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How Decisions Are Made
Major Considerations for Aircraft Programs

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Abstract

Aircraft programs, both civil and military, represent complex risk experiences. Success usually involves the attainment of a relatively long-term program to achieve efficient production volumes; this in the face of a constantly changing set of market conditions, competitive actions and technological alternatives. Key decision points are identified, and risk variables in finance, technology, management, and market readiness explored. Decisions are noted that can leverage long-term potentials for success and others, that once made, may become irreversible in view of program cost penalties. The author draws on his involvements and observations of program decision-making over a 40-year career span and involving over a dozen programs. While most are commercial, several fundamental observations applicable to military programs emerge. The character of decisions and influences leading to program success or lack thereof are examined to find the lessons learned and to comment on the road ahead.

I. Introduction

Over 80 years ago, the Wright brothers made decisions that led to the historical successes that this lecture commemorates. It is a great honor for me to be asked to join those who, through the years, have memorialized the Wright brothers and the achievements they attained.

Aircraft programs, both civil and military, represent complex risk ventures that are accomplished in an environment of constantly changing market conditions, competitive actions, and technological alternatives.

World aviation is moving into a new, and, I believe, an even more complex era in which affordability and internationalism are becoming major influences. While some of the historical tenets of aircraft decision making will remain the same, some will not. The objective of this paper is to discuss some of the major factors that have affected past aircraft decisions, and to consider the changes that aviation's new era may imply for the coming generation of decision makers.

We'll approach this by noting the decisionary forces evident following World War II and the major changes thereafter. We'll review technical progress made and note its future extensions. Following this will be an examination of the decisionary forces in play on some past programs and in particular, key decisions that led to their success or failure. Since aircraft program success is highly dependent upon engines, we'll also examine these decisions and their forcing factors as well. We'll then examine the decisionary forces forming the new fleet of commercial aircraft and the track of lessons learned from program decisions, and note their implications with respect to the environment of the road ahead.

II. Post War Overview

Aviation progress, of course, has been immersed in a much greater matrix of time and events, outside the scope of this paper. However, it is important to highlight the environment following World War II, since it involved a period of achievement in military and civil aviation unparalleled in later times.

Aircraft was a natural for post-war development, and a product that could readily respond to civil markets as well as the continued military concerns triggered by cold war events. This period launched a number of military and civil derivative programs, such as the B-50 from the B-29 and the DC-6 and DC-7 from the wartime C-54. Each was an incremental refinement step furthering technologies developed or proven during the war. All new jet-powered military programs were also initiated, such as the F-86 and B-47. This rapid progress turned the 1950s into a bow wave of advancements as this decade saw some 17 major military programs started plus an even larger number on the civil side. The key decision drivers for their go aheads are summarized in figure 1, and they will stand as key drivers for program decisions made today.

Key Decision Drivers

- Market Needs (and Timing)
- Government Actions (and Priorities)
- Competitor Actions
- Technology Readiness
- Fiscal Considerations

Figure 1

Conditions at this time were, for the most part, favorable to the fostering of competitive program starts. There was a large domestic market need (military and civil) and a large industry in place that was backed by a high quality research infrastructure. By comparison, the highly innovative European industry was constrained. This period was largely an American event in scale...it highlighted U.S. domestic markets and competitions.

Europe's industry gradually recovered and, over the following decade, laid the ground work for the many cooperative European developments that followed. Japan's aircraft industry, relatively constrained through this, has now emerged with credentials highly respected by both the U.S. and European industries. This, plus other new competitors and causative factors, has greatly changed the decision environment, as summarized in figure 2.

Changing Decision Environment

- Design Orientations
- Development Costs and Risks
- Military and Civil Priorities
- Internationalism
- Affordability

Figure 2

New requirements and new advancements have obviously affected design orientations and design decisions. Costs, risks, and priorities are not the same worldwide, nor are the affordability values that are attached to them. U.S. priorities were revalued and this has precipitated a dramatic change in the technological fiber of the nation. Nevertheless, as figure 3 illustrates, government outlays for aircraft through this transition remained surprisingly stable.

Federal Outlays for Aircraft, Missiles, and Space FY1947-77

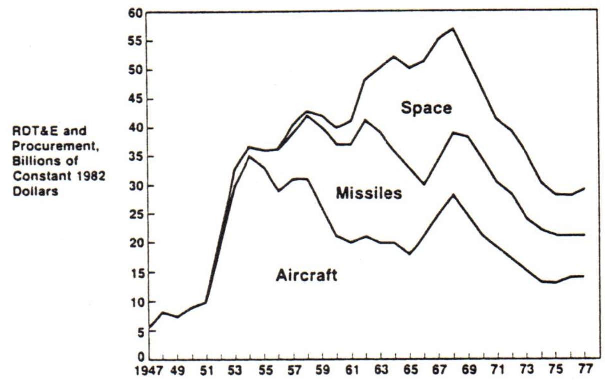
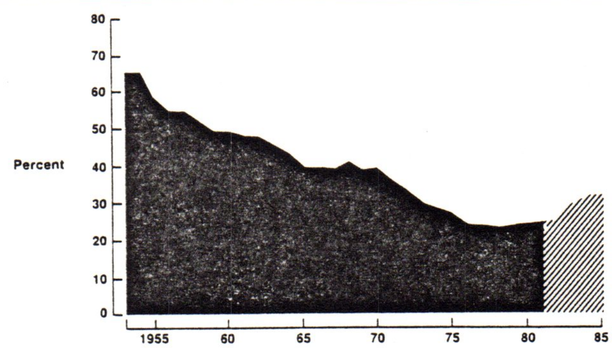


Figure 3

The downward trend that occurred in the late 1960s reflects a massive insertion for social spending with offsetting reductions in other government programs, including defense. The 40 year change in total defense outlays is shown in figure 4.

Defense Outlays: FY 1953 to 1985

(As Percentage of Federal Budget)



Sources: OMB: Budget of U.S. Government FY1978 through 1982; AIA

Figure 4

It should be noted that defense spending (in constant dollars) remained fairly stable, but total outlays increased steadily, thus reducing the defense percentage as shown. The reordering of national priorities has exerted a profound change on the momentum of U.S. aeronautical developments. Through the 1970s for example, new military program starts dwindled to a few, although paper competitions and false starts were many. Much of the advancement momentum was taken over by commercial industry developments. There was good reason for this because the growth realized in world air travel since the mid-1960s was beyond all earlier predictions. The history is illustrated in figure 5.

World Air Travel Growth
Scheduled Services

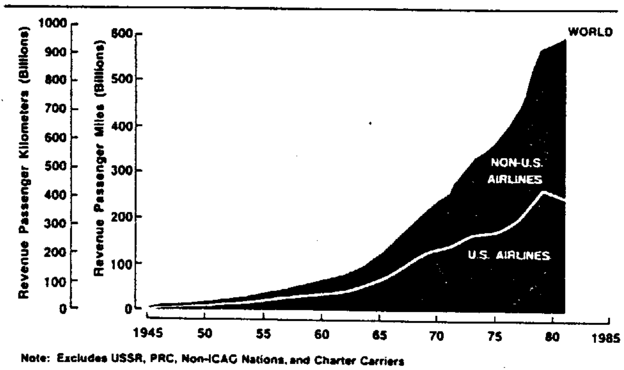


Figure 5

Figure 5 also illustrates the growing significance of the non-U.S. portion of the total world market. The technological achievements contributing to the creation and growth of air travel markets came from many nations to make air travel an affordable alternative, as illustrated by the air fare reduction history shown in figure 6.

Round Trip Air Fare
New York City-Los Angeles

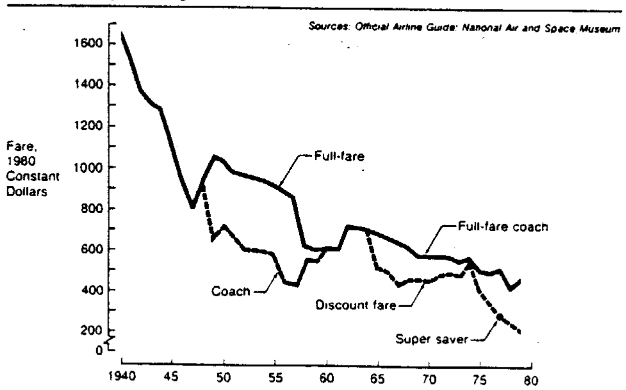


Figure 6

Our overview has shown that the U.S. maintained a healthy technological environment for some two decades beyond World War II. Since then, however, its pace slowed, and the advancement momentum in world aeronautics changed, reflective of the rapid expansions in Europe and Japan.

The pace and state of technology readiness is a major consideration in program competitions, as will be noted later. Therefore, we'll first examine the progress that has occurred in recent decades, and also the potentials that will form program considerations in the future.

III. The March of Technology

Technology decisions are relatively straightforward when the technology base is well understood, the development has been completed, the payoffs are clear and the risks are low. Such is not the usual case when new airplane programs are started or major airplane modifications undertaken. More likely is that competition will push the state of the art, shorten allowable development scheduling, and establish goals that strain credibility and involve considerable risk. It is essential that decisions don't repeat past mistakes but maximize the potential for the future.

You could ask...what causes people and organizations to strive for technology that could prove embarrassing to individuals or risk a company's existence. More and more technical advancement is demanded by the customer, forced by competition, or pressed by a public mandate to improve the environment. Other reasons are probably equally important and the pressures are inescapable. Therefore, goals and requirements must be clearly defined and understood by all participants before risk contracts are signed. Both the buyer and the seller can be seriously injured by overly ambitious dreams or impractical desires.

Aircraft technical advancements flow from many national sources and will continue to do so. The radar, jet engine, swept wing, and much of today's modern electronics are only a few examples of international contributions. Technical secrets are perishable with time, and since the period from discovery to validation and on through to application can take ten years or more, attempts to keep developments proprietary are mostly futile. It is more important that the developer make timely decisions in order to enjoy the advantage of one or more application cycles before outsiders acquire sufficient technical base to proceed with their own.

Trends

The most revolutionary advance in airplane productivity occurred virtually overnight with the introduction of the swept wing and turbojet engine. The resulting increase in speed and improvement in passenger comfort obsoleted the medium- to long-range propeller powered transports. In retrospect, the transition occurred with amazing ease to all concerned. Turbojet and turbofan engine developments have been among the biggest contributors to improvement in airplane efficiency. Figure 7 shows commercial jet engine specific fuel consumption to have decreased some 40 percent over the last 25 years.

Fuel Consumption Improvements

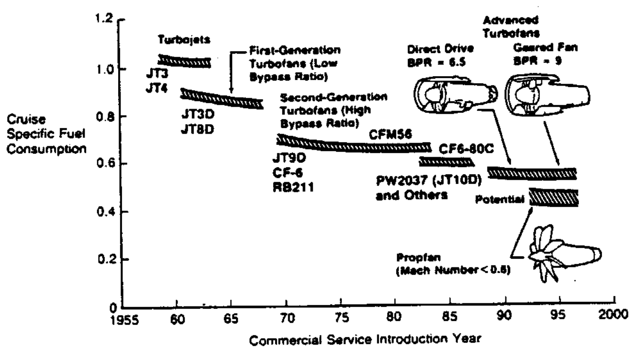


Figure 7

This phenomenal improvement occurred as a result of cooperative investments by both government and industry, but not without considerable pain to the users. Excessive parts replacement and high maintenance costs followed new engine model introductions when the validation periods were foreshortened. Further improvements in fuel efficiency are possible by using geared fans or, more radically, by eliminating the cowl through development of an advanced turboprop system. In these cases, adequate development and validation periods will become increasingly important and may require unreasonable investments.

Introduction of the turbojet engines caused a deterioration in the environment around airports. Since those early installations, progress in noise reduction has been continuous as shown by the trends on figure 8.

New engines are basically quieter than turbojets. Adding extensive acoustic treatment

Noise Reduction Trends

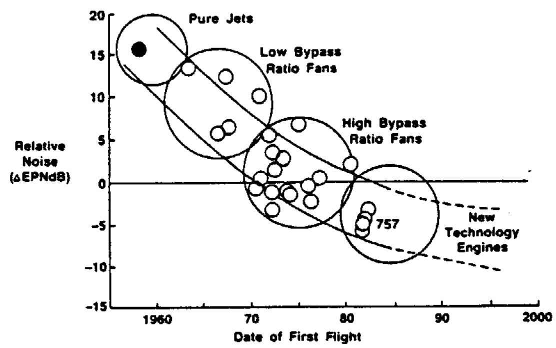


Figure 8

to the integrated nacelle-engine power package has further reduced community noise to the point where public outcries have largely subsided, or will as normal replacement occurs. This has been a painful problem to the aviation industry. Any further technology decisions that have environmental side effects must reckon with public opposition.

The progress in subsonic aerodynamic design over the past several decades has been significant but is more difficult to describe than the improvement in engine specific fuel consumption. This difficulty arises from the fact that airplanes are designed to unique market objectives, and mission requirements will emphasize high and low speed aerodynamic design capability and structural weight trades in differing proportions. This tends to obscure the significance of a specific technology advance such as improvements in high Mach number airfoil design. A good example of the hidden value of aerodynamic progress surfaces if one tries to compare the aerodynamic cruise efficiency of L/D of the 747 relative to that of the 707-320. The significant progress in aerodynamic design technology achieved in the twelve year interval between these programs is concealed by the differing design objectives, most notably the higher 747 cruise speed, and the relative difference in fuselage size. In fact, the L/D of the 320B is actually four to five percent higher than that of the 747 at respective cruise design points.

One way of illustrating the progress in wing aerodynamic design is to examine the trend with time of relative wing weight and streamwise thickness ratio for hypothetical wings designed to a fixed cruise Mach number and span loading.

Figure 9 shows that progress in airfoil aerodynamic design has allowed a steady increase in wing thickness ratio which can be translated into significant wing weight savings.

Aerodynamic Progress

Constant Mach Cruise

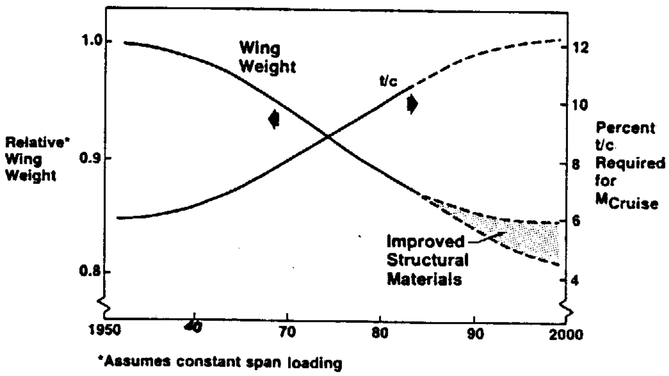


Figure 9

In actual practice there is a tendency to utilize the improvement in allowable thickness ratio to achieve a larger wing span for a given structural weight and to reduce wing sweep for improved low speed performance.

The next ten years offer exciting prospects for aircraft structural designers. New materials such as improved aluminum alloys and advanced composites are receiving widespread attention. A solid data base involving design standards and production techniques is being developed rapidly. If composite and aluminum-lithium structural materials are both successfully developed, a strong possibility exists for designing airplanes that would take maximum advantage of the properties of both. The potential for large structural weight savings is apparent in figure 10.

Future Structural Materials

Trend for Potential Weight Savings

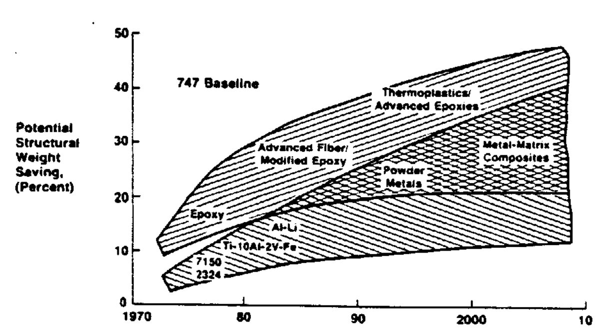


Figure 10

No technologies have advanced as fast as those associated with the electronic industry. In fact, the world expansion of electronic products is indeed revolutionary with no real end in sight.

In the aircraft industry these technologies have been introduced gradually in an evolutionary manner, although digital avionics did take one giant step with the 767/757 flight management systems. The development work to validate airborne applications takes time. For example, the present electronic flight deck displays were initially developed and tested for our SST back in the late 1960s.

Additional systems are becoming available that complement the work accomplished to date. Over the next ten years, for example, we will see increasing applications of fiber optics, flat panel displays, and electric controls, as shown in figure 11.

Avionic System Evolution

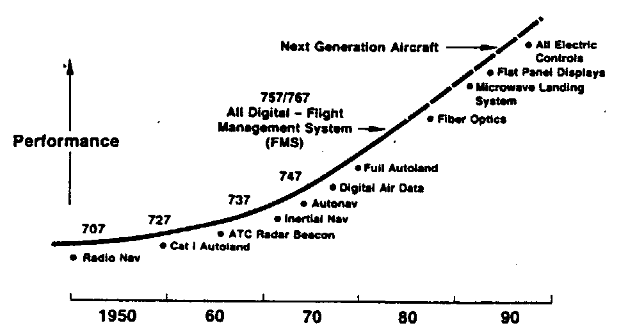


Figure 11

All must be carefully integrated into an efficient, high performance, low risk system. Premature introduction of a digital multiplex passenger accommodation system in the 747 created major situations of inconvenience and annoyance. The system simply wasn't ready. Fortunately, it was not a flight critical system, and safety was not impaired. It is of paramount importance that "flight critical" items such as electronic flight controls be technically ready when put into production.

Throughout commercial air transportation history, designer attention has focused on the "critical mass" of technology that is available for use. The critical mass is really a moving target, and its elements are usually evolutionary in their development and readiness. The next critical mass is now in formation with its roots incorporated as some of the improved efficiencies represented by our latest new airplanes. The relationships between these efficiencies and the aiming points of the next critical mass are illustrated in figure 12.

Aiming Points for New Technology Readiness

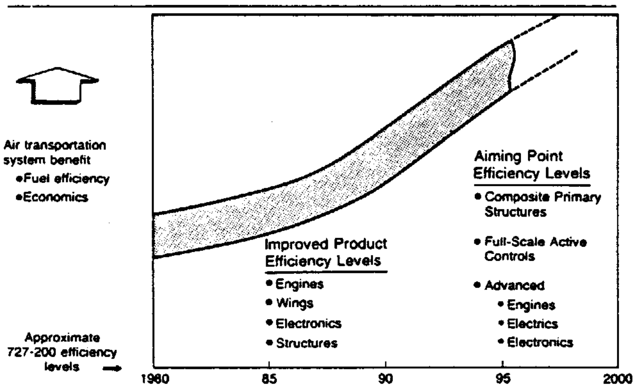


Figure 12

The 757 and 767, incorporating the improvements noted at the left of the figure, have a fuel mileage (seat miles per gallon) advantage over the 727-200 of over 50 percent, even after the effects of scale have been accounted for. The figure indicates that another major improvement of similar magnitude can occur during the decade of the 1990s. Beyond this are other major potentials such as boundary layer management and propfans.

As noted in figure 12, the aiming points will extend into the flight deck with a whole new relationship between the pilot and his aircraft. Control cables and the familiar yoke will disappear, and digitized voice technology can potentially reduce a large element of the communications workload. In their integrated product applications, the new efficiencies may represent a sizable advancement for aviation...perhaps the most significant that we've known since the marriage of the swept wing to the axial flow compressor. The timing of its eventual readiness will be influenced by the levels of effort applied.

Technology development passes through three phases that we sometimes refer to as Phases A, B, and C. Phase A is basic research. Phase B is the assembly of the body of technology until it can support actual use with acceptable risks. Phase C is application to a specific aircraft design. There are many words used to describe the three phases in the terminology of the Air Force, NASA, or others. Phase B tends to be the longest and most expensive. It generally includes a number of parallel actions over a number of years. For example, the increased use of composite applications in the newest airplanes is an evolutionary Phase B step which, along with other steps, will lead to Phase C, the actual use of a composite primary structure in a major commercial or military airplane. A part of the Phase B process is to develop the manufacturing technology required to commit a program to Phase C in this difficult affordability environment.

A good measure of overall technical progress in aviation is illustrated by figure 13.

Fuel Efficiency Trends

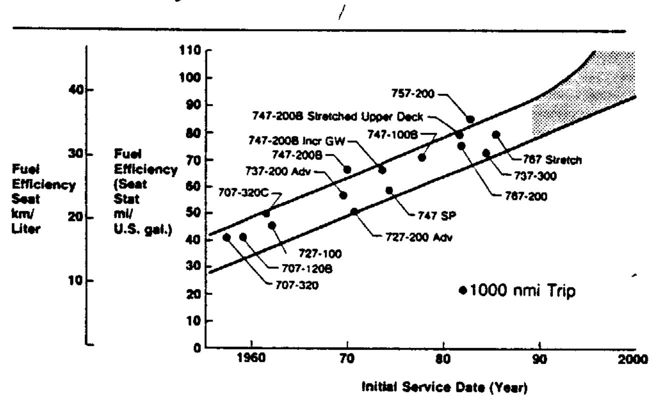


Figure 13

Airplane efficiency, in terms of seat miles per gallon, has increased almost *30 percent per decade* over the past 25 years. The individual technical trends just examined provide confidence that efficiency will continue to improve at this rate through the end of the century.

IV. Program Decisions Revisited

In our experience, we've seen that forces playing on aircraft decisions have frequently changed, often with little if any recognition or warning. Such circumstances can rapidly turn a seemingly sound program decision into a disaster...also, the reverse has happened.

Nonetheless, industry experience has shown a track of predictability through all this, and while not "golden," this track is useful when considering future decision environments that can be anticipated on the road ahead.

Much of this track, I believe, will be illustrated by the decisions and forces highlighted in the ten programs that we shall examine next. Of necessity, the coverage of each is brief and quite selective.

Boeing 377 Stratocruiser

The 377 Stratocruiser program was a post war commercial offshoot derived from the C/KC-97 series tanker/transports. Like the C-97 series, the 377 incorporated advanced systems that had been developed for the B-50 bomber. The lower portion of its double-bubble design was a B-29 circular cross section. The upper section was superimposed onto the lower as shown in figure 14.

Boeing 377 Cross Section

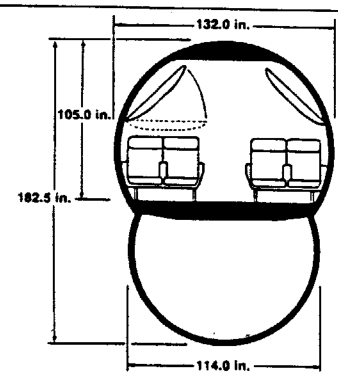


Figure 14

The illustrated design compromise yielded a narrow upper deck floor that proved to make five abreast seating virtually impossible. Similarly, it provided more height than necessary for the lower lobe. This in turn was used for the "lower deck lounge" extrapolation that amplified the airplane's luxury theme. The airplane in flight is shown in figure 15.

Boeing 377 Stratocruiser

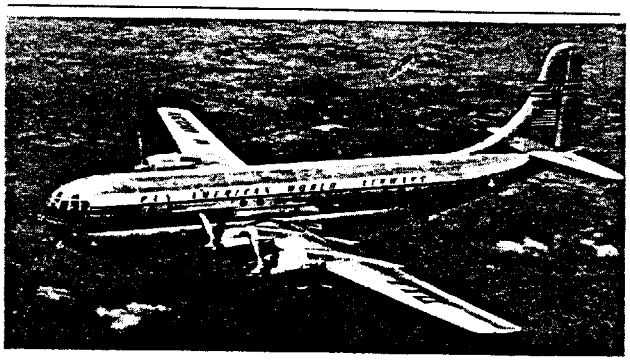


Figure 15

The Stratocruiser was a very large airplane with respect to its passenger capacities, which varied between 50 and 100 depending on route length and service class. Its R-4360 power plant represented the latest in piston engine technology, which at that time had been pushed to its limits with propeller combinations and super-octane fuels for added power gains.

The Pratt & Whitney R-4360 "corn cob" was a four row radial configuration of 28 cylinders. It had 112 spark plugs that were subject to very frequent fouling and change. In total it proved to be a complex and expensive engine, particularly during its introductory years.

The real problem, however, was not the engine but the propeller, particularly Hamilton Standard's. It incorporated new technology developments, which by today's standards, suffered from inadequate validation testing. The blades were constructed with an internal steel tube and a foam-filled external aerodynamic shell. Inspections to maintain airworthiness to commercial standards proved impossible, and most Stratocruiser accidents were due to magnesium housing fires or blade failures, with resulting imbalances that could tear off the engine. Pilots learned to fear the onset of any suspect vibration. In one such instance, a Northwest Airlines 377 was recovered after a water ditching in Puget Sound. Inspection revealed that in this case the propeller was blameless, and the feared vibration had been caused by cowl flaps left in full-open positions. Figure 16 summarizes the power plant difficulties.

377 Propulsion System Observations

- R 4360 engine an ambitious P&WA/Government program yielding higher thrust but lower reliability
  - No commercial experience
- Required major modification program to correct most engine performance and reliability deficiencies
- Hamilton Standard steel tube/foam core blade construction problems
  - Foam core delamination
  - Fatigue inspection difficult
- Implications of potential propeller blade fatigue were very serious
- Alternate propellers were available and were used in some cases

Figure 16

The Stratocruiser achieved a fine reputation for luxury but remained deficient in operating economics and power plant reliability. This led to an early production termination, and, of course, the program was a dismal financial experience for Boeing. I believe, of the many program decisions made, the following are of particular significance to this discussion.

1. The decision to proceed with a new airplane program with success expectations overly dependent upon luxury markets rather than operating economics. Thus, success was premised on premium fares and the higher-income travelers. The airplane could not stand up to competition of air fare reductions that were to become the real stimulants to U.S. travel growth.

2. In part, it could be said that the program's go ahead was justified as a means of holding a military design team together and also in providing that team commercial experience and presence in the post war era. However, it is doubtful that this could stand as a relevant consideration for a U.S. manufacturer today.

3. The Stratocruiser's power plant decisions suffered from use of technology that had not been sufficiently proven. More fundamental, however, was the fact that reciprocating engine technology had been extended *beyond* the limits of its operating efficiency to become overly expensive, complex, and unreliable. As such, this program describes a decision consideration that will remain highly relevant for decades.

B-52 Program

The B-52's concept was derived from the most significant advancement of post war aviation...the *revolutionary integration* of a swept wing with the axial flow compressor, achieved with the Boeing B-47. This development made the jet engine's potentials for high speed flight possible.

Thirty years after its initial flight, the B-52 remains the backbone of the nation's long-range bombardment capability. Almost 750 were produced, and the later models have been continuously updated since production ended in 1962. It is expected to remain a significant component of U.S. strategic forces, possibly into the next century.

The program was started as a large, straight-wing turboprop. It was to become the U.S. second generation long-range bomber, capable of carrying 10,000 pounds for 10,000 statute miles or, by Air Force rules, an operating radius of three-eighths of this (3,800 nautical miles) without refueling. By 1948, it became evident that the necessary engine and propeller for its mission were unavailable, and Boeing was hurriedly asked to provide the Air Force its concepts for a jet alternate. Figure 17 illustrates the evolution of the B-52 from that point into its jet-powered design.

Early Days of the B-52 Evolution

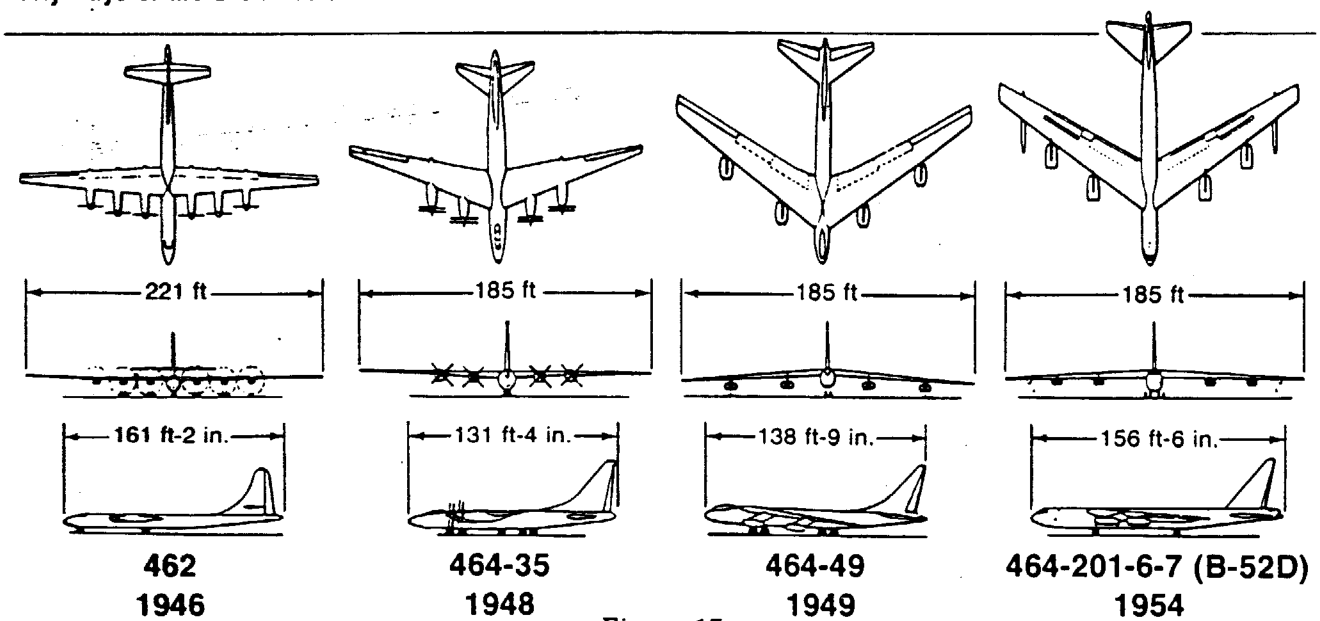


Figure 17

Boeing's successful work in developing the swept wing B-47 greatly encouraged the change, and really validated much of its concept. However, the B-52 involved other problems and the feasibility of proceeding with a jet configuration was also leveraged by the many rapid technological advancements made that were really unrelated to the B-52 objective, or for that matter, any specific design application objectives. One was the independent development of the J57 two-spool jet engine. The full significance of this to U.S. aviation is noted later. The main point, however, is that a new military engine was under development *before* its application was known. The timeliness of the earlier J57 start, of course, resolved the B-52's propulsion dilemma.

Similarly, aerodynamic advancements (unrelated to the B-52's needs) had occurred. Much of this technology readiness work was done by NACA, and much was Boeing's independent high speed airfoil work. Both were major contributors in providing the improved understanding of swept wing technology that was needed to support the jet bomber decision. Boeing's work, for example, had earlier revealed that the wing root could be grossly thickened without adversely affecting the high Mach number characteristics of the integrated airframe. This discovery, illustrated in figure 18, allowed the use of very long span wings on the B-52 without excessive wing weight.

B-52 Wing Thickness vs Span

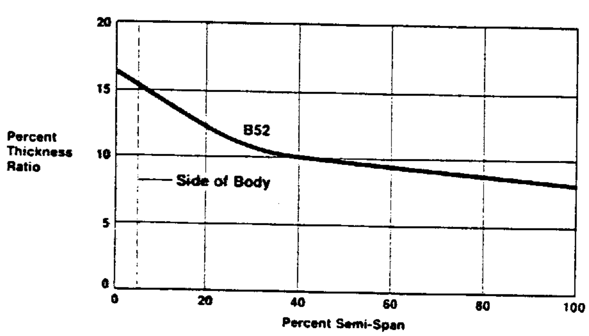


Figure 18

The program involved a prototype phase to validate the application of such advancements. There is much controversy today as to prototype cost-benefit relationships. Military acquisition methodologies of the time routinely included them, and the B-52 prototype cost in relationship with that of the total program is shown in figure 19.

B-52 Program History

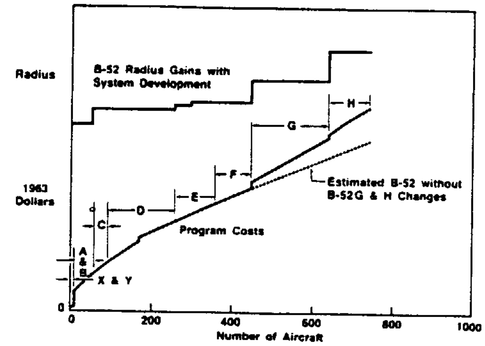


Figure 19

In terms of total program costs, the X and Y prototypes were insignificant. The B-52G and H series have been updated to incorporate a variety of offensive and defensive capabilities, including those shown in figure 20. In total, the airplane has exceeded its original design capabilities significantly and has been redesigned to perform missions for which it was never originally intended.

B-52 Program Phases

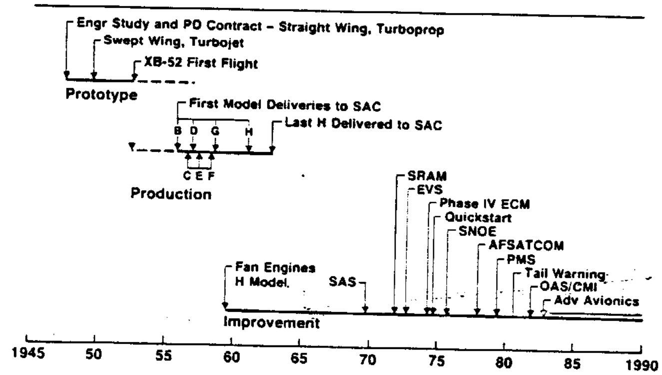


Figure 20

Improved capability costs have no doubt exceeded those of the initial development and prototypes several times over. Nonetheless, the total is probably far smaller than for production of an all-new airplane. I think the fundamental reason that the B-52 has remained in the Air Force's inventory plans for so many years is because of a fundamental change in the technological environment that was of its creation. With this in mind, the following decision points are illustrative.

1. The *then* acceptable government decisions that permitted funding of a new engine development with the intent of new technology readiness, but without specific applications defined. Similarly, the *then* acceptable decision environment that permitted the development of aerodynamic technology *and its validation* to the extent possible, again without the constraint of an audit track to a specific application.

2. The subsequent era of government decision making that has constrained the flow of aeronautical research to support the orderly and timely development of new advancement potentials. This started in the 1960s, at about the time the last B-52s were produced. Within a short span of years, NACA was recast into a different role, military research diminished and the nation has yet to achieve its third generation long-range bomber.

Lockheed Electra/Orion

The Electra program started as a four engine turboprop designed specifically for the medium and short range market beneath the 707 and DC-8. The go-ahead decision was made in 1955 in response to a requirement issued by American Airlines. First delivery occurred in October of 1958, the same month as the delivery of the first 707 commercial airplane. Although the Electra had some wing and power plant structural problems that bothered its early years, it developed into a technically successful commercial airplane. However, timing of the program was poor with respect to the emergence of the jets, and this would have been a financially disasterous program except that Lockheed cleverly exploited its broad product capabilities to use the airframe as an efficient naval surveillance platform. As the military Orion, the Electra has been in production since its first delivery in 1962. The combined program timings are shown in figure 21.

Lockheed has sold about 600 units, and the Orion is now also produced under license in Japan. The Orion military system in its various models was purchased by the U.S. Navy and also the military forces of Australia, Canada, Iran, the Netherlands, New Zealand, Norway, and Spain. The U.S. Navy version is shown in figure 22.

Lockheed Electra/Orion Programs

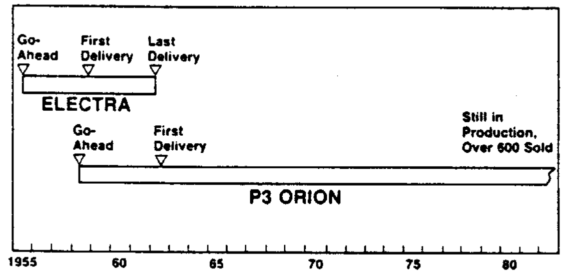


Figure 21

P-3 Orion

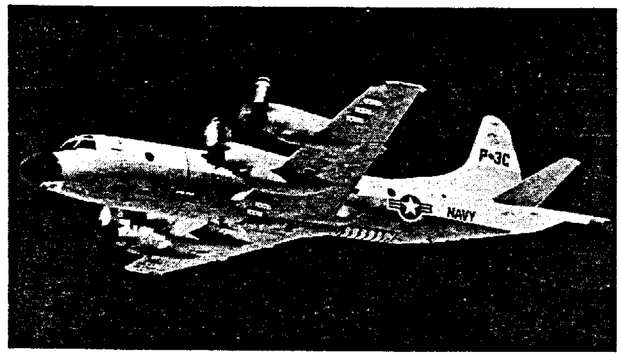


Figure 22

This program illustration exemplifies the hazards of new program starts with respect to market timing and technological obsolescence. The Electra came too late and with the wrong technology for its intended commercial market. It also illustrates a unique situation of extrapolating a failure into a remarkable success. As such the following decisions were key:

1. Failure: The decision to stay with better known technology and launch a four engine turboprop after the Caravelle (a twin engine jet) was launched for the same market. The power plant selected was the Allison 501. It should be noted that more efficient and proven commercial turboprop engines were available from the British industry. However, there was at that time a reluctance to become dependent upon an engine supply line extending across the Atlantic, and consequently a lesser experienced U.S. manufacturer was chosen. We'll discuss engine decisions later, but the point serves now to illustrate that supplier

decisions, if anything, have become more significant today, and programs can readily become win or loss situations by virtue of such decisions.

2. Success: The Orion's success, of course, represents another series of sound decisions that have tracked its long production life. The first of these was Lockheed's decision to market an airborne surveillance system designed around the Electra's obvious competitive advantages in this role. Thus, a competitive failure in terms of commercial requirements was reversed with its military mission.

707 Program

After its Stratocruiser experience, leaving propeller problems to others and proceeding with jet designs was not a difficult decision for Boeing to make. However, company efforts at convincing the military tanker people and commercial airlines that "jet was right" proved fruitless. Finally, after two frustrating years, Boeing's Chairman Bill Allen okayed the go ahead for a company-funded commercial prototype to demonstrate our conviction. This one-of-a-kind, the 367-80, was the beginning of the 707 and KC-135 programs. It was a big day when it rolled out, as shown in figure 23.

Dash 80 Roll Out

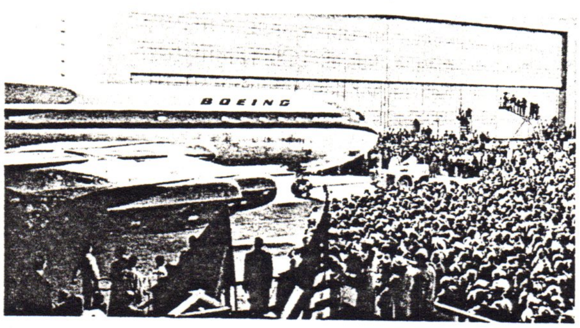


Figure 23

The Dash Eighty's first flight occurred on January 15, 1954. However, between go ahead and this event, the Air Force initiated a design competition for a tanker, not unlike the paper version that Boeing had tried to sell the Air Force earlier. Boeing lost the competition (partly due to Boeing's prototype knowledge) but Boeing delivery guarantees (with a prototype in hand) were irresistible, and by late 1954 Boeing was awarded the KC-135 production contract. The win was viewed as an opportunity to gain tooling that would have commonality for commercial production, and this became an influence in the increase of the cross section diameter from the prototype's 132 inches to the KC-135's 144 inches. Douglas came on to the market with a DC-8 which had a slightly wider body that was preferred by certain key airline customers.

The commonality decision was very right at a later time, but in this case it proved wrong for commercial competitiveness, and this forced a very costly redesign to a 148 inch cross section for Boeing. Figure 24 illustrates the three body widths involved.

Body Cross Section Evolution

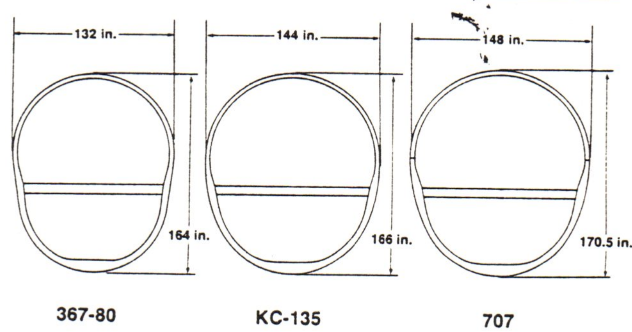


Figure 24

The DC-8 had also offered a larger and longer range wing, causing another major redesign headache and also invalidating what little was left in tooling commonality with the KC-135. The new wing change is illustrated in figure 25.

Wing Planform Comparison
707-120, 320

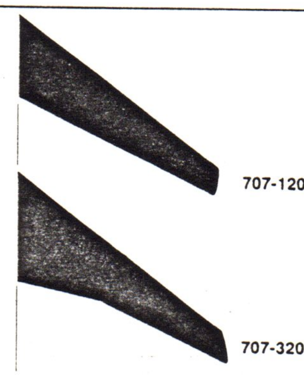


Figure 25

It was obvious from all this that gambling a quarter of the company's total net worth on building a prototype was only the start. Douglas was firmly entrenched in the commercial business and Boeing could either fold or increase its risks to obtain additional customers. Thus before delivery of the first 707, the production program involved two different wings, two body lengths, and two engines. By this time it also involved a commitment to build the 720, a lighter and shorter derivative. There were others as well, and a composite break-even situation developed as shown in figure 26.

Risk-Breakeven 707/720 Program

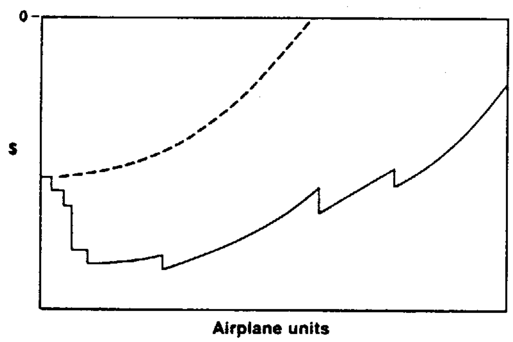


Figure 26

What actually happened is illustrated by the lower line of figure 26, as compared to the expectations which are represented by the upper line. Despite the turbulence of its launching, the program did evolve into a success and, as we've described, some of its more significant decisions were made in the program's early years as competitive pressures from the DC-8 exposed the 707's design vulnerabilities. I would consider the following decision points key to the 707's successful outcome.

1. The commitment (and collective decisions) that were to keep the 707 competitive. Much of this, as noted, was forced by specific competitive actions, and as such, Douglas really made some of the decisions for Boeing. However the commitment was fully a Boeing decision. It really preceded the 707 and has extended much deeper and far beyond the scope of this one program. *That commitment was to become a viable commercial competitor and to remain so.* It sustained the subsequent development of the Boeing jet transport family and over thirty years of continued product advancement. It has involved a continuity of discipline in design and production quality and the formation of a global customer support capability.

2. The second key decision was to proceed with the development of a company funded prototype after the unsuccessful and discouraging efforts in selling paper iterations to either the airlines or military. The prototype was invaluable, not only in paving the way for the 707's commercial acceptance, but for validation of the new technology integrations into its design. We may see this decision resurface in civil transport development within the next two decades.

Convair 880 Program

Convair emerged from World War II as a highly successful builder of the CV240, 340, and 440 series of transports...all for the short-range market. By the mid-1950s, Convair dominated this market segment, and knew its requirements better than the other U.S. manufacturers. Beyond the 440, the company was considering turboprops for additional short-range offerings, either as re-engines for its current designs or possibly as an all new airplane. With the exception of Sud's Caravelle (a tail-mounted twin jet), turboprops had become the primary short-range product focus on both sides of the Atlantic. However, despite its short-range market expertise, the company became enticed with a proposal from Howard Hughes to undertake the design of a big long-range jet transport for TWA. Working with Hughes was difficult, and by 1955 it became apparent that decision procrastinations had left Convair with no hope for a chance in the long-range market. Instead, the company lowered its sights onto the medium-range area with the CV880, a four engine design, thereby deferring its much better short-range market opportunities to other contenders. The timing of Convair's 880 decision with respect to this is illustrated in figure 27.

Go ahead was authorized on an order base of forty...ten from Delta and thirty from TWA. The CV880 was of sound technical design, but it persisted in a five abreast cross section, despite market objections. This made it vulnerable to the six abreast capability that Boeing countered with in offering the 720. The cross section comparison is shown in figure 28.

Competition

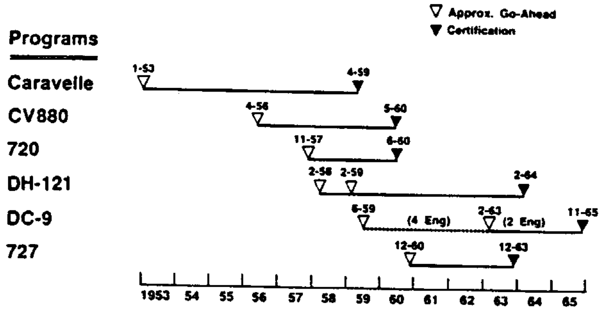


Figure 27

Cross Section Comparisons

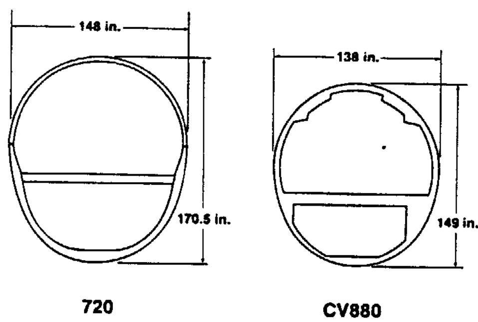


Figure 28

The noted difference in body diameter gave the 720 lower operating costs per passenger mile, and this, along with 707 fleet commonality advantages, virtually eliminated the CV880's market opportunities. Convair tried to recoup with the CV990, a larger version designed around an up-rated aft-fan version of the General Electric CJ805. The CV990 again was a good technical airplane, but continued disputes with Hughes over the CV880 and the high investment and concessions made to American in selling the CV990 were too much. Convair was, for practical purposes, through with the commercial aircraft business.

There were many decisions that affected Convair's fortunes with the CV880, but the following are particularly noteworthy with respect to the initial go ahead.

1. The decision to proceed with a four engine medium-range configuration when an intermediate-range twin-jet competitor was known to exist. Had Convair at this time moved directly into the short-range market, Boeing and Douglas could not have countered because of their other jet aircraft commitments, and the 720 could not have competed against a good short-range entry.

2. The decision to go ahead with the five abreast cross section when opposition from United, a key potential launch customer, was well known. Convair's firm position was not based on passengers; rather the five abreast decision was considered as an aerodynamic and performance solution to satisfy both transcontinental range and short field requirements.

3. The decision to proceed with a small order base and design that were both dominated by Howard Hughes. The peculiarities of Hughes' business arrangements were well recognized at the time. In fact, Convair had suffered first-hand experience a few years earlier in an aborted piston transport sale.

deHavilland Trident Program

The Trident was a sound high technology configuration executed by a very competent team that started design work substantially in advance of the 727. Unfortunately, the program was delayed as design requirements became oriented toward the specific needs of British European Airways, a government-owned airline, and also because the British Government was restructuring the industry, which was creating uncertainty as to the future management of the project. Government policy of the day was forcing the domestic carrier to purchase British equipment. The BEA needs produced a tight body cross section, which the earlier 707 and DC-8 competitions had proven as unacceptable to the U.S. market. A comparison is shown in figure 29.

Cross Section Comparisons

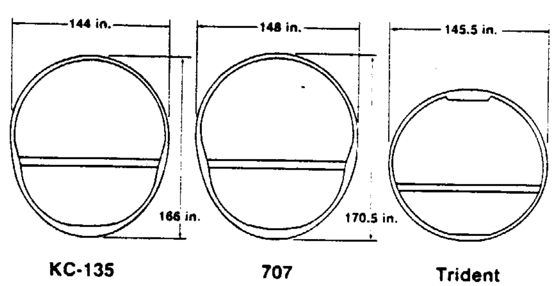


Figure 29

BEA's payload-range requirements and less demanding takeoff field length scaled down the Trident's original design, and at six abreast seating, this produced exceedingly tight shoulder clearances and very narrow swing-in entry doors that wasted floor space. This was all unacceptable to most airline customers. It also caused abandonment of the RB141 engine and start of a scaled-down engine, the RB163 Spey. Technologically, the airplane was very advanced, as noted in figure 30.

Trident Technical Features

- An integrated, clean-wing aft engine configuration having good characteristics in all flight regions
- A very advanced flight control system, combining triplicated power controls, an all-movable horizontal tail, and flight instrument innovations
- An improved bonded structure technology incorporating advanced fail-safe and safe-life techniques
- A new and efficient fan engine; the product of an orderly Rolls-Royce development program

Figure 30

Hawker Siddeley later produced stretch versions which sold at home and abroad. However, despite its technical soundness, only 117 Tridents in total were purchased by some nine airlines, and it was a financially unsuccessful program. It would be speculative to say just how much the British Government's policies flavored the program decisions that were made. Nonetheless, the following were key factors that affected the Trident's opportunity for success.

1. The decision (or decisions) that tailored the airplane's design to the needs of a single customer when only a cursory examination of the world market would have revealed differing requirements.

2. The decisions that cumulatively caused development to stretch into a six year program, thus allowing competitive aircraft to offer earlier deliveries.

<u>727 Program</u>

The 727 program began in May 1958 with a task force effort to identify the technology and configuration that would make a successful short- to medium-range commercial jet to complement the 707. The first designs produced a miniaturized 707, just as the initial "DC-9" was configured as a miniaturized DC-8. For economic reasons, we felt a two engine configuration would have better economics and our prime considerations in 1958 and 1959 were for two engine configurations having engines mounted under the wing. The torturous configuration path that covered the two-and-a-half year period is illustrated in figure 31.

727 Development History

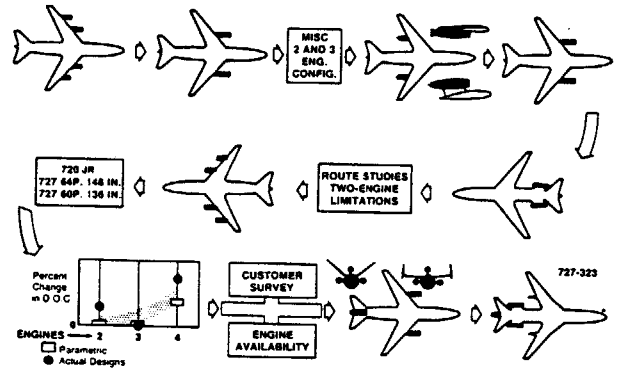


Figure 31

Conditions at that time precluded a European launch customer (due in part to the Trident start), and of the four major U.S. airlines, only United and Eastern were interested or financially capable. Eastern wanted to maximize economics with a two engine airplane, and United was seeking a four engine airplane because of their high altitude Denver requirements.

One must include a mention of the excruciating pain of trying to achieve a common denominator among varying airline requirements. All commercial programs go through a similar process and the engineers must work with a great many airlines, not just the few who are most likely to become program launch customers. It is a painstaking and iterative process, as illustrated in figure 32.

As this occurred on the 727, two other mainstream technical efforts were also proceeding. One was the development and wind tunnel verification of the many potential designs under consideration. The other was on-going technology staff developments that were independent of the program. The latter produced a triple-slotted flap which could yield a higher

One of Life's Frustrations

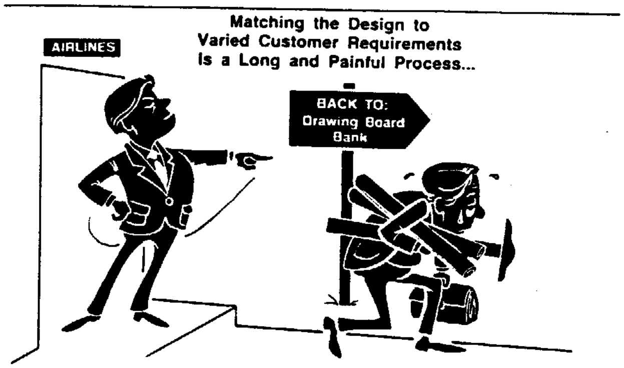


Figure 32

lift coefficient than any swept wing existing or contemplated. A three engine design was accepted as a compromise by both United and Eastern. The triple-slotted flap was incorporated to meet the short field requirement imposed by New York LaGuardia Airport runway 4-22.

The airplane really had two lives, and production rates have been highly variable as shown in figure 33.

727 Delivery History

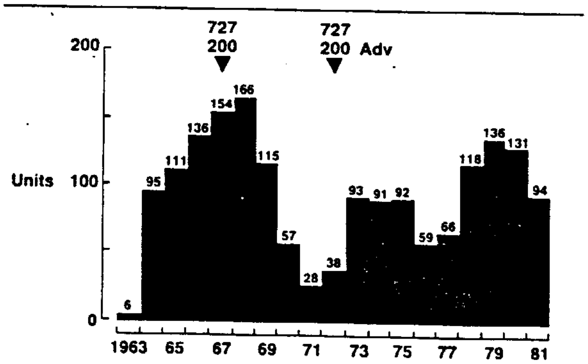


Figure 33

The first life included the original 727-100 and the early version of the 727-200, which made a fundamental mistake of adding body length at the expense of range, resulting in an airplane of limited performance and partially unusable economics. In late 1970 this was rectified by introduction of the "advanced" 727-200 having a higher gross weight, an upgraded engine, a new "wide body" interior and a variety of other improvements. Keeping the airplane competitive over its long production has entailed continuous nonrecurring investments, as illustrated in figure 34.

Cost of Nonrecurring Product Improvements as a Percent of Initial Nonrecurring Cost (Current Dollars)

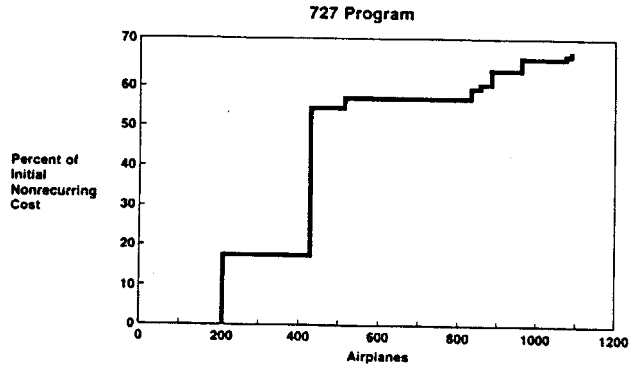


Figure 34

The cumulative investment for improvement has continued with production beyond that illustrated, and currently approaches 100 percent of the cost for initial development.

Evaluations of the 727's estimated market share were carefully made by Boeing's management before the initial production program was authorized. History has shown how wrong and how right these estimates were. This is illustrated in figure 35.

727 Market

Estimates vs Actuals

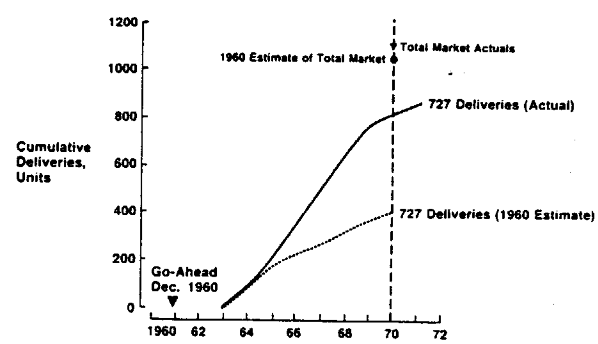


Figure 35

As noted, the 1960 predictions were that by 1970 the total market would stand at slightly over a thousand units, with the 727's share at about 400 units. These forecasts were made on the assumption that the 727 would face a U.S. competitor as well as Caravelle and Trident.

The 727's market position has held on through its "second life" with production approaching 2000 units. Some wrong decisions made by competitors and for the most part, some good decisions by Boeing ultimately gave the 727 the enviable position of being unchallenged. The following decisions by Boeing at the time of go ahead were key. Given different circumstances, they could have become "wrong" decisions, since they represented considerable risk in terms of the company's total situation at the time.

1. The decision to seek a satisfactory (three engine) middle ground solution between conflicting major customer desires for a two engine and a four engine aircraft. (Despite Boeing preference for a two engine configuration).

2. The decision to push state of the art in order to achieve desired competitive performance objectives within the intended market.

3. The decision (and its timing) to commit a major production program for a new state of the art aircraft in a situation of turmoil and without a prototype.

DC-9 Program

Douglas launched the DC-9 in 1963 as a direct competitor to the BAC-111. The British program had a two year lead, and with flying prototypes, it successfully penetrated the U.S. market. The Douglas program was started without a prototype and with Delta as the only customer.

The initial DC-9 series 10 was aimed at the BAC-111, not at a potential Boeing entry. The possibility of Boeing's 737, to an extent, caught Douglas by surprise. Rather than risk defeat by unexpected competition, Douglas decided to "stay with the game." The pace of basic model development increased, and to stall Boeing, work on a *major* improvement derivative (the DC-9 Series 30 for Eastern) was authorized. Douglas successfully curbed the BAC-111 delivery advantage, but the Series 30 derivative failed to stop Boeing's initial 737 sale made in February 1965. Additional stretches were initiated, and Douglas maintained the order advantage. However, the DC-9 market share successes also incurred financial penalties which contributed to the Douglas take-over by McDonnell in 1967. Figure 36 illustrates the DC-9 program timing, and the ambitious pace of its developments before this happened.

DC-9 Program

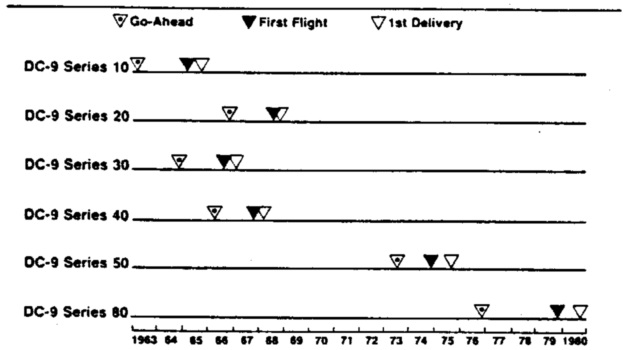


Figure 36

As noted, McDonnell Douglas has continued to stay with the game, and the DC-9's growth has nearly doubled passenger capacities over that of its initial model.

The DC-9 uses a cross section totally different from that of the DC-8, and this was probably a correct decision for the time of its launching. To an extent, however, its smaller dimensions opened the way for a 737 start with cross section and parts common with the 727. This plus the 737's conventional tail and wing-mounted engines produced a much shorter airplane with respect to passenger capacities and made growth versions easier. Figure 37 illustrates the cross section differences between the BAC-111, DC-9, and 737.

Cross Section Comparisons

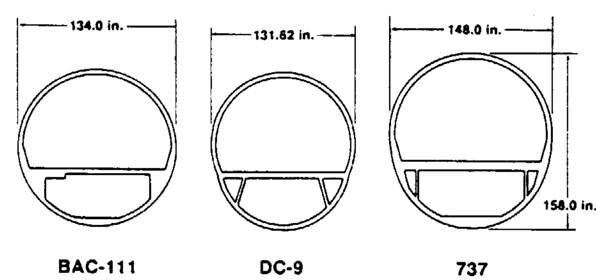


Figure 37

The DC-9 decision had much in common with the 707-320 decision made by Boeing in its earlier competition with the DC-8. It was a matter of staying in the game with additional major nonrecurring investments.

This unquestionably produced better airplanes by both. The real market loser in the DC-9 case was the initial market entrant, the BAC-111. With respect to this, the following DC-9 program decisions are noteworthy.

1. Douglas had correctly assessed its late-start market opportunities in U.S. market competition against the BAC-111. The Douglas airplane featured an upper deck cross section affording superior passenger appeal features (significant to this market), whereas the BAC-111 used the more restrictive circular body favored by the European industry.

2. Boeing probably would not have started the 737 had Douglas initiated the DC-9 program with an airplane more resembling its Series 30 derivative. In this matter, Douglas may have incorrectly assumed that the BAC-111 was the only competitor.

Supersonic Transport Programs

Even as the first subsonic jet transports were developed, the commercial potentials for supersonic flight came under serious study in the four nations that fostered their development. The costs for development were recognized to substantially exceed any civil aircraft program previously accomplished. As such, this caused British and French interests to merge into the Concorde. On this side of the Atlantic, funding required direct U.S. government sponsorship, with a series of competitions that selected Boeing as the airframe manufacturer. The Soviets operated in a manner conventional to their style, with the government assigning the SST task to Tupolev. However, the decisions surrounding the U.S. and European programs were unconventional, and the timing of the two is shown in figure 38.

Supersonic Transport Programs

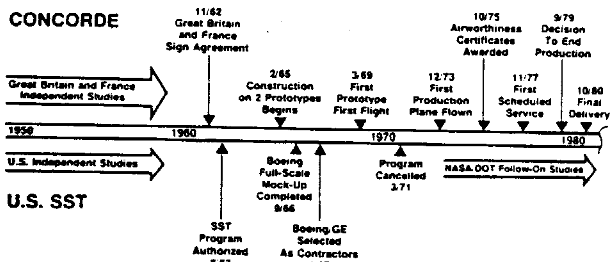


Figure 38

The Concorde, of course, is still in service, but the decision to terminate production was made several years ago as the market could no longer substantiate its economics. The earlier termination of America's SST, in my mind at least, has proven with hindsight to be a right decision but it was made for all the wrong reasons. Unfortunately, these wrong reasons have afflicted the pace of U.S. technology ever since, and the nation has suffered deeply because of this.

Both programs were conceived at a time when fuel prices (in constant dollars) were tracking a downward path. Both were known to be sensitive to fuel, since supersonic cruise requires more energy per unit of payload and range. The subsequent increase in fuel price made the U.S. decision "right" nearly two years after it was made. Nevertheless, the Concorde, shown in figure 39, has been providing safe and reliable Atlantic service since 1976.

Concorde

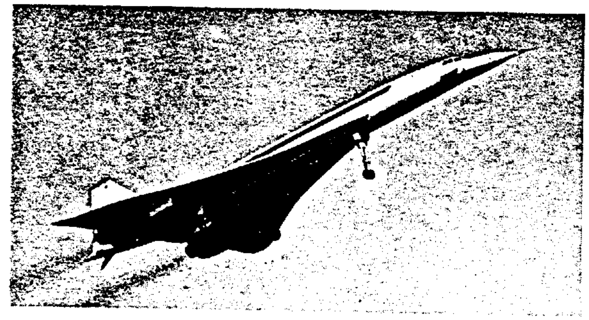


Figure 39

The funding nations, including the U.S., have reaped enormous legacies from their SST programs. A partial summary of the achievements derived from the U.S. program is noted in figure 40.

SST Spin-Off Contributions

- Modern flight deck technology, now being introduced on new generation commercial and military airplanes
- Large scale application of computers to aeronautical engineering problems
- Titanium alloy developments and new structural concepts
- Miscellaneous developments: lightweight seats, fuel tank sealants, noise reductions, guidance, hydraulic tubing, etc.
- Augmented flight control systems having current military and future commercial applications (relaxed static stability – active controls)

Figure 40

The European experience is similar, although of course, the actual SST production and service have enriched their development knowledge extensively. Both programs are graphic demonstrations that high technology efforts, regardless as to how they are sponsored, will find applications to generate values not thought of at the time.

However, the diverse decisions surrounding these two programs warrant two final observations with respect to their legacies:

1. The Concorde program proved that a large-scale international program could be made to work. Much was wrong, but it forced solutions that paved the way for internationalism that is becoming widespread today.

2. The U.S. decision, unfortunately, may have accomplished the opposite. It appears to have validated a growing trend of public and government opposition to technology that made the 1970s a decade of drought for U.S. research and development. We are reaping the bitter harvest of such decisions today. More specifically, the "wrong" aspect of the SST's cancellation was that, in the absence of a supersonic long-range bomber, it ended the idea of government supported high risk prototypes. Its completion would have made the B-1 and F-16 into better programs and the Space Shuttle a cheaper program. It also would have allowed the earlier introduction of many advancements in new subsonic airplanes.

747 Program

The 747 was conceived at a high point in world travel growth. Mass travel markets were in rapid expansion with the air system and major airports approaching capacity limits. The objective was to design a "super plane" that would capture high performance and low seat mile costs by its economy of scale. The airplane was intended to leap-frog the DC-8-63 and also to be oversized at introduction. It was intended that it become a "market fit" about four years after introduction. Such philosophy guided the DC-8 and 707 developments, and is illustrated in figure 41.

747 Sizing

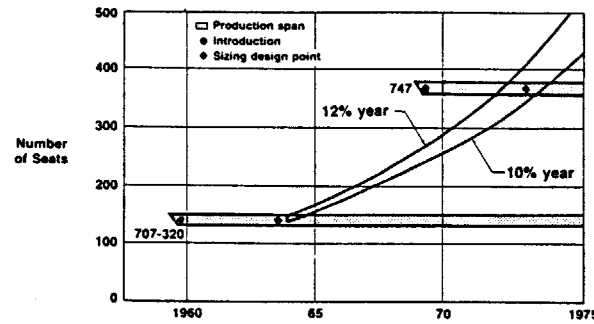


Figure 41

The risks were of a magnitude scale also, and most were recognized before go ahead. It required a new factory concept, and the 747's success would be dependent upon the development of the new and untried JT9D engine. Furthermore, all of the critical elements (factory construction, airplane design, and engine development) had to proceed concurrently to meet delivery schedules. On the plus side of this was the fact that the 747 was establishing a new size platform, one that competitors would be hesitant to challenge.

The expected emergence of the SST as a principal long-haul passenger transport was a significant consideration in both sizing and configuration. The body width had to be sized for freighter efficiency in the event this became a principal job as the SSTs took over passenger service. The resultant cross section, shown in figure 42, had little to do with passenger appeal in its selection, but was marketed as a great passenger comfort "breakthrough" by use of an innovative mockup and promotional campaign.

Body Cross Section Comparison

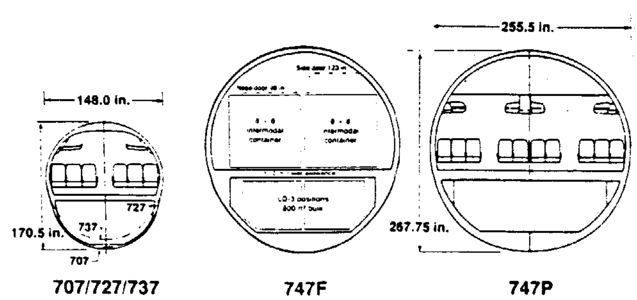


Figure 42

The airplane was designed for higher speed objectives to improve productivity without significant erosion to seat mile costs, which were to be substantially below that of any vehicle flying. Scale, of course, was a major factor, as figure 43 illustrates. However, the results exceeded those of scale effect alone.

Direct Operating Cost Comparisons

1979 U.S. Domestic Rules, 1979 Dollars, 1000 nmi Average Trip

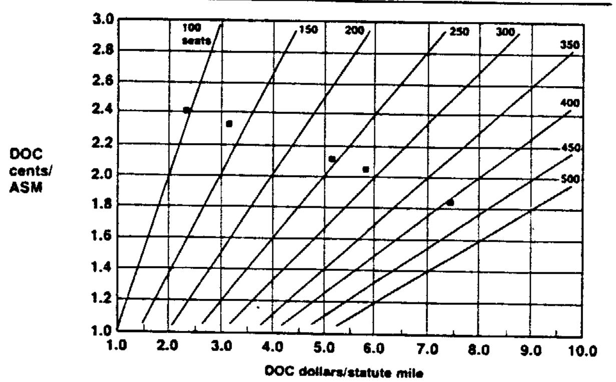


Figure 43

Bringing it all together on time was unquestionably the largest aircraft task (and the greatest risk) that Boeing had faced. The rollout is pictured in figure 44.

The Boeing 747

First Airplane Rollout

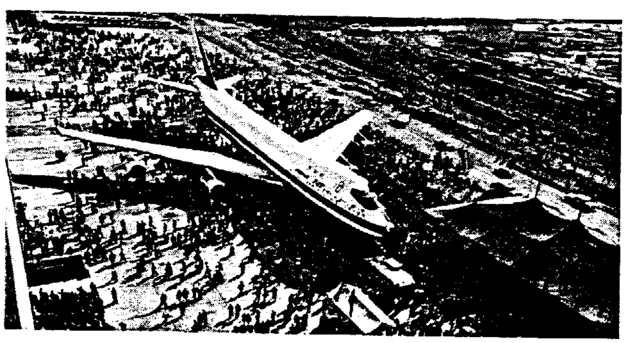


Figure 44

The airplane proved to have extremely good flight characteristics once initial bugs were corrected. Considering its uncontested "platform position," the program has gone on to contain an unusual array of product improvements and derivatives, including some 20 engine options. Figure 45 illustrates this, showing the derivative models available.

Current 747 Family

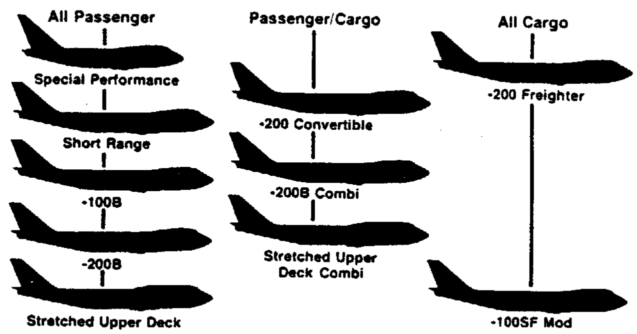


Figure 45

The additional nonrecurring costs for all this have fairly well tracked the 727 program experience noted earlier, by nearly matching initial development costs and following a similar time pattern as well. Critical decisions abounded on this program, in character with its size. However, the following are noted because of their significance to subsequent wide body programs.

1. The decision (before actual go ahead) to rebuild the entire production and management control systems of the company. The 747 really ushered in a new era of production management for Boeing, and without such, the later concurrency of the 767, 757, and 737-300 programs would have been unthinkable.

2. The decision that risked success on the concurrent start and development of both a new airframe and a new engine.

3. The decision to size the airplane to a relatively high assumption of market growth, with a relatively secure confidence that its scale would not be easily challenged.

Head-on Competitions

Many conclusions and contradictions can be drawn from the ten programs we've just covered. However, on the commercial side, decisions that surrounded head-on competitions have appeared particularly critical, and worthy of some special observations. For such, I've selected the four sets of competitions illustrated in figure 46.

Head-on Competitions

CV240 M202	707 DC-8
DC-10 L-1011	767 A310

Figure 46

We noted Convair's successful piston experience earlier. But the first of its post war pistons, the CV240, appeared in the short-range market as a direct challenge to the slightly earlier Martin 202. The objective of both was to replace the DC-3 in a market that was fairly small but had good opportunity for expansion. In this case the M202 was underpressurized and had some structural deficiencies, faults that the CV240 avoided. The market was too small to carry both, or to tolerate fixes. Consequently the M202 was forced to terminate production at 31 units. Convair sold over 570 of the CV240s, and produced a total (including derivatives) of over 1,100 aircraft.

The 707 and DC-8 competed in a market that was sufficiently large for both. Boeing was first, but with some mistakes in size and range requirements that were *immediately* corrected. Had this not been done, the competition might have ended differently. However, it should be noted that the 707's ultimate success is due in part to Douglas' decision to terminate DC-8 production in favor of increased DC-10 sales. The 707 did not put the DC-8 out of production. It was a Douglas decision that favored Boeing.

The DC-10 and L-1011 competition involved a different market situation. These airplanes were caught, along with the A300 and 747, with a market expanding at a substantially slower rate than predicted at the time of their launch. Both were "too big", which depressed their sales while benefitting those of smaller aircraft such as the 727. Both are technically acceptable, but have suffered primarily because the market failed to develop sufficiently to support both or possibly even one.

The 767 and A310 competition must be regarded as still in its infancy. However, they are of a size, a timing and a technology that should support both in the market. The two unknowns at this time are the implications of affordability and internationalism on the market and its decisions. We'll cover this in more detail later.

These cases have pointed out the significance of decisions leading to head-on competitions. Mistakes may be tolerated, but only under circumstances of rapid correction. One can't correct the market need however, and head-on competitions in the face of insufficient market size means that one or both competitors may be unsuccessful.

Military vs Commercial Decisions

The purpose of this section is to briefly explain the fundamental differences between the military and commercial environments in which decisions are made. Commercial practices seem to be more streamlined than military practices and the Department of Defense is spending considerable time studying them. However, one must recognize the basic differences between the two environments. These are overviewed in figure 47.

Commercial vs Military Program Relationships

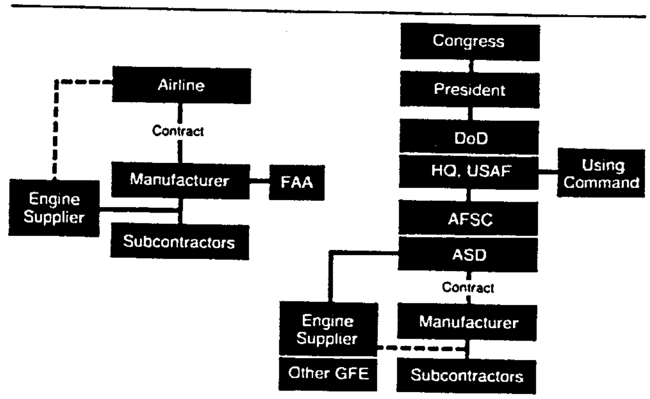


Figure 47

Commercial communication lines are short, including those involving decisions. After the product is agreed upon, manufacturer initiatives dominate. The number of people involved for the airline and for the manufacturer in administrating all aspects of the contract, including technical, is perhaps a dozen or so on each side. The FAA issues type and airworthiness certificates. They also issue a contractors production certificate. Their interface with the manufacturer in terms of numbers (not influence) is heavily dominated by Designated Engineering Representatives (DERs) and Designated Manufacturing Inspection Representatives (DMIRs) certified for the duty from the manufacturer's ranks.

The illustrated Air Force program is immersed in a far different environment, one which is not easily changed. The buyer is the Air Force Systems Command and its designated Aeronautical System Division as noted. The relationships are much more complex and formal, and Congressional oversight is maintained on a line item approval basis where major aircraft programs are concerned.

The Air Force must be prepared to publicly defend any decision it makes, which is not a requirement in commercial business (*public accountability vs private accountability*). Similarly, the Air Force must be prepared for a formal protest on its procurement decisions and has procedures for this purpose. The method for commercial protest to be heard is the loss of future business. The only established process is through the courts, and this is generally avoided. The commercial product relies on a fixed price based on an end item specification, performance guarantees, service life policies, and warranties. The military system relies upon a complex interface in which every decision must be extensively reviewed and documented. Military logistics and spares requirements tend to prevent in-line product improvement except at rare intervals. Commercial practices assume that such improvement is normal, and no approval is needed so long as performance guarantees, price, and delivery are unaffected.

The military system is much more formal and derives advantages and disadvantages from this situation. Because of this formality, I have chosen to illustrate a common civil/military decision situation with a military chart as shown in figure 48.

The situation is oversimplified but is applicable to either the civil or the military case. For convenience, it uses the military definitions which, of course, have their civil counterparts. It omits the military "milestones". The objective of the system is to reduce risk...hopefully to zero when *production* is finally entered.

Risk and Decision Cost Profile

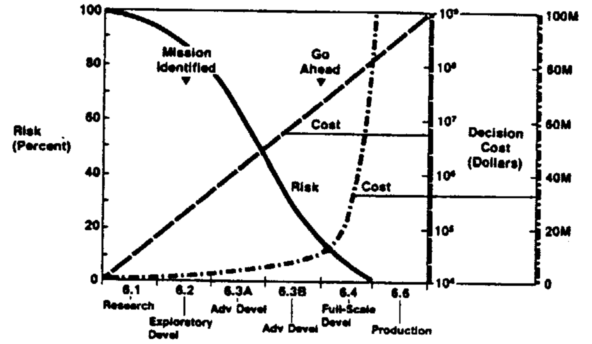


Figure 48

The cost of a major decision is shown on two scales. The diagonal straight line is plotted on a logarithmic scale; the curved line, similarly identified, is plotted on a normal scale. The message (applicable to civil or military) is that pre go-ahead decisions are cheap. But the decisions made after go ahead increase rapidly in cost until they become essentially prohibitive.

Since commercial programs are based on a market price (without relationship to cost), there is a very large incentive to apply large amounts of early capital (before go ahead) to facilitize and train for productivity and low recurring costs. Military programs, on the other hand, have difficulty authorizing large amounts of "up front" money and disincentivize large productivity investment by the contractor. Military program's profit is limited, and, when nonallowables, potential renegotiation, and other contractual burdens are considered, the profit may prove unattractive to some suppliers.

The type of technical and manufacturing decisions to be made are similar. The manner in which they are made is very different and will remain so.

The technology base for military and commercial aircraft is generally the same. At one time the flow was from military into commercial. Today much of the flow is reversed. In addition, the "audit trail" requirements that now force DoD to link research and technology to identified future weapon systems tend to constrain the military input to the base. This tends to increase the military reliance on civil and NASA basic research. Such "compartmentalization" is generally not practiced by other nations in the western world today.

V. Engine Decisions

The success path of an airplane program, whether commercial or military, is heavily dependent upon the success of the propulsion system. From an aircraft manufacturer's standpoint, engine selection is critical and is sometimes more complex than decisions made on the airframe itself because three parties are involved (the airplane manufacturer, the customer, and the engine manufacturer) and because engines take longer to develop than airplanes. The purpose of this section is to discuss a few of the pivotal engine developments and to identify some of the more significant engine decisions involved. Thirty years ago it was commonplace for the U.S. Government to fund development of engines before the airplanes on which they were to be fitted were configured. While the policy has tended to disappear, the facts that supported it have not.

JT3/J57 Program

General Electric and Westinghouse, with sizable experience in turbine and supercharger technologies, were selected as principals to develop the first U.S. turbine engines.

Nonetheless, Pratt & Whitney recognized the probable future of the newer technology and initiated its independent design work on two engines. The larger of these, (the JT3), was a two-spool 10,000 pound thrust design. Its concept looked so promising that the Air Force joined to fund further development as the military J57, the first U.S. engine in the 10,000 pound thrust class, and forerunner to the JT3C and JT3D. The J57 is illustrated in figure 49.

JT3/J57 Engine

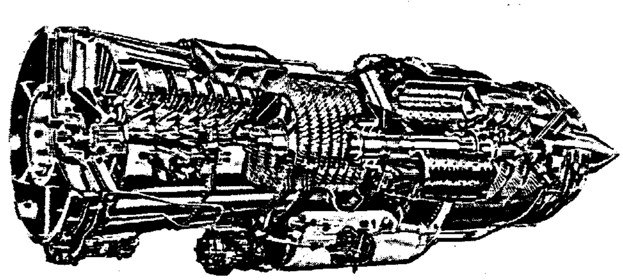


Figure 49

Development was not without difficulty. The original JT3 was designed with a constant external diameter and only two were built. The remainder incorporated a "wasp-waist" constant internal diameter (with higher efficiency, better sealing, and lower weight) and an engine accessory arrangement that reduced its frontal area. As noted earlier, the J57 military version became the propulsive foundation for the B-52. The critical decisions were:

1. The decision by Pratt & Whitney and the Air Force to develop a 10,000 pound thrust jet engine with no identified application.

2. The Pratt & Whitney decision that a two-spool axial flow configuration was correct and that they should work toward an opportunity to develop it and stick with that development.

3. The Air Force decision to change the B-52 from a turboprop to a jet bomber powered by eight J57s.

4. The Boeing decision to back commercial and military programs based on four JT3/J57 engines, which culminated in the decision to build the prototype.

Pratt & Whitney refined the JT3's technology and developed a larger, higher thrust engine called the JT4 (J75). This was the original engine used on long-range versions of DC-8 and 707 aircraft.

Bypass Fan Engine Development

The first bypass engine was a Rolls-Royce Conway with a bypass ratio of 0.3. The U.S. fan-engine developments tracked competitions between two technical paths: the single-spool aft-fan technology followed by General Electric and the two-spool front fan technology pursued by Pratt & Whitney.

Their development and timing were occasioned by Convair's abortive attempt to recoup its CV880 market failure by offering a larger CV990, designed around the CJ805-23. This was a superior aft-fan version of the engine that Convair had used on the CV880. The CV990's success was to depend largely on its being the sole market entry with the much more fuel efficient and higher thrust fan engine. Convair, General Electric, and American Airlines (the CV990 launch customer) were confident that

Pratt & Whitney couldn't counter with a competitive fan engine for Boeing's 720.

Pratt & Whitney was obviously in a spot; however, the company had previously initiated experimental test work on both rear and front fan engines, noting the potentials of the earlier Rolls-Royce Conway. Pratt simply built a front-fan engine by quickly configuring a JT3 demonstrator two-spool engine from which the first three stages were removed, and two stages from the larger diameter J75C were bolted in their place. This demonstrator provided a bypass ratio competitive to that of the CJ805-23. It evolved into the JT3D, and to this day, the engine has no third stage.

The JT3D was quickly adapted to the 720, giving the airplane a 41 percent increase in power and a decisive advantage over the CV990. It eventually powered the 707, DC-8, B-52, and some KC-135 aircraft. A comparison of the General Electric CJ805 aft-fan with that of Pratt & Whitney's JT3D is shown in figure 50.

Aft Fan vs Forward Fan

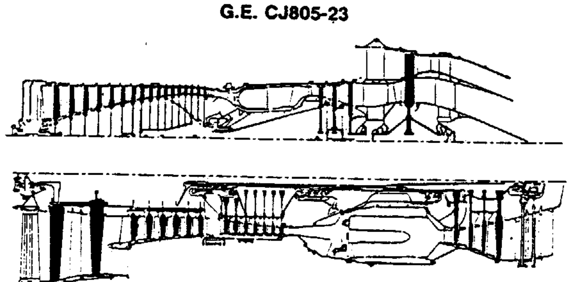


Figure 50

The key decisions appear to have been:

1. Decisions by Convair and American Airlines to launch the CV990 program based on the advanced General Electric aft-fan engine.

2. Pratt & Whitney's decision to immediately counter with a competitive fan engine (based, of course, on earlier experimental work).

<u>The JT8D</u>

Commercial competition of a different type initiated the Pratt & Whitney JT8D program. In this case, Boeing had selected the Rolls-Royce AR963 engine for the 727. The engine was to be assembled in the U.S. by Allison under a Rolls' license. However, Eastern Air Lines, one of the 727's launching customers, insisted that the engine must be totally of U.S. origin to assure that adequate engineering and critical parts support were provided. Boeing attempted to overcome Eastern's objections by persuading Rolls to establish a factory (with adequate technical staff) in this country. Rolls elected not to do so.

This provided Pratt & Whitney the opportunity to offer the JT8D, a fan version of its J52. This engine change was acceptable to the launching airlines, and last minute changes to the airplane were hurriedly made.

The development period was short, and engine failures during the initial 727 flight tests were frequent. However, Pratt corrected the deficiencies with a major redesign and the engine went on to power the DC-9 and 737 as well as all 727s. A "refan" version was later developed, stimulated primarily by noise compliance needs. The circumstances are noted in figure 51.

JT8D Engine

- A rapidly devised, fanned version of the Navy J52 core
- Lack of de-bugging resulted in initial flight hardware that destructed with engine surge (rotor/stator contact)
- Finally resulted in reliable and fuel efficient engine powering half the world's transports. The biggest peace-time engine program ever
- U.S. Government sponsored a re-fan to increase bypass ratio, and improve community noise and specific fuel consumption. The re-fanned engine now powers DC-9 Series 80 aircraft

Figure 51

The most important decisions were:

1. The Eastern Air Lines decision that it could not accept the 727 based on an engine with transatlantic technical and logistics support...coupled with the Rolls-Royce decision not to build a factory in the United States.

2. The Pratt & Whitney decision to rapidly offer an alternative solution.

The High Bypass Ratio Fan

The first high bypass ratio fan program was the General Electric TF39 resulting from the General Electric/Pratt & Whitney engine competition for the C-5 military transport. Pratt & Whitney lost the competition, but when the 747 program was under study they were the only U.S. manufacturer with capacity to build the engine Boeing needed.

Their proposed engine for the 747 was of a higher temperature and bypass ratio than the one Pratt had proposed for the C-5A. The initial JT9D was rated at 41,000 pounds of thrust and grew to 43,500 pounds of thrust over the course of the 747 development program. An outline drawing comparing the TF39 and JT9D is shown in figure 52.

TF39 vs JT9D

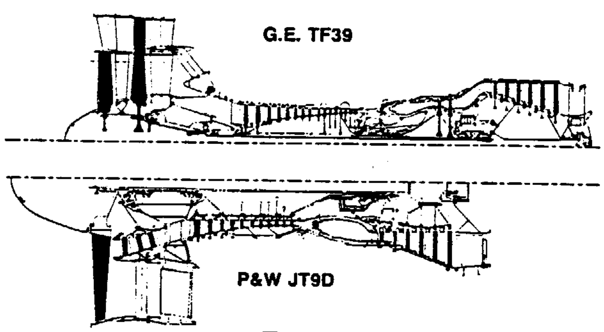


Figure 52

As a direct result, Boeing found itself in a situation with no alternative engine fall back position should the JT9D development program encounter difficulty within the time frame required. The schedule assumed that an all-new engine could be developed in the same time period as an all-new airframe (which violated historical relationships). In addition, Pratt had limited experience with compressor variable geometry and cooled turbine blades, both of which were necessary in the JT9D. The initial JT9D experience on the 747 was painful from the standpoint of maintenance cost, thrust deterioration, and engine reliability.

Lockheed also initiated the L-1011 with the all new RB211 engine, again assuming that Rolls-Royce could develop the engine within the time constraints of a new airframe development program. The consequences of that decision were even more grim.

The critical decisions were:

1. The aggressive General Electric decision to offer a very high technology and very high bypass ratio for the C-5 competition.

2. The Pratt decision to offer Boeing an all-new engine, incorporating a more advanced technology than used in their C-5 bid.

3. The Pratt and Boeing decision (followed by Rolls-Royce and Lockheed) to base a new airplane program on an all-new engine program having a go ahead at the same time as the airplane.

The 747 experience ended at least one manufacturer's willingness to stake an entire airplane program on a single, all-new engine. Although the DC-10 and A300 both started with one engine, neither involved an all-new development.

The 747's use of the General Electric engine option came as the result of the JT9D troubles. General Electric, by this time, had developed a TF39 derivative, the CF6, suitable for the 747. The Rolls-Royce installation came later. Some 20 engine models are now involved as shown in figure 53.

747 Engine Options

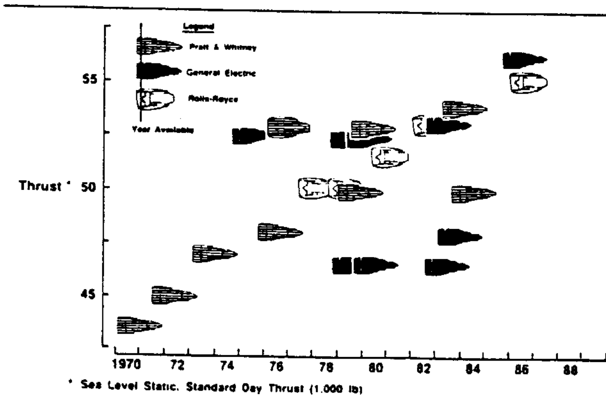


Figure 53

Historically smaller engines of the same technology have cost substantially more per pound of thrust than larger engines, as shown in figure 54.

Engine Cost Trends
1977 Data

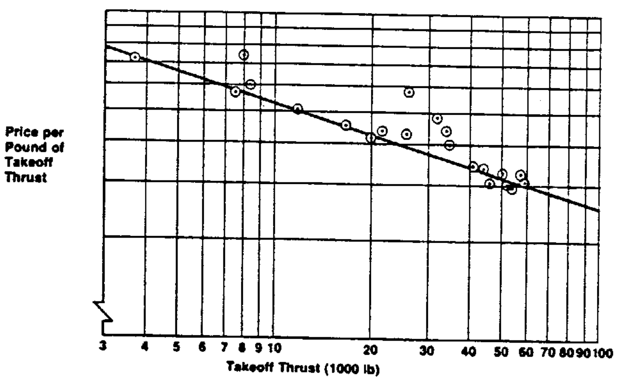


Figure 54

This plot was prepared several years ago from data available at that time. A similar plot prepared on the basis of today's pricing indicates a greater scatter and a less definite trend. One might speculate as to the reasons, but it would appear that aircraft manufacturer decisions cannot be based on a consistent engine price relationship and must be examined using a relatively independent estimate of the price pattern to be expected (with time) for the particular engine and engine manufacturer involved.

Engines for the 767, A310, and 757

The 767, in its study of three engine configurations used a version of the CFM56 and a proposed Pratt & Whitney engine, the JT10D. On the basis of that airframe configuration, Pratt began development of the newer technology JT10D having a thrust level of about 22,000 pounds. When the 767 design changed to two engines, it used derivatives of the 747 original engine (JT9D), a derivative of the DC-10/A300 engine (CF6), and a derivative of the L-1011 engine (the RB211). All three engines were seriously considered, and two, the JT9D and CF6 have been sold on the 767 and the A310.

The 757 required a larger engine than the then current JT10D, and was launched with a major derivative of the RB211 series and a derivative of the General Electric CF6. When it became evident that the 757 program would go ahead, Pratt & Whitney scrapped its earlier JT10D and offered a new scaled version, the PW2037 with 37,000 pounds of thrust. The result was that General Electric dropped its CF6 derivative program for the 757, and Rolls was forced to develop an even more advanced derivative of the RB211 (the 535E4). This has required considerable investment by Rolls in technology and development to compete with the economic performance of the PW2037. Final judgments as to which decisions were good must await the passage of time.

The newest trend in engine development is one of international cooperation and joint risk taking. Three programs will be briefly examined as noted in figure 55.

International Programs

- CFM56
- JT10D
- RJ500

Figure 55

The CFM56 is a joint development program between General Electric (U.S.) and Snecma (France) on an equal cost-share basis, using the General Electric core designed for the B-1 bomber and a Snecma developed low spool. The engine is assembled in both France and the United States. The joint engine program was constrained by U.S. military security of the General Electric core, and this entailed a complex set of operating circumstances, restricting the technology's exposure to Snecma. In spite of this the two companies have managed to "make it work", and the engine has been purchased by U.S. airframe manufacturers and by the U.S. Government.

The Pratt & Whitney/Rolls-Royce program centered on the JT10D. Restrictions on technology transfer imposed by the U.S. Government made true technical cooperation impossible. Also, the absence of a "lead" authority resulted in significant technical disagreement. The joint program was dissolved when Rolls-Royce decided to proceed with an RB211 derivative for the 757 program that was considered competitive to the JT10D by Pratt. The current Pratt & Whitney 2037 program includes limited foreign design and production associates, but not Rolls-Royce.

The RJ500 is an arrangement between Rolls-Royce and Japan Aero Engines Ltd. to design and build an engine aimed at the 150 passenger airplane market. The arrangements may be extended to include other companies, perhaps even Pratt & Whitney. The circumstances for the joint program are still in their early stages and the final outcome is yet to be determined.

Advanced Turboprops

Today, there is a strong possibility that the right way to go for certain civil applications and certain military applications is with an advanced multi-bladed turboprop as shown in figure 56.

Propfan

Figure 56

This may or may not require an all-new gas generator, but it will require all-new gearbox and propeller developments. Although renewed interest in the turboprop was launched under NASA's sponsorship, the major effort and the major funding to support it lies ahead. Assuming that such a development offers fuel efficiency, perhaps 15 percent better than that available with a turbofan, it would appear that the following decisions need to be made:

1. How will the propeller development be funded? Development time appears to be longer than engine and gearbox development time.

2. How will an engine and gearbox development be funded?

3. Will the resulting program be multi-national?

4. What is the correct size for the initial development system?

These questions are based on the probability that such a propulsive system will most assuredly have a development time longer than that of an airframe and that it is probably not feasible to wait until the aircraft requirements are established before such a propulsive system development is committed.

VI. Decisions Forming the New Fleet

Fleet selections for future 1980 decade deliveries will be made from equipment options that are already known, and most of this equipment will incorporate one of the latest fuel efficient high bypass ratio engines that were just discussed. The majority of new commercial airplanes delivered will be selected from the range and size options presented in figure 57.

Commercial Airplanes for the 1980s

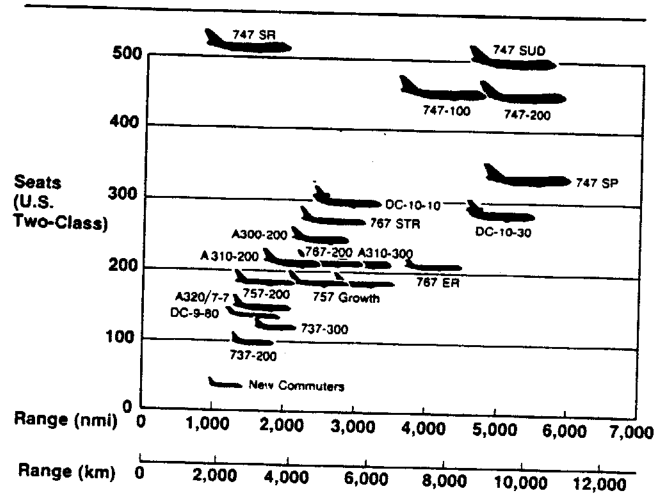


Figure 57

For purposes of discussion, figure 57 has included the A320, 7-7, and 767 stretch, although none have been firmly committed by their manufacturers. We shall next examine decisions leading to the Airbus equipment (A300/A310) and to the 767 and 757.

Airbus

The same high air travel growth rates that stimulated the 747's wide body start for the international market pointed to the need for smaller-sized wide bodies configured for domestic service in Europe and the United States.

The Europeans jointly explored their domestic alternatives for developing a short-haul, high capacity airliner for several years, starting in 1965. However, the less constrained U.S. domestic market acted first, expressing a variety of airline range, airport,and route requirements, thus further tempering the course of the European program's definition.

On the U.S. side, some airlines favored a program committed to transcontinental ranges, and others would accept a shorter initial range with potentials for transcontinental growth. Supporting the latter was the 1966 specification issued by Frank Kolk (American Airlines) for a jumbo twin (high bypass fan engines) carrying 250 passengers (one class) with operating capabilities between La Guardia airport in New York and Chicago and, of course, Chicago to the West Coast. The Denver requirement (which forced the 727 to have three engines) and several other considerations also entered the equation.

However, the fundamental decisions changing to a transcontinental tri-jet and afterwards selecting the DC-10 were made by C. R. Smith, Chairman of American Airlines, who overruled Kolk's specification and demanded an initial transcontinental capability. *Rarely have decisions been so critical as these made by Mr. Smith.* Lockheed, the loser in this competition, decided to proceed in a head-on competition with its L-1011, and the big twin slot was open on both sides of the Atlantic. The timing of the three programs is illustrated in figure 58.

Wide Body Programs
(Post 747)

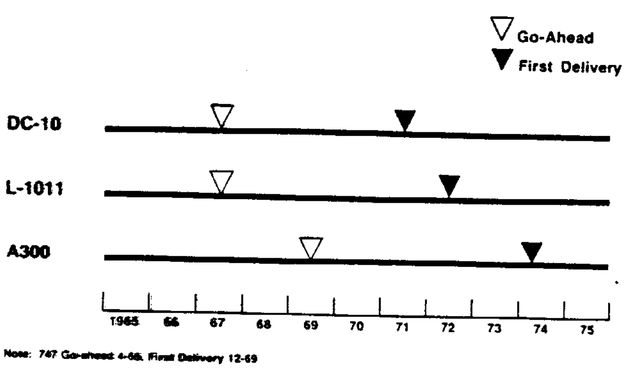


Figure 58

The emergence of the larger-sized U.S. airplanes caused the A300 to be scaled down by about 50 seats and, so sized, the Airbus consortium program was officially sanctioned for go ahead by the participating governments in May 1969. The key forces motivating the decision are summarized in figure 59.

A300 Program Influences

- Provided base for European industry expansion
- Market need recognized by Europe's airlines
- No similar two-engine aircraft competing
- Suitable engine available
- Government support

Figure 59

The timing was right. There appeared to be a definite market need, and it could be years before another opportunity would develop. Furthermore, the program had been carefully planned, recognizing the many difficulties that had surfaced in earlier joint European efforts. The biggest problem was to create an authority that would make binding decisions in the presence of conflicting partnership views...technical, financial, or political.

Affordability, as we have already noted, has different meanings to differing political or societal structures. Nowhere is this more aptly demonstrated than by the European value judgments in the decisions that initially funded the Airbus development and then provided the "staying power" to sustain Airbus through its first six years with less than 30 orders booked and only 13 deliveries.

The decision values considered that the industry was a pacesetter for Europe's technical progress, and as such, its employment must be maintained. It was stated that the Airbus base could provide stability, and, furthermore, it could be sustained by airline profits and the money market, thus reducing the European taxpayer burdens by an equivalent amount. If it could be sold abroad...so much the better.

The A300's start represented far more than the go ahead of a specific airplane. Its decision values stated a cohesive linkage between industry and government objectives, which has no parallel within the U.S. decision-making environment.

As traffic growth improved, the A300 was more closely sized for a number of world markets than was the DC-10 or L-1011, thus forcing the latter out of production. The European partners committed sizable reinvestments for A300 production needs and also to expand this initial product into the product tree illustrated in figure 60.

Airbus Products

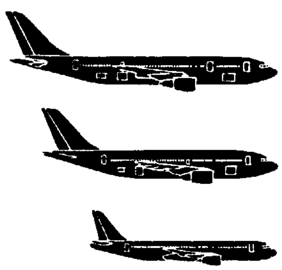


Figure 60

Although the A320 is not firmly committed as yet, we can assume that its go ahead (and also that of the A310) will require levels of competitive reinvestments over time, similar to those experienced by the U.S. industry...essentially doubling the costs of their initial development.

There were significant decisions leading to the Airbus start...we have chosen not to enumerate them. However, the most noteworthy point is the result...a new premise of internationalism and affordability to affect world decisions in commercial aircraft.

The 767 Program

The 767's origins were also very carefully considered, and over a time period that went back to a 1971 alliance with Aeritalia. Thereafter, the Boeing-Aeritalia team gradually recognized a sizable market and product opportunity below the A300 and above the 727-200. This involved replacement of the various 707 and DC-8 airplanes used in this range-size area. These aircraft had excessive range capabilities for the market and were also of an older and less efficient technology, thus of diminishing credibility with respect to market needs. The efforts in the general 1973 time period (7X7 program) were oriented toward the medium-range market, but with transcontinental growth. A Japanese industrial team also joined the program as an additional risk-sharing design and production associate.

There ensued a long period of study during which a three engine configuration appeared best, particularly with the transcontinental potential in mind. This consideration spawned Pratt & Whitney's development of the JT10D, sized for a 200 passenger 7X7 tri-jet configuration with transcontinental capability. However, it later became apparent that a twin engine configuration could be designed for the job with better efficiencies, and the program was so reoriented.

One of the most agonizing decisions was that of cross section. Extensive studies and work with the airlines throughout the 7X7 program identified the lower lobe configuration requirements and also the need for inclusive tour provisions. What was to emerge from this work was confirmed in the 767's larger cross section, which provides a standard seven abreast seating with a dual tight eight abreast inclusive tour provision. The cross section also provides a container and cargo capability that features an eight-foot wide flat floor.

The program's long development history was a plus in many respects, and this is summarized in figure 61.

767 Development

- Unusually long preparation period prior to go-ahead (about six years) allowed exceptional opportunity for orderly program
  - Preparation stressed product and cost definition
- An international collaborative effort from start with Italians and Japanese acting as risk sharing, design and production associates
- May be the most smoothly executed commercial development program in history

Figure 61

The 767 is also the first new aircraft to incorporate the full digital flight management system that was generated from the U.S. SST, then on through the NASA 737 demonstrator to become the new standard, which will eventually be applied to all western world major aircraft. The 767's long development period has also provided for the most thorough pre-production planning that has ever been accomplished. The principal decisions in the 767 program were:

1. The decision on the 7X7 program to carefully prepare for a medium-size, medium-range airplane deliberately placed below the DC-10/L-1011/A300 and above the 727-200.

2. The decision to include Italy and Japan as risk-sharing design and production associates.

3. The decision to develop an all new cross section specifically designed for fuel economy in the specific market intended and offering improved passenger accommodations with an inclusive tour backup.

4. The decision to orient the program specifically to a two engine configuration.

The 757 Program

The need for a successor to the 727 was recognized in the early 1970s. At first it was felt that a wide body version of the 727 with CFM56 engines could be generated, and considerable work was done on a configuration, the 727XX. Later a less ambitious but still expensive derivative (727-300) came close to go ahead but was rejected by United Airlines at the last minute. Fuel prices had escalated rapidly and it became quite apparent that a new wing would be required. The 757 was originally configured as a smaller airplane, but with a new wing, and with a two engine, under-wing configuration, much as it remains today. The cockpit was initially a two crew member modification of the 727 cockpit, but later the new 767 cockpit was adopted along with a great deal of 767 commonality. The design is now a well integrated, *all-new airplane*.

The present 757 size came from the beliefs of the two starting airlines,British Airways and Eastern Air Lines, that the traffic would support the size, and that fuel burn per seat mile would be improved by a size increase. The size was also somewhat influenced by the engines (General Electric and Rolls), both derivatives of larger engines that were down-sized to fit the 757. The smaller size JT10D, that had been developed to fit the three engine 767, was not a candidate when the 757 was originally committed. This situation dramatically changed when Pratt & Whitney offered to completely resize their engine for the 757 as the PW2037. The initial 757s will be delivered with the Rolls engines. The Pratt engine will not be delivered until one-and-a-half years later. The 757 has the *same* direct operating cost in dollars per mile as the 727-200 but has 50 additional seats. The basic 757 decisions were:

1. To optimize the airplane as an all-new design with 727 airplane operating cost but with much lower seat mile and fuel costs.

2. The Pratt & Whitney (and Boeing) decision to build an all-new engine for the 757 (the PW2037).

3. The Rolls-Royce decision to compete by offering a major derivative engine, making the aircraft competively available with either Rolls or Pratt engines.

The 757 and 767 are key members of the new airplane family as is shown in figure 62.

The Boeing New Airplane Family

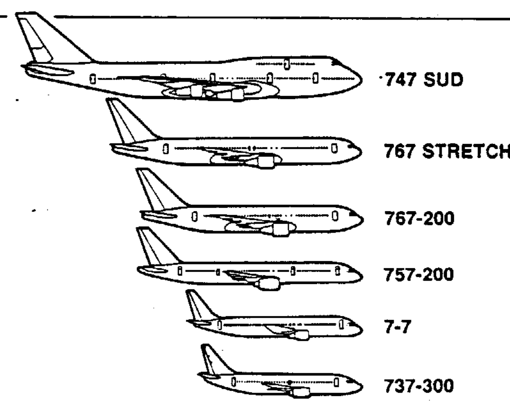


Figure 62

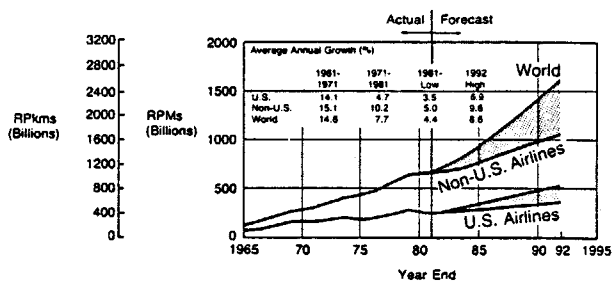
Ultimately, the airplanes noted will incorporate as much commonality as feasible.

Airplane Sizing Considerations

The basic fundamentals of airplane size, of course, include growth in revenue passenger miles. This must be modified by considerations of airline service proliferation and competition, which would drive the size below percentage increase in RPMs, and by airport and air space constraints, such as airport terminal slots, and peak period ATC capability, which would tend to keep the size up. All of the original wide body airplanes (747, DC-10, L-1011, and A300) were conceived at a time when RPM traffic growth throughout the world was close to 15 percent per year. It was fundamentally from this 15 percent number that the 11 percent shown in figure 41 was selected for the basic sizing of the 747.

In the decade that followed, traffic growth severely diminished. This and anticipated growth rates for the future are shown in figure 63.

World Revenue Passenger Traffic
All Services

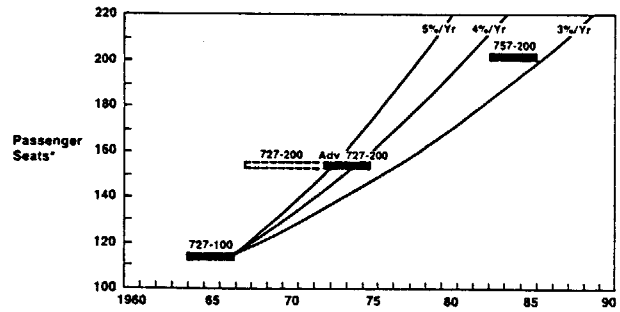


Note: Excludes U.S.S.R. and non-ICAO nations, but includes Taiwan and all-charter carriers.

Figure 63

In addition to the lower traffic growth, U.S. domestic competition proliferated by reason of airline deregulation enacted in late 1978. On a somewhat similar basis, international routes increased, due in part to more liberal bilaterals allowing more competition on both long and short range international segments. We are currently in a most unusual situation which finds the world's traffic growth stabilized and the U.S. growth negative. This has not happened before, and all forecasters, I believe, predict future growth within range of the bands shown. We tend to swing in cycles and to design our airplanes oversized when the growth cycle is high and undersized when the growth cycle is low. Since successful airplane programs must be of long duration, it is not appropriate to design new airplanes such that they will be a perfect market "fit" on the year of introduction. As noted in the discussion relative to figure 41, it is proper to design for a market fit three or four years after initial introduction. Figure 64 carries this philosophy to the relationship between the 727 and the 757.

757 Sizing



* Seating Capacities on 10/90, 38/32, Modern Stowage Bin Basis

Figure 64

Considering *all* the factors we've noted, figure 64 shows that the 757 is based on a "vehicle size for similar job" growth assumption of about three percent per year. This is far enough below the predicted growth values (highs and lows) of the next decade to account for deregulation and other causes of route proliferation. Unlimited proliferation is not feasible by reason of airport and airway constraints. The PATCO strike has given us a preliminary view of constraints that would have otherwise surfaced several years from now.

Keeping in mind the factors noted, and adding considerations for DOC and fuel burned per airplane mile and per passenger mile, one must conclude that the 757 is on the low side of the replacement spectrum for most of the world's 727 aircraft. The 727's replacement will be by the 757, 767, and A310 aircraft. The latter two depend on a growth from the 727 of about four percent a year instead of three.

The current fixation on a "150 passenger" airplane can only be based on the requirement at the bottom of the trunk system replacing the DC-9 and 737. It most assuredly has nothing to do with replacement of most of the 727s, and the market for such an airplane should be expected to be smaller by far than the combined markets for the 757, 767, and A310. Decisions in sizing must include the following:

1. The overall long-term airplane size for a given job has increased and will continue to do so. The only question is how much.

2. Past decisions which have resulted in improperly sized aircraft indicate that one must moderate thinking between "highs" and "lows" of market growth and seek a middle ground.

New Commuters

There is a worldwide need for new commuter airplanes that are as efficient as possible. In the United States this need has been accelerated by deregulation, which has created a large number of new commuter companies to service short-range segments dropped by the major airlines. To meet the world need there are a number of new programs aimed at the market. Four of these are displayed in figure 65.

Four New Commuters

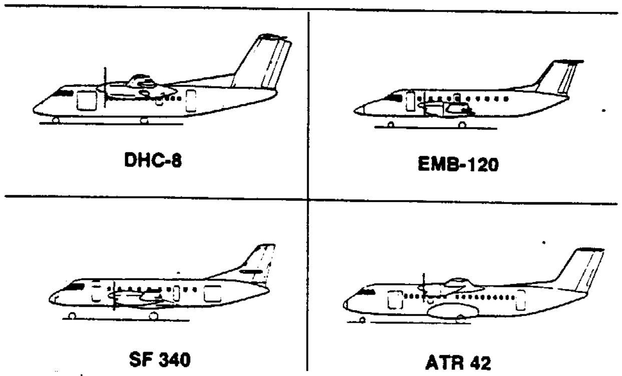


Figure 65

The DHC-8 is a new wing, two engine derivative of the existing four engine DHC-7. It has a four abreast body. It's development is funded by the Canadian Government. The SAAB-Fairchild 340 is an all-new airplane with development substantially funded by the Swedish Government. It involves a joint Swedish-American design accomplished at Fairchild with assembly in Sweden. The Embraer 120 Brasilia is a successor to the Bandeirante and is funded by the Brazilian Government. The ATR 42 is a joint effort between Aerospatiale and Aeritalia and is jointly funded by the French and Italian Governments. Three of the airplanes use a Pratt & Whitney engine manufactured in Canada, and one, the SF 340, uses the General Electric CT7 produced in the United States.

The commuter market has its own growth and constraint situation and growth is quite high. Financially, this market is difficult to design to since the aircraft must be complex enough to fit into the modern airline environment, yet the commuter airlines capital formation capabilities are limited.

This situation illustrates the affordability dilemma confronting the U.S. commuter industry. It is questionable that its risk environment would allow a U.S. company to participate, except in a partnership that would provide foreign risk capital. Also, government supported or not...our past experience would indicate a reasonable prediction of failure for one or more of the programs illustrated in figure 65. Despite the turbulence of the program decision environment, there is a predictable thread that emerges, which we'll examine next.

VII. Lessons Learned

The threads of predictability that we've picked from program decisions form a series of lessons learned. The "learned" appears open to question, since some persist as mistakes repeated. Some have been learned at huge expense...including failure of the company involved. A majority will still be applicable within the environment of internationalism and affordability on the road ahead. There will be new lessons ahead as well, and some of these may be emerging very soon. Nonetheless, the following are offered for consideration:

1. Engines take at least a year longer for development than do aircraft. Funding for a new engine independent of a specific airplane program is advisable unless interim engine use is contemplated or a large risk knowingly accepted.

2. When the market is ready, the successful manufacturer may have to *go*. The eventual prize sometimes goes to the company which is fast on its feet and strong enough...technically and financially.

3. A competitive loss sometimes motivates the loser more than it does the winner. Such possibilities should be examined by both, and in a timely manner.

4. Generally, the highest validated state of the art has produced the longest term, and therefore, the most rewarding program. The

key word is *validated* and the potential for unanticipated costs and risks must be weighed and program actions to minimize them taken.

5. The good designer provides for growth without allowing the accumulation of design team security cushions, which may make the program unsuccessful and invalidate its need.

6. If one wishes to build commercial airplanes, one must be prepared for investments of about twice the original nonrecurring costs. These may cover a ten year period (as in the 727 and 747) or a three year period (as in the 707 and DC-9). A manufacturer must be prepared for either.

7. Commercial programs require "staying power" to carry them over market depressions or unexpected actions by competitors or governments. This is a requirement that will be accentuated in the future.

8. The use of a parallel design team or "red" team to examine alternatives and to play a major devil's advocate role may be a valuable procedure. If used, the team must have access to technical and financial resources and cannot be "throttled".

9. A good airplane requires a great deal of "up-front" money *before* go ahead if lowest recurring costs are to be achieved. This includes commitments for new technology machinery, training, and equipment. There is no provision in U.S. Government acquisitions procedures to adequately accommodate this need.

10. Government paper competitions that start production programs without prototypes *may* result in selection of the bravest and least informed winner, with uncorrectable consequences.

11. The readiness of technology is a long and expensive process and will frequently warrant funding stimulation. The payoff, when the need and technology readiness match, can be enormous.

12. Changes in a manufacturer's management team can change the company's responsiveness to problems and its ability to *use* basic company strengths. This does not mean that changes should be avoided...only that they should be well considered and deliberate.

13. Past decisions that have resulted in improperly sized aircraft indicate that one must moderate one's thinking to seek a middle ground between the "highs" and "lows" of market growth, competitor proliferation, and airport constraints.

14. A good airplane program requires at least two years of concentrated pre go-ahead study and planning. The penalty for omitting this phase is greater exposure to large changes late in the development program.

15. There is no substitute for understanding the real commercial or military market need and opportunity, especially the predictable change with time. The job of the airplane designer is to design the airplane the customer wants *while* still meeting or providing for the product criteria the customer will want five years after all the basic decisions are made.

16. Defining what constitutes "success" in the program is a necessary exercise. Designing two (or more) "head on" airplanes for the same market may result in financial failure (on normal profit criteria) of one unless the market is unusually large or segmented.

17. A good airplane must be designed to meet a broad spectrum of market requirements. Compromises are essential. In the commercial case, *designing* to the detailed requirements of one customer can result in an unsatisfactory program. *Starting* the right program with one customer while designing to a broad market is another matter and can be satisfactory.

18. Product support after delivery is just as necessary as a successful design. It is a commitment burden that grows with success.

19. In the world competition to acquire the most rewarding technology, the prize will go to the nation or manufacturer who runs the fastest. He who stops running will lose, regardless of lead or protection.

20. The most constructive emphasis today or in the future is to build a superior product at the lowest manufacturing cost.

VIII. The Road Ahead

Early in this discussion, we noted that the future contained significant technological advancement potentials. Aeronautics has not reached its maturity and the efficiency gains of the past half century will be continued well into the next. Thus, new program starts prior to the end of the century could *potentially* supersede every airplane now flying, either civil or military. While the road ahead contains an abundance of technical opportunities, capital availability and other financial challenges accompany these opportunities. Furthermore, the long technology readiness process will be at least as difficult and at least as misunderstood.

The road ahead will also require that the manufacturer better understand the real market needs, and in cooperation with the customer, go through the agonizing process of compromise that has formed every successful aircraft program. The slogan "back to the drawing board...back to the bank" shown in the earlier cartoon is symbolic of the process, except now the drawing board has been replaced by a computer terminal, and the bank may be replaced by a trading company. The engine situation will be similar.

We have noted lessons learned and most will be applicable in some context to the future as well. So what will be different? The answer, from many aspects, is "everything."

National Policy and Planning

To an ever greater extent, aircraft have become an increasingly visible part of a much larger and complex high technology, international, commercial, and military scene. In this arena, national security implies a context beyond that of conventional arms balance...it implies a state of *national economic security*. In this field the United States finds itself the exception rather than the rule among the western democracies. For example, economically, the U.S. tends to formulate its domestic and foreign policy in terms of *process*; it sets rules and lets things turn out as they may. Elsewhere, such policy is more often defined in terms of desired economic outcomes; if the rules do not seem to be producing desired *results*, the rules will be changed. U.S. relationships between government and industry tend to be adversarial, while those elsewhere tend to be mutually supportive. The United States has great trouble forming and executing a long-range plan, while other countries, to a greater extent, tend to perform national planning in a more consistent manner. In most cases this has little to do with "democracy" and is more cultural or attitudinal in nature. Whether industries are privately or government owned, or a combination of the two, has some effect, but generally is not a deciding factor.

The U.S. is the major contributor to the western nations' umbrella against Soviet aggression. This means that a greater share of other western nations' GNP or national budgets can be allocated toward stimulation of industrial output, including aircraft.

What has this got to do with aircraft decisions? A lot. For example, if the countries support their aircraft industries by providing capital and by reducing risk through mechanisms of one type or another, or with low interest loans, then U.S. companies have little alternative but to seek alignments with foreign companies having access to such devices. U.S. companies are reluctant to align in mutual support on commercial programs, partially due to their historic competition...which in some cases no longer really exists. A much more forceful reason is fear that they will be exposed to anti-trust litigation. It's *not* the anti-trust law that is the problem, it is the history of an unpredictable and sometimes decade long process of interpreting the law. The volatility of aircraft programs makes exposure to such discontinuity unendurable, and one simply avoids the issue in favor of foreign teaming.

Military Considerations

The technology base for commercial and military aeronautics is the same...compartmentalization is generally not possible. Thus, such teaming exposes the U.S. to some amount of technology transfer which could go to third parties. However, since technology generally has a time value and Western Europe and Japan are running about as fast as the U.S., the transfer value is often more imagined than real, and reverse flow will be of greater and greater value.

Beneath both military and civil "name" manufacturers lies a vast network of suppliers. Programs dip into this network, and accomplishment would be impossible without it. The real "power" of American industry is here, and the reason this industry has been able to accomplish large national programs is because it exists. The start-stop-sputter character of U.S. military programs does far less to maintain the supplier base than do the more consistent commercial programs...so military preparedness, to a great extent, rests upon decisions affecting the health of the commercial industry. Erosion is not apparent until some form of national emergency arises, and it is then much too late to rebuild.

Elements of the base will be tied into foreign entities (or foreign owned entities) because the continuity and strength are improved and risks reduced by so doing.

U.S. military procurement tends to have two flawed characteristics, in addition to its burdensome procedures built to do business under rules of public accountability and potential protest. The real problems are: (a) unreliability of funding, and (b) lack of "up-front" money. Multi-year procurement, if it *really* became the norm and not subject to the whims of ensuing Administrations and Congresses could ameliorate the first, but the second is even more difficult, unless finalists in a government competition are authorized to implement machinery and training for productivity and low recurring costs. In such case, the loser would need to be protected from loss. As it is, commercial airplane manufacturing will be sounder and cheaper, and there is no foreseeable cure for the military problem. As a further consideration, U.S. military aircraft procurement has drifted into a combination of risk reduction focus and audit trail protection which, for many programs, means lower technology than will be available from foreign sources. A means of stabilizing military programs in any country is through foreign sales, and the trend toward a common international technological base is accentuating competition.

Commercial Market Considerations

The U.S. itself was, at one time, a large part of the total world commercial airplane market. Such is no longer true and there are now really three major markets of varying size: the U.S., Western Europe, and all the rest. The latter market is fragmented, but it includes a very important component...developing economies that will become major customers of the future.

Historically, the U.S. airline market has gone through immense cycles of feast and famine. When airlines make money, they buy aircraft. When they don't make money, they can't buy aircraft. U.S. airlines have been highly leveraged and, with predicted long term traffic growth, this will not change. Thus, access to the foreign markets is essential for a U.S. manufacturer if it wishes to reduce risk of financial failure in the cyclical domestic market slumps, and if it is to maintain the decisive economy of scale and program longevity. The governmental ownership of both manufacturers and airlines in Europe has largely closed this market to competitive U.S. products, which are thus very dependent upon the remainder of the world market for financial stability. However, much of the remainder is leveraged due to its growth, and is thus very subject to financing terms. European industry has government support for exports that is generally greater than EXIM and is available with more assurance of continuity.

Very simply, the cost of money has become difficult, and world airline deals may involve far more than aircraft and financing terms. In many cases they are decision drivers and negotiated as government-to-government deals involving other things the buying government wants...almost on a barter basis. Examples are technical assistance in nuclear or petrochemical fields, arranging markets for products or raw materials, military equipment, or bilateral treaties yielding landing rights or possibly military and civil advantages of some other kind.

The GATT offers rules governing a limited portion of these considerations, and some stability may be obtained through its administration. However, procedures are long and facts difficult to prove. U.S. companies must operate in a complex world linkage environment that involves U.S. government decisions. Private trading companies may be deficient in scope. U.S. government and industry, it would seem, are at a crossroads.

Future Considerations

The correct U.S. answer is better aircraft at a lower cost. The role of manufacturing technology is in ascendancy, because it represents a very meaningful solution to affordability. This does not mean an era of simple, cheap products, since the marketplace will call for greater operating efficiency, but at affordable prices. These demands will still dictate technological superiority for the winner. However, complexity must be justified by cost-benefit considerations to an ever greater extent. The situation is also exacerbated by some additional circumstances. Our changed national priorities have gradually increased social obligation until all else is consequentially reduced, and the Federal budget squeeze appears to be with us for decades.

These, then, are the underlying reasons for our new era of "internationalism and affordability" into which the U.S. is already immersed...apparently without recognition by many, in its international context.

Internally the U.S. is still a "free market" for breakfast cereal...but airplanes, whether commercial or military, are in an international environment...one in which success may be dependent upon markets outside the U.S. and even outside Western Europe. Each decision now takes on a new dimension...the most complex dimension of them all.

The bottom line for the U.S. is unquestioned excellence at low manufacturing costs. It is a hard combination. It requires economies of scale, but scale requires an international market...and so on through the complex circumstances already described. The road ahead is surrounded by this environment.

IX. Conclusion

Aircraft programs, both commercial and military, differ, and their individual characteristics will affect the multi-billion dollar decisions made. It has not been my intention to say that any formula can be derived to assure success. There are, however, some trends and lessons that appear to override program individualism. If these have been largely identified, we have been successful.

Even the word *success* must be defined, since in our international world it will mean different things to the companies and governments involved. In many cases success will depend as much on decisions that are made outside the program as those made from within.

Many of the decisions we have noted are factored to market needs and their correct timing...the areas that historically have been the most immediate and critical. This has not really changed in the last 40 years, and I would expect that market needs and timing will also weigh heavily in future decisions.

Successful airplane programs are usually large and long term, almost by definition alone. Commercially, the phrase *bet the company* often applies, and military programs cannot be very constructive for either manufacturer or government if funding is on an unreliable start-stop basis. Advanced technology should be applied if a long program life is to be achieved. The importance of technology validation before application cannot be overemphasized. It requires substantial continuity of effort long before application is defined. Similarly, the fundamental base for manufacturing efficiency must be addressed before a program is started...not during it.

Beyond these influences are others that are exerting a change. *Internationalism* and *affordability* are the two that this discussion has particularly noted. By their nature, we cannot overlook a third...that of governments. Combined, these are powerful forces. They are changing the market's character and exerting a sizable stress on the manufacturing industry. What this implies for tomorrow is the question for today.

We live in a small world, and this nation is but one of the established players. All are not marching to the same drummer, and the rules of the competition are not constant. Our technology got us to the playing field, but will it get us to the goal? Can we adapt to this difficult situation? I believe the answer is yes. However, it will take understanding and judgment in the decisions we make. It is toward this understanding...in the field of aircraft...that this lecture is respectfully submitted.

Acknowledgement

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