92	94.22	76.83	54.31
		4579.63					156.66		124	53	100
B757-200	3.13	3691.53	690.69	598.92	5.34	6.16	450.17	913.29	59.99	7.37	47.61
		4591.16					351.66		158	127	143
DC10-30	7.79	4703.09	854.91	811.44	5.50	5.80	579.79	2272.23	101.82	81.56	75.17
		4559.11					671.04		166	235	158
DC10-30	6.92	4656.63	813.05	734.16	5.73	6.34	579.79	2017.70	78.99	198.57	53.33
		4604.77					671.04		204	208	183
L-1011-5	6.80	3573.39	838.81	785.68	4.26	4.55	826.91	1983.87	174.37	134.01	255.23
		4393.75					620.38		165	169	158
B727-200	3.66	3277.68	669.76	568.33	4.89	5.77	389.93	1067.20	146.93	92.18	65.52
		4556.34					339.26		160	182	156
DC-9-30	2.30	3335.19	603.75	483	5.52	6.91	251.31	671.44	144.60	108.77	87.46
		4640.37					213.43		116	70	107
BAC111-2	2.22	2721.75	539.35	434.70	5.05	6.26	271.03	646.07	219.94	99.13	166.35
		4598.73					208.53		140	68	117
DC8-61	5.14	2982.02	716.45	618.24	4.16	4.82	397	1499.32	171.12	4.93	252.74
sample:		4439.56					485.88		177	133	166

(1) See table 11 for model input
(2) including training
(3) per block hour
(4) labor and parts
(5) Depreciation did not include capital inflation

TABLE 7: MODEL INPUT

type	#	Range	seats	Vc	mto	moe	Tto	ne	TET	sew	DOC(1)
B747	28.20	3178.14	411.90	978	356	167	880	4	1520	.20	2.13
B747SP	11.60	6990.62	230.90	978	300	146	880	4	1520	.20	3.13
A300B4	29.50	1608.39	244.50	889	157.50	88.20	480	2	1640	.20	2.60
B767-200	52.60	1740.41	199.30	937	136	81.70	440	2	1520	.20	2.55
BAE146-200	1.90	491.05	96.90	776	36.60	20.70	120	4	1500	.19	4.11
MD80	46.40	1194.62	142.50	892	63.50	36.20	168	2	1300	.23	2.36
B737-200	205.40	550.62	112.80	927	54.20	26.90	140	2	1300	.22	3.67
F28	4.50	444.36	65	808	31.50	17.60	88	2	1300	.23	5.42
B757-200	15.30	1175.30	185	915	100	59.30	340	2	1500	.24	2.49
DC10-30	7.10	6089.02	241	917	251.70	119	690	3	1600	.18	2.77
DC10-30	5.10	2885.12	354.90	917	251.70	119	690	3	1600	.18	2.04
L-1011-500	9.60	4462.92	230.60	925	225	109	561	3	1500	.22	2.56
B727-200	105.90	899.99	160.10	964	95	45.30	210	3	1300	.22	3.23
DC-9-30	61.80	648.83	106.20	918	49	26.50	136	2	1300	.22	3.50
BAC111-200	23.20	442.75	78.80	871	47.40	24.70	114	2	1300	.21	2.88
DC8-61	10.30	1331.47	199.20	938	158.70	69.73	328	4	1300	.24	2.95
sample:	618.40										

(1) As defined in the model

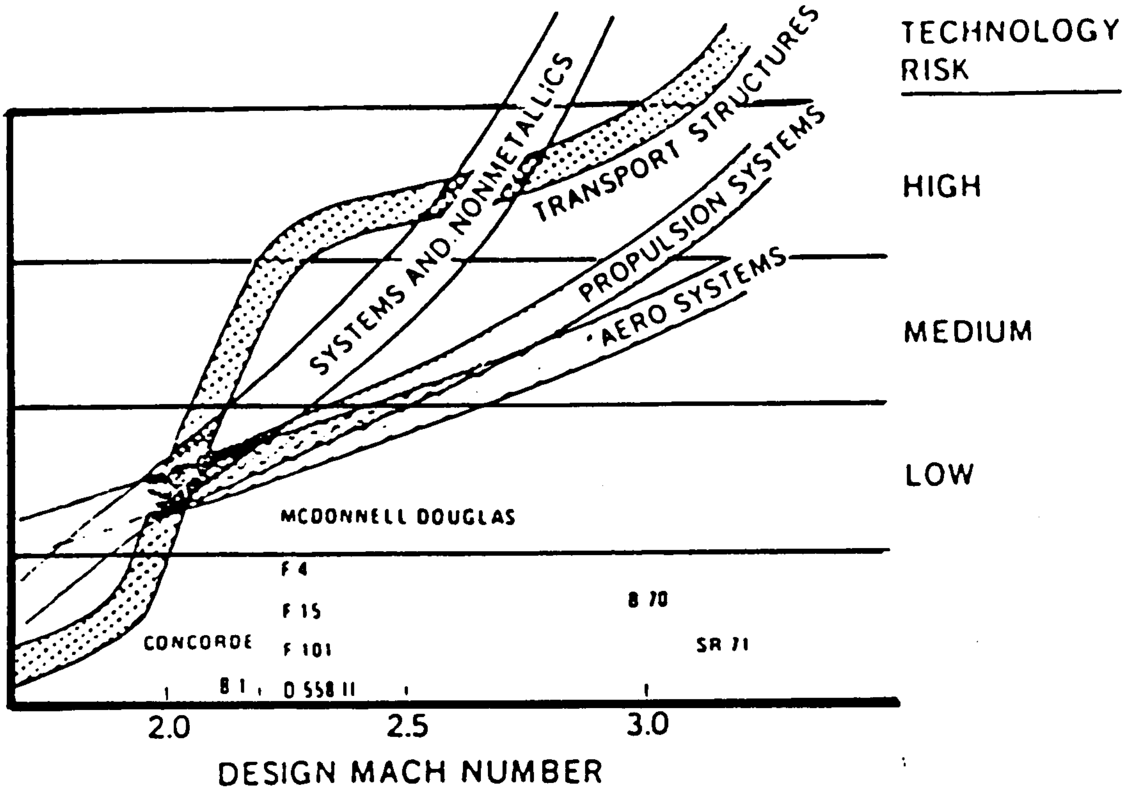


Figure 1. Technology risk as a function of Mach Number. (ref. 12)

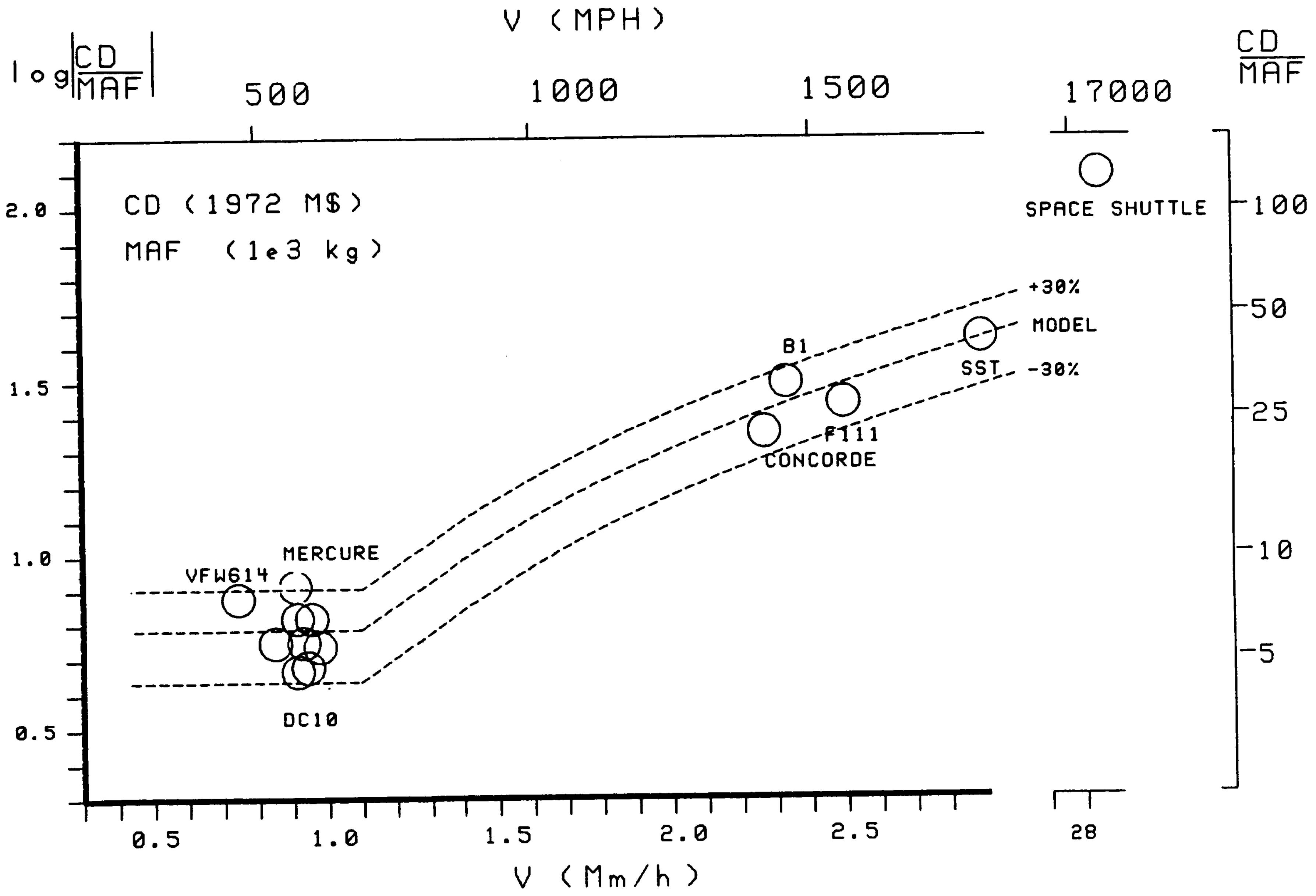
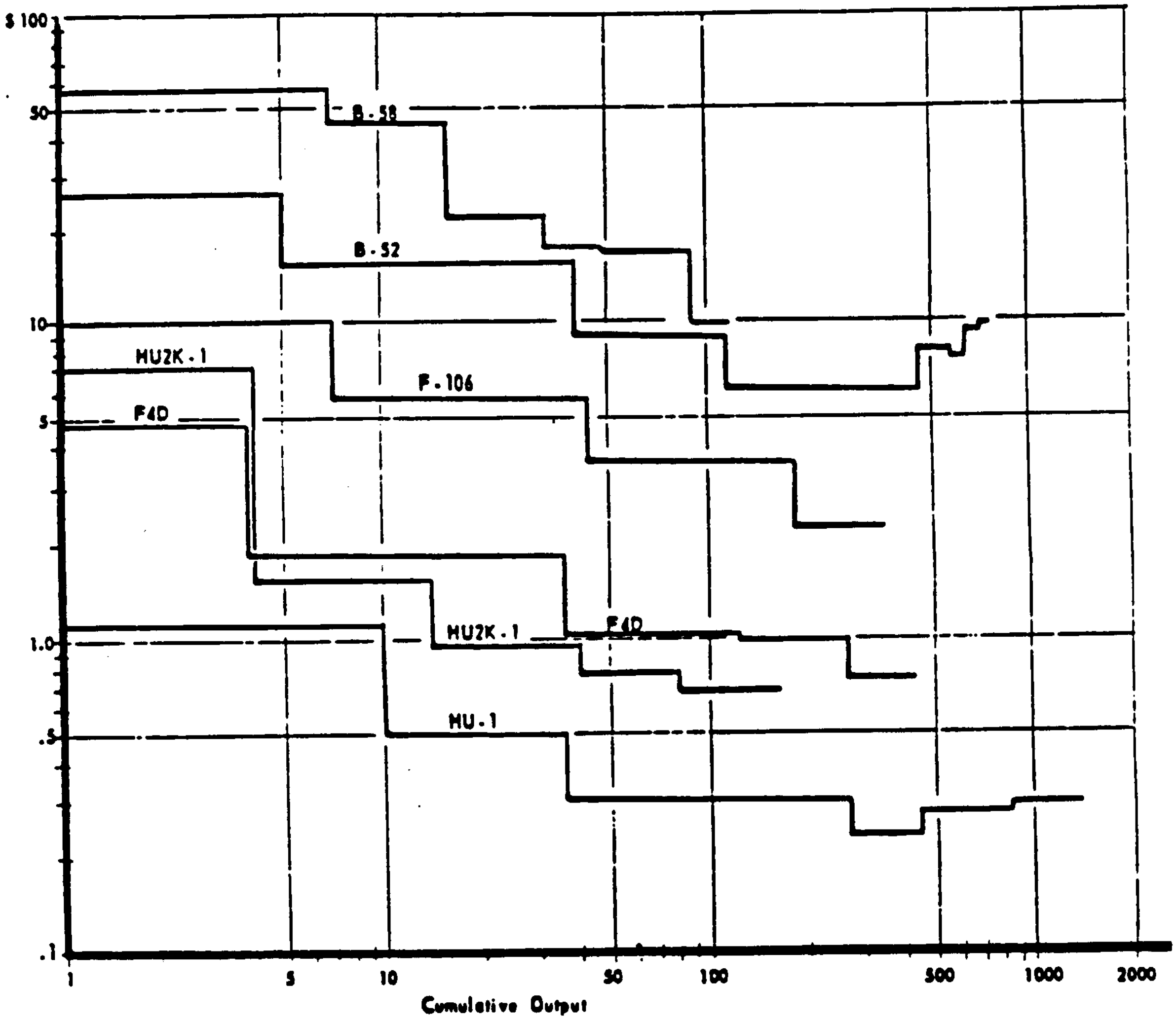


Figure 2. SPECIFIC COST OF DEVELOPMENT OF THE AIRFRAME AS FUNCTION OF THE MAXIMUM CRUISE SPEED

Examples of Aircraft Models Included in Estimating Slopes of Cost Curves

(Millions of Dollars)



SOURCE: Directorate for Statistical Services
Office of the Secretary of Defense Reports for CY 1950 - 1964

Figure 3. The production learning curve (ref. 4)

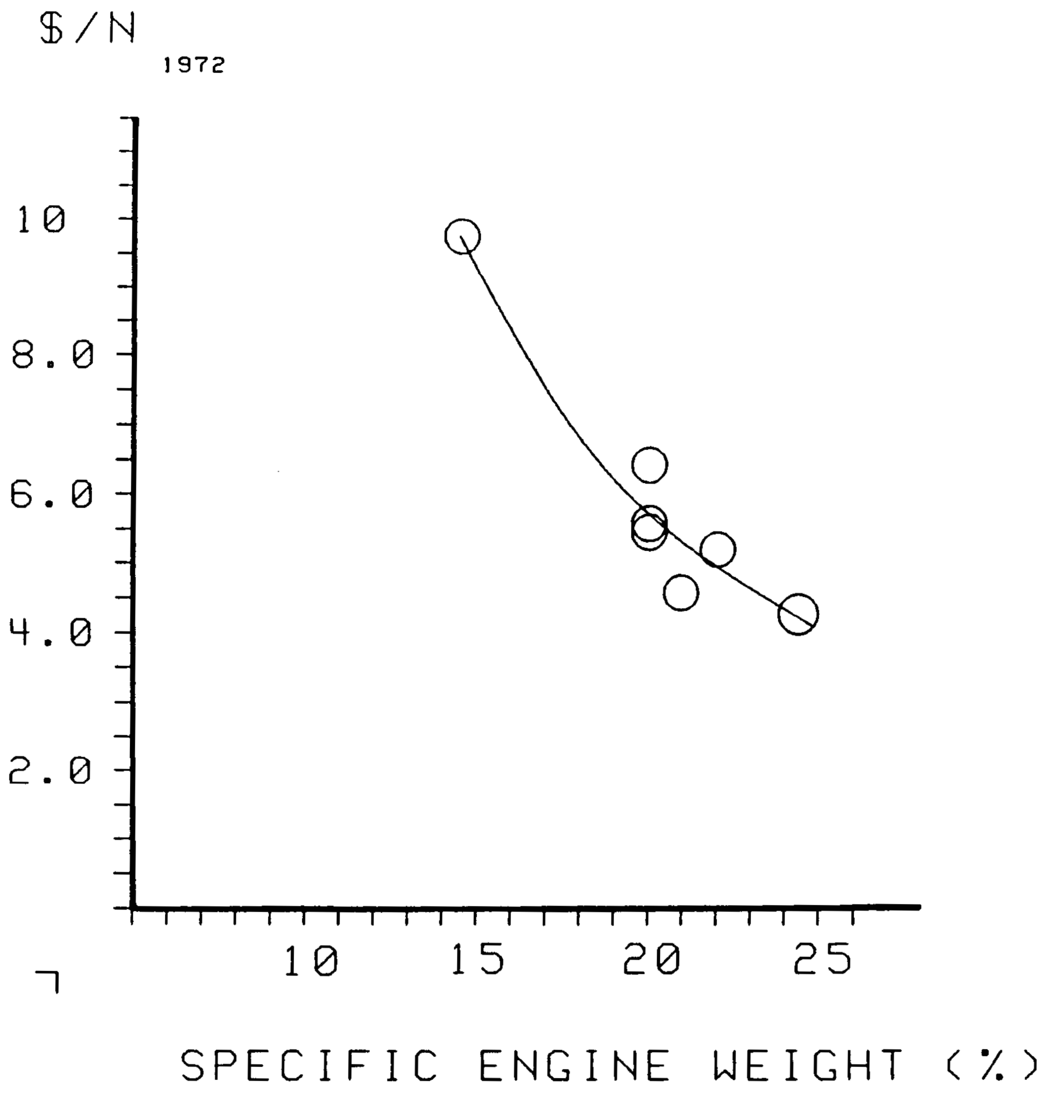


Figure 4. SPECIFIC ENGINE COST AS A FUNCTION OF SPECIFIC ENGINE WEIGHT

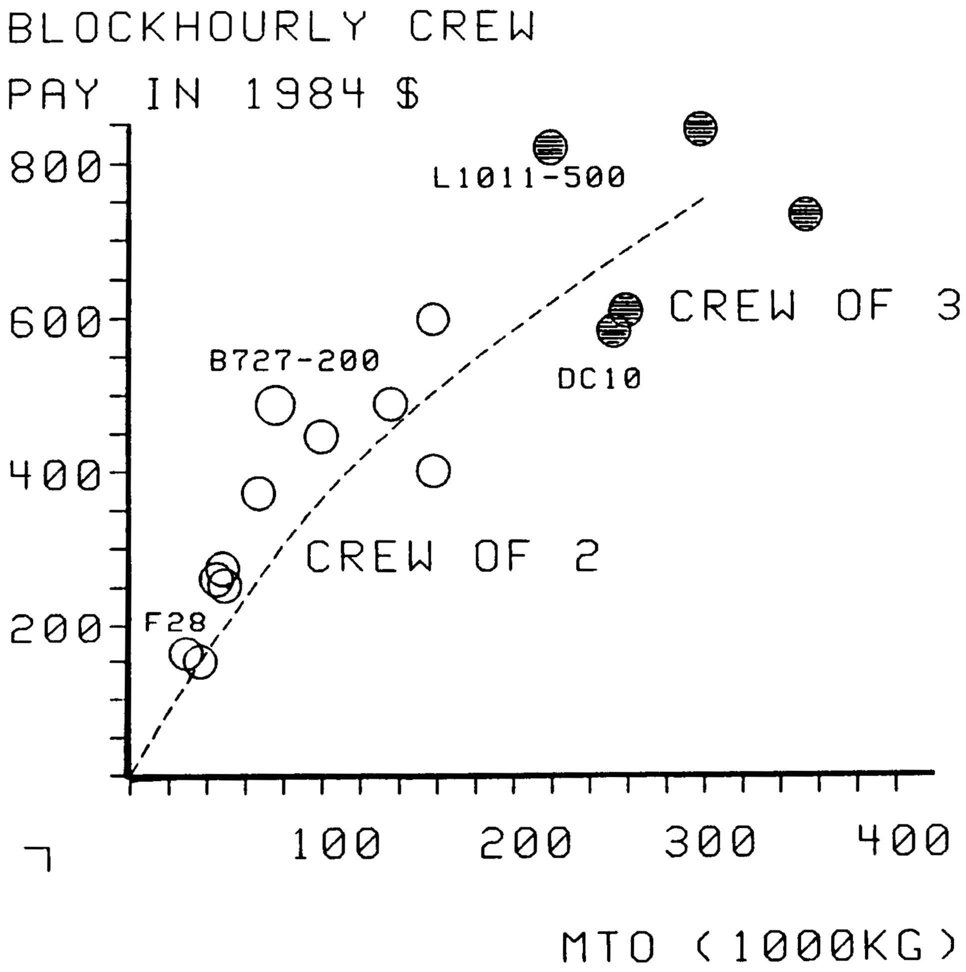


Figure 5. CREW PAY AS A FUNCTION OF MAXIMUM TAKEOFF MASS

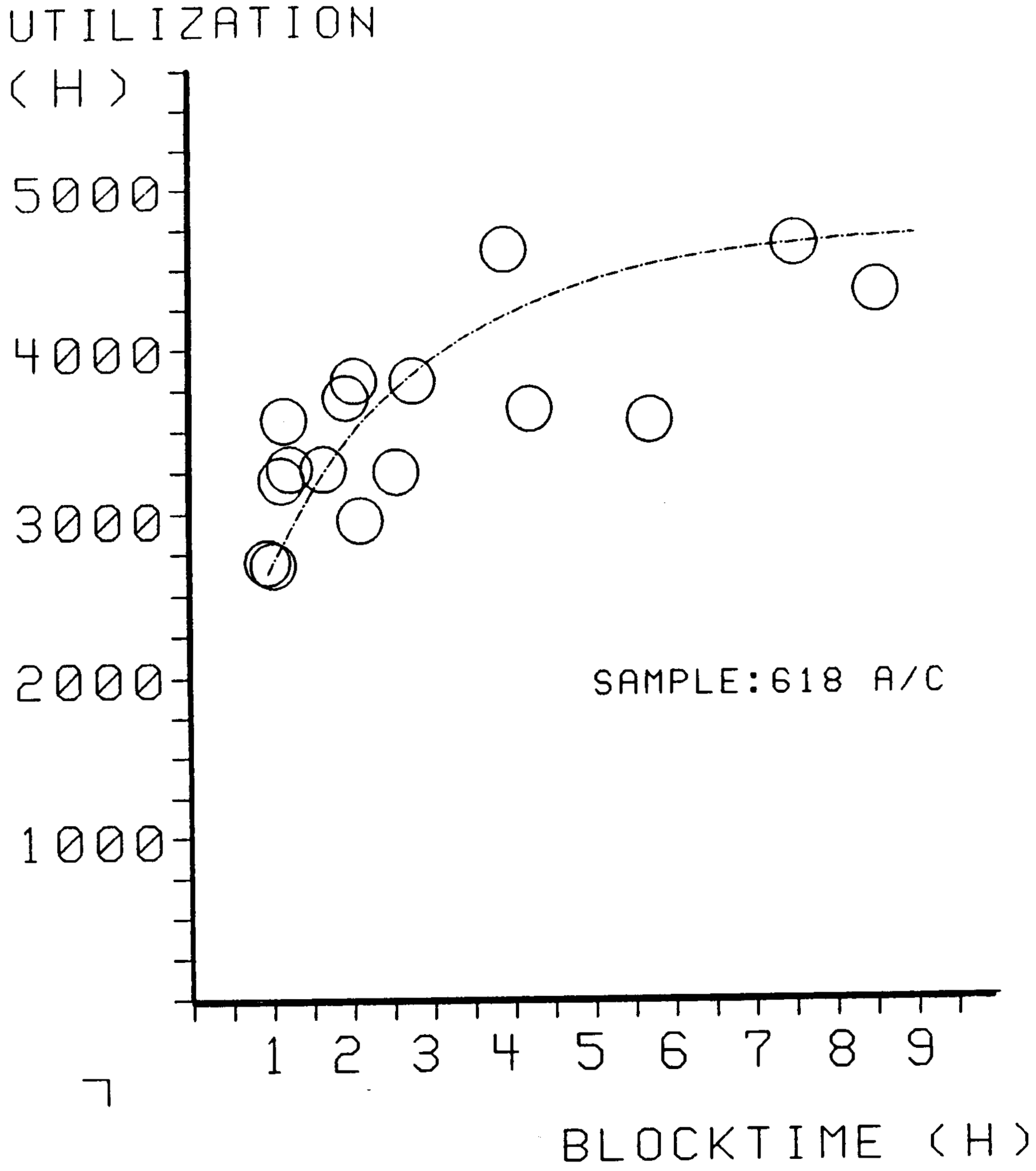


Figure 6. ANNUAL UTILIZATION AS A FUNCTION OF BLOCKTIME

Fig. 7. Historic Operating Costs (ref. 11)

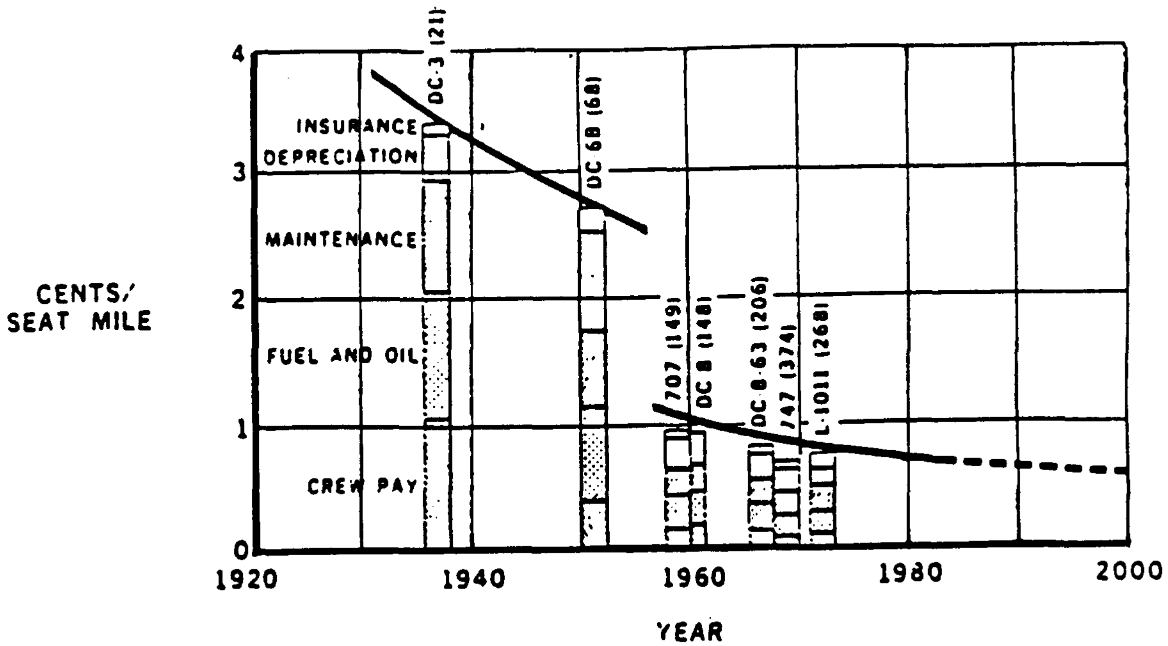
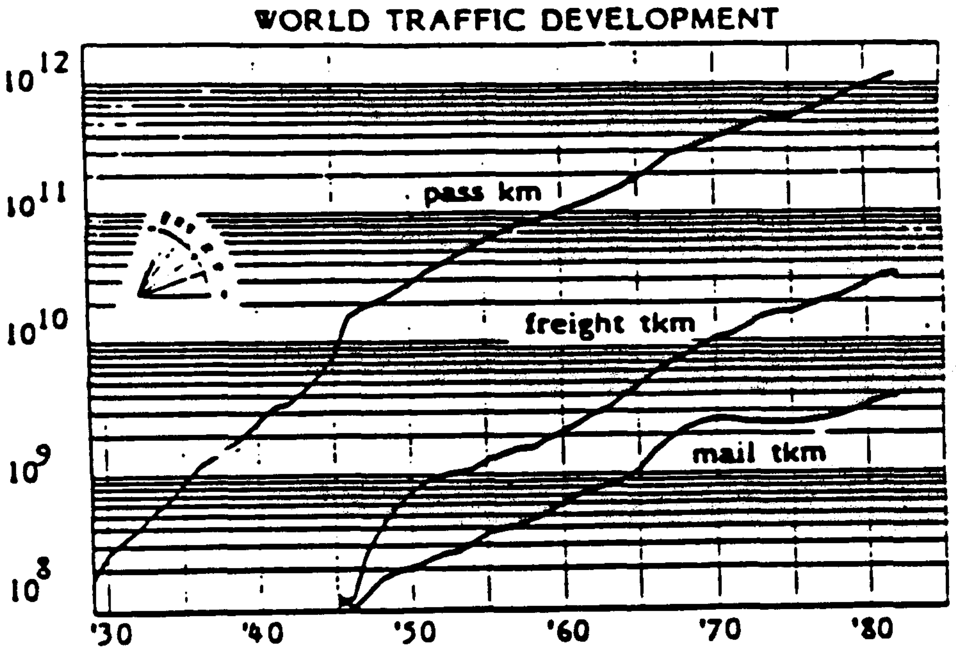


Fig. 8 (ref. 11)



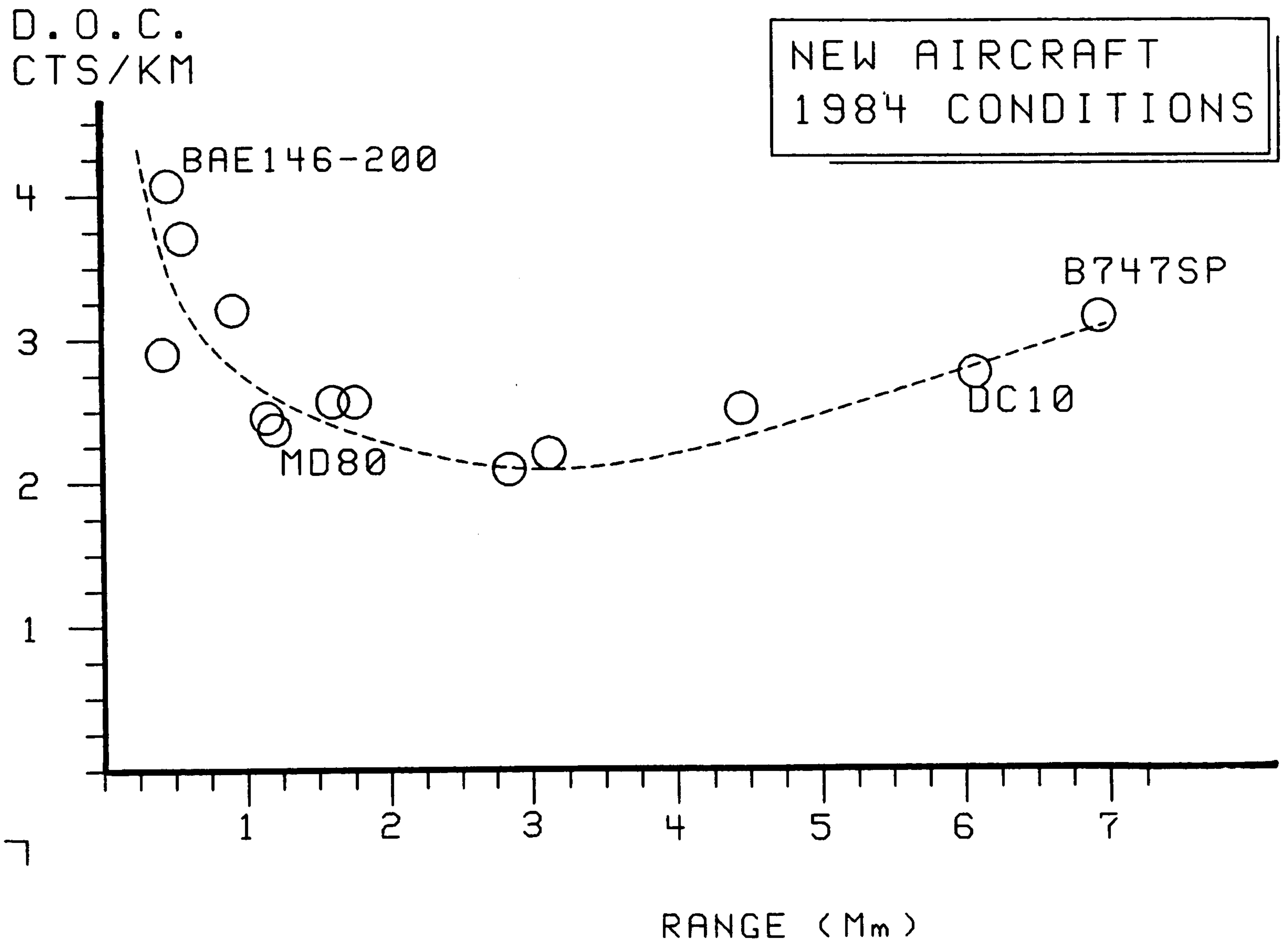


Figure 9. TYPICAL DIRECT OPERATING COSTS AS A FUNCTION OF RANGE

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16. Abstract

In this paper we will introduce a Class I method for determining whether further development of a new aircraft design is desirable from all viewpoints. For the manufacturer the model gives an estimate of the total cost of research and development from the preliminary design to the first production aircraft. Using Wright's law of production we will derive the average cost per aircraft produced for a given break-even number. The model will also provide the airline with a good estimate of the direct and indirect operating costs. From the viewpoint of the passenger the model proposes a tradeoff between ticket price and cruise speed. Finally all of these viewpoints are combined in a Comparative Aircraft Seat-kilometer Economic Index.

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