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ADVANCED TECHNOLOGIES APPLIED TO REDUCE THE OPERATING COSTS OF SMALL COMMUTER TRANSPORT AIRCRAFT*

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ABSTRACT

The "New Commuters" entering the market are mostly very conventional and have similar operating costs. Pilatus won a contract from NASA to study the application of advanced technology to a derivative of a small transport aircraft and to evaluate the effectiveness of these technologies on reducing the operating costs and increasing the fuel efficiency. The baseline aircraft used for this study was the Pilatus Britten-Norman TRISLANDER. On this aircraft the effect of aerodynamic changes, with various wing profiles, planforms and flap configurations were studied. The effects of new materials including advanced alloys, composites and hybrids were investigated. The trends in powerplant technology for turboprop, advanced spark ignition, diesel and rotary combustion engines were examined.
The study shows the influence of these technologies and the savings which can be achieved with them, optimised for a particular mission. The evaluation was carried out using an operating cost model developed during the study.

INTRODUCTION

Usage of advanced technologies can significantly reduce the operating costs of small commuter aircraft. The study presented in this paper examines the application of each of the selected technologies on a specified "Baseline" aircraft. In a further step the most promising technologies are successively applied and their benefits used to reduce the aircraft's operating costs and improve passenger comfort and safety. The consequential application of the technologies examined leads to an aircraft which is similar in concept but bears no direct resemblance to the Baseline aircraft. The "Ground Rates" defined for limiting the scope of the parameter variation may be defined as follows:

Passenger number : 19 or less
Range : Target 600 nm with full payload
Cruise speed : Target 250 kts
Terminal speed : Target 180 kts
Field length : 4'000 ft or less
Interior noise level : 85 dB(A) or less
Interior geometry : 32 inch seat pitch, 18 inch seat and aisle widths

BASELINE AIRCRAFT

The aircraft selected to act as a baseline is the Pilatus Britten-Norman BN-2A Mk III "TRISLANDER". The aircraft is of unconventional design incorporating two wing- and one tail mounted piston engines. The cabin seating is arranged for 2 pilots and 16 passengers on two-abreast bench seats without an aisle, but with each pair of seats having access to a door.

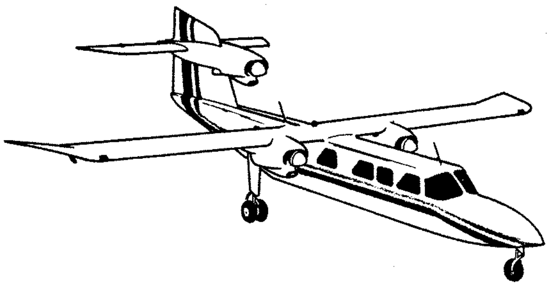

Figure 1. PBN-2A MK III "TRISLANDER"

The principal data are given in the table below:

Max. Weight	45'360 N	Cruise speed	144 KTAS
Wing Area	31.3 m^2	Field length	565 m
Aspect Ratio	7.95	Flyover noise	85 dB(A)

Table 1. Trislander Basic Data

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*A Study conducted under NASA contract.

The Trislander has similar seating capacity to the medium size turbo-prop commuters, but due to the installation of piston engines it can be offered significantly cheaper. However it has never had a very good market penetration. The reasons for this are not known, but could be attributed to the relatively higher cabin noise level and to the impression of less cabin space, even though the seat dimensions are larger than comparable small commuter aircraft.

TECHNOLOGY REVIEW

The following technologies have been reviewed in detail. A brief assessment is given below. A much more complete comparison and assessment is given in Ref. 1 with an extensive reference list.

Aerodynamics

Twenty wing sections were analysed ranging from the "conventional" NACA 5 digit and 6 series profiles to the Natural Laminar Flow profiles under current investigation at NASA. Several European profiles including some from Wortmann and from the Swedish Aeronautical Research Institute were also included. (Ref. 1 gives the key to the profile numbers which are only included here for demonstration of the principles).

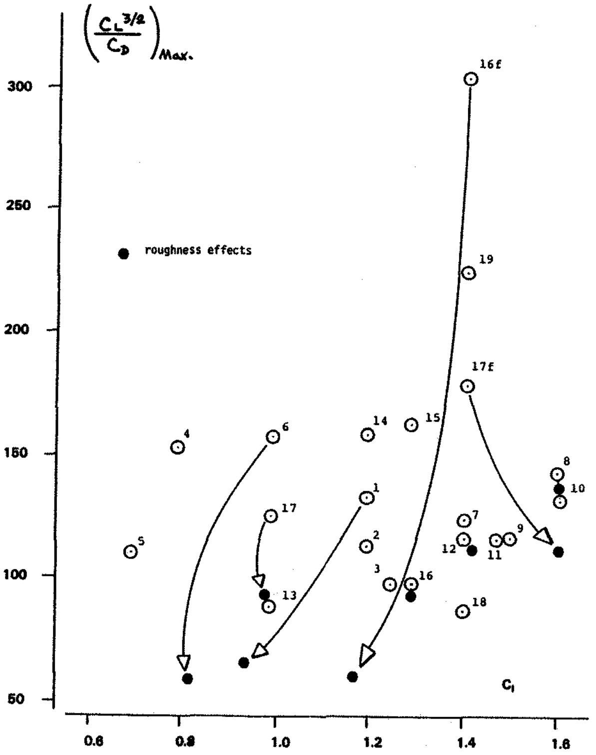

Figure 2. Profile Qualities

The NLF profiles show great promise, but the effects of roughness can destroy these excellent characteristics. The GA(W) profiles show a good insensitivity to roughness and good lift/drag ratios but have undesirably high pitching moments. Derivatives of these have however shown improvements. Fig. 2 illustrates the various profile characteristics and their modification due to roughness. The vertical scale is a measure of power requirement. The arrows show the decay of the aerodynamic properties of selected profiles due to roughness effects.

An assessment of high lift devices has been made but selection deferred until field performance requirements and wing geometry is defined.

A review of wing tip devices showed that equivalent performance may be obtained by careful selection of the wing planform without the complexity of a wing tip device. They could be interesting for improving especially the performance at high lift coefficients for an existing design. On the other hand the wing planform itself has a greater potential and can, in the case of the Trislander lead to significant induced drag and wing weight reduction by optimising the taper ratio.

Structures

New materials in the form of advanced aluminium alloys, laminated sheet metals and a variety of composites have been examined, as well as various production techniques. From these the most promising for future commuter aircraft application seems to be the composite structure and among the composites Carbon fibre offers the greatest potential. A combination of this with Aramid fibres offers an improvement in toughness.

Savings in weight could be in excess of 13 % on the structural weight of the Trislander, for a Carbon/Aramid fibre utilisation of about 40 %, if it was to be redesigned in composites for primary and secondary structures.

Figure 3 below shows the predicted worldwide trends in the application of materials technology. This is in fact for a short haul transport, taken from Ref. 2.

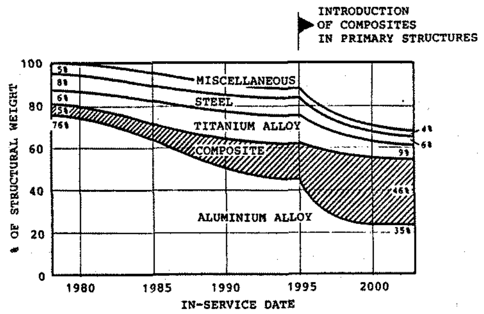

Figure 3. Weight Saving Trends (Ref. 2)

Propulsion

Four basically different types of engine were studied: Turbo-prop, Spark Ignition Reciprocating, Rotating Combustion and Lightweight Diesel. Most of these technologies have been subject to intensive studies in recent years, some under NASA contracts. From the literature available on these studies it is apparent that significant improvements on both performance and weight can be achieved. However the large price difference between the turbo-prop and other engines does not show any prospect of reducing.

The understanding of propeller noise problems allows a marked noise reduction to be achieved without penalising horzontal speed performance, by careful selection of propeller parameters.

Table 2 gives a summary of hypothetical engines scaled to 225 KW according to the referenced studies.

	TURBO-PROP	SI RECIPROCATING	ROTATING COMB	A.C. DIESEL
CURRENTLY AVAILABLE ENGINES (Nearest)				
Sea level max. power	313 kW	224 kW	not available in large scale production for aircraft application.	
Cruise power (75 %)	235 kW	168 kW		
Fuel flow	85 kg/hr	49 kg/hr		
Weight	88,5 kg	213 kg		
Price	$ 92'500	$ 17'250		
LEVEL 1 ADVANCED TECHNOLOGY (1985 AVAILABLE)				
Cruise power (75%)	169 kW	169 kW	169 kW	169 kW
Fuel flow	52 kg/hr	Not known (Assumed equal to Level 2)	56 kg/hr	38 kg/hr
weight	59 kg		137 kg	146 kg
Price	$ 66'500		$ 17'250	$ 15'500
LEVEL 2 ADVANCED TECHNOLOGY (1990 AVAILABLE)				
Cruise power (75 %)	169 kW	169 kW	169 kW	169 kW
Fuel flow	47 kg/hr	44 kg/hr	39 kg/hr	33 kg/hr
Weight	45 kg	149 kg	137 kg	114 kg
Price	$ 66'500	$ 17'250	$ 19'000	$ 17'250

Table 2. Hypothetical Engine Performance

ASSESSMENT MODELS

Three mathematical models were developed in order to evaluate the advantages of the advanced technologies. All were developed for usage on a hp 9825 desktop calculator with plotting capabilities. A detailed description of these models is given in Ref. 1.

Sizing Program

This computes the aircraft weight breakdown for a given wing geometry, engine data, range at max. payload and aerodynamic "cleanliness". The program determines iteratively the weight at which a specified climb performance can be achieved, and computes performance at this weight. The breakdown is computed from statistical data. Figure 4 shows the flowchart.

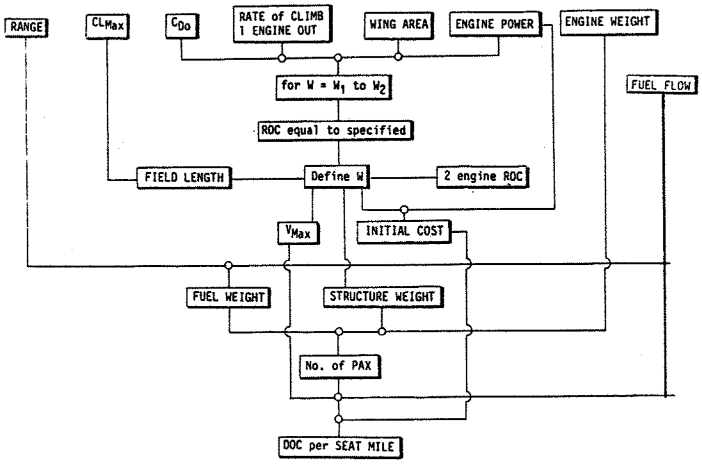

Figure 4. Sizing Program Flow Chart

Operating Cost Program

The direct operating costs (DOC) and DOC per seat-mile are computed with this program. The input requirements are for detailed purchase price, weight and performance information. Cost analysis is split into fixed costs (depreciation, insurance and interest) and variable costs (fuel, maintenance and crew costs). The annual utilisation rate and stage lengths flown may be varied as required and the solutions plotted.

Passenger Ride Qualities Model

Passenger trip satisfaction is dependent on many factors. Various studies have been conducted to quantify this satisfaction. This program brings together the results of these studies, for the motion effects only, and combines this satisfaction level with an aircraft dynamics and gust model. The models have been verified with flight test results. This model allows the aerodynamic characteristics to be "tuned" for passenger satisfaction. Figure 5 shows the method of utilising the model.

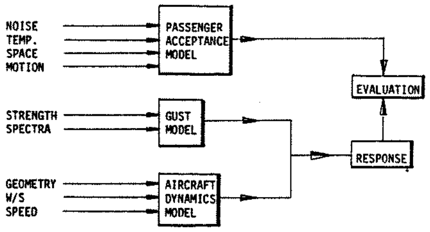

Figure 5. Passenger Ride Qualities Model

EVALUATION

The application of the advanced technologies described above can be achieved in several ways. For this study a step-by-step approach has been selected in which a decision must be made before passing to the next step. Fig. 6 shows the flowchart for this operation. The results give a clear indication of the benefits although accurately an iteration process should be used.

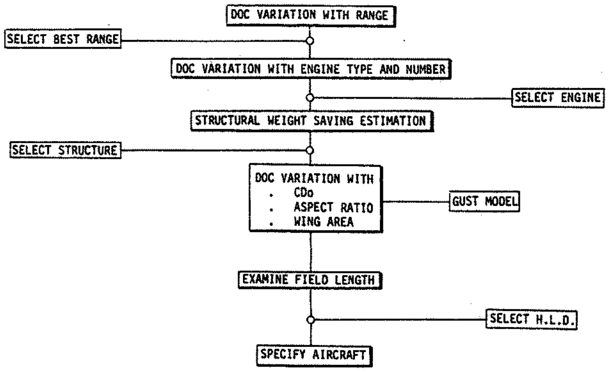

Figure 6. Evaluation Technique

Range

For any given take-off weight, the number of passengers which may be carried reduces with increasing range and hence fuel load requirement. This is clearly reflected in the seat mile cost analysis of Figure 7. It will be observed that very short stage lengths are uneconomic, an optimum for this particular configuration lying between 150 and 200 naut. mi. The detrimental effect of reducing take-off weight and hence increasing climb rate can also be observed. The form of the diagram is very similar for all of the powerplants examined although the scale differs. An improvement in aerodynamic efficiency will however move the minimum to higher stage lengths.

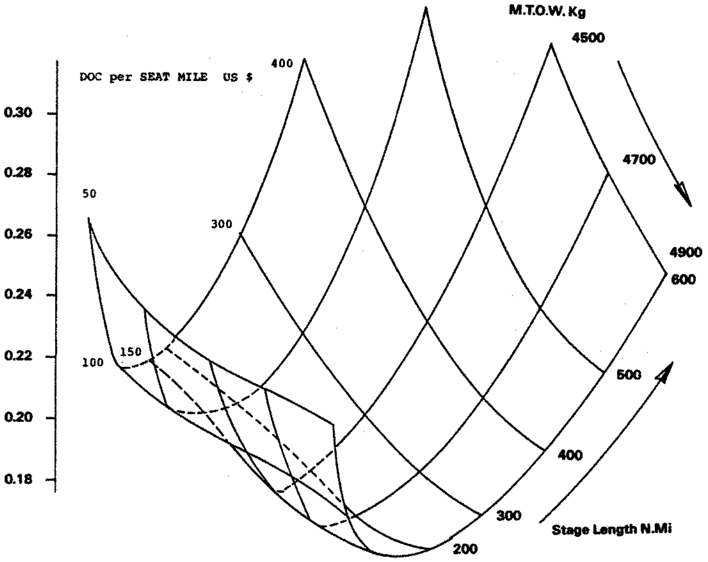

Figure 7. DOC per Seat Mile
vs. Stage Length and MTOW

From these results it has been decided to select 300 nautical miles with full payload as being the design stage length for further parametric analyses. This does not seem unrealistic if the results of a commuter service study is observed (Ref. 3).

Number and Type of Engines

The calculations until this point have been based on the three-engined Trislander configuration. The question is, does this configuration offer any economic benefit? The following diagrams attempt to show that there is an advantage. If an aircraft is sized for a particular rate of climb with one engine inoperative and a particular stage length (here 400 fpm and 300 naut. mi. resp.), then the two-engined aircraft will have to have more installed power (to have an equivalent available power in the one-engine-out case). The magnitude is shown in Figure 8.

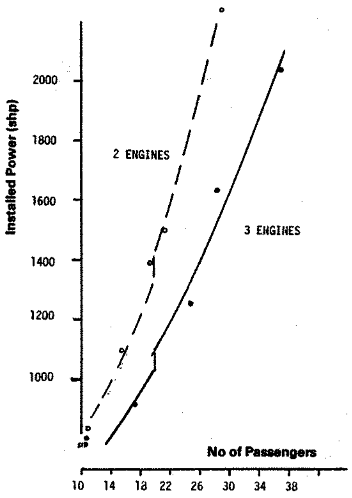

Figure 8.

Power Requirements

As engine costs have a very strong dependence on their power, the aircraft purchase price will also reflect this trend, although to a lesser degree because of installation complications.

The total effect is a slight reduction in seat-mile costs for the 3 engined aircraft with the same passenger capacity, as shown in Figure 9.

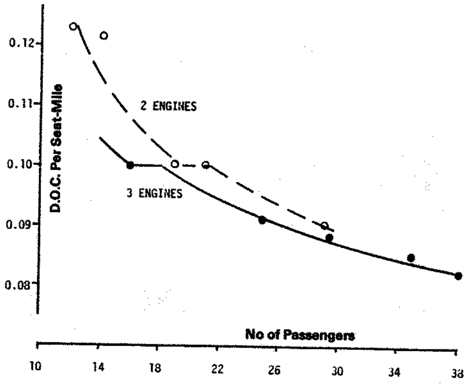

Figure 9. Seat-mile Costs

The selection of the type of engine also showed interesting trends. Figure 10 shows how the seat-mile costs decrease with increasing take-off weight, similar to the results of Figure 7. This figure however relates to 1980's technology (available in 1985). It should be noticed that for any given weight the turbo-props installation offers the lowest seat mile costs in spite of the significantly higher costs and fuel consumption. The reason being that the installation is so much lighter that additional passengers may be carried.

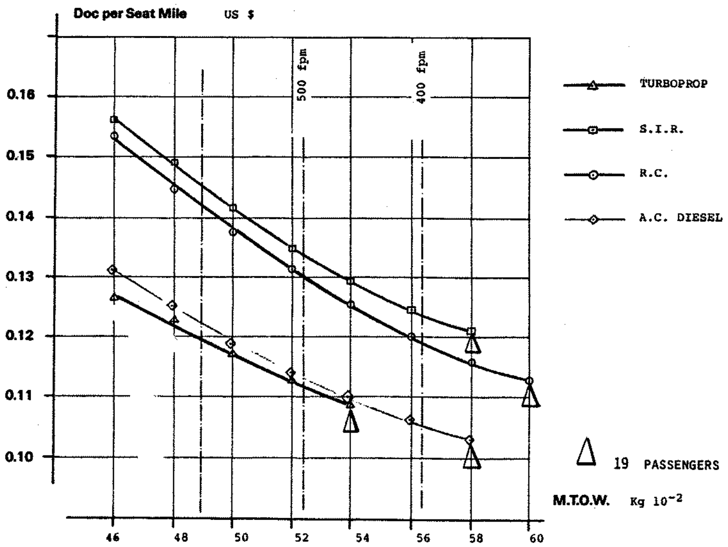

Figure 10. DOC per Seat-mile
vs. MTOW

The situation is changed slightly if one observes the costs at a 19 passenger capacity instead of weight. Here the diesel engine seems to be most attractive, but for a larger aircraft. The whole picture will be transformed if a greater stage length is taken, where the more economical engines can reduce their weight disadvantage.

To allow progression to the next step of the analysis a selection in favour of 3 turbo-prop engines has been made. This gives good economics with a light aircraft, low vibration levels and due to the relatively light engines, a flexibility to position the engines for low cabin noise.

Structure

Composites are selected for both primary and secondary structural items on our advanced technology aircraft, after the review described above. Through this choice several objectives can be fulfilled: significant weight savings can be accomplished (ca. 13 % of structural weight). The surface can be improved giving better drag characteristics and allowing the usage of more advanced laminar profiles, maintenance can be enhanced due to modular construction and, once a familiarity of the usage of these structures becomes available, it could be possible to incorporate certain crashworthiness potential into the passenger compartment. But at what price? The price is always a question which cannot be satisfactorily answered when applied to composites. There are so many variables to be considered. Most of the studies which give some comparison of price levels with metallic structures are based on civil airlines or military combat aircraft, neither of which is directly applicable to the relatively thin skinned commuter aircraft designs. It can only be observed that for carbon composites the manufacturing costs per kg can be significantly more, but the assembly costs significantly less than those of a metallic structure, so that the total costs are similar per unit weight. Since the costs cannot be accurately predicted the influence will be examined only later (see "Payback" section).

The weight savings are not going to be utilised to reduce the total aircraft weight in this study, but in order to increase the cabin volume whilst maintaining the same fuselage weight. This will provide the passenger with an environment more closely resembling that of an airliner with 2 abreast seating, an aisle and toilet facilities.

Wing Selection

Before the wing planform selection can take place, a general drag "clean-up" should be performed. An investigation showed that it would be necessary to retract the undercarriage and to redesign the cockpit and engine nacelles. Furthermore the wing profile can be exchanged for a thicker Natural Laminar Flow type and the engines should be moved so as to be able to use its benefits across the whole span.

The variation of wing geometry can now be examined on a parametric basis. Figure 11 shows the cost variation with wing area and aspect ratio. The scale has been changed to kg-mile instead of passenger seat-mile costs so as to avoid discrete steps in the function. The two peaks at eigher end of the carpet plot represent at the lower end a high drag for low AR and S and at the upper end a high wing weight for high AR and S.

This form of presentation is convenient because it allows other variables to be overlayed on the same figure. The first is the rate of climb with one engine inoperative. Both parameters have a significant influence here so the boundary cuts across the carpet plot. A further boundary is produced by limiting the wing weight which will allow the carriage of 19 passengers.

The final boundaries which conclude the framing of our optimisation window are lines of constant passenger comfort and the limiting specified field length.

The select wing geometry therefore has an area of 26 m^2 and an Aspect ratio of 9.

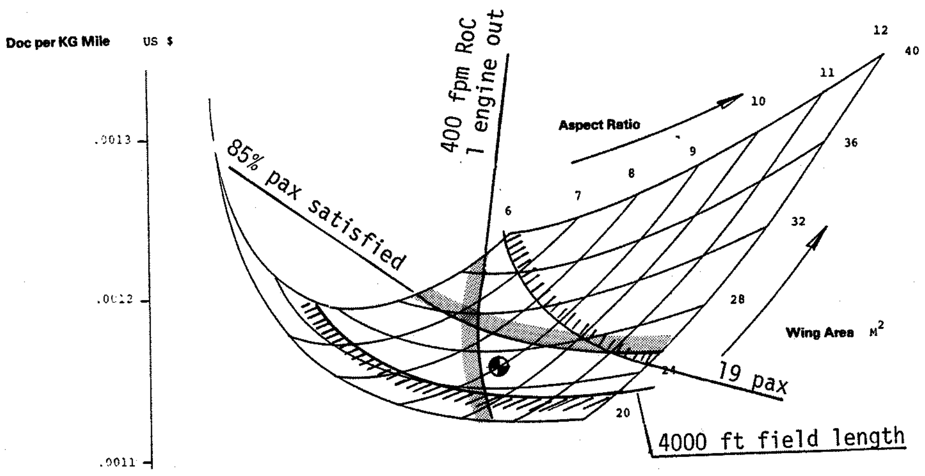

Figure 11. Wing Sizing

Configuration

The landing distance was examined for the above configuration and it was discovered that it would be necessary to use Fowler flaps to achieve distances compatible to those of the take-off.

A possible final configuration incorporating the above technologies is given in the artist's impression of Figure 12. A summary of the performance is contained in Table 3.

	ATA	Baseline
Max. Speed	**214 KTAS**	**144 KTAS**
Cruise Speed (75% of Power)	**191 KTAS**	**144 KTAS**
Max. Roc	**1259 fpm**	**980 fpm**
Max. Roc 1 Engine out	**578 fpm**	**290 fpm**
Field Length	**1008 m**	**565 m**
Number of Passengers	**19**	**16**
Range with max. Payload	**300 n.mi**	**150 n.mi**
External Noise Level	**69 dB(A)**	**85 dB(A)**
Direct Operating Cost	**298 U.S.$**	**256 U.S.$**
Doc per Seat Mile	**0.09 U.S.$**	**0.15 U.S.$**

Table 3. Advanced Technology Aircraft Performance

PAYBACK

Although the cost of a conventional aircraft is well identifyable, the advanced concept, in particular the usage of composite materials, does not allow the costs to be satisfactorily determined. It has been decided, under these circumstances to investigate the effects of these costs in a parametric manner. Figure 13 shows the amount of years of operation necessary to regain the additional expenditure of purchasing an advanced technology aircraft dependent on the cost savings experienced. Not accounting for any improvement in load factors due to improved passenger comfort!

For the advanced technology derivative aircraft specified above, a 40 % DOC saving is anticipated compared to current well established commuter aircraft! A saving of almost 20 % is even possible when compared to aircraft of comparable size just becoming available. This means that it may cost up to 10 % more in purchase price and still show benefits within one and a half years of operation.

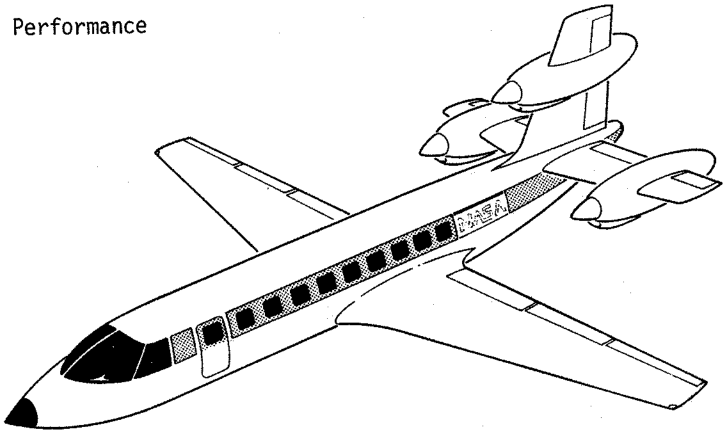

Figure 12.

Advanced Technology Derivative Aircraft

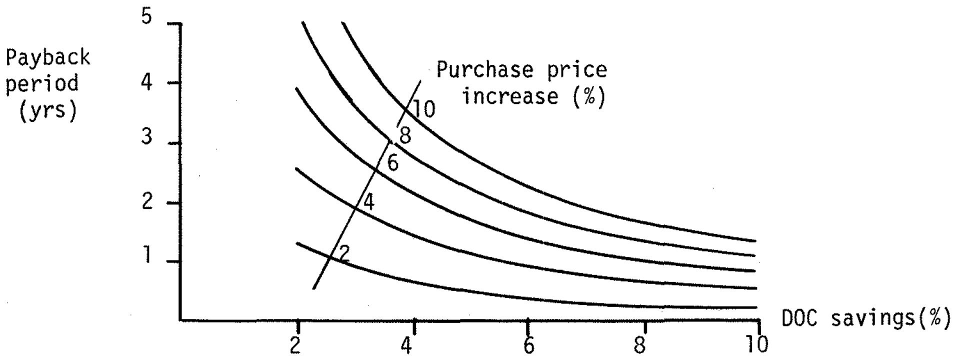

Figure 13. Payback Relationship

CONCLUSIONS

Advanced technology application, when used consequentially to optimise an aircraft for a particular mission, can produce significant benefits. It is however very important to establish the limitations of the parametric survey.

Available equipment and technology readiness (also on the part of the certification authorities) will very much dictate the limitations of the parameter variations possible.

The results of the study, based on direct operating costs per seat-mile, showed that great care should be exercised when optimising an aircraft for a particular stage length and rate of climb with one engine inoperative. If the market requirements for both of these parameters are fulfilled by a bare minimum margin then the aircraft will be very economic operated under those conditions. The one problem remaining is to predict what the market will require at the end of a development program. But for that we would have to exchange our computer for a crystal ball!

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