A METHOD FOR THE ANALYSIS OF THE BENEFITS AND COSTS FOR AERONAUTICAL RESEARCH AND TECHNOLOGY

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ABSTRACT

This paper presents a relatively simple, consistent, and reasonable methodology for performing cost-benefit analyses which can be used to guide, justify, and explain investments in aeronautical research and technology. The elements of this methodology (labeled ABC-ART for the Analysis of the Benefits and Costs of Aeronautical Research and Technology) include estimation of aircraft markets; manufacturer costs and return on investment versus aircraft price; airline costs and return on investment versus aircraft price and passenger yield; and potential system benefits--fuel savings, cost savings, and noise reduction. The application of this methodology is explained using the introduction of an advanced turboprop powered transport aircraft in the medium range market in 1987 as an example.

INTRODUCTION

As part of the NASA Aircraft Energy Efficiency (ACEE) program formulation, a benefit analysis was performed to estimate the potential fuel savings which could be obtained by applying the advanced technologies in the ACEE program (ref. 1). At the time this analysis was performed the only benefit that was estimated was fuel savings and the economic consequences could not be determined. However, it was recognized that even with very large potential benefits it is also desirable to determine whether the technology, if developed, would be economically attractive to the potential users. In order to provide the capability for investigating these tradeoffs between the benefits of advanced technology and the economics of the air transportation system, a cost benefit methodology with the acronym ABC-ART has been developed. ABC-ART is an abbreviation for the Analysis of the Benefits and Costs of Aeronautical Research and Technology. The name also is meant to imply that the intention is to develop a methodology that is as simple as ABC. The objective of ABC-ART is to provide a consistent, simple, and reasonable methodology for performing cost-benefit analyses which can be used to guide, justify and explain investments in aeronautical research and technology. The elements of ABC-ART include aircraft market projection, manufacturer research, development, test and evaluation (RDT&E) and production cost estimation, manufacturer return on investment (ROI) versus price estimation, airline ROI versus price estimation, required passenger yield calculations, and the tabulation of the potential system benefits--fuel savings, cost savings, noise reduction, etc.

As a means of illustrating the application of the ABC-ART, an example using the introduction of a 1987 Propfan Transport into the U.S. trunk and local service carrier medium range aircraft market will be used. This example also assumes a revenue-passenger-mile growth rate of 6% per year, a constant passenger load factor of 55%, a 16-year aircraft retirement age, and that the 1987 Propfan Transport is the only medium range transport aircraft produced from 1987 to 1995. The Propfan Transport used for this example is the Boeing wing-mounted propfan study aircraft shown in figure 1. This aircraft was designed to carry 180 passengers for 1800 n.mi. at a cruise speed of Mach 0.8. The aircraft has a take-off gross weight (TOGW) of 122 062 kg (269 100 lb) and an operating empty weight (OEW) of 83 710 kg (184 550 lb). The aircraft has 2 Pratt & Whitney study turboshaft engines (STS476) with 22 721 kW (30 470 shaft horsepower (SHP)) each. Based on the airline recommendations received on the aircraft examined in the RECAT studies, the manufacturer specification of 180 seats was reduced to 171 seats to allow for garment stowage areas.

AIRCRAFT MARKET PROJECTION AND FUEL SAVING BENEFITS

In order to develop the aircraft market projection, data are required on the current fleet and its history. These data include (figure 4) information on the current fleet aircraft years of introduction; aircraft productivity data in terms of average aircraft seating capacity, block speed, and utilization; aircraft retirement age; fuel consumption rates; revenue-passenger-mile (RPM) growth rates; load factors; and projected retrofit, derivative, or new aircraft data:

Inputs:

(a) Current and historical fleet data by aircraft type

- (1) Aircraft year of introduction
- (2) Aircraft productivity data (seats, block speed, utilization)
- (3) Retirement age
- (4) Fuel Consumption

(b) Growth Rates

(c) Load Factors

(d) Projected retrofit, derivative, or new aircraft data

Outputs:

(a) Projected future fleet information

- (1) RPM's by year and aircraft type
- (2) Fuel usage by year and aircraft type
- (3) Aircraft requirements

For this example, the aircraft data used are shown in table I. These data are the average for the U.S. trunk carriers as reported to the Civil Aeronautics Board in 1975 (ref. 2). It is grouped into the aircraft type categories for the two-engine narrow-body turbofan aircraft (2ENBTF), three-engine narrow-body turbofan aircraft (3ENBTF), four-engine narrow-body turbofan aircraft (4ENBTF), four-engine narrow-body turbojet aircraft (4ENBTJ), three-engine wide-body turbofan aircraft (3EWBTF), and four-engine wide-body turbofan aircraft (4EWBTF). For the purposes of this analysis these aircraft are further grouped into the short, medium, and long range market categories on the basis of aircraft range capability. Because it appears that about one-half of the 4ENBTJ and 4ENBTF aircraft are being used on route segments where they could be replaced by an aircraft with medium range capability, these aircraft were split into both markets equally. The new aircraft being evaluated is the new two-engine wide-body propfan aircraft (N2EWBPF) with the same operating characteristics as the 3ENBTF it is intended to replace, except for a larger passenger capacity and lower fuel consumption.

These data are input to a computer program (BET) and information on RPM's and fuel usage by year and aircraft type are computed. The projected information on the medium range aircraft market share by aircraft type (fig. 2) shows the RPM's carried by the four-engine narrow-body turbojet aircraft (4ENBTJ), four-engine narrow-body turbofan aircraft (4ENBTF), three-engine narrow-body turbofan aircraft (3ENBTF), new two-engine wide-body propfan aircraft (N2EWBPF), and new 1995 aircraft(N1995AC). The N1995AC has the same characteristics as the N2EWBPF, but it is included in order to finish the production run of the N2EWBPF in 1995.

The only medium range aircraft available from 1975 to 1987 is the 3ENBTF. During this period new buys of this aircraft are used to accommodate the RPM growth and the retirement of the 4ENBTJ and 4ENBTF aircraft. The N2EWBPF is introduced in 1987 and production of the 3ENBTF is stopped. The N2EWBPF is produced until 1995 when the N1995AC production takes over for the remainder of the case through 2005. The demand for the N2EWBPF results in a required production run of 872 aircraft. The fuel usage for these medium range aircraft, corresponding to the RPM's carried, is shown in figure 3. The fuel savings for the N2EWBPF relative to continued use of the 3ENBTF is indicated by the cross-hatched area. This fuel savings is 38×10^9 liters (240 million barrels) from 1987 to 1995 alone.

MANUFACTURING ROI VERSUS PRICE

The manufacturing ROI versus price estimation procedure is illustrated in figure 4. From the fleet projection information obtained previously (RPM's versus year by aircraft type), a production schedule is developed to closely approximate the required demand while maintaining the production rate fixed as much as possible. This production schedule is input to a computer program which estimates the aircraft manufacturing costs as a function of the aircraft component weights, labor rates, and learning curves. This program (ACCOST) has been developed at Ames Research Center over the past several years. It was first based on some original work on total airframe costs by Planning Research Corporation in 1964 (ref. 3) and subsequently has been continually improved by The Rand Corporation. The current version of ACCOST determines the production cost for each system and the assembly and delivery costs for the complete aircraft using cost estimating equations developed in reference 4. This current version of ACCOST is described in detail in reference 5. The resulting estimated RDT&E costs, first-unit costs, learning curves, and assumed airline prepayment schedule are input to a manufacturing cash-flow ROI calculation which computes the manufacturer ROI versus price. The manufacturing cost breakdown is shown in table II. The RDT&E is the sum of the airframe design and engineering development, subsystem development, propulsion development, and development support. The first unit manufacturing cost includes the airframe, avionics procurement, propulsion procurement, and final assembly and checkout.

The manufacturing costs and revenues per month are illustrated in figure 5. For this example, the propulsion RDT&E costs were assumed to be uniformly incurred over a period from 4-1/2 years prior to first delivery until first delivery. The airframe and subsystem RDT&E costs were assumed to be uniformly incurred from 3-1/2 years prior to first delivery until first delivery. And the development support was assumed to be uniformly incurred from 2-1/2 years prior to first delivery until one year after first delivery. The manufacturing costs begin one year prior to first delivery and reflect a one year "pipeline." The influence of an initial production rate of 7 per month increasing to 11 per month and the manufacturing learning curves can clearly be seen on the manufacturing cost curve. The airline payments shown on figure 5 are for an aircraft price of $20 million per aircraft with a prepayment schedule of 5% down on order (assumed two years before delivery), 25% in payments from order to delivery, and 70% on delivery. The notches in the airline payment curve reflect a production adjustment at the end of the 7 per month production period and end of the production run to match the required demand.

The cumulative manufacturer cash flows (without any discounting) are illustrated in figure 6. The net cash flow curve indicates a bucket of about $1.5 billion just after first delivery and a breakeven point 2-1/2 years after first delivery. The manufacturer internal rate of ROI (corresponding to the discount rate which makes the sum of the discounted cash flows equal to zero) is shown as a function of aircraft price and total production quantity in figure 7. For an ROI of zero (corresponding to constant dollars), the required aircraft price is a little over $11 million for a production run of 872 aircraft or $15.7 million for a production run of 436 aircraft. The ROI for 436 aircraft corresponds to the case when two manufacturers compete for the same market and make the same RDT&E investments or when a manufacturer estimates a price based on that production quantity. For a more reasonable

ROI of 15%, the required prices are $14 million for 872 aircraft or $20.5 million for 436 aircraft.

AIRLINE ROI VERSUS PRICE

The airline ROI versus price estimation procedure is illustrated in figure 8. The first step in this procedure involves the calculation of the aircraft direct and indirect operating costs using a computer program called OPLIFE. This calculation requires input information on the aircraft weights and performance characteristics; aircraft price, prepayment schedule, and depreciation schedule; and airline labor and overhead rates. The DOC relationships were developed by the Massachusetts Institute of Technology (refs. 6 and 7) and represent a modification of the 1967 Air Transport Association (ATA) formulae updated to agree with the actual operating expenses reported by the U.S. domestic trunks to the CAB in 1975. The IOC relationships were also developed by MIT (ref. 8) using the CAB Version 6 costing methodology (ref. 9) developed to meet the costing needs of the Domestic Fare Structure Study which the CAB initiated in 1966 (ref. 10). These IOC costs reflect the 1973 operational experience for the U.S. domestic trunk airlines.

The DOC and IOC as well as the assumed aircraft price and prepayment and depreciation schedules are input to an airline ROI calculation. This program uses the discounted cash flow method to calculate the aircraft internal rate of ROI over a specified operational period. This computer program was developed by MIT (ref. 11) around a basic methodology developed in 1971 by Eric Anderson of NASA Ames Research Center. This ROI calculation can be tailored for a variety of considerations including yearly variations in revenues per year, operating costs per year, different prepayment or depreciation schedules, interest rates for external financing, as well as different corporate tax rates and capital gains tax rates. Although the ROI in this example is for a single aircraft operated at an average stage length over its entire operational period, the ROI calculation procedure can handle up to 100 aircraft in a fleet purchased by an airline over a planning horizon of 25 years. For this example the revenue per year is input to the ROI calculation, but it could also be made a function of the traffic volume, as indicated in figure 8. The assumptions used for this example are:

(a) DOC & IOC - MIT Mod. of ATA & CAB

(b) Annual revenue input

(c) Investment--5% down two years before delivery - 25% payments until delivery - 70% balance financed @ 10% on delivery

(d) Depreciation--double declining for 8 years - (ECLIFE/2)-straight line for next 8 years - 15% residual value - recovered at 16 years

(e) 48% corporate income tax rate.

The tax computation reflects normal corporate practices and takes into account the carrying backwards and forwards of normal operating losses as well as of capital gains and losses.

The resulting airline ROI is shown as a function of aircraft price and revenues per year in Figure 9. In this case, the ROI calculation after taxes already includes interest of 10% on the 70% of the aircraft price which is financed on delivery. The $8.0 million revenue per year level corresponds to the revenue which would occur if the fares resulted in a yield per RPM equal to the 1975 average yield for the U.S. domestic airlines. If the airline required a 15% ROI and the fares resulted in revenues of $8.0 million per year, the airline could pay up to $17.5 million for the new propfan transport. If the aircraft price is higher, the fare levels would have to be raised to achieve the same ROI. Or if the aircraft price were lower, the fares could be reduced for the same ROI level.

ABC-ART EXAMPLE CONCLUSIONS

If we overlay the manufacturer ROI versus price and airline ROI versus price relationships we can see the tradeoffs that result (fig. 10). If we assume that a 15% ROI is a reasonable target for both the manufacturer and the airline there are several values of aircraft price that may be acceptable depending on the manufacturer production quantity or airline fare levels. If the manufacturer price is $14 million, based on the full 872 aircraft production quantity, the airline could also achieve a 15% ROI at a fare level 6.25% lower than the 1975 levels. If the manufacturer price of $20 million is based on one-half of the projected market or 436 aircraft, the airline fare levels would have to be raised by 6.25% to achieve a 15% airline ROI.

In summary, the example conclusions from this cost-benefit methodology are:

(a) U.S. airline medium range market requires 872 new propfan aircraft from 1987-1995

(b) 1987 propfan could save 38×10^9 liters (240 million barrels) of fuel from 1987-1995

(c) Fuel savings equal $4.0 billion @ 10.6¢ per liter (40¢ per gallon)

(d) Manufacturer price for 15% ROI must be at least -- $14M for 872 aircraft production - $20M for 436 aircraft

(e) Airline cost for 15% ROI must be less than -- $17.5M for 1975 fare levels - $20.5M for 1975 fare levels plus 6%

(f) At 15% ROI the 1987 propfan appears economically feasible.

Based on the assumptions in this example, the U.S. airline medium range aircraft market would require 872 new propfan transports from 1987 to 1995. During this period alone, the 1987 propfan could save 38×10^9 liters (240 million barrels) of fuel. This fuel saving equals $4 billion at a fuel price of 10.6¢/liter (40¢/gallon). The manufacturer price for a 15% ROI must be at least $14 million for an 872 aircraft production run or $20 million for a production run of 436 aircraft. The airline cost for a 15% ROI must be less than $17.5 million at 1975 fare levels or $20.5 million at 1975 fare levels plus 6.25%. It appears that a reasonable aircraft price could be found where the 1987 propfan would be economically feasible.

POTENTIAL ABC-ART APPLICATIONS

This example has only indicated one potential application of the ABC-ART methodology. This tool can also be applied to examine many air transportation system interactions. These interactions should include the examination of a general airline route network and aircraft mix. This would insure that the overall system benefits for a new aircraft are obtained. Otherwise it is possible to miss some of the benefits that can occur when an aircraft improves the total system operation by allowing the other aircraft in the fleet to be used more efficiently. The examination of the economic feasibility of a new aircraft should also include the examination of other alternatives, particularly the continued production of the existing aircraft. The potential ABC-ART applications are:

(a) Examine system interactions

- (1) General airline route network and aircraft mix
- (2) Compare aircraft alternatives
- (3) Fare-demand elasticity

(b) Develop technology goals

- (1) Operating cost improvements versus aircraft cost
- (2) Evaluate technology scenarios under economic constraints
- (3) Noise, emission, congestion benefits
- (4) Subsidy -- fare surcharge questions

Questions involving fare-demand elasticity can be addressed by adding another interactive feedback loop to the entire process to take the required fare levels, compute the resulting demand, and recompute the projected fleet requirements. The ABC-ART methodology can also be used to develop technology goals. It can examine the tradeoffs in operating cost reductions versus aircraft cost increases. It can be used to evaluate technology scenarios under economic constraints to insure that the assumptions on new aircraft appear reasonable. Other benefits of technology can also be calculated. The capability to examine aircraft noise has been added to the ABC-ART under a NASA contract with the Stanford Research Institute. This capability is currently being used to examine future noise reduction scenarios in cooperation with the FAA.

Because the ABC-ART fleet projection estimates numbers of aircraft of each type in the future years, this information can also be used to indicate potential emission and congestion effects. The ABC-ART methodology can also examine subsidy and fare surcharge requirements and the impact of new technology on these requirements.

In conclusion, the ABC-ART methodology is not capable of predicting the future, but it can be a useful tool for examining many air transportation system alternatives and provide guidance on what is required to move in the preferred direction.

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TABLE I.- BASELINE AIRCRAFT DATA U.S. TRUNKS 1975.

AIRCRAFT TYPE	MARKET (RANGE)	INTRO. YEAR	NO. OF SEATS	FUEL CONSUMP. kg / SEAT km	lb / SEAT mi	BLOCK SPEED km/hr	(mph)	UTILIZATION hrs/yr	RETIREMENT AGE years
2ENBTF	SHORT	HIST.	89.7	0.0608	(0.2157)	501	(311)	2849	16
3ENBTF	MED	HIST.	112.2	0.0603	(0.2140)	576	(358)	3079	16
4ENBTJ	MED & LONG	HIST.	134.0	0.0711	(0.2523)	657	(408)	2509	16
4ENBTF	MED & LONG	HIST.	144.3	0.0552	(0.1959)	650	(404)	3102	16
3EWBTF	LONG	HIST.	236.3	0.0438	(0.1553)	663	(412)	3042	16
4EWBTF	LONG	HIST.	352.6	0.0394	(0.1398)	731	(454)	3259	16
N2EWBPF	MED	1987	171.0	0.0321	(0.1140)	576	(358)	3079	16

REF: AIRCRAFT OPERATING COST AND PERFORMANCE REPORT – CAB JULY 1976

TABLE II.- 1987 PROPFAN AIRCRAFT COST ESTIMATION (MILLIONS OF DOLLARS).

RESEARCH, DEVELOPMENT, TEST, AND EVALUATION			
AIRFRAME DESIGN AND ENGINEERING DEVELOPMENT			223.73
SUBSYSTEMS DEVELOPMENT			130.27
PROPULSION DEVELOPMENT			466.32
DEVELOPMENT SUPPORT			445.44
GROUND TEST VEHICLES (1.0)		26.49	
GROUND TEST SPARES		2.65	
FLIGHT TEST SPARES		22.57	
TOOLING AND SPECIAL TEST EQUIPMENT		330.45	
FLIGHT TEST OPERATIONS		32.92	
GROUND SUPPORT EQUIPMENT		28.11	
TECHNICAL DATA		2.26	
			(1265.76)
(MANUFACTURING – FIRST UNIT)		(34.74)	
AIRFRAME	(26.49)		
AVIONICS PROCUREMENT	(.62)		
PROPULSION PROCUREMENT	(5.98)		
FINAL ASSEMBLY AND CHECKOUT	(1.65)		
AIRCRAFT PRODUCTION,			
OPERATIONAL VEHICLES (872.0)			5111.83
SPARES			918.51
FACILITIES			0.00
SUSTAINING ENGINEERING			642.89
SUSTAINING TOOLING			522.21
GROUND SUPPORT EQUIPMENT			766.77
TECHNICAL DATA			102.24
MISCELLANEOUS EQUIPMENT			10.46
TRAINING EQUIPMENT			34.43
INITIAL TRAINING			261.60
INITIAL TRANSPORTATION			34.21
			(8405.16)
TOTAL COST			9670.92
TOTAL NUMBER OF FLIGHT VEHICLES PRODUCED			872
AVERAGE UNIT AIRPLANE COST			$11.09M

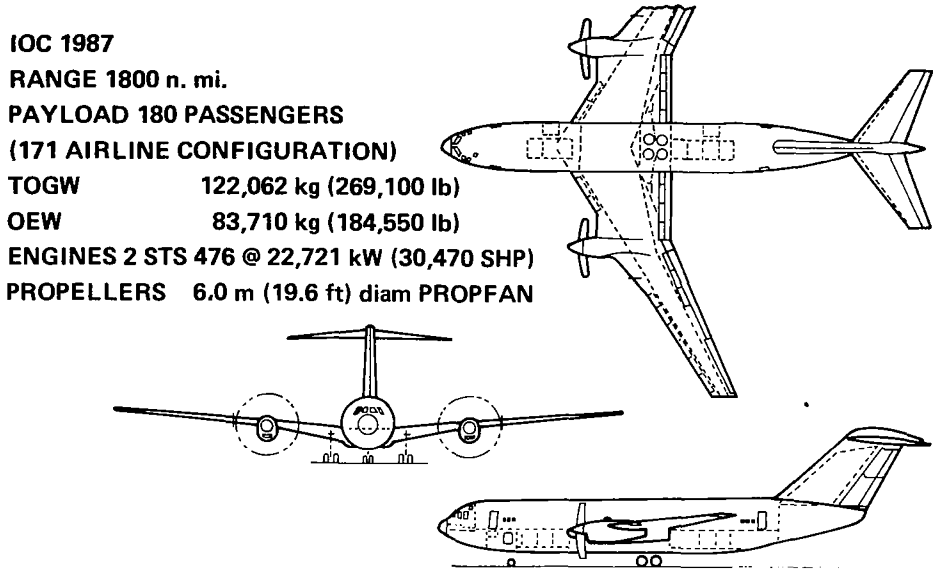

Figure 1.- Candidate new propfan aircraft - Boeing propfan study aircraft (767-762).

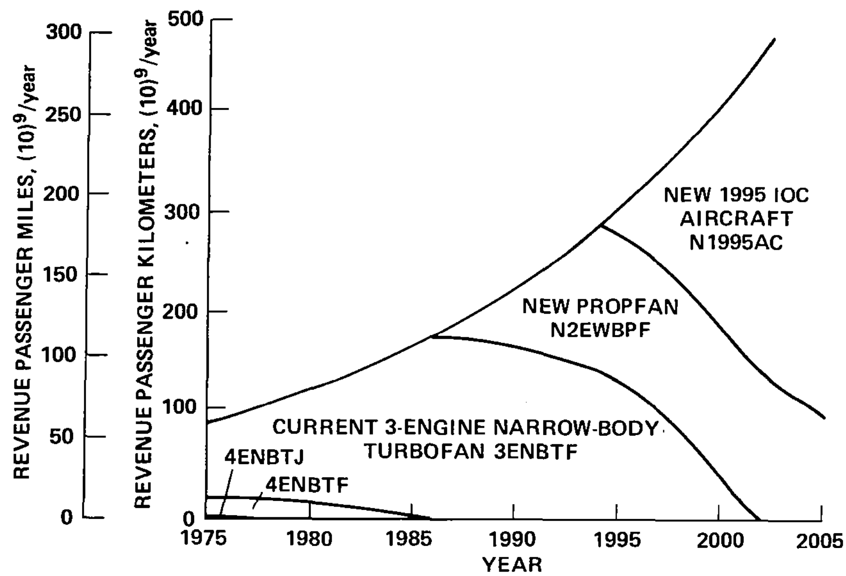

Figure 2.- Medium range aircraft market share by aircraft type. 6%/yr RPM growth.

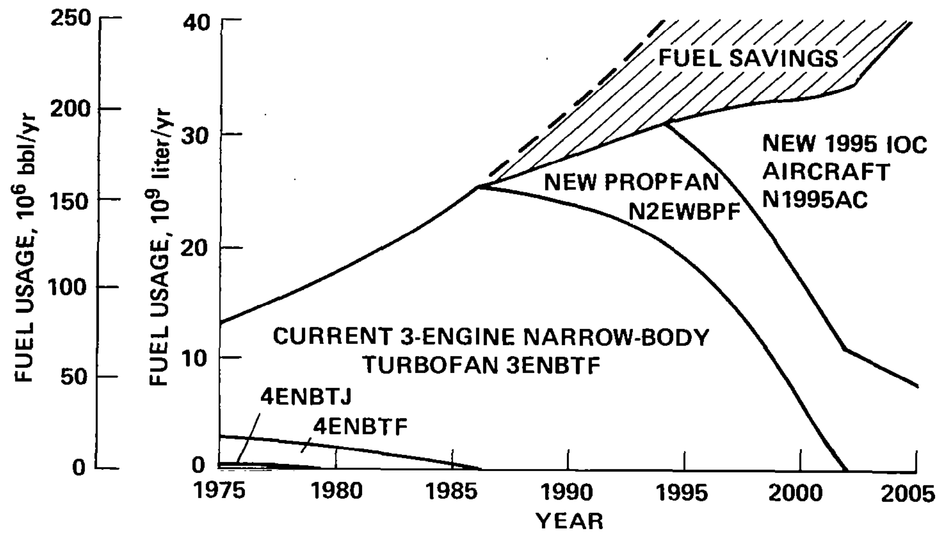

Figure 3.- Medium range aircraft fuel usage by aircraft type. 6%/yr RPM growth.

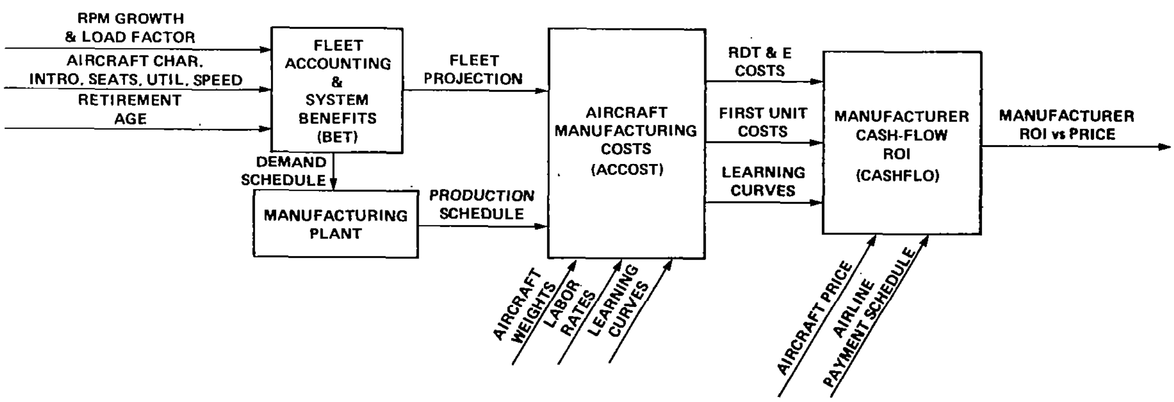

Figure 4.- Manufacturing ROI versus price estimation procedure.

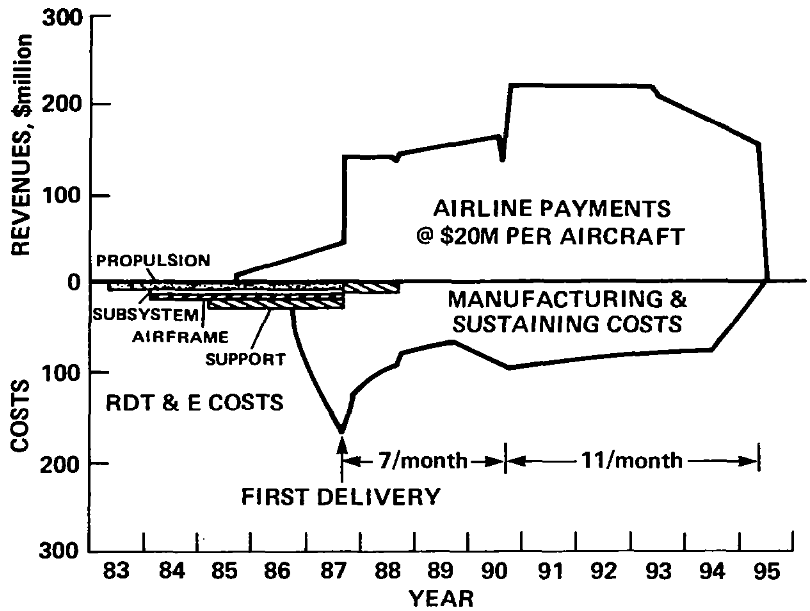

Figure 5.- Manufacturer cash flows per month.

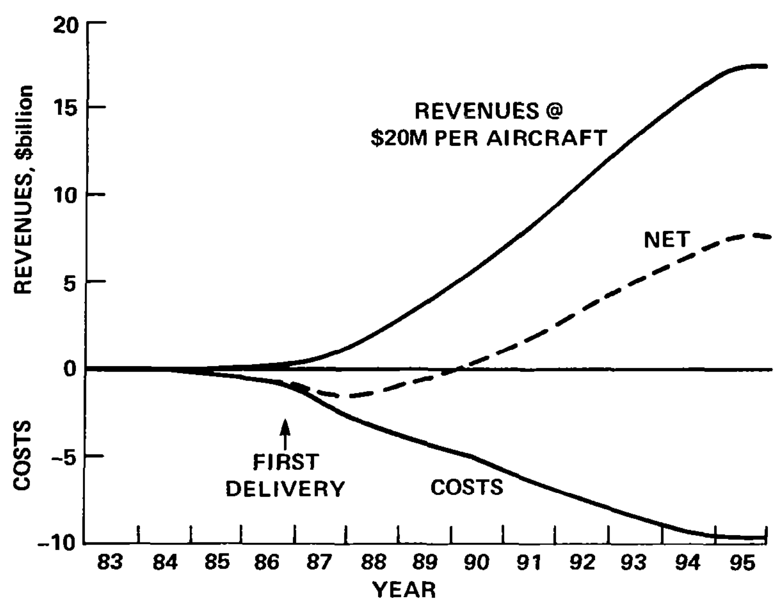

Figure 6.- Manufacturer cumulative cash flows.

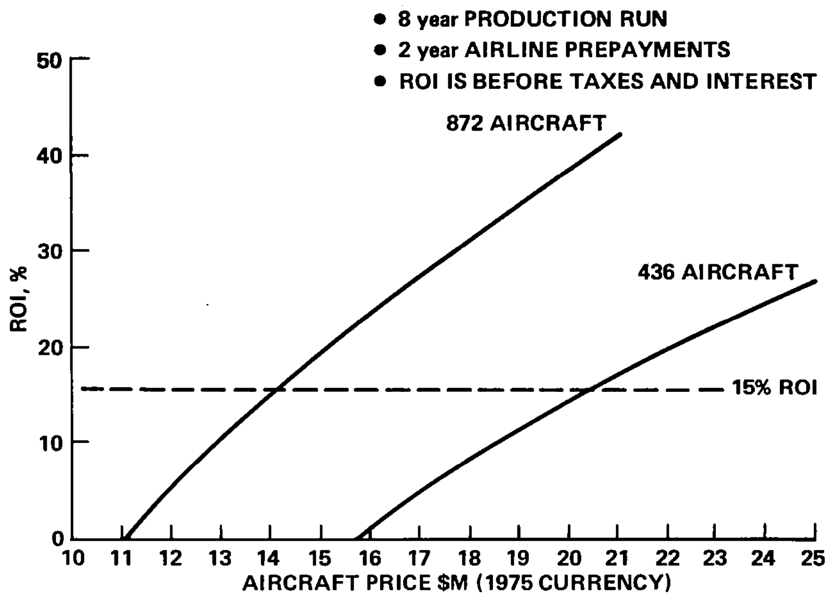

Figure 7.- Manufacturer ROI versus price.
1987 propfan aircraft.

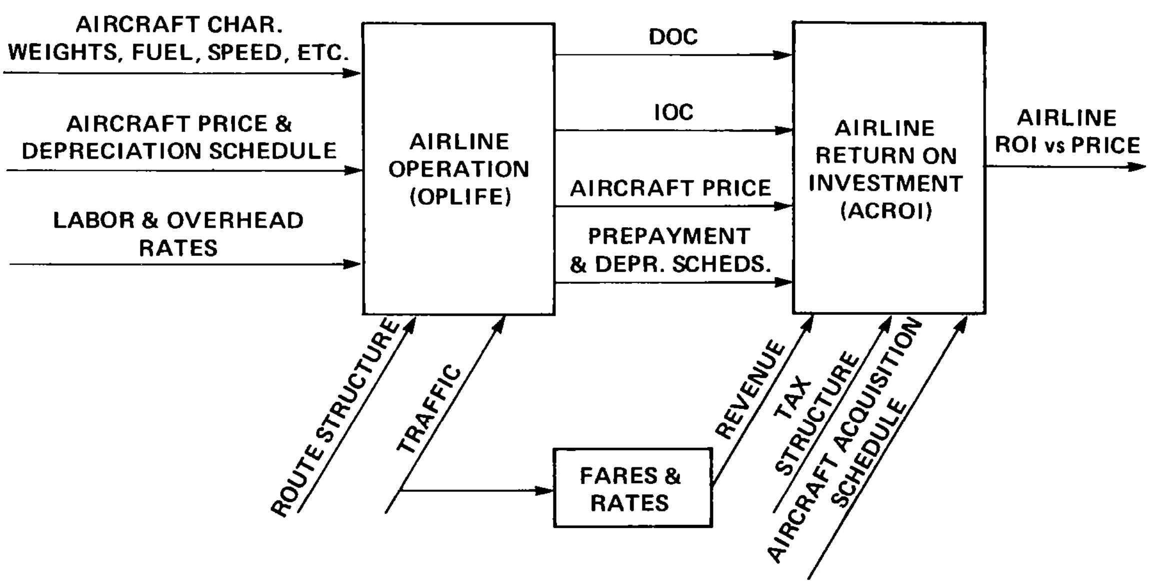

Figure 8.- Airline ROI versus price estimation procedure.

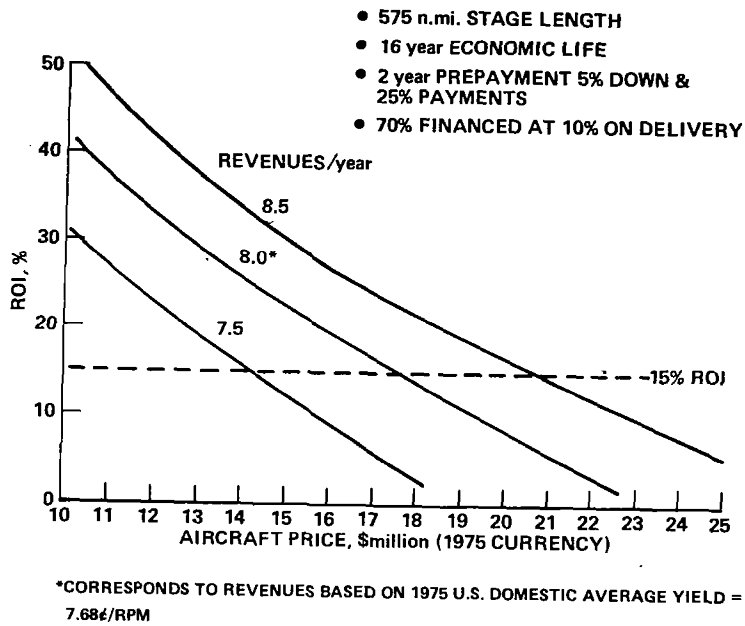

Figure 9.- Airline ROI versus price. 1987 propfan aircraft.

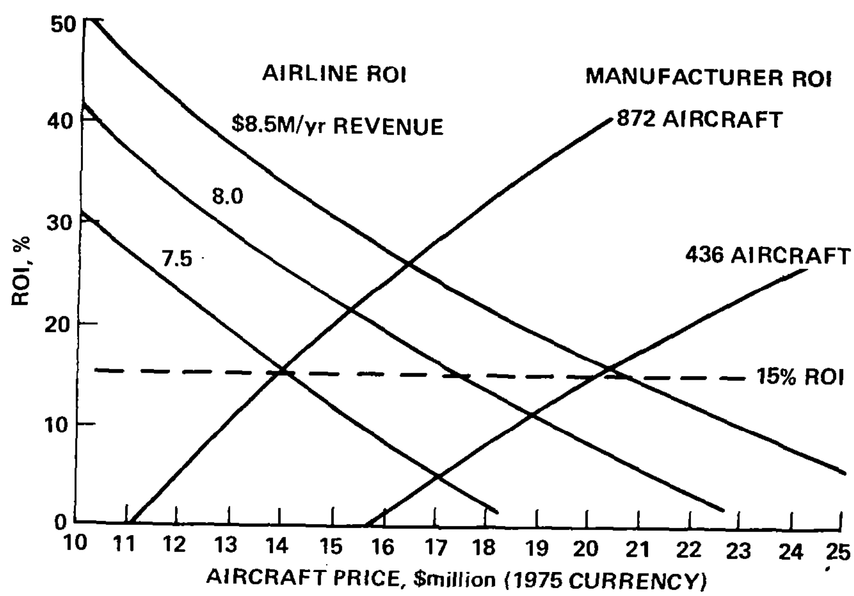

Figure 10.- Industry ROI'S versus price. 1987 propfan aircraft.