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Military Technology Pull and the Structure of the Commercial Aircraft Industry

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The commercial aircraft industry, if left to its own, would naturally tend toward monopoly and technological lethargy. However, throughout the 20th century the military energized the commercial industry by injecting critical technologies and providing competitors from the military industry. As a result, product evolution has been rapid and business failures prolific. In the last 20 years the technological interests of the military and civilian sectors have diverged. The result, which is only now beginning to be felt, is a single American commercial airframer with little incentive to take technological risks in product development. This paper develops the economic theory of the interaction of the commercial and military sectors, summarizes the economic history of the U.S. commercial aircraft industry in the 20th century, and draws examples from history to illustrate the theory.

Introduction

THE American aircraft industry has been critically important throughout the 20th century for providing commercial air transportation, defense, substantial exports, and jobs, particularly high-paying technical jobs. The behavior of the industry is an intricate interaction of the government-funded military sector with the free-market commercial sector.

The influence of the government is profound. It performs the following functions: 1) funds research and development to improve performance through technology; 2) increases the size of the market, doubling the market through the first half of the 20th century; and 3) bails out failing firms. As a result, a commercial industry that naturally tends toward monopoly and slow technological advance has been made extremely competitive (in the sense that many firms compete for business, frequently incurring losses), and the rate of technological innovation has been greatly accelerated. In the 21st century, with much lower investments in military aircraft and a technological divergence between military and commercial aircraft, the commercial aircraft industry is returning to its natural, monopolistic form with conservative product designs.

There is no laboratory large enough to clinically test a theory of the dynamics of an industry. Therefore, we must resort to history in an imperfect attempt to validate, or at least illustrate, theory. This paper begins by presenting the theory of the industry dynamics in Part I. Part II provides a condensed economic history of the U.S. aircraft industry, which is provided as a testbed for the theory. Part III identifies three specific examples of industry dynamics drawn from the history that illustrate and corroborate the theory. The examples are 1) all-metal monoplane technology, which culminated in the DC-3; 2) first-generation jet airliners, which culminated in the Boeing 727; and 3) wide-body, high-bypass turbofan-powered airliners, which culminated in the Boeing 767.

Part I: Theory of the Dynamics of the Aircraft Industry

In summary, the theory presented in this section predicts the following:

1) Commercial aircraft (airliners) win or lose in competition based on surplus value, the difference between the revenue they earn, and their operating cost combined with their manufacturing cost. Revenue is primarily driven by payload, range, safety, speed, and reliability. Operating cost is primarily influenced by fuel efficiency, maintenance cost, crew, and speed.

2) A new commercial aircraft can only become profitable by substantially exceeding the status quo in surplus value, such as by reducing operating cost by 10%. In addition, the new aircraft must significantly beat the surplus value of other new entrants, or enter the market much sooner than the others.

3) In an even competition between two or more aircraft in the same market segment, any advantage in market share provides lower cost because of the learning curve and provides an edge in future sales because of customer lock-in. Therefore, even, balanced competitions are unstable. Given enough time, one of the competitors should move ahead and take almost all of the market share. That is, the market tends toward monopoly. Once monopoly is achieved, it is essentially impossible for an outside firm, using its own resources, to successfully challenge the monopolist because of the high-performance hurdle required for a profitable new aircraft.

4) Developing a new commercial aircraft is expensive, time consuming, and risky. The current market leader has no motivation to bring out a new aircraft unless threatened by a competitor with a potential product that can substantially beat the status quo. Even when so threatened, the market leader has no business case for launching a new product unless it expects to outdo the competitor in surplus value, or roughly equal the competitor but introduce the aircraft first. Therefore, once a manufacturer has driven out competitors and achieved monopoly status it would be expected to cease developing new aircraft models.

5) Radical technologies, such as metal wings, jet engines, or wide-body aircraft, can only be introduced on completely new aircraft. If the industry has naturally proceeded to its monopoly state, such technologies will not be introduced.

6) The military has developed aircraft to achieve levels of speed, agility, ruggedness, stealth, payload, and range that were unavailable in the commercial market. To achieve these capabilities, radical technologies have been introduced. The resulting new aircraft were either financed by the government or funded by industry in anticipation of profiting from government acquisitions.

7) Radical technologies and aircraft designs created in response to military capability needs (technology pull) have enabled the development of major advances in commercial aircraft technologies. The risk of the new technologies has been greatly reduced by fielding the technologies in military products. Often factories and even tooling usable for commercial aircraft have been created in military industry. Components, such as jet engines, have directly transitioned from

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military to commercial products. As a result, commercial aircraft technology has advanced at a very rapid pace in the last 100 years, particularly between 1920 and 1985. This rapid development would not be expected from the commercial market without the influence of the military market.

8) Military development experience can enable companies to enter the commercial market with revolutionary new products. When this happens, incumbents in the commercial market might have little or no advantage over the newcomers. This effect has created periodic bursts of competition that oppose the commercial markets natural tendency toward monopoly.

9) Since 1980, military aviation has focused on capabilities such as supersonic cruise and stealth that are not relevant to commercial airliners. Opportunities to build revolutionary commercial aircraft designs on military bellwethers have dried up. Thus, for the foreseeable future the commercial market should follow its natural tendency toward monopoly and conservative product evolution.

The theoretical economic interaction of military technology pull on the commercial aircraft industry will be described by the following:

1) *Consider the dynamics of the commercial market in isolation from the military*. Commercial market demand is analyzed, and competition in the commercial market is summarized using surplus value theory. In the context of the commercial market, product development is considered. Technology development is viewed as a precursor and partner of product development.

2) *Understand military technology pull with relation to the commercial industry*. The forces behind military product development, the iron triangle, are considered. In this context military technology pull is introduced. The conflicts pressed on aircraft manufacturers by serving as suppliers to the military while competing in the commercial market are considered. The impact of military cycles on airframers is also considered.

3) *Determine the combined effect of military technology pull with commercial dynamics*. This subsection will predict how the expected behavior of a commercial aircraft manufacturer should change under the influence of the military aircraft market.

The resulting theory will then be compared to actual performance in the historical record.

Internal Dynamics of the Commercial Market

The commercial market is characterized by a large, fairly homogenous set of airline customers; very expensive, long-duration, high-risk product development programs; and fierce competition, particularly during initial product introduction.

Market Demand

The airlines who purchase aircraft are broadly similar in their business plans: they sell transportation and pay for the operation of aircraft. Profit is determined by the capability of their aircraft fleet to transport passengers, less the cost of operating the fleet. Thus, when shopping for aircraft, airlines are principally concerned with the ability of an airplane to earn revenue, described by its passenger payload and its range, and the corresponding operating cost. Speed, reliability, and safety are also primary concerns. Speed and reliability affect both revenue and cost. Safety flaws can destroy the revenue-earning ability of an aircraft model, although the primary motivation for airframers with regard to safety is a sense of social responsibility rather than profit.

Phillips[1] conducted a study of the characteristics of successes in the U.S. aircraft market. Of 14 successful commercial aircraft established before 1965, each had operating costs substantially below existing products, generally so far below that the operating cost of the new aircraft plus depreciation was smaller than the operating cost of existing aircraft. That is, the new aircraft could be purchased to replace a fully paid-off aircraft and still create a savings. The only exceptions occurred when two successful aircraft were introduced simultaneously—they did not necessarily have a such a cost advantage over each other. Without such a substantial cost advantage over the status quo, new aircraft designs were not purchased or were purchased only in token amounts.

The trend recognized by Phillips has continued into the jet age, although the impact of range has become more important in competitions because jets are more substantially differentiated by range than propeller airplanes. For example, in 1991 Singapore Airlines switched a pivotal order for the MD-11 to the A340 because of the difference in range. The MD-11 was subsequently driven out of the passenger transport market, although it fared well as a freighter.

Also, in comparing jets to propeller aircraft, the impact of speed, comfort, and reliability are very important to airline profit. Speed improves aircraft utilization, amortizing the aircraft cost over a greater number of available seat miles, and reduces crew cost for equivalent range. Speed, comfort, and reliability all contribute to the price customers are willing to pay to fly, as directly evidenced in the 1990s competition between jets and turboprops on regional airline routes.

In summary, airlines purchase aircraft to earn profit. Salient characteristics in aircraft competitions are payload, range, operating cost, and speed; and, where major differences are apparent, comfort and reliability. The only important product improvements with respect to selling airplanes are ones that directly contribute to these qualities.

Competition—Performance Impacts

The rub is that the firm does not know if the new product will be a success. To win requires a substantial edge in economic performance over the status quo and, generally, entry into service sooner than competitors with similar performance.

The revenue less the operating cost less the amortized manufacturing cost is an aircraft's surplus value, the joint profit potential for the manufacturer and the airline.[2] Because the airline customers are well understood, there is a consensus among the airlines as to the revenue and cost impact of a particular model, and this consensus, together with competition, sets actual sale prices. In a competition each aircraft earns a profit equal to its own surplus value less the surplus value of the second-place competitor. This means that, in theory, the aircraft with the greatest surplus value earns a profit; the second-place competitor breaks even (but never recovers its development cost); and everyone else loses money. If a market splits between two fairly even competitors, such as the DC-10 vs the L-1011, neither makes money. Instead, tight competition allows the airlines to take all of the surplus value. Reality is not so clearly delineated, but roughly follows the theory: "The number two commercial airliner in market share in a segment is usually unprofitable. To maintain a product in third place requires a willingness to accept large losses."[3]

Newhouse[3] predicted in 1982, as Airbus entered the commercial aircraft market, that it would drive out McDonnell Douglas. In 1996, Douglas, with only 10% of the market, was purchased by Boeing, and the commercial lines were liquidated, except for the MD95.

Competition—Time to Market

Being first to market is critical, for two reasons:

1) Airlines are locked into the aircraft models they purchase because of necessary investment in ground support and maintenance infrastructure. That is, once an airline purchases Airbus A340s in preference to Boeing 777, they must buy support equipment, spare engines, and maintenance infrastructure for A340s. In future fleet expansions, as they compare A340s to 777s, they only need to buy aircraft if they continue with A340s. If they mix in 777s, they must buy aircraft plus all of the infrastructure. This is strong incentive to stay with the original model. Thus, the first aircraft into a market locks up many airlines, who then become nearly unavailable to competing aircraft.

2) As an aircraft production line turns out units, they become less and less expensive, an effect commonly described as the "learning curve."[4] Thus, if the first competitor in a market produces 100 aircraft before the second competitor begins production, the first firm has a significant cost advantage just from learning curve effects, which adds to its surplus value.

The learning curve further punishes the late competitor if it falls short in surplus value because the leader will command greater market share and outproduce, undercost, and underprice the second entrant. "A six month delay in introducing a new generation of equipment can cost a manufacturer 50% or more of the total market."[5]

Observing Boeing's dash to field the first commercial jet, McDonald[6] predicted that, by waiting, one of the two dominant firms in large commercial aircraft, either Douglas or Lockheed, would find themselves shut out of the first round of jets. Although McDonald's prediction was made four years before the first flight of the 707, it proved true, as Lockheed failed to compete with the 707 and DC-8.

Competition—Break Even

The concept of a break-even point, a certain number of units that must be sold to recover development cost, is mythical in the aircraft business. Price and profit are set by the market, not by business plans. If aircraft are sold at or below cost to stay in the market, there is no break-even point. Even if profit is achieved, margins might be so small or sales might be so slow that, from a discounted cash flow perspective, the program never goes into the black. In fact, in the jet age Douglas (considered as a separate entity from McDonnell) never made a cumulative profit until the 1990s, shortly before its dissolution.

In summary, commercial aircraft competitions are winner take all. Winners are determined by impact on airline revenue and cost and by manufacturing cost. Being first to market is often a decisive advantage because the learning curve provides a manufacturing cost advantage, and infrastructure costs tend to lock airlines into the first model they purchase.

Product Development

With the DC-2, Electra, and 247 airliners in the 1930s, aircraft became truly complex products, in the sense that no single person could completely understand their design. Thus, a design team was required.[7] For modern jet aircraft the design team comprises thousands of engineers distributed over dozens of companies. Designs of complex products grow organically; they are not summoned forth by edict.

The implication for aircraft manufacturers is that aircraft design and development are very expensive, very time consuming, and fraught with uncertainty with regard to the performance and cost of the product and the time required for development.

"No other industry operates in a market in which the cost of developing a single new prototype is so immense that it can make or break a billion dollar enterprise."[5]

For large firms with tens of thousands of employees, developing a new aircraft will occupy a significant fraction of the workforce for several years, and paying for the development out of the aircraft's revenue will often require a decade or more, assuming it is a success.

The impact of development uncertainty on the aircraft manufacturer is profound. Uncertainty in performance and uncertainty in manufacturing cost combine to create uncertainty in the product's surplus value. Uncertainty in development time means uncertainty of entry into service.

If a firm does not know the surplus value and entry date of its own aircraft, it knows less about its competitor. Thus, unless the firm is unchallenged (as with the Boeing 747), there is great uncertainty about whether a product development effort will yield any profit stream at all. Every investment in a new aircraft is money placed at great risk.

Technology Development

The only reason to launch a new aircraft development is to field a technology that improves economic performance so decisively that airlines will park their current fleets to buy the new product. Thus, the backstory to aircraft development is the search for path-breaking technologies. The firm that discovers the next killer innovation and fields it in a product will dominate the next round of competition.

Edwin Mansfield[8] found that the incorporation of technology in new products follows certain rules across many industries:

1) A threshold amount of research and development funding is necessary to be effective.

2) All research and development programs that meet the threshold are equally effective. (More money does not buy better technology.)

3) Larger firms have less inventive output for the same research expenditure.

The implication (as was observed by Almarin Phillips[1]) is that if a group of aircraft firms are competing to create new technology, and all firms have adequate research teams, no firm is more likely than any other to find the next big innovation. In particular, the largest and most profitable firm with the best funded research program has no real edge in the technology development game.

Trend Toward Monopoly

Assume an initial condition with several airframe firms competing in a sector, such as 150 passenger jets with about 2500-mile range. One of the firms, at random, develops a significant innovation that reduces airlines' cost of operation. Two other firms get wind of the idea and try to imitate it. All three firms launch development programs, and one, again chosen essentially at random, delivers the aircraft with the greatest surplus value, perhaps because it entered the market first. This firm drives out all of the legacy aircraft and, eventually, its two competitors. The result is a monopoly. Once in a monopoly position, the winner downsizes its technology research and product development organizations because there is no longer any benefit to introducing new products. The very high cost of product development will act as an impregnable entry barrier against any firm that might hope to break the monopoly's hold on the market.

This is the natural behavior of the commercial aircraft market. A field of multiple competitors is dynamically unstable. Eventually, a killer technology improvement will be found, and one firm will use the technology to wipe out all the others, leaving a stable monopoly.

However, history has not reflected this logic because external to the commercial aircraft industry is a pulsating source of technology and potential competitors: the military aircraft industry.

Military Influence

"Long before the United States had a policy on school desegregation or social security, it had a policy on the aircraft industry."[5] Through most of the 20th century, the industry was completely dependent on government policy and government purchases. It was a monopsony, a market with a single major buyer.[5] The commercial industry was a minority component prior to 1957, with the exception of a period from 1927 to 1939 (see Fig. 1).

The effect of military influence on the commercial aircraft industry has been profound. The military has 1) injected crucial technologies into the commercial industry with little or no commercial research investment; 2) created new commercial competitors, or revived competitors that had been shut out in earlier rounds of competition; 3) structurally weakened aircraft firms that participated in military production; 4) contributed a highly trained workforce to a technically demanding commercial industry; and 5) periodically decimated that same workforce with huge swings in demand. The military aircraft industry is a juggernaut, propelled by a combination of political and military forces.

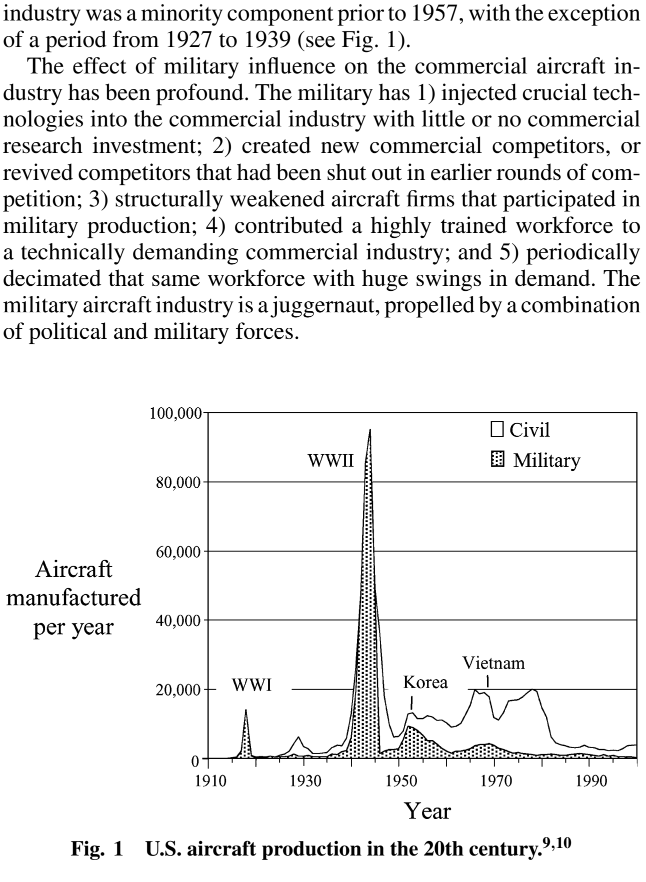

Fig. 1 U.S. aircraft production in the 20th century.[9,10]

Iron Triangle

The "iron triangle"[11] is a powerful confluence of interest between the legislature, the government bureaucracy, and industry. With respect to military aircraft, the iron triangle is the common interests of aircraft manufacturers, the Pentagon service chiefs who want the airplanes, and congressmen who represent the regions where the aircraft and components will be built.[12] When these three groups work in concert, the result is an irresistible force that accelerates the introduction of higher and higher technology systems. For example, the F-22 and B-2 might never have been developed without the push from the iron triangle.

What are the interests of these stakeholders?

1) The military wants to possess the assets needed to win wars. Unlike the commercial world, where performance has cardinal value, in the military only ordinal measures count. Fighter maneuverability always must be one step ahead of the threat fighter. Attack aircraft must always outperform enemy air defenses, whatever it takes. Being good has no value in itself—all that counts is being better than the opposing force. This posture naturally engenders technology races. One side upgrades, forcing the other side to upgrade, forcing the original side to upgrade again. Thus, the military hungers for technology improvements like no other sector of the economy.

2) Industry, as detailed next, is economically compelled to maximize profit by maximizing revenue. That is, industry wants more aircraft systems, more units produced for each systems, and most especially, a higher price for each system, which translates to a higher cost for each system. Particularly in raising cost, industry has been very effective.[13] The most dependable strategy for legitimately increasing the unit manufacturing cost of aircraft is the incorporation of advanced technology. Thus, the military aircraft industry naturally advocates high technology.

3) Congress responsibly supports the military's need for superior weapons, and supports industry insofar as it positively contributes to the economy. Individual representatives also particularly support weapon programs that create or sustain jobs in their districts. New military technologies often receive popular political support because they strengthen the national image, increase the safety of members of the armed forces, or reduce the inhumanity of war by, for example, reducing collateral damage.

Technology Pull

The collective result is a powerful pull of desired military capabilities that draw out new technology and incorporate them into new aircraft. New technology and new product development are elements of the military aircraft industry that regularly command the full support of all sides of the iron triangle.

Deleterious Effect of Military Production on Commercial Industries

The normal form of military contracting is the sole-source, cost-plus-fee contract. Even fixed-price production contracts are effectively cost plus fee because the fixed price is based on historical cost plus a profit allowance. Many military contracts are awarded to a sole source without competition because only one firm is qualified in a very special area. Most contracts are not competed because they are follow-on procurements, such as a sole-source production contract following a competed development contract.

Because of the cost-plus-fee structure, military aircraft firms focus on increasing revenue through winning contracts rather than maximizing profits through balancing price and cost. Because competition only occurs at the earliest prototype phase of product development, competitors can "buy-in," submitting unrealistically low bids during the competition, knowing the money can be recovered through negotiation once they have achieved a sole-source situation.[12]

Permanent receivership[14] describes businesses that government stabilizes and sustains through whatever means are necessary. Two preconditions are that the businesses are regarded as essential and that intervention is necessary to maintain their effective operation. An aspect of permanent receivership is the "bail-out imperative."[12] Major U.S. defense contractors are protected from bankruptcy by research and development subsidies, plant and equipment subsidies, military aircraft purchases, financing of export sales (military and commercial), loan guarantees, and outright bailouts (when necessary).[12]

The combined effect of revenue maximization and permanent receivership is a weak and inefficient industry. Unlike a free commercial industry, there is no imperative toward cost control or economic efficiency. In fact, runaway costs are usually rewarded with larger future contracts. Furthermore, the creative destruction that normally clears the deadwood from an industry is inoperative in military aircraft. The number of firms in the industry is managed by Congress and the Pentagon rather than the operation of a free and competitive market.

Military technology pull creates the opportunity for new commercial aircraft and often creates new competitors in the commercial industry. However, it simultaneously weakens these competitors and the overall industry through government contracting practices. Nationalization of aerospace firms would be expected to have a similar weakening impact.

Military Cycles

The most pronounced feature of the production history of U.S. aircraft (see Fig. 1 below) are the spikes in military aircraft production associated with major wars. In each case an extremely rapid buildup was followed by an equally rapid contraction. This has positive and negative impacts on the commercial industry. The positive impacts are listed here:

1) Each expansion creates new businesses, many of which join the commercial industry after the contraction. Introduction of these new competitors directly opposes the commercial industry's natural tendency toward monopoly.

2) Each expansion trains technicians and engineers in aircraft production.

3) Each expansion trains large numbers of new pilots, who help fuel commercial aircraft demand after the contraction.

The negative impacts are as follows:

1) Every contraction induces massive layoffs throughout the industry. These are very difficult for the workers involved. The periodic layoffs have also given the entire aerospace industry a bad reputation as a place to work.

2) In the past when military and commercial aircraft were similar (through World War II), contractions in military demand resulted in second-hand military aircraft flooding the commercial market, stifling demand for new aircraft.

Impact of the Military Aircraft Industry on the Commercial Market

The primary impacts of the military industry on the commercial business are the injection of technology and the introduction of new competitors.

Historically, virtually all of the important technologies in the commercial industry were incubated by the military, with the notable exception of the Wright Flyer. That is not to say that all military technologies transition to commercial application—only certain technologies are commercially relevant. Todd and Simpson[12] note that the military continually requires faster and sturdier aircraft, which then create new commercial market opportunities. Speed has been a transferable technology up to the sound barrier. Durability improvements have been largely transferable. However, since the 1980s, emphasis in the military has been on supersonic performance, such as supercruise, and on stealth. These capabilities are not relevant to the commercial industry, and the associated enabling technologies are, for the most part, not beneficial to commercial aircraft.

The introduction of new commercial firms from the military industry has been key. Every manufacturer of airliners in the United States started out in the military industry. Many firms were driven out of the commercial industry, such as Boeing in the 1930s, only to be nurtured by the military market and eventually reenter the commercial side. The natural tendency of the commercial aircraft market is toward monopoly, but this has been repeatedly forestalled by the introduction of new firms from the military aircraft manufacturing business.

Part II: Short History of the American Aircraft Industry

The economic behavior of the U.S. aircraft manufacturing industry is evidenced in its history. A brief summary of the history illustrates trends and provides examples to support the theoretical assertions made in the previous section. For simplicity, this summary addresses the U.S. market in isolation, which perhaps oversimplifies the period from 1950 to 1980, and excludes the considerable importance of Airbus after 1980. Also, the focus is on large aircraft, particularly airliners. Although not the bulk of the market in units, airliners make up most of the dollar volume of the commercial industry.

Figure 1 summarizes the story: From nothing in 1915, the industry exploded during World War I and collapsed at the war's end. The small core of a military industry remained in the 1920s, and by middecade a similar-sized commercial industry evolved. In the late 1920s the commercial industry soared. The Great Depression hammered the aircraft industry, but it survived. By the late 1930s Douglas had established a healthy dominance of the large aircraft market with the DC-3. World War II brought another explosion in aircraft volume and types, with an emphasis on large transports and bombers. Research during the war instigated the jet age, which changed the face of commercial air travel. The war ended with another collapse in production, but this leveled out to a much larger industry than in the 1930s. The 1950s were a period of consolidation in the midst of strong military development and production of jets. The 1960s saw further consolidation and a separation of military and commercial aircraft types. The 1970s were a commercial boom, as jet airliners came into their own, while the military industry contracted to a small fraction of the market. In the 1980s and 1990s the commercial market contracted and consolidated while the military industry further differentiated from the commercial, leaving few technology linkages.

First World War

Although the airplane was born near Kitty Hawk in 1903, the American aircraft industry was born in the First World War. The Wright brothers' demonstrations and promotions were more effective in Western Europe than at home in the United States. By 1909 an aircraft industry existed only in name. Between 1909 and 1912 the two major manufacturers, Wright and Curtiss, made more revenue from aviation meets and exhibitions than from aircraft sales.[9] Even by 1914, home-built aircraft outnumbered manufactured aircraft in America. Total production was about 200. The industry finally moved from the garage into the factory in 1916, when Curtiss mass produced 92 JN-4 trainers.[9]

England, France, and Germany possessed thousands of military aircraft at the onset of the War.[15,16] Almost 500 were stationed at the front in the summer of 1914 (Ref. 17). America was well behind. In its first use of airplanes in combat (by Pershing against Pancho Villa in Mexico in 1916), less than 10 planes were operational.[9,15] When the United States entered the War in 1917, 55 operating aircraft were in the Army inventory, and 54 were in the Navy.[9] Once in the War, Congress appropriated the fantastic sum of $640 million for airplane manufacturing to "darken the skies over Germany with our warplanes." To date this was the largest U.S. appropriation ever made for any purpose.[18]

Although the need for military airplanes was widely supported, there was little coherent vision as to exactly what the aircraft were to do. The initial role was reconnaissance, but additional tasks were soon added: sighting for artillery; attacking other aircraft, including reconnaissance balloons (which were thereby obsoleted) and dirigible bombers; bombing; and strafing ground targets.[15] In the summer of 1918, Col. Billy Mitchell organized 1476 allied aircraft to attack St. Mihiel, tasking aircraft to air superiority, battlefield deep interdiction, reconnaissance, and forward artillery spotting.[18] Still, many in the military considered the airplane an accessory rather than an essential tool of 20th century warfare. Many in the Navy insisted on the minor role of aircraft in control of the seas. Mitchell saw things differently. In 1921, in a widely publicized demonstration of air power he sunk three scrap German warships with a squadron of aircraft, humiliating many naval theorists. The ships were a destroyer, a cruiser, and a supposedly unsinkable battleship. Each went down in less than half an hour, presaging the air–sea battles of the Second World War.[18]

The U.S. military did not press to improve the design or technology of aircraft during the war. The DeHavilland DH-4 design was licensed from Britain, and the initial effort was to retool automobile factories to build DH-4s en masse.[9] The British, too, regarded the War as a period of improving existing aircraft designs rather than creating new ones. However, in Germany, fundamental and important advances were made. Professor Hugo Junkers of the University of Aachen developed a series of aircraft, designated J 1 through J 9, before and during the War. These designs evolved a revolutionary all metal wing that was cantilevered (requiring no stays), swept, and low mounted.[17] The Junkers wing was a forerunner of the U.S. airliners introduced in the 1930s, and its influence can be seen in every subsonic transport in the air today.

America built 16,000 airplanes during the War, of which only 602 made it to France. At the War's end only 200 U.S. aircraft (all DH-4 designs) were at the front. In November 1918 the U.S. government cancelled orders for 61,000 aircraft, almost four times the total U.S. aircraft manufactured to date.[9]

Roaring Twenties

At the end of the War, the manufacturing evaporated overnight. However, with so many production foremen and designers with aircraft experience and thousands of newly trained pilots, the air could not remain empty for long. Three key sources of demand were the military, air mail delivery, and air passenger service. The world's first scheduled air mail service commenced in 1918 between New York, Philadelphia, and Washington.[9,16] Funded by the government postal service, the air mail became a major conduit for government support of the aerospace industry over the next two decades. Meanwhile, international passenger air service began in 1919 with service between Key West and Havana. Organized airlines soon evolved, including American, TWA, and the precursor to United Air Lines, called Boeing Aircraft and Transport. Airlines in the 1920s usually covered their costs with air mail deliveries and counted passenger revenue as extra profit.

In the late 1920s aircraft manufacturing became an investment gold mine, similar to the internet bubble of the late 1990s. Aircraft stocks traded at 100 times their annual earnings.[9] (Fourteen is a normal ratio for a blue chip stock.) Figure 2 shows the major aircraft manufacturers of the 1920s and their relative market valuation.

In the first wave of aerospace mergers and acquisitions, giant holding companies such as AVCO, UATC, and Detroit Aircraft bought up aviation firms like Monopoly properties. The most interesting of these firms in retrospect was UATC, the United Aircraft and Transportation Company. A vertical trust, UATC incorporated air transport, aircraft manufacture, and component manufacture. Elements included United Air Lines (passenger traffic and mail), Boeing Airplane (airplane manufacture, military and commercial),

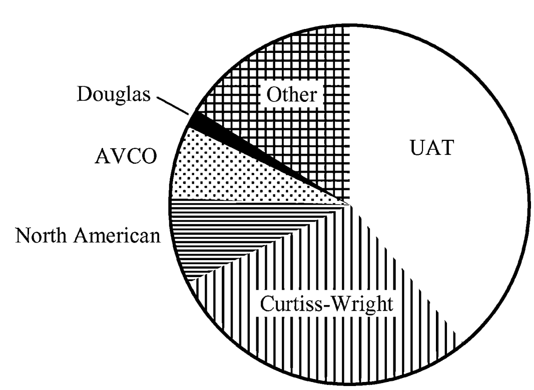

Fig. 2 Market valuation of aircraft manufacturers, 1928 (based on data from Pattillo[9]).

Stearman (small aircraft), Avion (John Northrop's aircraft firm), Chance Vought (aircraft manufacture), Hamilton Metalplane (aircraft manufacture), Sikorsky (helicopters), Pratt and Whitney (engines), and Standard Steel Propellers (propellers).[13]

The Detroit Aircraft Company was the most noticed of the aviation holding companies. Set up by auto-company barons, Detroit began acquiring aircraft manufacturers in 1927 and purchased Lockheed in 1929 (Ref. 19).

Consolidation in the 1930s

The stock market crash and the Great Depression drastically truncated aircraft production, as it impacted all industries. Still, the market survived, and was strengthened by improved designs.

In 1930, the Boeing division of UATC first flew the model 247, a radically new airliner.[9,20] Using technology developed on the B-9 experimental bomber and the Monomail mail transport, the 247 was low-wing monoplane, with all metal construction, cowled engines, and retractable landing gear.[21] The aircraft was more rugged and potentially faster than its predecessors. The 247 made the Ford, Fokker, and Stinson wooden trimotors that constituted airline fleets of the early 1930s obsolete. The development of the B-9, Monomail, and 247 overlapped. Both the Monomail and 247 first flew in May of 1930 (Ref. 20). The preproduction B-9 did not fly until April 1931, but was preceded by prototype models 214 and 215 (Ref. 20). Serling suggests that all three were influenced by the arrival of a Soviet ANT-4, a copy of the World War I Junkers all-metal low-wing monoplane, which stopped in Seattle in the summer of 1929 for servicing by Boeing prior to a goodwill flight across the United States.[21]

The market for all-metal airliners was forced on 31 March 1931, with the tragic crash of a TWA Fokker F10A carrying Knute Rockne. The crash, attributed to structural failure, brought on more restrictive government aircraft certification rules, which made the traditional wooden wing structures impractical.[19] Such rules were only possible because metal-wing monoplanes were already being introduced into service.

In 1931, the Detroit Aircraft holding company slipped into bankruptcy. Most divisions closed their doors immediately, but Lockheed persisted for several months, attempting to operate while bankrupt. The effort failed, and Lockheed was liquidated, but the assets were quickly purchased for $40,000 by a new management team to build another all-metal airliner, the Electra.[19]

Although focused on the commercial airline market, in which the Electra was very successful, the new Lockheed continued to pursue the military market, selling Electras as transports and VIP aircraft, developing derivative fighter designs, and developing the long-range Electra Junior as a photo-reconnaissance aircraft for Britain.[19,20]

The most successful airframer of the 1920s was Douglas, which built 392 aircraft in 1928, mostly military. However, to fill in the lulls in its military business, the company attacked the commercial air transport market in the 1930s. The Douglas DC-1 all-metal airliner was designed for TWA in direct response to the Knute Rockne crash. After flight test the design was modified to the DC-2, a very successful design which dominated the Lockheed Electra and drove the Boeing 247 from the market. The DC-2 was stretched, originally to accommodate sleeper quarters for American Airlines transcontinental flights. The result was the DC-3, possibly the most successful American aircraft in history. Four-hundred and thirty DC-3s were delivered to customers before World War II (as compared to 75 Boeing 247s and 147 L.10 Electras), and over 10,000 were purchased by the military during the war. The model's key advantage was size. The DC-3 carried 28 passengers, as compared to 10 for the 247 and L.10 Electra. The result was significantly lower costs per seat mile. Many DC-3s remained in service for over 40 years as C-47 Skytrains or Dakotas.[9,20]

For seven years following the introduction of the DC-3, Douglas commanded an effective monopoly in large commercial aircraft, winning 95% of sales.[9] However, the war rejuvenated Lockheed and Boeing.

Second World War

The Second World War required a 40-fold increase in aircraft production. United States production peaked in March of 1944, when 9117 aircraft were built in a single month, more than were manufactured in the three years 1991–1993. The industry rapidly changed beyond recognition. Few of the aircraft plants operating in 1945 had existed before the war.[5]

Industry normally funds production expansion out of profits, but large profits for defense contractors are unpopular. The War Department addressed this conundrum by directly funding the construction and equipage of factories, then leasing the plants to industry. Many aircraft plants remained government property until the 1980s when they were sold to the occupying businesses.[5]

The most important advance in aircraft technology in World War II was the jet engine, although it played a minor tactical role in the war. Jets were developed the furthest by Germany. The Junkers 109-006 engine, which actually flew in combat, employed an axial compressor, cooled turbine blades, ceramic airfoils, nickel alloys, and a variable area nozzle—most of the important technologies to be found on military jets and commercial jet airliners of the 1960s (Refs. 17 and 22).

Even without jets, the aircraft developed during the war flew higher, faster, and further, and carried more payload than the largest planes of the 1930s.

Postwar: The Jet Age

As in 1919, the postwar market collapsed, but settled at a higher volume than the prewar market. Industry employment dropped 89% between 1945 and 1946 (Ref. 9). Hundreds of aircraft firms were driven out of the industry, but two dozen giants remained.[5] Commercial manufacturing, which had been discontinued during the war, resumed. However, design and development focused on the military, particularly on high-speed, high-altitude jets.

The President's Air Policy Commission (also known as the Finletter Commission) described the extenuating circumstances of the aircraft industry in the postwar years: 1) a product that is, almost indivisibly, a weapon of war and a carrier of commerce; 2) a market with but one major customer, government, which purchases 80 to 90% of its entire output; 3) a violently fluctuating demand, caused by the uncertainty of requirements of its major customer; 4) a lack of the production continuity that is vitally important in sustaining a trained workforce and in keeping production costs to a minimum; 5) a rapidly changing technology that causes a high rate of design obsolescence and abnormally high engineering costs; 6) an extremely long design-manufacturing cycle; and 7) an organization in excess of present requirements.[23]

By 1954, 13 of the 500 largest American firms derived most of their revenue from the design and manufacture of aircraft. The largest were Boeing, Convair, Douglas, Lockheed, McDonnell, Northrop, North American, Republic, Chance Vought, and Grumman. During this time, aerospace established its place as the largest employment sector in the U.S. economy, with 800,000 employees, and the sector with the highest percentage of technical jobs.[9]

By the mid-1950s the jet age had arrived, at least with respect to military applications. One important change was the divergence of fighter designs from bomber/transports. In World War I airplanes were not differentiated significantly by function. By World War II bombers and transports were larger, slower, and had higher wing loadings (which limited maneuverability). In the late 1940s fighters pushed into supersonic speeds with delta-wing designs that resembled arrows more than birds. Most military research focused on high-speed, highly maneuverable aircraft because they embodied the deepest technical challenges. Thus, a continually smaller fraction of government aerospace research fed into commercial aircraft. There were indirect contributions, such as the extensive use of titanium in the engines for the Mach 3 SR-71 Blackbird and XB-70 Valkyrie. Titanium disks and airfoils became standard practice in commercial engines of the 1970s because of military development experience. But in no way could commercial aircraft be made as derivatives of military fighters.

Supersonic bombers were studied, and some were developed, but no U.S. models were successful, with the arguable exception of the B-1B. Similarly, supersonic commercial transports drew much design attention, but never developed a sound economic base.

The first American transport aircraft to exploit jet propulsion in a practical manner was the Boeing B-47 bomber, which first flew in 1947. The B-47 was remarkably similar to all the subsonic jet transports which have followed to this day. Over 2000 were eventually produced. A larger, turboprop-powered long-range bomber was designed at the same time. With the success of the B-47, Boeing redesigned the second bomber to use a Pratt and Whitney turbojet engine. The result was the B-52, an intercontinental bomber with three times the gross weight of the B-47. The B-52 has experienced the longest service life of any aircraft in the U.S. inventory.[9]

Boeing used its bomber experience to create a jet-powered tanker and a commercial transport. The tanker was designated the KC-135. The commercial transport was the first U.S. passenger jet, the 707, which entered service in 1957 (Refs. 22 and 24).

Douglas responded two years later with the DC-8. The 707 and DC-8 were similar in range (transatlantic) and payload (150 to 250 passengers). In the end they competed fairly evenly, with Boeing winning the market 60 to 40%, including the Boeing 720 derivative but excluding the sizable KC-135 military market.

Convair (a merger of Consolidated and Vultee) introduced the next jets, the smaller 880/990 family. The aircraft was a failure, driving Convair into a purchase by General Dynamics, in spite of the firm's considerable military business.

Lockheed chose to sit out the risky first round of jet development, relying on their dominance of the large propeller airliner market with the Constellation.

Boeing's next model, the 727, found the heart of the jet airliner market. With 150 passengers and 2000-mile range the 727 had sole occupancy of the market segment that the Airbus 320 and Boeing 737 contest today. For 20 years the 727 outsold the 707 and DC-8 combined, facing no direct competition. It was eventually obsoleted, not by a competitor, but by Boeing's own 737-300 and 757.

In 1965, one year after the 727, Douglas introduced their most successful model, the DC-9. A smaller, shorter-range twinjet, the DC-9 sold very well to domestic airlines prior to its introduction. Nevertheless, manufacturing problems caused Douglas to miss delivery dates resulting in financial troubles. This led to a takeover by McDonnell, a military aircraft firm.

In 1969 Boeing introduced the original 737, positioned as a competitor to the DC-9, but targeted specifically to European airlines. The undercarriage was short and strong to cope with rough runways. Emphasis was on reliability and durability rather than performance. In the long run, through two major revisions (the -300 in 1984 and the -700 in 1997) over 5000 units have been sold, making the 737 the highest volume airliner in history. However, the model was a late bloomer. In the 1970s it faced severe competition from the DC-9 and in Europe from the BAC-111. By 1982 the competition between the 737 and DC-9 was a draw, with 54 and 46% market shares respectively, not considering the other competitors. Boeing always held a cost advantage, though, because the 707, 727, and 737 shared the same upper-lobe fuselage cross section.

In the first 30 years of the jet age (1952–1982), 22 jet airliner models entered production. In this period of high development costs and frenetic competition, only two earned a profit, the Boeing 707 and 727 (Ref. 3).

Emergence of an Independent Commercial Industry: 1965–1990

In the 1960s and 1970s the preponderance of aircraft manufacturing shifted from military to commercial. Commercial industry reduced its dependence on government subsidies and the military market. In turn, the government reduced its control over industry.[5] By 1967 only eight of the Fortune 500 firms derived a majority of their sales from aircraft manufacturing: McDonnell-Douglas, Boeing, Lockheed, Grumman, Northrop, Fairchild Hiller, Cessna, and Beech.[9]

In the 1960s the Department of Defense funded the design and development of a large payload-long range transport capable of flying heavy armor from the United States into a foreign war zone. Five airframers received contracts in 1964 to design competing concepts for the CX-HLS (Heavy Lift System). Three firms—Douglas, Boeing and Lockheed—were selected to proceed with the design. At the same time, General Electric (GE) and Pratt and Whitney competed to provide radically new high-bypass turbofan engines for the aircraft. In 1965 Lockheed was awarded the development contract for the transport, renamed the C-5 Galaxy. GE received the engine contract.

Lockheed's C-5 development was plagued with problems, chiefly wing stress, landing gear durability, and cost overruns. Boeing, meanwhile, built on its C-5 design experience to create a jumbo commercial airliner with 11-abreast seating separated by two aisles, a layout that came to be known as wide body. The 747 used Pratt and Whitney's high-bypass turbofan engine design, another also-ran in the C-5 competition. The huge wing and four powerful, efficient engines provided the 747 with global reach, the ability to carry 400 passengers 6500 miles.[22] With the encouragement of launch customer Pan American, Boeing introduced the 747 into service in January 1970, just one month after the first Lockheed C-5A became operational.

In retrospect, the 747 was too large for the market of the 1970s. Except for the initial order by Pan Am and small prestige orders by many of the world's flag airlines, the 747 order book was quiet until transpacific routes became popular in the 1980s (Ref. 3). Eventually, the model became a major success, with sales of over 1000 planes. It is now the backbone of intercontinental air freight and a major link between North America and eastern Asia.

The range and payload gap between the DC-8/707 market and the 747 was large and inviting. Long before the first flight of Boeing's jumbo jet, Lockheed and McDonnell Douglas began developing smaller, transatlantic range wide-body jets powered by high-bypass turbofans.[3]

Lockheed's L-1011 was perhaps the more elegant design, but the development program was quite difficult, primarily because of design and cost problems with the Rolls-Royce engine. When it became clear that the aircraft could not be delivered on time or at the planned cost, both firms faced bankruptcy. However, they were vital components of their countries' defense infrastructure and were therefore rescued. The U.S. government provided loan guarantees to both companies, and Rolls was placed in receivership by the U.K. government, effectively nationalizing the firm. The aircraft entered service in April 1972, nine months behind McDonnell Douglas's DC-10. It was the last airliner produced by Lockheed.[3]

Neither the DC-10 nor the L-1011 performed well in the market. Less than 650 were sold, total, split 60/40 in favor of the DC-10. A decade later, in 1982, Boeing introduced its 767 into this market segment, which soon drove out the L-1011 and spelled the eventual end to the DC-10. To date, the 767 has sold 830 units, substantially more than its two competitors, despite their 10-year head start.

In 1980, aerospace, with one million employees, was the second largest job sector in the U.S. economy, behind automotive. Aerospace was the largest employer of skilled blue collar machinists, engineers, and technicians. At the time it was noted that the least secure careers in the United States were in the aircraft industry, where "hundreds of thousands of jobs can disappear in a matter of months."[5]

Division and Monopoly: The 1990s

The 747/DC-10/L-1011 were the last U.S. airliners whose designs owed a substantial immediate debt to a military program. By the late 1980s military aircraft designs had little in common with commercial aircraft. When the C-17 military transport was developed, it was a consumer of existing commercial technology rather than a font of useful commercial innovations.

New airliner designs slowed to a trickle. The only substantially new model introduced in the 1990s was the 777, although the layout was very similar to the 767. The press developed a nickname for Boeing, "Derivatives-R-Us."[25] In 1996 Boeing acquired McDonnell Douglas and discontinued all commercial production except the MD-95, a shortened derivative of the DC-9.

The two commercial aircraft of the 1990s, which had the most impact on the industry, were the Bombardier CRJ-200 and Embraer EMB-145 50 passenger regional jets. Boeing never entered this market segment.

By 2002 only one large American firm (Boeing) earned the majority of its revenue from aircraft design and manufacture. Aircraft manufacturing also dominated significant subsidiaries of Lockheed Martin, Raytheon (Beech), Textron (Cessna), and General Dynamics (Gulfstream), but none manufactured airliners except Raytheon's Beech 1900 turboprop, which finished the year on the verge of program cancellation. Boeing holds a monopoly in the U.S. commercial aircraft industry, and nothing on the horizon suggests a change.

Part III: Examples of the Industry Dynamic at Work

The root dynamic of the commercial aircraft industry under the influence of military technology pull is that 1) a capability is desired by the military; 2) an important technology is developed by the military to realize the capability; 3) the technology is demonstrated on military aircraft; 4) one or more manufacturers of military aircraft enter the commercial industry with products incorporating the new technology; 5) existing products are obsoleted by the new models; 6) one of the new competitors introduces a follow-on product that is so successful it marginalizes or drives out the other firms, in accordance with the industry's natural tendency toward monopoly; and 7) another military technology comes along, and the cycle repeats. Figures 3–5 illustrate this dynamic with examples from the industry history.

Example 1—All Metal Monoplane

The cantilevered, low-wing metal monoplane was developed prior to and during World War I by Hugo Junkers to provide the strength for a highly maneuverable aircraft and open the way to achieve higher speed. For a decade after the war, the idea did not gain any traction in the United States.

At the end of the 1920s, Boeing had a position in a commercial industry dominated by Ford and Stinson trimotor airliners. Boeing engineers obtained first-hand contact with the Junkers monoplane when they serviced the Soviet copy in 1929 (Ref. 21). In the next year three monoplane designs were developed: the Monomail, B-9, and 247. All of these developments were financed by Boeing.[21] It is not clear whether the development of the 247 would have been justified alone for the commercial market without the promise of a military market for the B-9 and a government postal market for the Monomail. The other aircraft development that Boeing undertook in the transition from biplanes to monoplanes, the Army XP-15 with its Navy sister, the XF5B-1, were clearly feeding the military pull. In any case the 247 launched the era of single wing metal airliners.

Lockheed, with the Electra, and Douglas, with the DC-1 and DC-2, were new entrants to the commercial business, Douglas from the military and Lockheed from scratch, although the prebankruptcy

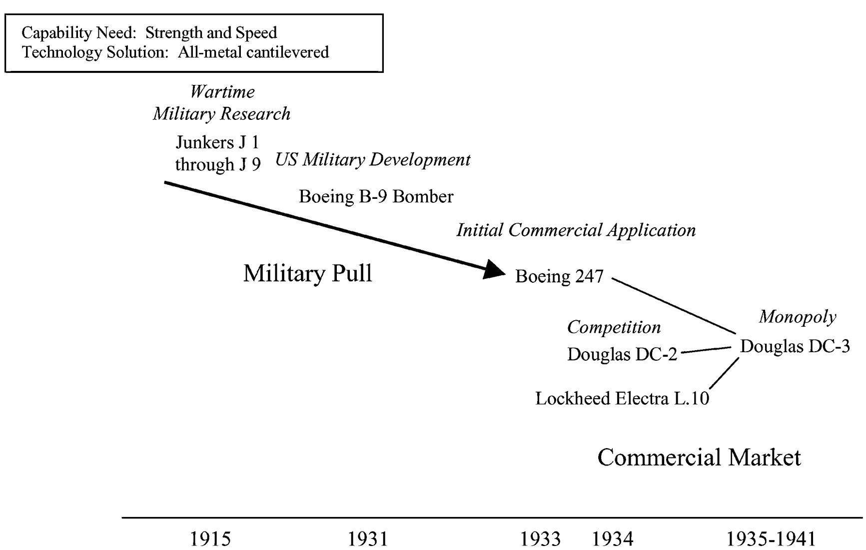

Fig. 3 Commercialization of the metal-wing monoplane.

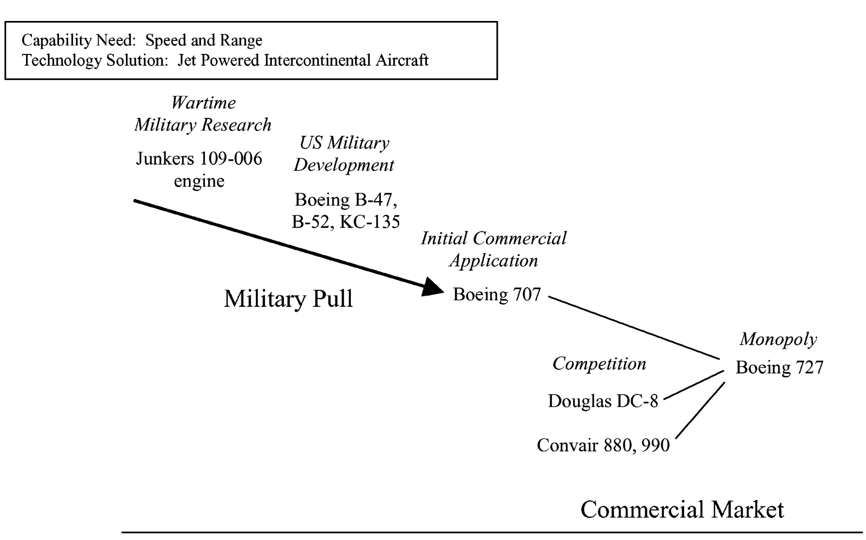

Fig. 4 Commercialization of jet propulsion.

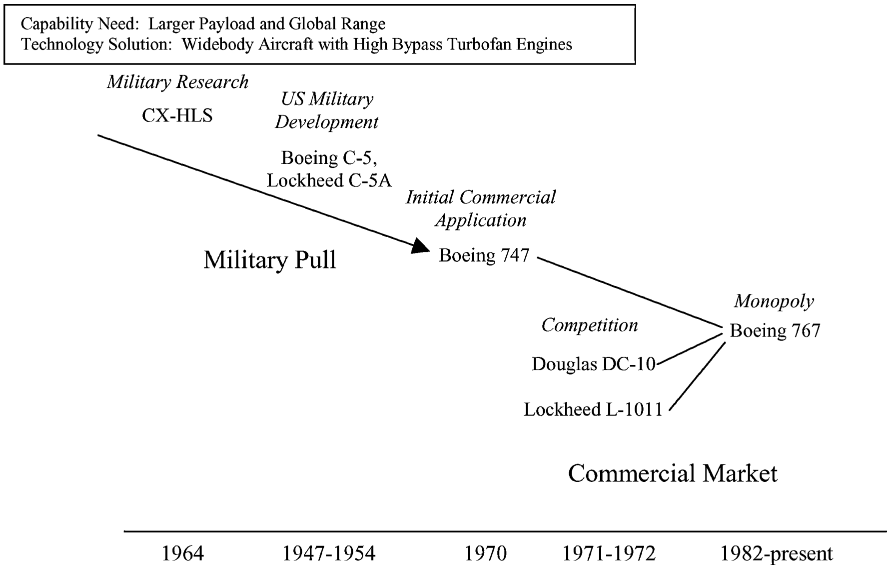

Fig. 5 Turbofan-powered wide-body airliners.

Lockheed had a primarily military product line. With the second-generation metal wing airliner, the DC-3, Douglas achieved a monopoly and drove Boeing and Lockheed from the market. The key advantage of the DC-3 was not any particular technology, but rather that it was sized to take maximum advantage of the market. Apparently, any of the three contenders could have stumbled on the right size for the 1930's airliner. Douglas found it and won.

Example 2—Jet Airliners

In the second example the military pull originated in the desire for intercontinental-range strategic bombers. To achieve the range, payload, and response time, turbojet engines and highly swept wings provided the solution. An essential element of the intercontinental air attack concept was in flight refueling for the bombers. Practical refueling required an aircraft with similar performance to the bomber. Boeing developed the B-47 and the B-52 bombers and the KC-135 tanker, and these paved the way for the first U.S. jet airliner, the Boeing 707 (Ref. 24).

The preexisting market had two competitors, the purely commercial Douglas and the mostly military Lockheed, which was able to reenter the commercial market on the fruits of World War II. Boeing entered the market in 1958 with its jet airliner, after an absence from commercial sales of over 20 years. The 707 was squarely based on Boeing's military bomber experience, particularly with respect to the B47. In turn, the B47 was based on wing sweep technology obtained from the German Luftwaffe and upon jet engines developed during the war. The 707 and the KC-135 tanker were jointly developed from a prototype, the Dash-80, which was funded by \$3 million of Boeing investment and \$13 million of IRAD funds, which were during this period at Boeing completely reimbursed by the government. Cook estimates that the cost of the prototype was only 5% of the nonrecurring cost of the KC-135 and the 707. He also notes that the U.S. Air Force funded the KC-135 tooling, which was then used for the 707, although with high volume production of the 707, much of the tooling cost was later reimbursed to the Air Force.[24]

Douglas fielded a competing long-range jet, the DC-8, but was marginalized by the second-generation 727. Lockheed was chased out of the market for 10 years.

Example 3—Wide-Body Jets

In the third example the three finalists in the CX-HLS global military transport competition—Boeing, Douglas, and Lockheed—became the competitors who introduced the first generation of high-bypass turbofan powered wide-body airliners. None of these firms based their commercial widebody designs on their military transport designs, but it is not coincidental that the same firms participated in the military and commercial competitions or that the C-5 and 747 entered service at essentially the same time. For Lockheed the L-1011 was a reentry into the commercial market, whereas Douglas hoped its DC-10 would rejuvenate a flagging business. Competition was tight in the first round of wide-body competition, with little profit to any firm. Boeing squarely won the second round with the 767, driving out Lockheed, and has dominated the American industry since.

Summary of the Examples

The interesting question in the introduction of the wide-body jets is whether it would have occurred without the CX-HLS development. Even with the risk reduction and technology development (such as the engines) from the military program, Boeing "bet the company" on the 747 (Ref. 3) and flirted with bankruptcy in the early years of production. The theory presented here infers that, without the government program, under the pure influence of the commercial market, the wide-body airliners would never have been built. History supports the theory, but not so strongly as to leave no room for debate.

The first example is even more open to speculation. Several airframers in 1930 were financially capable of taking the risk to develop metal monoplanes. The first monoplanes built by Boeing owed a clear debt to Hugo Junkers, who developed the concept building fighters for Germany in the War. However, Junkers was an academic, to whom the aircraft were experiments. With modest funding the study might have been undertaken in commercial industry.

The strongest example is the introduction of the jet airliner. It is hard to imagine a purely commercial industry, in a world with no military aircraft at all, adopting the gas turbine as a power plant. Frank Whittle certainly received no such encouragement in the 1930s.

The greatest endorsement of the theory is the lack of counter-examples. In the United States, since 1914, there has never been a revolutionary development in commercial aircraft that has not been prefigured by military technology development. The three most important developments are probably the three noted in the examples. There is evolutionary development underway today. Efficiency and reliability are constantly being improved, and new features such as in-flight entertainment are being introduced. However, compared to the Wright Flyer, today's airliners distinctly resemble the DC-3, and very closely resemble the 767 and 727 designs. Changes comparable to the revolutions that culminated in these landmark aircraft have not been seen for decades and are not on the horizon.

Airbus

Today the market in large commercial jets is an interplay between Boeing and Airbus. The theory presented in this paper does not apply well to this situation because so far Airbus has not been a profit maximizing firm. That is, the business decisions made at Airbus do not seem to be consistent with a primary desire to maximize the net present value of the firm. Airbus displays a concern toward increasing profits through improving aircraft performance and decreasing cost. However, the firm's dominant concern appears to be market share, not profit. Therefore, it is reasonable to Airbus to enter into market segments and launch products that would be unreasonable for a profit maximizing firm. Correspondingly, it is not clear that Boeing can benefit by competing with Airbus in the same manner that it would compete with a profit maximizing firm. For example, if Airbus were determined to win a certain percentage of sales in a particular market segment, the profit maximizing strategy for Boeing would seem to be to behave as a monopoly player in the remaining market share. In this case Boeing would not price compete with Airbus in a traditional sense. Analysis of this interaction between Airbus and Boeing falls outside the scope of the present paper.

Conclusion

The behavior of the commercial industry has resulted from an interplay of military injections of technologies and competitors against the natural tendency of the commercial market toward monopoly and technical stagnation. Without the military technology pull, commercial jets would have never been developed, to say nothing of wide-body transpacific airliners. The development of metal airliners that seat more than 10 passengers would have taken decades longer and might have never left the drawing boards.

However, the commercial industry is now in a period of isolation from military influence. The commercial industry is now much larger than the military, and the military is pursuing technologies that are, for the most part, irrelevant to commercial (operating cost) performance. Therefore, the commercial industry is stabilizing in its natural, monopolistic form, with the exception of the anomalous presence of Airbus.

From the economic perspective it is not at all surprising that Boeing recently abandoned the development of the Sonic Cruiser. Major new aircraft developments are expensive and risky, and monopoly manufacturers can get along without them.

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