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THE PORTFOLIO MODEL OF
TECHNOLOGICAL DEVELOPMENT
IN THE AIRCRAFT INDUSTRY

The Management and Technology Program



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THE PORTFOLIO MODEL OF
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David M. Snyder
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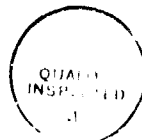
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EXECUTIVE SUMMARY

The aircraft industry has long been considered the quintessential high technology industry. By examining the dynamics of technological change in this industry the portfolio model of technological advancement is developed. This model may be used to describe technological advancement in large sophisticated, technology intensive systems. The rapid advancement of individual technologies as measured by improvements in specific performance parameters is evident in the aircraft industry. However, the ability of a technology to improve performance in one or more key performance parameter may lead to adverse effects in other performance parameters or may not be compatible with other technological developments that are occurring in the industry. Individual technical improvements can be characterized as either portfolio reinforcing or portfolio shifting depending on whether or not they promote shift in the way the technologies are combined into a total system or portfolio. The commercially and economically successful products appear to be those that combine technologies into an optimum bundle of performance characteristics or portfolio. Technologies that flourish are not always the technologies on the leading edge of the performance frontier, but are those technologies that produce the optimum portfolio.



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TABLE OF CONTENTS

Executive Summary	1
Table of Contents	11
List of Figures	111
Introduction	1
Diffusion and Substitution	4
Portfolio Model of Technological Development	8
Portfolio Reinforcing	19
Portfolio Shifting	21
Why the Portfolio Approach to Technological Development is Evolving in the Aircraft Industry	25
Conclusion	29
Figures	31
Selected Bibliography	49

LIST OF FIGURES

FIGURE		PAGE
1	Market Share of Aircraft Engine Technologies	31
2	Shipments of Regional Transports and Executive Aircraft	32
3	Commercial Transport Engines: Thrust-to-Weight Ratio	33
4	Military Engines: Thrust-to-Weight Ration	33
5	Commercial Transport Engines: Cruise Specific Fuel Consumption	34
6	Estimated Deliveries of Newly Produced Aircraft to Domestic Trunk Carriers, 1936-1941	35
7	Starship Advertisement	36
8	Canard on the Avtek 400	37
9	Lear Fan Technology Development Portfolio	38
10	Lear Fan Composite Materials Technology Profile	39
11	Lear Fan Technology Portfolio, Parameter #1	40
12	Benefits Possible From Technology Improvements	41
13	Advanced Turboprops	42
14	Advanced Turboprops (Continued)	43
15	Advanced Transport Technology	44
16	Comparison of Growth in Airliner Prices, Productivity, & the Consumer Price Index	45
17	Typical Cash Flow Curve for Large Transport Aircraft Program	46
18	Load Factors and Breakeven Points of Major Airlines Before and After Deregulation	47
19	Domestic Operating Profit of the Major Airlines Before and After Deregulation	47
20	Airports Served by Regional and Major Airlines	48
21	Number of Certificated Carriers Before and After Deregulation	48

INTRODUCTION

Technological growth is often viewed as the diffusion of a new technology or the substitution of one technology for another. Aircraft technology has experienced a rapid diffusion since the Wright brother's first flight in 1903 and the aerospace industry is considered the supreme technological industry. New technological advances have substituted for earlier technologies in classic multi-level substitution patterns. However, when viewing technological change in the aircraft industry in a broad sense, which includes transport, business, utility, military and commercial aircraft and their associated engines, avionics, payload and aerodynamic features in the entire general set of aircraft technology, the diffusion and substitution models of technological change becomes less descriptive. While many examples of technological substitution and diffusion characterized by incremental technical performance advances are evident when focusing on certain technological attributes of aircraft; a broader look at aircraft technology supports a different model. It appears that aircraft technology advances in such a way as to provide the optimum performance in the selected operating environment. Each new aircraft represents a "portfolio" of technologies that result in the best performance for the particular designed mission or task. Often an old

technology is used in the portfolio because it provides the best tradeoff with other operating constraints. I will call this concept the portfolio model of technological development.

In the portfolio model of technological advancement each aircraft is viewed as a portfolio of technologies that make up a complete system. There can be advancements, as measured by certain performance parameters, in individual technologies or advancements in the way that the portfolio of technologies are put together. However, the distinguishing difference in the types of technological change is whether technological change is "portfolio reinforcing" or "portfolio shifting" Portfolio reinforcing changes are usually changes in specific performance characteristics that do not have a significant impact on the fundamental method of combining the technologies into a total system or portfolio. On the other hand, portfolio shifting technological advancements are technological changes that force an alteration in the way that technologies are combined into a system. This usually means altering the basic assumptions around which the portfolio is assembled into one system. Technological advancements that result in portfolio shifting are not necessarily radical new developments. In fact the classic radical versus incremental classification is of limited value in the portfolio model of technological development. Portfolio shifting advancements are often the result of several technological advancements in the technologies that make up the portfolio or in unrelated technologies. Environmental factors

can amplify the shifting of an optimum portfolio of technologies.

My intent is not to discredit the diffusion and substitution models of technological growth, but to highlight an additional framework for examining technological advancement in some general technical areas. In fact, aircraft technology provides some excellent examples of diffusion and substitution when looking at specific parameters or components. These models are very useful and effective for modeling these micro-level technological changes. However, on the macro-level of aircraft development the portfolio model explains the use of a select group of technologies that are best suited for a particular market segment. Additionally, the portfolio model helps us identify those technological advancements that reinforce the existing portfolio from those that promote a shift in the portfolio.

This paper will highlight the diffusion and substitution of technology as evidenced by various aircraft performance parameters. By examining a few of the more technically, commercially, and economically successful aircraft the portfolio model will be developed. In this model one will see that while specific technical performance parameters follow identifiable diffusion and substitution patterns, the overall economic success depends on the ability to combine technologies into a complete package which optimizes total performance for the desired mission. This often leads to the diffusion or substitution of

technologies that are not at the leading edge of the technology frontier, but rather leads to the use of technologies that offer attractive tradeoffs with other performance parameters for a given mission and external environment. The technologies that flourish in the short term are the individual technologies that aggregate together into an optimum "portfolio" for a specified mission at a specified time. We will examine advancements that reinforce this optimum portfolio and advancements that cause a reevaluation of the optimum portfolio and assumptions on which the portfolio is built. This brief report will conclude by suggesting reasons for the emergence of this portfolio approach to technological diffusion.

DIFFUSION AND SUBSTITUTION

The substitution and diffusion of specific aircraft technologies often follow classic patterns. Girifalco amplifies the research of Blackman (1976) to graphically represent the multi-level substitution of piston engines, turboprops, and turbojets in the commercial aircraft industry.¹ As shown in Figure 1, the engine technology at the beginning of the sixties was characterized by a high state of development, as evidenced by

1. L.A. Girifalco, The Dynamics of Technological Change, Chap. 4, p. 17.

market share, for piston driven aircraft. However, this market share rapidly declined with the substitution of both turboprop and turbojet technology for piston power. The improvements in engine technology caused a shift in how a portfolio of technologies were put together for commercial air travel. Long distance air travel evolved as one of the fundamental assumptions on which to base the commercial aircraft portfolio. Contributing to this portfolio shift was the public acceptance of air travel and the improvements in passenger comfort. It was clear that the next generation of commercial aircraft would not use piston driven engines, but as Lockheed found out after producing the turboprop Electra, turbojet technology would dominate the large airline market in the seventies. However, this illustration only tells part of the story as it applies to market share of the engine technology for a limited set of aircraft, large commercial airliners. The turboprop, and to a lesser extent the piston engine, are in no way a dead or obsolete technology as this substitution model would indicate. In the business, cargo, and military markets turboprop aircraft play a significant role. The optimum portfolio in this class of aircraft was reinforced by the development of turboprops. The Lockheed C-130 military/civilian cargo turboprop is still being produced in significant quantities as it has since its introduction in 1954. In addition to the C-130 Hercules, other current military turboprop acquisitions include 80 Beech C-12Fs and 18 Shorts C-23A Sherpas, both variations of civilian turboprop aircraft delivered in large

numbers.

The business and commuter aircraft market is dominated by turboprop aircraft. Shipments of regional transports and executive aircraft, shown in Figure 2, indicate expansion in this market. Currently there are several new designs in turboprop aircraft, named superprops, entering production or seeking certification including the Beech Starship, the Lear Paggio GP-180, OMAC Laser 300, and the Avtek 400.² These planes combine emerging new technologies such as extensive use of composites and new aerodynamic structures with some revisions of older technologies like turboprops and canard surfaces. High-speed turboprops or propfans are highly regarded as holding great promise to general aviation aircraft and regional aircraft.³ It appears that we are in the midst of a significant shift in the optimum portfolio of technologies for this class of regional and business aircraft. The old portfolio was based on assumptions predicated on the use of metal turbojet aircraft with traditional wing/tail configurations. New technological advancements in composite materials, engine technology, and aerodynamic theory have combined with market factors to shift the optimum portfolio.

2. DeMeis, High Technology, October 1984, p. 85.

3. The Competitive Status of the U.S. Civil Aviation Manufacturing Industry, 1985, p. 114.

One of the hottest aircraft technologies being developed for the early 1990's is advanced turboprop engines for airliners. These engines will provide fuel economy that is 50% better than current turbojet engines.⁴ Turboprops have some very favorable tradeoffs when compared against turbojets and this technology is experiencing a revival in some major market segments. The classic model of substitution does not fully describe the changes that have occurred in the aircraft industry.

Incremental improvements in engine technology show some classic patterns of diffusion. In both commercial and military aircraft engines thrust-to-weight ratios have improved over the last two decades in a decaying exponential rise as shown in Figures 3 and 4. Technologies contributing significantly to this trend in this parameter are light-weight, high-strength, and high-temperature materials, as well as improved design and configuration.⁵ Cruise specific fuel consumption (a measure of fuel efficiency of the engine) for commercial transport engines has experienced a similar decaying exponential decrease as shown in Figure 5.⁶ While many of these individual performance parameters follow classic diffusion patterns, when considering the evolution of

4. O'Lone, Aviation Week and Space Technology, February 1985, p. 41

5. The Competitive Status of the U.S. Civil Aviation Manufacturing Industry, 1985, pp. 123-127.

6. Ibid., p. 122

aircraft technology in the aggregate the pattern does not flow as nicely. The portfolio model of technological development is more descriptive for examining a set of technologies that are combined in a particular aircraft and, therefore, become proliferated as individual technologies.

PORTFOLIO MODEL OF TECHNOLOGICAL DEVELOPMENT

The portfolio model of technological development is based on the concept that a sophisticated, high technology system such as an aircraft is developed and operated under a myriad of constraints and tradeoffs. As individual component technologies become more advanced the tradeoffs become more pronounced. For example, as jet engine technology improves higher cruise speeds are possible and wing design must accommodate these higher speeds. However, higher cruise speeds and associated wing design means faster landing speeds and, thus, longer landing distances, a negative development. As technology removes technical constraints and pushes the performance frontier of one parameter out further, new constraints are imposed often on a different parameter. The portfolio model concludes that a technical system will be composed of a collection of individual technologies that combine together to make the most effective total system. This may often mean returning to a mature technology for one component of the total system because of the impact that it has on other

components of the system. It may also imply that as related technologies diffuse or advance in regard to one parameter, an opportunity may avail itself to use a previously abandoned technology in another component of the system.

The portfolio model suggests that the "best" or most effective airplane for a particular mission may not be the technological leader in all, some, or even any of the critical performance areas. Rather, the most effective airplane is the one that bundles the technologies in the most efficient way. This will lead to the proliferation of those technologies that can be bundled with other technologies, whether or not they are state of the art. A very good example of this portfolio approach can be found in the Douglas DC-3. First produced in 1936, the DC-3 dominated the market for new commercial planes until the U.S. entered WWII as shown in Figure 6.⁷ Phillips succinctly describes the DC-3 from a technological standpoint:

The DC-3 was not at the time of its appearance the largest or the fastest or the longest-ranged aircraft the carriers had ever used. Neither was it the only all-metal, low-wing plane with retractable gear, variable-pitch propellers and other modern equipment. It was, rather, among the largest and the fastest and longest-ranged planes. It was, more importantly, an aircraft which combined other desirable technical characteristics in a way which resulted in much lower operating costs per seat mile than were those of any other plane up to that time. Its seat mile costs were, in fact, so much lower than those of alternative aircraft that even with a relatively low load factor its passenger mile costs were often lower than those

7. Phillips, Technology and Market Structure, 1971, p. 94.

for other planes....It appears, however, that the lower costs of the DC-3 came not from whatever design differences gave the DC-3 greater range. Rather, the lower costs came from the design changes which permitted the comfortable carrying of additional passengers. Only as the number of passengers carried in the DC-3 exceeds the capacities of alternative new aircraft do the estimated passenger mile costs of the DC-3 fall below those of the other aircraft.⁸

The DC-3 bundled technologies in such a way as to provide an optimum seat mile cost while not exceeding critical constraints in other performance parameters. But even in the 1930's airlines had a variety of route leg lengths and cost performance parameters. Costs for one average leg length do not correspond to efficient operating costs for significantly different leg lengths. Phillips demonstrated with a regression analysis that the DC-3 was, from an operating cost perspective, more efficient on all leg lengths than any other plane of the time except one. The DC-3 was not the leader in any one technology but the total package or portfolio of technologies made an extremely competitive product that is still in service today with several cargo carriers. The development of the DC-3 represented a major shift in the optimum portfolio of technologies.

There are other examples of the development of a portfolio of technologies into a very effective product. The Boeing 727, the third entry behind the DC-8 and the 707, combined several technologies including swept wings, three fanjet engines, and

8. Phillips, Technology and Market Structure, 1971, pp. 94, 98.

wing high-lift devices (triple-slotted flaps, leading edge slats and vortex generators).⁹ This portfolio of relatively new, but not radical, technologies combined to produce an airliner with the short field capabilities of the turboprop Lockheed Electra and the cruise speed and comfort of the 707 and DC-8.

The McDonnell-Douglas F-4 Phantom II is a fighter aircraft that was a composite of technologies, none of which were on the frontier, that combined to make a very successful and enduring product. The F-4 was the first supersonic, moderate range, air-to-air fighter that combined technologies in a portfolio that combined maneuverability with speed and payload representing a shift in the optimum portfolio of technologies. First produced in 1955, the F-4 is still in use by the U.S., Japan, Israel, and several NATO countries. While the General Dynamics F-111, which incorporated the most modern technology including advanced avionics, variable geometry wings, and capsule ejection systems, failed to live up to the very high expectations many people had for it when it was developed in the early 1960's. Originally designed to fill a wide spectrum of fighter roles, the F-111 is only used in the night ground attack role with small numbers of FB-111's and EF-111's variants used as medium bombers or for electronic counter measures. The F-111 was only produced in

9. White, "Management Criteria for Effective Innovation", Innovation/Technology Review, pp. 25-26.

moderate numbers, about 500 total aircraft¹⁰ compared to over 5500 F-4s. The F-111 is effective in its high-speed, low level, night, ground attack role, as evidenced by the recent U.S. attack on Libya, but it failed to put together a portfolio of technologies that would make it the "all-purpose" fighter that it was designed to be.

In the business aircraft market the Lear Fan showed great promise as a portfolio of technologies that where not individually radical, but combined in such a way that the total package had remarkable potential and represented a fundamental shift in the technology portfolio. The fuel efficiency and the short field capabilities of a turboprop were combined with the range and altitude of a turbojet while keeping the aircraft weight under 12,500 lbs. The new generation of business aircraft have quickly followed in the footsteps of the Lear Fan and combined technologies into similar portfolios. Individually, some of the technologies are almost archaic. Several use canard surfaces, similar to what the Wright brothers used for control surfaces. Additionally, these planes use pusher props, again just as the Wright brothers did. Gear box, materials, manufacturing, and aerodynamic technologies have combined to make the tradeoffs in using some relatively dormant technologies attractive. In fact, the Beech (purchased by Raytheon) Starship

10. "The Military Balance 1985/86", Air Force Magazine, February 1986, p. 62.

return to a basic technology in its advertisements as shown in Figure 7. The use of canards, horizontal stabilizers located forward of the wing, are incorporated in the Starship and many new designs (see Figure 8 for further description). This technology has been around since the Wright Flyer in 1903, but it is only recently that other technologies (composite materials and advanced aerodynamics) have made canards a viable part of a modern aircraft's portfolio.

With a conceptual understanding of the portfolio approach to technology, we may now look at how the possible portfolio model of technological development is formed. As stated earlier, the portfolio model focuses on the tradeoffs that individual technologies provide between performance parameters. A technology that improves one performance parameter may affect several other parameters either favorably or negatively. The most important consideration is how one technology interacts with the other technologies. Figure 9 is a portfolio profile of the technological performance parameters of the, now defunct, Lear Fan. Each of the critical (cruise speed, load/passenger capacity, range, etc.) performance parameters are plotted on the horizontal axis. In the case of the Lear Fan, nine key performance parameters were identified for this particular class of aircraft. Positive valued attributes (e.g. speed, range) are plotted above the axis and a minimum acceptable level of performance is identified. The performance attributes of the Lear Fan and the minimum level of performance required to be

competitive are expressed in terms of a percentage of the maximum capability of the "best" technology for that performance parameter. The negative valued attributes are plotted below the line in a similar fashion with the maximum level of acceptable performance also identified as a percentage of the minimum capability of the "best" technology. The relative thickness of each critical performance parameter represents that parameter's overall importance in the total aircraft package for that particular class of aircraft.

The usefulness of this model is that each individual technology or technological development aggregates with the other individual technologies to produce the portfolio. For example, the cruise speed performance parameter is affected by a variety of technologies including advanced turboprop technology, gear box technology, the use of canard surfaces, and composite material construction techniques. Each of these technologies impacts the final cruise speed as well as affecting other critical parameters. As shown in the Lear Fan portfolio (Figure 9), The use of its portfolio of technologies increases cruise speed a given percentage over conventional turboprops (the minimum acceptable level of performance), but is a certain percentage less than the best turbojet (the maximum capability of the "best" technology). The impact of the use of advanced turboprop technology adds to the maintenance hours per flying hour relative to that of conventional turboprops (the minimum capability of the "best" technology for this parameter) while still keeping

maintenance time below that of the maximum acceptable level. Use of advanced turboprop technology increases noise level while decreasing fuel consumption. Once the impact of each technology on each parameter, within a given range of the percentage of the "best" technology, is determined, then an assessment of the tradeoffs can be made.

When new technologies are developed or older technologies are incrementally improved the effect of these changes can be shown on each of the key performance parameters. Each technology has its own profile of how it impacts the key performance parameters and these profiles combine to become the technology portfolio. This can be graphically represented by breaking the technology portfolio down one more level to document the impact of each technology on the portfolio. Figure 10 is the performance profile of composite material technology used in the Lear Fan. Each performance parameter that is affected by the use of composite material technology is annotated by the shaded area. In the case of the composite material profile (Figure 10), we determine that the use of composites accounts for significant changes in seven of the nine key performance parameters. The lighter weight and aerodynamic smoothness of the composite airframe results in improved cruise speed (10% improvement), greater load/passenger capacity (30%), longer range (15%), and higher (5%) maximum altitude. However, the use of composites causes an increase (approximately 10%) in maintenance hours per flying hour because routine inspections and structural repairs

are more difficult and time consuming. This is represented on the composite technology profile in performance parameter #5. The use of composites reduces the noise level in the cabin by about 8% and reduces fuel consumption by 12%. The crew requirements (parameter #7) and the landing distance (parameter #9) are not affected by composite technology. The effect of composites on each of the performance parameters form the technology profile. The technology profiles of all the new technologies used in the Lear Fan (composites, canards, advanced turboprops, etc.) aggregate together to yield the technology portfolio.

A closer look at a specific performance parameter illustrates the aggregation of several technologies to form the technology portfolio. Figure 11 represents the cruise speed performance parameter for the Lear Fan and shows the effects of several new technologies on the cruise speed. The use of advanced composites improves cruise speed by allowing for a significantly lighter airframe with less aerodynamic drag. There is also a small improvement in cruise speed that can be attributed to the use of canard surfaces because they decrease the overall drag on the Lear Fan. The Lear Fan also uses a new gear box technology that permits two engines to power only one propeller, which also reduces drag and improves the cruise speed of the Lear Fan. All of these technologies have a positive effect on the cruise speed performance parameter. However, some of the technologies have a negative effect on other parameters. In such a case, that

technology's impact on the particular performance parameter that is negatively affected is depicted on the opposite side of the 0% line.

The cumulative effects of a portfolio of technologies on specific performance parameters can be depicted in other ways. For example, figure 12 shows the benefits in the fuel efficiency parameter from various technological improvements in commercial transports.¹¹ A range of the synergistic effects of combining a portfolio of technologies is graphically illustrated in this diagram. However, this method of depicting the impact of technologies does not lend itself to the formation of a complete technology portfolio representing the effects on all key performance parameters.

This portfolio model is a graphic representation of information that could be determined from a series of constrained maximization and minimization linear program problems. The scope of this report does not permit a detailed formulation of the mathematical linear program equations. But the concept of the portfolio is just as valuable in expressing the need to evaluate technology tradeoffs and in understanding that "leading edge" technologies may have benefits that are outweighed by technological costs in other parameters. This would explain the

11. The Competitive Status of the U.S. Civil Aviation Manufacturing Industry, 1985, p.107

market success and proliferation of large, sophisticated, technology intensive systems that do not incorporate the most recent technological advances. It is the total package that is important with "the whole being greater than the sum of the parts".

This portfolio model can serve many purposes. For Lear Avia, the company that attempted to produce the Lear Fan, this model highlights their product's position relative to competitors with regard to key technological performance parameters. When analyzing the aircraft industry, a technology portfolio can be compiled for each aircraft in that particular class to determine how effectively other aircraft combine available technologies. As specific technologies advance the maximum and minimum capabilities of the "best" technology improves in the appropriate parameters and the portfolio shifts. Some technologies will reinforce the current mix of technologies by incrementally improving one or two performance parameters. However, other technologies will combine together to produce a noticeably different mix or portfolio. This type of discontinuity is technological advancement that is portfolio shifting not portfolio reinforcing. A time series analysis of the shifts in the technology portfolio provides a means of modeling technological change within a large system. Large perturbation in the analysis represent discrete shifts in the optimum portfolio. This portfolio development model is helpful in explaining the recurrent use of mature technologies such as

canards, winglets, and turboprop engines in certain market segments as the portfolio shifts. Figures 13, 14 and 15 show some of the new commercial and business aircraft incorporating new uses of "old" technologies.

PORTFOLIO REINFORCING

Technological advancements that produce an improvement in one or two performance parameters, but do not alter the tradeoffs between the technologies used, can be thought of as portfolio reinforcing advancements. These improvements are usually incremental and are championed by the technology or market leaders of the industry. This happens because the market leaders have a great deal invested in products that combine technologies into the current portfolio. Evidence of this in the aircraft industry is rampant as manufactures incrementally improve existing models by stretching, adding fuel tanks or avionics packages, or using newer engines on the same basic design. The development of follow-on versions of successful designs has prolonged the life and profitability of successful portfolios. Established aircraft manufactures tend to make small changes based on experience in an effort to prolong that aircraft's vogue in production. This development effort is restricted to conservative changes in a basic design acceptable to the

customer.¹² The cost of developing the basic package must be amort. over the maximum time possible by stretching out production. Phillips points out that there is an "apparent proclivity on the part of the once successful manufactures to remain too long with the basic technology of their original success."¹³ Industry leaders promote portfolio reinforcing technologies and resist portfolio shifting advancements. The technology leaders become the technology losers when a shifting of the optimum portfolio occurs. Phillips further states:

Aircraft firms that successfully innovate appear to press for stretched versions of their originally successful models. In the course of their doing so, they seem to have ignored advances in technology that were creating opportunities for more basic innovations. Eventually, a new success appears from either established or new producers and the market structure changes. These changes in structure, it can be argued, depend on changes in technology.¹⁴

When the technology shift comes it is often hard for the former technology leader to recover because the old rules and assumption have less validity and the former leader has not investing R & D money into combining technologies into the new portfolio. Shifts in the technology portfolio represent major changes for that industry.

12. J.C. Hunsaker, "Forty Years of Aeronautical Research", The Smithsonian Report, 1955, p. 263

13. Phillips, Technology and Market Structure, 1971. p. 91.

14. Phillips, Technology and Market Structure, 1971, p. 115.

PORTFOLIO SHIFTING

Portfolio shifting occurs when technological advancements create a significantly altered relationship among the performance tradeoffs for the current set of technologies. Certain technological advances lend themselves more to a new way of putting the total package or bundle of technologies together. Often, portfolio shifting is not the result of just one radical technological development, but rather a series of smaller technological developments. These technological advancements can occur in industries that are on the periphery of the basic technology. For example, materials and electronics technology has enabled major technology portfolio shifts in the aircraft industry. Many times these small technological changes will take place at the same time that external factors are influencing the basic industry. The environmental factors serve as catalysts for the new technical developments to change the way technologies are combined into a portfolio. This is often the result of changes in the fundamental set of assumptions upon which the old technological portfolio is built. In the portfolio model of technological advancement the true innovators are not the developers of incremental or even radical improvements in existing technology, but are rather the people that combine technologies into a portfolio or bundle that better serves a

particular market segment.

Portfolio shifting has resulted in dramatic changes throughout the history of the aircraft industry. While the business, military, and commercial aircraft industries all provide examples of technological developments that may be characterized as portfolio shifting, the airline manufacturing industry illustrates the portfolio shifting concept nicely.

Except for a brief period during World War I, from the invention of the aircraft in 1093 to 1926, the aircraft industry had difficulty surviving.¹⁵ While aircraft captured the public interest with romantic appeal, they were considered to have only limited commercial value. The predominant portfolio at this time was the wood and fabric biplane. However, improvements in monoplane design, metal fabrication, and radial engine technology combine with external events such as the Air Mail Act of 1925, the Air Commerce Act of 1926, and Charles Lindberg's historic 1927 flight to bring about a new generation in the aircraft's technology portfolio.

In 1936, as mentioned earlier in this paper, the DC-3 represented the next shift in the commercial aircraft portfolio. The DC-3 was a combination of many good technologies, but not necessarily the best technologies, into a portfolio that made

15. G.R. Simonson, The History of The American Aircraft Industry, 1968, p. 23

reliable, comfortable, long distance air travel more economical while providing the flexibility for varied route lengths. Several aeronautical developments combined to shift the optimum portfolio. The most significant changes was the use of a thicker fuselage to accommodate more passengers while actually reducing drag. It was also the DC-3 that made use of retractable landing gear, low-wing design, and variable pitch prop that became the industry standard portfolio to which other designs were compared.

In the mid-50s the development of the Boeing 707 and the less successful DC-8 ushered in another significant shift in the technology portfolio. These airliners combined turbojet technology with swept wings to produce comfortable high speed cross country travel giving birth to the modern airliner. With long range jets driving the pistons and propjets onto the medium and short range routes and combining with other factors to create a period of over capacity, the large aerospace manufactures turned their attention to the latter market and developed technologies that shifted the portfolio in this medium/short range market.¹⁶ The result was the Boeing 727 tri-jet, whose success encroaches that of the Douglas DC-3, and the twin engine DC-9. These aircraft brought turbojet speed and comfort to the mid-length route structure by combining many small technological

16. Bright, The Jet Makers, 1978, p. 97

changes into a new technology portfolio for this market.

Although there have been incremental and even some radical improvements in the technical capabilities of airliners since the late 1950s, the basic portfolio or way of combining technologies into an airliner has only been reinforced by improvements in specific performance features. Airliners today are essentially the same package of technologies that existed when the 707 development was followed up by the development of the 727 in the early sixties. Engine fuel and noise efficiency have improved markedly and the limited use of composites in airliners has helped reduce weight, but the basic portfolio remains the same. One radical technological advancement that only reinforced this portfolio was the development of the jumbo jet, the Boeing 747, McDonnell Douglas DC-10, Lockheed L-1011, and C-5A. This generation of wide bodied aircraft took the existing portfolio and produced it on a significantly larger scale using improved manufacturing techniques. The one recent attempt at portfolio shifting in the commercial airliner industry was the development of the Super Sonic Transport (SST) which was not an economic success. A potentially new portfolio of advanced technologies is being assembled, as shown in Figure 15, for use in the airline market utilizing a canard surface, pusher-type propfan, and winglets.¹⁷

17. O'Lone, Aviation Week and Space Technology, February 18, 1985, p. 42.

WHY THE PORTFOLIO APPROACH TO TECHNOLOGICAL DEVELOPMENT IS EVOLVING IN THE AIRCRAFT INDUSTRY

The use of the portfolio model to explain the use of resurrected technologies or technologies that are not on the leading edge of the technology envelope is becoming more pronounced in recent years. While the portfolio approach to examining why particular technologies are used is not unique to the aircraft industry, there are three factors that have amplified the portfolio approach in the aircraft industry.

First, the rapidly rising cost of aircraft systems has become a critical parameter when assessing the tradeoffs of technologies. Small marginal improvements in specific performance parameters come at a very high marginal cost when considered in isolation. But by shifting the portfolio of technologies it is possible to produce a package or mix of technologies that provides desired improvements in those parameters that are needed for that particular market. Successful new entrants in a particular aircraft market can not simply copy the existing technology with slight improvement in one performance parameter. Rather, the new entrants must create substantial cost advantages while improving performance for carriers using the new type of aircraft. This can only be done by reexamining and reorganizing the portfolio.

In the Lear Fan portfolio example we did not even consider cost, yet the proposed price of the Lear Fan was a very strong selling point contributing to the fact that there were over 200 orders for the plane before it even flew.¹⁸ Costs have become an overriding factor in commercial, business, and military aircraft. As shown in Figure 16, since World War II the price of commercial aircraft has increased at an exponential rate, far outstripping inflation.¹⁹ This effect has continued today with some new wide body aircraft costing close to \$100 million. In some cases it is possible to purchase a small fleet of used airliners for the price of a new jumbo jet.

The price escalation in military aircraft has been even more pronounced in the last four decades. For example, the Rockwell B-1B, of which a 100 aircraft production run was ordered in 1981, now costs \$283 million a copy in 1986 dollars.²⁰ Many of the cost increases and overruns are due to technology changes that are attempted to be incorporated after the aircraft has entered production. The focus now is on low cost options that may not incorporate all the latest technologies, but that do a cost effective job of performing the mission.

18. Lear Avia, data provided in sales literature, 1981.

19. Bright, The Jet Makers, 1978, p. 150.

20. Beazley, The Wall Street Journal, March 21, 1986, p. 9.

Compounding the cost problem is the long lead times for development and the long time required to reach a point of economic return. A production run of 700 medium size aircraft can take almost 12 years to reach the break even point for the manufacturer, as shown in Figure 17.²¹

Secondly, the changing nature of air travel is affecting the way aircraft are used. Twenty years ago air travel was not as commonplace as it is today. The most dramatic change came in 1978 with the deregulation of the U.S. airline industry. During the era of regulation short-range jet transport was traditionally subsidized by the longer routes, with the Civil Aeronautics Board controlling the level and degree of subsidization. The termination of regulation removed the artificial distortion of the market, lowered the barriers to entry and opened the door to new routes, new carriers, and unprecedented competition and flexibility in fares and services. Figures 18 and 19 show the detrimental effects that deregulation had on break even load factors and profits for major airlines.²² The number of airports serviced as well as the number of certified air carrier was also

21. The Competitive Status of the U.S. Civil Aviation Manufacturing Industry, 1985, p. 59

22. The Competitive Status of the U.S. Civil Aviation Manufacturing Industry, 1985, p. 39, 41.

abruptly affected as shown in Figures 20 and 21.²³ These changes in the airline industry had a pronounced effect on the size, type, and performance of the aircraft that are desired. Entire fleet structures had to change overnight. Technologies that offered attractive tradeoffs in 1977, did not offer the same tradeoffs in the deregulated market. The optimum portfolio of technologies shifted and became more segmented as the route structure became more segmented.

Another external perturbation in the technology tradeoff was the dramatic change in fuel prices. With the Arab oil embargo of 1973, aviation fuel costs increased rapidly and fuel consumption became a very important parameter in forming a technology portfolio. In fact this parameter caused Eastern airlines to organize its fleet structure around this parameter and incur massive debts to modernize its fleet with new fuel efficient Airbus 300s and Boeing 757s and 767s. In recent months the price of fuel has reversed itself in just as dramatic a fashion as the increase was. The net effect has been to have airlines and manufactures focus strategically on the tradeoffs between technology, performance and costs. The external environment has forced top managers to take the portfolio approach when investing in new technologies or new combinations of technologies.

23. The Competitive Status of the U.S. Civil Aviation Manufacturing Industry, 1985, p. 32-33.

The final reason for increased concern for the tradeoffs of a portfolio of technologies is the increased specialization of aircraft in both military and civilian uses. No longer does one aircraft attempt to meet all the needs as the DC-3 or the F-4 did, and the F-111 and Electra attempted to do. In the military, special aircraft with unique performance parameter tradeoffs are being developed to accomplish specific missions. Many of these aircraft use older technologies that combine well with other new technologies to make an effective total package. In the commercial and business market the same thing is happening, aircraft are being produced and sold that do not have all the latest technologies but have advanced versions of older technologies that combine in such a way as to be very efficient for their market segment. The commercial market is undergoing increased segmentation further compounding the specialization by aircraft manufactures.

CONCLUSION

The portfolio model of technological development is a very useful tool to explain the unique way old and new technologies are combined in the aircraft industry. Some technological changes encourage the status quo and reinforce the current portfolio of technologies, while other advancements cause a shift in the portfolio. The portfolio shifting advancements are the

most significant technological advancements and are often the result of improvements in several technologies combined with external factors that aggregate together to cause a reevaluation of what is the optimum mix of performance characteristics. However, the ramifications of this concept extend beyond the aircraft industry and are applicable in other technology intensive, rapidly changing industries that involve the incorporation of a wide spectrum of technologies into one relatively large package. Other applications where the portfolio model of technological advancement may provide insight includes; the nations air traffic control system, satellite communications and positioning, strategic defense systems, and computer networks. On a smaller scale technological changes in the automobile and personal computer industry show evidence of portfolio shifting and portfolio reinforcing changes. Individual technologies may diffuse and substitute or be substituted for, but the proliferation of these technologies depend on how they fit into the overall portfolio of technologies.

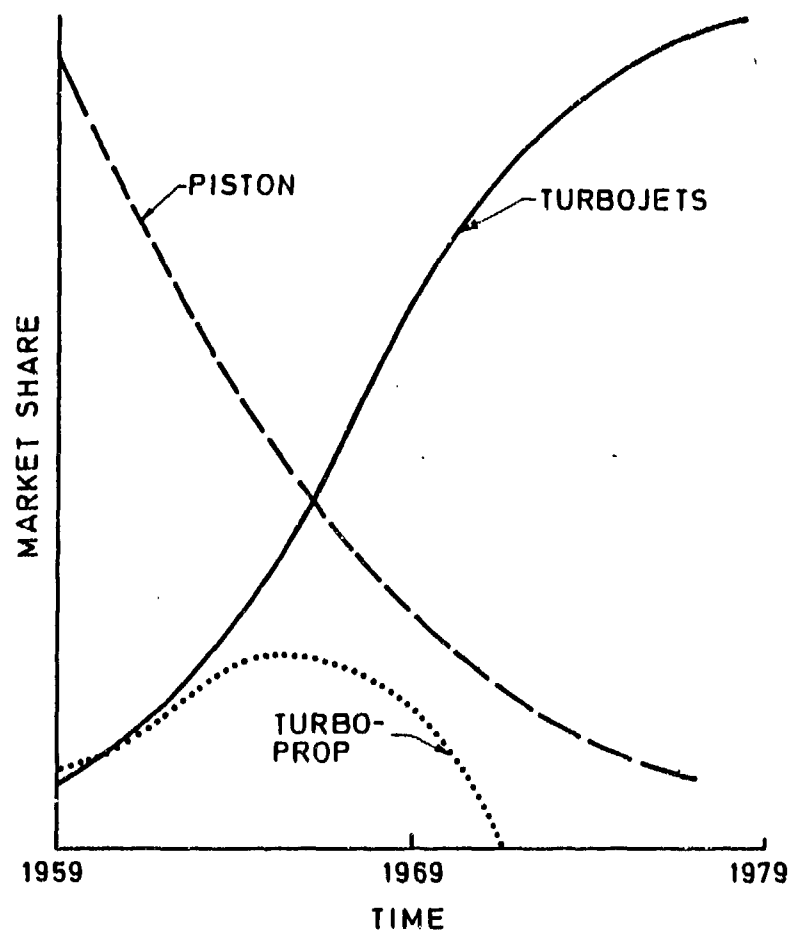


FIGURE 1. Market Share of Aircraft Engine Technologies

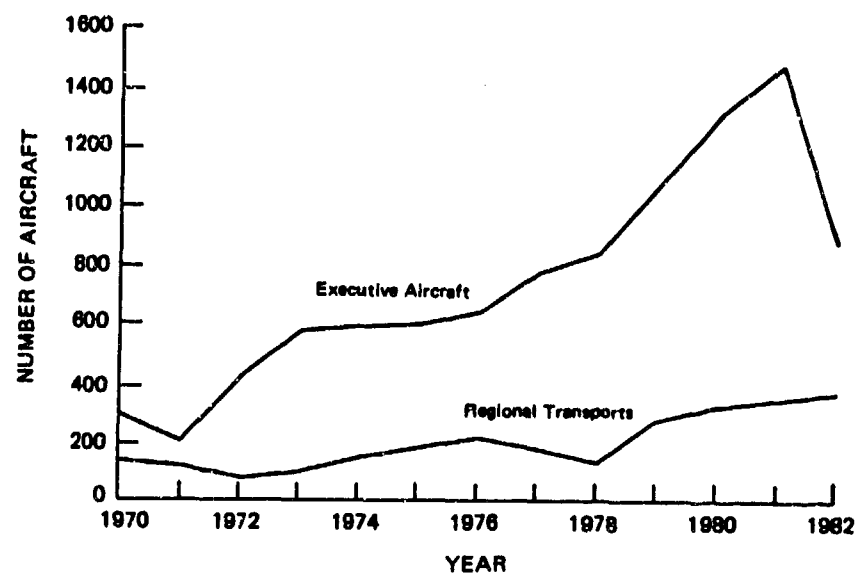


FIGURE 2 Shipments of Regional Transports and Executive Aircraft (turboprop and turbofan), 1970-1982

SOURCE: Garrett Turbine Engine Company.

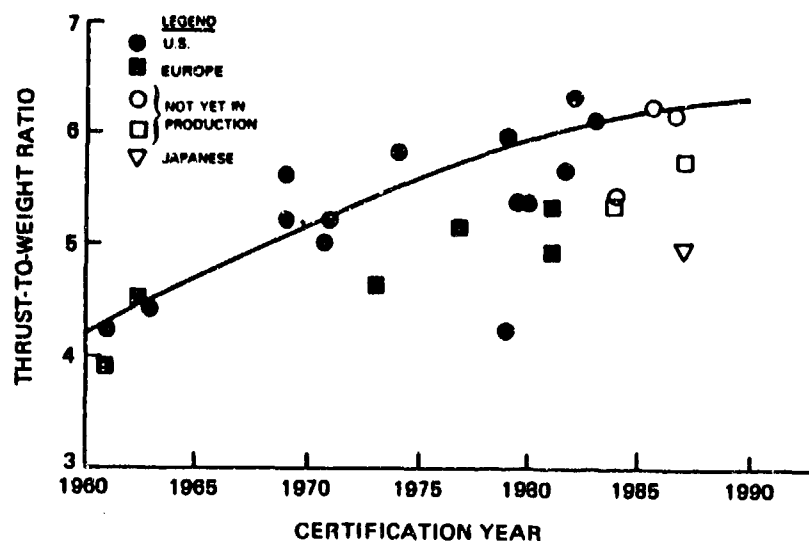


FIGURE 3 Commercial Transport Engines--Thrust-to-Weight Ratio (manufacturer's quoted performance)

SOURCE: Pratt and Whitney, from data supplied by manufacturers.

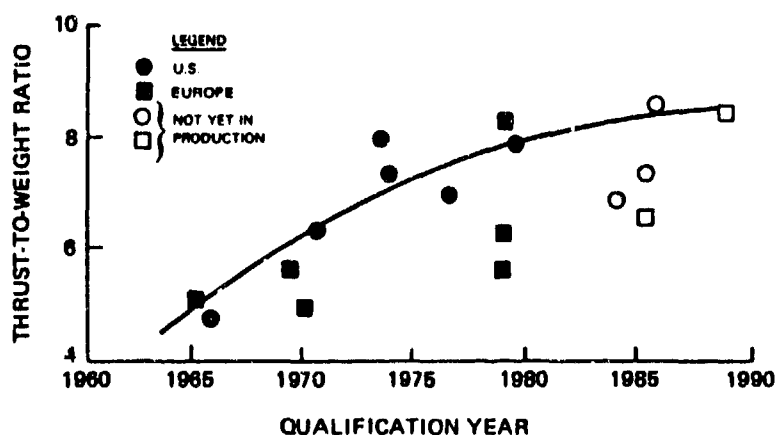


FIGURE 4 Military Engines--Thrust-To-Weight Ratio (manufacturer's quoted performance)

SOURCE: Pratt and Whitney, from data supplied by manufacturers.

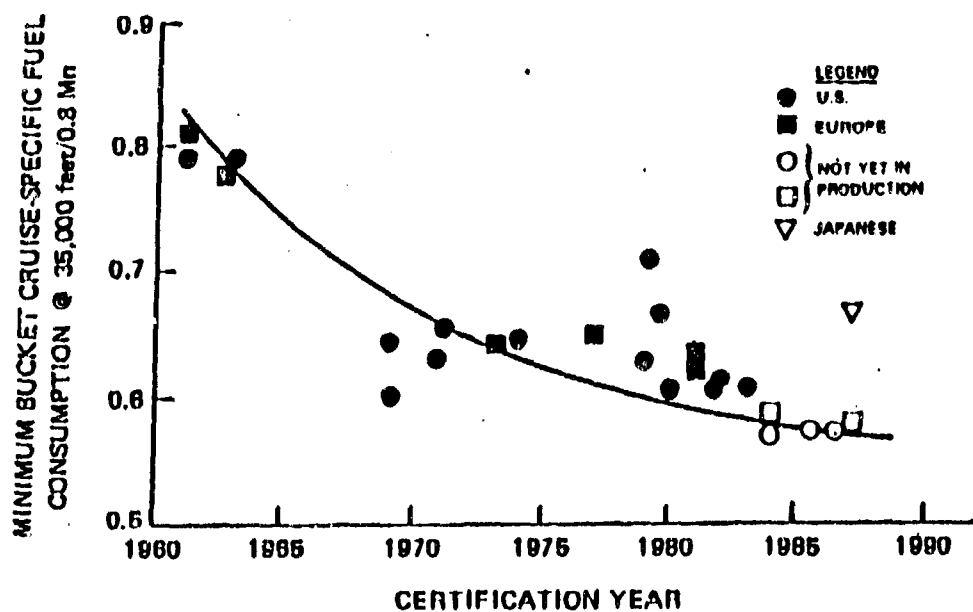


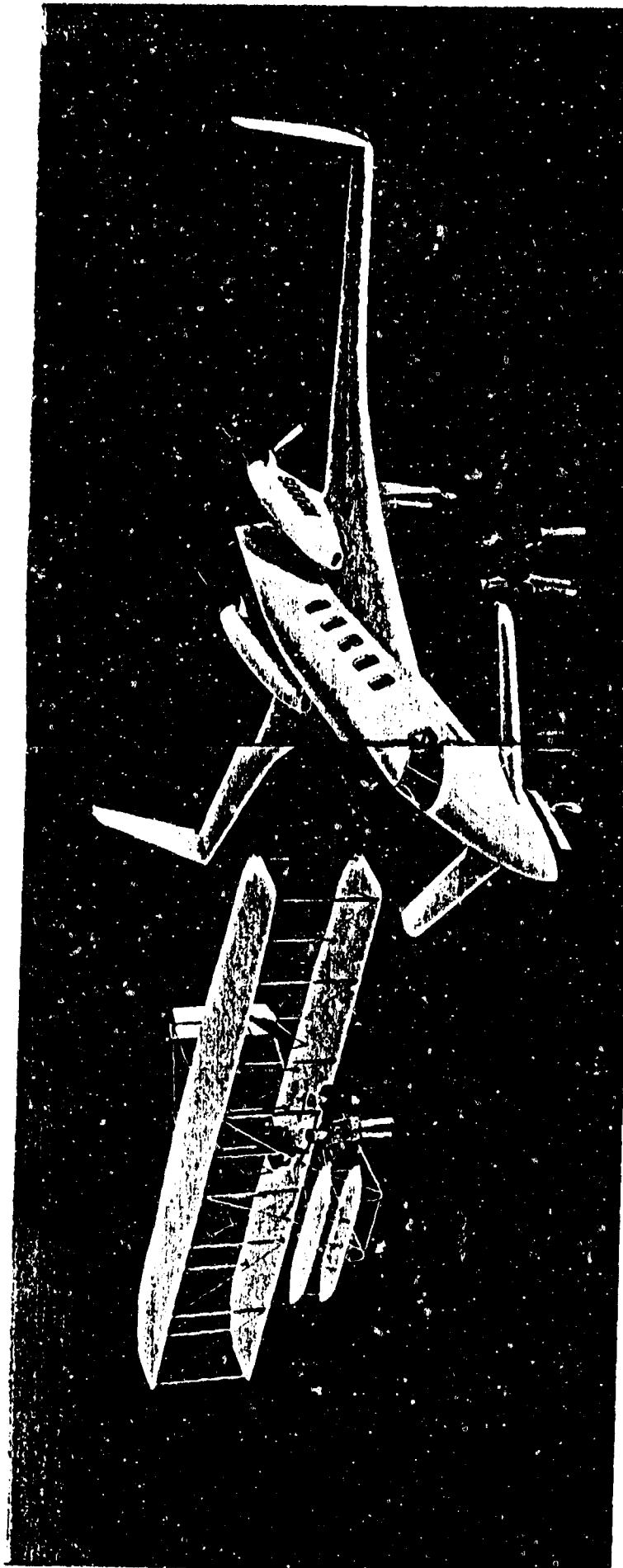
FIGURE 5 Commercial Transport Engines--Cruise Specific Fuel Consumption (manufacturer's quoted performance)

SOURCE: Pratt and Whitney, from data supplied by manufacturers.

Estimated Deliveries of Newly Produced Aircraft to Domestic Trunk Carriers, 1936-1941.

<i>Year</i>	<i>Total Deliveries of New Aircraft</i>	<i>Deliveries of Particular Types</i>						
		<i>DC-3</i>	<i>L-10</i>	<i>L-12</i>	<i>L-14</i>	<i>L-18</i>	<i>Beechcraft 18</i>	<i>B-307</i>
1936	42	29	10	3	—	—	—	—
1937	54	47	—	—	6	—	1	—
1938	24	21	—	—	3	—	—	—
1939	41	40	1	—	—	—	—	—
1940	112	95	—	—	—	12	—	5
1941	36	35	—	—	—	1	—	—
Total	309	267	11	3	9	13	1	5

FIGURE 6



History repeats itself.

Look at Starship 1 and you glimpse the future taking flight. But with a hint of the past. For the spirit of Kitty Hawk lives in this bold new aircraft from Raytheon's Beech Aircraft Corporation.

Note the twin engines at the rear that produce a whisper-quiet interior. And the forward wings for added lift and stability. Both features reminiscent of the Wright brothers' first plane.

But there the similarities end. Because Starship 1 is a product of advanced technologies. Computers helped shape it from composite material that is light, and far stronger than aluminum.

So it carries up to ten passengers at near-jet speeds but with far greater fuel economy. By combining new technologies with the fundamentals of aerodynamic design, we have created an aircraft truly ahead of its time. Starship 1... further evidence that at Raytheon, quality starts with fundamentals.



Raytheon

For our new corporate brochure, write Raytheon Company, 141 Spring Street, Lexington, MA 02173.

FIGURE 7 Starship Advertisement

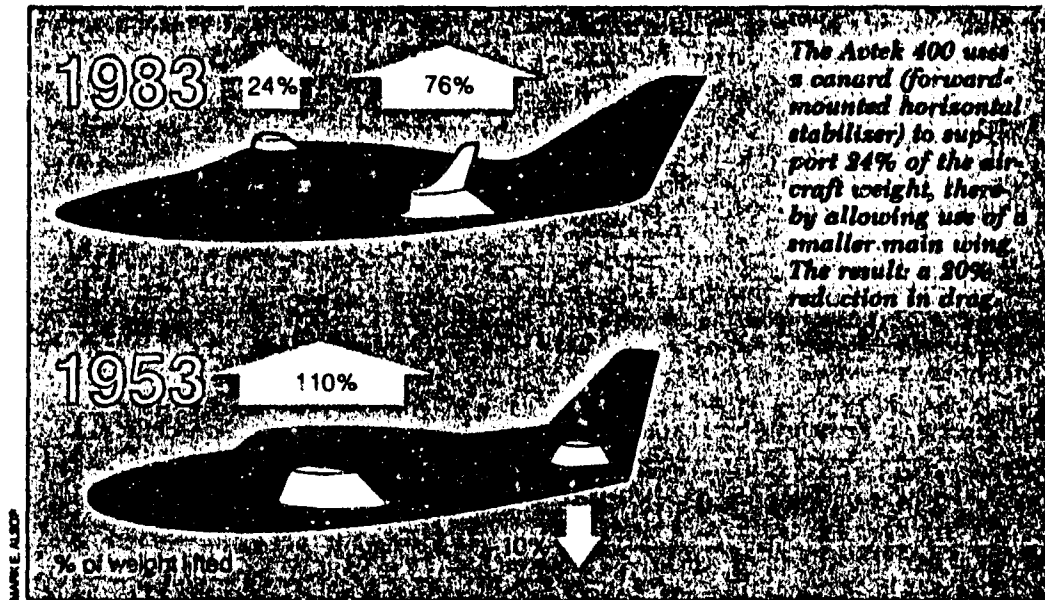


FIGURE 8. Canard on the Avtek 400

LEAR FAN TECHNOLOGY DEVELOPMENT PORTFOLIO

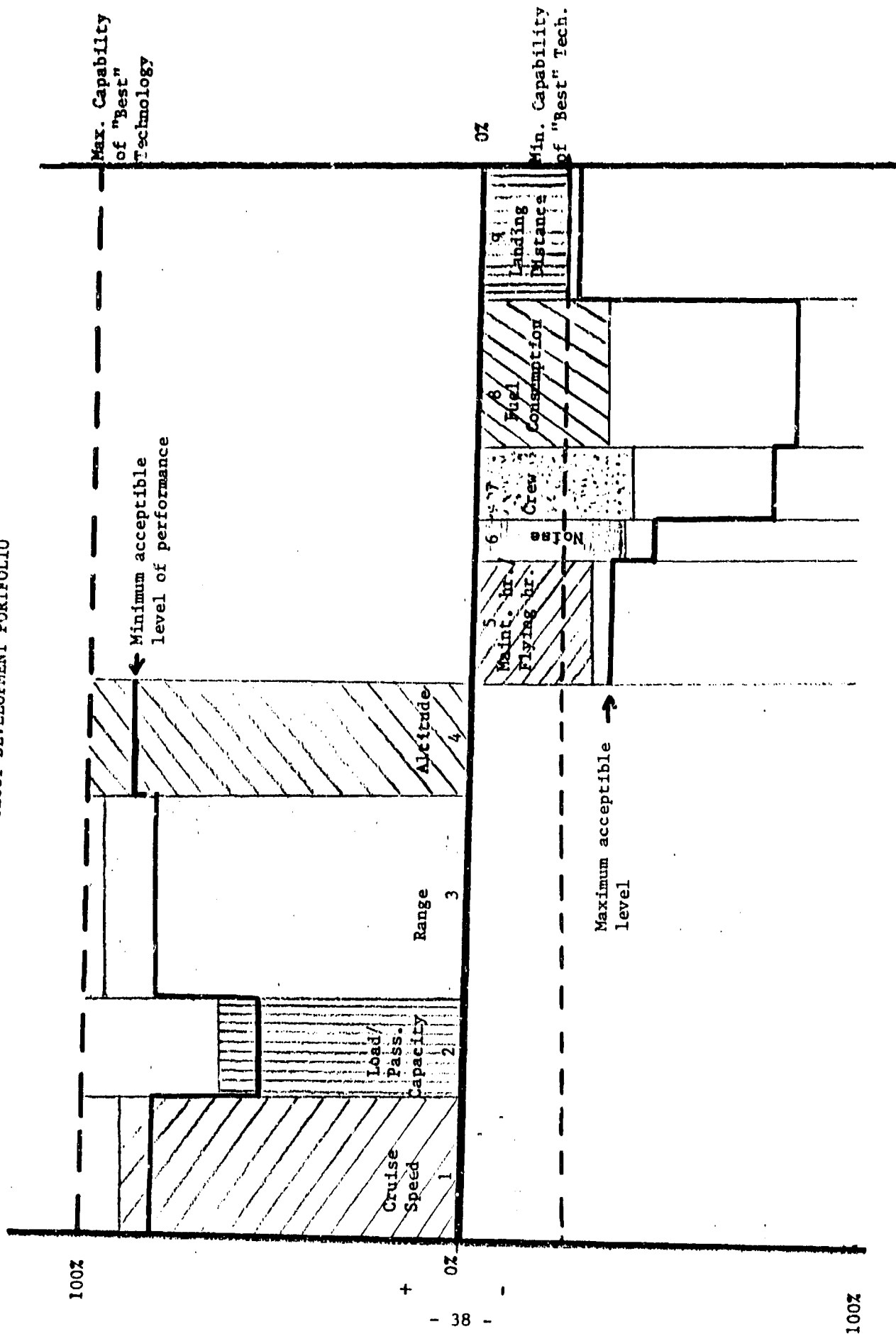


FIGURE 9

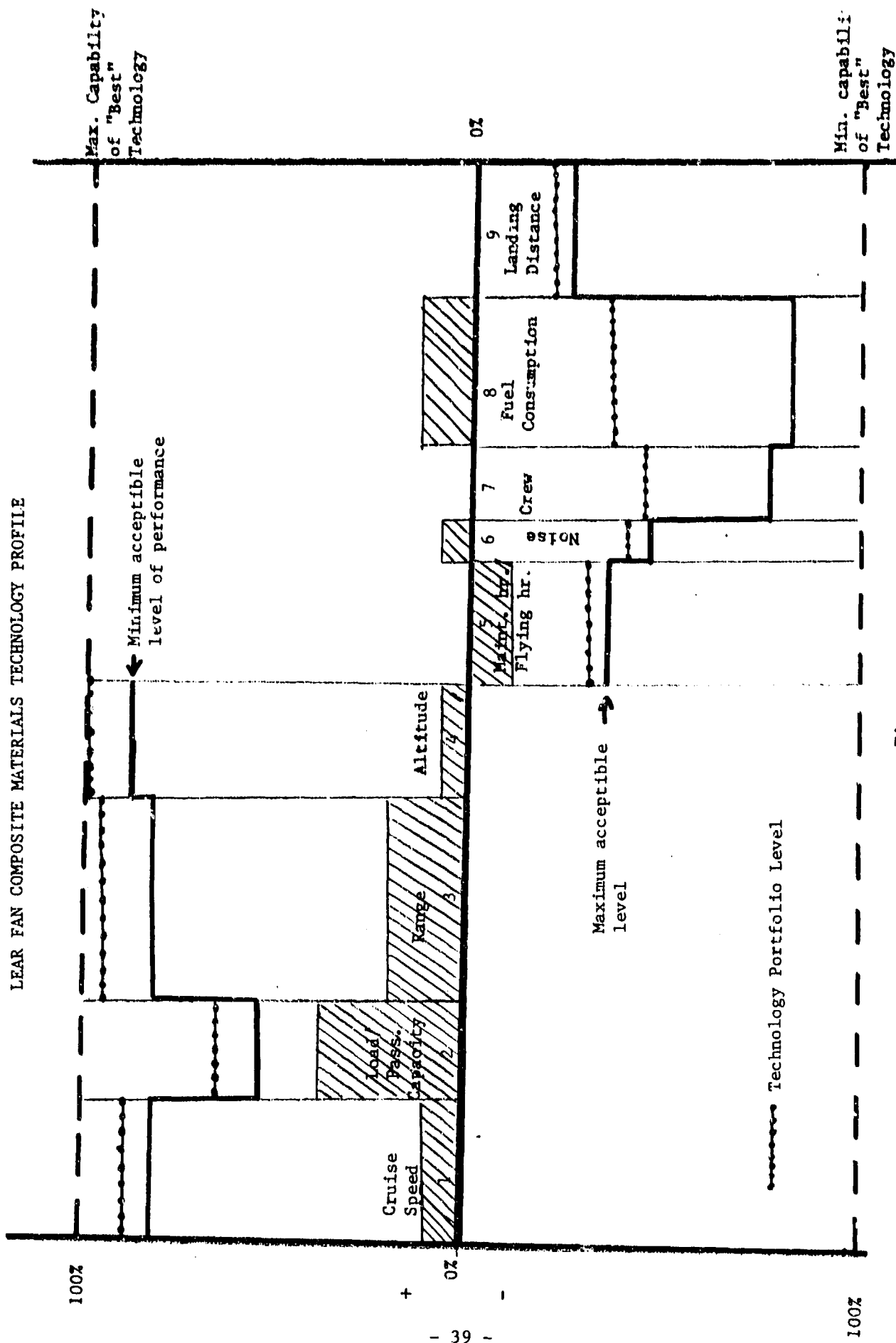


Figure 10

LEAR FAN TECHNOLOGY PORTFOLIO
PARAMETER #1 - CRUISE SPEED

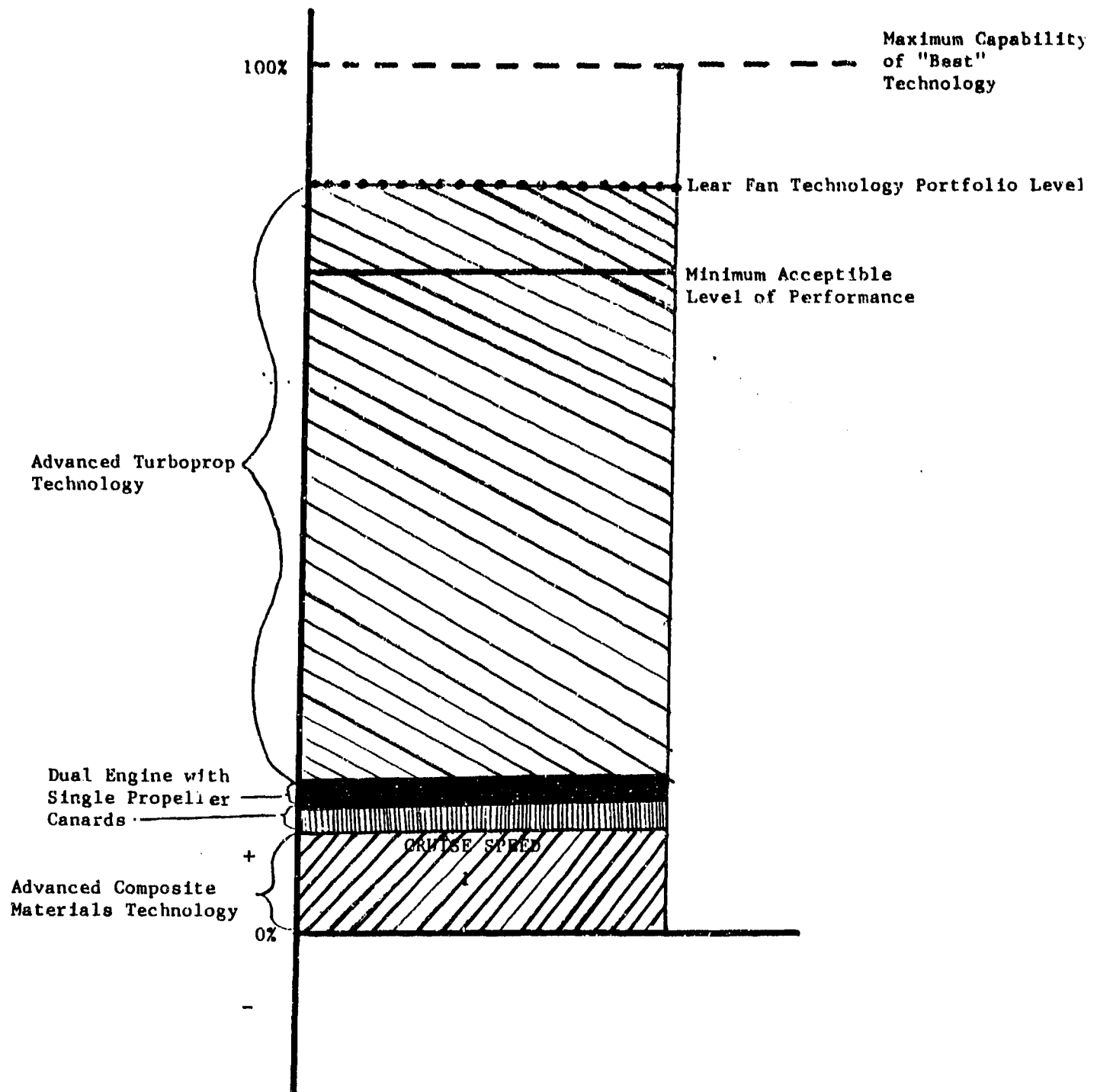


FIGURE 11

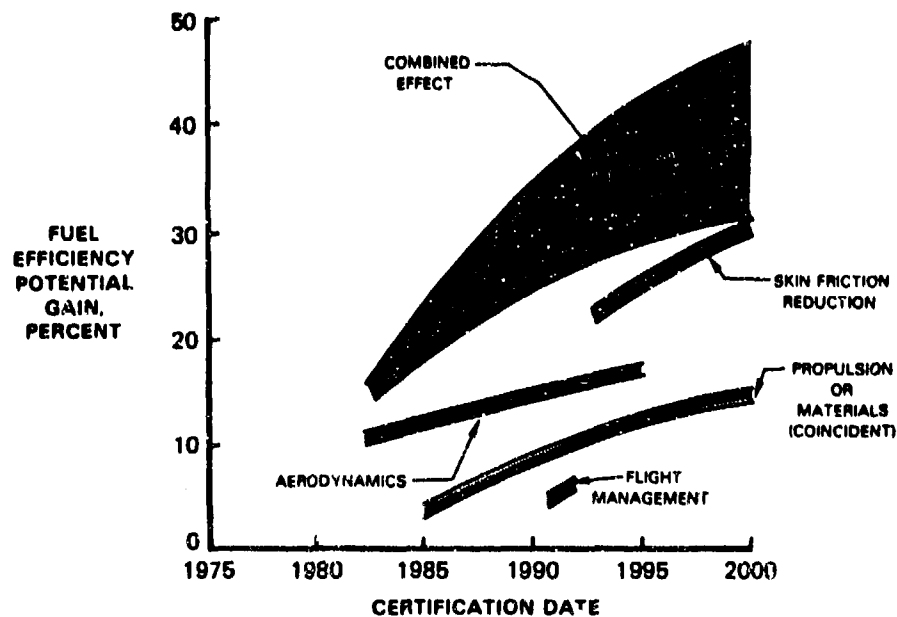
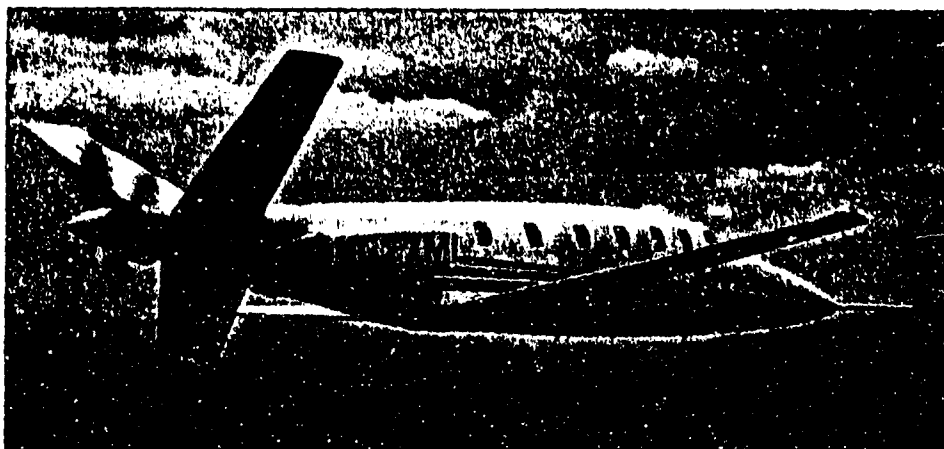


FIGURE 12 Benefits Possible From Technology Improvements

SOURCE: Derived from NASA Technology Program for Future Civil Air Transports; H.T. Wright, Aerospace Industries Association of America, International Air Transportation Conference, June 1983, Montreal, Canada.

The Lear Fan's pusherprop is powered by two jet engines buried in the tail to reduce drag. The underslung vertical stabilizer protects the propeller on takeoff or landing.



SOURCE: Richard DeMeis, "Business Aircraft: Sleeker Turboprops Take Wing", HIGH TECHNOLOGY, Oct. 84

The Avtek 400's canard is mounted above the cabin, affording the pilot a clear view forward and downward. The winglets streamline air flowing around the wingtips and thereby eliminate drag-inducing turbulence.

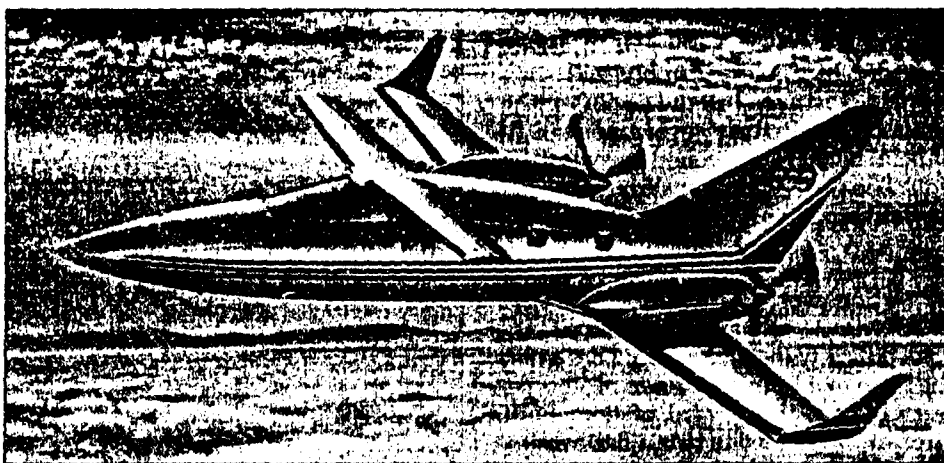
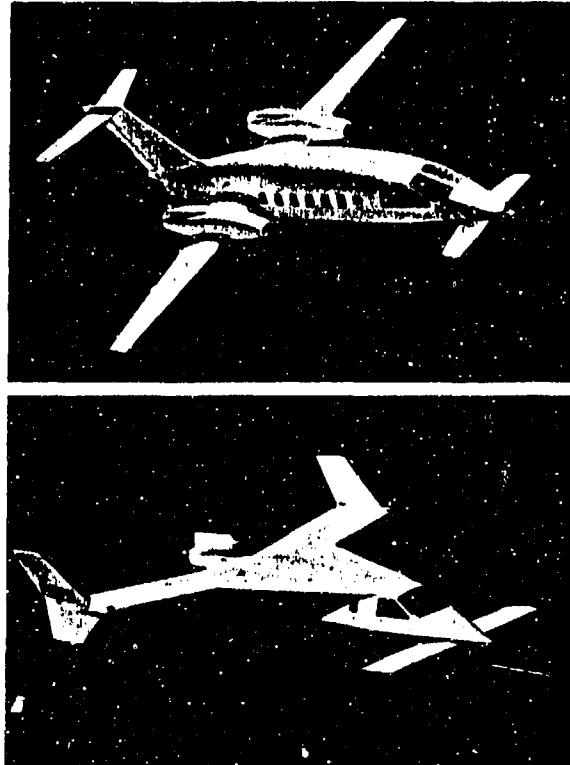


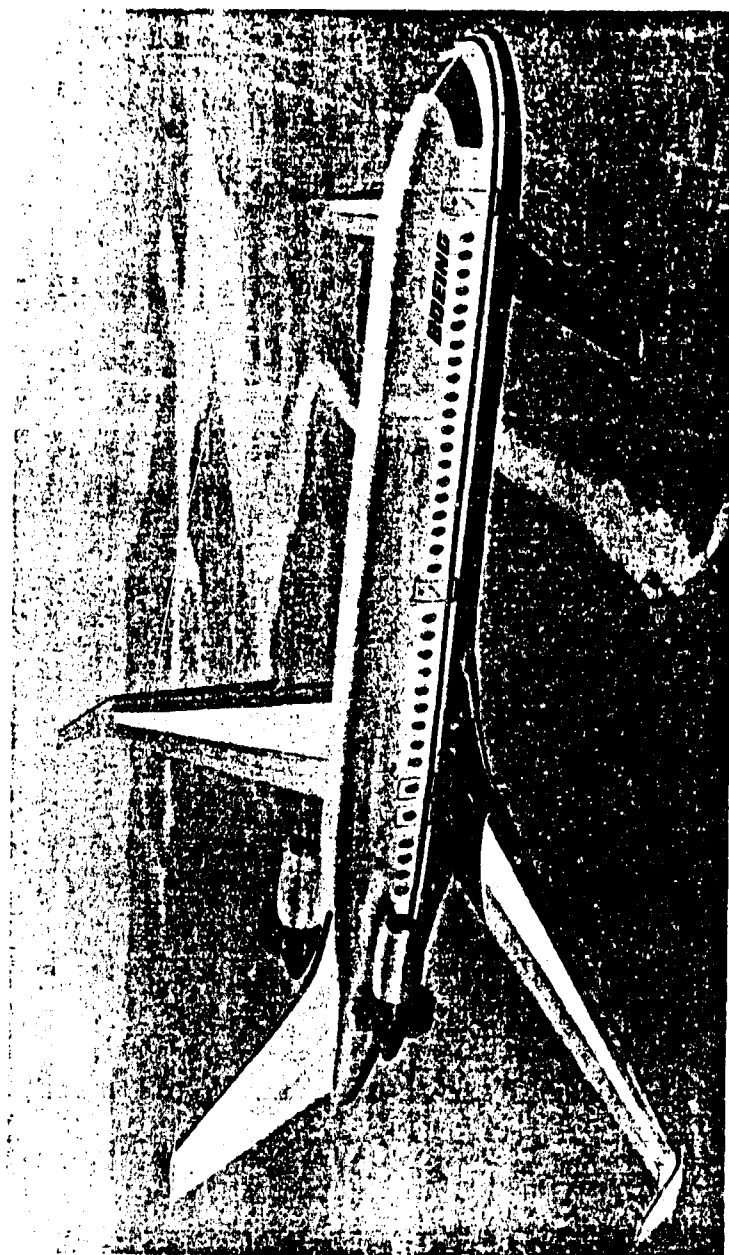
FIGURE 13 Advanced Turboprops



The Gates-Piaggio GP-180 (top) employs composite materials sparingly. The OMAC Laser 300 (bottom) is even more conservative: It is all aluminum.

SOURCE: Richard DeMeis, "Business Aircraft: Sleeker Turboprops Take Wing", HIGH TECHNOLOGY, October 84

FIGURE 14 Advanced Turboprops



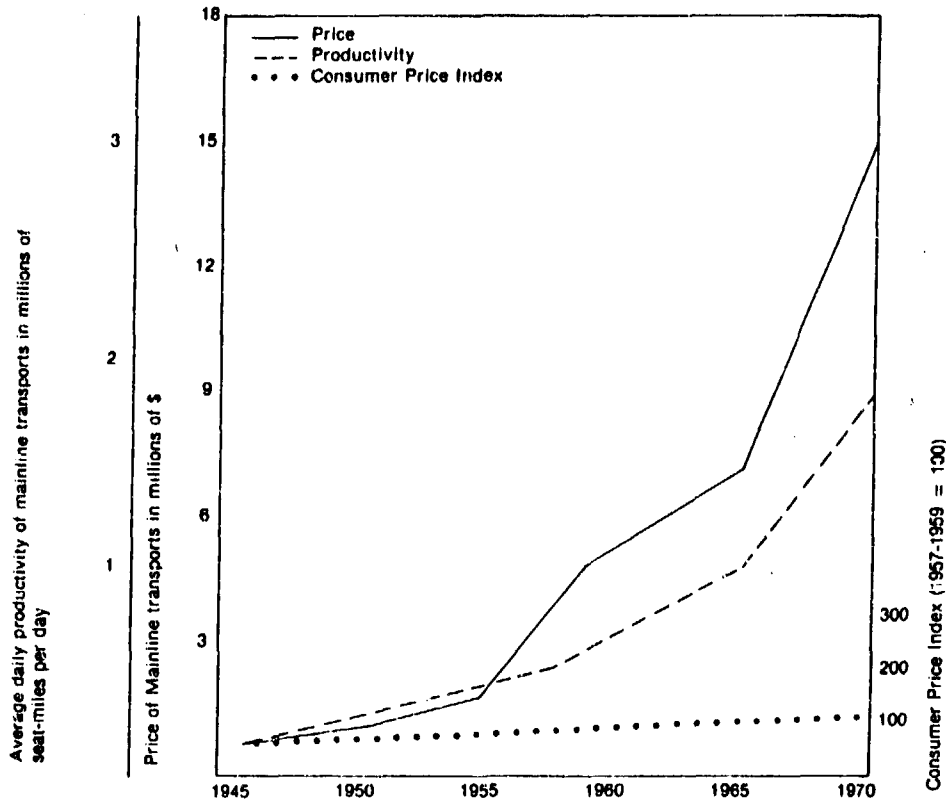
Type of advanced technology that Boeing is exploring for application to an early 1990s transport aircraft is depicted. The company emphasized that the design features—a large canard surface, pusher-type prop fans, winglets—are only possibilities. The body cross-section also has

not been determined; Boeing is discussing this with the airlines. While referred to as a 150-passenger transport, Boeing officials said the aircraft will be designed with the flexibility to meet a range of airline requirements from as few as 120 seats to as many as 200.

SOURCE: Richard G. O'Lone, AVIATION WEEK AND SPACE TECHNOLOGY, February 18, 1985

FIGURE 15 Advanced Transport Technology

**COMPARISON OF GROWTH IN AIRLINER PRICES, PRODUCTIVITY, &
THE CONSUMER PRICE INDEX**



*1970 point estimated on productivity.

Sources:

Airliner prices from *Aviation Week* and *Wall Street Journal*.

Airliner productivity from *Aviation Week*, Jul. 11, 1966, p. 109.

Consumer Price Index from *Economic Almanac, 1967-1968 Business Factbook* (New York: Macmillan, 1967) and *The World Almanac and Book of Facts* (New York: Newspaper Enterprise Assn., 1973).

FIGURE 16

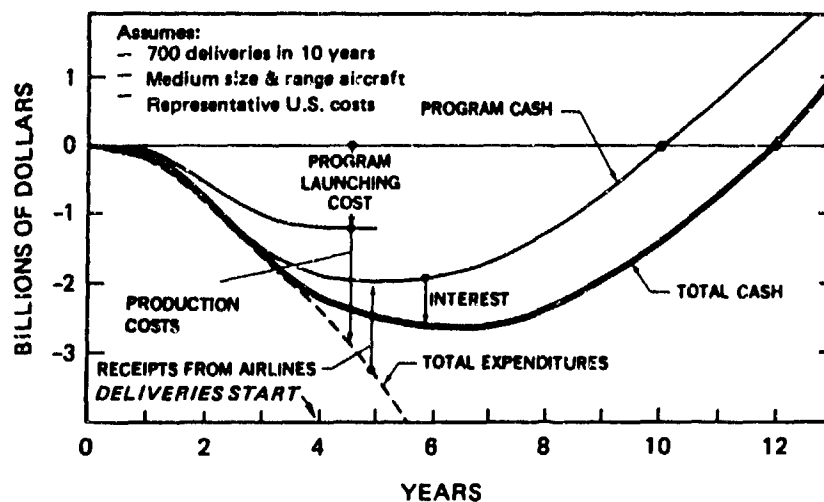


FIGURE 17 Typical Cash Flow Curve for Large Transport Aircraft Program

SOURCE: International Competition in the Production and Marketing of Commercial Aircraft, Boeing Company, March 1982. Based on curve from "Long Range Needs of Aviation," a report of the Aviation Advisory Commission, January 1983.

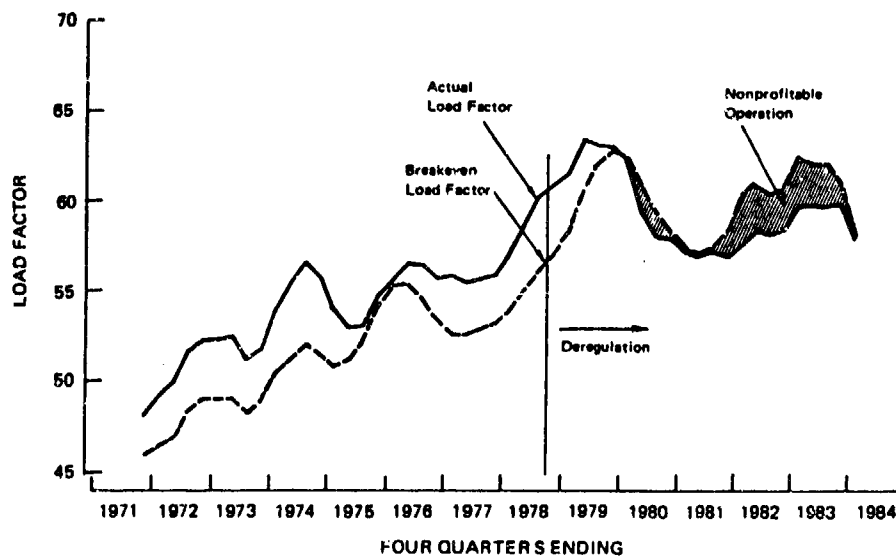


FIGURE 18 Load Factors and Breakeven Points of Major Airlines Before and After Deregulation

SOURCE: Derived from Civil Aeronautics Board data.

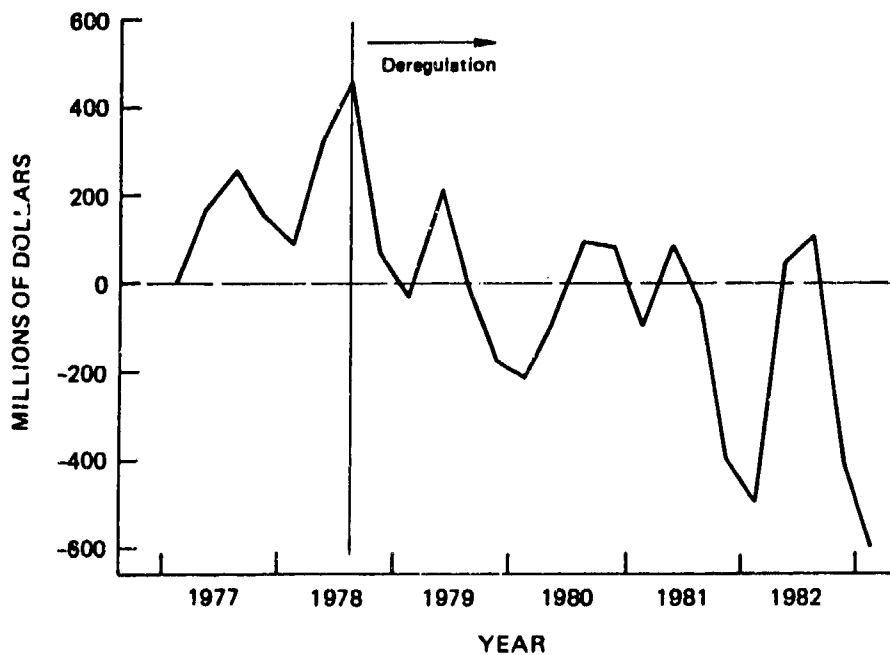


FIGURE 19 Domestic Operating Profit of the Major Airlines Before and After Deregulation

SOURCE: Civil Aeronautics Board.

FIGURE 20. Airports Served by Regional and Major Airlines, 1978 Versus 1982

	1978	1981	1982	% Change 1978-1982
Airports served				
Regional/Commuters	630	766	817	+30
Major/Nationals	673	389	323	-52
Exclusive airports served				
Regional/Commuters	359	504	566	+58
Major/Nationals	230	80	49	-79

SOURCE: Fairchild Industries, Inc.

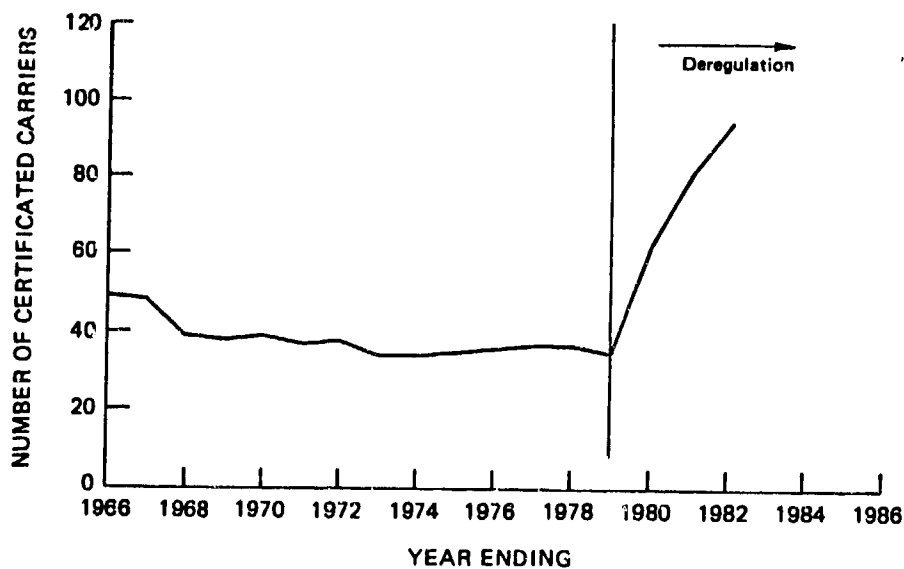


FIGURE 21 Number of Certificated Carriers Before and After Deregulation (Civil Aeronautics Board documentation of air carrier traffic statistics for September of each year)

SOURCE: Civil Aeronautics Board.

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