Challenge to Advanced Technology Transport Aircraft Systems

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The successful synthesis of all-new advanced technology transport aircraft system concepts that can compete economically with less advanced additional, or derivative, aircraft from programs initiated earlier is a difficult task in view of the adverse impact of inflation and other economic factors on later programs. Reasonable projections promise technologically superior concepts. The adverse impact of continuing inflation on relative economic performance, however, must be considered carefully. A conflict between minimizing fuel usage and achieving best economics also is addressed. Some potential solutions for future all-new advanced technology transport systems are examined.

Introduction

ATTEMPTING to forecast the future potential for any portion of the entire spectrum of the air transportation industry is highly hazardous and generally unrewarding. Many knowledgeable people have been questioning or criticizing the myriad independent and interdependent events and attitudes of the recent past including: inflation, recession, fuel embargoes, escalating fuel costs, environmental and energy conservation concerns, anti-DOD, antitechnology, antibusiness, anti-anything-and-everything cults, and, of course, unique aircraft concepts and advances in aerospace technology.

New concepts and advancing technologies always have met dedicated skepticism. Defining the most promising path toward achievement of technologically advanced and economically viable transport aircraft systems is a particularly difficult task today, in view of three major factors: our apparent position on our classic "technology vs time" curve of Fig. 1, which is bending over and giving less advance per year than in the past; the serious adverse impact of production program learning curve effects, which always challenges the viability of new systems, but much more powerfully when the concomitant technological increment is small; and the recent and current inflation, which makes past nonrecurring development costs of current aircraft vastly lower than those predictable for competitive new systems. This effect is significant both in its own right and in its impact on direct and total system operating costs.

In other words, we now can carry a payload about as large and heavy as we require, into and out of a reasonable-sized airport, at speeds and altitudes near optimum, for as far as we need to go. Each of these factors can be somewhat better, and the sum of possible improvements may be significant; the issue is whether or not this sum can justify undertaking a brand new system development program that is economically intelligent and acceptable.

Technology

From the point of view of providing a potential for improved economic performance, six areas of advancing technology are particularly significant: supercritical aerodynamics, friction drag reduction, induced drag reduction, active controls, composite materials, and improved specific fuel consumption.

Supercritical Airfoils

The advantages of supercritical aerodynamics include options of increased speed capability for a given level of thrust or thicker airfoil sections for a given cruise speed. The latter permits reduced empty weight or increased aspect ratio for a given weight and results in reduced block fuel, or increased range for a given fuel capacity, or increased payload for a given range. The thin trailing edges of supercritical airfoils, however, make high-lift system design more difficult, with at least some increased high-lift system weight. Trim drag increases, resulting from fairly high zero-lift pitching moments, need to be balanced carefully by further aft c.g. positions and careful enroute c.g. control. Trim drag can be minimized by use of control-configured concepts.

The drag divergence Mach number/thickness ratio advantage of current "advanced" supercritical airfoils over both state-of-the-art and the conventional NACA 60-4, 5, and 6 series airfoils is indicated in Fig. 2, where it is shown that the improvement in either divergent Mach number or thickness ratio is substantial. The potential advantage in terms of maximum range factor is shown in Fig. 3 for both trimmed and untrimmed cases compared to the current wide bodies. The untrimmed case could represent and advanced active control configuration with a further aft c.g. location and reduced static stability. The potential is significant, perhaps 3.5 to 4.5%.

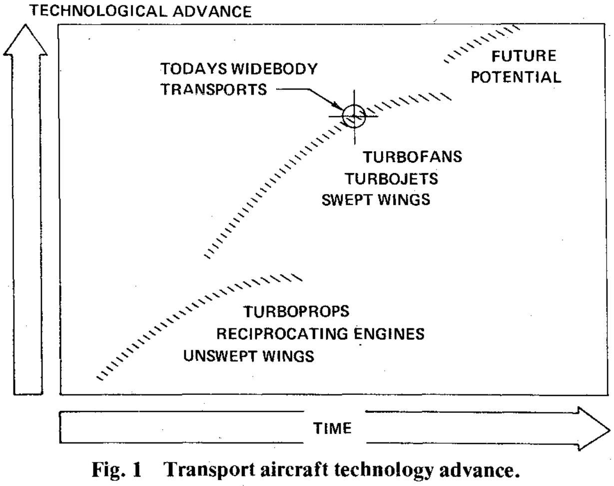

Fig. 1 Transport aircraft technology advance.

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The several alternate potential advantages for supercritical aerodynamics for possible future advanced transport aircraft systems may be summarized as 1) a potential cruise speed increase of Mach 0.03 for a constant wing weight to result in a fuel saving of 4 to 5 % for a given range, if the added cruise speed potential can be exploited realistically in everyday air traffic control circumstances; 2) a substantial reduction in wing weight which results from an allowable increase of perhaps 2% in thickness ratio at a given cruise speed; 3) a reduction in required wing sweep of perhaps 6° for a given wing weight; and 4) a substantial increase in aspect ratio, say 10%, at a constant wing weight.

For advanced cargo systems, where maximum productivity as a function of available thrust at a moderately high subsonic cruise speed is the criterion, it is probable that exploiting the greater thickness ratio to achieve improved aspect ratio is the proper course, since both takeoff and cruise configuration lift-to-drag ratio will improve, allowing higher operational weights, reduced fuel usage, increased payload allowances, and thus improvements in productivity of perhaps 5 to 7%.

Friction Drag Reduction

The Air Force/Northrop laminar flow control studies of the 1960's were fairly extensive in analysis, ground test, and flight. They showed interesting gains in added payload if the system could be made operationally acceptable and if the estimated costs for research, development, test, and evaluation, acquisition, and, in particular, maintenance could be achieved. Failing this, the potential gain could turn into a substantial loss.

With higher fuel prices, the potential direct operating cost improvement increases, but the technological uncertainty remains. Even with a fuel price increase of four (relative to other costs), maximum potential gain is estimated as perhaps a 15 to 20% reduction in DOC for an all-new, very large, advanced transport aircraft.

A different, more difficult, and less certain reduction of friction drag may someday be possible through the use of compliant surfaces on fuselage and airfoil skins to achieve boundary-layer eddy suppression. An intriguing concept is one of providing a surface whose natural frequency is in reasonance with the dominant frequency of the boundary-layer eddies that impinge on the aircraft outer surface. Although the potential may be conceived, its mechanization is not easily visualized. Its conceptual simplicity, compared to most other boundary-layer control methods, is great; but preservation, to say nothing of creation, of a surface having the needed compliance characteristics to accomplish eddy suppression has not yet been achieved. A maximum potential reduction of 25 to 50 % friction drag is attractive, and this might someday be a major technological breakthrough.

Induced Drag Reduction

Considerable attention has been given lately to several varieties of wing tip treatment to reduce induced drag. A simple extension of span can be considered as a modification of an existing aircraft to increase aspect ratio, but in all-new design this is just a part of the wing optimization and not a separate feature. More lively is the investigation and debate on carefully tailored and located aerodynamic surfaces not in the wing plane which may either reduce induced drag and/or provide a net thrust component (view it as you find most comfortable) by taking advantage of the aerodynamic geometry of the tip vortex structure. In the viscous, complex, multiple vortex situation at and near the tip of a real swept wing, predictions are difficult; interference drag is likely at higher Mach numbers; design of the new surfaces is structurally challenging; wing structure loads are probably increased; and flutter speeds may decrease. The current uncertain state-of-the-art leads to the conclusion that, although possibly beneficial for modification programs, there is great uncertainty about the gain on all-new aircraft; it is just too new to be properly assessable.

Active Controls

One active control concept involves exploitation of the movable surfaces on an airplane for tailoring the wing span load distribution during off-design flight conditions. When movable trailing edge elements are not being used for maximum lift purposes, they could be employed so as to more nearly optimize span load distribution, as illustrated in Fig. 4, and therefore reduce induced drag during times when the airplane is not in its completely clean cruise configuration. The

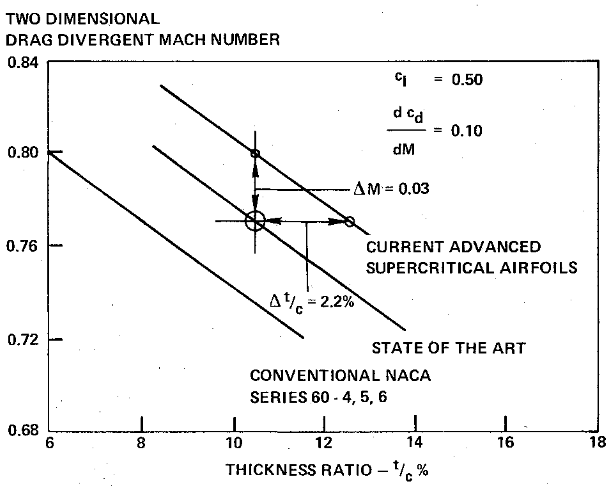

Fig. 2 Effect of airfoil technology on divergence Mach number.

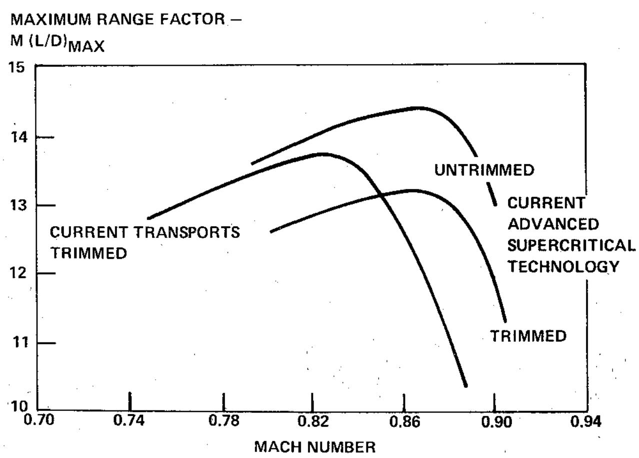

Fig. 3 Effect of technology level on maximum range factor.

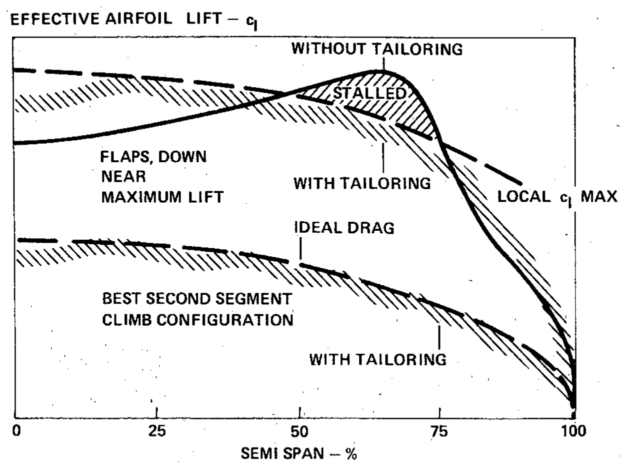

Fig. 4 Tailored lift potential: off-design operation.

contribution in fuel and DOC saving would be small, but it is one more possible technological innovation. Such devices also may provide substantial wing weight reduction because of alleviation of maneuver and gust loads.

Another apparent benefit of active control concepts derives mainly from an aft movement of c.g. range to reduce trim drag and permit reduced empennage areas. Figure 5 shows that an 8 to 10% aft movement of c.g. gives a possible reduction of 25% in the horizontal tail area. The practical application of active controls for new transport aircraft is to convert the fuel and structural weight savings into added payload weight at the maximum operational weights possible with the available propulsion system so as to maximize productivity. The net effect under such circumstances might be a 6 to 8 % improvement in productivity.

Composite Materials

By far the greatest single and most confident promise of advanced technology lies in the application of new composite materials and structural concepts. Economic performance will be enhanced by coupling the additional weight savings thus possible with supercritical airfoil sections, so as to further improve wing aspect ratio in an iterative process designed further to increase maximum pay load, and thereby improve the productivity of transport aircraft. Figure 6 indicates the tradeoffs possible among wing weight and aspect ratio on the one hand, and drag, fuel, and allowable payload weight on the other, for an airplane of about the same size as today's wide-body jets. The greater potential when composite materials are used throughout the entire airframe is discussed later.

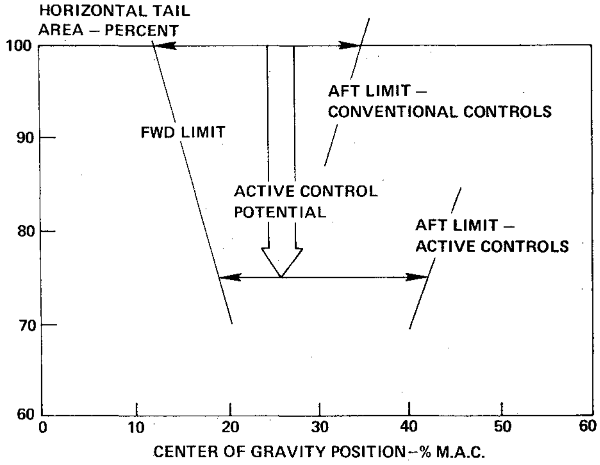

Fig. 5 Horizontal tail area reduction.

Improved SFC

So far, the airplane has been dealt with primarily from the viewpoint of its drag and weight relationships. A brief examination from the propulsion viewpoint is equally in order. The topics can be grouped into three:

1) Nacelle/engine installation design is something of a catch-all, intended to recognize the several potentials that are applicable with relative simplicity and low cost to existing aircraft and, of course, to new ones. They include improvements in detail fairings and internal duct lines, application of mixing to the bypass and primary gas exhaust streams for higher propulsive efficiency, and even reconsideration of the long-recognized principle of boundary-layer air ingestion for the engine inlet.

2) Potential engine advances include increases in the thermodynamic cycle maximum temperature and pressure ratio, improved component efficiencies, higher bypass ratios, and lower fan pressure ratios. The NASA Lewis Aeronautical Propulsion Conference of May 1975 summarized these potentials for the next generation of turbofans as saving 10 to 20% in trip fuel for a given airplane cruise speed and payload/range performance, which is applicable directly to transport aircraft. Depending to some degree on the outside geometry dictated by the design difference, such engines and their advantages may be applied to derivatives as well as new aircraft.

3) As for "new" engines in terms of cycles, only two are recognized frequently: regenerators and turboprops, the former being really new (in aeronautical applications) and the latter being so only by a free interpretation of the unique features involved in high propeller efficiency at Mach numbers above, say, 0.65. The regenerative engine promises specific fuel consumption improvements of 20 to conceivably 40%, but its mechanization, weight, cost, and maintenance are challenging. The turboprop (much maligned but, even more significant, still produced and used with great success) offers today as much as a 40% fuel saving at speeds up to Mach 0.60. As implied in Fig. 7, the NASA Conference cited the potential for maintaining in propeller efficiency above 80% to at least Mach 0.75 and perhaps even to Mach 0.85 with advanced propeller designs. Such performance would seem extremely attractive from both the fuel conservation and the direct operating cost points of view. This may provide an opportunity to exploit the well-understood characteristics of a familiar powerplant, while at the same time improving substantially its soft spots in certain aspects of maintenance and dealing with a single advance in technology, that of propeller

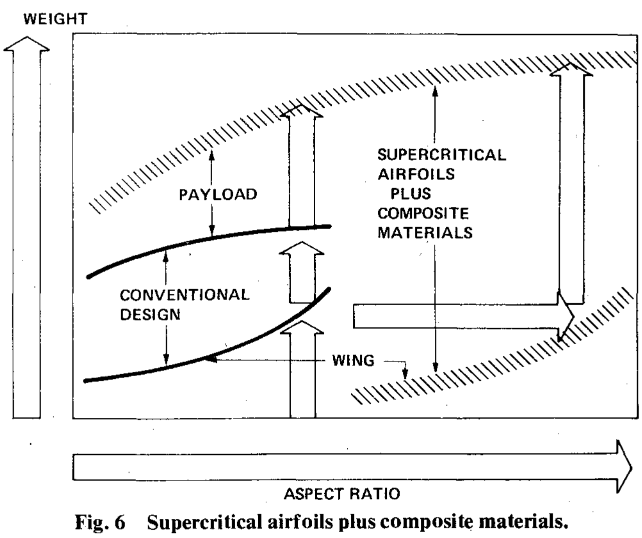

Fig. 6 Supercritical airfoils plus composite materials.

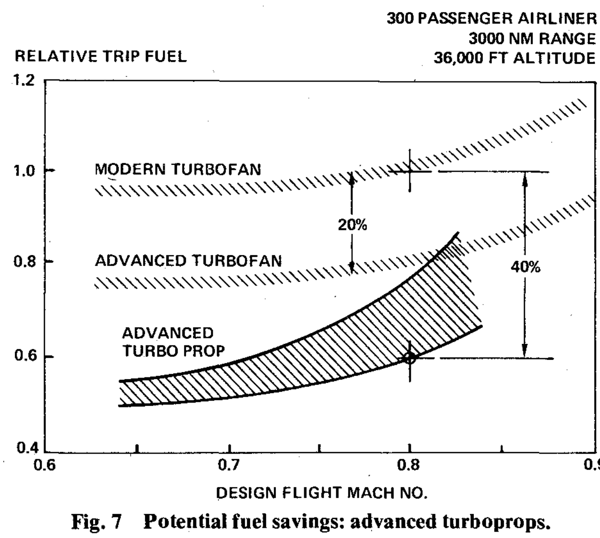

Fig. 7 Potential fuel savings: advanced turboprops.

design for high efficiencies at Mach numbers such as those cited.

Fuel

Forecasting fuel shortages and price gyrations is not properly a part of this paper, but consideration of the effects of conservation and fuel prices over the reasonable ranges of possibilities is, insofar as it bears on the subject being discussed. Unfortunately, it is extremely difficult to deal with fuel shortages that are defined and attacked by other than economic means. The analytical confusion from conservation, no matter how structured, results from two enigmas. The first is that one cannot optimize the design of an aircraft derivative, or a new design, or the operation of either, if an unquantified desire is supposed to be considered in the optimization process. A certain amount of compatibility exists in the direction of fuel conservation as fuel prices increase, but the notion that some further value beyond the economic one should be factored into the analysis is troublesome; and most hazardous is the fact that arbitrary value judgments of this sort are very much subject to change with time. The capriciousness of such change could be very serious to the operator, who has done his best to modify or purchase his equipment in accord with an original set of ill-considered ground rules and who subsequently finds that abrupt and perhaps irrational changes take place.

Ignoring any element of fuel consumption bias other than cost and economics, Fig. 8 portrays the impact of fuel costs on both direct operating costs and on fuel use for an optimized series of hypothetical, new, long-range cargo transports. Absolute values are not shown for either, nor are they for fuel prices which are handled as three fuel price factors: one, two, and four times the fuel price relative to the general economic price levels in terms of similar ratios in 1972. In the lower box, the broad dark bands shown for turboprop DOC indicate some uncertainty in the degree of improvement attainable in turboprop maintenance costs, whereas the crosshatched extensions of these same bands indicate the uncertainties in maintaining high propeller efficiencies at higher cruise speeds. Note that all data shown are in terms of ton miles. Recall also that each point on each curve represents an airplane optimized to achieve minimum DOC for the selected conditions of cruise Mach number, propulsion system type, and fuel price factor.

Several observations may be made from the figure. First, as fuel price factor increases for turbofans, the design cruise speed for minimum DOC decreases. For turboprops the minimum DOC falls around Mach 0.5 to 0.6. Second, for either cycle, the cruise speed for minimum fuel use is always lower than that for minumum cost. Third, the turboprops substantially reduce fuel usage per ton mile at lower cruise speeds and, depending on advancing technology, may at modestly higher cruise speeds. Finally, at current fuel prices, the turbofans, which use considerably more fuel per ton mile, exhibit substantially better DOC performance, in large part because of currently low turboprob speeds and high turboprop maintenance costs. These are areas of major challenge of advanced turboprop concepts.

Most importantly, it may be seen that, even with a high degree of success in developing advanced turboprop powerplants, there is little likelihood that turboprop DOC performance will become a significant factor in decision making, since even at a fuel price factor of 4 the minimum DOC per ton mile for a Mach 0.65 turboprop will be no better than that for a Mach 0.80 turbofan. On this basis, a case can be made for turboprops only by the spectre of severe fuel shortages.

A quick review of U.S. petroleum fuel consumption during the recent past is pertinent, however, since it puts commercial aircraft in perspective with the total consumption spectrum, as shown in Table 1. This 4.2% clearly is not a fertile field for massive reductions in the total, but presumably every area will be expected to contribute. By way of comparison, a 40% reduction in commerical aircraft fuel consumption would be the equivalent of about a 4% reduction in motor vehicle fuel use.

Table 1 U.S. petroleum fuel consumption – 1972

USER:	GALLONS (MILLIONS)	PERCENT
MOTOR VEHICLES	105,062	42
RAILROADS (CLASS I)	4,002	1.6
MARINE VESSELS	4,973	2.0
AIR CARRIERS	10,690	4.2
OTHER AVIATION	1,126	0.4
TOTAL	125,853	50.2
OTHER U.S.	125,747	49.8
TOTAL U.S.	251,600	100

Ecomomic Viability

It is axiomatic that what really must be considered are economically viable advanced concepts. For the civil case, the least cost requirement is usually "least operating cost," either in terms of direct or total operating cost, derived from some version of the 1967 ATA Standard DOC Method. This is useful in military aircraft systems as well.

Typical Program Cost Relationships

The severe adverse impact of production learning curve effects and inflation on later new programs is a major factor in determining the relative economic viability of suggested all-

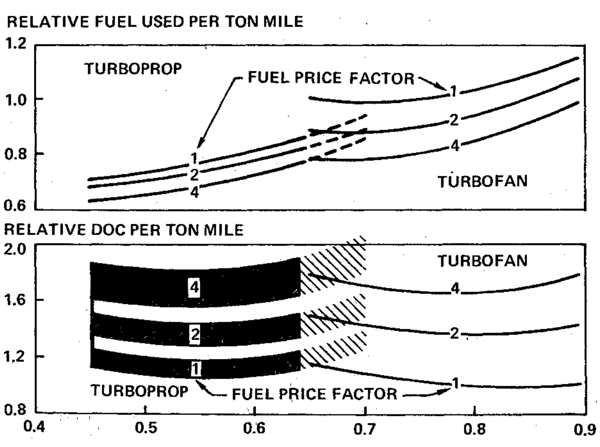

Fig. 8 Relative fuel consumption and DOC: advanced turboprop and turbofan aircraft.

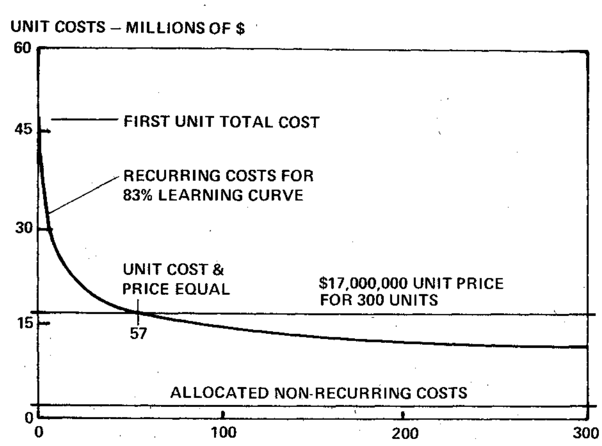

Fig. 9 Typical program cost/price factors: no inflation.

Table 2 Reference program characteristics

• FINANCIAL (MILLIONS)	NON-RECURRING COST	500
	TOTAL RECURRING COSTS	4,000
	TOTAL COSTS	4,500
	PROFIT	600
	SALES	5,100
	UNIT PRICE (300 UNITS)	17
• SCHEDULE	GO-AHEAD	JAN. 1975
	INITIAL DELIVERY	JAN. 1978
• PRODUCTION	RATE REACHED	UNIT 32
	PRODUCTION RATE	4/MONTH

new transport systems that must compete with additional aircraft from, or derivatives of, programs initiated earlier. Consider Fig. 9, which presents typical relationships among the various program cost factors, including profit and production unit price. When no inflation is considered, the necessary selling price and unit cost for this hypothetical program become equal at about the 57th unit, and unit costs continue to decrease throughout the entire initially planned program of 300 production units. The curve represents unit costs associated with an 83% learning curve, typical of such programs when all recurring costs (i.e., not just AMPR weight-related costs) are considered.

Figure 9 is based on a hypothetical new cargo airplane program as defined in Table 2. It is a conventional high-wing, low-cargo-floor cargo transport with four turbofan engines, Mach 0.82 cruise speed, 260,000-lb takeoff gross weight and a 70,000-lb payload.

Inflation and Learning Curve Considerations

Figure 10 shows how the costs for this same program are affected adversely by a continuous annual rate of inflation of only 5% during the tenure of the program. The dotted lines are from Fig 9. It may be seen that the necessary selling price for the same program profit percentage is increased by about 33%; selling price and unit cost become equal sooner, at the 41st unit; and unit costs now become minimum at about the 225the unit, beyond which unit costs then increase gradually.

Figure 11 shows the dramatic adverse impact of production learning curve effects and inflation as time increases between the time of initiation of two competitive programs, exemplified here by a 10-yr difference in go-ahead date. For this illustration, both programs are identical to the program of Fig. 10 and include the effect of a continuous annual rate of inflation of 5%. For both programs, nonrecurring costs are allocated over the first 300 production units.

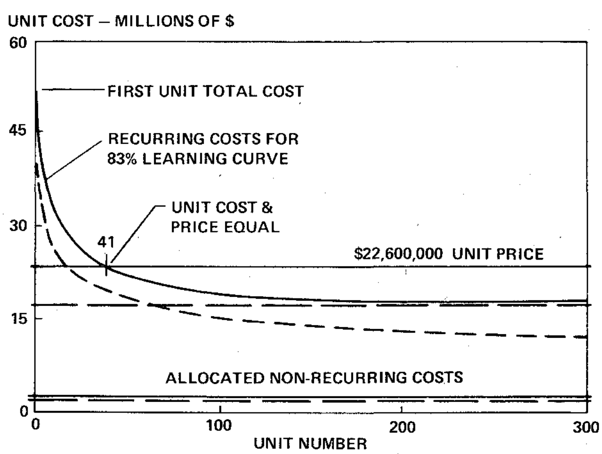

Fig. 10 Typical program cost/price factors: 5% annual rate of inflation.

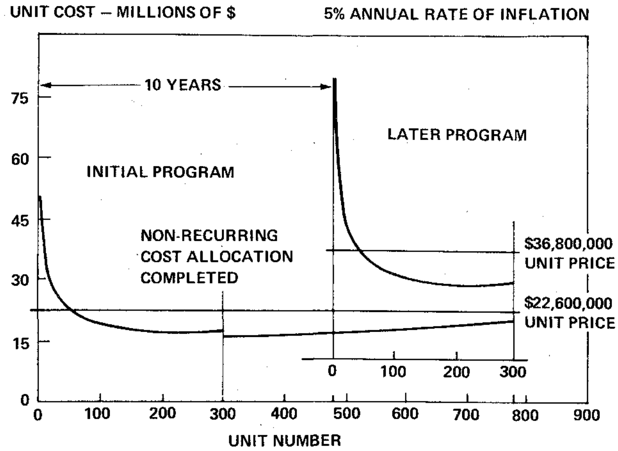

Fig. 11 Typical cost/price relationships: succeeding competitive programs.

There is one adjustment in the first program, evidenced by the discontinuity at the 300th unit, which represents the drop in unit cost because all of the nonrecurring costs are amortized completely over the first 300 units. This permits the additional units of the first program to be sold at the original $22.6 million unit price through the time period of interest, even with the continuing 5% annual rate of inflation, since the first 300 units of the first program had been priced at $22.6 million based on an anticipated total quantity of 300 units, as shown earlier in Fig. 10.

The necessary selling price for the first 300 production units from the later program must, on the same basis of planning, be 162.9% of that for the additional units of the earlier venture. This brings the procurement cost issue clearly into focus, but not the entire cost picture. Direct operating cost is a major consideration. For the sake of simplicity, familiarity, and credibility, the ATA DOC method is used to illustrate the problem. This approach cannot be used with absolute accuracy, particularly for military airplanes, but it provides a tolerable comparison.

Relative DOC

Table 3 lists the basic ATA cost factors on a percentage basis for the programs shown in Fig 11. Case A is for an airplane from the first program put into civil operation during 1978. Case B is for an additional identical airplane from that program purchased and put into operation during 1988, 10 years later. Case C is for an identical airplane from the later program when also put into service in 1988. Since the aircraft for all three cases are identical, a comparison of cases B and C indicates the devastating adverse impact of learning curve consideration coupled with the 5% annual rate of inflation on the cost of operation of airplanes from the later program. The penalty in this case is over 22%.

It is necessary to re-examine cases B and C to determine what approach can be taken to overcome this penalty for case C. Table 4 shows the data recomputed with case B as the baseline. The entire 22.3% difference in total DOC falls in maintenance and depreciation and insurance, since the latter

Table 3 Relative DOC–$/airplane statute mile

ITEM	CASE A	CASE B	CASE C
FLIGHT CREW	0.62	1.01	1.01
FUEL & OIL	0.91	1.47	1.47
MAINTENANCE	1.05	1.43	1.72
DEPRECIATION & INSURANCE	1.46	1.46	2.37
TOTALS	4.04	5.37	6.57

Table 4 Relative DOC – normalized to case B

ITEM	CASE B	CASE C
FLIGHT CREW	18.8	18.8
FUEL & OIL	27.4	27.4
MAINTENANCE	26.6	32.0
DEPRECIATION & INSURANCE	27.2	44.1
TOTALS	100.0	122.3

and the spares-cost portion of maintenance are related directly to original unit cost in the ATA method. But this 22.3% penalty seriously understates the total problem. There is a pretty fair rule-of-thumb among the passenger airlines that, because of other known factors associated with new equipment introduction, crew training, etc., something like a 20% improvement in DOC over that of existing passenger systems is necessary to attract the attention and support of those who underwrite new aircraft development programs. Since a certain amount of passenger and market appeal usually comes along with such new passenger ventures, it is reasonable to expect that an even greater advantage, perhaps in excess of 25% would be required to justify initial financial support for a new cargo system. Now the problem is to enhance case C sufficiently to have a saleable system development program in the face of the competitive existence of case B. This means that we somehow must achieve a reduction of case C DOC to 75% of the case B DOC; this calls for Case C DOC to be 16% of its value here, or a saving of 39% of that value.

Benefits of Advanced Technology

The exploitation of all beneficial advances in the technological art which have become available in the period between the two programs can reduce airplane size, weight, and thrust required significantly while providing an airplane with equal productivity. The question becomes a matter of the degree of beneficial impact on DOC.

In 1972, the Lockheed-Georgia Company reported on a study[1] that it made for NASA-Langley of the effects of certain advanced technology applications to a Mach 0.95 transport carrying about 85,000 lb of payload 5500 n. mi. As an outgrowth of that study, the results have been translated so as to apply to a Mach 0.767 cargo aircraft with a 71,000-lb payload and a 3450-n. mi. *X*-point range. The technological advances included those listed in Fig. 12. Advanced propulsion systems were not considered, since they also could be used on derivatives of earlier programs. The baseline design incorporated all three of the advanced technologies indicated, and their contributions are measured as changes from that base when they are removed.

It may be seen that the greatest contribution comes from the composite structure. The supercritical wing is also quite beneficial, wheras active controls are only modestly so. The integrated benefit may be as much as a 20-25% improvement

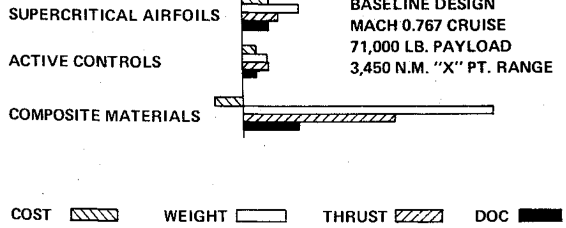

Fig. 12 Effects of removing selected technologies from advanced aircraft.

in DOC. The technological advantages are apparent; but, when considering relative DOC, a 10-yr difference in the initiation date between the baseline program and the advanced technology program, together with a 5% annual rate of inflation, must also be taken into account. The results appear in Fig. 13, where it is evident that the resulting relative DOC is not as good as the 61% value called for earlier in comparing cases B and C.

The situation is really even bleaker than it looks. The comparison has taken no account of the possibility of selected modification or derivative development of the original baseline airplane. No attempt is made here to quantify such options because the quantification is arguable: nonrecurring costs for partial new design and test reappear; basic recurring material and equipment costs change; and the learning curve slope changes (and probably keeps changing under the mixed production circumstances involved). But the original baseline program airplane certainly can exploit some of the new technologies to some degree and with generally less risk, and so it essentially fights back and makes the DOC reduction target for the later new program become understated in terms of justifying initiation of the all-new program.

Benefits of Increased Size

If the problem cannot be resolved adequately with an all-new airplane of equal productivity, then the airplane for the second program can be resized so that its productivity is increased and DOC is driven down further by the effects of increased size and productivity. There is a backlash possible in this approach, however, if the total productivity market is fixed. Increased size may not then be as beneficial if it reduces the total number of units that can be sold and thus drives the selling price up, because less advantage may be taken of

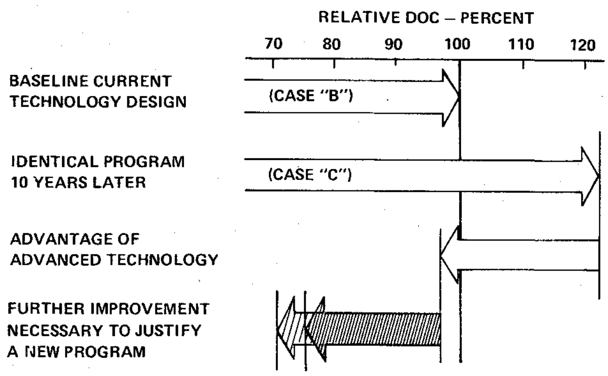

Fig. 13 Integrated economic appraisal.

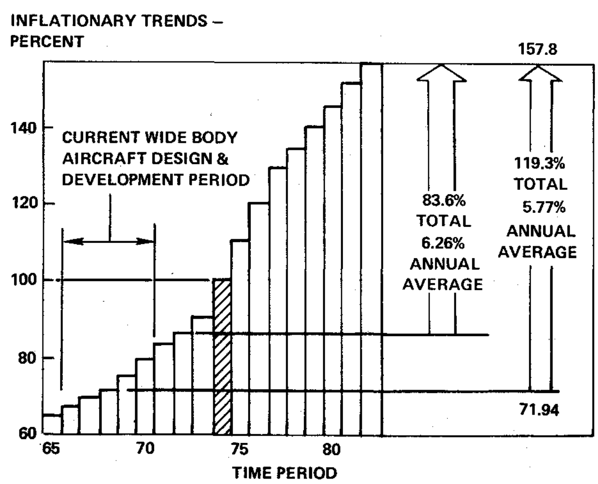

Fig. 14 U.S. government economic indices.

Table 5 All-new airplane scaling factors – size study

FOR AN AIRPLANE WITH 50% GREATER PAYLOAD, SAME "X" POINT RANGE CAPABILITY & SAME TECHNOLOGY LEVEL

GROSS WEIGHT	1.43 x BASELINE
OPERATING WEIGHT	1.42 x BASELINE
ENGINE THRUST	1.40 x BASELINE
FUEL TO REACH "X" POINT	1.40 x BASELINE
RDT & E COSTS (NO INFLATION	1.35 x BASELINE
UNIT PRICE (NO INFLATION)	1.37 x BASELINE

Table 6 Operating cost parameters – size study

PARAMETERS		BASELINE	ALL-NEW
MAXIMUM TAKEOFF WEIGHT	(LB)	775,000	1,163,000
AIRFRAME WEIGHT	(LB)	278,000	416,000
UNIT ENGINE THRUST	(LB)	47,000	70,000
CREW SIZE		3	
ANNUAL UTILIZATION		3650 HRS	
DEPRECIATION PERIOD		12 YRS	
INSURANCE, ANNUAL LIFETIME AVERAGE		2%	
AIRFRAME SPARES		10% AIRFM COST	
ENGINE SPARES		40% ENGINE COST	
1972 MAINTENANCE LABOR RATE		$5.83/HR	
		1972	1982
FUEL COSTS	(¢/U.S.G.)	12.7	40.0
OIL COSTS	($/U.S.G.)	8.69	16.02

beneficial production learning curve effects and broader nonrecurring cost allocation.

To evaluate more specifically the potential economic viability for such a possible all-new, very large cargo aircraft system, a brief study was undertaken by the Lockheed-Georgia Company. The analysis considered both acquisition and operational costs for an all-new system and for a current technology system that still could be in production in 1982. In this effort, 1982 dollars were based on historical inflation rates through 1974, obtained from Department of Commerce sources, and on forecasts by the Department of Defense from 1974 through the early 1980's, published in 1974 and presented as indices in Fig. 14. Note that the total rate of inflation indicated for the period 1972-1982 is 83.6%, substantially greater than 62.9% that results from the 5% annual rate of inflation used in earlier examples.

The airplanes considered in this study are, first, a hypothetical, current-state-of-the-art, large cargo airplane from a program initiated in the mid-1960's but purchased and first operated in 1982. This airplane, which has a payload of 240,000-lb, if purchased and operated in 1972, would have a DOC of about 4.4¢/TSM. When purchased in 1982 for initial operation in 1982, DOC becomes 7.4¢/TSM. The baseline airplane price in 1972 dollars is $28.9 million. By 1982, it is expected that between 400 and 500 units will have been sold. The price in 1982 dollars, $29.5 million, recognizes both learning curve benefits and intervening inflation, whereas all development and other nonrecurring costs are assumed to have been $1 billion spread over the first 300 units.

Second is a new and larger airplane of the same state-of-the-art but with a payload 50% greater, i.e., 360,000 lb, and with program spans from initial development to initial service period the same as for the earlier program, that is, 1975-1982. The prorated development costs for the new and larger airplane are based on an estimated total nonrecurring cost for the period 1975 to 1982 of $2.479 billion, derived from the development costs of the baseline program, which are assumed to be $1 billion expended in the 1965 to 1972 period, escalated to the 1975 to 1982 period, giving $1.836 billion, and then factored by 1.35 to reflect the larger size of the all-new airplane.

The scaling factors of Table 5 were applied to define the all-new, larger airplane. The operating cost parameters listed in Table 6 were applied in an analysis to evaluate the relative DOC of these large aircraft. The results of these analyses are presented in Fig. 15. For the baseline airplane from 1972 to 1982, these results show an inflationary increase of 69% in DOC (i.e., 4.4 to 7.4¢/TSM), whereas the DOC of the larger, all-new airplane is even higher. Such an all-new, larger, but same state-of-the-art airplane would not be competitive in 1982 with additional production aircraft from the baseline program.

If this airplane cannot compete, what is the potential for an otherwise identical program that employs all of the advances in the state-of-the-art indicated earlier in Fig. 12? This possibility for an overall DOC improvement of as much as 25% through use of advanced technology is probably much too optimistic for an airplane to be operational as early as 1982 but is used in Fig. 16 to illustrate the depth of the problem faced by any future, all-new, advanced transport aircraft. The lower shaded band assumes that a 25% improvement in DOC is possible for the all-new larger 1982 airplane through exploitation of advanced technology. Even on this basis, a large production quantity (200-300) is necessary as a basis for pricing policy just to achieve a DOC equal to or slightly better than that of additional units of the smaller, less productive, conventional technology aircraft from the earlier program. This thin possible margin in DOC is not adequate in view of the production quantity required, the "20% better" concept (or some version of it), the uncertainty in both technology and economics, and the lack of flexibility of a larger airplane on a real multi-route system.

Modular Design

There is another scenario that should be considered: the cases where realistic needs cannot be matched and met economically with additional or derivative aircraft because of some special requirements, perhaps of size or some military necessity. It is possible under such circumstances to make an effort to expand the potential total number of the new aircraft and its derivatives in the new aircraft family so that a modular design development and production approach can be exploited to insure best economic performance for the entire family.

In a recent study, three members of a single family of aircraft were sized to fit three general categories: 1) a twin-engine, short-range aircraft with a payload of 35,000 lb; 2) a four-engine, medium-range aircraft with a payload of 55,000 lb; and 3) a four-engine, long-range aircraft with a payload of 100,000 lb. By adding two more engines, a fuselage plug, a vertical stabilizer plug, and a center wing plug, the light aircraft becomes the medium aircraft. By adding additional

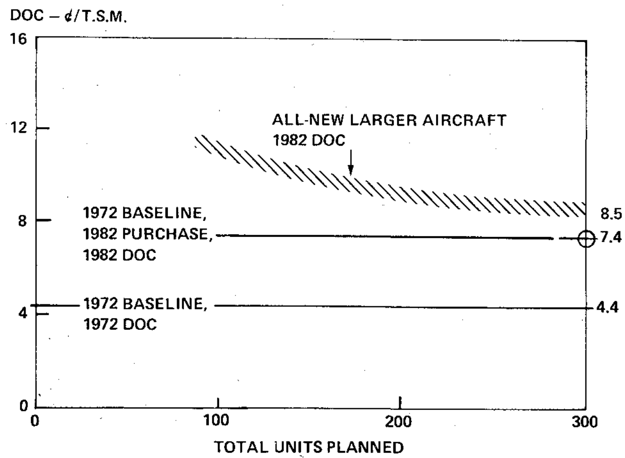

Fig. 15 Economic potential estimate: size study.

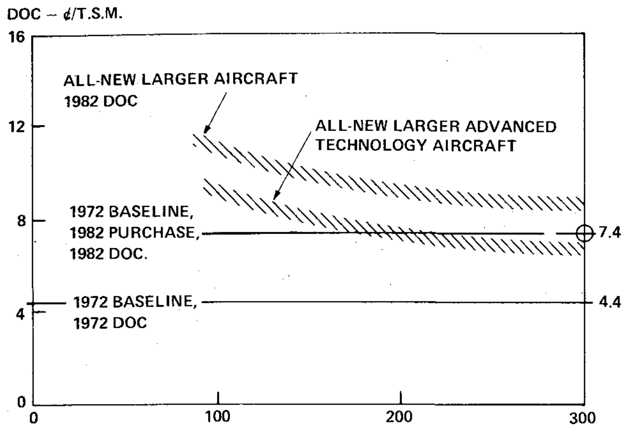

Fig. 16 Advanced technology benefits: size study.

fuselage plugs and extending the wings still further at the root, the medium aircraft becomes the heavy aircraft. Functional system commonality, particularly in individual components, is substantial.

The net result of the study was favorable and indicated that, although recognizing the modest weight penalties associated with such a high degree of structural and functional system compatibility across several sizes of airplanes, the benefits in terms of cost reduction were significant, approximately 15% in procurement cost. Support material costs also would benefit, and per unit costs for training and service manuals would be reduced. For commercial airplanes, this approach would result in 3 to 5% improvement in DOC.

Concluding Remarks

For the sake of completeness, it seems appropriate to recognize by at least listing, if not by discussing and analyzing, the many factors partially outside of the overt and immediate control and influence of aircraft manufacturers and airlines. These factors will affect the ultimate results and decisions between the continuation and derivatives of present programs on the one hand and new aircraft systems on the other. Table 7 is a simple listing of both those items that tend to oppose the development of a new system and encourage the prolongation of present models and their derivatives and, conversely, situations where circumstances become more favorable to the development of new aircraft systems. This overall picture of interaction between both domestic and international affairs and the aircraft and airline industries has gone beyond that to which we are accustomed and should, therefore, command more than the usual degree of attention.

It is possible that military requirements may demand a new cargo capability beyond those of existing systems. The happy circumstances of the past, where this need caused research and development that applied either directly or peripherally to commercial applications, may occur once again. Relative economic viability will be the criterion.

The modular approach to a family design that has maximum commonality offers a possibility that could be applied across a broad spectrum of potential air cargo transports. It never has been easy to accomplish this, but the scenarios now being considered may make the effort worthwhile, particulary in view of the continuing rapid escalation in research, development, test, and evaluation costs.

Table 7 Derivatives vs new designs – some factors to consider

FACTORS	DERIVATIVES	NEW DESIGN
ECONOMICS		
AIRCARGO MKT	LOW GROWTH	HIGH GROWTH
CONTINUING INFLATION	HIGH	LOW
FINANCE		
GOVERNMENT SUPPORT	WEAK	STRONG
MANUFACTURERS STATUS	WEAK	STRONG
AIRLINES STATUS	WEAK	STRONG
TECHNOLOGY		
MAJOR ADVANCES	COMPONENT ORIENTED	CONFIGURATION ORIENTED
ENVIRONMENTAL REQUIREMENTS	LITTLE CHANGE	MUCH MORE STRINGENT
NEW CAPABILITY REQUIREMENTS	FEASIBLE BY DERIVATION	NOT FEASIBLE BY DERIVATION
FUEL		
COST	NEAR STATIC	MUCH HIGHER
CONSERVATION REGULATION	IF RELAXED	IF STRINGENT
OTHER PETROLEUM USERS	AGRESSIVE USE OF OTHER SOURCES	LITTLE USE OF OTHER ENERGY SOURCES
HYDROGEN AS A FUEL	NO	POSSIBLE

It is clear that one possible approach to solving the problem and making a new airplane economically attractive is a broad and concerted attack on the costs of production, principally by combined design and manufacturing innovations that are fundamental and intrinsic enough that they can be exploited only slightly in derivatives or extensions of existing programs. The use of composites continues to offer promise in this regard, but the reductions do not appear large enough yet to bridge the gap. Actually, since the fabrication and assembly of aircraft structure generates only 60% of the recurring costs of an airplane at, say, the 200th unit, major inroads also must be made in the costs of equipment and systems that constitute the balance.

Finally, regardless of the many factors of Table 7 which will bear on the final outcome, there certainly should be a heightened emphasis on research and development work related to future potential aircraft systems, with emphasis on improved efficiency at reduced cost. Whether derivatives or new systems prevail, only through aggressive and dedicated research and development efforts can the many potential improvements in fuel conservation, other operational cost factors, and production costs be brought to fruition. It is through this entire mechanism, of course, that one should reasonably expect to discover one or more "breakthroughs," which will be the means of a shift from our current technology curve to another more beneficial level, thus alleviating the adverse cost impact factors now faced by all-new transport systems. When one reflects that it has been only a little over 20 years since the first service of a British commercial jet-propelled passenger airplane and less than 17 since the first commercial service of a U.S. jet, the supposition that a few more years might have to pass before a significant breakthrough may be made with new advanced transport aircraft should cause no great disappointment.

Reference

[1] Lange, R.H., "Parametric Analysis of ATT Configurations," AIAA Paper 72-757, Los Angeles, Calif., 1972.