

MARKETING STRATEGY IN THE COMMERCIAL AIRCRAFT ENGINE BUSINESS:

A CASE STUDY

by

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Submitted to the Sloan School of Management on April 30, 1986 in partial fulfillment of the requirement for the Degree of Master of Science in Management.

ABSTRACT

The Commercial Transport Aircraft Engine Business is a high technology, long lead time, low volume, high risk business requiring massive infusions of capital for a manufacturer to remain competitive. Against this backdrop, the commercial product development strategy of General Electric's Aircraft Engine Business Group (AEBG) has been to share the risks and the gains with the government by using military engine development programs as springboards for new commercial engine offerings. However, in the face of bulging budget deficits and mounting pressures to curtail military spending, it is unlikely that the Department of Defense will divert any significant amount of its resources to help fund the development of the next generation of subsonic transport aircraft engines, preferring rather to purchase off-the-shelf commercial engines.

A second element of AEBG's product development strategy, often shared by the other major competitors in the commercial jet engine industry, has been that of meeting the competitor's latest product offerings with engines that are derivatives of existing products. However, the potential reward for introducing such "me-too" products simply no longer justifies taking the risk, given the \$1 billion investment required. Marginally better engines do not create sufficient new value to warrant the price premiums necessary to achieve an adequate return. To reap profitable price premium, a major technological advancement is needed in order to achieve the required degree of product differentiation. This thesis critically examines one element of AEBG's product differentiation strategy for the 1990's and beyond.

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CHAPTER 1

INTRODUCTION

The General Electric Company has operations in nine main industry segments; consumer products, major appliances, industrial systems, power systems, materials, technical products and services, financial services, natural resources and aircraft engines. Revenues for 1985 were about \$29 billion, placing it in tenth position on the Fortune 500 scoreboard, with net earnings of about \$2.3 billion. A breakdown of financial results by industry segment is presented in Table 1.1. The Aircraft Engine Business Group (AEBG), accounted for about 16% of both revenues and net earnings. With major plants in Lynn, Massachusetts and Evendale, Ohio (AEBG headquarters), satellite manufacturing facilities scattered across North America, and service facilities around the world, AEBG is the leading producer of gas turbine engines in the free world, having taken the lead last year from Pratt & Whitney (a division of United Technologies). The bulk of revenue comes from sales of aircraft engines, both for military and commercial use.

As can be seen from the bottom line figures in Table 1.1, sales revenues for the company have been essentially flat for the past five years, while net earnings had been growing at between 10 and 12% per year, until they leveled off in 1985. Most of this earnings growth has been derived from margin expansion. However, this trend will be difficult to sustain, and similar net earnings growth in the future will require revenue growth. AEBG is being heavily counted upon to provide a major portion of the revenue growth necessary to maintain corporate net earnings growth at acceptable levels. By the end of the

decade of the 80's, AEBG is expected to account for up to 20% of total revenues.

TABLE 1.1
Revenues and Net Earnings by Industry Segment

(Years end 12/31) (In millions)	1985	1984	1983	1982	1981
REVENUES (sales plus other income)					
Consumer products	\$ 3,569	\$ 3,858	\$ 3,741	\$ 3,943	\$ 4,202
Major appliances	3,617	3,650	3,078	2,751	3,132
Industrial systems	4,571	4,274	4,228	4,705	5,364
Power systems	5,552	6,010	5,878	6,093	6,015
Aircraft engines	4,712	3,835	3,495	3,140	2,950
Materials	2,459	2,241	2,060	1,791	2,050
Technical products and services	5,197	4,803	3,823	3,546	3,005
Financial services	499	448	397	286	239
Natural resources	--	609	1,579	1,575	1,722
Corporate items and eliminations	<u>(904)</u>	<u>(792)</u>	<u>(598)</u>	<u>(638)</u>	<u>(825)</u>
Total	<u>\$29,272</u>	<u>\$28,936</u>	<u>\$27,681</u>	<u>\$27,192</u>	<u>\$27,854</u>
NET EARNINGS					
Consumer products	\$ 217	\$ 228	\$ 163	\$ 146	\$ 225
Major appliances	224	223	156	79	82
Industrial systems	143	73	84	148	212
Power systems	449	486	439	384	242
Aircraft engines	381	251	196	161	149
Materials	266	262	182	148	189
Technical products and services	261	232	210	218	144
Financial services	406	336	285	203	145
Natural resources	--	117	301	318	284
Corporate items and eliminations	<u>7</u>	<u>72</u>	<u>8</u>	<u>12</u>	<u>(20)</u>
Total	<u>\$ 2,336</u>	<u>\$ 2,280</u>	<u>\$2,024</u>	<u>\$ 1,817</u>	<u>\$ 1,652</u>

SOURCE: General Electric Company, Annual Report 1985, Fairfield, CT, 1986, p. 34.

During the 1970's, AEBG's commercial aircraft engine business grew from an almost non-existent status to a major force in the commercial transport market, and is approaching parity with AEBG's military engine business. This trend of increasing importance of the commercial engine business is expected to continue as the U.S. budget deficit is beginning to receive more than lip service by the Congress with the recent passage of the Gramm-Rudman-Hollings deficit reduction bill (requiring a phased reduction of the deficit to zero by 1991). Under the provisions of this, or similar budget-reducing measures, AEBG's revenues from the military side of the business will likely flatten-out and may actually decline by the end of the decade. Budget cuts in the area of military spending are not the only cause for concern, as the Department of Defense has embraced a dual sourcing concept whereby they are splitting orders between two engine manufacturers for the same engine, thereby eroding both revenues and margins. Thus, sustained growth of AEBG's commercial engine business is essential.

Fortunately, just as the adverse effects of these trends in military engine contracts are expected to begin taking their toll on AEBG, a commercial aircraft buying binge by the airlines is anticipated throughout the remainder of this decade. Gail Landis, a securities analyst at Sanford C. Bernstein & Company expresses this rather generally held view as follows:

The airline industry is on the verge of a sharp profit recovery that will lead to a major equipment purchasing cycle; this cycle will benefit the major aircraft manufacturers and their suppliers. ... The mainspring of the cycle will be the combination of limited capacity additions and strong

traffic growth [which] will be impelled by continuing world-wide economic recovery. ... We expect airline capacity to be 'sold out' by 1987, causing yields to rise sharply, producing record operating profits for the airline industry, and thus establishing the basis of a strong new equipment cycle.¹

AEBG's commercial engine business is fairly well-positioned to ride the crest of this equipment-buying wave into the next decade. But what of the early-to-middle 1990's and beyond? The aircraft engine business is a very long lead time business, as it typically takes about seven years to bring a totally new product to the marketplace. Therefore, this question must be addressed now, and the costs of a wrong answer are incredibly high. It may cost over \$1 billion to design, to develop, to certify an all new engine, to tool up for its production and to support the aircraft manufacturers' certification efforts. These costs must be spread over a production run of say 1,000 engines in order to keep the price of the product competitive. Yet, there is a significant risk that long before such a volume of the basic product is produced, costly product improvements must be introduced to keep the product's performance competitive, thereby adding to the net earnings deficit. A manufacturer is constantly chasing his tail, i.e., in order to sell more to increase revenues to offset expenditures, he must spend more. Thus, it is very difficult to determine when and if a given product actually breaks even. In summary, the commercial jet engine business is a high technology, long lead time, low volume, high risk business requiring massive infusions of

¹Gail Landis, "GE's Market Place," Bernstein Research, Sanford C. Bernstein & Co., Inc., New York, Apr. 1983, p. 18.

capital to remain competitive.

Against this backdrop, AEBG's commercial engine development strategy has been to share the risk and cost of its commercial business with the government by using military engine development programs as springboards for new commercial engine offerings. This strategy has spawned AEBG's two families of large commercial high bypass turbofan engines; the CF6 family which is used on the DC-10, A300/310 and 747/767, and the CFM56 family which is used on the new 737's and retrofitted DC-8's. These families were derived from the TF-39 and F101 military engines respectively. Lest the reader feel that AEBG is getting a free ride at the American taxpayer's expense, several points bear mentioning. It should be noted that AEBG does carry a considerable amount of the financial burden, as it typically plows back 20% of its revenues into research and development (R&D). This is a much higher proportion than reinvested by most American industries, which typically spend between 3 and 10%. Furthermore, AEBG reimburses the government in the form of healthy recoupment fees paid to the government on each delivered commercial engine derived from a government-funded design. In addition to being reimbursed, the government benefits from the fact that engines in commercial service typically accumulate operating hours at many times the rate of engines in military service, and problems are uncovered and corrected before they ever appear in military service. Furthermore, these engines are used on military aircraft such as the KC135, KC10, and the E-4. Thus, this is a very symbiotic relationship.

Unfortunately, this strategy of sharing the risks and the gains

of the commercial side of AEBG's business with the government is becoming untenable. It is very unlikely that the military will divert any significant amount of its scarce resources to help fund the development of the next generation of sub-sonic transport aircraft engines. The economic realities are such that in this area, the military is turning to "off-the-shelf" commercial engines as indicated above, thereby saving the bulk of their R&D budget to devote to advanced, high performance engines for special military applications, particularly for supersonic vehicles. The bottom line is that an already risky business has become riskier still.

A second element of AEBG's strategy is also becoming less tenable; specifically, a strategy of meeting the competition's latest product offerings with engines that are derivatives of existing products. This strategy works for a period of time following the introduction of a radically new design which creates tremendous value for the market, as was the case when jet engines first displaced piston engine driven propellers, or when turbofans replaced turbojets. However, having taken such a quantum jump, each successive incremental improvement to the basic design comes at a higher incremental cost, while creating incrementally less new value. Obviously, when playing this game, one ultimately reaches the point where the new value created does not justify the cost (i.e., the customer will not pay the incremental price increase needed to achieve a satisfactory return). AEBG is approaching that point with its current families of commercial engines, particularly with the lower thrust CFM56 family whose supremacy will be severely challenged in the late 1980's/early 1990's by a new competi-

tive engine, the V2500. This thesis examines how AEBG plans to meet this challenge, while contributing to growth in GE revenues and net earnings.

Let us pause momentarily to briefly look at how we will proceed with this examination. This thesis is divided into six chapters, including this, the introduction. Chapter 2 provides the reader an elementary education in jet propulsion and gas turbine technology. This, hopefully, will provide the foundation necessary for the reader to better appreciate subsequent discussions on alternative technical approaches to this marketing challenge. In this introductory chapter, we have taken a very quick look at the characteristics of AEBG's business. Chapter 3 expands the field of view to encompass the broader industry of which AEBG is part; i.e., the commercial air transport industry which includes the airlines and their suppliers (e.g., aircraft and engine manufacturers). Given the long lead time, high product development cost nature of industry, it should be obvious that a good long range market forecast is an essential element of a sound marketing strategy. Chapter 4 presents my findings on how many of the key players in the commercial aircraft and aircraft engine industry develop their forecasts, and examines their forecasts for the 1990's. Chapter 5 discusses the implication of these forecasts vis a vis what market segment should be the focus of current product development efforts, and discusses where the major commercial aircraft and engine manufacturers are directing their efforts. Finally, Chapter 6 presents my analysis of the market and of AEBG's marketing strategy.

CHAPTER 2

JET ENGINE PRIMER

AN HISTORICAL PERSPECTIVE

The earliest applications of jet propulsion actually pre-date the advent of mankind, as denizens of the deep such as squid and cuttlefish jet propelled themselves through the primordial seas. The first application of the principles of jet propulsion by man is credited to Hero of Alexandria who, in about 100 B.C., invented a device known as an Aeolopile.

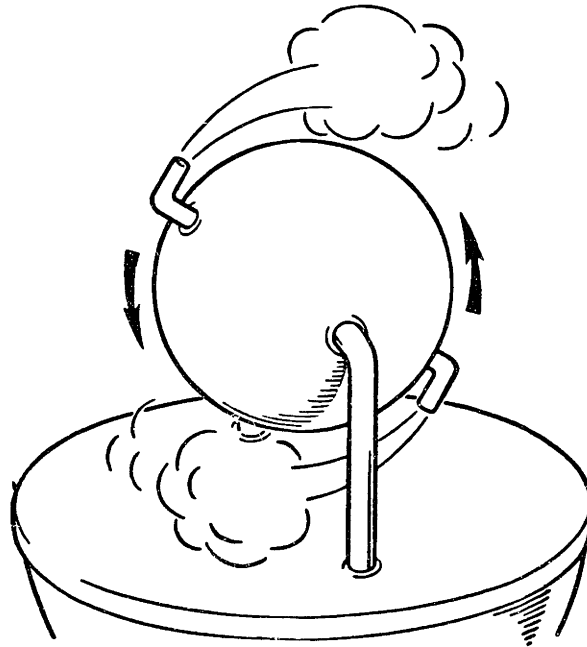


FIGURE 2-1 HERO'S ENGINE

SOURCE: Rolls Royce Limited, The Jet Engine,
Publication Ref. T.S.D. 1302, Derby, England,
July 1969, 3rd Edition, p. 2.

This device, pictured in Figure 2-1, converted water into steam which it directed through two jet nozzles on a spherical vessel. The nozzles

were arranged and the sphere mounted in such a manner that the escaping steam caused the vessel to rotate. Then, in about 1200 A.D., the Chinese invented gunpowder which they used to propel their rockets and fireworks displays. In the early 16th century, Leonardo da Vinci developed a machine called the chimney jack which used the energy from hot air rising from an open fire to spin a turbine-like wheel which drove a roasting spit.

The laws of motion upon which all jet propulsion devices are based were developed in 1687 by Sir Isaac Newton. Newton is also credited with the design of a jet-propelled horseless carriage which was driven by steam escaping through a nozzle facing rearward. Thus, throughout recorded history there are numerous examples of the use of Newton's reaction principle. However, there was a gap of nearly 2000 years from the first recorded use to the point at which technological advancements in the areas of engineering, metallurgy and manufacturing made jet propelled flight a reality on August 27, 1939 when the HE-178, a German aircraft lifted off.

America entered the jet age in October 1942 with the first flight of the Bell XP59A aircraft which was powered by a General Electric IA turbojet engine. The IA engine was developed from plans carried to this country from England by Sir Frank Whittle, generally considered to be the father of the jet engine (even though the Germans were the first to actually fly a jet-powered aircraft). America provided a safe haven for the development of the Allies' jet engine, and General Electric was selected to work with Whittle to develop the engine because of its experience under Dr. Sanford A. Moss with turbosuper-

chargers (very similar devices to jet engines, lacking only the combustion chamber and associated systems). For security reasons, Whittle carried the plans for his design to this country in his head. The story goes that he dictated the specifications for his engine to his secretary while sitting on the beach in Swampscott, Massachusetts, a few miles from the General Electric facility at which the engine would eventually be produced.

BASIC THEORY OF OPERATION

The underlying principle of jet propulsion is Sir Isaac Newton's Third Law of Motion which states that for every unbalanced force applied to a body, there is an equal and opposite reaction. There is a simple analogy to jet propulsion of aircraft with which virtually everyone is familiar and which, therefore, serves as a useful tool in explaining the phenomenon. When a balloon is inflated and released with the stem unsecured, the balloon moves in a direction opposite to the escaping air.

It is commonly misinterpreted that the escaping air pushes against the atmosphere, thereby propelling the balloon forward. In fact, the reaction of the balloon is due solely to forces acting on the balloon, not on the air outside the balloon. When inflated, the pressure inside the balloon is greater than that of the outside air. Let us call this pressure differential P_d . If the stem is tied, the internal pressure pushes equally on the entire inside surface of the balloon as depicted by Figure 2-2a. However, if the stem is opened, a force imbalance is created, i.e., there is no internal pressure being felt by the balloon at the point of the opening, while there is still

a force applied to the opposite surface. This unbalanced force (equal to P_d times the area of stem opening) is evidenced by the balloon moving in a direction opposite to the opening and the escaping air as shown in Figure 2-2b.

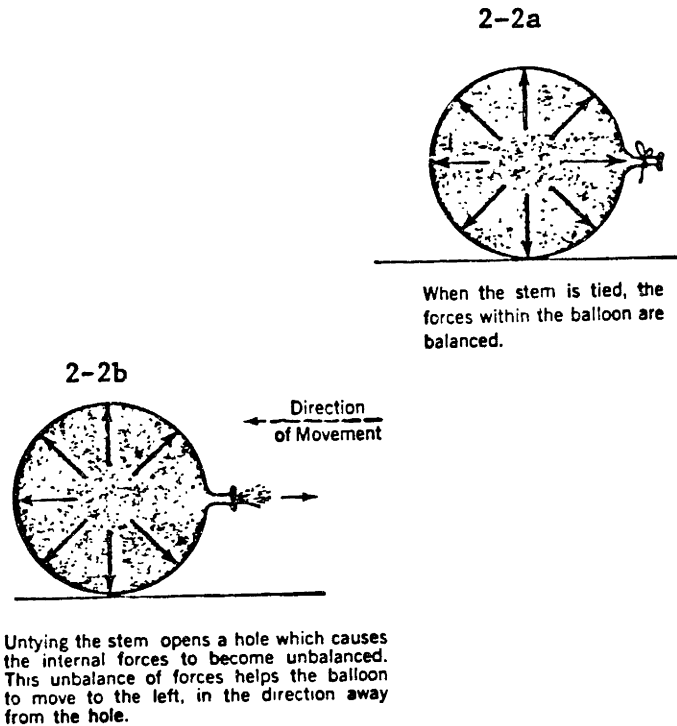


FIGURE 2-2 THE BALLOON ANALOGY

SOURCE: N.E. Borden, Jr., Pratt & Whitney Aircraft, Jet-Engine Fundamentals, Hayden Book Company, Inc., New York, 1967, p. 11.

The movement of the balloon is relatively short-lived because the pressure inside the balloon quickly reaches equilibrium with the pressure outside the balloon (i.e., P_d goes to zero), and the unbalanced force disappears. If air could somehow be continuously pumped into the balloon at a sufficient pressure and flow, the movement of the balloon could be sustained. A jet engine is similar to such a balloon

in that it carries its own compressor to maintain the necessary flow and pressure to sustain the propulsive thrust.

The thrust (reactive force) produced by a jet engine can be expressed in terms of Newton's Second Law of Motion (more commonly known in the form $F = ma$) by the following formula:

$$F = \dot{m} \Delta v$$

where \dot{m} is basically the mass flow rate of air through the system, and Δv is the change in velocity of the air between the points at which it enters and exits the system.

Thus, there are two dials, if you will, which can be adjusted to produce thrust, i.e., mass flow or change in velocity of air through the system. It should be noted that the same fundamental relationship applies to the thrust produced by a propeller. In the case of a propeller, the change in velocity is relatively small, but the mass flow is enormous. In the case of a turbojet engine, the opposite is true.

TYPES OF JET ENGINES

There are three generic forms of jet engines, or more properly - gas turbine engines, that have been used to power commercial aircraft; the turbojet, turboprop and turbofan. We will now take a brief look at each of these engines.

Turbojet - A turbojet engine is the simplest form of a gas turbine engine. The basic Whittle-type turbojet engine is comprised of a five-component "gas generator," which includes an air inlet, a compressor, a combustion chamber, a turbine and an exhaust nozzle (reference Figure 2-3). Atmospheric air is sucked in through the inlet by the compressor which raises its pressure to many times that

at which it enters. The compressed air then enters the combustion chamber where it is mixed with fuel and burned to produce a hot expanding gas. This hot gas rushes out the back of the engine through the exhaust nozzle, but not before it passes through a turbine which extracts sufficient energy to drive the compressor to which it is mechanically linked through a common rotating shaft. As mentioned above, the thrust of a turbojet engine is due primarily to the Δv component of the thrust equation.

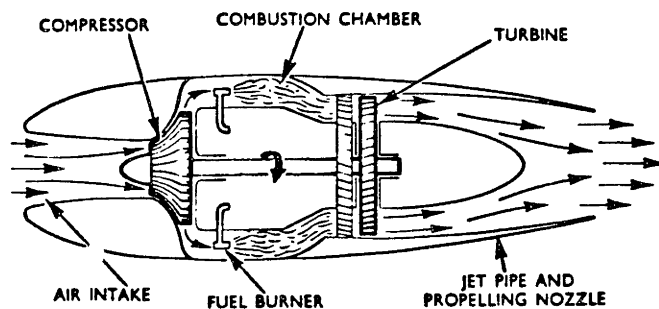


FIGURE 2-3 A WHITTLE-TYPE TURBOJET ENGINE

SOURCE: Rolls Royce Limited, The Jet Engine,
Publication Ref. T.S.D. 1302, Derby, England,
July 1969, 3rd Edition, p. 1.

Turboprop - The core of the turboprop is fundamentally the same as the gas generator described above. To this core is added a second "compressor" in the form of a propeller. The propeller is driven either by the same turbine that drives the core compressor or a second "free" turbine. In either case, most of the remaining energy in the hot escaping gases not used by the core compressor is used to drive the propeller. Therefore, very little thrust is derived from the exhaust of the gas generator. The propeller uses the energy to acceler-

ate a large mass of air, and although the change in velocity of that air is not great, the mass flow of air is sufficient to produce considerable thrust. Before leaving this discussion of the turboprop engine, it is important to note, as it will become obvious in a later chapter, that the most efficient rotational speeds of the propeller and turbine are typically quite different, the turbine running significantly faster. A gearbox is, therefore, incorporated between the turbine and propeller to allow both to operate in their respective optimal rotational speed ranges.

Propulsive Efficiency - Prior to discussing the turbofan engine, let us digress for a moment to define and discuss propulsive efficiency. The performance of an aircraft propulsion system depends not only on the amount of thrust produced, but on how efficiently the system converts kinetic energy to propulsive work. Propulsive efficiency may be expressed by the following relationship:

$$\eta_{\text{prop}} \propto \frac{2V}{V+v_j}$$

where V = velocity of the aircraft and v_j is the velocity of the gases exiting the propulsion system (e.g., the hot exhaust gases from a turbojet or the air stream behind a turboprop's propeller). Therefore, when the velocity of the exiting gases is high, so too must be the velocity of the aircraft in order to achieve a high propulsive efficiency. This is the case with a turbojet engine. The lower the velocity of the gases exiting the system relative to the aircraft velocity, the higher the propulsive efficiency at a given air speed. This would imply that a turboprop engine should have a higher propul-

sive efficiency than a turbojet over the entire spectrum of possible air speeds. However, in the case of a turboprop, the relationship does not hold at forward velocities greater than about 350 mph at typical cruising altitudes (or about Mach 0.5). Above this speed, the so-called helical velocity of the propeller discharge air near the blade tip begins to approach Mach 1.0 and significant energy begins to be lost in the form of severe air flow disturbance.

If this somewhat technical dissertation on propulsive efficiency leaves the reader confused, Figure 2-4 hopefully will clarify the matter. It shows that a turboprop is more efficient than a turbojet only at the lower end of the aircraft flight speed regime, while the turbojet is more efficient at higher velocities.

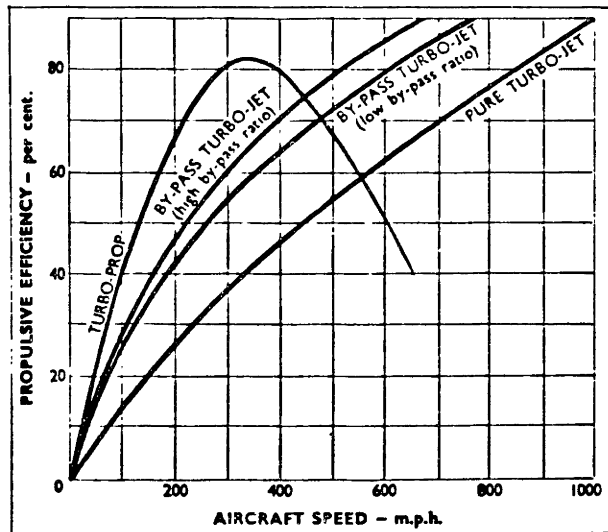


FIGURE 2-4 PROPULSIVE EFFICIENCY VERSUS AIRCRAFT SPEED

SOURCE: Rolls Royce Limited, The Jet Engine, Publication Ref. T.S.D. 1302, Derby, England, July 1969, 3rd Edition, p. 226.

The figure also shows that there is a third type of gas turbine engine which offers a good compromise between the high speed, high altitude capability of a turbojet, and the high efficiency, high thrust at low speeds and altitudes of a turboprop. This is the so-called bypass turbojet or turbofan engine.

Turbofan - The operation of a turbofan is similar in principle to a turboprop in that the \dot{m} component of the thrust equation dominates, but not to the extent it does with a turboprop. However, as shown in Figure 2-4, a turbofan does not suffer from the same cruise speed limitation as a turboprop. The turbofan avoids the airflow disturbance problem at the blade tip by replacing the propeller with a duct-enclosed fan whose blades are similar to but much larger than those of the core compressor. Like a turboprop on which the propeller is driven by a separate free turbine, so too is the fan on a turbofan engine. However, unlike a turboprop which requires a speed decreaser gearbox between the turbine and the propeller, the fan on a turbofan engine is driven directly by the free turbine in the same manner that the core compressor is driven by the gas generator turbine. The air mass accelerated through the fan on the high bypass turbofans in commercial service today is typically six to eight times that which passes through the core. The ratio of bypass flow to core engine flow is called the bypass ratio or BPR. As can be seen from Figure 2-4, the higher the BPR, the higher the propulsive efficiency. The problem with increasing the BPR to much more than the current levels is that the size of duct which shrouds the fan becomes so large that the weight and drag penalties become limiting factors.

Specific Fuel Consumption - Prior to leaving our discussion on gas turbine fundamentals, let us take a moment to introduce another efficiency term. The overall efficiency of a gas turbine engine is related to both the propulsive efficiency as described above, and the so-called thermal efficiency of the machine. The thermal efficiency is a measure of how efficient the engine is in terms of converting the chemical energy in the fuel to propulsive energy. It is expressed as a dimensionless decimal calculated by dividing the output energy by the input energy. A more common way of expressing the fuel efficiency of a gas turbine engine is via a ratio known as specific fuel consumption or SFC. SFC is the ratio of fuel flow to engine output. In the case of a turbojet or turbofan engine, the units are pounds of fuel burned per hour over the pounds of thrust delivered, or simply pounds/hour/pound. In the case of a turboprop, the units are pounds of fuel burned per hour over the shaft horsepower delivered to the propeller, or simply pounds/hour/SHP.

THE FUTURE

In the late 1950's/early 1960's, the turbojet engine provided a quantum leap in technology for commercial air transportation. The turbojet engine was more powerful than its predecessor, the piston-engine-driven propeller, and significantly increased both the speed and range of the aircraft. Then came the bypass turbojet, or turbofan, which with its improved propulsive efficiency extended the range and improved the economics of air travel even more. Over the past decade, further improvements have come in small increments based to a large extent on incremental improvements in SFC, each successive im-

provement coming at a higher cost than the last. This history is summarized in Figure 2-5.

Historical Trend of Subsonic Engine SFC
(35,000 ft, 0.8M, Std Day)

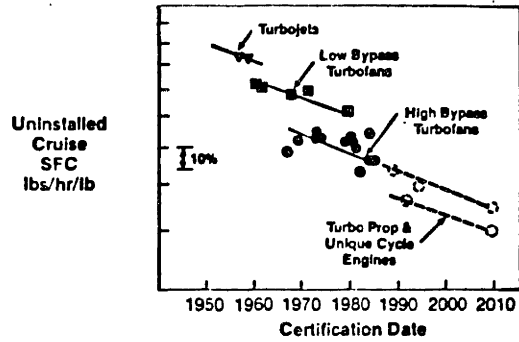


FIGURE 2-5

SOURCE: General Electric, The Unducted Fan Engine, ASME 30th International Gas Turbine Conference, Houston, Texas, March 17-21 1985, p. 4.

As discussed in Chapter 1, the point is fast approaching at which the costs of further incremental improvements can simply not be economically justified. To create real value for commercial airline industry which, in turn, would translate into a profitable product for aircraft and engine manufacturers, another quantum jump in technology is needed. In looking at Figure 2-4, it is obvious that such a quantum jump might be achieved, if only the propulsive efficiency curve for the turboprop engine could be prevented from turning downward in the typical cruising speed range of a commercial transport of about Mach .8 (on the order of 500 mph).

There is a technology which could be made commercially available within the next decade that would achieve such a goal. It is, in essence, an advanced design propeller which prevents the flow distur-

bance so detrimental to propulsive efficiency at high speeds as is experienced with a typical propeller. The blade design, depicted in Figure 2-6, was only made possible by modern computer-aided design technology. It pushes the efficient cruising speed range for the propeller up above Mach .8. Where the peak propulsive efficiency for a modern high bypass turbofan is 60-65%, an engine with one of these advanced design propellers can achieve propulsive efficiencies in the 80-85% range at the same high cruising speed.

CURRENT BLADE DESIGN



ADVANCED BLADE DESIGN

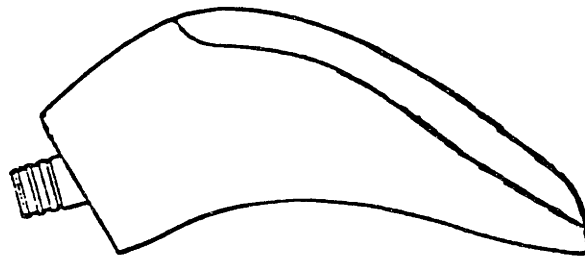


FIGURE 2-6 COMPARISON OF CURRENT AND ADVANCED PROPELLER BLADE DESIGN

SOURCE: A.T. Reiff, Jr., Potential and Technology Readiness, Asian Aerospace Technology Conference, Singapore, Jan. 13, 1986.

CHAPTER 3

THE INDUSTRY

Before proceeding with a discussion of commercial aircraft market forecasting and of AEBG's large commercial engine marketing strategy, let us pause and take a look at the general characteristics of the that market, and of AEBG's customers and competitors.

COMMERCIAL AIRLINE INDUSTRY

Prior to the introduction of jet-powered aircraft, only about 10% of the American public had ever used a commercial airline. The speed and convenience afforded by jet-age air travel resulted in a significant shift from surface to air travel such that today, over 65% of Americans have flown in a commercial jetliner. Furthermore, the percentage of total U.S. travel dollars flowing to U.S. certified air carriers has risen from about 35% in 1950 to 95% in 1985. As one can see from these statistics, the impact of the jet engine on commercial air travel has been very significant.

As noted above, the increase in speed of a jetliner vs. a propeller-driven aircraft was one of the primary reasons for the increase in popularity of air travel. Figure 3.1 graphically presents one estimate of the extent of the impact of speed. The solid line represents actual revenue passenger miles (RPM's) flown on U.S. certified air carriers. A regression model which closely approximates this line was developed by E.H. Burgess, former forecasting expert at Rolls Royce, and current consultant to the industry. He used GNP, yield (a single number representation of the aggregate airline fare structure) and block speed (the average trip speed from point of origin to destina-

tion) as the independent variables. The dashed line represents the output of the model with block speed held constant at its 1960 level. Per this simplified description of the air travel market, the effect of the jet engine on that market due solely to decreases in travel time has been to increase current RPM's by about 42%.

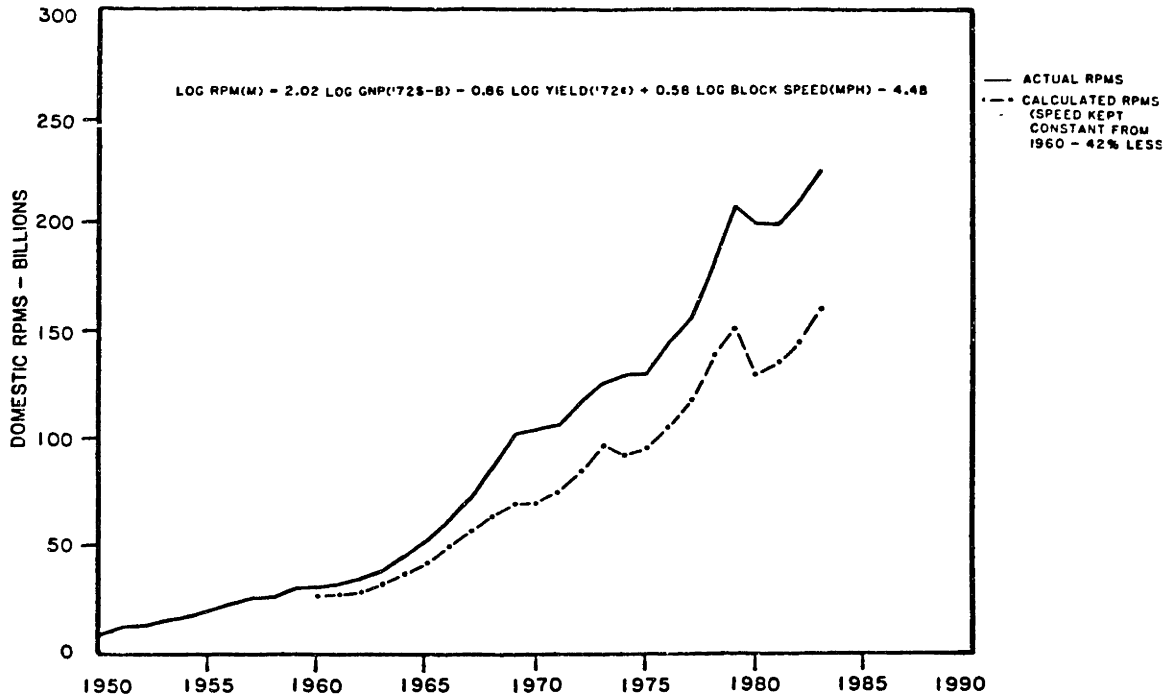


FIGURE 3-1 IMPACT OF JET-POWERED AIRCRAFT ON AIR TRAVEL GROWTH!

SOURCE: E.H. Furgess, The Market for Advanced Supersonic Transports, AIAA Annual Meeting, April 1985, Washington, D.C. p. 7.

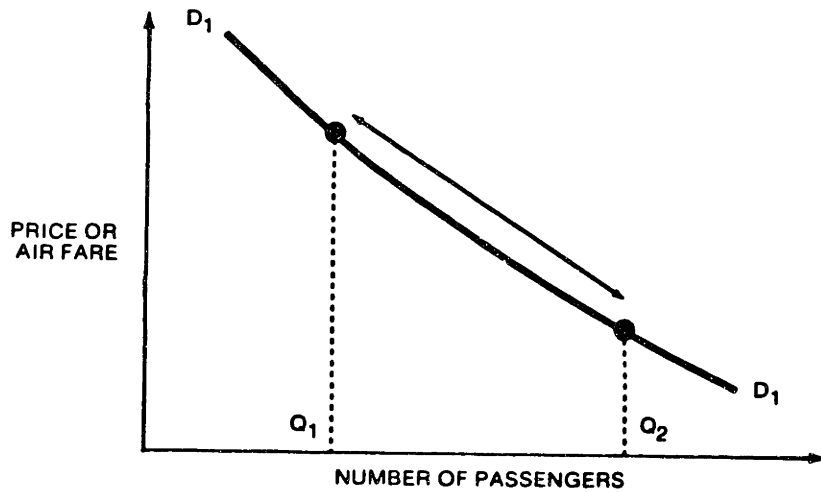
Another factor contributing to these impressive statistics is that jet-powered aircraft could be made larger to carry more passengers and fuel since jet engines were significantly more powerful than their predecessors. Jet liners could therefore carry more people over longer distances more quickly than piston-engine-powered propeller

driven aircraft. The net effect was to greatly increase the productivity of the aircraft. The resulting improvements in operating economics lead to fare reductions, i.e., lower yields. From the regression equation shown on Figure 3.1, it can be seen that a decrease in yields results in an increase in RPM's. If yields were held at their relatively high 1960 level along with block speed, the dashed line would be lower still, indicating an even greater positive impact of the jet engine on RPM's.

Lower yields changed the demographics of commercial airline travel. In the middle 1950's, businessmen accounted for about 80% of the total domestic and 90% of the trans-Atlantic air travelers. Today, 50% of the domestic and 90% of the trans-Atlantic air travel is discretionary. This is a very significant fact for airlines, for although their customer base has expanded tremendously, the vast majority of that base is very price sensitive. Anything which adversely affects either operating cost structure, and thereby the fare structure of airlines, or the disposable income of the general traveling public, or both has a substantial negative impact on airline profitability. Figure 3-2 graphically presents this story in the reverse sense, i.e., when travel costs decrease or personal income increases, air travel increases. Figure 3-3 represents the air travel market as a pyramid. If the market is to expand it must penetrate lower the income categories, which are even more sensitive to air fares.

Because the demand for air travel is so price and income sensitive, airline profits have been on a roller-coaster ride over the past decade. The oil price shocks of 1973/74 and 1979/80 spelled double

Movement along demand curve--as cost of travel declines, travel growth increases



Shift-in-demand curve--as travel market income increases, passenger demand increases

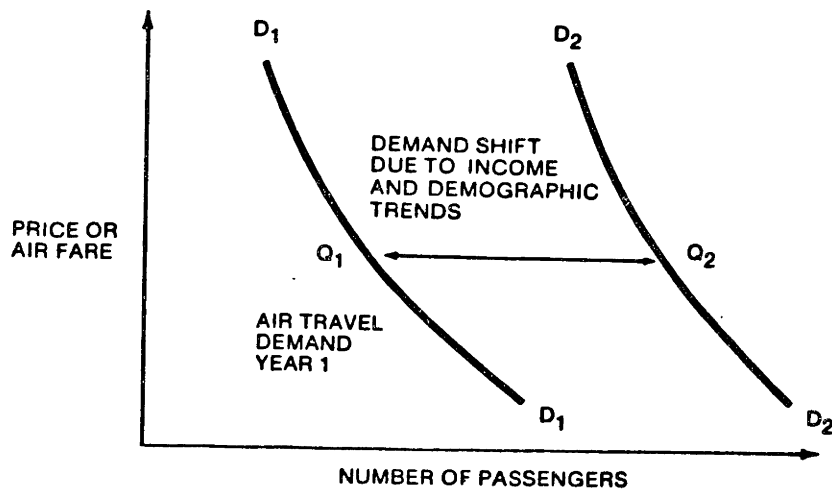


FIGURE 3-2 AIR TRAVEL DEMAND FUNCTION

SOURCE: World Air Travel Market Perspective, Boeing Commercial Airplane Company, Seattle, Washington, February 1985, p. 8.

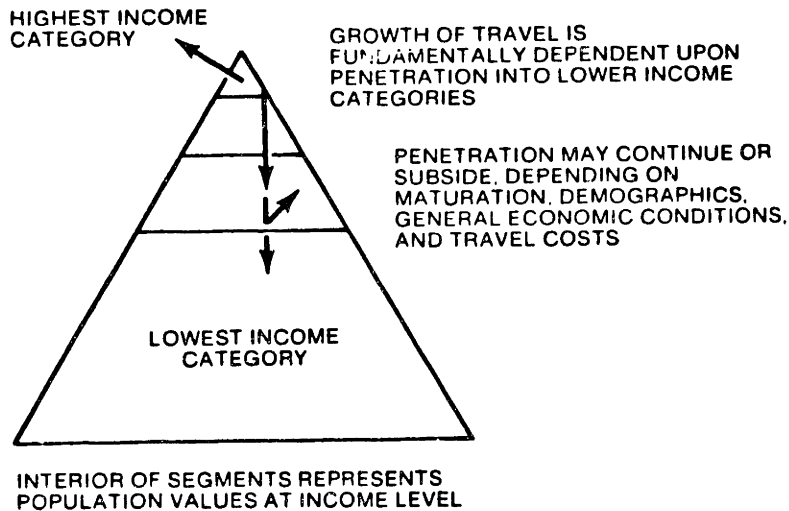


FIGURE 3-3 TRAVEL POPULATION BY INCOME CATEGORY

SOURCE: World Air Travel Market Perspective, Boeing Commercial Airplane Company, Seattle, Washington, February 1985, p. 19.

trouble for the airlines in that they resulted in significant world-wide economic downturns, unprecedented inflation and a deep erosion of discretionary income. Coupled with this were skyrocketing fuel and labor prices which drove airline operating costs through the roof. In an effort to keep revenues from dropping to the point at which day-to-day operating expenses could not be met, airlines maintained their face structures at as low a level as possible, resulting in record losses. Periods of record losses were followed by record profits during the economic recoveries. In his recent book on the commercial airlines industry, John Newhouse underscores this point by his assertion that

... probably no other industry has endured as many ups and downs - as much 'cyclical shock,' as it is called. The volatility of the airline's finances is reflected in their earnings and stock prices. In the early 1960's [before the

full positive impact of jetliners had been felt], the average price of airline stock was a little over \$5; by 1966, it had soared to \$47, but in 1970 [in the midst of a major recession] had fallen 75% to \$13. The major, or trunk, airlines earned over \$1 billion in 1978 and \$400 million in 1979, and lost \$225 million 1980!¹

As if the picture painted by this passage were not sufficient to make capital and equipment suppliers to the industry a little nervous, deregulation has exacerbated the risks and uncertainties. While under the regulatory control of the Civil Aeronautics Board (CAB), the airline industry was relatively stable. The CAB controlled the route and fare structures, and limited new entrants to the industry. The Airline Deregulation Act of 1978 changed all this. Analysts have observed three major stages to deregulation:

1. The industry began to gravitate toward a hub and spoke route structure whereby "numerous flights (the spokes) feed passengers into a large central airport (the hub) where they change flights (same carrier) to other cities."² With this system, airlines often fly less productive, less profitable short routes into a hub to feed the longer, more profitable routes. In other words, the airlines began to take a systems approach to looking at their overall profitability, no longer looking at each leg of their route structure in isolation.
2. Non-union upstart operators poured onto the scene, offering lower prices, and precipitating the now-famous fare wars of the early

¹John Newhouse, The Sporty Game, Alfred A. Knopf, Inc. New York, 1982, pp. 8-9.

²The Jet Engine Industry, prepared for General Electric Company, Management Analysis Center, Inc., 1983, p. 7.

1980's. This phase, during which the number of certified U.S. carriers increased from 30 to 130, coupled with the after-effects of the 1978/79 oil price shock, sent airline profits into a tailspin as depicted by Figure 3-4.

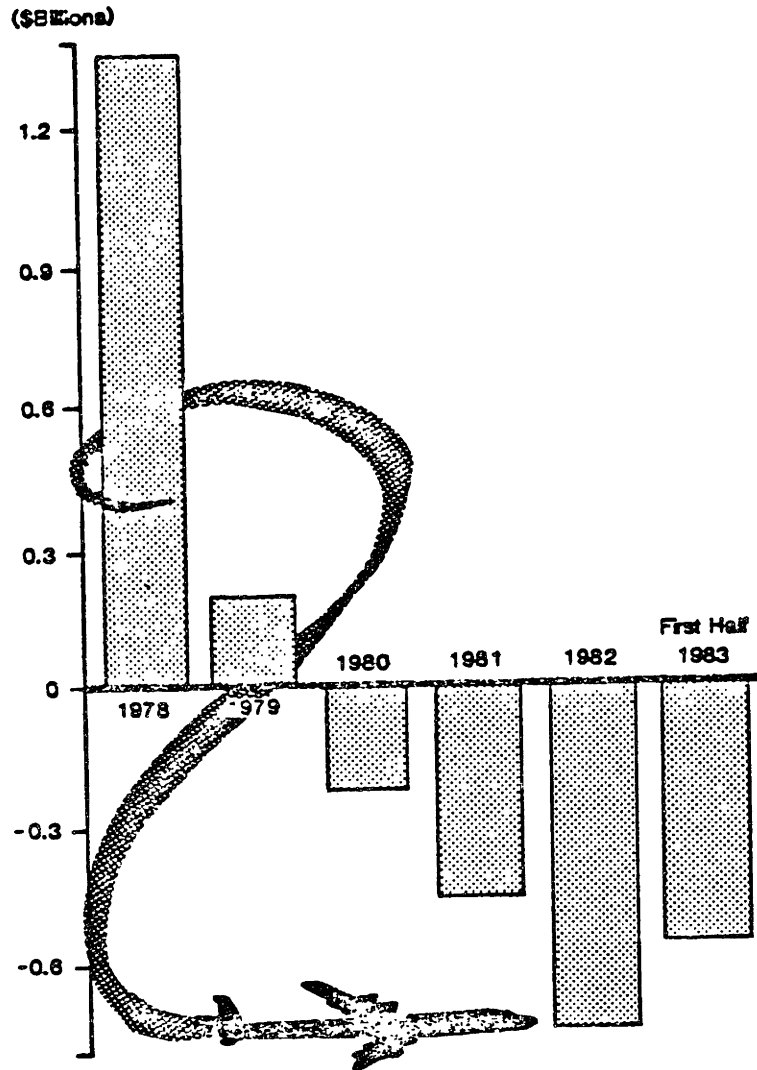


FIGURE 3-4 AIRLINE PROFITS

SOURCE: The Jet Engine Industry, prepared for General Electric Company, Management Analysis Center, Inc., 1983, p. 6.

3. The air travel market served by U.S. certified carriers is simply

not large enough to support 130 airlines, and a weeding-out process has begun. Every week it seems that a new merger or major acquisition is announced on the business pages as financially troubled airlines are swallowed-up by stronger competitors.

Furthermore, the wage advantages of the upstarts are eroding as a two tier wage structure has successfully been negotiated into the union contracts of many of the majors. Table 3.1 shows typical differentials between the old and new rates.

TABLE 3.1

TWO-TIER WAGE STRUCTURE DIFFERENTIALS

	<u>OLD RATE</u> (PER HOUR)	<u>NEW RATE</u> (PER HOUR)	<u>% REDUCTION</u>
PILOTS, CAPTAIN, 727, 12TH YEAR	\$120.35	\$60.17	50%
FLIGHT ATTENDANTS, 12TH YEAR	33.02	17.50	47%
TWU			
MECHANIC, 1ST YEAR	16.60	10.00	40%
FLEET SERVICE, 1ST YEAR	13.48	8.00	41%
BUILDING CLEANER, 1ST YEAR	12.83	4.50	65%
STOCK CLERK, 1ST YEAR	13.35	8.00	40%
AGENT AVERAGE	12.93	5.77	55%
CLERICAL AVERAGE	10.07	5.77	43%

SOURCE: "Our Sporty Game" An Airline Perspective, presented to Lloyd's of London Press by Robert E. Martens, American Airlines, Inc., May 1985, p. 54.

Thus upstarts no longer enjoy quite the labor rate advantages they once did, and they typically operate older, less efficient equipment. The result is that the majors have become increasingly cost competitive. Fare wars will continue to break out from time to time, but increasingly will be fought on terms set by the majors. The majors will no longer cut fare across the board, but restrict them only to markets where they are being severely challenged, and only then if the route

is a critical element of the hub and spoke route network.

The bottom line is that, after phase 3 runs its course, there is likely to be a healthier, more profitable U.S. airline industry, with money to spend on new equipment necessary to meet replacement and growth demands. Operating profits have already shown signs of a strong rebound, on the order of \$2 billion in each of the last two years, and operating costs have been on a downward trend as shown in Figure 3-5, due to reduction in labor costs and fuel prices. Coupled with this bright outlook for the U.S. certified carriers is an equally rosey picture for airlines worldwide.

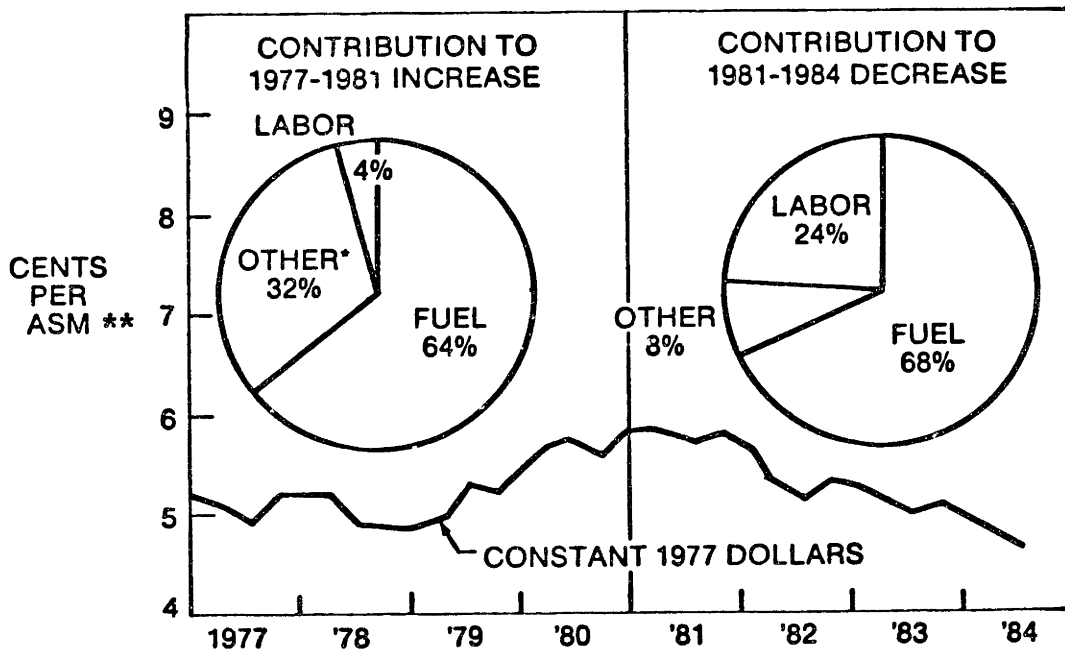


FIGURE 3-5 OPERATING COST TREND FOR THE MAJOR US AIRLINES

*Primarily consists of material, commissions, and depreciation

**Available Seat Miles

SOURCE: World Travel Market Perspective and Airplane Equipment Requirements, Boeing Commercial Airplane Company, August 1985, p. 18.

Figure 3-6 shows that the aggregate profits of free-world airlines have come out of the recession of the early 1980's very strongly, and are expected to grow to unprecedented levels throughout the rest of this decade. According to Sanford C. Bernstein, a New York brokerage firm, operating profits in 1985 were about \$5 billion. This is expected to more than triple over the next three years as air travel demand begins to out-strip capacity, triggering a new equipment buying binge.

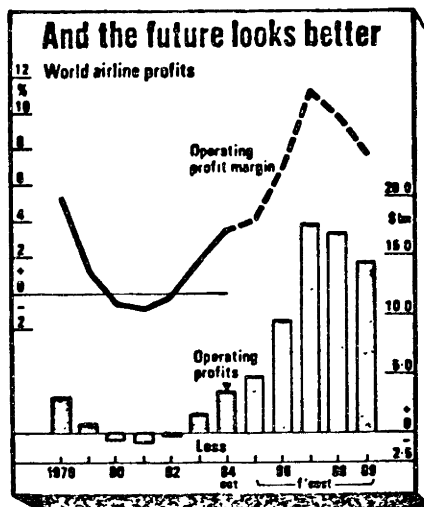


FIGURE 3-6

SOURCE: "The Big Six," The Economist, The Economist Newspaper Ltd., London, England, Vol.295, No. 7396, June 1985, p. 50.

Up to this last point, our discussion had centered on the U.S. airline industry. This is not due to American chauvinism on the part of the author, but to the fact that, historically, the U.S. certified airlines have dominated the world air travel markets. Because of this

dominance, the U.S. airline industry has shaped the structure of the industry worldwide, and has been the primary driving force for the development of new equipment by the major aircraft and engine manufacturers. Without a solid base in the U.S. market, a new engine or aircraft program would likely be doomed. U.S. dominance had declined since the early 1970's when U.S. certified airlines held over 60% of the total world market. This share has slipped to just over 40% in recent years. However, it should be noted that the combined share of the airlines of no other country approaches the 40+% share of U.S. airlines.

THE AIRFRAME MANUFACTURERS

The first jet-powered commercial airliner was the British-built DeHavilland Comet which entered commercial service in 1952. However, several early failures plagued this aircraft, and it was not until the U.S.-built Boeing 707 entered commercial service in 1958 on trans-Atlantic routes that commercial jet aviation really took off. To date, over 20 different models of large commercial jet airliners have been produced, totalling about 8,500 aircraft. The breakdown is shown in Table 3.2. According to Boeing Company estimates, the cumulative market value of these aircraft is \$181.5 billion (\$1984). Since the aggregate capacity of these airliners is over 1.25 million seats, the average price per seat is about \$150,000.³

The problem is that cumulative cost per seat has been more than \$150,000 when one includes the up-front non-recurring design, develop-

³"The Jetliner Business," First Boston Research, Special Report, Oct. 1984, p. 3.

Table 3.2
Commercial Jet Airliner Scoreboard

Delivering the jets		1954	'55	'56	'57	'58	'59	'60	'61	'62	'63	'64	'65	'66	'67	'68	'69	'70	'71	'72	'73	'74	'75	'76	'77	'78	'79	'80	'81	'82	'83	'84	Total			
707		8	77	91	80	68	34	38	61	83	118	111	58	19	10	4	11	21	7	9	8	13	6	3	6	8	8	8	8	8	889					
727							6	86	111	135	155	160	115	54	33	41	92	91	91	61	67	118	136	131	97	26	11	8	8	1834						
737										4	105	114	37	29	22	23	55	51	41	25	40	77	92	111	95	82	67	1078								
747												4	82	88	30	30	22	21	27	20	32	67	73	58	25	23	16	889								
DC-9																															866					
DC 9 MD-80		21	91	42	22	19	20	31	32	41	102	85	33	15	4	44	32	29	48	42	50	22	22	39	23	73	44	50	44	1166						
DC-10									5	88	152	203	121	54	13	82	57	47	43	19	14	18	36	40	23	11	4	2	379							
L-1011																17	38	41	25	16	11	8	14	24	29	14	6	4	368							
BAC-111			14	23	23	16	4	2																							182					
757																															2	25	18	48		
767																																20	56	29	104	
US																																				
Manufacturers																																				
Subtotal		8	88	196	156	122	75	157	210	319	470	681	498	289	211	202	281	325	280	223	167	251	369	386	387	243	264	196	7882							
Comet		7*	19	20	14	13	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	112	
Caravelle			18	30	39	35	23	22	18	18	21	17	11	8	4	6	3	4	6	9	7	4													279	
Trident								12	18	11	1					2	13	11	7																117	
VC-10							14																												64	
BAC-111								11	7	10	8	2	1																							221
F-28								34	46	20	26	40	22	12	7	2	4	2					6	3		3	2	2							218	
Mercure																																				18
A300																																				18
A310																																				18
BAC 146																																				18
VFW-614																																				14
Concorde																																				14
Non-US																																				
Manufacturers																																				
Subtotal		7*	37	58	53	48	25	50	74	82	93	80	71	45	38	36	31	27	43	49	49	33	38	58	62	56	64	78	1261							
Total		15*	135	255	209	178	100	207	284	401	523	741	569	334	250	238	312	352	323	272	216	284	412	445	459	302	328	272	8443							

*Plus 33 Comets delivered 1952-1957

Source: Boeing and company reports

SOURCE: "The Big Six," The Economist, The Economist Newspaper Ltd., London, England, Vol. 295, No. 7396, June 1985, p. 50.

ment, certification and tooling costs. Prior to 1982, when John Newhouse wrote The Sporty Game, there were probably only two models which had broken even, the Boeing 707 and 727.⁴ Since then, with a sudden resurgence of sales, perhaps we can add the Boeing 737 and the McDonnell Douglas DC-9/MD-80 series to the list of money-makers, although when one takes into account the time-value of money, the impact on the projects' net present value (NPV) of this late surge in sales is questionable. It is not coincidental that Boeing is one of only two U.S. manufacturers left on the scene, given that three of these four profitable aircraft are Boeing products. The other, Douglas Aircraft division of McDonnell Douglas, lay near death back in about

⁴Newhouse, p. 4

1980, ravaged by a destructive head-to-head competition between its DC-10 and Lockheed's L-1011. Only a merger with McDonnell Aircraft of St. Louis, a major supplier to the military aircraft market, saved the company. Today, there is clear evidence that Douglas is back on its feet and again a major force in the commercial business. The fates were less kind to Lockheed's commercial airline business. Only a bail-out by the U.S. government kept Lockheed afloat and they subsequently withdrew from the commercial market to concentrate on their military business. DeHavilland, Vickers, Hawker Siddeley, Dassault and Convair were also big losers in the commercial airliner business, and have left the field to Boeing, McDonnell Douglas and Airbus Industrie, a heavily subsidized European consortium.

As this list of casualties suggests, building and selling commercial airliners is very risky business. Former Undersecretary of State and senior manager at Lehman Brothers, George W. Ball said that "there are no historic precedents or current parallels for the magnitude of financial exposure risked by an American airframe company."⁵ John Newhouse echoed these thoughts in The Sporty Game by asserting that "... in deciding to build a new airliner, a manufacturer is literally betting the company, because the size of the investment may exceed the company's entire net worth."⁶ It may cost the company about \$2.0 billion in design, development, certification and tooling costs to launch a new aircraft program. Superimposed on these non-

⁵Ibid., p. 214.

⁶Ibid., p. 1

recurring costs are even greater recurring costs such as wages and facilities upkeep. The peak cumulative cash outlay occurs some five to six years after program launch, at which point the cumulative loss may be greater than \$5 billion, or more if one includes interest. Figure 3-7 graphically presents the cumulative cash flow for a "successful" medium-size aircraft program. For a program to be successful, "... it must sell well enough early enough to overcome the burden of interest payments on the initial investment. If 400 aircraft are sold within the first seven or eight years of production (i.e., 12-13 years after the decision to go ahead with the program) the company may break even on its investment."⁷

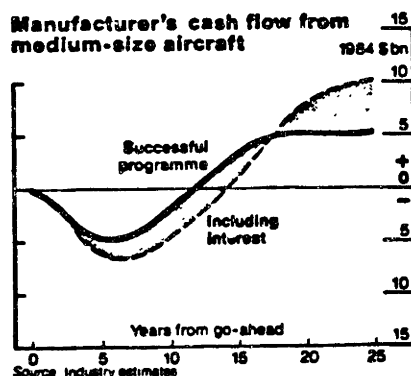


FIGURE 3-7

SOURCE: "Boeing V. Airbus"
The Economist, The Economist Newspaper Ltd., London,
 England, Vol. 296, No. 7413,
 Sept. 1985, p. 67.

One reason it takes so long to reach the break even point is that

⁷"The Big Six," The Economist, The Economist Newspaper Ltd., London, England, Vol. 295, No. 7396, June 1985.

marginal costs are so high in the early stages of production. Pricing is based on the assumption of a successful program, i.e. at least a 500 or 600 aircraft program, and on the projected costs at, say, the 250th unit, since the cost is not constant but decreases as the cumulative production volume increases. The cost can, in fact, be closely approximated using the learning curve concept. There is a very high skilled labor cost content in the overall cost roll-up, and reductions in direct labor cost of about 20% result with each doubling of the cumulative number of units produced. As the price is based upon the projected cost at the 250th unit, or thereabouts, there is intense pressure to sell considerably more than this number of units, since all the early units are sold at a sacrificial price, it is essential to drive the costs the down learning curve as quickly as possible. Therefore, emotional pricing often wins over cost-based pricing. As the manufacturers vie for launch orders, they are often willing to accept extraordinarily heavy losses up front to move quickly down the learning curve. John McDonnell, President of McDonnell Douglas describes the price cutting that goes on in each competition as follows: "You rationalize each additional cut in price, because with each additional airplane sold, you are further down the learning curve."⁸

To avoid such concessionary pricing, and, therefore, increase the chances of turning a profit, aircraft and engine manufacturers alike are always looking for a hole in the market, a niche they can fill. The problem is that, as soon as a niche is identified, the competi-

⁸The Jetliner Business, p. 28.

tors typically rush in to help fill the void. As a leading industry analyst, Wolfgang Demisch of the First Boston Corporation cautions:

the trouble is there's only room for one manufacturer in the niche, at most two, but not three. Someone loses, and big! The current hole in the market is considered to be a 150-seat plane. But, niche holes can bring disaster. One old aerospace executive used to say "sure there is a hole, but that doesn't mean we have to fall into it." It was falling into the same hole with McDonnell Douglas on a giant widebody that put Lockheed out of the commercial business. Douglas came up with the DC-10, Lockheed with the L-1011, and having little to do with qualitative differences ... and everything to do with timing, Lockheed came out second and last.⁹

Having identified a niche, and having made the decision to proceed to fill that niche, there are two basic approaches being followed relative to airplane development. Boeing has opted for the clean sheet of paper design approach by which they design an all new airplane from the nose to the tail. They feel that this is the right way to meet the needs of their customers for it is only in this manner that the airplane can be designed for maximum economic benefits. Airbus has also opted for this approach. McDonnell Douglas on the other hand believes that derivative airplanes, i.e. airplanes modified from existing designs by adding a plug to the fuselage to expand seating capacity, for example, offer the most economical solution. Just as the purchase of new aircraft and engines represents one of the most difficult decisions for an airline, choosing the best design to meet the airlines' needs is absolutely critical and one of the most difficult problems that an airframe manufacturer faces. Projections for airline orders over the next 20 years amount to about \$500 billion

⁹Ibid., p. 23.

(\$1984),¹⁰ and the big question is what type of aircraft and power-plants will win these orders.

AIRCRAFT ENGINE MANUFACTURERS

The aircraft engine industry shares many of the same basic elements of the airframe industry. The product is based on extremely sophisticated, state of the art technology. The investment requirements are nearly as staggering, as it costs over \$1 billion to design, to develop and to certify a new product and tool-up for production. It typically takes longer to bring a new engine to the market than a new airframe, usually about seven years in total (versus about four years for an airframe). A typical engine development schedule is shown in Figure 3-8. Just as airframers are faced with very low production volumes, so too are engine manufacturers. Production costs for commercial aircraft engines tend to follow an 80% learning curve, very much like the aircraft they power, and are similarly priced. The engine manufacturers do have a somewhat greater chance to recover their investment than an airframer in that there are two, three or four times the number of installed engines sold as there are aircraft, depending upon whether it is a two, three or four engine aircraft. Also, airlines typically purchase an additional lot of spare engines, usually totalling about 20% of the number of installed engines. Spare parts sales add significantly to the revenue potential for an engine manufacturer. When an airline buys an aircraft, the installed engines represent between 20 to 30% of the total purchase price. Spare en-

¹⁰"The Big Six," The Economist, p. 50.

TYPICAL ENGINE DEVELOPMENT SCHEDULE

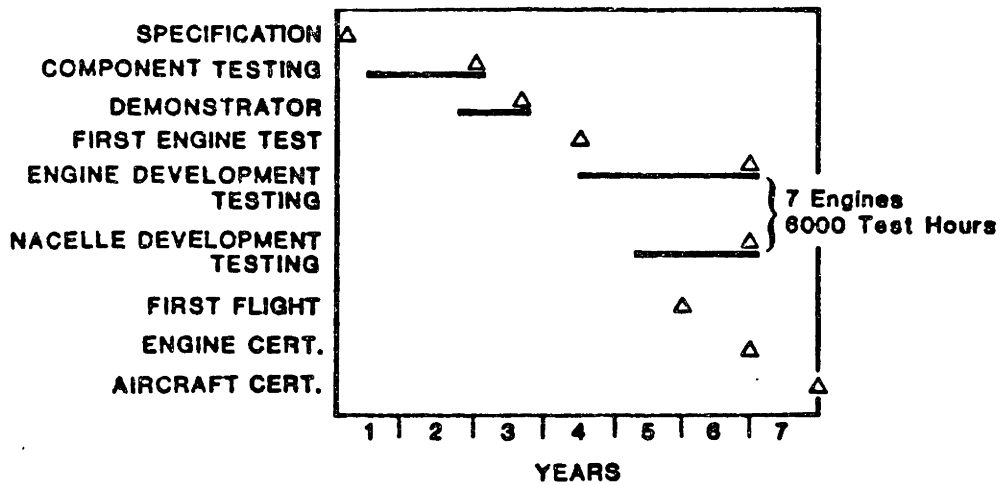


FIGURE 3-8

SOURCE: The Jet Engine Industry, prepared for General Electric Company, Management Analysis Center, Inc., 1983, p. 15.

gines and spare parts sales raise this percentage to almost 100% over the life of the aircraft. However, to sell engines or spare parts, the manufacturers must obviously target their products at the right markets. Given a seven year cycle from an initial conception design to initial production, an engine manufacturer must accurately anticipate the needs of the airlines and how the various airframers will approach meeting those needs. "Makers must ante up vast sums on promises and guesses. Where will fuel prices be at the end of the decade? How fast will personal income [and therefore discretionary air travel] grow? Where's inflation headed?"¹¹ The high risk nature of the commercial airframe business carries over directly to the commercial engine business and as a result, the industry has un-

¹¹The Jet Engine Industry, pp. 25-26.

dergone a rationalization, or weeding-out process if you will, similar to that which has occurred in the airframe industry. The result of this process is that there are essentially only three major engine manufacturers building engines for the large commercial transport aircraft market; Pratt & Whitney, a division of United Technologies, General Electric's Aircraft Engine Business Group (AEBG), both U.S. firms, and Rolls Royce Limited, in England.

About 15 years ago, there was a major change in the industry which has had significant repercussions on the structure of the industry. In the 1960's, Pratt & Whitney (P&W) held 90% of the commercial engine market, Rolls Royce about 7 or 8%, and GE was virtually non-existent in the market. In the early 1970's, GE entered the market with its CF6 engine on the Douglas DC-10 tri-jet. At that time, an aircraft was offered without any options relative to the engine. For example, the DC-10 was offered only with the CF6, the Lockheed L-1011 was offered only with the Rolls Royce RB211 engine, while all the airplanes in the Boeing stable used P&W's JT8D or JT9D engines. However, in 1971, P&W broke with this tradition by offering a financially strapped Douglas Aircraft Company approximately \$150 million to modify the DC-10 to accept a P&W engine, and to recertify the aircraft with the P&W engine option. Douglas accepted the offer and the P&W engine became available on the DC-10. Boeing was more than a little upset with P&W's "disloyalty." They called GE and indicated they would consider installing a GE engine on the 747. GE willingly paid Boeing \$12.5 million for installation and recertification work to get the CF6 engine on that Boeing airplane. The result is that today, there are

usually two, if not three, competing engines available on every commercial jetliner. Therefore, the airlines have significantly more leverage in their negotiations, and price competition on engines has been greatly intensified. As mentioned in Chapter 1, the engine manufacturers have adopted a strategy of introducing new products which offer relatively small incremental improvements in performance over the previous model. Therefore, differences in performance between competing models is usually small, and the winner of an engine competition is often determined based on pricing and other factors such as innovative financing. Table 3.3 summarizes the aircraft/engine combination from which airlines may choose.

Let us take a closer look at AEBG's two competitors. Pratt & Whitney (P&W), a division of United Technologies had total sales in 1985 of about \$ 4.5 billion (versus about \$4.7 billion for AEBG) which was 33% of the corporation's total. GE and United Technologies, are both headed by chairmen who consider market share as the critical measure of success. John F. Welch, General Electric's chairman has ordered the operating officers of the company's divisions to make their businesses No. 1 or No. 2 in market share, or face divestment. Similarly, Harry Gray, United Technologies' CEO, is highly sensitive to market share. It has been noted by one of P&W's managers that "with Harry Gray, there's only one market share that's okay: 100%."¹² With the two giants of the industry given these same marching orders, it is no wonder that the competition today is more fierce than it has

¹²The Jet Engine Industry, p. 11.

Table 3.3

Engine/Aircraft Choices Available to the Airlines

Type of aircraft	No of engines	In service	Number of seats (Approx. *)	Range (Nautical miles)	Engine maker	
Boeing (USA)						
Narrowbody (single aisle)	737-200	2	✓	110	1,900-2,500	P&W
	737-Lite	2	Under study	100	1,500-2,500	P&W, CFM(?); R-R(?)
	737-300	2	✓	128	1,900-2,800	CFM
	727-200	2	✓	156	1,900-2,700	P&W
	757-200	2	✓	186	2,600-4,000	P&W; R-R
Widebody (twin aisles)	767-200	2	✓	216	3,300-4,000	P&W; GE
	767-200ER	2	✓	216	5,300	P&W; GE
	767-300	2	Late 1986	261	4,000	P&W; GE
	767-300ER	2	Offered	261	5,000	P&W; GE
	747SP	4	✓	331	6,000	P&W, GE; R-R
	747-200	4	✓	452	6,100	P&W, GE, R-R
	747-300	4	✓	496	5,600	P&W; GE; R-R
McDonnell Douglas(USA)						
Narrowbody (single aisle)	MD-81	2	✓	142-155	1,560	P&W
	MD-82	2	✓	142-155	2,050	P&W
	MD-83	2	✓	142-155	2,360	P&W
	MD-87	2	Late 1987	100-130	2,370-2,830	P&W
	MD-89	2	Under study	170	2,135	IAE
Widebody (twin aisles)	DC-10-10	3	✓	250-380	3,300	GE
	DC-10-15	3	✓	250-380	3,780	GE
	DC-10-30	3	✓	250-380	5,090	GE
	DC-10-40	3	✓	250-380	4,995	P&W
	MD-11X	3	Offered	277-337	4,500-6,200	P&W; GE; R-R
Airbus Industrie (France, West Germany, Britain, Spain)						
Narrowbody (single aisle)	A320	2	Spring 1988	150-184	1,900	IAE; CFM
Widebody (twin aisles)	A300 B2	2	✓	251	1,550-1,910	GE; P&W
	A300 B4-100	2	✓	251	3,050	GE; P&W
	A300 B4-200	2	✓	251	3,300	GE; P&W
	A300-600	2	✓	257	3,550-3,750	GE; P&W
	A310-200	2	✓	218	2,850-3,800	GE; P&W
	A310-300	2	end 1985	218	4,650	GE; P&W
	TA9-200	2	Under study	243-288	4,000-6,000	GE; P&W
	TA9-300	2	Under study	328-420	4,000	GE; P&W
	TA11	4	Under study	220-280	6,000-6,600	CFM, IAE

* Based on manufacturers' estimates of first and economy class mix. IAE = International Aero Engines, consortium of Pratt & Whitney, Rolls-Royce, Japanese Aero Engine Corporation, MTU (West Germany), Fiat (Italy); P&W = Pratt & Whitney (USA); GE = General Electric (USA); R-R = Rolls-Royce (Britain); CFM = Joint company of General Electric and Snecma (France).

SOURCE: "The Big Six," The Economist, The Economist Newspaper Ltd., London, England, Vol. 295, No. 7396, June 1985, p. 50.

ever been, and both companies are shaving prices and offering unique innovative financing terms to the airlines to gain orders.

Rolls Royce (RR), in contrast to GE and P&W is state-owned and therefore somewhat isolated from market pressures. It had 1985 revenues of about £1.6 billion, and ranks second to British Aerospace in

high-tech jobs and in exports from the United Kingdom. It has very capable engineering talent which has been responsible for many innovations. Yet, RR has suffered high losses in recent years, due in large part to an industry recession and to the fact that most sales revenues have been tied to the L-1011, a technically beautiful aircraft and engine marriage, yet a resounding failure in the market as previously noted. Substantial cash infusions from the British government have been required to keep RR afloat.

Despite initially strong market positions vis a vis GE, their commitment to the commercial engine business, and the strong financial backing of their respective parents, both P&W and RR have lost significant market shares to GE over the past 15 years. In 1984 and 1985, GE won over 1/2 of the new orders for commercial engines. P&W was a close second, and RR a distant third.

It should be noted that GE did not achieve this remarkable growth in market share alone. In 1984, an exceptional year in which AEBG captured 57% of the large commercial engine orders, the engine accounting for the greatest number of those orders was the CFM56, an engine jointly produced with SNECMA of France. Collaboration between AEBG and SNECMA dates back to the late 1960's when they signed an agreement which would allow SNECMA to participate in the production of AEBG's CF6-50 engines for the Airbus A300B and the Boeing 747. This relationship has been expanded over the years to cover derivatives of this engine, the CF6-80A and -80C. SNECMA assembles and tests a proportion of these engines, and produces certain component parts. In December 1971, AEBG and SNECMA organized a joint venture company

called CFM International. From this partnership sprung the CFM56 family of engines which, as noted above, accounted for the lion's share of AEBG's sales in 1984 when orders for one hundred and seventeen 737-300's powered by CFM56-3's were signed.

Prior to the signing of the AEBG/SNECMA joint venture agreement, such a concept was totally alien to the jet engine industry. The principle manufacturers jealously guarded their designs and processes. The impetus behind such joint ventures is to share the huge risks faced by an engine or aircraft manufacturer when the decision is made to bring a new product to the market. The best collaborations are those in which the potential gains for both sides are essentially equal. The gains referred to here are not necessarily only financial. When AEBG and SNECMA formed CFM International, for example, the benefit to AEBG was the money that SNECMA brought to the table which was needed for the development of an engine in the 22,000 to 25,000 pound thrust to compete with P&W on the Boeing 727 and 737, and the Douglas DC-9. SNECMA's motivation to link-up with AEBG was the technology transfer and exposure to the commercial market.

Fred Brown, former Vice President and General Manager of AEBG's overseas operations recently discussed the subject of joint ventures and collaborations in an interview with one of the industry's major publications, Aviation Week and Space Technology. According to Mr. Brown, technology is changing quickly enough that the transfer of existing technology does not pose a significant threat to future market share. Furthermore, if the transfer is a two-way street, the resulting product can be greatly enhanced without greatly increasing the

development costs. AEBG prefers a joint venture partnership approach to a multi-member consortium, because such consortiums tend to be unwieldy and inefficient. Partners should be chosen on a case by case basis, and AEBG enters joint venture arrangements "... only when there is a good chance of capturing a part of the market that it would not be able to obtain itself."¹³

For AEBG, ownership is a critical element to a successful joint venture. The basis for the partnership must be work sharing, not cost sharing. "Shares" are purchased with cash and/or work effort during the design and development phase. Partners share in sales, concessions, financing, and liabilities such as warranty claims according to the ownership split determined up front. Each is responsible for its own tooling, facilities, manufacturing and inventory costs, and therefore each determines its own profitability.

AEBG has also formed a partnership with Rolls Royce, but of quite a different sort than that with SNECMA. A few years ago, AEBG dropped out of the competition to provide a new engine for the new Boeing 757 aircraft, and today has no engine in the medium thrust range which can compete with RR's RS211-535 and P&W's PW2037 for the 757 business. In the high thrust class, Rolls Royce does have an engine, the RB211-534. However, this engine is no longer competitive with the latest AEBG and P&W offerings, the CF6-80C2 and PW4000 respectively. To achieve a greater balance in their respective product lines and sources of reve-

¹³"GE Official Cites Trade Barriers as Threat to Multinational Programs," Aviation Week and Space Technology, June 3, 1985, p. 335.

nes, AEBG and RR entered into an arrangement whereby AEBG would produce and sell up to 25% of RR's RB211-535's, while RR will similarly produce and sell up to 25% of AEBG's CF6-80C2's.

P&W is a late entry into any type of collaborative arrangement. However, faced with a shrinking market share and having invested heavily in two new engine lines, the PW2037 and the PW4000, P&W recently entered into a consortium with RR, MTU of W. Germany, Fiat of Italy, and the Japanese Aircraft Engine Company (JAEC) to produce a new 20,000-30,000 pound thrust engine to compete with the CFM56. The consortium is called the International Aero Engine Company or IAE, and the engine is called the V2500. IAE also believes that revenue sharing rather than cost sharing is the key to a successful collaboration relationship. A summary of commercial engine joint ventures is presented in Table 3.4.

In conclusion, the three major engine manufacturers GE (AEBG), RR and P&W are locked in the same type of high stakes poker game in which the major aircraft companies find themselves, and GE's pile of chips has been growing in recent years at the expense of the other two. In the words of a recent report on the jet engine industry prepared by an outside consultant for GE:

Both [P&W and RR] have responded [to the GE challenge] with increased R&D spending; younger, more aggressive management teams; and more attention to product quality and support. Each has emulated GE's successful international team approach, including a joint venture with each other. Neither has been slow to adopt successful GE technical ideas. With the full attention and resources of both the largest and most innovative engine competitors now focused on maintaining [or improving] their existing market shares, ...the competitive situation has never been more demanding. ...There will be a premium on picking and developing the

right products at the right time, teaming up with the right partners for market access and technology, and innovating in airline financing and support.¹⁴

¹⁴The Jet Engine Industry, p.18.

Table 3.4

Commercial Aircraft Engine Joint Ventures

<u>Engine</u>	<u>United Technologies</u>	<u>General Electric</u>	<u>Rolls Royce</u>	<u>Other</u>
CF6-80C2	-	75-85%	15-25%	-
RB211-535	-	15-25%	75-85%	-
V2500	30%	-	30%	40% (1)
CFM-56	-	50%	-	50% (SNECMA)

(1) Other V2500 Participants

<u>Company</u>	<u>% Participation</u>
JAEC	23%
MTU	11%
Fiat	6%

JAEC - Japanese Aero Engines Corporation
 MTU - Motoren-und-Turbinen-Union

SOURCE: Benasuli, A. and Phil Friedmand, Aerospace/Defense Quarterly, Drexel Burnham Lambert, Inc., New York, December 1985, p. 41.

CHAPTER 4

INDUSTRY FORECASTING TECHNIQUES AND FORECASTS

Before examining the product development strategies of the key players in the large commercial transport aircraft industry, we must establish what the market "landscape" will look like early in the next decade. Recall that it takes about seven years to bring a new engine to market, so the time frame of interest for our discussion begins in the early 1990's. Long range forecasting is, therefore, an essential element of marketing strategy formulation and evaluation. A summary of literature survey findings on long range forecasting techniques is presented in Appendix A. In this chapter, we will first explore how several of the major manufacturers involved in the commercial aircraft business generate their long range forecasts. We will then direct our attention to what a number of industry forecasters predict for the early 1990's relative to the type(s) of aircraft that will be in greatest demand by the airlines. By "type" of aircraft, what we are referring to is a rather broad, generic classification by seating capacity and range. Each manufacturer seems to have a slightly different definition of the various classes, biased by its own product mix. A fairly representative breakdown is that of McDonnell Douglas, presented in Figure 4-1. Existing models are noted below the aircraft silhouette representing the appropriate class.

The companies included in the following survey were selected with an eye toward providing a broad cross-sectional view of the methods employed by several major suppliers to the airlines. The airlines themselves were not included, for their forecasts would obviously be

PASSENGER AIRCRAFT GENERIC TYPES

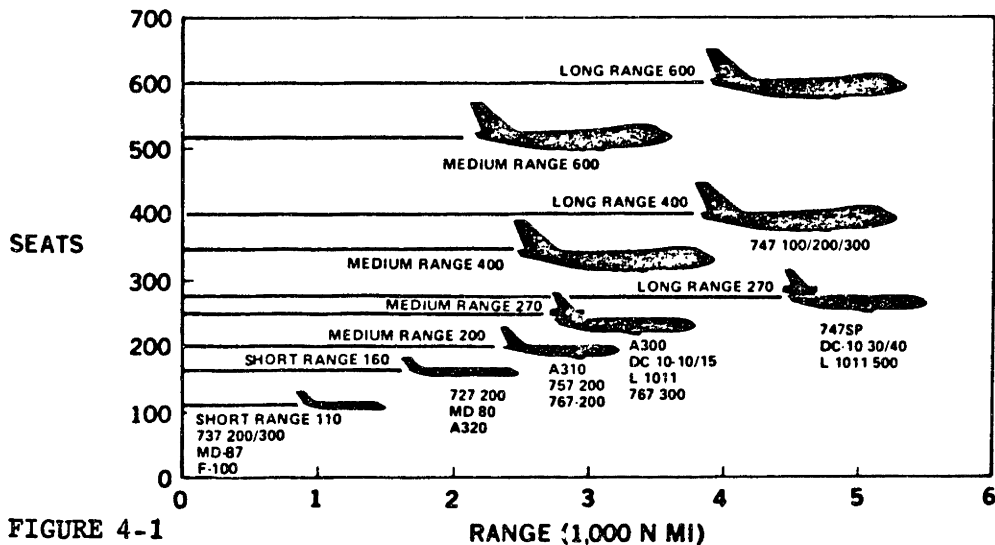


FIGURE 4-1

SOURCE: 1985-1999 OUTLOOK FOR COMMERCIAL AIRCRAFT, Marketing Strategic Plans, Douglas Aircraft Company, Long Beach, CA, September 1985, p. 22.

considerably more focused on distinct segments of the air travel market rather than on the overall market. Furthermore, experience has shown that, whatever the forecasting technique applied, each airline's forecast relative to its own equipment needs tends to be overstated. This is quite natural, since each airline wishes to project as positive an image to its stockholders as possible. Therefore, any bottoms-up forecast of equipment demand (i.e., a simple aggregation of individual airline forecasts) is typically well overstated. We will examine the forecasting techniques of two of the major aircraft manufacturers (Boeing and McDonnell Douglas), two of the major engine manufacturers (GE and Rolls Royce), and two of the major second tier suppliers (TRW and Rohr), as well as a consulting firm, Forecast Associ-

ates, which provides forecasting services to the industry. Their customers are often smaller vendors in the industry who do not have the resources to do their own in-house forecasting, or larger companies who use the Forecast Associates material as a cross-check on their own forecasts. The forecasting techniques of these seven organizations will now be discussed in the sequence listed above.

BOEING COMMERCIAL AIRPLANE COMPANY

The Boeing Commercial Airplane Company uses very complex models to project the demand for air travel, and the resulting aircraft delivery requirements. First, let us examine their methodology relative to forecasting air travel demand. They use what they refer to as a "closed-loop" model to forecast the demand for commercial air travel as measured by revenue passenger miles (RPM's) or kilometers (RPK's). A schematic of the closed-loop model is presented in Figure 4-2.

One portion of the model develops a variable called yield. Yield, which is generally proportional to aggregate fares, is defined as revenue/RPM (or RPK), and is forecast by relating it to revenue and operating cost in such a manner

... [that the airlines attain] a 5% operating margin. This appears reasonable because of inherent market pressures on both higher and lower operating margins. Greater profitability should result in further new entrants with resulting fares competition and lower yields. Less operating return probably would cause more bankruptcies, further consolidation, and, ultimately, rising yields.¹

Operating costs are dominated by two variables; labor costs and fuel costs. These two variables account for 36% and 27% of direct op-

¹World Air Travel Market Perspective, Boeing Commercial Airplane Company, Seattle, Washington, February 1985, p. 72.

erating cost respectively.² Although certainly an important consideration in the purchase of new equipment, interest charges for the major U.S. airlines amount to only about 3% of the total. Boeing's forecasts for labor and fuel costs are presented in Figures 4-3 and 4-4.

Closed-Loop Market Forecast Process

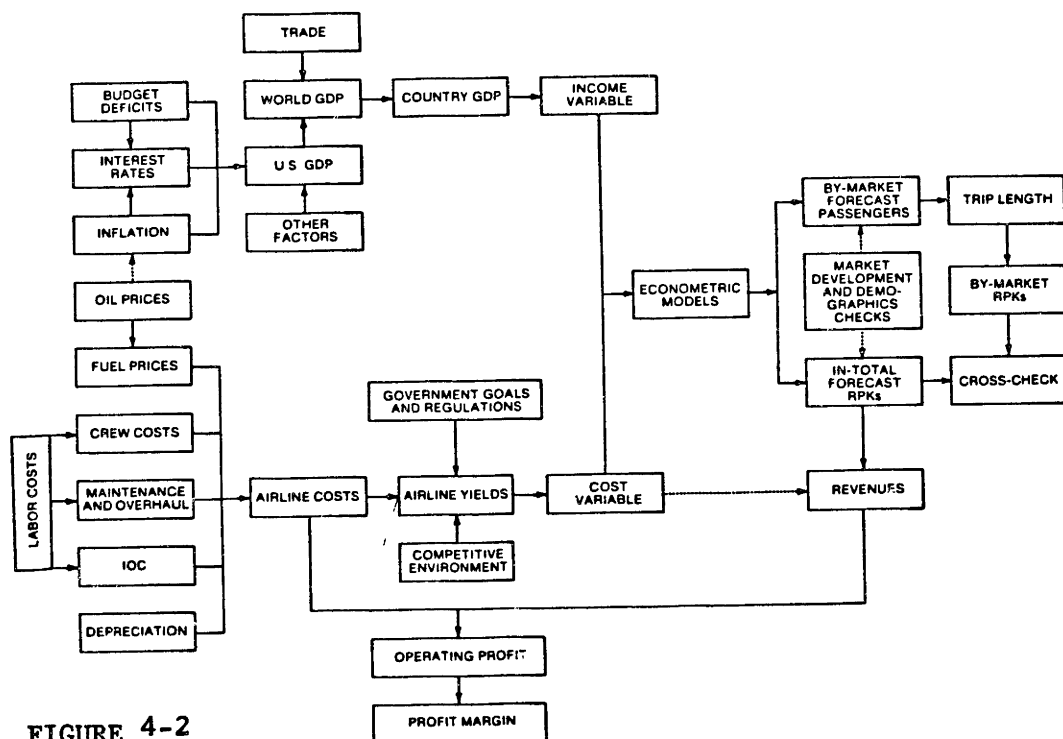


FIGURE 4-2

SOURCE: World Travel Market Perspective and Airplane Equipment Requirements, Boeing Commercial Airplane Company, August 1985, p. 65.

²ibid., p. 13.

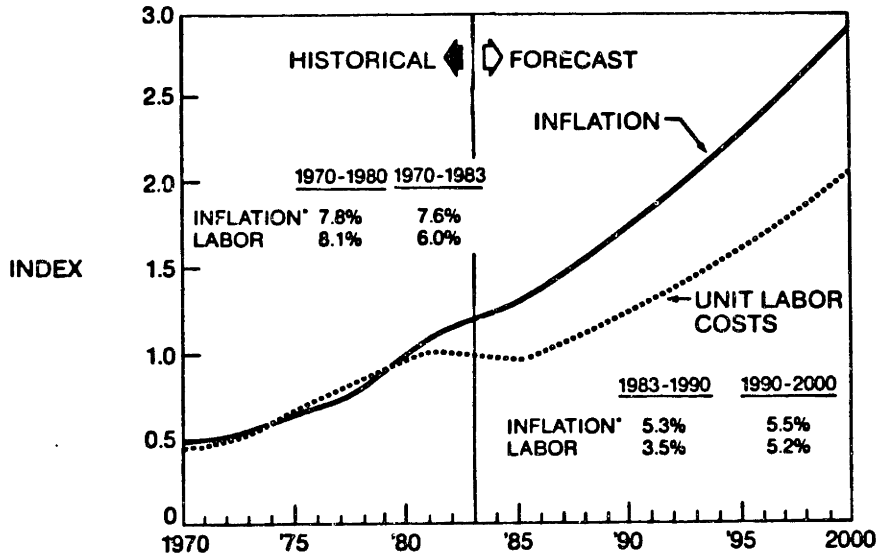


FIGURE 4-3 Labor Costs - ICAO Airlines vs. Inflation
 SOURCE: World Travel Market Perspective and Airplane Equipment Requirements, Boeing Commercial Airplane Company, August 1985, p. 23.

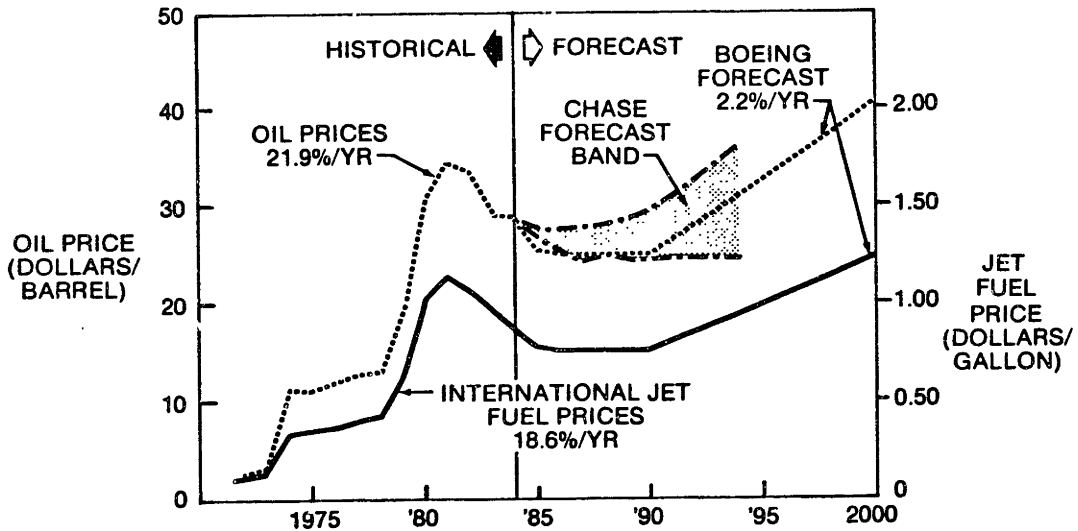


FIGURE 4-4 Fuel and Oil Prices (Current Terms)
 SOURCE: World Travel Market Perspective and Airplane Equipment Requirements, Boeing Commercial Airplane Company, August 1985, p. 19.

The fuel price forecast, based heavily upon data, qualitative information, and projections of other sources such as Chevron, and Chase Econometrics, represents an essentially flat price schedule in current terms (or declining in real terms) through 1990. Then, prices are projected to rise at the rate of inflation (about 2.2%/year) through the remainder of this century. The labor cost forecast was taken from projections by Chase Econometrics, and reflects the fact that airlines have labor costs well under control relative to inflation, due to the two-tiered wage schedules discussed in Chapter 3, a generally leaner work force, cross-utilization of workers, and the influence of improved technology which has made possible the two man flight crew, for example.

The bottom line is that since both fuel and labor costs are expected to either decrease or remain constant in real terms throughout the remainder of this century, the target operating profit of 5% can be maintained with lower yields than in recent years. Using this 5% criteria, coupled with the RPM forecast (the ultimate output of this model), Boeing has projected that yields for the world airlines will decrease in real terms at about 3.4%/year through the remainder of this decade and 2.2%/year over the rest of this century. These projections are presented in Figure 4-5.

This yield forecast is derived iteratively with the overall RPM forecast. Recall that, by definition, yield equals revenue (assumed to be 1.05 times the operating costs) divided by RPM's. Yield, in turn, is used as an input to an econometric model which forecasts RPM's. The model must check to determine if the RPM's inferred by the

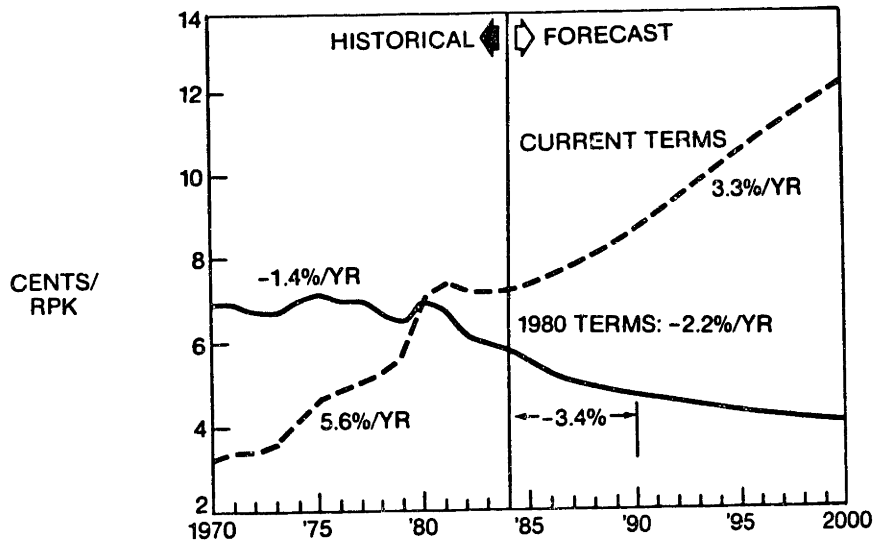


FIGURE 4-5 World Yields - ICAO Airlines

SOURCE: World Travel Market Perspective and Airplane Equipment Requirements, Boeing Commercial Airplane Company, August 1985, p. 27.

yield input into the econometric model is consistent with the RPM forecast generated by the model. If not, the discrepancy triggers a new estimate of yield, and the process continues until the inputs and outputs of the econometric model are in balance and satisfy the 5% operating profit margin requirement.

The other key input to the econometric model which forecasts RPM is gross domestic product (GDP). Rather than attempting to develop their own GDP forecasts, Boeing uses the services of Chase Econometrics. The Boeing forecast through the year 2000 is shown in Figure 4-6. It is interesting to note that this forecast shows no major recessions or business cycles. The two major recessions of the past 25 years (the shaded areas of Figure 4-6) were both related to oil price shocks, and there are no repetitions of these events expected throughout the remaining years of this century. One might infer from

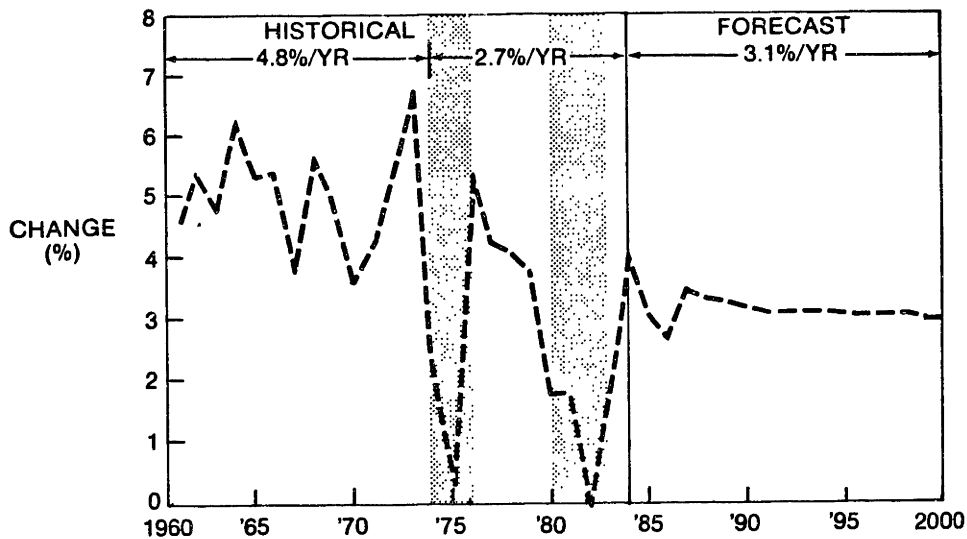


FIGURE 4-6 World GDP (Real Terms)

SOURCE: World Travel Market Perspective and Airplane Equipment Requirements, Boeing Commercial Airplane Company, August 1985, p. 37.

the very regular nature of the projection line that no major business cycles are expected either. This is not the case. Boeing does expect such cycles, but they feel that the timing of these cycles cannot be predicted with any degree of accuracy. Therefore, Boeing concentrates on the underlying trend with the business cycle effects removed.

This brings us to the econometric models used to forecast RPM's. Before discussing these regression models, however we must digress for a moment to discuss the life cycle of the air travel market, and where we currently are in that life cycle. The life cycle can be approximated by the Gompertz Curve pictured in Figure 4-7. The market will have reached maturity when it grows at the same rate as real GNP. Therefore, according to Figure 4-8, clipper ships reached the maturity phase in about 1860, the railroads in 1884, and motorcars in 1930.

Life cycle of a travel market

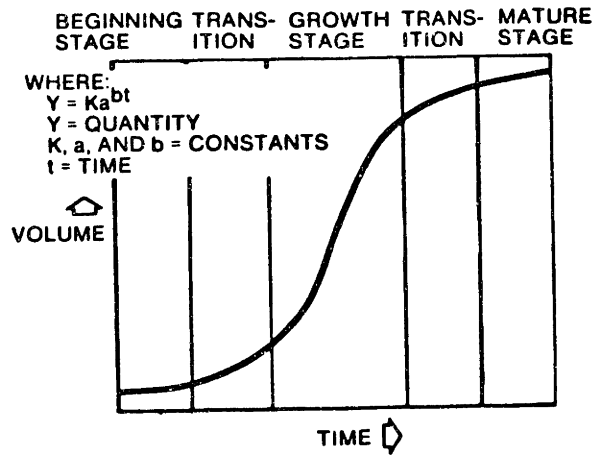


FIGURE 4-7

SOURCE: World Air Travel Market Perspective, Boeing Commercial Airplane Company, Seattle, Washington, February 1985, p. 96.

U.S. travel indicators vs. GNP

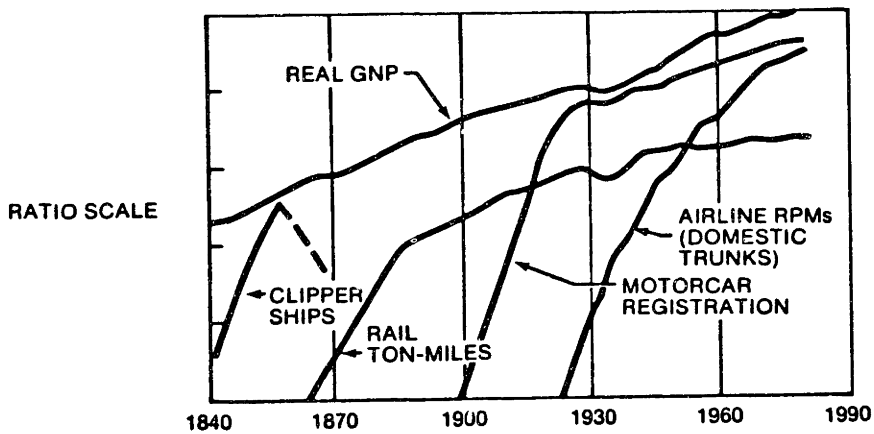


FIGURE 4-8

SOURCE: World Air Travel Market Perspective, Boeing Commercial Airplane Company, Seattle, Washington, February 1985, p. 96.

The domestic air travel market is nearing maturity (as is the European market). This is an important point for forecasters, because it must be reflected in the form of the regression equation used for long range forecasting.

Boeing believes that we are fast-approaching the mature phase of this market, although we are not quite there yet. They define three forecast periods: 1985 through 1990, 1991 through 1995, and 1996 through 2000, and they use a different equation to forecast RPK's for each period. They begin by defining two regression equations, one each for a growth phase and mature phase market. The equations³ to forecast world travel growth are as follows:

$$\text{Growth: } \text{Log (RPK's)} = 11.04 + 2.05 \text{ Log (World GDP)} - .425 \text{ (Yield)}$$

$$\text{Mature: } \text{RPK's} = 484 + 2,038 \text{ (World GDP)} - 56.92 \text{ (Yield)}$$

A line which splits the difference between the data points projected by these two equations represents the 1986 through 1990 forecast. The 1991 through 1995 forecast is represented by a line which transitions from the 1990 forecast to the 1995 forecast defined by the "mature market" equation. The 1996 through 2000 forecast is represented by the "mature market" line.

The resulting forecast represents the "In-Total Forecast RPK's" block in the model schematic shown in Figure 4-2. Recall that this number is first cross-checked against the RPK's inferred by the yield variable, and adjustments made in an iterative fashion until the two balance. Having achieved this balance, the in-total RPK forecast is

³Ibid., p. 65.

cross-checked against the sum of the "By-Market RPK's" which are forecasts derived using the same methodology as above, but with inputs appropriate to the various market segments which make up the world market. For example, using estimates for U.S. GDP and airline yields, the basic forecast equations⁴ for the U.S. market are defined below.

$$\text{Growth: } \text{Log (RPM's)} = - .783 + 1.817 \text{ Log (GDP)} - .550 \text{ Log (Yield)}$$

$$\text{Mature: } \text{RPM's} = 6.272 + 121.7 (\text{GDP}) - 11.20 (\text{Yield}).$$

Similar equations for the other major segments lead to the "by-market" forecasts, which, when summed, should equal "in-total" forecast. Any significant deviations require a close review of the underlying assumptions and of the input variables. The model must be revised and re-run until the "by-market" and "in-total" forecasts are in balance.

Having achieved an acceptable cross-check of the closed-loop model, the resulting "by market" forecasts for air travel demand (expressed in either RPK's or RPM's) are fed into the airplane requirements forecast model, shown in Figure 4-9, as an input. RPM's are combined with a load factor forecast to generate an available seat mile (ASM) forecast. By definition, $\text{ASM} \times (\text{load factor}/100) = \text{RPM's}$, where the load factor is the average percentage of seats filled. If the average load factor were to approach 100%, obviously many potential passengers would have to be turned away, since most flights would be full. If load factors were to drop much below 60%, airlines would lose money.

⁴Ibid., p. 77.

Methodology To Determine Required Airplane Supply

Total number of airplanes required to meet air travel demand was forecast by range category. The current airline fleet was subtracted to determine new airplane order potential. The world delivery forecast and fleet mix were derived by model type.

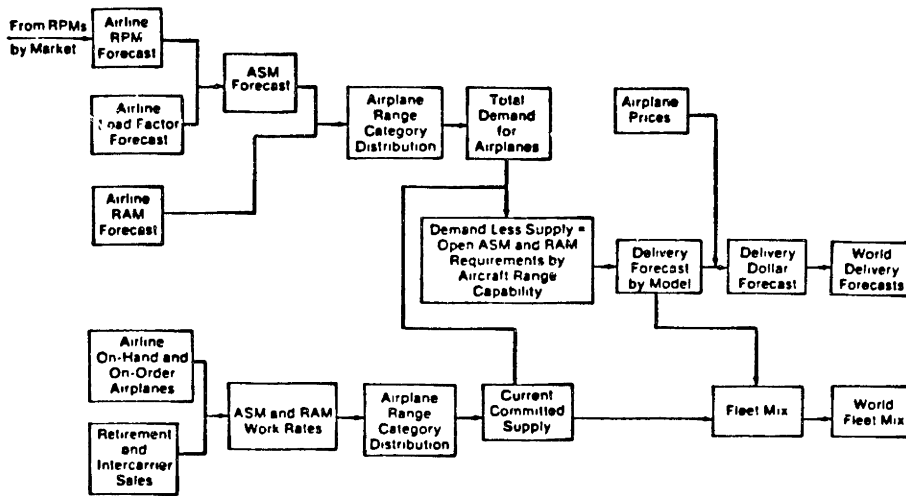


FIGURE 4-9

SOURCE: "World Travel Market Perspective and Airplane Equipment Requirements," Boeing Current Market Outlook, Boeing Commercial Airplane Company, Seattle, Washington, February 1986, p. 83.

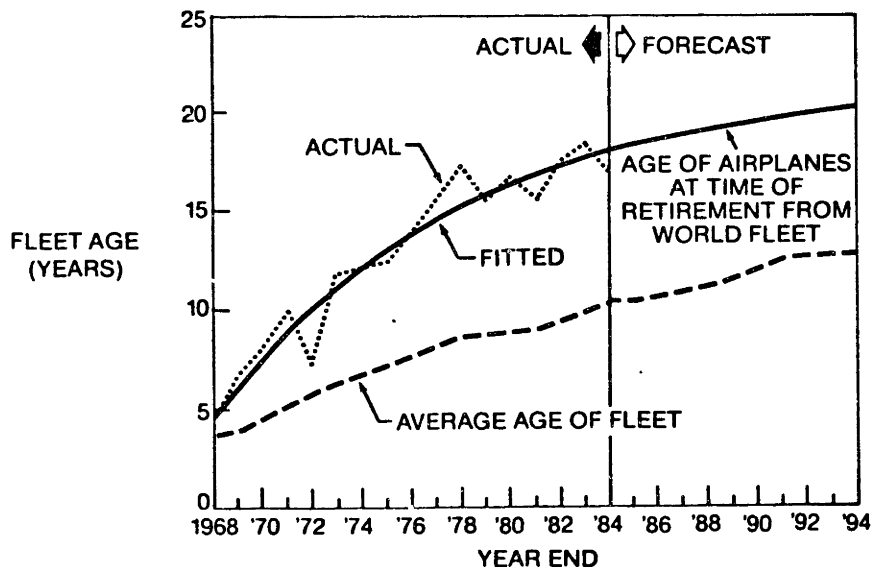


FIGURE 4-10 World Airline Jet Fleet Age

SOURCE: World Travel Market Perspective and Airplane Equipment Requirements, Boeing Commercial Airplane Company, August 1985, p. 55.

Recall from our discussions in Chapter 3 that added convenience has been a key determinant in the growth of the air travel business. Deregulation has increased competition and reduced margins to the point where the break-even load factor has moved up from around 50% to above 60%, as indicated above, thereby discernably reducing the convenience aspect of air travel. The trade-off for the traveling public has been, of course, greatly reduced air fares. If, however, load factors get too high, the low fares do not provide much solace to the excessive number of people being left at the gate. The highest the airlines dare push load factors is between 65 to 70%, and most forecasts show load factors leveling off in this range. Currently, they are running in the mid-60's and trending gradually upward.

As shown in Figure 4-9, ASM's and RAM's (revenue airplane miles) are factored together with the seating capacities of aircraft in a typical fleet to produce an estimate of the demand for aircraft. The supply of aircraft is defined by the number of airplanes on hand plus those on order for delivery in the time period of interest, less the expected aircraft retirements (reference Figure 4-10), all adjusted by a productivity factor to reflect that airplanes are not used 24 hours a day. The difference is the overcapacity or shortfall expected.

Portions of the overall Boeing forecasting methodology outlined in Figure 4-9 contain information and assumptions which Boeing considers company sensitive. Thus, the level of coverage provided herein relative to those portions of their overall forecasting model is shown in Figure 4-9 is significantly less detailed than the description of those portions shown in Figure 4-2.

MC DONNELL DOUGLAS - AIRCRAFT COMPANY

In general, Boeing was willing to share significantly more detail about their RPM forecast model than McDonnell Douglas (MD) which considers their forecasting process company sensitive. MD was quite willing to share the resulting forecasts in considerable detail. Thus, the discussion of MD's market forecasting methodology which follows presents only a broad overview of the MD models.

The MD aircraft forecast is generated in a manner somewhat similar to that employed by Boeing. They begin with RPM forecasts generated using regression techniques. The independent variables in these regression models include such economic factors as GNP, personal consumption and disposable income. Forecasts of these variables are developed by the Wharton Economic Forecasting Associates World Model using MD assumptions. RPM forecasts are made for each of the top 160 airlines in the world. The forecast for each of the top 70 airlines is based on a tailored RPM model for that airline. The forecasts for the next 90 airlines are based on aggregate forecasts by region which are then split into individual airline forecasts using certain market share assumptions. Figure 4-11 presents the resulting forecasts.

Next the model projects load factors for each of the airlines. As can be seen in Figure 4-12, the average aggregate load factors are predicted to rise linearly for each of the major markets through the end of this century. They will not exceed the 70% ceiling discussed in the section on the Boeing methodology. As before, these load factor forecasts are combined with the RPM forecasts to generate an ASM demand forecast.

**PASSENGER TRAFFIC
ALL SERVICES**

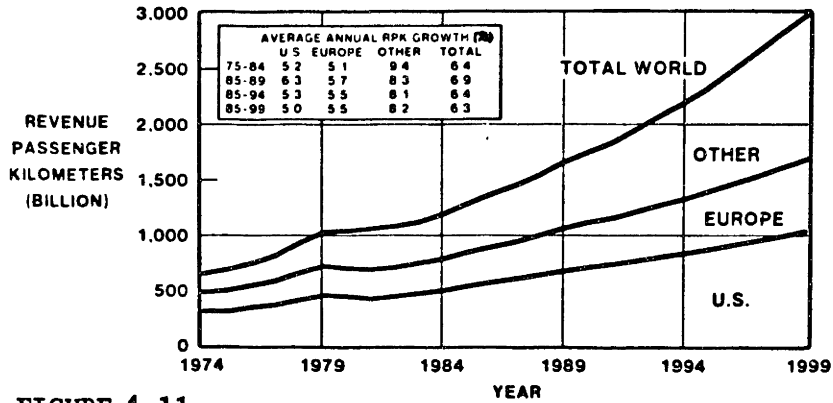


FIGURE 4-11

SOURCE: 1985-1999 Outlook for Commercial Aircraft, Douglas Aircraft Company, Long Beach, CA, September 1985, p. 8.

**AVERAGE PASSENGER LOAD FACTORS
ALL SERVICES**

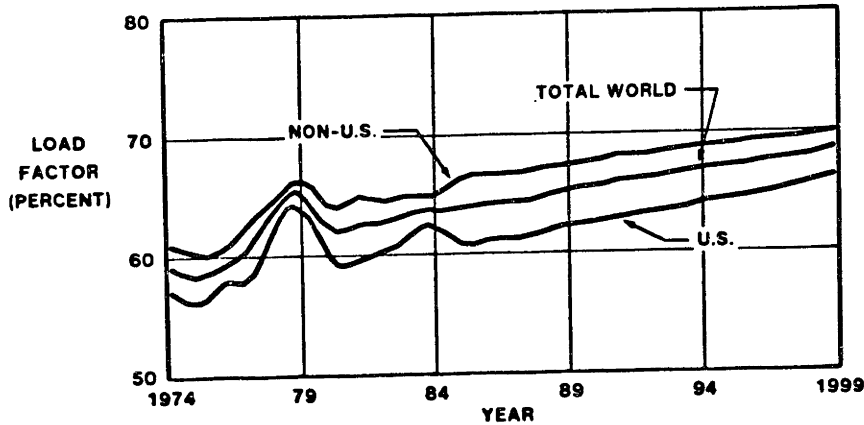


FIGURE 4-12

SOURCE: 1985-1999 Outlook for Commercial Aircraft, Douglas Aircraft Company, Long Beach, CA, September, 1985, p. 9.

On the supply side, the experts who are assigned to cover certain airlines and/or regions factor their knowledge of the airlines' productivity vis a vis equipment utilization and of the airlines' equip-

ment purchase (both new and used) and retirement plans to generate the by-airline ASM supply forecast. The difference between the ASM supply and demand forecasts is the overcapacity or capacity gap, shown in Figure 4-13. Where capacity gaps exist, the airline experts fill those gaps with aircraft of various generic classes shown in Figure 4-1, based upon their knowledge of the current fleet mixes and route structure both now and in the future. Any anticipated changes in route structure would be reflected in changes in the fleet mixes.

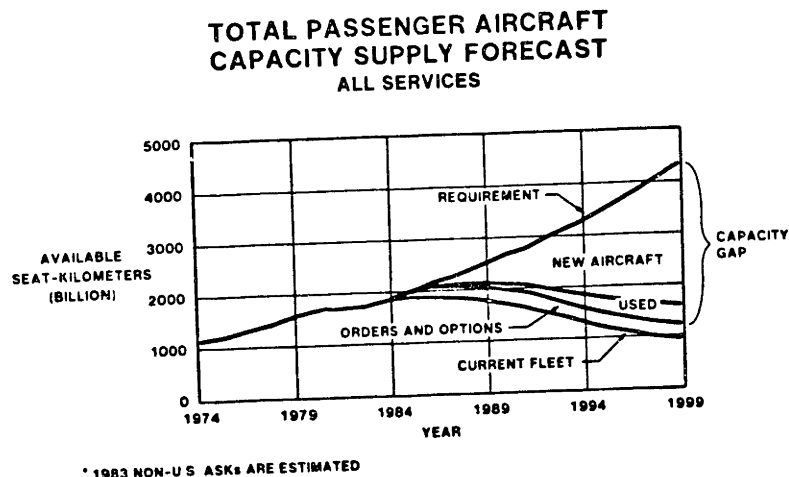


FIGURE 4-13

SOURCE: 1985-1999 Outlook for Commercial Aircraft, Douglas Aircraft Company, Long Beach, CA, September 1985, p. 17.

MD also has a model which views the world as if it served by one large airline. The details of this model are strictly proprietary. In general, it starts with a world wide RPM forecast generated using regression techniques and inputs from Wharton Economic Forecasting Associates relative to key economic variables. From this RPM forecast and certain assumptions about yields and airline costs, the model calculates the aggregate operating profit of the airlines. This profit

forecast is then cross-checked against the aircraft demand forecast to determine if the airlines can, in fact, afford the equipment to fill the capacity gap. This model is run repeatedly with various inputs to determine which inputs and assumptions have the most impact on the aircraft sales forecast.

GENERAL ELECTRIC - AIRCRAFT ENGINE BUSINESS GROUP

AEBG's forecasting methodology follows much the same general format as that of Boeing and McDonnell Douglas; specifically, an RPM forecast is combined with load factor forecast to determine demand for aircraft on an ASM basis. This, then is compared with the ASM supply which is derived from the current fleet plus orders on the books, less expected retirements, adjusted for the anticipated level of productivity. The difference between ASM demand and supply is the capacity gap which must be filled with new aircraft.

As indicated above, the starting point for the AEBG aircraft demand forecast is an RPM forecast. Back in about 1980, rather complex econometric models were used to generate RPM forecasts by region. According to Tom Wilson, Manager - Support & Operational Planning in the early 1980's;

we used to forecast by geographical area, using some fairly detailed regional models. That produced a terribly complex and nearly unintelligible set of forecasts, and I'm not sure it provided any more accuracy than a more global ... approach.⁵

He decided that a much simpler approach was needed, and went on to describe what he was looking for in this new method.

⁵"General Electric Aircraft Engine Business Group," Harvard Case Study, Harvard Business School, Boston, MA, 9-183-136, p. 6.

Our system has to be reasonably accurate, of course. But we have several other criteria to meet as well. No forecast will be fully accurate, but a forecast that no one can follow, or that is unconvincing, is a wasted forecast. Its level of accuracy becomes irrelevant if no one believes it. So one thing we need to have is a clear line of argument, something management will understand and accept. We need forecasts that don't require a huge staff to generate -- because we haven't got a huge staff. And we need forecasts that "feel" right. I'm no statistical expert, but I've been in the aircraft engine business a long time, and I have to find the forecast compelling if I'm to get behind it and sell it to management.⁶

The job of developing a new, simplified methodology for forecasting RPM's was assigned to Gordon Blowers, then Manager - Traffic Forecasts. While researching the problem, Gordon read a book by Herman Kahn entitled World Economic Development. According to Gordon:

Kahn convinced me that the development and growth of commercial aviation follows the same general pattern observable for many, if not most, natural and man-made systems [reference Figure 4-8]. While it is often convenient to think of growth in terms of linear relationships for a relatively short, specific time period, long-term growth is much more typically represented by S-shaped curves [reference Figure 4-7]. Moreover, the basic growth curve for any particular system or phenomenon is usually determined by internal dynamics, rather than by external pressures. Of course significant external pressures on the airline industry exist today, as they have in the past. But it is not worth treating the effects of each of these pressures individually, because foreseeable future events will collectively have about the same influence on the long-range trend in commercial aviation as have those of the past or the present. The system, therefore, has the potential for predicting its own future growth relatively independently of external factors and influences.⁷

Gordon decided to regress the log of world RPM against time, then to exponentiate that regression equation to get a direct estimate of RPM. He found that by introducing a dummy variable to offset the ex-

⁶Ibid., p. 1. ⁷Harvard Case Study, 9-183-137, p. 2.

ceptionally high peak in demand associated with the end of World War II, he obtained a virtually perfect fit. Figure 4-14 shows the output from the least squares analyses. Note the form of the curve. It looks very much like the Gompertz Curve shown in Figure 4-7, as it should since the analysis produced an equation of the form $RPM = a^{bt}$, where t is time.

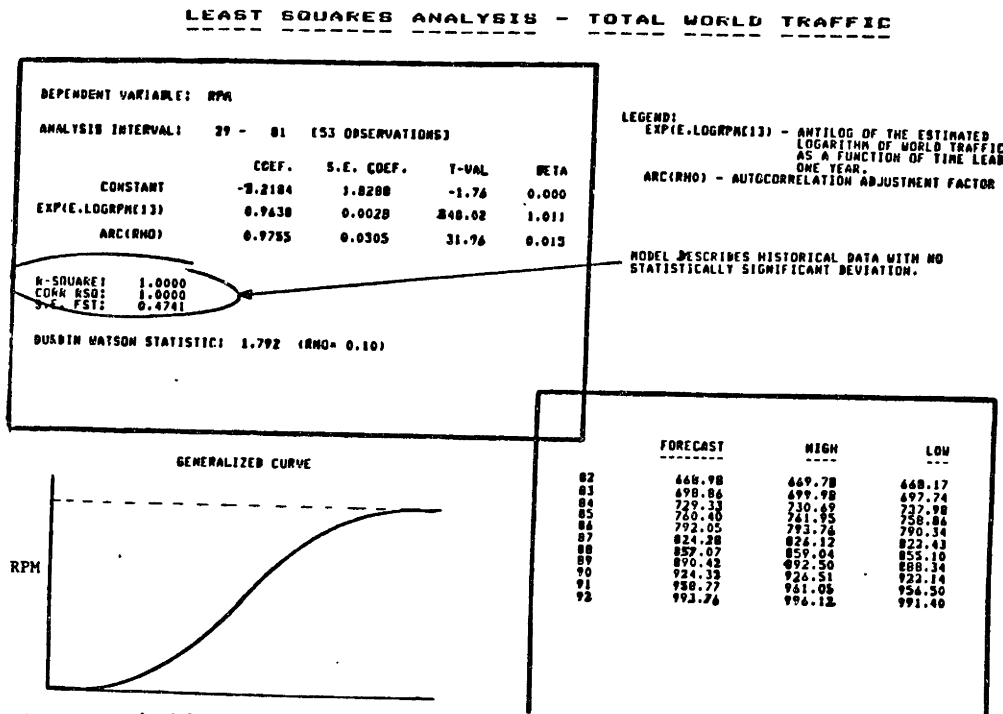


FIGURE 4-14

SOURCE: Harvard Case Study, "General Electric Aircraft Engine Business Group," Harvard Business School, Boston, MA, 9-183-137, p. 7.

Taking a somewhat different cut at the problem, Gordon noted that, if the annual RPM data were converted into annual RPM growth rates, and a five point moving average was taken of the actual and forecast growth rates, a smooth trend line emerged (reference Figure 4-15). This trend

line flattens out in 1990 at about 3%, indicating that the world air travel market will have reached its mature phase by then. This is fairly consistent with the Boeing's view point.

As previously discussed, converting this RPM forecast into an aircraft sales forecast, and finally an engine sales forecast, requires the generation of both an aircraft demand and an aircraft

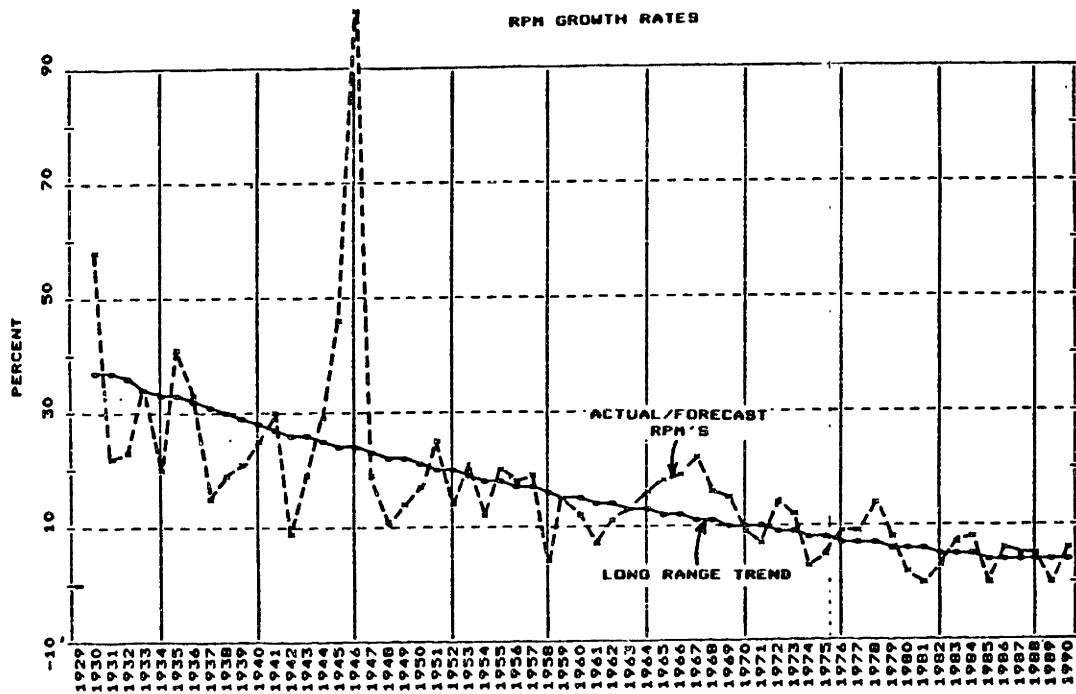


FIGURE 4-15

SOURCE: Harvard Case Study, "General Electric Aircraft Engine Business Group," Harvard Business School, Boston, MA, 9-183-137, p. 12.

supply forecast. To generate the demand forecast, Gordon used an assumed load factor of about 63% which when combined with the forecast RPM's inferred an ASM demand. Given this inferred ASM demand, an assumption that the proportion of aircraft in each range category remains relatively constant, and some judgement relative to the aircraft

productivity (ASM/aircraft) by range category based on past and recent trends, a "by category" aircraft demand forecast falls out.

To generate the aircraft supply forecasts, one critical parameter must be estimated; that being the number of aircraft that will be retired by category over the forecast period. A general algorithm was developed to make this projection. The algorithm assumed that the average aircraft would be retired after 22 years in service, and that the cumulative percentage retired of a given aircraft model would follow the distribution shown in Figure 4-16. Given the number of aircraft in service at the beginning of the forecast period, the aircraft supply forecast may be generated by adding new aircraft on order and subtracting the aircraft expected to retire based upon this algorithm.

Having defined the number of aircraft in each category to be delivered throughout the forecast period, the engine sales forecast by thrust category becomes a simple matter of multiplication. The number of two engine aircraft in a given category is multiplied by two, the number of three engine aircraft by three, and the number of four engine aircraft by four. These products are then summed to yield the installed engine sales forecast. The total engine sales forecast assumes that the airline will maintain a spare engine to installed engine ratio of 0.2. This forecast then becomes the focus for discussions with marketing and project managers who add their own intuitive judgements. The process becomes an iterative one during which the forecasting group fine-tunes the model and its underlying assumptions such that the ultimate result is acceptable to all parties.

CUMULATIVE PERCENT OF RETIREMENTS FROM AN INDIVIDUAL AIRCRAFT FLEET

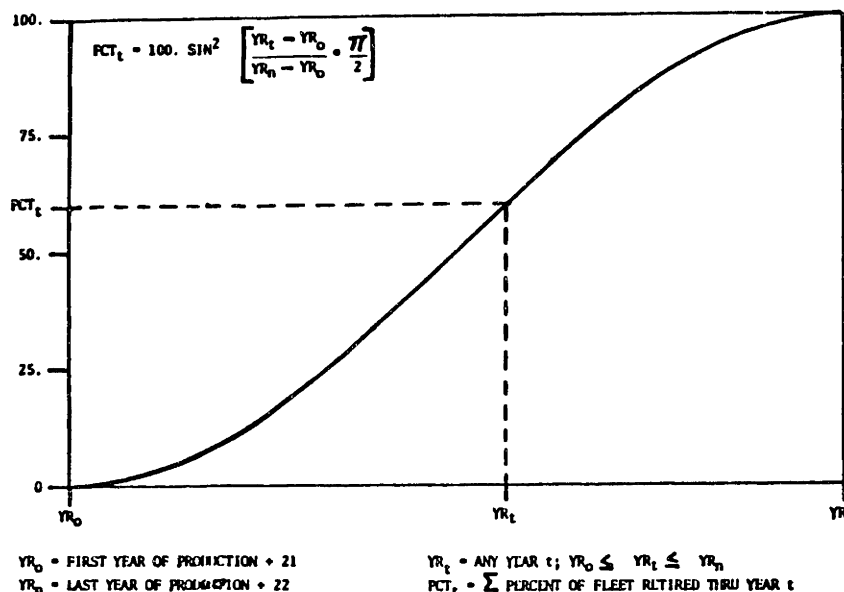


FIGURE 4-16

SOURCE: Harvard Case Study, "General Electric Aircraft Engine Business Group," Harvard Business School, Boston, MA, 9-183-137, p. 19.

ROLLS ROYCE LIMITED

The Rolls Royce (RR) forecast is based on the following assumptions.

Traffic is forecast to grow at an annual average rate of 5.5% over the next 15 years but will fluctuate in individual years such that variations of anywhere between 1% and 10% are possible. ... Narrow-bodied aircraft will retire at an average age of 22 years. [The implication is that wide-body retirements over the forecast period will be minimal.] ... Load factors will rise to 67% by the end of the forecast. ... ASM's flown will grow at an annual average rate of 5% over the next 15 years. ... Total operating profit of the world's airlines will remain around 5% of operating revenues for the short term, accompanied by rises in net profit sufficient to finance the additional capacity required.*

*Market Potential for Commercial Jet Engines 1985-1999, Rolls Royce Limited, Derby, England, 1985, p. 1.

The methodology used to develop most of these assumptions was not provided to the author. However, it can be said that these assumptions are consistent with those of most of the other companies with whom I spoke. From these assumptions one can develop a forecast in a rather straight forward manner using the basic calculations discussed in previous sections.

Although, as noted above, RR did not share with me what is behind most of their assumptions, they did share the methodology used to generate their RPM forecast.⁹ For the short term, they use a logarithmic regression of RPM against GNP, yield, and block speed (elapsed time between leaving the departure gate and pulling up to the arrival gate). The regression equation is of the form:

$$\text{Log RPM} = k_0 + k_1 \text{Log(GNP)} + k_2 \text{Log(Yield)} + k_3 \text{Log(Block Speed)}.$$

For the out-years in the forecast period, they use the linear form:

$$\text{RPM} = k_0 + k_1 (\text{GNP}) + k_2 (\text{Yield}) + k_3 (\text{Block Speed}).$$

This is somewhat similar to the Boeing approach, although Boeing is more conservative relative to the short term forecast. Recall that Boeing uses a forecast which lies between their logarithmic and linear regression lines for years one through five and transitions to the linear regression forecast line in year eleven.

ROHR INDUSTRIES, INC.

Rohr has, in the past, been a "make-to-print" manufacturer of propulsion system hardware such as engine cowls, and other related nacelle hardware, their specialty being composite materials. By make-

⁹Reference conversation with E.H. Burgess, 12/18/85, (former RR forecasting guru, and currently retained as a consultant to RR).

to-print, we mean that Rohr manufactures the parts ordered by their customers according to design specifications and drawings supplied by their customers. Rohr is becoming less of a make-to-print vendor and more of an integral part of the propulsion system design and development team, and a risk sharing partner in the production phase of a program.

About 60% of their business is related to the commercial aircraft and engine industries, and they are vitally interested in the future market developments facing those industries. They, therefore, maintain a small staff which looks at the market using a true blend of analysis and judgement. Their approach to market forecasting is significantly more intuitive than any of the approaches discussed so far. The people in this group have technical backgrounds, blended with business training, whereas the people with whom I spoke at Boeing and McDonnell Douglas, for example, were basically economists. Therefore, unlike the forecasting groups at the airframers, they tend to look more deeply into what types of products will best fit a market need, not just what the generic types of aircraft and engines will be needed, and in what numbers.

Think for a moment about the flow of the forecasting technique used by Boeing. The Boeing model, as represented by Figure 4-2 begins with estimates of key economic variables such as fuel prices, labor rates, interest rates, etc. These variables, in turn are factored into forecasts of GDP and airline yields. Moving from left to right across this figure, we see that these two variables are inputs into an econometric model used to predict RPM's. This RPM projection is cross-

checked against the RPM assumption implicit in the yield forecast. The model then shifts to Figure 4-9 which uses the RPM forecast from Figure 4-2 as an input. Moving left to right across the figure, we see that RPM's are combined with load factor projections to produce an ASM demand forecast, which is compared to an ASM supply forecast. The difference between ASM supply and demand forecasts by generic type of aircraft yields a forecast of aircraft deliveries by generic type.

Now picture a room which Rohr calls "The Chart Room," on the walls of which are graphs and tables summarizing the projections taken from numerous sources of the parameters enumerated above in our discussion of the Boeing technique. Further, picture that these graphs and tables are arranged in basically the same order, from left to right, as they are presented in Figures 4-2 and 4-9. You now have a mental picture of Rohr's Chart Room. The difference is that the Chart Room attempts to capture the dynamics of the situation by superimposing on these graphs and tables the actual monthly results as they occur. In this manner, it is fairly easy to see if major deviations from prediction are occurring and to see if these deviations seem to indicate a trend not captured by the assumptions underlying the predictions. Rohr, therefore, does their forecasting dynamically on a month by month basis, always looking at results and re-examining underlying assumptions.

Rohr does maintain their own analytical model (the details of which were not shared with me) which takes the industry forecasts for RPM's and load factors, modifies them for emerging trends and superimposes on them Rohr's own assumptions about the effects of the business

cycles, and predicts ASM requirements,. These projections, when coupled with assumptions about aircraft retirements and public knowledge about firm orders, yields an aircraft forecast by generic class. Aircraft delivery forecasts are converted to Rohr-supplied hardware forecasts based upon certain assumptions relative to market share.

Rohr breaks their forecast into two pieces; the long term, defined as longer than three years ahead, and the short term, defined as less than three years. The short term forecast is further broken down into three segments; 0-12 months, 13-24 months and 25-36 months. The 0-12 month forecast is formulated by their contracts and program management people who know what is under contract and what is imminent. The 25-26 month forecast, is generated by Rohr's market analysts, and the 13-24 month forecast is "arm-wrestled" between these groups. The output of the analytical model described above is cross-checked against the short term forecasts of these specialist groups. It should be noted that hardware provided by Rohr to either the aircraft or engine manufacturers must lead the aircraft delivery schedule by up to a year or more, so the analytical model output is time-lagged vis a vis the short term forecasts of Rohr's functional specialists. The analytical model output with necessary lead time adjustments forms the primary basis for the long range forecast.

Rohr scrutinizes this forecast in light of several factors which could restrict the ability of the aircraft and/or engine manufacturers to produce the forecast quantities, or limit the ability of the airlines to purchase and/or utilize these products. For example, Rohr looks carefully at the demands that the forecast infers for materials

such as aluminum and titanium, to see if the demand would strain or exceed the capacities of the various material suppliers. They look at the financial conditions of the airframers and engine manufacturers to determine if the forecast volumes are within their capabilities (i.e., do these manufacturers have the financial reserves necessary to accommodate the production capacity expansions and/or new product developments inferred by the forecast). They look closely at the airlines' profitability to see if they can afford additional equipment in the quantities indicated. Finally, they examine the implications of the increased number of aircraft relative to the capacity of the air travel system. In other words, will there be enough pilots to fly the airplanes, and can the airports handle the additional volume. In short, Rohr makes several reality checks against the forecast before proceeding to the next phase.

Having established a realistic long range baseline demand schedule for aircraft by generic type, Rohr uses a modified Delphi Technique to forecast which specific models will fill this demand, and in what proportions. It is during this process that Rohr attempts to establish the product split between aircraft and engine manufacturers and between existing and new products. This, of course, is critical to Rohr in establishing their marketing focus for the long term. This forecast is generated once a year by Rohr managers representing the various functional groups within the company. The technique they employ differs from the Delphi Methodology described in Appendix A in that the managers confront one another directly during the feedback/interrogation phases. The basic ground-rule for these meetings is

that the participants "put their badges on the table" (i.e., there will be no pulling rank during the meeting or negative repercussions against those holding dissenting views after the participants leave the meeting room). This internal forecast is supplemented by a Delphi forecast based upon the views of seven to ten experts from throughout the industry. Here, anonymity is guaranteed, and the results are freely shared with the participants. Rohr has found that the resulting consensus opinion of these experts almost invariably agrees quite closely with the internal forecast.

TRW - AIRCRAFT COMPONENTS GROUP

TRW is one of the major suppliers of fan, compressor and turbine blades and fuel pumps to the gas turbine manufacturers. They, like Rohr, are a second tier supplier, and like Rohr, maintain a relatively small staff to generate their forecasts. This is not where the similarity ends, however. It was deja vu when I walked into the TRW forecasting area. After a brief introductory session, we adjourned down the hall to a room which was set up almost identically to the Rohr chart room, and used in much the same manner.

Like Rohr, TRW maintains their own analytical aircraft demand model which uses various inputs from the chart room. The details of the model were not shared with me, but my understanding is that the model takes RPM, ASM and retirement projections as inputs to generate an aircraft forecast. The model also generates a load factor projection which is used as a reality check. If the projected load factor is too high or too low (i.e., outside the 60 to 70% range) the aircraft forecast is called into question and the inputs reviewed for

validity. Like Rohr, TRW tracks orders very closely and uses firm orders as a cross-check for the short run forecasts of aircraft demand generated by their model.

Another similarity between the approaches of Rohr and TRW is that the forecasting of the product mix, and of new products, including the timing of their entry, is done qualitatively. However, TRW does not use as rigorous a qualitative methodology as is used by Rohr. Their forecast boils down to the judgement of essentially one or two men operating with input from other experts throughout the industry (versus the Delphi methodology utilized by Rohr).

FORECAST ASSOCIATES, INC.

Forecast Associates (FA) is a forecasting consulting firm whose focus is the aerospace industry, particularly aircraft and engines. They forecast both commercial and military markets, as well as industrial and marine applications for gas turbine engines. What will be described here is their forecasting methodologies vis a vis large commercial transport aircraft and engine market.

FA categorizes their forecasts into three groups; year zero through four, five through seven and eight through ten. They typically do not publish forecasts beyond a ten year time horizon. The zero through four year period forecast is based primarily on a bottoms-up analysis; i.e., upon data drawn from a detailed study of known orders on the books, and an assessment of how many of the so called "options" will be converted to firm orders, based on experience and an analysis of current trends. The mid-term forecast (years five through seven) is more intuitive. It starts from a general knowledge of products be-

ing developed and industry forecasts for those products, coupled with industry forecasts for sales of existing products. The FA analysts temper these forecasts based upon historical patterns, and their qualitative judgements on the probabilities of success or failure of new programs. Alternative political and economic scenarios are factored into their thought process. Finally, for the far term (years eight through ten), they generate an overall aircraft market forecast based upon the general industry concensus of RPM growth, and some general "rule of thumb" type estimates of load factors and aircraft retirements. To convert their estimate of total aircraft sales to sales by product class and manufacturer, FA relies upon historical precedents in light of recent trends, and the anticipated impact of new products and new technologies. Given this aircraft forecast, a market split forecast for the engines powering those aircraft is arrived at in a similar manner. The number of engines by model is simply the product of the number of engines per aircraft of a given type multiplied by the number of aircraft of that model which FA expects to have a given engine model. This calculation provides a forecast of installed engines. The spare engine forecast is generated by applying a spares factor to the installed engine forecast. FA then compares notes with companies involved in the industry (from components manufacturers to engine and aircraft manufacturers), and modifies their forecast as deemed appropriate based upon inputs from this panel of experts.

SUMMARY OF MODELING TECHNIQUES

From the preceding discussion, one can see that a broad range of forecasting techniques are applied by the various companies in the in-

dustry. The methodologies employed are summarized in Table 4.1.

TABLE 4.1

Summary of Techniques Employed for Long Range Forecasting

<u>Company</u>	<u>Technique(s)</u>
Boeing	<u>Qualitative</u> - Apply their own judgement to macroeconomic forecasts provided by consultants, and to the results of their own quantitative models. <u>Quantative</u> - Primarily regression.
MD	The basic techniques employed are very similar to Boeing's -- the models themselves differ.
GE	<u>Qualitative</u> - Quantative forecast is fine-tuned by judgement of marketing and project managers. <u>Quantative</u> - Regression, using time as a proxy variable.
RR	<u>Qualitative</u> - expert judgement. <u>Quantitative</u> - Regression analysis.
Rohr	<u>Qualitative</u> - Apply their judgement to inputs from many sources to use as inputs to an analytical model. Then apply their judgement again to the output of that model. <u>Quantitative</u> - Analytic model.
TRW	Very similar to Rohr.
FA	Although they do not maintain a "Chart Room," their technique is generally similar to that employed by Rohr and TRW.

MARKET FORECASTS

The ten year forecasts of several of the companies discussed above are presented in Table 4.2. Also included is a Merrill Lynch (ML) forecast, because it provides an interesting contrast to the industry forecasts. The methodology behind their forecast is not described in the source document, but the results are considerably more optimistic than any of the forecasts of the various players in

the industry. If the Merrill Lynch forecast had been considerably lower than any of the industry forecasts, perhaps we should have been somewhat concerned, in that one inference which could then be drawn is that the various companies were painting an overly optimistic picture for their boards and stockholders. However, given that the reverse is true, it lends more credence to the forecasts of the companies involved in the industry. Note that the GE forecast is right in with a cluster of others somewhat below the mean.

TABLE 4.2
Aircraft Delivery Forecasts (1986-1995)

<u>Source</u>	<u>86</u>	<u>87</u>	<u>88</u>	<u>89</u>	<u>90</u>	<u>91</u>	<u>92</u>	<u>93</u>	<u>94</u>	<u>95</u>	<u>Total</u>
Boeing ¹	395	426	426	386	334	315	413	424	408	382	3909
MD ²	165	219	329	387	397	358	506	489	430	458	3738
GE ³	390	305	285	325	360	387	385	397	493	483	3810
RR ⁴	280	384	421	431	432	405	402	398	346	319	3818
Rohr ⁵	354	445	304	345	379	421	529	391	433	479	4080
TRW ⁶	390	433	422	373	356	361	384	404	434	462	4019
ML ⁷	394	444	460	375	450	490	505	490	490	490	4588
Amalgamated	338	379	378	375	387	391	446	428	433	439	3994

SOURCES:

¹"World Travel Market Perspective and Airplane Equipment Requirements," Boeing Current Market Outlook, Seattle, Washington, February 1986, p. 70.

²1985-1999 Outlook for Commercial Aircraft, p. 45.

³Commercial Market Outlook, General Electric Airline Marketing Division, Cincinnati, Ohio, November 1985, p. 4.

⁴Market Potential for Commercial Jet Engines, Section 4 p. 2.

⁵Chart from Rohr's "Chart Room," dated 11/07/85.

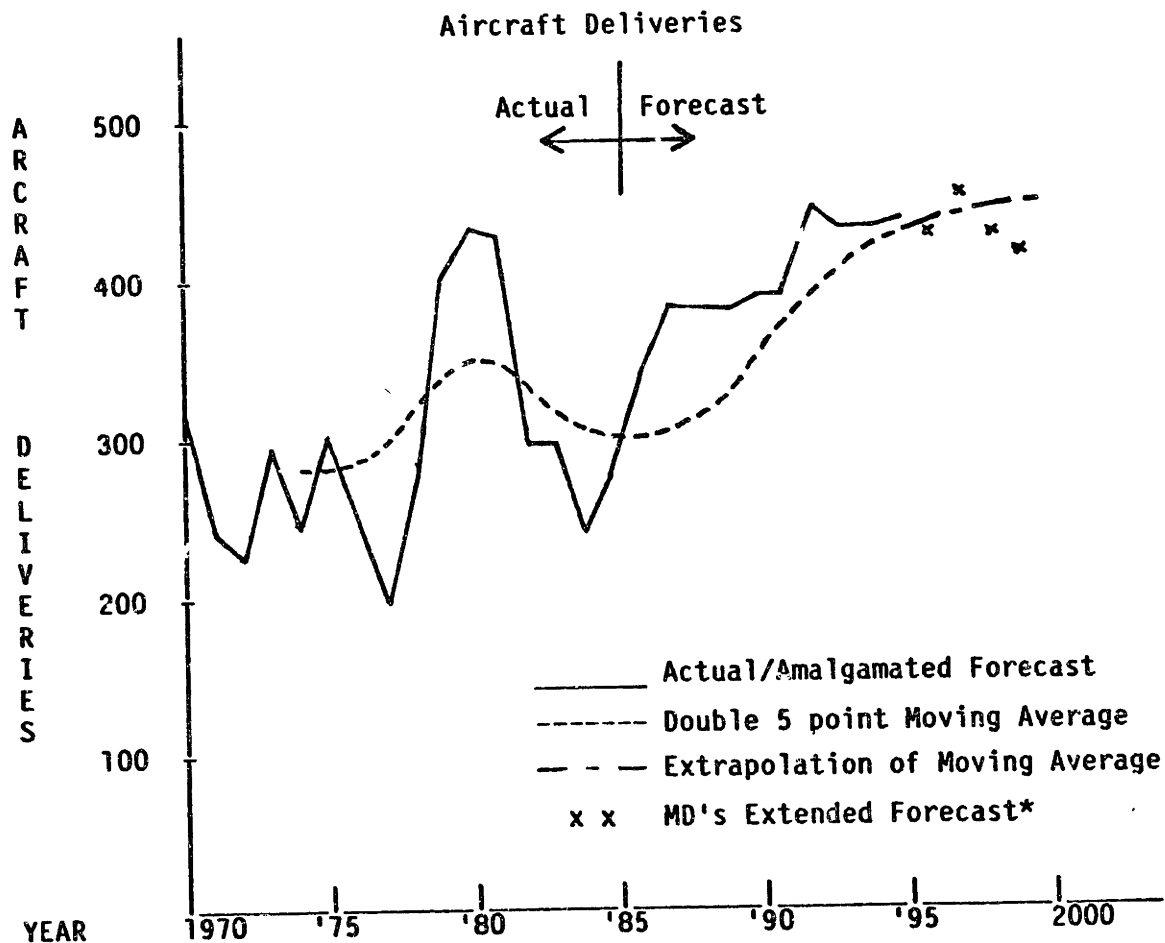
⁶Interview with William Wilder, Market Analysis Specialist, TRW Aircraft Components Group, 03/05/86.

⁷Merrill Lynch, Industry Review, Aerospace-Commercial-1985, October 1985, pp. 8 and 12.

Figure 4-17 presents the history of aircraft orders during the

period 1968 through 1985, and the amalgamated forecast for 1986 through 1995. Superimposed on the plot is a double five point moving average of the actual and amalgamated forecast data, and an extrapolation of the five point moving average through the end of the century. This line begins to bend over in the mid-1990's, when the market is expected to be fully mature. The small "x's" spot the MD extended forecast for 1996 through 1999.

FIGURE 4-17



*SOURCE: 1985-1999 Outlook for Commercial Aircraft, p. 45

TABLE 4.3

Proportions of Aircraft Deliveries By Generic Class

<u>Forecaster</u>	<u>Short</u>	<u>All Other Classes Combined</u>
Boeing ¹	55.3%	44.7%
MD ²	53.3%	46.7%
GE ³	61.1%	39.9%
RR ⁴	48.1%	51.9%
Rohr ⁵	50.0%	50.0%
TRW ⁶	58.0%	42.0%
ML ⁷	51.4%	48.6%

SOURCE:

¹"World Travel Market Perspective and Airplane Equipment Requirements," Boeing Current Market Outlook, Seattle, Washington, February 1986, p. 70.

²1985-1999 Outlook for Commercial Aircraft, p. 45.

³Commercial Market Outlook, General Electric Airline Marketing Division, Cincinnati, Ohio, November 1985, p. 4.

⁴Market Potential for Commercial Jet Engines, Section 4 p. 2.

⁵Interview with John Walsh, Director Market Planning and Proposals, Rohr Industries, Inc., 01/08/86.

⁶Interview with William Wilder, Market Analysis Specialist, TRW Aircraft Components Group, 03/05/86.

⁷Merrill Lynch, Industry Review, Aerospace-Commercial-1985, October 1985, pp. 8 and 12.

Table 4.3 summarizes what the various forecasters interviewed feel the split between short, and medium/long range aircraft (reference Figure 4-1) will be throughout the forecast period. The people with whom I spoke and the published material I read consistently point to the short range market segment as the dominant market through the 1990's. The underlying reason for the high potential of the short range market is that there are almost 3,000 short range aircraft in service, over half of which are more than 15 years old. Therefore,

over the next 10 to 15 years there will be a tremendous boom in the sale of aircraft in the short range category due primarily to a burgeoning replacement market. GE has pegged the total market for this category of aircraft in the 1990's at 2,360 airplanes.

MARKET FOR SHORT RANGE AIRCRAFT 1992-2000

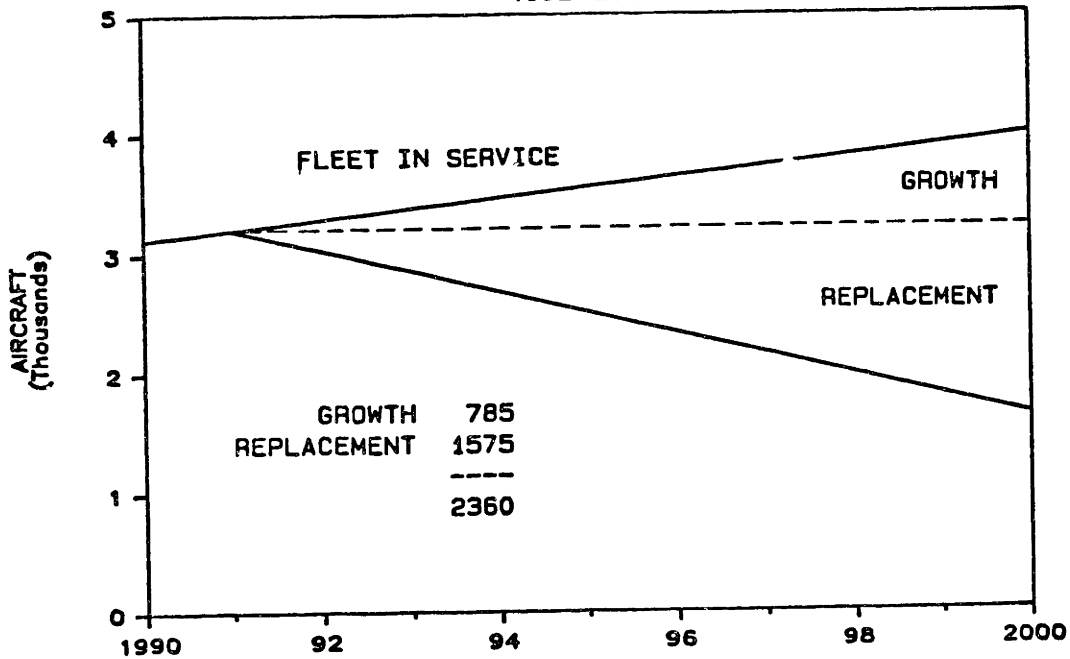


FIGURE 4-18

SOURCE: Commercial Market Outlook, General Electric Airline Marketing Division, Cincinnati, Ohio, November 1985, p. 16.

Figure 4-18 presents GE's forecast for 1992 through 2000. The difference between the upper and lower lines is the capacity gap which must be filled. The average annual market volume over the forecast period is about 260 units. MD's forecast for the same time frame is just under 2000 airplanes, or about 220 aircraft per year. Boeing, which typically holds over 1/2 of any market segment in which they compete, sees a Boeing market share of 1,100 aircraft, out of a total market of about 1,800 aircraft (about 200 per year, on the average). The aver-

age deliveries predicted by the moving average line in Figure 4-17 for the period 1992 through 2000 is about 430. Assuming that half of these will be short range aircraft as indicated in Table 4.3, the average annual market for such aircraft is about 215 units, or almost 2,000 aircraft for this nine year period. By historical standards, this is a very large market segment indeed, given that the average annual deliveries (all categories) from 1970 through 1985 was about 300 aircraft per year.

CHAPTER 5

THE MARKET AND THE PRODUCTS

In the concluding section of the last chapter, we saw that the major manufacturers in the industry have, with a high degree of unanimity, declared that the short range narrow body aircraft market will be where the action is over the next 10 to 15 years. The principal reason cited was the need to replace an aging fleet of Boeing 727's and 737's and Douglas DC-9's. However, although the age of this segment of the fleet is a prime determinant of the market potential for this type of aircraft, it is not the only factor involved. It is conceivable that the market could have evolved away from this size aircraft, such that they would not be replaced with similarly sized equipment upon their retirement but with, say, medium or long range wide bodies. The second key ingredient which cemented the need for a new fleet of short range aircraft was the move toward the hub and spoke system discussed in Chapter 3.

According to a recent report by First Boston Research,

This change precipitated a transformation in jetliner demand, away from the larger, longer-range designs suitable for a nationwide network to smaller, more cost-effective aircraft able to fly the spoke hops at a profit. The result has been a decline in the average size of airliners ordered in recent years, from 201 seats in 1980 to 176 in 1983 and a renewed shift toward narrow body twin jets, away from the larger designs such as the A-310 and the 767 that had been designed in the late 1970's before deregulation became effective. The shift to smaller aircraft is still underway. Moreover, the drastic changes in the cost of airline personnel, especially aircrews, that have taken place over the last five years [see Table 3.1] have dramatically reduced the cost disadvantage of the smaller jetliners which have fewer seats to cover the fixed cost of the crew. As the customer prefers convenient service, i.e., frequency, to other amenities, such as wide body roominess, the shift

to smaller aircraft is still going strong. The only constraint on this trend is the limited capability of the principal hub airports to accommodate more traffic.¹

This constraint should not impact the replacement portion of the overall market. Furthermore, to ease congestion at existing hubs, the system may evolve to incorporate "mini-hubs" and more "point-to-point" routes, thereby increasing the growth demand for smaller aircraft. Thus, the 2,000 unit estimate of the market through 1990, developed at the end of the last chapter, might significantly understate the size of the market. Given this conservative estimate of the market potential, and that this represents a major market segment which cannot be ignored, let us now turn to a discussion of how the major manufacturers are approaching this market. Since it takes four or five years to bring a new aircraft to the commercial transport market, and about seven years to introduce a new engine, the major manufacturers have, for the most part, already placed their bets on their respective next generation products to serve this market. We will first focus on AEBG's market strategy for, as we shall see, it has been the driver relative to the strategies of the other manufacturers.

GENERAL ELECTRIC AIRCRAFT ENGINE BUSINESS GROUP

As indicated in Chapter 3, AEBG has wrested half of the commercial transport engine market away from P&W and RR, greatly due to the success of the CFM56 family of engines. The biggest selling airliner powered by the CFM56-3 is the Boeing 737-300, which seats about 120 passengers. The response of the market to this aircraft has exceeded

¹The Jetliner Business, p. 20.

both AEBG's and Boeing's wildest expectations, and its strong sales are indicative of the strength of the short range, narrow body market. Recall that in 1984 alone, Boeing took orders for 117 CFM56-powered 737's. Looking at this market as primarily a replacement market for the 727 which has a somewhat greater seating capacity, Airbus has announced a new 150 to 160 seat aircraft, the A320, in 1987. This aircraft will require an engine with somewhat greater thrust than the 737, and the AEBG/SNECMA team will introduce a derivative of the CFM56-3, the -5, which will produce the additional required thrust while offering incremental improvements in fuel efficiency. The CFM56-5 will be available in 1987, and Airbus has taken orders for over fifty A320 aircraft powered by this engine.

This incremental improvement approach to new products as used here by GE-SNECMA is the approach traditionally followed by the industry, and as could be predicted based upon past history, other competitors followed suit so as not to leave this market to the GE-SNECMA team. As indicated in Chapter 3, P&W and RR have teamed up with Fiat of Italy, MTU of West Germany, and a group of three Japanese firms to form a consortium called International Aero Engines (IAE), which has announced a new engine to compete with the CFM56-5. The engine, called the V2500, will incorporate the latest in turbofan technology. Its introduction will lag the CFM56-5 by a year or so, but it claims four to five percent better fuel economy than the CFM56-5, in order to give potential customers some incentive to delay their purchases until the V2500 is available.

What then should be GE's next move? An obvious choice might be

to continue along the path followed to this point, i.e., announce an engine which would offer a small incremental improvement over the V2500, and, in fact, this was considered. However, as indicated in Chapter 2, each successive incremental improvement comes at a higher cost than the last, and GE concluded that the point had been reached at which the added value to the customer was no longer sufficient to justify the price increase needed to achieve a reasonable return. The fact that P&W has limited its financial exposure on the V2500 to a 30% share by teaming up with RR, Fiat, MTU and the Japanese, all of whom are considerably less sensitive to the bottom line than a U.S. firm such as P&W, seems to indicate that they too are skeptical about the returns that the V2500 might produce, and are therefore, hedging their bet.

At GE, the engineers began to look at alternatives to a conventional turbofan. Recall from our discussion in Chapter 2 that there is an alternative which offers the type of quantum jump in performance that these engineers were seeking; specifically, advanced design propeller systems. NASA had been sponsoring research in so-called propfan technology since the mid-1970's, following the first of the oil price shocks. The technology was there. The question with which GE wrestled was whether or not this was commercially viable technology. There were potentially significant obstacles in the way, not the least of which were noise, vibration, ground hazards, and maintenance concerns. Furthermore, the advantage of the propfan over the best turbofan technology translated into a 15% efficiency improvement. The GE engineers were looking for more.

In search of a 20 to 25% efficiency improvement, the engineers turned their attention to an old concept whose origins could be traced to the 1940's; i.e., that of counter-rotating propellers. The idea is to place a second stage of propeller blades behind the first, but rotating in the opposite direction. This second stage recaptures the energy which would otherwise be lost in swirling discharge of the first stage. This two stage approach, when applied to the propfan, could produce the kind of performance differential which the engineers sought. Figure 5-1 summarizes the performance improvement which can be achieved with single and counter-rotating advanced design propellers.

Efficiency Trends

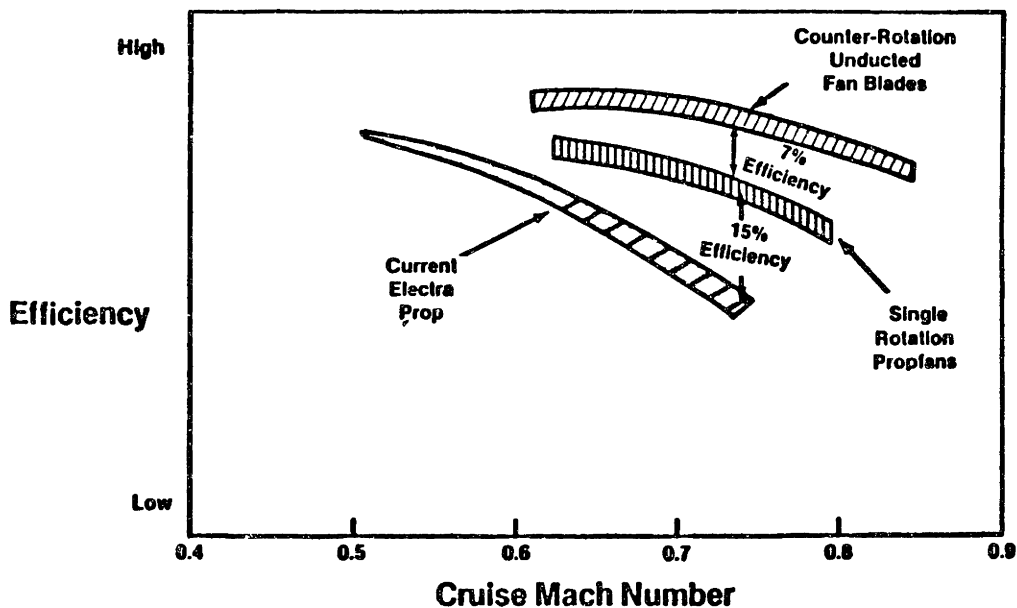


FIGURE 5-1

SOURCE: The Unducted Fan Engine, General Electric, ASME 30th International Gas Turbine Conference, March 1985, Houston, Texas, p. 5.

An important secondary benefit results from the use of counter-rotation. The torque of the second stage counteracts that of the first stage, thereby eliminating the net torque which the engine mount system feels. Thus, the system can be "soft mounted" on rubber-like mounts which significantly reduces the vibration transmitted to the airframe, and therefore significantly improves passenger comfort.

Another benefit of counter-rotation is that it permits the blades to be more highly loaded (i.e., absorb more power per square foot of swept area). With a single row of blades, the loading must be limited to reduce the swirl coming off the blades and thereby limit the energy loss. The incorporation of a second stage results in the recovery of the energy which would otherwise be lost in this slipstream swirl. Thus, the loading may be increased. The result is that the diameter of the propeller may be reduced for a given power input. The reduction in diameter makes an aft fuselage mounting scheme viable. Aft mounting further reduces cabin noise by moving the plane of rotation of the blades away from the cabin. Furthermore, it eliminates most of the hazards to ground personnel by moving the plane of rotation away from aircraft service points. Figure 5-2 shows a top view of the tail of an aircraft with two alternative counter-rotating propfan configurations; the so-called "pusher" and "tractor" configurations.

In order to keep the far field noise levels of the prop at acceptable levels, the rotational tip speed of the blades must be kept at about 800 feet per second or less. The smaller the diameter of the blades, the faster the rotational speed in revolutions per minute for a given tip speed in feet per minute. As indicated above, the higher

ALTERNATE PROPFAN CONFIGURATION

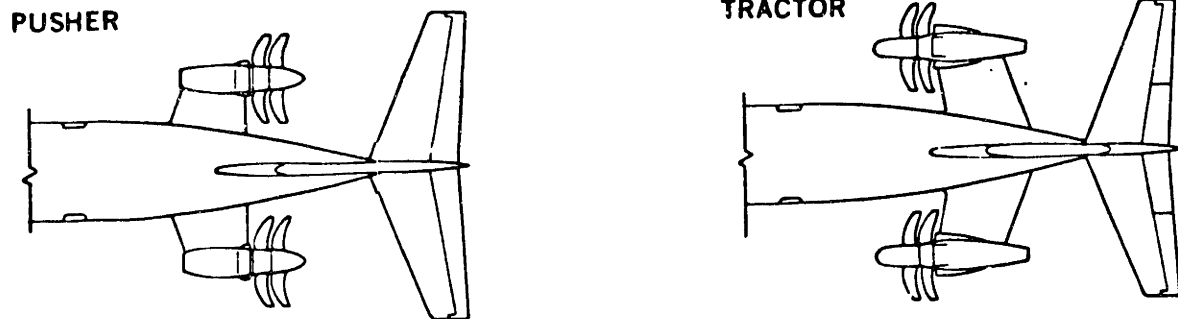


FIGURE 5-2

SOURCE: Paris 85, Aircraft Engine Business Group, General Electric, Paul Denarie, "In Sight Insight," p. 147. (Reprinted from Le Quotidien Du Bourget, June 3.

the acceptable disc loading, the smaller the diameter of the propeller for a given power input. GE engineers found that they could increase the disc loading while reducing the prop diameter to the point that the rotational speed of the propeller blades approached the efficient range of rotational speeds of the turbine driving the propeller, thereby eliminating the need for a speed reduction gearbox. This eliminates another source of noise and vibration. It also eliminates a major maintenance headache for the operator, based upon the maintenance history of such gearboxes on standard turboprop aircraft.

The direct drive approach ultimately selected by GE places the prop blades at the aft end of the engine in the plane of rotation of the turbine. With a conventional mounting arrangement for an engine (i.e., the air inlet and compressor forward of the turbine), this drives the design of the propfan system to the pusher configuration depicted in Figure 5-2. The GE system is presented in Figure 5-3. As shown in the picture, GE will provide the complete propulsion system

UDF™ — The Simple Approach

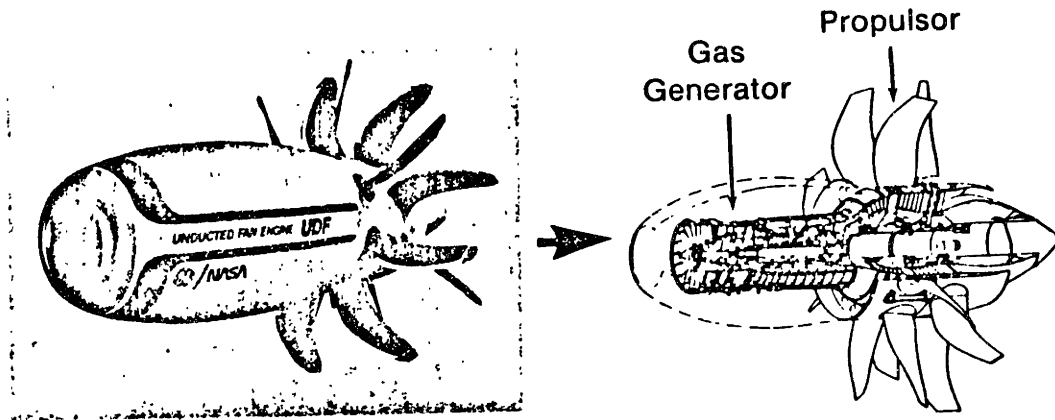


FIGURE 5-3

SOURCE: General Electric, "A New Thrust in Commercial Aviation," The Revolutionary UDF, April 1986, p. 18.

including air inlet exhaust and nacelle (the shell in which the engine is enclosed) including mount system. GE has dubbed this propulsion system the UDF (or unducted fan).

The propulsive efficiency for the various flight segments of the UDF and of modern technology turbofans are compared in 5-4. Figure 5-5 translates the UDF's greater efficiency into a fuel burn advantage vis a vis various generations of aircraft and engine combinations. On a 1700 nautical mile flight, an advanced technology aircraft powered by the UDF will require less than 30% of the fuel per pound of payload than the 727's it will be replacing, and less than 60% of the fuel per pound of payload than an A320 powered by the CFM56-5.

AEBG disclosed its revolutionary new design in December 1983,

UDFTM PROPULSIVE EFFICIENCY

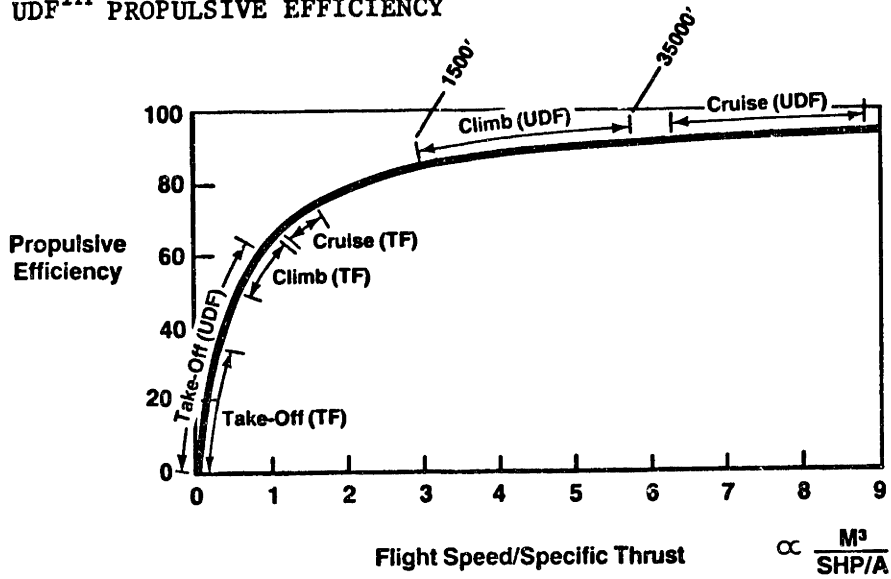


FIGURE 5-4

SOURCE: The Unducted Fan Engine, General Electric, ASME 30th International Gas Turbine Conference, March 1985, Houston, Texas, p. 8.

FUEL EFFICIENCY TRENDS

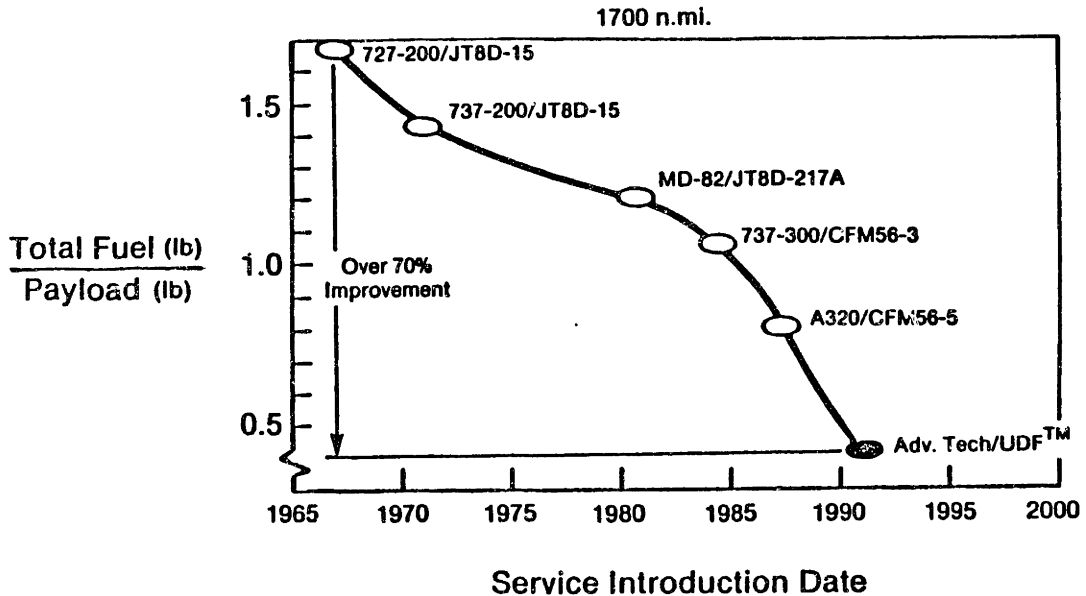


FIGURE 5-5

SOURCE: The Revolutionary UDF, "A New Thrust in Commercial Aviation," prepared by The General Electric Company, 1985, p. 4.

before a NASA-organized gathering of senior technical personnel from both the airlines and airframer manufacturers. NASA responded to AEBG's presentation with a \$20 million grant to design a demonstrator engine; a clear indication that NASA thought that AEBG might be on the verge of a significant breakthrough. In reaction to the potential for a commercial transport powered by such a propulsion system, Murray Booth, then director of future programs at Boeing, noted that it "... blows your socks off."² To help foster the development of this technology, Boeing is providing a 727 aircraft and technical support to AEBG for a flight demonstrator program at GE's Mojave Flight Test Center. The aircraft will fly this summer with the UDF demonstrator engine mounted in the number 3 (starboard) engine position. A similar program with McDonnell Douglas will be undertaken in early 1987, using a modified MD-80 aircraft. Bill Eccles, MD's Chief engineer for this program shares Murray Booth's enthusiasm. He thinks that "... at least through the year 2000, there will be an ever-increasing number of aircraft with this technology."³

Thus, the two U.S. commercial transport aircraft manufacturers are caught up in the excitement of the UDF's development, and are formulating their product plans for the 1990's based on the assumption that the UDF and possibly similar propulsion systems will be ready for commercial service introduction in about 1992. Only Airbus Industrie, the European consortium remains reticent on the subject, insisting

²Howard Banks, "The Next Step," Forbes, May 7, 1984, p. 31.

³ Kevin Maney, "Fan Fare for Remakes of Prop Engines," USA Today, December 17, 1985, p. 2B.

that their A320 will meet the needs of the airlines through the 1990's. We will discuss the reasons for this reaction later.

The NASA-funded demonstrator engine went to test this past summer. An existing core engine was used to drive the new gearless propulsor unit, since the purpose of the program was to demonstrate the feasibility of the gearless counter-rotating design of the propulsor, and not the potential efficiency improvements of a new core. The results of this testing have been extraordinary, and all key technical concerns have been allayed to AEBG's satisfaction. The engine met its performance targets, and model tests indicate that the system will meet the most stringent community noise regulations, either on the books, or likely to be promulgated in the foreseeable future. This demonstrator engine will soon be shipped to GE's Flight Test Center at Mojave California for the flight test program on the 727.

The projected full scale development costs for the UDF including an all new latest technology core engine are on the order of \$1.25 billion for a 22,000 pound thrust vehicle for a 150 to 160 seat aircraft. A smaller version of about 14,000 pounds thrust which could be used on a 100 to 110 passenger aircraft would cost an additional \$250 million. These numbers include all non-recurring design, development and certification costs, and start-up tooling for production. SNECMA has signed on as a 35% participant for the full scale development effort, and for the production program if there is a "go" decision in 1987. Based upon previous development programs, the year-by-year breakdown of the GE/SNECMA team's costs will be approximately as follows:

<u>YEAR</u>	<u>CUMULATIVE PERCENT NON-RECURRING COST</u>
1986	4.5
1987 (Production Decision)	10.0
1988	30.0
1989	30.0
1990	50.0
1991	90.0
1992	100.0

The approximate price for the 22,000 pound thrust version will be \$5 million. This compares with an estimated base price for the CFM56-5 of about \$4.4 million on an "apples-to-apples" basis with the UDF (i.e., a full propulsion system package). It is expected that the V2500 will be priced to be competitive with the CFM56-5. The question then basically becomes, does the UDF's fuel savings justify this additional cost to the airlines?

Based upon a 1984 interview with Murray Booth of Boeing, Forbes translated the fuel burn advantages of a UDF-powered aircraft into potential operating cost savings for an airline as follows.

This means a 160-seat ... [UDF-powered aircraft] flying full would use as little as 3.8 gallons of fuel per passenger on a 500 mile journey. The best conventional jet turbofan expected in 1991 [the V2500] would use 5.8 gallons. Today's most common type, the 145-seat Boeing 727, burns close to 9 gallons per passenger. At today's fuel prices [then about 85¢/gallon in the U.S.] ... The 727 uses fuel costing \$1,090 to carry a full load on that 500 mile flight. The best conventional jet turbofan foreseen for 1991 on a 160-seat plane would use fuel costing \$820. The new [UDF or] propfan? Only \$600 of fuel. ... Multiply this savings for a major airline with 100 such ... planes, a United or an American Airlines, and it works out to an annual fuel bill savings of at least \$65 million.⁴

Before preceding with a further discussion of the announced plans

⁴Banks, Forbes, May 7, 1984, p. 31.

of GE's competitors, let us make one final point about the UDF relative to subsequent applications on larger aircraft. Since the UDF does not require a gearbox, there appears to be no limit to its thrust potential. Therefore, up-sized versions could be developed using demonstrated technology to power mid-to-long range aircraft. The same cannot be said for a propfan engine requiring a gearbox. A geared propfan in the 22,000 pound thrust range will require a 14,800 horsepower gearbox. Since this power will be split between two rows of blades, each gear train must be capable of transmitting about 7,400 horsepower. This is straining the limits of current or foreseeable gearbox technology for aircraft application.

THE COMPETITION

P&W and RR are both pursuing propfan technology research, but neither has made the type of commitment that AEBG has made to a specific design, or a target introduction date. According to Selwyn D. Berson, P&W Group Executive Vice-President, "... when more basic research questions are answered we'll decide if we're going to build a demonstrator and what type of technology it will employ."⁵ David A.A. Marshall, head of new projects at RR's Civil Engine Group echoed these sentiments as follows.

The technology looks promising, but there are many questions that need to be answered. The issues of blade integrity and noise all need to be addressed. We feel and so do others, that NASA's [not to mention GE's, Boeing's, and MD's] predictions of a 1992 turboprop-powered [UDF] aircraft are optimistic. It just looks like its going to take a bit

⁵Stanley W. Kandebo, "Increase in Aircraft Engine Sales Follows Commercial Traffic Growth," Aviation Week and Space Technology, November 11, 1985, p. 123.

longer to examine the problems and develop the technology.⁶

Although neither P&W or RR have approached this new technology with GE's fervor, they have initiated independent preliminary design studies, and both have seemingly settled on a design which would incorporate a speed decreaser gearbox with counter-rotation. Both claim that AEBG's gearless design is an inefficient compromise, in that the UDF's turbines must be running much slower than the optimal design speed. Furthermore, they both claim that there remain significant technical problems to be overcome in the areas of noise and safety. It must be remembered from whence these comments down-playing AEBG's initiative come. Both P&W and RR are deeply involved in the development of the V2500 engine which will be competing for business in the UDF thrust range. Both recently developed a turbofan engine for the Boeing 757 (the PW2037 and the RB211-535 respectively). More recently, each has been immersed in the design of yet another new turbofan engine; P&W's PW4000 for the Boeing 747, and RR's Tay engine for the Fokker F-100. In discussing P&W's involvement in the IAE consortium, Robert Carlson, P&W's former president, once said that "... without the consortium, Pratt would not be in this engine size program. We would simply cede to GE-SNECMA. We don't have the physical facilities or staffing in place to do three simultaneous programs by ourselves."⁷ The same could be said for RR in that both their plates are full, and neither is in a strong position to undertake a major new development

⁶Ibid.

⁷The Jet Engine Industry, p. 50.

program at this time. They have been trying to persuade the airlines through their public statements that UDF/propfan technology will not be available in a commercially viable form until later in the 1990's, and further, that the operating economics of this technology will simply not be attractive enough to warrant the expense until the late 1990's. However, both are quietly pumping significant amounts of R&D funding into their own propfan programs. P&W will reportedly spend over \$100 million on propfan research over the next two years,⁸ while RR will invest between £ 3 and 4 million per year over the next two to three years (about 25% of their total R&D budget).⁹ Obviously, AEBG's moves have caught their attention.

The potential of this new technology has resulted in the emergence of a new potential competitor, Allison Gas Turbine Division of General Motors, who has announced the initiation of a pusher propfan demonstrator program. Like P&W, Allison intends to use a gearbox with counter-rotating propfan blades from Hamilton Standard Division of United Technology. To simplify the development task as well as to reduce both development and production costs, Allison will use a derivative of their model 571 engine, which was developed for military helicopter service, to power their model 578 propfan propulsion system. Allison's sale pitch for this system is that they are minimizing risk by using a derivative core engine. The trade-off involved in using a

⁸"Stories Tall and Small," Flight International, June 8, 1985, No. 3963, Vol. 127.

⁹Pierre Condom, Nick Cook and Bill Sweetman, "Are Propellers Coming Back - and When," Interavia, June 1985, p. 615.

derivative core is 10% fuel efficiency penalty versus the all new state-of-the-art core being developed by AEBG. However, MD has indicated that, on an apples-to-apples basis (i.e., full propulsion system), the 578 system will cost the airframer about \$2.8 to \$2.9 million.

According to Dr. Allen Novich, Manager-Advanced Turboprop Programs at Allison, "the real challenge to Allison in developing this engine will be in the gearbox. ... We chose a geared system because we felt that it was the way to achieve optimum propfan engine performance."¹⁰ Their geared design will rely heavily upon their years of experience with aircraft gearbox technology gained on the T56 turboprop engine, originally designed in the 1950's.

Allison has been discussing the possibility of flight demonstrator programs with both MD and Boeing, and is "... participating in studies with Boeing directed at their 7J7 aircraft."¹¹ However, Allison has a severe problem relative to the Boeing aircraft in that the model 578 simply does not develop enough thrust. They, also, have a second problem which is much like that of P&W and RR. They too have a very full plate, having won two major military engine development contracts within the past year; one for the Army's new LHX helicopter, the other for a joint services tilt-rotor vehicle called the J VX. Furthermore, they face a very significant barrier to entry into the large commercial transport market. They are an unknown quantity in this market,

¹⁰Stanley W. Kandebo, "Allison Propfan Development Centers on Gear Box Design," Aviation Week and Space Technology, December 23, 1985, p. 46. ¹¹Ibid.

particularly in the critical area of service and support. As of this writing, the author has heard that P&W and Allison have joined forces to perform a flight demonstrator program involving Allison's model 578. A logical extension of this program would be a joint design/production effort. Together, P&W and Allison might mount a serious challenge to the UDF, whereas neither appears to have the necessary resources to go it alone.

THE AIRFRAMERS

As mentioned previously, both Boeing and McDonnell Douglas are extremely interested in this emerging technology, and are shaping their product lines for the early 1990's and beyond assuming that a propulsion system such as the UDF will be available. However, they are taking quite different routes to the market. Boeing's product strategy is to offer an all new, state-of-the-art aircraft incorporating major technical advances including new materials such as a new aluminum-lithium alloy and advanced composites which will be used extensively to reduce weight. The combined effect of a fuel efficient engine such as the UDF and light weight materials is summed up nicely by Howard Banks, a writer for Forbes.

There's a snowballing effect at work here. An engine that burns less fuel needs to carry less fuel. That, in turn, affects the weight of the entire structure, which means a smaller engine will do. The aluminum-lithium alloys and composite materials will cut structural weight by 10% of such, meaning less fuel to carry a given payload the same distance. A great slimming cycle could begin.¹²

According to Bruce Gordon, AEBG's UDF Program General Manager, "a 150-

¹²Banks, Forbes, May 7, 1984, p. 33.

seat airline requiring 25,000 lb. thrust turbofans, will require only 20,000 lb. thrust unducted fans."¹³ Thus the size and weight of the engine is reduced, thereby reducing the total aircraft weight even further.

Boeing is also setting challenging targets for both maintenance, and airframe and equipment costs with a goal of providing the customers for this new aircraft, currently designated the 7J7, with a 10% advantage in direct operating costs over the best in derivative aircraft and engine technology available in the 1990's. Boeing has declared that it is their intention to introduce the 7J7 to the marketplace in 1992 and has gone out to their customers and asked them to wait for this aircraft rather than buy, say, an A320. They are, in a way, putting their reputation on the line with the 7J7. This provides a clear indication of the confidence that Boeing has in the technologies involved, including the UDF. To ensure that finances will not be an obstacle to meeting this customer commitment, Boeing has entered into a collaborative arrangement with a group of Japanese companies (Kawasaki Heavy Industries Ltd., Mitsubishi Heavy Industries Ltd., and Fuji Heavy Industries Ltd.) who will shoulder 25% of the up-front costs. In return, the Japanese will get a share of the revenues, and an education in manufacturing, marketing and service techniques used by Boeing. Interestingly, this Boeing/Japanese team was originally formed to produce a 7X7 powered by the IAE V2500, of which the Japanese own 23%. However, so impressed was Boeing by the possibilities

¹³Graham Warwick, "UDF: GE Dares to Differ," Flight International, November 10, 1984, p. 1242.

offered by propfan technology in general, and the UDF in particular, that they advised their Japanese partners in early 1985 that the 7J7 would be delayed from 1988 to 1992 in order to incorporate this technology.

McDonnell Douglas is following a completely different route to the short range commercial transport aircraft market of the early 1990's. They too are committed to propfan/UDF technology as evidenced by the terms of a recent agreement reached with Delta. Delta placed a firm order for thirty MD-88's, a derivative of the MD-82 aircraft, with an option on fifty more. These aircraft will be powered by P&W JT8D-219 turbofan engines. However, an interesting aspect of the deal is that MD will modify those aircraft to incorporate propfan-type engines, if requested to do so by Delta, and this was reported to be a key factor in Delta's decision to buy MD-88's instead of Boeing 737's, which cannot be so modified.¹⁴

In addition to offering such a modification arrangement, MD has announced its intention to introduce a derivative of the MD-80 series, called the MD-91, which will be powered by UDF/propfan-type engines. As indicated by the model designation, MD plans to make this aircraft available in the 1991 time-frame. However, MD may steer clear of a head-to-head competition with Boeing's 7J7 with the MD-91, in that they are considering seating capacities of either 150 or 110. The smaller aircraft would take them out of direct competition with Boeing, but its attractiveness to the market is far less certain than a

¹⁴Patrick Wallace, "Delta Will Buy Up to 80 Jets of McDonnell," Wall Street Journal, January 24, 1986 p. 6.

150-seat aircraft. As indicated before, there will be a flight demonstrator program involving an MD-80 aircraft modified to incorporate a UDF in early 1987. Bill Eccles, chief program engineer, feels that "... with this [derivative aircraft] approach, we expect to have a technology readiness in 1987 that is at the same level of technical risk as launching a turbofan-powered aircraft."¹⁵ Like Boeing, MD is hedging their financial risk, having entered into collaborative arrangements with foreign firms (Italy's Aeritalia, and China's Shanghai Aviation Industrial Corporation) to develop the MD-91.

The key date for the MD-91, B7J7, UDF and 578 programs is 1987, for it is then that go/no-go decisions will be made relative to production, and if it is go, what the configurations will be. Therefore, 1987 also represents a critical time for Airbus Industrie, for the future of the company may hinge on the decisions made by McDonnell Douglas, Boeing, AEBG and Allison. Deliveries on Airbus's A320 start in 1987. However, the production capacity for A320's from 1987 through 1990 is only about 100 aircraft, so Airbus will not be in a position to get a major jump on the competition for the 150-seat market. If Boeing and MD can convince key customers such as American, Delta and United to wait for the new technology;

Airbus would be left with its huge investment in an outdated plane and with dubious hopes of squeezing more development money from its government backers, like the U.K., which was dragged kicking into the A320 project, and West Germany, which already has spent more on Airbus Industrie than its own troubled steel industry. Airbus then would

¹⁵Keith F. Mordoff, "Douglas Plans Continuing Upgrades to Main MD-80 Competitiveness," Aviation Week and Space Technology, November 11, 1985, p. 61.

limp from crisis to crisis.¹⁶

Airbus's anxieties must be shared equally or felt even more acutely by the IAE consortium. The initial block of A320's will be powered by the CFM56-5, since the V2500 will not be available when the first aircraft are delivered. Therefore, IAE will likely get caught in even a greater squeeze than that which Airbus faces. Thus, it is fairly obvious why both Airbus and IAE publicly down-play the significance and question the commercial viability of UDF/propfan technology.

AEBG is confident that there are no major technical stumbling blocks which cannot be overcome, and all manufacturers agree that the market for an engine in the UDF thrust range will be sizable indeed. The remaining questions to be answered in light of the volatility of fuel prices which have dropped from about \$25/barrel in the fall of 1985 to under \$15/barrel today are: (1) what will the price be in the early 1990's; and equally important, (2) what is the airlines' perception of where fuel price will be? Relative to the first question, if fuel prices remain at today's levels in real terms through the early 1990's, the value of the UDF will be eroded to the point that AEBG could not charge a sufficient price premium to achieve an adequate return. However, reports in the media, of late, consistently predict that the combined effect of a steeply declining U.S. oil production curve and a mildly upward-sloping demand curve will ultimately drive prices back up to late 1985 levels, or higher. These same reports indicate that this price recovery will have occurred by the 1992 time-

¹⁶Banks, Forbes, May 7, 1984, p. 33.

frame, when the UDF is introduced. This view is obviously shared by Boeing, (reference Figure 4-4, which has not been modified by Boeing in spite of recent price movements¹⁷) McDonnell Douglas, GE and Allison as they aggressively forge ahead with propfan technology. Henry D. Jacoby, noted Professor of Economics at M.I.T., and recognized expert in the area of oil price economics generally concurs. He places subjective probabilities of 0.3, 0.5 and 0.2 on 1992 crude oil prices of \$15, \$25 and \$35 per barrel, respectively.¹⁸ The answer to the second question is important, since the airlines' perception of where fuel prices are going will greatly effect their buying patterns. Figure 5-6 shows how closely related airline profits have been to fuel price movements since deregulation in 1978. Thus, the likelihood that the airlines will wait for a UDF powered aircraft, or for that matter, pay the price premium necessary for AEBG to achieve a reasonable return is highly dependent on the answer to question number two.

¹⁷Per telephone conversation with David Sepanen, Manager of Market Research, Boeing Commercial Airplane Company February 21, 1986.

¹⁸Interview with Henry D. Jacoby, Professor of Economics, at M.I.T. on March 17, 1985.

PERCENT OF FUEL COST VS OPERATING PROFIT (OR LOSS)
 U.S. AIR CARRIERS
 1970-1984

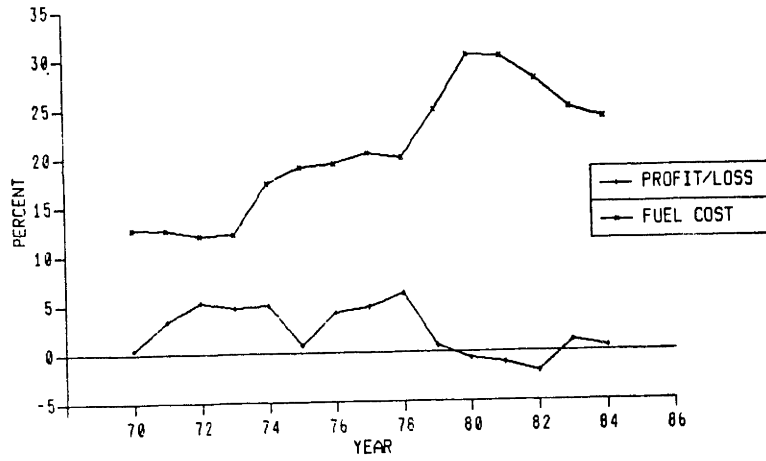


FIGURE 5-6

SOURCE: DAC Market Outlook 100-Seat Passenger Aircraft, "Marketing Plans," November 1985.

CHAPTER 6

ANALYSIS AND CONCLUSIONS

Product differentiation is the cornerstone of AEBG's product strategy for the 1990's and beyond. No longer is it very profitable to introduce incrementally better products, for they create so little new value that the buyers will not pay a sufficient price premium to provide an adequate return on the investment. According to Michael E. Porter, noted author in the field of Strategic Management;

a successful differentiator finds ways of creating value for buyers that yield a price premium in excess of the extra cost. ... A firm creates value for a buyer that justifies a premium price (or preference at an equal price) through two mechanisms: by lowering buyer cost [and/or] by raising buyer performance. ... If a firm is able to lower its buyer's cost or enhance its buyer's performance, the buyer will be willing to pay a premium price.¹

To reap profitable price premiums from its airline customers, AEBG is planning to introduce a new product, the UDF, which represents a major technological advancement and which is thereby differentiated from engines of its competitors. However, although necessary for a successful differentiation strategy in this context, technological leadership alone is not sufficient. It is Porter's view that;

technological leadership is strategically desirable when first-mover advantages exist. These allow a leader to translate a technology gap into other competitive advantages that persist even if the technology gap closes. First-mover advantages rest on the role of timing in improving a firm's position vis a vis sustainable sources of cost advantage or differentiation. In general terms, a first-mover gets the

¹Michael E. Porter, "Creating and Sustaining Superior Performance," Competitive Advantage, The Free Press, New York, 1985, pp. 130-131.

opportunity to define the competitive rules in a variety of areas.²

In the case of the UDF, a one to two year head start may translate into a sustained cost advantage due to the learning curve effects discussed in Chapter 3. Furthermore, technological innovations tend to converge on a common design philosophy. High bypass turbofans, for example, share many of the same design features, and there is little to differentiate one from the other. In the case of advanced propeller/ultra high bypass engines (UBE's) such as the UDF, which represents the next logical step beyond high bypass turbofans, there are two schools of thought as to how to drive the counter-rotating propellers. AEBG's gearless design is unique, and the UDF could set the design standards for the industry by being the first widely used and accepted engine of its type. The competition might then be forced to drop their geared designs in favor of a gearless approach, placing them even further behind in terms of market penetration, and production cost competitiveness, due to delayed market entry.

Porter cautions that "... uniqueness does not lead to differentiation unless it is valuable to the buyer,"³ and as indicated in the opening remarks of this chapter, he says there are two basic criteria which determine just how valuable a differentiated product is to a buyer; i.e., the amount by which the product lowers the buyer's costs, and/or raises the buyer's performance. He goes on to assert that these criteria can be further subdivided "... into those that are easy to measure and those that are difficult for the buyer to perceive

²Ibid. p. 186. ³Ibid. p. 130.

and/or quantify."⁴ Figure 6-1 presents Porter's view of the various types of value added which may result in a willingness on the part of a buyer to pay a price premium. Porter concludes that:

... differentiation that lowers buyer cost provides a more persuasive justification for paying a sustained price premium ... than differentiation that raises performance. Financial pressures on buyers ... often mean that buyers are willing to pay a premium only to firms that can demonstrate persuasively that they lower buyer's cost. Differentiation with a readily measurable connection to buyer value is also frequently more translatable into a price premium than differentiation that creates value in ways that are hard to perceive or measure.⁵

VALUE ADDED MATRIX

		Readily Measurable	Difficult to Measure
SOURCE OF VALUE	Lower Buyer Cost		
	Raise Buyer Performance		

FIGURE 6-1

SOURCE: "Creating and Sustaining Superior Performance," Competitive Advantage, The Free Press, New York, 1985, p. 149.

In addition to the matrix presented in Figure 6-1, Porter provides further guidance as to where one should look for opportunities to increase the value of a product to a buyer. According to Porter, "the starting point for understanding what is valuable to the buyer is

⁴Ibid. p. 149. ⁵Ibid.

the buyer's value chain,"⁶ depicted in Figure 6-2. The area in which the UDF will have the greatest impact on an airline's value chain is operations. Recall from Chapter 4 that fuel prices at 1984/1985 levels account for about 27% of an airline's direct operating cost (DOC). Since the UDF will offer a 25% fuel burn advantage over the best available high bypass turbofan engine in 1991/1992, it has an obvious value added potential for an airline relative to DOC. Furthermore, the UDF's value added for airline operations falls into the upper left-hand block of the matrix presented in Figure 6-1, which is the optimal position relative to translatability of value added into a price premium. Let us now turn to defining the maximum price premium that an airline might pay for the UDF, given Porter's framework.

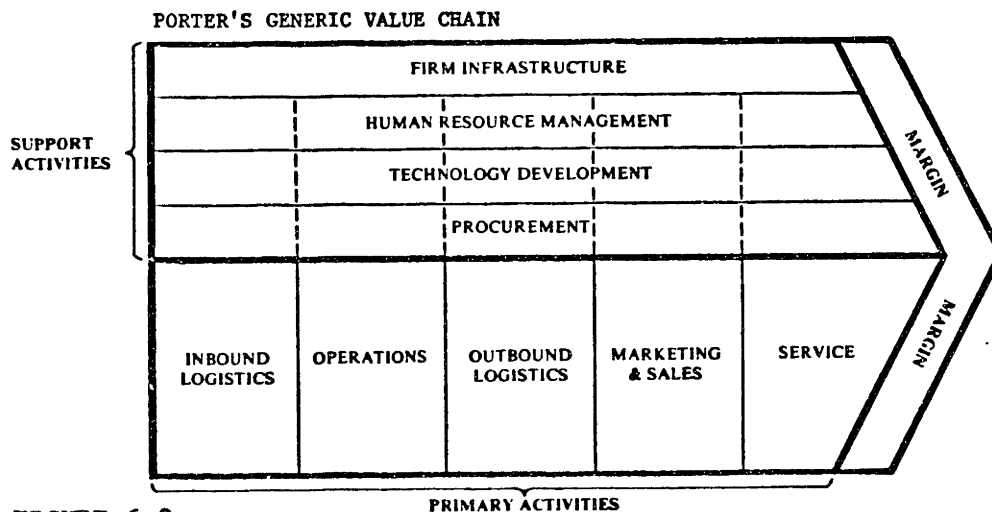


FIGURE 6-2

SOURCE: "Creating and Sustaining Superior Performance," Competitive Advantage, The Free Press, New York, 1985, p. 37.

⁶Ibid. p. 130.

The first step in defining an acceptable price premium is the establishment of the fuel cost savings per engine per year. This annual fuel savings is then converted into an equivalent present value via a simple discounted cash flow analysis. I say simple because the mechanics of the calculations are quite straight forward. However, establishing the proper discount rate is much more complex. This subject is covered in detail in Appendix B. Let us now consider the other key element for a discount cash flow analysis, i.e., the annual fuel savings. We begin with the calculations behind Murray Booth's statement on fuel saving quoted in Chapter 5. Mr. Booth indicated that a fleet of 100 UDF-powered aircraft would produce a \$65 million per year savings for the airline. This figure can be accounted for as follows:

$$\begin{aligned} &(\$1,090 - \$600) \text{ savings/trip/aircraft} \times 100 \text{ aircraft} \\ &\quad \times 3.6 \text{ trips/day} \times 365 \text{ days/year} \approx \$65 \text{ million savings/year.} \end{aligned}$$

However, it should be noted that Mr. Booth's comparison was between fully loaded Boeing 7J7's and 727's. This over-states the savings considerably for two reasons: first, as indicated in Chapter 4, a load factor of about 65% should be used in lieu of 100%; and second, a more meaningful statement of value results if a 7J7 is compared to a competing aircraft such as the A320, not to the aircraft it is replacing, the 727. Taking these two points into account, we see that the annual savings can be roughly approximated as follows:

$(\$820 - \$600) \text{ savings/trip/aircraft} \times 0.65^* \times 100 \text{ aircraft}$

$\times 3.6 \text{ trips/day} \times 365 \text{ days/year} \approx \$20 \text{ million savings /year;}$
or about \$200,000 per year per aircraft. Using a typical spare engine factor of 0.2 spares per installed engine, the airline will purchase 2.4 engines per 7J7. Thus, the annual fuel savings per UDF will be about \$83,000 with fuel at 1984/1985 levels.

One might legitimately argue that the value added is considerably more than this, because this calculation does not address the fact that the UDF-powered aircraft has a significant range advantage over other aircraft in its category. Because of the UDF's fuel efficiency, a UDF-powered aircraft can be flown much further with a given payload and load of fuel. This, in turn, makes a UDF-powered aircraft such as a 7J7 a much more flexible piece of equipment than a similarly sized aircraft powered by an advanced design turbofan. It defies the current categorization of such aircraft as "short-range," for it could be used for flying legs in an airline's route structure which must now be flown by larger aircraft, not necessarily because of load factor considerations, but because of range requirements. Furthermore, a greater level of comfort can be designed into the aircraft by using a wide-body configuration, since the additional drag which results can be tolerated due to the extreme fuel efficiency of the propulsion system. This additional flexibility based upon superior performance certainly brings with it additional value, but this added value would be

*NOTE: Since the fuel savings figures for the fully loaded cases were based upon the per passenger fuel burn requirements of the aircraft times the number of passengers on a fully loaded aircraft, the fuel savings at a 65% load factor can be approximated by applying a 0.65 multiplier.

difficult to quantify, and as such, it would fall in the lower right-hand box of Figure 6-1. Such value elements command a significantly lower price premium than those anchored in the upper left-hand box. Therefore, we will take a conservative approach to quantifying the value added potential of the UDF by restricting our focus to savings on expenditures for fuel.

The calculation of fuel savings above reflects one possible scenario relative to fuel price and competition; specifically, a fuel price of about 85¢/gallon (i.e., @ 1984/1985 levels), and an advanced turbofan-powered aircraft being the only real competition. Recall from our discussion of fuel prices in the previous chapter that most sources with whom I spoke, or which I read indicate that, by the early 1990's, fuel prices will be back to their 1985 level in real terms. If one were to use a somewhat more detailed analysis, one could propose different "macroscenarios"⁷ as Porter calls them relative to fuel prices, assign subjective probabilities to those scenarios, and run the fuel savings calculations based upon the resulting expected value of fuel prices. Using the probabilities assigned by H.D. Jacoby, Professor of Economics at M.I.T., as reported in the previous chapter, and assuming jet fuel prices are directly proportional to crude oil prices, the expected value of jet fuel prices in 1992 may be calculated as follows:

$$(0.3 \times 15/25 \times 85¢/\text{gal.}) + (0.5 \times 85¢/\text{gal.}) \\ + (0.2 \times 35/25 \times 85¢/\text{gal.}) = 81.6¢/\text{gal.}$$

⁷Ibid. p. 446.

Before proceeding further with our analysis, it should be noted that what is crucial to establishing the value to the buyer of a differentiated product such as the UDF is not the seller's perceptions relative to the key variable(s) which go into determining the product's value, but rather the buyer's perceptions. Therefore, it is not the view of outside experts relative to future fuel prices that determine the value of the UDF to the airlines, but the perception of the airlines as to what fuel prices will be. As Porter says, "buyers will not pay for value that they do not perceive, no matter how real it may be. Thus, the price premium a firm commands will reflect both the value actually delivered to its buyer and the extent to which the buyer perceives this value."⁸ It is, therefore, critical that the seller work very hard to ensure that the buyer's perception of the value of the seller's product approaches its actual value. Porter points out that "a firm that delivers only modest value but signals it more effectively may actually command a higher price than a firm that delivers higher value but signals it poorly."⁹ This "signaling" to which Porter refers becomes increasingly important for value added elements which fall into the boxes on the right-hand side of the matrix presented in Figure 6-1. However, regardless of the seller's or the buyer's initial perception relative to a given product's value, "... in the long run, the upper limit of the price premium a firm can command reflects its actual impact on buyer value - impact on buyer cost and performance relative to competitors."¹⁰

⁸Ibid. p. 139. ⁹Ibid. ¹⁰Ibid.

In our scenario analysis, let us assume the airlines' perception of fuel price movements will be consistent with the expected value calculation presented previously. This might be a dangerous assumption if there were considerable disagreement among the experts. However, since the experts seemingly are fairly well aligned in their views on this subject, it appears unlikely that the airlines' economists would have any inside information that would lead to a significantly different view. If anything, one might expect that the airlines would tend to err on the conservative side relative to fuel price projections given the devastating effects that upward movements of fuel prices have on airline profitability as we saw in Figure 5-6.

As noted previously, Porter refers to scenario analysis involving variables such as fuel prices to be macroscenario analysis. This is the traditional style of scenario analysis in which

... scenario building has concentrated on creating alternative views of the national or global economic and political environment, including such things as the rate of economic growth, inflation, protectionism, regulation, energy prices, and interest rates. ... Oil, natural resources, and aerospace companies were the early leaders in employing scenarios for planning. ... [However], macroscenarios, despite their relevance, are too general to be sufficient for developing strategy in a particular industry. ... Other uncertainties that macroscenarios leave out such as technological change and competitor behavior can emerge as dominant factors driving industry structural change in particular industries.¹¹

Porter goes on to say, "... industry scenarios ... explicitly include competitor behavior, a key source of uncertainty in the choice of strategy. ... Identifying uncertainties with the most important rami-

¹¹Ibid. pp. 446-447.

fications for competition lies at the heart of the industry scenario technique."¹² In the case of the UDF, the competitor's responses are obviously an important factor in the determination of the price premium airlines are willing to pay for the product, and therefore to the profitability of the UDF program to AEBG.

Returning again to our scenario analysis of the potential price premium of the UDF, let us now focus on the influence of competitors' behavior. As we saw in Chapter 5, the only engine manufacturer that has firmly announced its intention to compete in this market is Allison. However, their engine will not be truly competitive for the 737 market, or the MD91 market, should McDonnell Douglas choose to make it a 150-seat aircraft, for the engine is short on cruise thrust at altitude. Also, recall that Allison is a virtual unknown in the large commercial transport market. To be a viable competitor, either on a 110 or 150-passenger commercial transport jetliner, Allison must somehow overcome a natural reluctance on the part of the airlines to purchase such a major piece of capital equipment representing brand new technology from an untried source. A joint venture with P&W, which could very well develop out of their recently established collaborative relationship on the Model 578 flight demonstrator program, would certainly go a long way to overcoming this problem. However, if the Allison/P&W team were to enter production with the current Model 578, they would still face the problem that the engine is too small for a 150-passenger aircraft. If, on the other hand, they were to pursue a

¹²Ibid. p. 448.

new design with sufficient thrust to be competitive on the 7J7, or a 150-passenger MD-91, their product would lag the UDF's entry into the market by up to two years, potentially giving the UDF a tremendous competitive advantage due to the "first-mover" advantages mentioned previously. Perhaps the greatest of these advantages is that the UDF production line could be well down the learning curve prior to the entry of a competitive product, particularly if early sales are brisk.

As indicated by Porter, "the number of combinations [of relevant scenario variables] generated by differing assumptions about each scenario variable can multiply rapidly, and with it the number of scenarios that might be analyzed."¹³ To limit the proliferation of scenarios, Porter recommends that the number of scenario variables be kept to a minimum by ensuring that each is independent and truly variable. Then, having pruned down the list of scenario variables, the number of assumptions relative to each variable should be constrained to reflect those cases with the most likely and most profound impact on the competitive strategy. Therefore, the extreme points of the feasible range, along with the most likely event form a three-case set that might be evaluated. Relative to competitive alternatives to the UDF, the three cases might be no viable competitor, a viable competitor by 1994, and a viable competitor by 1992. The first and last scenarios are extremely unlikely. Therefore, to limit the proliferation of scenarios, let us concentrate on the central case (i.e., a truly competitive product available in 1994).

¹³Ibid. p. 459.

Given this scenario, the first-mover advantages for the UDF will be determined, to a great extent, by the delivery rate of UDF's in the 1992/1993 time period, as indicated above. If deliveries are substantial in these first two years, the first-mover advantage of rapid movement down the learning curve would greatly reduce the true competitiveness of the alternative design. Again, for purposes of reducing the number of scenarios which must be analyzed, let us assume that the UDF will enjoy a significant first-mover advantage in this regard, and that the price premium may be calculated based upon a comparison of the UDF's fuel burn advantages vis a vis an advanced technology turbofan. In other words, even though there may be a performance competitive propfan engine available in the early-to-mid-1990's, it will not be cost-competitive, and it will not be in a position to sustain a price significantly below that which AEBG chooses to set. Under this overall macro/industry scenario of recovery of fuel prices to their 1984/1985 levels in real terms by 1992, coupled with no price competitive substitute products available to the airlines, let us proceed with our analysis of the price premium which the UDF might command.

As indicated earlier in our discussion, the UDF's value added may be determined by calculating the present value of a stream of fuel savings vis a vis the competition. Under the assumptions listed above, the fuel burn comparison versus a V2500-powered A320 would be the appropriate starting point, against which the per engine annual fuel savings were determined to be about \$83,000 with fuel at 85¢/gallon. Using instead the expected value price of 81.6¢/gallon, this translates into an annual per engine savings of about \$80,000.

Given an annual fuel savings of \$80,000 and a discount rate of 8%, as developed in Appendix B, both expressed in real terms, it is rather straight forward to calculate the maximum price premium for the UDF for any given time horizon. Table 6.1 summarizes the maximum price premium for time horizons of 5, 10, 15, 20 and 25 years.

TABLE 6.1

UDF PRICE PREMIUMS FOR VARIOUS TIME HORIZONS	
<u>TIME HORIZON (years)</u>	<u>PRICE PREMIUM</u>
5	\$ 319,000
10	537,000
15	685,000
20	785,000
25	854,000

Although the average age of retirement of an aircraft is about 22 years, it is safe to assume that an airline would want to recover its costs well before the retirement time horizon. Taking a very conservative view that fuel burn is the only value added, and that an airline would run its investment analysis calculations based on a five year breakeven time frame, an acceptable UDF price with maximum price premium would be about \$4.72 million (\$319,000 listed above plus the \$4.4 million price for a V2500). GE's position in establishing a planning price of \$5.0 million can be defended by asserting that a longer break-even time frame is in order, that fuel prices will be slightly higher than assumed here, and/or that other factors such as added operational flexibility contribute a significant amount to the overall value to the buyer. Therefore, a \$5,000,000 planning price is certainly reasonable.

Finally, let us examine the profitability of the UDF program from AEBG's perspective. In order to do this job rigorously, a production cost estimate for the engine must be used in the calculations. However, the production cost bogey is competitive sensitive information, and can not be disclosed. Therefore, we will back-calculate what the cost bogey must be in order to achieve an acceptable rate of return for a given price premium, under a given set of assumptions. As was the case in looking at what price premium AEBG might charge, there are many possible scenarios, both industry and macro, which could be developed. The goal of the following analysis is not to determine the profitability of the program over the entire range of alternate scenarios, but rather to develop a general methodology to make such a determination given a set of assumptions which, for our analysis, are as follows.

1. The price of the engine will be sustainable at \$5.0 million, (\$ 1986).
2. The cost of capital for the program is equal to the cost of capital for the customer (i.e., 8% real), under the assumption that the risk premium that AEBG should assign to such a program is essentially the same as the aggregate risk premium of the potential customers.
3. Underlying the 8% real discount rate assumption is one which pegs the real risk-free rate at about 3%.
4. An 85% learning curve will apply over the first 250 engines, and a 90% learning curve thereafter.
5. The indirect costs are a constant 20% of sales.

6. The advanced propfan technology-type aircraft including UDF-powered aircraft will pre-empt advanced turbofan-powered aircraft such as the A320, creating a hole in the market in the late 1980's.
7. The overall size of the market is 2,000 aircraft. (Reference the introductory remarks in Chapter 5.)
8. The UDF will capture 100% of the market for two years of its production given the further assumption that there will be no viable competitor until 1994; and 50% thereafter, based upon the very conservative assumption that, as soon as a truly competitive engine is available in 1994, AEBG's market share will immediately slip to its current aggregate level of about 50%.
9. The cumulative delivery schedule for UBE-powered aircraft will follow a distribution defined by the cumulative totals of 727, 737 and DC-9 aircraft deliveries at the end of each of the first eight years of their respective production runs as listed in Table 3.2 (e.g., in production year one, the cumulative total is $6 + 4 + 5 = 15$). The projected delivery schedule for UDF-powered aircraft, based upon this distribution, coupled with assumption #8 above, is shown in Table 6.2.
10. The maximum acceptable break-even time horizon is 15 years (seven years of development/certification plus eight years of production).
11. The development/certification costs follow the "typical" distribution defined in Chapter 5 per Table 6.3.

TABLE 6.2

PROJECTED DELIVERY SCHEDULE FOR UDF-POWERED AIRCRAFT

<u>Production Year</u>	<u>Cum. No. of 727's, 737's & DC-9's Del.*</u>	<u>Cumulative Percentage*</u>	<u>Cumulative UBE A/C Delivered**</u>	<u>Cumulative UDF A/C Delivered***</u>
1	15	1	20	20
2	284	15	300	300
3	661	35	700	500
4	1,036	55	1,100	700
5	1,341	71	1,420	860
6	1,577	83	1,660	980
7	1,759	93	1,860	1,080
8	1,900	100	2,000	1,150

NOTES: *Based on assumption #9.
 **Based on assumptions #7 and 9.
 ***Based on assumption #8.

TABLE 6.3

NON-RECURRING EXPENDITURES FOR UDF DEVELOPMENT/CERTIFICATION

<u>Year ('86 - '92)</u>	<u>Cumulative % Expended</u>	<u>Amt. Expended By Year (current \$'s)</u>
1	4.5	\$ 56,250,000
2	10	68,750,000
3	30	250,000,000
4	50	250,000,000
5	70	250,000,000
6	90	250,000,000
7	100	125,000,000
TOTAL		<u>\$1,250,000,000</u>

The aircraft delivery schedule for UDF-powered aircraft is translated into a UDF delivery schedule in Table 6.4 based on a 0.2 spares to installed engine ratio. Also presented in this table is the approximate total shop cost for engines delivered in each of the first eight years of production based upon the learning curve effects outlined in the basic assumptions listed above (expressed as a function of the first unit shop cost); sales revenues net of indirect costs

(i.e., \$5,000,000 X 0.8 per engine = \$4,000,000/engine); and net cash flow (expressed as a function of the average engine shop cost).

TABLE 6.4

UDF PRODUCTION PROGRAM CASH FLOWS

<u>Production Years ('92 - '99)</u>	<u>UDF Sales (Units)</u>	<u>Direct Cost (\$M)</u>	<u>Sales Net of Indirect Costs (\$M)</u>	<u>Net Cash Flow (\$M)</u>
1	48	25x	192	192 - 111y
2	672	177x	2,688	2,688 - 786y
3	480	107x	1,920	1,920 - 476y
4	480	96x	1,920	1,920 - 426y
5	384	77x	1,536	1,536 - 342y
6	288	58x	1,152	1,152 - 258y
7	240	48x	960	960 - 213y
8	168	34x	672	672 - 30y
TOTALS	<u>2,760</u>	<u>622X</u>	<u>11,040</u>	

Where x = Direct Cost of First Unit
 y = Average Direct Cost = $(622x/2760) = .225x$
 (Therefore $x = 4.44y$)

The discounted cash flow analysis for the program is presented in Table 6.5. To break even in 15 years, the cumulative discounted cash flow at year 15 must be greater than or equal to zero. Setting the bottom line of Table 6.5 equal to zero, we calculate that the average cost of a UDF engine over the first eight years of the production program must be kept below \$3.36 million per unit in current dollars to break even by 1999.

TABLE 6.5

UDF PROGRAM DISCOUNTED CASH FLOW ANALYSIS

<u>YEAR</u>	<u>CASH FLOW (\$M)</u>	<u>DISCOUNT FACTOR</u>	<u>DISCOUNTED CASH FLOW (\$M)</u>
1 (1985)	-- (Sunk)	--	--
2 (1986)	- 28 (1/2 Sunk)	--	- 28
3 (1987)	- 69	.93	- 64
4 (1988)	- 250	.86	- 215
5 (1989)	- 250	.79	- 198
6 (1990)	- 250	.74	- 185
7 (1991)	- 250	.68	- 170
8 (1992)	67 - 111y	.63	42 - 70y
9 (1993)	2,688 - 786y	.58	1,559 - 456y
10 (1994)	1,920 - 476y	.54	1,037 - 257y
11 (1995)	1,920 - 426y	.50	960 - 213y
12 (1996)	1,536 - 342y	.46	707 - 157y
13 (1997)	1,152 - 258y	.43	495 - 111y
14 (1998)	960 - 213y	.40	384 - 85y
15 (1999)	672 - 30y	.37	249 - 11y
CUMULATIVE DISCOUNTED CASH FLOW			4,573 - 1,360y

Using the analytical framework developed in this chapter, and the actual target production cost and non-recurring cost figures and schedules, management might run several alternative scenarios covering what Porter calls "... the feasible range of uncertainty"¹⁴ to ensure that even if all do not result in an exceptional program from a profitability view point, at least none would have disastrous results for AEBG. If any such scenarios are identified, it might be determined that they could be avoided, or that the scenario variable(s) which are driving the poor results may be sufficiently influenced to achieve at least a modicum of profitability, in the unlikely event that such a scenario were to come to pass.

¹⁴Porter, p. 460.

Conclusions - As indicated in the introduction, the focus of this thesis has been AEBG's product strategy to meet the challenge of IAE's V2500 engine in the 150-passenger commercial transport aircraft market. Our discussions have centered on the 22,000 pound thrust UDF engine, although it was noted that a 14,000 pound thrust model could be simultaneously introduced, should market forces dictate. The more powerful version is sized to compete with the V2500, or any other engine which might be developed for the 150-passenger-size aircraft, which, as we have seen, represents a major market segment through the 1990's.

Given the impressive potential of the 150-passenger aircraft market, we have examined the UDF's profit potential in this chapter. We have established that a planning price of \$5 million is certainly reasonable, as it would allow AEBG's airline customers to share significantly in the additional value that the UDF will create. Using this price, and what I consider to be, in aggregate, a relatively conservative set of assumptions about the market and the competition, we reached the conclusion that the UDF program would be a very profitable one for the AEBG/SNECMA team if an average production cost for the engine of less than approximately \$3.4 million can be achieved.

APPENDIX A

LITERATURE SURVEY FINDINGS ON FORECASTING

FORECASTING: AN OVERVIEW

Forecasting techniques are based upon simplified models of reality which can be readily understood by management, yet capture the key aspects of the real system, and reliably predict future trends and values of the key decision variable(s). The specific model used in a given application must be continually re-evaluated against new developments and its results continually checked against reality to ensure that the model and its underlying assumptions are still valid. The importance of this constant scrutiny of modeling techniques and assumptions is now more important than ever given the "... roller coaster business cycle of ups and downs"¹ we have witnessed in recent years. Often, when forecasts are significantly in error, it is not the basic model which is at fault, but the underlying assumptions.

Against the ever-changing, complex business environment in which we find ourselves, forecasting techniques available to management have become increasingly sophisticated. As the level of sophistication has increased, a new service industry has grown up to support businesses in developing their forecasts. Consulting firms such as Predicasts, Chase Econometrics, Data Resources and Wharton Econometrics Forecasting Associates which provide general econometric forecasting services to businesses have proliferated in this environment. Others (e.g.,

¹Charles L. Olson, Mario J. Picconi, Statistics for Business Decision Making, Scott, Foresman & Co., Glenview, Illinois, 1983, p. 709.

Forecast Associates and DMS) are focused on a specific industry such as aerospace.

Forecasting techniques can be broadly categorized as either qualitative or quantitative. Qualitative techniques generally rely upon expert opinion and intuitive judgement, and require little or no statistical analysis of historical data. Quantative techniques, on the other hand, require a significant historical data base. Quantitative methods can be subdivided into two basic types; regression techniques, and time-series models, otherwise known as autoregressive models. Let us examine each category in some detail, taking them in reverse order.

TIME-SERIES (AUTOREGRESSIVE) MODELS

Time-series models project future movements of the forecast variable based solely on past movements of that variable. These models assume that the underlying patterns of the past will continue into the future and are, therefore, of little use in studying causality effects. Due to their relative simplicity, they are also sometimes referred to as Naive Models. Yet, as simple as they are, they may be quite effective when relevant environmental factors which influence movements in the forecast variable remain relatively stable over the forecast period. The most common time-series method is simple curve fitting; either "eyeballing" a curve through the data, or using the least squares method to determine the appropriate coefficeint(s) for the equation assumed by the analyst to describe the underlying pattern of the data. Other methods include the simple moving average, weighted moving average and single exponential smoothing techniques which are useful when no trend is present, and the double moving average,

Brown's linear exponential smoothing, and triple exponential smoothing methods which were developed to handle data with a definite trend component. The most common trends are linear, parabolic, exponential and S-shaped (including the so-called Gompertz and Logistics curves).²

To determine if a trend does exist, and if so, in what form, a simple visual inspection of a scatter plot of the data can be quite useful. Unfortunately, the pattern is often obscured by seasonal variations in the data which must first be removed. Perhaps the most widely used technique to remove the season component in time-series data was developed by the National Bureau of Economic Research in 1920. Known as the Census II or X-11 method, it is described in a document available through the U.S. Government Printing Office entitled "The X-11 Variant of the Census Method II Seasonal Adjustment Program" (Bureau of the Census Technical Paper No. 15).

Returning again to our discussion relative to identifying the underlying trend in the data, an alternative to the visual method is the technique of differencing. To employ this method, one simply calculates the differences between successive deseasonalized data points. If the differences are relatively constant, the trend is linear. If the differences tend to vary significantly, determine if the squares of the differences are relatively constant. If so, the trend can be represented by a second order polynomial. This procedure should be

²Gompertz Curve is defined by the equation $\log Y = \log L + kG^t$, and the Logistics Curve by the equation $1/Y = 1/L + KG^t$; where Y is the dependent variable, L is the upper asymptote, k is a coefficient to be estimated, G is the growth rate expressed as a constant ratio per unit of time, and t represents time.

repeated using higher and lower powers or logs of the differences until a stable, relatively constant series results.

REGRESSION TECHNIQUES

Time-series analysis implicitly assigns a causal role to time, or more accurately, to the passage of time. It "... can be rationalized ... that we are using time as a proxy variable for other determining variables (e.g., income preferences, economic growth or similar phenomena)."³ However, "... as the time horizon lengthens, uncertainty increases, as does the need for a theoretical foundation;"⁴ a foundation not provided by time-series analysis. Therefore, regression techniques are generally more useful for long range forecasts, for they allow the analyst to incorporate theoretical relationships between the forecast variable and various independent causal variables.

The starting point of regression analysis is the postulation of a causal relationship between two or more variables, e.g., the relationship between air travel demand as expressed in revenue passenger miles (RPM'S) traveled in a given year and the aggregate level of economic activity (say in terms of GNP) on the one hand, and the aggregate airline fare structure (known as yield) on the other. One might reasonably expect RPM's would be positively correlated with GNP and negatively correlated with yield. One might, therefore postulate a model such as the following:

³Dale G. Bails, Larry C. Peppers, "Forecasting Techniques and Applications," Business Fluctuations, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1982, p. 117.

⁴Ibid., p. 105

$$\text{RPM} = A + (B \times \text{GNP}) - (C \times \text{yield})$$

In this equation, RPM is the dependent variable, both GNP and yield are independent variables, and A, B and C are regression coefficients which are estimated using the available historical data. The validity of the resulting equation is then evaluated using statistical tests of significance (e.g., "t" and "F" statistics), and goodness of fit checks using the correlation coefficient ("r") and the coefficient of determination ("r²"). A good model should also accurately predict turning points in the data.

There are basically four types of errors which can be identified in relation to regression models: (1) the underlying process contains a random element which will, in and of itself, virtually ensure that the forecast and actual data will differ; (2) the process of determining the regression coefficients is imperfect; (3) errors resulting from an erroneous model formulation (e.g., the underlying relationship is logarithmic, not linear); and (4) predictions must be made for the independent variable(s), and errors in these forecasts will be reflected in the forecast of the dependent variable.

The choice of how many independent variables to include represents a trade-off. On the positive side, the more relevant variables included, the greater the predictive accuracy of the model. However, this increase in accuracy comes at a cost; the cost of a greater data base, greater reliance on the estimated values for independent variables, and greater complexity. Also, with an increased number of independent variables, the greater the likelihood that two or more of them are related and redundant. Care must be taken not to over-fit

the data by introducing an excess number of independent variables which "... appear to be significant when in fact, they have only a spurious correlation. If one leaves these variables in the equation, he is likely to generate a very poor forecast."⁵

If, however, one errs in the opposite direction, i.e., omitting one or more key independent variables, equally poor forecasts can be attained as in the case where too many variables are included. Often, when insufficient variables are incorporated into the model, the error term is not randomly distributed with a constant variance as is required for valid forecasts to be produced. This condition, known as autocorrelation or serial correlation, results in forecast errors which worsen as the time horizon of the forecast increases. The so-called Durbin-Watson (or "d") statistic is frequently used to test for the presence of autocorrelation.

When the regression model produces error terms with a definite increasing or decreasing trend or a step increase or decrease (a condition known as heteroscedasticity), it usually means that changes in the environment (e.g., changes in laws, habits or governmental policies) have not been adequately addressed in the model. To correct this situation, the model must be revised, often with the incorporation of dummy variables. A statistical test known as Bartlett's or the Goldfeld-Quandt test may be used to check for the existence of this undesirable characteristic.

As can be seen from the foregoing discussion, the development and

⁵Bails, p. 173.

use of regression models requires people with an in-depth understanding of economic theory and statistical methods. Such people do represent a significant labor cost for the firm, whether they be on the payroll, or hired as consultants. Furthermore, since these techniques are relatively more complex than time-series methods, they are often difficult for management to fully understand, and the results are often looked upon with a fair degree of scepticism by decision-makers who "... who must be able to comprehend the projections yielded by alternative techniques."⁶

As to which of these two fundamental types of forecasting techniques (i.e., autoregressive or regressive) is the better forecasting tool, the picture is cloudy, at best. Different studies cited by Bails and Peppers⁷ draw very different conclusions, and these authors conclude that "... there is no best forecasting technique or model for all forecasting situations. Rather, it is necessary to weigh strengths and weaknesses of alternative methods before making a technique selection."⁸

QUALITATIVE METHODS

Although regressive techniques are, in general, better suited for long range forecasting than time-series (autoregressive) techniques, as the time horizon continues to recede, "... enough variables creep in to put limits on statistical forecasting, and statistical forecasting should be supplemented or replaced by other approaches,"⁹ this

⁶Ibid., p. 107. ⁷Ibid., 385, ⁸Ibid.

⁹Harvard Business School Report, Forecasting, Distributed by HBS Case Services, Harvard Business School, Boston, MA, 9-371-036, p. 12.

according to a Harvard Business School paper on forecasting. This article asserts that "statistical tools are, at best, only a part of forecasting. Managerial judgement must direct and supplement the use of these tools, and in many cases, judgement must over-ride statistics. ... The manager's knowledge and judgement of the total situation determines when statistical projections should be used and how reliable they may be."¹⁰ Brian H. Rowe, AEBG's Senior Vice-President and Group Executive, echoed these sentiments when he recently addressed an M.I.T. Sloan Fellows group. Paraphrasing Mr. Rowe, '... sometimes you just have to temper what the numbers say you should do with your own instincts.'¹¹ Instinct should, as a minimum, be used as a check against statistical techniques.

In support of pure intuition or informed judgement, there are a few more rigorous qualitative techniques such as polling, panel discussions and the Delphi technique. Polling is the least structured; the Delphi technique the most structured. Polling is merely a sampling of opinions of experts in the field. Panel discussions also rely on the pooled opinion of experts, but adds real time feedback on the experts' opinions by other experts. The resulting interchange of ideas often results in the development of new lines of reasoning and a different, more informed consensus than would be achieved by polling. The Delphi technique differs from a panel discussion in that it re-

¹⁰Ibid., p. 12.

¹¹Brian H. Rowe, Massachusetts Institute of Technology Sloan Fellows Program Seminar in Management, October 1, 1985.

places direct debate with a sequential process of individual interrogation (usually via questionnaires), "... interspersed with information and feedback derived from concensuses which are computed from earlier parts of the program. Both inquiries concerning their own reasons and subsequent feedback of the reasons adduced by others may serve to stimulate the experts to consider points which they had inadvertently neglected, and to give more weight to factors they had dismissed as unimportant on first thought."^{1 2}

AMALGAMATED FORECASTS

In the mid-1960's, a biologist name Levins suggested that the average of several independent forecasts which were developed from the same data base, but differing methodologies would yield superior results than any of the component forecasts taken individually. Furthermore, Levins asserted that the wider that the spectrum of forecast methodologies represented in this amalgamated forecast, the greater the potential for gains in accuracy. Furthermore, the potential gains would tend to be greater the more distant the time horizon of the forecast. This technique can be refined somewhat by weighting the individual forecasts being averaged according to the confidence level the analyst has in each component forecast.

J. Scott Armstrong of the Wharton School at University of Pennsylvania notes that although several researchers in the field of forecasting have strongly recommended the use of the amalgamated forecast

^{1 2}Technological Forecasting for Industry and Government: Methods and Applications, edited by James R. Bright, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, p. 147.

methodology in business applications, empirical evidence to date provides only mild support for its use. "Although the amalgamation reduced risk by avoiding the bad forecast, it provided only small improvement in accuracy. Furthermore, the gains were no more likely, as had been expected, in long range forecasting. Whether these small gains are worth the added expenditures depends upon the situation."¹³

SUMMARY

In conclusion, qualitative and quantitative techniques should not be viewed as mutually exclusive, but should compliment one another. "Statistics without judgement can be misleading, and it is unwise to use judgement alone when knowledge may be gleaned from statistics."¹⁴ The best quantitative technique to be blended with expert judgement depends upon many factors such as the time horizon of the forecast; whether a stable environment is expected to exist throughout the forecast period, and if so, is it consistent with the environment which existed during the period for which there is historical data; how much historical data is available; what resources, both financial and technical expertise, are available; and what level of sophistication of the technique can be understood and therefore accepted by management.

¹³J. Scott Armstrong, "From Crystal Ball to Computer," Long-Range Forecasting, A Wiley-Interscience Publication, John Wiley & Sons, New York, 1978, p. 265.

¹⁴Harvard Business School Report, Forecasting, Distributed by HBS Case Services, Harvard Business School, Boston, MA, 9-371-036, p. 12.

APPENDIX B

DETERMINATION OF AN APPROPRIATE COST OF CAPITAL

FOR A DISCOUNTED CASH FLOW ANALYSIS ON FUEL SAVINGS

We will use the capital asset pricing model (CAPM) to determine a weighted average cost of capital. CAPM defines the expected rate of return on a project to be:

$$r = r_f + \beta_a (r_m - r_f)$$

where r_f is the risk-free rate of return which is taken to be the going Treasury Bill rate, β_a is the so-called asset Beta, and $(r_m - r_f)$ is the market risk premium which historically has run at about 8.3%.¹ The asset Beta, in turn, can be represented by the equation:

$$\beta_a = \beta_{\text{debt}} \frac{\text{debt}}{(\text{debt} + \text{equity})} + \beta_{\text{equity}} \frac{\text{equity}}{(\text{debt} + \text{equity})}$$

Debt Betas are typically close to zero, particularly for "blue-chip" companies. Although most airlines are not considered blue-chip companies, we will approximate their β_{debt} 's as equal to zero. Thus, the equation defining the asset Beta reduces to:

$$\beta_a = \beta_{\text{equity}} \frac{\text{equity}}{(\text{debt} + \text{equity})}$$

By β_{equity} , we are referring to the variability of a given stock relative to the variability of the market portfolio. Equity Betas, and

¹Richard Brealey and Steward Myers, Principles of Corporate Finance, McGraw-Hill Book Company, New York, 1984, p. 176.

the debt and equity levels of the airlines of interest, as listed in Table B.2, were extracted from a weekly publication called The Value Line Investment Survey.

Before calculating a weighted average asset Beta, we must first define the airlines which should be included in the calculations, and how the weighting factors are to be determined. Table B.1 presents a summary of the top ten U.S. airlines relative to the totals of Boeing 727 series 100 and 200, Boeing 737 series 200, and DC9 series 10, 20, 30, 40 and 50 aircraft in their respective fleets. These models were singled out because they constitute the bulk of the replacement market for a new 150-passenger aircraft, while the ten airlines listed operate nearly one third of the 3,000 such aircraft in service.

TABLE B.1
TOP TEN CANDIDATES FOR THE 150-PASSENGER REPLACEMENT MARKET

AIRLINE*	FLEET SIZE (NO. OF A/C)**	RELATIVE FLEET SIZE (%)
AMERICAN	125	12.7
DELTA	139	14.2
EASTERN	182	18.6
NORTHWEST	57	5.8
PAN AMERICAN	34	3.4
PEOPLE EXPRESS	36	3.7
PIEDMONT	35	3.6
REPUBLIC	111	11.3
UNITED	172	17.5
US AIR	90	9.2
TOTALS	981 AIRCRAFT	100.0

NOTES: *TWA has a fleet of 88 aircraft in this category, but complete financial data was not available, so it was not included.
**Combined fleet of B727 -100/200's, B737 -200's, and DC9 -10/20/30/40/50's.

SOURCE: November 12, 1984 listing of aircraft fleet mixes of all the airlines of the world. Provided to AEBG by Aerospatiale (a French airframe manufacturer).

The relative fleet size column will be used as the weighting factors in the weighted average asset Beta calculation. It should be noted that AEBG's list of prime potential customers also includes SAS, KLM, Lufthansa, ANA, Swissair, British Airways, and Air Canada. These airlines, along with Delta, United, and American, form an advisory board which is helping to define the product requirements for the UDF. However, since financial data as used herein was not readily available for the foreign airlines, the ten U.S. airlines which account for the lion's share of the domestic replacement market were used as proxies. Table B.2 summarizes the weighted average β_a calculations.

TABLE B.2
WEIGHTED AVERAGE ASSET BETA CALCULATIONS FOR THE TOP TEN AIRLINES

AIRLINE	β_e^*	DEBT(\$M)*	EQUITY(\$M)*	β_a^{**}	WEIGHTING FACTOR***
AMERICAN	1.30	1,700	2,360	.76	.127
DELTA	1.20	620	1,539	.86	.142
EASTERN	1.05	2,040	358	.16	.186
NORTHWEST	1.15	575	1,029	.74	.058
PAN AM	.95	850	989	.51	.034
PEOPLE EXP.	1.35	700	237	.34	.037
PIEDMONT	1.25	695	680	.62	.036
REPUBLIC	1.05	710	443	.40	.113
UNITED	1.35	2,400	1,764	.57	.175
US AIR	1.25	595	941	.77	.092

WEIGHTED AVERAGE $\beta_a = .56$

NOTES: $\beta_a^{**} = \beta_e \frac{\text{equity}}{\text{debt} + \text{equity}}$

***Relative fleet size from Table B.1.

SOURCE: **Air Transport Industry, "The Value Line Investment Survey, Value Line, Inc., New York, January 3, 1986, pp. 253-274.

The result of these calculations is a weighted asset Beta of 0.56. Since the debt Beta is not really zero in the case of these airlines, this asset Beta is understated. Therefore, we will round-up to an even 0.6, which may still be somewhat understated, but in the right range. Before we can plug this value into the CAPM model to determine the required rate return for the airlines, we must first decide whether we will run our subsequent discounted cash flows on a real or nominal basis. Since the fuel savings are expressed in real (current) terms, we will use the real risk-free rate. The question then becomes what real risk-free rate should be used. Historically, it has run about 2%. However, in recent years, the rate has been running abnormally high at about 4%. The question boils down to where will the rate be in the 1990's. Corporate staff economics at GE feel the rate will gradually drop to the historical norm by 1992,² and H.D. Jacoby of the M.I.T. concurs.³ Taking a somewhat more conservative view, let us assume that the risk-free rate will return only to 3% by 1992. Alternate macroscenarios can obviously be run, but we shall limit our work load by using this single, relatively conservative value. The resulting rate of return calculated using CAPM is as follows:

$$r = r_f + \beta_a (r_m - r_f)$$

$$r = 3.0 + 0.6 (8.3)$$

$$r = 8.0$$

²Conversation with Frank Murphy of the GE Corporate Staff Long Range Economic Forecasting Department, January 22, 1986.

³Conversation with H.D. Jacoby, Professor of Economics, M.I.T., January 14, 1986.

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BIOGRAPHICAL NOTE

Prior to his involvement in the Sloan Fellows Program, the author was a Program Manager for General Electric Company's Aircraft Engine Business Group in Lynn, Massachusetts. In this role he was responsible for integration of propulsion and aircraft systems in a new commercial aircraft being jointly developed by Spanish and Indonesia airframers. Prior to assuming this position in 1982, he worked to establish the technical and product requirement for the engine which powers this new aircraft. From 1973 to 1979 he held several engineering positions in General Electric's Steam Turbine and Aircraft Engine Groups. A registered Professional Engineer, he received both a B.A. and a B.E. from Dartmouth College in 1972 and 1973, respectively. In 1978, he received an M.S. in Industrial Administration from Union College.