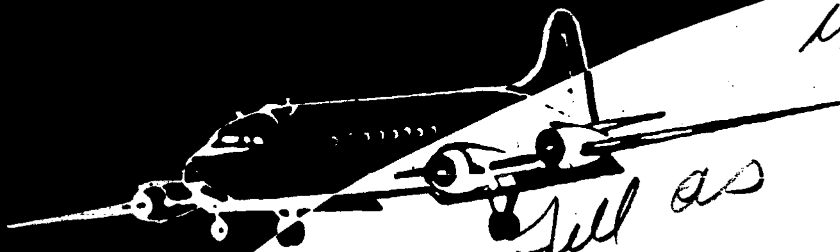

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R&D CONTRIBUTIONS TO AVIATION PROGRESS (RADCAP)

VOLUME I

SUMMARY REPORT

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13. ABSTRACT

This report contains the results of a joint DoD-NASA-DoT study of U.S. aeronautical progress since 1925. This study - R&D Contributions to Aviation Progress (RADCAP) - reviews the positive contributions of military aeronautical research and development programs to civil aviation, and assesses some possible future contributions of those military programs. This Summary Report consists of a summary of detailed results concerned with (1) a review of the progress that has been made in aviation since 1925 and the significant technological advances that have been made, (2) an examination of current and planned military aeronautical "research and technology" programs and an assessment of their relevancy to the aeronautical R&D needs of civil aviation, (3) the relationship of the development base generated by military programs to the needs of civil airliner design, development and production, (4) information on aeronautical R&D funding, and (5) the findings and observations of the RADCAP Study.

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R & D CONTRIBUTIONS TO AVIATION PROGRESS (RADCAP)

SUMMARY REPORT

AUGUST 1972

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SECTION I

INTRODUCTION

BACKGROUND

The Joint DoD-NASA-DoT Study of Research and Development Contributions to Aviation Progress (RADCAP) traces its origins to a report issued by the Senate Committee on Aeronautical and Space Sciences in January 1968. This Committee recommended that "*an in-depth study should be made to analyze the relationship between benefits that accrue to the Nation from aviation and the level of aeronautical R&D effort.*" The Committee also suggested that the study might include "*a detailed analysis of the divergence of military and civilian aeronautical requirements in order to assess better the diminishing benefits to civilian needs from military R&D.*"

In response to these recommendations, as well as to a report prepared by the House Subcommittee on Advanced Research and Technology in March 1970, a Joint DoT-NASA Civil Aviation Research and Development Policy Study, or "CARD" Study, was initiated, with the report being published in March 1971. This study placed emphasis on an examination of civil aviation benefits to the Nation, the relationship of research and development to these benefits, the criteria for Government support of civil aviation, and the identification of R&D needs appropriate to continued advance in the future.

Since the CARD Study examined military contributions only in a general sense, Mr. William M. Magruder, Special Consultant to the President, suggested in a 9 September 1971 Memorandum to Mr. David Packard, then Deputy Secretary of Defense, that a detailed study should be conducted to show the following: first, the flow of military technology that has made the U. S. civil air transport industry dominant in the free-world; and second, the changes in military requirements that might indicate that this flow of technology, or perhaps the timing of this flow, may no longer be of the same nature as in prior years. The DoD agreed that such a study could highlight the bonus effects of military programs and be valuable to civil aviation planning. The result was the initiation of the RADCAP review.

STUDY OBJECTIVES

Specific objectives of the RADCAP Study were defined as follows:

- *To identify the major technological advances that have been made in aviation since 1925 - including background, sponsor, user, application, timing, and trends.*

- *To show the relevancy of currently planned and funded DoD aeronautical R&D programs to the R&D needs of civil transport aviation - research and technology, development, application, and transfer process.*

ORGANIZATION AND DIRECTION

Overall guidance and direction for the study was provided by a Steering Group comprised of representatives from the DoD, NASA, and the DoT. The Study Team consisted of a Working Group and nine Working Group Panels. Principal participants are listed inside the back cover of this Summary Report (Volume I of the study report). The Working Group Panels accomplished the primary effort associated with RADCAP's objectives, and the detailed results are incorporated in the Appendices to this report (Volume II). The "Appendices" listing also is included inside the back cover of this Volume.

During the conduct of the study, maximum use was made of existing data and documentation, as reflected in the Bibliography, and the CARD Study was used as the source for the civil aviation R&D needs that are discussed in the RADCAP report. A substantial amount of historical data was obtained from "old-timers" in the R&D community, and only the major contributions and technological advances in aviation, as assessed by the Study Team, have been highlighted in the study report. In addition, the focus of this study was on transport aviation, rather than on the fighter, interceptor, or bomber aircraft that are purely military in nature. Finally, the RADCAP report has been kept unclassified in order to facilitate the distribution and general use of the information contained herein.

INCLUSIONS AND EXCLUSIONS

As the study progressed, it quickly became clear that the military services have made, and will continue to make, many significant contributions to the progress of aviation. DoD investments in the design, development, production, and operation of aircraft for the defense mission, and in related research and technology, have led to advances over a broad range of technical disciplines and RDT&E activities: propulsion, materials, specifications, manufacturing technology, meteorology, plant and test facilities, electronics, and the like. It also became clear that most technological advances involve many disciplines and many agencies, and that growth in aviation is a very complex and interactive process. This requires organizations, dedicated and responsive to their individual missions, to work together to develop the common base of knowledge needed by all. Thus, although NASA, DoT, and other Government and private agencies direct much of their attention to civil aviation, they also provide significant support to the military. For this reason, NASA, DoT and other agency programs that are joint with the military, or that relate to military needs and efforts, also are included in this report. However, major emphasis has been placed on DoD activities, and NASA and DoT participation has been primarily for background information and general expertise.

It also is important to note that the RADCAP Study is concerned only with the relevancy of military aeronautical R&D programs to civil aviation R&D needs, and not with the "adequacy" of these programs in fulfilling these needs. The issue of adequacy, or "sufficiency", would involve a very different kind of effort. Similarly, the RADCAP Study does not address the financing, competition, or other current issues of civil transport aviation. It is expected that these questions will be addressed by other agencies in other studies.

SUMMARY REPORT ORGANIZATION

- Section II of this report, which follows, contains a summary of the results of the RADCAP Study. Included are observations derived from the review of significant technological advance, overview remarks on the "relevancy" discussion, and the findings of the study.

- Section III includes the review of the progress that has been made in aviation since 1925 and a summary of the significant technological advancements that have occurred.

- Section IV examines current and planned military aeronautical "research and technology" programs, and assesses their relevancy to the aeronautical R&D needs of civil aviation, as identified by the CARD Study.

- Section V describes the relationship of the development base generated by military programs to the needs of civil airliner design, development, and production. Included are relevancy and trend assessments on the hardware transfer process.

● Section VI contains information on aeronautical R&D funding. Costs and trends in aircraft development are also discussed.

● Section VII outlines the findings and observations of the RADCAP Study. These also have been summarized in Section II.

ACKNOWLEDGEMENTS

The Joint DoD-NASA-DoT "Study of Research and Development Contributions to Aviation Progress" acknowledges the assistance and support of many personnel and several organizations during the course of the study. Special acknowledgement for technical assistance, comments, advice, and counsel is extended to the personnel of the Government agencies who served as points of contact for the Study Team and to the personnel and officials of several aerospace organizations. These include the Aerospace Industries Association of America, Inc., the McDonnell-Douglas Corporation, the Boeing Company, the Pratt & Whitney Aircraft Division of the United Aircraft Corporation, and the General Electric Company.

Also significant and important to the RADCAP Study were contributions from the efforts of:

● The Joint DoT-NASA Civil Aviation Research and Development Policy Study.

● Booz Allen Applied Research, Inc., under Contract No. NAS2-6741.

● Mr. David A. Anderton, Technical Consultant, under Contract No. NASA-2420.

Special acknowledgement is also due to the secretaries, typists and support personnel of the Aeronautical Systems Division and the Laboratories of the Air Force Systems Command who prepared and produced the written reports.

SECTION II

SUMMARY

The Joint DoD-NASA-DoT Study of Research and Development Contributions to Aviation Progress (RADCAP) was initiated in mid-December 1971 to examine the flow of technology from military aeronautical research and development to civil aviation. *The study was designed to accomplish two specific objectives: (1) to identify the major technological advances that have been made in aviation since 1925; and (2) to show the relevancy of current and planned military aeronautical research and development to the R&D needs of civil aviation.* In essence, the study was a review of the bonus effects of military aeronautical R&D programs on civil aviation, and an assessment of what these might be in the future.

MAJOR TECHNOLOGICAL ADVANCES

The historical review of aviation progress in the United States resulted in the identification of 51 major technological advances occurring since 1925 that were considered by the RADCAP Study Team to be especially significant. The review was divided into four time periods: 1925-1940, 1941-1950, 1951-1960, and 1961-1972. The results of the review show that there were approximately the same number of advances, and approximately the same number of advances per year, in each of the time periods. The period that included World War II contained the greatest number of advances per year, indicating the effects of the large wartime effort.

The year of 1925 was selected for beginning the study due to the increase in public awareness of aviation, and the resultant activity that was directed to aviation, at about that time. U. S. aviation really began prospering and growing in the late Twenties. A large number of the early advances, which were largely airframe and engine oriented, were stimulated by civil aviation needs, and nearly all were influenced by the work of Government agencies.

Especially since World War II, military sponsorship and first use have characterized most of the significant technological advances that have been made. Furthermore, military research, development, test, and evaluation usually have provided the basis for the acceptance and use by civil aviation of the technological advancements. The jet airliner is probably the best example of the civilian application of the military sponsored research, development, and production base.

About 70 percent of the major technological advances in aviation since 1925 are the result of military sponsorship. Another 20 percent were sponsored by civil agencies of the Government. The remaining advances were sponsored by the private sector, including aerospace and airline industries.

The selected advances are diverse in nature, so there are wide variations in the time lags experienced between the experimental demonstration of a significant technological advance and the first operational use by military or civil aviation. However, the average time lags for the advances studied were 3.04 years for the military, and 5.19 years for civil aviation. The shorter time lag to use by the military reflects the urgency often associated with the superior aeronautical performance required for the national defense.

The Study Team was impressed by the fact that the progress of aviation has been marked by the efforts of many contributors. Several advances have had their basic origins in foreign countries, with the U. S. exploiting them in further development and use. Also, technical disciplines and sciences in many areas are involved, such as those in meteorology, human factors, and aviation medicine that are often not considered. *In addition, Government non-defense agencies, whether the need has developed from military or private sector aviation sources, have been key contributors to the progress that has been achieved.*

Another observation is that recent advances show a trend to total system consideration in growing recognition of the fact that the aircraft itself is only one part of a larger capability problem. The military has pioneered in this area of integrated system design, and now civil aviation is adopting a similar approach.

MILITARY "TECHNOLOGY" RELEVANCY TO CIVIL AVIATION NEEDS

The current and planned DoD aeronautical research and technology programs were reviewed and compared with the R&D needs of civil aviation. The related or joint efforts of other Government agencies also were included in the review. This assessment shows that the relevancy of these military efforts to the R&D needs of civil aviation is high, and that this relationship is expected to continue in the future.

The major problems of civil aviation that require increased emphasis and high priority R&D programs, as outlined in the recently completed Joint DoT-NASA Civil Aviation Research and Development

(CARD) Policy Study, are noise abatement, relief of congestion in areas of high traffic density, and low density short-haul transportation. Additionally, there are other problems of high importance to the future of civil aviation, especially those relating to long-haul transportation (including the possible advanced supersonic transport consideration), air pollution, air cargo and the broad technology base supporting all of these.

In both noise abatement and air pollution, the military services are major participants in several interagency programs, and separately are conducting a wide variety of fundamental research and technology programs. In noise abatement, however, the military projects are just getting underway, and so the relevancy assessment is "low", with an upward trend indicated. In air pollution, on the other hand, the military has been active for several years, so the relevancy assessment is "moderate", with an upward trend also indicated.

In the airways aspect of congestion, it is clear that the military services have many important air traffic control, navigation, and communication research and technology programs. Accordingly, a "high" relevancy rating is assigned. Regarding the airport aspect of congestion, however, only military runway efforts seem pertinent to the civil problem. Thus, the relevancy assessment is "low". No change in trend in either case is anticipated.

The degree of compatibility between military research and technology programs and the short-haul transportation R&D needs of civil transport aviation also is clearly "high". The numerous helicopter, STOL, and VTOL efforts of the military certainly will be beneficial to civil aviation.

In long-haul transportation, there are several significant military research and technology efforts with important spin-off possibilities. However, only a "moderate" relevancy assessment was made because it cannot be shown that the military projects are broad-base in nature when all of the long-haul R&D needs are considered. In addition, a downward trend is indicated because the military does not have any long range transport aircraft development programs under active consideration at this time. Thus, the extent and number of future military R&D programs in this area could decrease.

In air cargo R&D, relatively few new military projects are in progress. However, because of past work, and because improvements in cargo handling and containerization still are being made, a "moderate" rating has been assigned.

Finally, the relevancy of the underlying technology base developed as a result of military programs is excellent in all of the disciplines, and a "high" relevancy assessment is the result.

MILITARY "DEVELOPMENT" RELEVANCY TO AIRLINER DEVELOPMENT

A review of the contributions of the military aeronautical "development" base to civil transport aviation also was accomplished. Six case studies were made to examine the application and transfer of aeronautical technology and hardware to civil airliner design, development, and production.

It is clear that the military technology and hardware developed for the post-World War II swept wing jet powered aircraft provided the basis from which the first commercial subsonic jet transports were developed and produced. However, a reduction in large military aircraft development beginning in the mid-1950s has diminished the direct transfer of hardware, and the direct application of the military development base (manufacturing technology, tooling, plant and test facilities, production methods, etc.), to the development of civil airliners and transports.

The recent initiation of military prototype programs, together with a continuing strong R&D program, will demonstrate the feasibility and operational capabilities of new aeronautical concepts. For example, the proposed Advanced Medium STOL Transport prototype could provide much of the design data and experience needed for development of a commercial Medium STOL Transport for short-haul transportation. In this area, the downward trend in hardware transfer may improve.

The trend in the transfer of hardware and development experience from the military to large long-haul commercial aircraft development has been downward. Even though much fundamental work in technology is underway, the future is uncertain. If an improved subsonic commercial airliner should be desired, the transfer could be significant. However, if an advanced supersonic transport should be desired, especially if needed by the mid-1980s, development effort would have to be expanded and accelerated. The current absence of a firm military need for a new long-haul transport, either high subsonic, transonic, or supersonic, could significantly impact the technology and development base that historically has existed in the long-haul area.

MILITARY AERONAUTICAL FUNDING TRENDS

The long term trend in U. S. aeronautical R&D expenditures is upward for all three major elements of the total: Federal defense, Federal non-defense, and industry. Unless there is a complete reversal in national aeronautical goals, the general increase in funding for aeronautical R&D is expected to continue. With economic escalation considered, the trend is still slightly upward for all elements. However, since 1954, the availability of aeronautical R&D funds, taken as a percentage of the ever-increasing Gross National Product (GNP), has suffered a severe reversal in the former upward trend.

Development costs of new aircraft have been rising much more rapidly than the rate of increase in aeronautical R&D funds. The costs have risen because modern aircraft, whether military or civilian, have become increasingly complex and sophisticated in the drive for improved performance and productivity. Any decrease in the relevancy of the military aeronautical R&D program to the needs of civil aviation could add even further to the already increasing costs of civil airliner development.

SUMMARY OF STUDY FINDINGS

The findings are based on the assumption that currently funded and programmed military aeronautical R&D programs will continue to completion. The findings of the RADCAP Study are summarized below:

- Government sponsorship, primarily military, has provided most of the significant technological advances that have been made in U.S. aviation.

- Early military application of technological advances in accomplishing the defense mission has provided the basis for their acceptance and use in civil aviation.

- Other bonus effects, or spin-off benefits, of military aeronautical R&D have been extensive - manufacturing technology and techniques, production methods, tooling, and plant and test facilities.

- The military aeronautical R&D program, in support of defense objectives, will continue to be substantial.

- With possible exceptions in the area of large, long range transonic and supersonic cruising aircraft, the research and technology generated by the military R&D program will continue to be available for civil aviation application, essentially as in the past.

B

- The benefits accruing to civil aviation from the military sponsored development and production base, however, have decreased in both relevance and importance.

  - In short-haul transportation, the downward trend in the hardware transfer process should reverse, and relevancy should begin to improve.

  - In long-haul transportation, little change to the current "low-to-moderate" relevancy status is forecast.

SECTION III

MAJOR TECHNOLOGICAL ADVANCES IN AVIATION

This section of the RADCAP report summarizes the major technological advances that have been made in aviation since 1925. The discussion is divided into four time periods: 1925-1940, 1941-1950, 1951-1960, and 1961-1972. Each review is preceded by a brief resume of the important historical events that impacted on the progress of aviation during the period under discussion.

As noted in the introduction, the selection of a relatively few "major technological advances" from the many achievements that have marked the growth of aviation was a very difficult and subjective process. The rationale or criteria used in selecting a particular advance as "major" centered on timeliness, magnitude, and overall applicability to aviation progress. A major consideration was the value of the advance to the solution of R&D problems slowing growth in aviation, or to the removal of obstacles preventing desired improvements in aircraft capability. Assessments were made on the basis of available data and documentation, on the recollections and judgment of the Study's advisors, and on a careful evaluation of the total worth of the listed advance to the overall progress of aviation.

Listings of technological advances such as those compiled in this report do not recognize, however, the many other advances, the vast amount of basic research, the painstaking development of engineering data, the complex and varied interactions of people and organizations, the dynamic interchange of information and ideas, or the magnitude of the total national involvement that have made it all possible. These considerations always must be regarded as basic and vital ingredients, or foundations, to any technological achievement.

The singularly important role of ground and flight test facilities in the development of aeronautical systems, for example, has not been specifically addressed in the RADCAP report. However, the contributions of the U.S. Government in providing the expensive test facilities so necessary to the development of modern aircraft must be recognized throughout this report on aviation progress. The test facility story, like many others, is an entity in itself.

AMERICAN AVIATION IN 1925

The year of 1925 was selected as the appropriate starting point for RADCAP's historical review of aviation progress because of the rebirth of purpose and general reawakening that began to characterize U.S. aviation during that year. Even though the airplane had been developed and flown by the Wright Brothers in the United States in 1903, foreign nations were the first to recognize the outstanding potential of this machine. By 1914, for example, when World War I began, Germany, France, and England had over 2,200 combat airplanes ready for action. By contrast, the U.S. had produced less than 50 military aircraft by that date, and only a few more civil aircraft - about 60. Though production of aircraft increased dramatically in the U.S. during the war years to a peak of over 14,000 in 1918, the end of the war brought this upward trend to a sudden halt. In 1922, a post-war low was reached when only 263 new military and civilian aircraft were produced.

The situation was not much different in early 1925. Capital invested in the aviation industry had largely been withdrawn; engineering talent had scattered; and, except for the air mail service, Government interest was low. The only aviation lead that the U.S. could claim was in night flying. Foreign governments, on the other hand, had exhibited keen interest in developing aviation as a valuable means of transportation. They routinely supported their air transportation industries, and miles flown over regularly operated air routes in Europe exceeded those of the U.S. by three to one.

Fortunately, however, many Americans had recognized the lagging position of this country in aeronautical research. In 1911, for example, a proposal was made to Congress that the Smithsonian Institute be given responsibility for establishing an Aeronautical Research Laboratory. When Congress did not approve, the Smithsonian then recommended, in 1915, that a National Advisory Committee for Aeronautics be established. Congress approved, and the NACA, to become NASA in 1958, was born. Two years later work began on its new laboratory - the Langley Memorial Aeronautical Laboratory, now the Langley Research Center - near Hampton, Virginia.

Soon thereafter, an Act of Congress in July 1921 created the Navy Bureau of Aeronautics with responsibilities in matters pertaining to Naval Aviation, and in March 1924 the House established the Lampert Committee to examine questions and issues pertaining to U.S. air services.

Later, in 1925, the Department of Commerce and the American Engineering Council formed a joint committee to survey the national development of commercial aviation in the United States. Its recommendations on air navigation, facilities, licensing of pilots, inspecting and registering aircraft, and promoting public confidence and interest helped set the stage for the rapid growth soon to follow. One of the recommendations, of particular interest to this report, was that Government should carry on fundamental research in furthering the cause of civil aviation. In addition, in 1925, President Coolidge responded to the years of compromise and controversy over aviation, and particularly to the public outcry raised by the criticisms of Billy Mitchell, by appointing the Morrow Commission to study the best means of "developing and applying aircraft in the national defense" and "creating a strong commercial service" to support this capability. Among the actions resulting from the Commission's findings were the establishment of the Army Air Corps and the passage of the Air Commerce Act, both in 1926.

All of these events, then, reflected a new interest in the airplane and its potential. The stage was set for the rapid growth and advancement that soon would permit the United States to become the world's foremost nation in aeronautical achievement.

AMERICAN AVIATION - 1925-1940

GROWTH AND PROGRESS

The period from 1925 to 1940 is one in which the U.S. clearly overtook the early European lead in aviation. Lindbergh's historic crossing of the Atlantic, the spectacular success of the DC-3, American geography and the American bent for travel, and the significantly increased attention being given to the development of U.S. military aircraft were perhaps the most important single factors in this achievement.

In 1926, the Ford Trimotor became the first successful large airliner to be built in America. It brought cruising speeds up to 105 miles per hour. By 1927, the Lockheed Vega appeared as America's first challenge to the lead in transport design so long held by Fokker and Junkers; and, by 1928, Commander Byrd had flown over both poles.

In 1931, the Boeing YB-9, an all-metal prototype bomber with a speed (188 mph) greater than that of contemporary pursuit ships, was flown and tested; and, by 1935, Pan-American transpacific "Clipper" service had begun. Also, in 1935, the XB-17, the four-engine prototype predecessor of the well-known "Flying Fortress" first flew. In 1939, the 42 passenger DC-4, at the time the world's largest transport, made its first public appearance in a flight from New York City to Chicago, and the pressurized Boeing 307 Stratoliner entered service a year later. Significantly, by 1940, American domestic airlines were carrying over 2,000,000 passengers a year in a new record for the air transportation industry.

During this period world records in endurance, range, altitude, and speed were routinely being set and broken by U.S. pilots flying U.S. aircraft. In 1931, a world distance record of over 5,000 miles was established in a flight from Floyd Bennett Field to Istanbul, Turkey; in 1935, Howard Hughes set a land plane speed record of over 352 miles per hour; and in 1939, an all-time, refueling-endurance record of 726 hours, one full month, was set.

This period also saw the rise and fall of another form of air transportation, the dirigible. After a series of major tragedies, including the Shenandoah, Italia, R-101, Akron, and Macon, the Hindenberg disaster at Lakehurst in 1937 wrote a fiery finish to the early promise of passenger carrying airships.

By 1938, the time had come for a major expansion of the Federal role in aviation, much beyond that of the development and operation of the airways system, and the Civil Aeronautics Act of 1938 was passed. This Act created the independent Civil Aeronautics Authority and became the basic statute for regulation of civil aviation.

And, by 1940, the aircraft industry had become big business. Its backlog of orders was over $2 billion, its exports were over $300 million, and it produced over 12,000 aircraft that year.

Thus the period from 1925 to 1940 saw aviation become a basic ingredient to the American way of life. Its progress - military, commercial, and private - was marked by a constant series of "headline" events, and the public now accepted the airplane as being actually capable of everything that its champions had claimed for it.

SIGNIFICANT TECHNOLOGICAL ADVANCES - 1925-1940

The spectacular advancements in aviation during this period would have been impossible without parallel advances in the technological base. In the drive to fly faster, higher, and further, it was essential that improvements in engines, airframes, aircraft handling and control, and flight operations and safety be achieved.

However, as has been characteristic of the entire history of aviation, the solution to any one problem usually led to the discovery of still other challenges in achieving further progress.

- Advances in Engine Performance

A series of major technological advances during the period resulted in improved engine power and efficiency that, in turn, permitted improvement in aircraft range, speed, payload, and economy of operation. *The foremost of these were the development of the radial air-cooled engine, higher octane fuels, supercharging, and the controllable pitch propeller.*

Radial Air-Cooled Engine - The most significant engine achievement of this period undoubtedly was the introduction and use of the radial air-cooled engine. The highly successful, nine cylinder, 200 hp model J-1 engine was developed by Lawrance with Navy funding starting in 1920. The engine passed its 50 hour test in 1922 and began flight tests soon afterward. This basic engine design was progressively improved in the years that followed and, in 1925, Wright Whirlwind radials powered the first practical passenger-carrying transport aircraft in the U.S. - the Fokker F-7 tri-motor. In 1927, a model J-5 engine powered Lindbergh's transatlantic flight. Competitive developments of the two leading U.S. engine firms, Wright and Pratt and Whitney, then led to radial engines of over 3,000 horsepower later in the period.

High Octane Fuels - In 1925, aviation gasoline only had an octane rating of about 50, although active research to improve fuels had been underway for years. This low octane rating was recognized as a limiting factor on the allowable compression ratio and efficiency of engine designs, a fact which led the military to stimulate the development, test, and use of higher octane aviation fuels. The superior performance that resulted led both the Army and Navy to adopt 100 octane fuel as standard in 1936. The airlines, however, continued to use the lower cost 90 octane fuels until after World War II.

Supercharging - The need to overcome the limitations to high altitude flight became very important to the military following World War I. Although the military had funded supercharger development as early as 1918, it was not until 1927 that the Pratt and Whitney "Wasp", the first U.S. production engine with a gear-driven supercharger, was introduced. From 1930 on, virtually all production engines for military and civil transport applications incorporated some form of supercharger. The first application of "turbosupercharging" to a military aircraft was the Consolidated P-30, later designated the PB-2, in 1935. The first heavy bomber with turbosuperchargers was the Y1B-17 in 1938. Following this, the Wright R-1830-51 engine was turbosupercharged to yield 1,000 hp at 25,000 feet, with these engines being used to power the B-17B. Commercial transport aircraft did not incorporate turbosuperchargers until the advent of the Boeing Stratocruiser in 1949.

Controllable Pitch Propellers - Early fixed-pitch propeller designs were a compromise between the different pitch settings that were best for take-off and cruise flight conditions. Because this compromise did not permit optimum performance, the Navy initiated a development program for controllable pitch propellers with Hamilton Standard in March 1931, and an early design was tested on a Navy Curtiss F6C-4 in September. Caldwell is the individual credited with development of the first practical controllable pitch propeller in 1932 while associated with the Hamilton Standard Propeller Company. The Navy used variable pitch propellers operationally as early as 1933 on Boeing F4B-4s. This two-position propeller also was incorporated in the Boeing 247 commercial transport in 1933. Conversion to the improved constant-speed propellers, with automatically controlled pitch, begin in 1934.

- Advances in Airframe Design and Materials

Just as increases in engine power and other engine-related improvements will permit higher performance in aircraft, so will the application of other advances in airframe design and materials. Thus, efforts to reduce aerodynamic drag and aircraft weight, without the sacrifice of strength or structural integrity, also received major attention during this period. Four of these advances are considered especially significant contributions - the retractable landing gear and NACA Cowling in drag reduction, and stressed-skin construction and new aluminum alloys in weight reduction.

Retractable Landing Gear - By the early Twenties, the aerodynamic drag of fixed, extended landing gear had become a severe limitation to the achievement of higher speed flight. Thus drag was considerably reduced with the advent of a retractable system. Though an early experimental configuration was tested in the Air Corps Dayton-Wright XPS-1 of 1921, it was not until 1930 that retractable landing gear appeared on an operational aircraft - the Boeing Monomail transport. This advance, however, was not used in production military aircraft until the Navy first flew its Grumman XFF-1 fighter in 1931. The basic XFF-1 line grew to include the later F2F and F3F series, with a total of 248 aircraft built. Introduction into the inventory of the Martin B-10 bomber, which also had retractable landing gear, occurred a few years later.

NACA Cowling - In specific response to the military need for improved aircraft performance, systematic testing in wind tunnels at the Langley Research Center led to the design of the NACA Cowling in 1928. This cowling not only reduced aerodynamic drag but, with the addition of baffles between the cylinder heads, also improved the cooling efficiency of the radial air-cooled engines previously discussed. When first incorporated on an Air Corps Curtiss AT-5A airplane in 1928, it permitted a speed increase from 118 to 137 mph, the equivalent of 83 additional horsepower in engine performance. This was recognized as a major achievement, and NACA received the 1929 Collier Trophy for this development. The NACA Cowling soon became the standard enclosure for air-cooled engines. The Lockheed Vega "Air Express", rebuilt from a prototype and fitted with the NACA Cowling, was certified in January 1929. Military use occurred in 1932 on the Martin XB-10 prototype, the XB-907A.

Stressed-Skin Metal Airplane - Initially, in the construction of metal aircraft, the metal skin was used to carry local airloads in the same manner as fabric. During the 1925-1928 time period, however, Wagner in Germany and Northrop in the United States saw possibilities for improvement, and independently evolved the theory for all-metal stressed-skin construction. This new design discovery employed the metal skin as an integral part of the airframe. The use of thin sheet metal supported at the edges to carry significant loads permitted greatly improved structural efficiency and lighter weight airplane construction. Beginning in 1930, four large stressed-skin metal airplanes were designed and built using varied methods of construction. They were, in order, the Boeing Monomail; the Northrop Alpha; the Boeing XB-901, from which the commercial 247 aircraft was derived; and the Martin XB-907A, known as the B-10 in its production version. In addition, the Boeing XP-9 was built as the first stressed-skin all-metal pursuit aircraft. It flew in November 1930.

Aluminum Alloys - The light weight and versatility of aluminum have made it the material of greatest use in the aircraft industry. Although the Wright Brothers used aluminum in the engine of their 1903 airplane, it was not until the mid-Twenties that aluminum alloys were developed with sufficient strength for aircraft structural use. Duralumin, which was developed in Germany about 1925, became the first high strength, heat treatable aluminum alloy. Then, in 1931, the 2024-T3 aluminum alloy, with a 25 percent higher yield strength was developed by U.S. industry. This alloy was used in 1935 on the Boeing Model 299 (XB-17) and the DC-3.

- Advances in Aircraft Handling and Control

Two significant technological advances took place during this period in the area of aircraft handling and control. The introduction of high lift devices permitted greatly improved handling characteristics during landing and takeoff, and the development of the autopilot contributed immensely to aircraft operation during cruise flight conditions.

High Lift Devices - Several high lift devices, including wing flaps, were developed in this time period. The simplest form of flap is a section of the trailing edge of a wing that can be hinged downward to increase the lift and drag of the wing. The initial advantage of flaps was to permit slower and more steep approaches for landing. The Fowler Flap, which was invented as a private venture in the mid-1920s, had the additional advantage of increasing the wing area, thus producing additional lift for improved take-off performance. The first military use of wing flaps to minimize landing speed appeared on the Curtiss A-8 Shrike, which entered service in 1932. First use in a civil application was the incorporation of split flaps on the Douglas DC-1, which first flew in 1933.

Autopilot - The ability to operate aircraft in level flight under automatic control was made possible by the autopilot. This device evolved over a long period of time, and was pioneered by Sperry in the United States. A successful test of an early Sperry gyrostabilized pilot in a Navy F5L was completed in 1920. In 1933, Wiley Post successfully used the Sperry A-2 three-axis autopilot in his round-the-world flight in the Lockheed Vega 5-C. The system included gyros with pneumatic pickoffs and three-axis control with proportional hydraulic servos. Sperry A-2 autopilots were first employed aboard DC-1 and DC-2 aircraft in 1935. The first military use of this autopilot was in the B-18A, in 1936. Four electric autopilot designs were subsequently developed and widely used by U.S. military aircraft during World War II.

● Advances in Flight Operations and Safety

During the period from 1925 to 1940, flying was often very hazardous and always subject to many uncertainties. Progress was substantial, though, and many advances emerged that related to flight operations and safety. Four of these that are considered especially significant were the development of the Standard Atmosphere, de-icing equipment, cabin pressurization, and two-way radio communication.

Standard Atmosphere - In the early 1920s, with all of the advances in aeronautics, engineers required increased knowledge and more accurate data on the characteristics of the atmosphere. This information was essential to aeronautical designers concerned with aircraft icing, propulsion systems, and aircraft pressurization. In response, NACA in 1925 developed the first modern Standard Atmosphere, a data book which describes the vertical structure of the atmosphere in terms of temperature, humidity, pressure, and density. By 1936, a national network of vertical atmospheric soundings was established. The data collected led to further knowledge and the development of an improved Standard Atmosphere. This network also provided the background for the development of improved upper-air observation systems which include wind measurements essential to preparing accurate aviation weather forecasts.

De-icing - Because of the many airplane crashes directly traceable to icing, and because of the many other hazards associated with this problem, the subject of ice formation on aircraft came under intensive investigation in 1928, when a conference was held by the Department of Commerce, Army, Navy, NACA, and the National Bureau of Standards. Between 1928 and 1931, flight tests and refrigerated wind tunnel tests by NACA identified the primary forms of ice which could be encountered, the effect of such formation on aircraft, and the direction for further investigation. Electrical, mechanical, and chemical methods of de-icing were explored. Pneumatic inflatable de-icer boots were developed and widely used on wing and empennage leading edges. Heated wing concepts were developed later. Other major benefits from these early efforts included alcohol spray for propellers, alcohol spray and wipers for windshields, electrically heated airspeed sensing probes, and carburetor anti-icing equipment. In 1935 de-icer boots were installed on the Douglas XB-18, and also were used on the TWA DC-2 commercial aircraft.

Cabin Pressurization - As a result of the early realization that high altitude flight offered many advantages, several exploratory investigations were conducted early in this time period on the effects of altitude on humans, and on survival at various levels in the upper atmosphere. Cabin pressurization seemed to offer the most promise, and a variety of pressure tank and other experiments were devised. The first successful demonstration of cabin pressurization was accomplished by the Air Corps in a Lockheed XC-35 aircraft in 1937. The Boeing 307 Stratoliner commercial transport, which flew in late 1938, then became the first production aircraft with cabin pressurization. Successive improvements have been made, and now high altitude operations proceed routinely while cabin pressures are maintained at a safe "altitude-level equivalent" of 8,000 feet or less.

Two-Way Radio Communication - In recognition of the need for air-to-ground communications, several telegraphy and radio demonstrations were accomplished in the early Twenties. By 1928, the military had two-way radio equipped aircraft in operation. At that time the Air Corps was experimenting with a C-2 radio laboratory airplane that included two-way radio telephone equipment for communication between the air and ground. Navy squadron VB-2B also was provided with radio telephone equipment in 1928. During that same year Boeing and the Bell Telephone Laboratories conducted a survey of the special needs of aviation for radio communications, and by 1929, two-way radio was introduced into commercial aviation.

SIGNIFICANT TECHNOLOGICAL ADVANCE SUMMARY - 1925-1940

From the preceding discussion of significant technological advances during the 1925-1940 time period, it is clear that there were many major achievements that contributed, in one or many ways, to the rapid progress that was taking place in U.S. aviation.

Table 1 is a summary listing of the advances, and a footnote to the table explains the headings that are used. Most of the advancements were Government sponsored, seven by the military and three by the civil agencies. "First" use was divided equally between military and private sector aviation, with the average time lag for use being about three years for the military and three and one-half for civilian aviation. As noted before, the advances were in materials and structures, engines and airframes, equipments and subsystems - and not concentrated in any one area.

Table 1*

Significant Technology Advances - 1925-1940

ADVANCE	DATE	SPONSOR	USER	
			MIL	PVT SECT
RADIAL AIR-COOLED ENGINES	1920	GOVT MIL	1922	1925
RETRACTABLE LANDING GEAR	1921	GOVT MIL	1931	1930
STANDARD ATMOSPHERE	1925	GOVT CIV	1925	1925
HIGH LIFT DEVICES	1927	PVT SECT	1932	1933
SUPERCHARGING	1927	GOVT MIL	1930	1930
NACA COWLING	1928	GOVT CIV	1932	1929
DE-ICING	1928	GOVT CIV	1935	1935
TWO-WAY RADIO COMMUNICATION	1928	GOVT MIL	1928	1929
STRESSED-SKIN METAL AIRPLANE	1930	PVT SECT	1930	1930
ALUMINUM ALLOY	1931	PVT SECT	1935	1935
CONTROLLABLE-PITCH PROPELLERS	1932	GOVT MIL	1933	1933
AUTOPILOT	1933	PVT SECT	1936	1935
HIGH OCTANE FUELS	1936	GOVT MIL	1936	1946
CABIN PRESSURIZATION	1937	GOVT MIL	1937	1938

* Note: The "date" listed for each advance is the one where something especially significant occurred in the United States. This

AMERICAN AVIATION - 1941-1950

GROWTH AND PROGRESS

The period from 1941 to 1950 could well be called the Golden Age of U.S. aviation because of the many types and kinds and large numbers of aircraft produced, because of the individual and group achievements that became almost daily routine, and because of the national "air-mindedness" that grew out of World War II.

In 1941 the Douglas XB-19, the world's largest land plane, and the Martin PB2M Mars, the world's largest flying boat, both in the 70 ton class, were flying. By the time of the attack on Pearl Harbor, all of the U.S. aircraft to play such a prominent part in the War were either in production or on order.

In World War II the airplane emerged as a major instrument of military power and, after the war, growth in the commercial industry was unprecedented. In 1944, the United States aircraft industry was the largest single industry in the world. Its $17 billion worth of business was over 10 percent of the United States Gross National Product. Even with the cancellation of over $26 billion in Army and Navy contracts in 1945, the industry survived and, by the end of the decade, was again growing and prospering.

The period saw development of the helicopter, the B-36 intercontinental bomber, the jet fighter and the jet bomber. In 1944 the "X" series of research aircraft was proposed by NACA in the initial planning for a long series of jointly-developed research aircraft that greatly expanded the frontiers of aeronautics. In 1946, a B-29 set an altitude record of 44,200 feet for operational aircraft in a flight over Guam; ejector seats were successfully tested at Wright Field and Lakehurst; the New York Yankees became the first major league baseball team to regularly use air

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could have been the full development of an idea, the discovery of something new, or the development of hardware with known application - sometimes direct, and sometimes after further development. "Sponsor" designations reflect the primary source of the funding that made the advance possible, rather than the origin of the need or the accomplishment of the work. Designations are by Government/Military, Government/Civil, and Private Sector. "User" listings are in Military and Private Sector categories, with the date shown reflecting application or use of the advance in operational or service aircraft.

transportation to meet its schedule; and the "Truculent Turtle," a Navy Neptune patrol bomber, set a new non-stop, long distance world record in a flight of almost 12,000 miles from Perth, Australia, to Columbus, Ohio. In addition, the year 1946 saw the first flight of an "X" aircraft, the X-1, which had been designed and built specifically to investigate and determine the feasibility of supersonic flight. And, in 1948, a Navy Mars carried 68,282 pounds of cargo, the heaviest payload ever lifted by an aircraft to that date.

During this period, prototyping matured as a standard procedure in weapon system acquisition, and the development of experimental and prototype aircraft was a major activity of the industry. The United States Air Force was formed in 1947, and during the next year the Berlin airlift began, in what was to prove a stunning setback to Communist ambitions.

By 1950, aircraft production had climbed back to over 6,000, after dropping from the all-time high of 96,000 in 1944. Industry sales were at $3.1 billion, with the DoD being the biggest customer ($2.6 billion); and over 19 million passengers were flown on domestic and international routes to set a new high of more than 10 billion revenue-passenger miles. The industry was in the forefront of the rapid advances and outstanding achievements that were characteristics of aviation in this decade.

SIGNIFICANT TECHNOLOGICAL ADVANCES - 1941-1950

Military needs for higher performance aircraft were responsible for most of the technological advances that were achieved during this period. The limitations of the piston engine/propeller propulsion system, the straight wing, and existing structural materials were widely known, and the search for new ways to reach a speed of 500 miles per hour, or even to cross the sound barrier, were aggressively pursued. The desires to fly in all kinds of weather, to improve equipment reliability, to carry more payload, and to operate at higher altitudes also were important stimuli to the advances that were sought. Those achieved and considered most significant have been grouped for discussion in three categories: improved aircraft performance, structures, and flight operations. The development and introduction of the "helicopter" also is considered a very significant achievement, and a discussion of this advance is included.

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Advances Contributing to Higher Performance Aircraft

There is little doubt that the advent of the jet engine was the major technical breakthrough of this period. Coupled with the engine, however, were other important advances in aerodynamic design - the swept wing and the delta wing. The eventual goal, of course, was supersonic flight.

Turbojet Engine - The turbojet engine was invented by Whittle in England and von Ohain in Germany. Some information on the British engine had filtered to the United States and, when General Arnold visited England in the Spring of 1941, he saw the engine and was amazed at the progress that had been made. Arrangements soon were made by the military for the General Electric Company to build a copy of the British engine in the United States. Although the GE engine ran hotter than desired, just like its British contemporary, it was not plagued by the turbine bucket breakage problem experienced by the British. The primary reason was the superior U.S. metallurgy that had been developed in the earlier turbosupercharger work. The first U.S. jet-powered airplane was the experimental Bell P-59A Airacomet, which was completed for the Air Corps in 1942. It did not reach quantity production, however, because it was too slow and had limited range. The first operational military jet aircraft was the P-80, which was introduced in 1944, and the first U.S. commercial jet aircraft was the Boeing 707, the prototype of which first flew in 1954. The success of U.S. endeavors in the turbojet field is one of the most interesting stories in the history of aviation, and nearly all developments were the result of military sponsorship.

Swept Wing - In the continuing search for aerodynamic design breakthroughs that would reduce drag in the transonic and supersonic flight regimes, and thus obtain the higher flight speeds desired, the idea of wing sweepback was conceived and developed by Jones of NACA near the end of World War II. About the same time it was discovered that Germany had started theoretical work on the swept-wing theory prior to the War and, by its end, already had jet-propelled, swept-wing aircraft designs in being that excelled any in the United States or Great Britain. In 1945, NACA published the first U.S. report on the aerodynamic theory of the swept wing, and development work was undertaken. The first U.S. military production aircraft with swept wings were the F-86 and B-47, both of which flew in 1947. The Boeing 707 prototype, which was the first U.S. swept-wing transport, flew in 1954.

Delta Wing - Another wing design with considerable promise in high speed flight, particularly supersonic flight, was the delta shape. Again, it was found that the Germans were working on delta-wing shaped prototype aircraft during the latter phase of World War II. One of these was tested in NACA wind tunnels after the war in about 1945, and the design was incorporated in the experimental XF-92A which flew in 1948. The F-102 of 1953 was the first production aircraft using this configuration. The XF4D Skyray flew earlier in 1951, but it was not a true delta wing aircraft, since it had curved-wing tips and a swept trailing edge.

Supersonic Flight - During the post-war period a series of experimental "X" aircraft were developed for research flight testing in the transonic and supersonic flight regimes. In 1947, Captain Charles Yeager flew the first of these, the rocket-powered Bell X-1, past the speed of sound in level flight to usher in the era of supersonic flight. Prior to this accomplishment, the sound barrier had been regarded as a serious technological obstacle to aviation progress. Supersonic military aircraft became commonplace in the 1950s, and in 1953 the North American F-100 Super Sabre became the first production aircraft to achieve supersonic speed under level flight conditions.

- Advances in Structures and Materials

The higher speeds permitted by jet engines and new aerodynamic designs required corresponding advances in structures and materials if the full benefits of potential aircraft performance were to be realized. Three significant advances in this area were fatigue testing, adhesive bonding, and titanium alloy development and fabrication.

Fatigue Testing - The fatigue life of aircraft structures has always been a concern in aircraft design. Fatigue is a structures problem that relates to the tendency of metals or other materials to crack and fail after the repeated application of stress. Prior to and during World War II, static strength design conservatisms and moderate performance demands provided an inherent fatigue resistance in the primary aircraft structure - in spite of the fact that there were no requirements for specific fatigue life in aircraft. With the advent of jet aircraft, however, increased performance demands and high maneuver-load factors eliminated this built-in fatigue resistance, and service problems started to develop. These problems were first attacked by laboratory tests, and in 1946 the first demonstration of full-scale "component" fatigue testing was accomplished on an AT-6D. The first "airframe" test to predict service life was accomplished in 1947 for the Martin 202 aircraft, and in 1948 the military followed with use of full-scale fatigue testing to correct service life airframe deficiencies of the F-84D. Improved test methods and instrumentation developed during this period made rapid full-scale tests possible, and continued development has taken place to improve these techniques. A major Air Force aircraft structural integrity program was initiated in 1958 to determine the service fatigue life of all front line aircraft. Many civil transports have benefitted from the results of this program.

Adhesive Bonding - Adhesives suitable for bonding airframe structures were developed for the military in 1941. Adhesive bonding permits joining of airframe parts without using fasteners, thereby decreasing weight and assembly costs. By 1942, this advancement had led to the incorporation of bonded components in the B-26 and P-40 airplanes. Later, adhesively bonded sandwich construction was extensively employed on the B-58, and now adhesively bonded components are being used on the Boeing 707 and 747 commercial transports.

Titanium Alloys - In 1947, the Navy, in the continuing search for new materials of high strength at high temperatures, initiated studies on the development and fabrication of titanium alloys. By 1948, the U.S. Bureau of Mines was able to produce 230 pound batches of titanium sponge using the Kroll extraction process. This accomplishment gave impetus to the DoD work, and a vigorous effort to develop titanium as an engineering material was undertaken. The first jet engine to use titanium was the J-57 in 1951. This engine was first operated in a military aircraft in 1952, and in the 367-80 commercial transport prototype in 1954. The first limited structural use of titanium was in the F-100. During the period from 1947 to 1961, the DoD invested over $200 million to establish the titanium mill products industry in the United States. This, and the development of vacuum melted superalloys, have been the key factors that enabled successful development and production of high performance military and commercial turbine engines.

- Advances in Flight Operations and Safety

During this period the increasing numbers of aircraft, their higher performance, the need to operate in all kinds of weather, and the passenger demands of commercial aviation were factors that placed new emphasis on safe, reliable flight operations. Thus, this period saw the development of instrument landing systems, radars, on-board power generating equipment, and thrust reversers as major technological advances.

Instrument Landing System - The capability for providing safe approaches to airfields and landings under conditions of poor visibility was recognized early as an urgent need of aviation. In the four year period from 1937 to 1941 numerous experimental instrument landings were accomplished by pilots of the various airlines, Army, Navy, and the Bureau of Air Commerce. Developments, investigations, and evaluations also were conducted by several National agencies during the same period. These efforts culminated in the establishment of the specification for the SCS-51 Instrument Landing System in January 1941 by the Air Corps. This became the standard landing system for both civil and military aviation with installation at over 500 ground stations and in about 18,000 aircraft. This is essentially the same system used today. Installation of equipment in military aircraft began in 1943. The first installations in commercial aircraft occurred in about 1947.

Ground-Based Weather Radar - During World War II, the English placed a very high priority on the development of ground-based radar systems that could detect the approach of enemy aircraft. Early in 1940 it became apparent that these systems might have other uses when it was calculated that radar systems capable of detecting aircraft would be affected by clouds, rain, and snow. Three months later, the first radar-detected storm was reported in England. After World War II, a limited number of airborne radars were modified for ground-based observation of precipitation; however, these radars had many deficiencies when applied to weather detection. The first ground-based radar designed specifically for weather detection purposes was developed by the Army in 1948, and the Weather Bureau began operational use of a similar radar, which incorporated refinements of the Army system, in 1959. Weather radars have contributed significantly to military operations as well as to the remarkable safety record established by commercial air carriers, through their ability to detect hazardous storms and to assist aircraft in avoiding or safely penetrating storm areas.

Doppler Navigation - Airborne radar was first developed in the U.S. for use in navigation and bombing during World War II. In 1944, MIT developed the radar-assisted Norden Bombsight, which resulted in improved bombing accuracy. In 1949, the first airborne Doppler navigation radar was delivered to the Air Force by General Precision Laboratory for flight testing. A vast improvement over earlier radars, the Doppler system was a self-contained, dead reckoning navigation system that used radar to measure the aircraft ground speed and drift angle, and, by means of a directional sensor and computer, provide distance and direction travelled from point of departure. The first operational military Doppler radar was installed in the F-101 aircraft in about 1954, and, in 1955, Bendix fabricated a doppler radar navigation system for use in commercial aircraft.

On-Board Power Generation - On-board electrical power requirements for aircraft initially were so nominal that they easily could be satisfied by automotive type storage batteries that were used in flight, recharged on the ground, and then used again. As power requirements grew to accommodate more electrical equipment, however, improvements soon were needed, and engine-mounted power generators were developed. Even this was not enough. The requirements for the B-36 intercontinental bomber were so large, for example, that a considerable advance in power generation technology was required. Light weight and ease of maintenance were also important considerations. Thus, the three-phase, 400 Hertz, 120/208 volt on-board power generation system, used in conjunction with a constant speed drive, was developed for the B-36, the experimental model of which first flew in 1946. Initial application to commercial aircraft occurred in 1955. The systems now in general use on most of the jet powered commercial transports are direct descendants of the system developed for the B-36.

Thrust Reversers - Associated with the higher speeds of aircraft in flight were the higher landing speeds that resulted. Thus, in the search for a means of slowing the aircraft and decreasing the ground roll after landing, thrust reversers for jet engines were studied in the U.S. during the 1940s. Initial funding on thrust reversers for turbojet aircraft was provided by the military, with experimental models being flight tested by the Navy as early as 1946. For most military applications, however, the associated weight penalty was difficult to accept, and it was not until 1963 that the military first used thrust reversers on operational aircraft (the Lockheed C-141). However, the first commercial application of thrust reversers occurred much earlier in 1954, when they were applied to the JT-3C engine on the Boeing Model 367-80, the prototype of the 707.

- Advance in Rotary Wing Aircraft Design

This decade also saw the introduction and acceptance of a new type of aircraft - the helicopter - one that could be lifted vertically and moved horizontally in any direction, or be kept hovering, by large, engine-driven, rotary blades that provided both lift and thrust.

Helicopter - The theory of lifting rotor aerodynamics, which had been developed in conjunction with the Autogiro during the 1930s, was crucial to the successful development of this aircraft. In 1941, Sikorsky successfully demonstrated in the U.S. a practical helicopter (the Model VS-300) of superior controllability by hovering for over one hour. For the next several years, advances were largely stimulated by industry, including Bell, Hiller, Kaman, and Piasecki. In 1941, the Army placed its first order, and by 1944 had received 130 of Sikorsky's two-place helicopters (Model R-4). These were used for observation, communication, and rescue work with enough success to guarantee their continued development and production. In 1946, commercial helicopter shuttle service was inaugurated by Helicopter Air Transport of Philadelphia.

SIGNIFICANT TECHNOLOGICAL ADVANCE SUMMARY - 1941-1950

The decade of the Forties in aviation was unique in several ways. The foremost feature, perhaps, was the achievement of supersonic speeds and the disappearance of "sound barrier" mythology into the literature of flight. Several significant technological advances served as major contributions to the progress that was achieved. Table 2 contains a summary listing of the advances that have been discussed. As before, the advances of this period were broad in both scope and nature, with the military being the leader by far in both sponsorship and use. The time lag between significant event date and use date remained at about three years for the military, but it had increased to over eight years for civil aviation.

Table 2

Significant Technological Advances - 1941-1950

ADVANCE	DATE	SPONSOR	USER	
			MIL	PVT SECT
HELICOPTER	1941	PVT SECT	1942	1946
ADHESIVE BONDING	1941	GOVT MIL	1942	1958
TURBOJET	1941	GOVT MIL	1942	1954
INSTRUMENT LANDING SYSTEM	1941	GOVT JOINT	1943	1947
SWEPT WING	1945	GOVT CIV	1947	1954
DELTA WING	1945	GOVT CIV	1948	-
FATIGUE TESTING	1946	GOVT MIL	1948	1947
THRUST REVERSER	1946	GOVT MIL	1963	1954
ON-BOARD POWER GENERATION	1946	GOVT MIL	1946	1955
TITANIUM	1947	GOVT MIL	1952	1954
SUPERSONIC FLIGHT	1947	GOVT MIL	1953	-
GROUND-BASED WEATHER RADAR	1948	GOVT MIL	1948	N/A*
DOPPLER NAVIGATION RADAR	1949	GOVT MIL	1954	1955

* N/A - Not applicable. Private industry does not currently operate weather radars, nor does it need to do so.

AMERICAN AVIATION - 1951-1960

GROWTH AND PROGRESS

Aviation progress in the decade of the Fifties developed against a background of several divergent events. Early in the *period the Korean conflict placed renewed emphasis on military aviation, particularly in the tactical area. However, with attention on ballistic missiles, and with the advent of the epochal Sputnik, the end of the decade saw aviation progress becoming secondary to the mounting U.S. efforts in ICBMs and space.*

Nevertheless, many significant events occurred in aviation as a whole. In November 1950 the world's first all-jet aerial dogfight occurred when an F-80 shot down a MIG-15 over Korea, and American pilots demonstrated exceptional skills in achieving a seven to one victory ratio during the three years of Korean combat.

In addition, the helicopter continued to show impressive utility in a variety of battlefield applications. In 1951, the Grumman Cougar became the first swept-wing, shipboard fighter to enter Navy service, and the Air Force began receiving the six-jet Boeing B-47. The first B-52 flew in October 1952. *Then in 1954, eight years after flight of the first jet bomber, the first flight of a U.S. jet airliner occurred.* This was the 367-80 prototype of the Boeing 707, an aircraft that traced much of its development to Boeing's experience with the B-47 and B-52. The 707 was placed in commercial use in 1958, and a year later the Douglas DC-8 began operation.

In 1954, the Convair XFY-1 "Tailsitter" airplane, which was directed at improvements in the launch and recovery of carrier-based aircraft, became the first fixed wing airplane to achieve vertical takeoff and then transition to level flight. In 1955, the supersonic F-100 set a world speed record of 822 miles per hour in level flight, and in 1958, the Navy developed McDonnell F-4 first flew.

The experimental series of X-aircraft also continued throughout the Fifties in proving the value of technological and design advancements to aircraft configurations for transonic and supersonic flight. The rocket-powered Bell X-2 established unofficial speed and altitude records of 2260 miles per hour (Captain Apt) and 126,200 feet (Captain Kincheloe). The Douglas X-3 was built to explore the efficiency of turbojets and thin, double-wedge airfoils at supersonic speeds. The Northrop X-4 was developed to prove the handling qualities of a near-delta wing airplane without the use of horizontal stabilizers, and the Bell X-5 investigated the effects of changing the angle of wing sweep in transonic flight. And finally, the famous X-15 hypersonic research aircraft had its first free flight in 1959, after being released from a B-52.

Commercially, annual aircraft production remained at about the 10,000 level, but new civil aircraft sales outnumbered military sales by a ratio of four to one. United States airline revenue-passenger miles were almost 40 billion, a fourfold increase over 1950, and in 1960, over 81 percent (2766) of the aircraft in operation (3376) on world civil airlines were manufactured in the United States.

The decade of the Fifties again was impressive for the growth in aviation that occurred. The jet aircraft, both military and commercial, was opening up new frontiers in the fascinating story of flight.

SIGNIFICANT TECHNOLOGICAL ADVANCES - 1951-1960

Although significant advances aimed at improving aircraft performance continued during this time period, increased emphasis was being given to the non-aircraft elements of growth and progress in the aircraft industry. For example, the application of electronics to aviation was beginning to have a substantial impact in improving the effectiveness and productivity of aircraft, and gave rise to a special field of technology known as "avionics". In addition, this time period produced significant advances in manufacturing technology and production methods. Twelve of these advances, representative of the variety of progress just mentioned, are considered major contributions to aviation in the decade of the Fifties.

- Advances in the Improvement of Aircraft Performance

The major advances of this time period that contributed to higher aircraft performance reflect the wide variety of options available for achieving increased capabilities. Two were in aerodynamic design - the area rule concept and the blown flap; one was in propulsion - the turbofan engine; and one was in structures - sonic fatigue testing.

Area Rule - One of the most significant aerodynamics discoveries of this period came from the laboratories of the NACA. Working to satisfy a military need for reduced aerodynamic drag in the transonic region, NACA engineers found that aircraft drag could be significantly reduced by indenting the fuselage to give it a "wasp-waist" or "coke-bottle" shape to produce a desired total cross-section area distribution throughout the full length of the airplane. Discovered and verified in 1952 by Whitcomb, the "area-rule" concept was followed in the design of such fighter planes as the Grumman F11F-1, which first flew in July 1954, and the Convair YF-102A, which flew in December 1954. It was also incorporated in the world's first supersonic bomber, the Convair B-58 Hustler, which flew in 1956. The first commercial application of this concept was to the Convair 990 in 1962. The "area-rule" concept has extensive potential application to future commercial transport aircraft.

Blown Flap - The concept of attaining very high lift by blowing air from rearward facing slots over the upper surface of a flap was not successfully used until the introduction of jet powered aircraft. The Navy requirement for low take-off and landing speeds for carrier operations proved to be the catalyst for this technology. Attinello's work on high-lift boundary layer control devices made practical the first blown flap. Applied experimentally to a Navy F9F-4 fighter in 1953, the blown flap has since been incorporated in such production aircraft as the Lockheed T2V (1954), the Lockheed F-104, the McDonnell F-4 and the North American A-3J. It also has been used experimentally on a Boeing 707 commercial transport. The use of power to augment flap effectiveness is expected to appear in civil aviation first on commuter type short haul aircraft.

Turbofan Engine - Another very significant event of this period that evolved from continuing advance in turbine engine technology was the development of the turbofan engine. Essentially, the turbofan is a turbojet engine in which additional thrust is obtained from the air that bypasses the engine and is accelerated by a fan in an enclosed duct. Advent of the turbofan permitted a variety of trade-offs in obtaining improved aircraft performance including larger aircraft, longer range, lower specific fuel consumption, shorter take-off distances, and quieter engine operation. In 1956 the first turbofan engine was assembled by Pratt and Whitney from military J-57 and J-75 engine components. This engine was further developed as the JT-3D, which was first used in the Boeing 707 in 1960, and then as the TF-33 in the B-52H in 1961. Development of a turbofan version of the J-79 was funded at General Electric by the Air Force. Commercial derivatives of this turbofan engine are used in the Convair 990 aircraft. It is interesting to note that the very first turbofan engine was the Packard XJ-49 built during 1943-1946. However, its development was terminated at that time for lack of a suitable application. Table 3 gives additional information on commercial/military engine derivatives and applications.

Table 3

Commercial Engine Derivatives of Military Engine Developments (Representative Listing)

MILITARY ENGINE			COMMERCIAL COUNTERPART			
DESIG-NATION	FIRST FLIGHT	AIRCRAFT	DESIG-NATION	FIRST FLIGHT	AIRCRAFT	NUMBER* BOUGHT
J-47	MAY 48	F-86, B-47	NONE	----	CERTIFIED ONLY	----
J-52	APR 60	GAM-77, A-4, A-6	JT-8A	FEB 63	JT-8D (FAN) 737, 727, DC-9	4501
J-57	APR 52	B-52, C-135, F-8, A-3, 100 SERIES FIGHTERS	JT-3C	MAR 58	707, DC-8	612
J-60**	JAN 60	C-140, T-39 T-2B	JT-12	FEB 60	JET STAR, SABRELINER	1180
J-75	MAY 56	F-105, F-106	JT-4A	NOV 58	707-320	660
J-79	JUL 57	F-104, F-4, B-58, A-5	CJ805-3	JAN 59	CONVAIR 880	366
J-85	JAN 59	GAM-72, T-38, F-5, T-2C	CJ-610	LATE 61	JET COMMANDER, LEAR JET	1139
TF-33	MAR 61	B-52H, C-141	JT-3D	JUN 60	707, DC-8	4060
TF-35	NONE	----	CJ805-23	JAN 61	CONVAIR 990	272
TF-37	NONE	----	CF-700	AUG 64	JET FALCON	697
TF-39	JUN 68	C-5	CF-6-6	AUG 70	DC-10	136
T-53	CIR.56	UH-1	T53L13	----	BELL 205	783
T-55	SEP 61	CH-47A	T-55L	----	VERTOL 114	63
T-56	DEC 56	C-130, P-3	501D-13	DEC 57	ELECTRA	2213
T-58	MAY 58	H-1, H-2 H-3, H-46 SERIES	CT-58	JUL 59	S-62, S-61 VERTOL 107	352
T-63	----	OH-6A, OH-58 OH-5A	250-C18	----	BELL JET RANGER HUGHES 500, HILLER FH-1100	2600
T-64	----	CH-53 SERIES	CT-64	----	SIKORSKY S-65	----
T-73**	----	CH-54 SERIES	JFTD-12	----	SIKORSKY S-64	78

* AS OF 15 FEB 1972 - INFORMATION PROVIDED BY ENGINE MANUFACTURERS.
** THIS WAS A COMMERCIALLY DEVELOPED ENGINE WITH MILITARY APPLICATIONS.

Sonic Fatigue Testing - Sonic fatigue damage results from structural vibrations caused by intense random noise. In the mid-1950s the sonic fatigue problem became serious enough to ground many B-52 airplanes for repairs. In 1956, B-52 sonic fatigue testing was accomplished, and in 1957 results of KC-135 tests were applied to the commercial Boeing 707 aircraft. Then a long range program was begun in 1958 to provide new design criteria for future airplanes. This technology has led to improved sonic fatigue resistant structures that have been beneficial in both military and commercial aircraft applications.

- Advances in Manufacturing Technology

During this time period, advances in manufacturing technology began to have significant impact on aircraft development. Two of these, both related to the increased size of aircraft structures and components, were the heavy press program and numerically controlled machines.

Heavy Press Program - The use of large capacity forging and extrusion presses has been one of the major advances in the "production" portion of the aviation story. In its search for better methods for the manufacture of aircraft structural members, in larger quantities at lower cost, the Air Force established the heavy press manufacturing technology program in 1951. By 1958, four new forging presses were constructed in sizes up to 50,000 tons, and seven new extrusion presses were developed with capacities up to 14,000 tons. The heavy presses were first used to manufacture parts for the B-52 in 1954, and for the Lockheed Electra in 1956. These presses have proven to be invaluable as the only way to produce the large plan-area components of high strength titanium and steel that are essential to the production of modern military and commercial aircraft.

Numerically Controlled Machines - Numerically controlled machining is one of the very important capabilities in industry that largely has been made possible by the manufacturing technology programs of the DoD. Today the process is used in 70 percent of the milling metal removal accomplished in aircraft manufacturing and makes possible the fabrication of fully integrated members that would not be feasible otherwise. Large solid pieces can be cast and subsequently machined for such areas as main wing beams, variable sweep-wing pivots, and landing gear.

Since there are no joints in these pieces, weight is substantially reduced. The machines also eliminate the need for templates and extensive mechanical drafting by hand. The first military contract to establish a numerical control system was awarded in 1951. Numerically controlled milling was applied to piston aircraft in 1956.

- Advances in Avionics

Three representative examples of the rapid progress being made in avionics during this period included such major achievements as inertial navigation, development of the airborne digital computer, and the first use of a satellite for communications.

Inertial Navigation - Air Force interest in a non-radiating, self-contained navigation capability to satisfy military mission needs resulted in the development of the Space Position Inertial Reference Equipment (SPIRE) system by MIT in 1953. Then, in the years that followed, the military sponsored development of the Litton series of medium accuracy, small, lightweight inertial navigation systems for the E-1, A-6, P-3, and F/RF-4C aircraft. The first of these systems was used in 1963. Also, in 1963, Pan American Airways installed a Litton system in a DC-8 for a 500 hour FAA-sponsored test program. This was followed in 1965 by a test program using the same system coupled with an improved computer. Next came the design and procurement of over 100 Sperry commercial inertial navigation equipments for installation in the 707 aircraft as an additional navigation aid. Although these were withdrawn from service in 1968 because they did not meet FAA accuracy specifications, they did form the basis for the Delco and Litton inertial navigation systems presently installed in the 747 aircraft.

Airborne Digital Computer - The inertial navigation system is highly dependent upon its associated computer. In 1957, the first general purpose airborne digital computer was developed as part of the Hughes fire control system for the F-106. The same year also marked the beginning of the development of the Autonetics solid-state computer and digital differential analyzer for the Hound Dog missile, as well as the first Librascope solid state general purpose digital computer for airborne use. This computer was tested on C-131s and became operational on the C-141. The first commercial use of an airborne digital computer was in conjunction with the inertial navigation equipment described above.

Communications Satellite - The use of satellites for communication purposes has permitted a global capability and coverage not otherwise attainable. The first demonstration of this use occurred in 1958 when the Presidential Christmas message was broadcast to the world from an orbital vehicle. This was accomplished as part of the ARPA-Air Force Project Score. During 1960-1961, point-to-point communication was demonstrated with the ECHO satellite, and then satellite relay of television transmission was first demonstrated with TELSTAR in 1962. Military use of satellite communications occurred in 1966, with launch of the pioneering Initial Defense Communication Satellite Program. This system was comprised of eight satellites which formed a belt around the earth at an altitude of 18,000 nautical miles.

- Advances in Flight Operations

During the Fifties technological advances continued to be made to improve further the reliability and safety of flight operations. Three of the most significant were computerized flight plans, the digital flight simulator, and weather satellites.

Computerized Flight Plans - Long range military flights require global weather coverage and accurate up-to-date weather information. Consequently, numerical weather prediction techniques, using electronic computers, were developed under a national program and became operational in 1954. The Air Weather Service expanded these techniques to develop computerized flight plans that incorporated meteorological data in flight weather reports. In 1959, the first operational testing of computerized flight plans began during transatlantic flights of C-118 aircraft. Extension of this program, to include fuel and aircraft performance factors as a function of predicted weather conditions, provided military aircrews fast and accurate flight planning information. By 1964, several thousand military computer flight plans were issued monthly. The value of these flight plans was recognized by civil aviation, and the National Weather Service now provides meteorological data to 13 private processors who, in turn, produce computerized flight plans for approximately 150 customers, including U.S. and foreign air carriers. First operational use of computerized flight plans by commercial air carriers occurred in 1961.

D

Digital Flight Simulator - A major advance in the use of simulators for pilot training and proficiency improvement occurred in 1960 when the University of Pennsylvania developed a digital flight simulator for military use. The simulator had two cockpits, one for an F-100 and one for an F9F, either one of which could be operated from the central computer. This development established the feasibility of real time digital simulation, using six degrees-of-freedom flight equations. All flight simulators developed over the next decade were based on this approach. The first commercial use was in a Boeing 727 simulator built by Link for Eastern Airlines and delivered in 1963.

Weather Satellites - A new era in the meteorological support of flight operations began in 1960 when TIROS I, the first weather observation satellite, was launched. Data from this satellite had immediate use in both military and commercial aviation. Although some of the original R&D had been accomplished under DoD sponsorship, responsibility for weather satellites was transferred to NASA in 1958. To date, twenty-two meteorological satellites have been launched, and NASA now has three R&D efforts for improving meteorological satellites, including the NIMBUS program. Weather satellites provide the aviation meteorologist with a unique observing tool to identify developing atmospheric storms over international routes. Through meteorological analyses, the early identification of flight hazards and the timely diversion of aircraft around affected areas can be accomplished.

SIGNIFICANT TECHNOLOGICAL ADVANCE SUMMARY - 1951-1960

All of the major technological advances of this time period were sponsored by the Government, again largely by the military. Time lags to use averaged just under three years for the military, and were reduced during this period to just over five for civilian aviation. This reduction on the civilian side might be traceable to the fact that most of the advances in this period were not airframe or engine oriented, and thus not safety of flight matters, but rather were in the areas of support systems and equipment and in manufacturing technology and techniques. Table 4 summarizes the date, sponsor and use data presented in the advance discussions.

Table 4

Significant Technological Advances - 1951-1960

ADVANCE	DATE	SPONSOR	USER	
			MIL	PVT SECT
HEAVY PRESS PROGRAM	1951	GOVT MIL	1954	1956
NUMERICALLY CONTROLLED MACHINES	1951	GOVT MIL	1956	1956
AREA RULE	1952	GOVT CIV	1954	1962
BLOWN FLAP	1953	GOVT MIL	1954	-
INERTIAL NAVIGATION	1953	GOVT MIL	1963	1967
SONIC FATIGUE TESTING	1955	GOVT MIL	1956	1957
TURBOFAN ENGINE	1956	GOVT MIL	1961	1960
AIRBORNE DIGITAL COMPUTER	1957	GOVT MIL	1957	1967
COMMUNICATIONS SATELLITE	1958	GOVT MIL	1966	1962
COMPUTERIZED FLIGHT PLANS	1959	GOVT MIL	1959	1961
DIGITAL FLIGHT SIMULATORS	1960	GOVT MIL	1960	1963
WEATHER SATELLITES	1960	GOVT CIV	1960	1960

AMERICAN AVIATION - 1961-1972

GROWTH AND PROGRESS

The period since 1961 has been greatly influenced by the pervasive effects of the struggle in Southeast Asia. Perhaps the most significant benefit to civil aviation that might derive from military air operations in Vietnam is the increased experience with helicopters gained by the Army and Marine Corps, and the resulting helicopter technology advancements. The outstanding success of the helicopter in Vietnam as a supply transport, troop carrier, communications vehicle, and utility transport is paving the way for new and extensive civil applications.

Other significant influences of the period on American aviation are the results of the effort to place astronauts on the moon; the growth of aircraft industries in foreign countries; and the impact on aviation of the noise, pollution and congestion issues of the day.

The end of the period finds several military aircraft in development, including the F-14 fleet defense aircraft, F-15 air superiority fighter, A-X close support aircraft, B-1 strategic bomber, and S-3A anti-submarine warfare aircraft.

In addition, advanced prototype developments underway or proposed are the Lightweight Fighter, Advanced Medium STOL Transport, and a V/STOL strike aircraft for the Navy's Sea Control Ship. Prototyping has been reinstituted as a method for military aircraft development. The program eventually should provide a variety of demonstrated hardware options that are readily available for further development and possible production, and should assist in maintaining industry design team continuity and the aviation industrial base.

During this period the XB-70 flew; and the F-111 swing-wing tactical fighter, the SR-71 high altitude strategic reconnaissance aircraft, the A-7 attack airplane, the C-5 transport, and other aircraft were developed. *Commercially, the wide-bodied and large jet airliners were introduced, and supersonic transports were built. The latter, of course, were not U.S.*

Approximately the same number of aircraft were produced in the U.S. in 1970 as in 1960 - some 10,000 - and the vast majority of the world's airliners still were of U.S. manufacture. By 1970, U.S. domestic and international airliners were up to 130 billion passenger -revenue miles - a threefold increase over 1960, and U.S. airlines now had achieved a level of safety, measured in terms of fatalities per 100 million passenger miles, comparable with, and perhaps better than, that of motor buses and railroads - approximately a hundred-fold improvement in three decades. However, signs were pointing to softness in production and sales, and to declines in profits.

Thus the period of the Sixties became one of transition and change, though the search continued for the advances that would make improved effectiveness and productivity possible.

SIGNIFICANT TECHNOLOGICAL ADVANCES - 1961-1972

During this period, the significant advances may be grouped in the areas of airframe design and materials, flight controls, and avionics, as well as those of V/STOL and STOL performance, and improved operating economy.

- <u>Advances in Airframe Design, Materials and Propulsion</u>

Two of the four major advances of this period in design, materials and propulsion involve innovations in the aerodynamics of wing design; another relates to the development of new strong lightweight material - advanced composites; and the fourth is the most recent in the turbine engine story - the high-bypass-ratio-turbofan.

<u>Single-Pivot Variable-Sweep Wing</u> - The theoretical advantages of variable-sweep wings to accommodate efficient flight at both high and low speeds were not fully realized until the single-pivot variable-sweep wing was developed. This concept was conceived by NASA, and was first incorporated on the General Dynamics F-111 aircraft in 1965. Although superior to earlier variable-sweep wing designs, the construction of the pivot assembly involved extremely critical design, manufacture, inspection, and testing considerations. The Navy F-14 aircraft also incorporates this variable-sweep design feature.

<u>Supercritical Wing</u> - The concept of the supercritical wing was originally developed by NASA and investigated by wind tunnel tests. The aerodynamics of the supercritical wing improve transonic flight by increasing the drag rise Mach number for a given wing thickness ratio. Flight tests on modified Navy T-2C and F-8 airplanes were initiated in 1970, and now an Air Force F-111 is being modified to evaluate maneuverability improvements of the supercritical airfoil to variable-sweep wings. Application of this concept is considered probable in future long haul civil transport aircraft.

<u>Advanced Composites</u> - The requirements for exceptionally high strength- and stiffness-to-weight ratio materials for higher performance aircraft led the Air Force to initiate an extensive advanced composites program in 1961. These are materials which are comprised of high strength fibers, such as those of boron and graphite, which are dispersed in plastic resin and metal matrices. Composite materials have provided significant weight reduction

where used in the airframes and engines of such military aircraft as the F-4, F-14, F-15, F-111, and CH-47. In 1969, 25 boron F-4 rudders were obtained for the initial service flight test of advanced composites. Use of these new materials in commercial airliners has not yet occurred though the probability for such use, perhaps by the middle or end of the decade, is very high.

High-Bypass-Ratio-Turbofan - High-bypass turbofan engines were developed and applied initially to meet Air Force C-5 requirements. This type of engine permits over 40,000 pounds of takeoff thrust at weights not appreciably greater than turbojets of half this thrust, with better fuel consumption, and with substantially lower noise and pollution characteristics. During the competitive contract definition phase of this program, the Air Force invested at least $30 million in the development of the Pratt and Whitney JTF-14. This engine then formed the direct base for the JT-9D turbofan engine which was used in the Boeing 747 in 1970. The General Electric TF-39 engine, which was used on the C-5A aircraft in 1968, also has a commercial equivalent, the CF-6, which powers the commercial DC-10.

- Advances in Flight Controls

Two major advances during this period in the area of flight controls were those of load alleviation and mode control, and fly-by-wire. More importantly, perhaps, the work leading to these advances is currently being extended and may result in an advanced active digital flight control system that will integrate stability augmentation, ride quality, load alleviation and mode suppression, and other flight control functions into a single system. Application in the design phase of a new aircraft could produce significant weight and drag savings and be translated into more range, payload, speed, maneuverability, operational life, and other desired qualities.

Load Alleviation and Mode Control - The first major program to establish the feasibility of actively controlling aircraft structural responses for load alleviation and mode suppression was begun by the Air Force in 1965, under the title "Gust Alleviation and Structural Dynamic Stability Augmentation System." This refers to the incorporation of properly located control surfaces that respond to local accelerations induced by turbulent air and smoothen the aircraft riding qualities. Primary emphasis was to show ride improvement and gust load alleviation for the low altitude, high speed strategic bomber penetration mission. In 1966, an advanced development program called "Load Alleviation and Mode Stabilization" (LAMS) was initiated. A flight test program of a B-52 equipped with the LAMS system demonstrated a 50 percent reduction in fatigue damage rate due to turbulence encounter. In 1971, modification of the B-52G and H fleet was begun to mark the first intentional use of the automatic control system to resolve problems resulting from structural response. The Lockheed 1011 commercial transport already has incorporated a direct lift control system that is directly traceable to the LAMS demonstration. Previous direct lift control devices had been developed by Douglas for the A3D and by Vought for the F-8.

Fly-By-Wire - A new concept in flight control is fly-by-wire, in which an electrical signal path, rather than mechanical connection between the cockpit controller and the control surface actuator, is used for primary flight control. This control technique, particularly when redundancy is important for survivability or reliability purposes, permits significant weight savings and simplicity in design. A single-axis (pitch) fly-by-wire system was flight tested by the Air Force in a B-47 in the 1967-1969 period. Beginning in 1970, further work, soon to result in C-141 flight tests, was accomplished, and additional important development and demonstration efforts were established. An Air Force survivable flight control program also is underway to demonstrate a quad-redundant three-axis fly-by-wire capability in a YF-4E aircraft. In addition, NASA has a fly-by-wire program directed at developing and demonstrating the application of reliable and low cost digital flight control systems to advanced civil aircraft. Initial flight tests, to begin in 1972, will help establish the feasibility of a single-channel digital fly-by-wire system using modified Apollo spacecraft equipment installed in an F-8C aircraft. A related Active Controls Technology program will provide design criteria and integrated design approaches to permit the application of these concepts to commercial transport aircraft.

- Advances in Avionics

Advances in avionics continue to provide for improvements in all phases of aircraft operation. Some of the most significant during this period were those in microelectronics and the airborne phased-array radar.

Microelectronics - The drive to reduce the weight, volume, and power requirements of electronic equipment has provided the stimulus for the miniaturization of this equipment through the development of microelectronics. The integrated circuit, for example, was announced early in the Sixties, and the industrial base for the development, application, and production of integrated circuits can be traced to two military contracts which first demonstrated production processes for these circuits in 1961. By 1963, the inertial navigation system for the Air Force F/RF-4C contained integrated circuits. In 1970, integrated circuit sales by U.S. industry were $887 million according to statistics published by the Department of Commerce. Today, integrated circuits are finding many applications in both military and civil aviation, including computers, altimeters, autopilots, displays, and communications equipment. The Boeing 747 has electronic equipment containing integrated circuits.

Airborne Phased-Array Radar - The Air Force and Navy both have sponsored substantial development effort in the area of airborne phased-array radar technology in the effort to acquire multi-mode radars that are capable of performing such multiple functions as terrain following, fire control, and weapon delivery. The components and other technology developed for electronic beam forming, scanning, and processing have possible future application to air traffic control and landing systems for use at high traffic density terminals. In 1965, the Air Force initiated effort to develop Radome and Radio Frequency (RARF) components for airborne phased-array radar applications, and flight tests were begun in 1970. Also starting in 1965, a phased-array antenna was built by Maxson Electronics for the Navy. It was flight tested in 1969. Another pioneering effort of the Air Force was the Molecular Electronics for Radar Applications (MERA) phased-array development, which demonstrated the solid state active element concept. Operational applications of this type of radar are expected in the near future.

- Advances Applicable to V/STOL Aircraft

This period saw high interest in both short takeoff and landing (STOL) and vertical takeoff and landing (VTOL) aircraft by all of the Services. Two of particular significance have been the V/STOL research aircraft and advanced blown flap program.

V/STOL Research Aircraft - Several experimental design approaches for V/STOL airplanes have been studied, and many experiments conducted, since the late 1950s. These efforts reached fruition in the tri-service experimental V/STOL Aircraft Program of the early 1960s. Three aircraft were developed: the LTV XC-142A tilt wing airplane which flew in 1964; the Curtiss-Wright X-19A tilt propeller airplane which also flew in 1964; and the tilt-ducted propeller Bell X-22A, which flew in 1966. Further studies and experiments have continued since that time. In addition, the U.S. Marines have introduced the British Hawker-Siddeley AV-8 Harrier vectored jet V/STOL airplane into operational use as a close support aircraft. The application of V/STOL concepts to high performance military fighters, fighter bombers and transports may permit very significant advantages in operation from austere and relatively unprepared and short forward airstrips, from carriers, or from any location where standard runways are not available, feasible, or desired. Significant commercial application may be in the short-haul area, either high density or low density, where the runway and runway location considerations are of major interest.

Advanced Blown Flaps - In the early 1970s, work was initiated by NASA and the DoD to develop advanced blown flaps and a powered-lift technology base for the design and operation of civil and military fan-jet STOL transports that would be safe, quiet, efficient, and have low pollutant emissions. A NASA C-8 aircraft is now being modified in a joint program supported by the Canadian Government. This aircraft will have an augmentor wing powered high-lift system for STOL proof-of-design and handling qualities flight tests. In addition, the externally blown flap concept will be evaluated in the planned NASA Quiet Experimental STOL Research Airplane (QUESTOL) Program and the Air Force Advanced Medium STOL Transport (AMST) advanced prototype program that has been proposed.

- Advances in Flight Operations

Two significant technological advances of this period contributed to the safety and efficiency of flight operations. These were the development of cold fog dissipation techniques and the navigation satellite.

Fog Dispersal - Delays due to weather cause great expense to airline operations and inhibit the full effectiveness of military air operations. Therefore, efforts have been made to modify various types of undesirable weather conditions. In the northern sections of the United States, cold fog has caused the delay, diversion, or cancellation of numerous scheduled airline flights. This has resulted in a considerable annual economic loss and, consequently, United Airlines developed the first cold fog dissipation system in the U.S. during the 1963-64 time period, dispersing crushed dry ice from light aircraft. This airborne system proved successful and today many other airlines and airports now share in the cost for this type of weather modification. In 1967, the Air Force also adopted this airborne system seeding technique. Using WC-130 aircraft, this cold fog dissipation capability is now operational at ten Air Force bases in the United States and Europe. The first ground-based system for cold fog dissipation was developed by the Air Force and initially used at Fairchild AFB, Washington, using liquid propane dispensers. Disruptions caused by the cold fog portion of the weather problem have greatly decreased through the use of these systems.

Navigation Satellite - An outstanding example of the application of space systems and technology to aeronautical use is the navigation satellite. In 1964, a low altitude orbital Doppler experiment in a polar orbit led to the Navy TRANSIT navigation satellite system, which is still operational today. In 1968, concept definition studies were begun for the advanced Air Force 621B navigation satellite system. These studies resulted in definition of equipment and experiments. Also in 1968, Army effort was initiated to study the establishment of common grid navigational compatibility to tactical aircraft and ground forces. From these efforts a new system with a wide variety of military, and possibly commercial, applications is expected.

SIGNIFICANT TECHNOLOGICAL ADVANCE SUMMARY - 1961-1972

The date, sponsor and user data for the most significant advances of the Sixties are summarized in Table 5. Again, almost all of the advances are Government sponsored, primarily military. The table also shows that many of the advances have not yet found application in operational use. This normally would be expected because of the time needed for testing and refinement. For those advances that have been incorporated into operational aircraft, the time lag has been three years for military aviation and just over three and one-half years for the private sector.

Table 5

Significant Technological Advances - 1961-1972

ADVANCE	DATE	SPONSOR	USER	
			MIL	PVT SECT
ADVANCED COMPOSITES	1961	GOVT MIL	1969	-
MICROELECTRONICS	1961	GOVT MIL	1963	1969
FOG DISPERSAL	1963	PVT SECT	1967	1963
NAVIGATION SATELLITE	1964	GOVT MIL	1964	-
V/STOL RESEARCH AIRCRAFT	1964	GOVT MIL	-	-
AIRBORNE PHASED-ARRAY RADAR	1965	GOVT MIL	-	-
SINGLE-PIVOT VARIABLE-SWEEP WING	1965	GOVT MIL	1965	-
LOAD ALLEVIATION AND MODE CONTROL	1965	GOVT MIL	1971	-
HIGH-BYPASS TURBOFAN	1967	GOVT MIL	1968	1970
SUPERCRITICAL WING	1970	GOVT JOINT	-	-
FLY-BY-WIRE	1970	GOVT MIL	-	-
ADVANCED BLOWN FLAPS	1970	GOVT CIV	-	-

TECHNOLOGICAL ADVANCE REVIEW

A review of the significant technological advances in aviation that have been identified and described in this section of the report shows that there are approximately the same number of advances, and approximately the same rate of advances per year, for all of the time periods, as shown in Table 6. The period including World War II contains the greatest number of advances per year, indicating the effects of the large wartime effort directed to air power.

Table 6

Rate of Technological Advances

TIME PERIOD	NUMBER OF ADVANCES	ADVANCES PER YEAR
1925-1940	14	0.9
1941-1950	13	1.3
1951-1960	12	1.2
1961-1972	12	1.1
	51	

Further analysis of these same advances with respect to whether the first action is creditable to Government or private sector sponsorship (source of funding) is shown in Table 7.

Table 7

Sponsorship of Technological Advances

TIME PERIOD	GOVERNMENT MILITARY	GOVERNMENT CIVIL	PRIVATE SECTOR	TOTAL
1925-1940	7 (50%)	3 (21%)	4 (29%)	14
1941-1950	9.5 (73%)	2.5 (19%)	1 (8%)	13
1951-1960	10 (83%)	2 (17%)	0 -	12
1961-1972	9.5 (80%)	1.5 (12%)	1 (8%)	12
TOTAL	36 (70%)	9 (18%)	6 (12%)	51

Since World War II, the military has been the unquestioned leader in the sponsorship and use of technological advances in *aviation. This has resulted from the demands of the defense mission and the need to maintain aeronautical system superiority.*

In the data, equipment, and components area, where there usually is relatively low risk in application, where safety of flight is not a problem, and where financial investment is relatively low, application of technological advance has been rapid, usually within one to two years for the advances studied. The application of advances in this area also is strongly influenced by the consideration of economics.

The application of major airframe and engine advances has been somewhat slower. Here, all of the many kinds of risks are at work, and users, particularly those in commercial aviation, wait for the completion of long periods of development, test and evaluation. Some examples are the introduction of the jet engine - 1 year to military first use, 3 years to commercial use; swept wings - 2 years military, 9 years commercial; and titanium - 5 years military, 7 years commercial.

Table 8 reflects the time lag to use for all of the advances discussed in this section.

Table 8

Average Time Lag to Use

TIME PERIOD	MILITARY	PRIVATE SECTOR
1925-1940	2.79	3.57
1941-1950	3.46	8.10
1951-1960	2.91	5.36
1961-1972	3.00	3.67
OVERALL AVERAGE	3.04	5.17

In regard to the time lag between military and civilian achievement of a given level of overall aircraft performance, the data shown in Figure 1 is of interest. Originally cited by Lenz*, this data shows a clear "lead-trend" relationship of military fighter and bomber speeds to civil transport aircraft speeds. The divergence in the transport speed trend shows the difference between subsonic and supersonic aircraft.

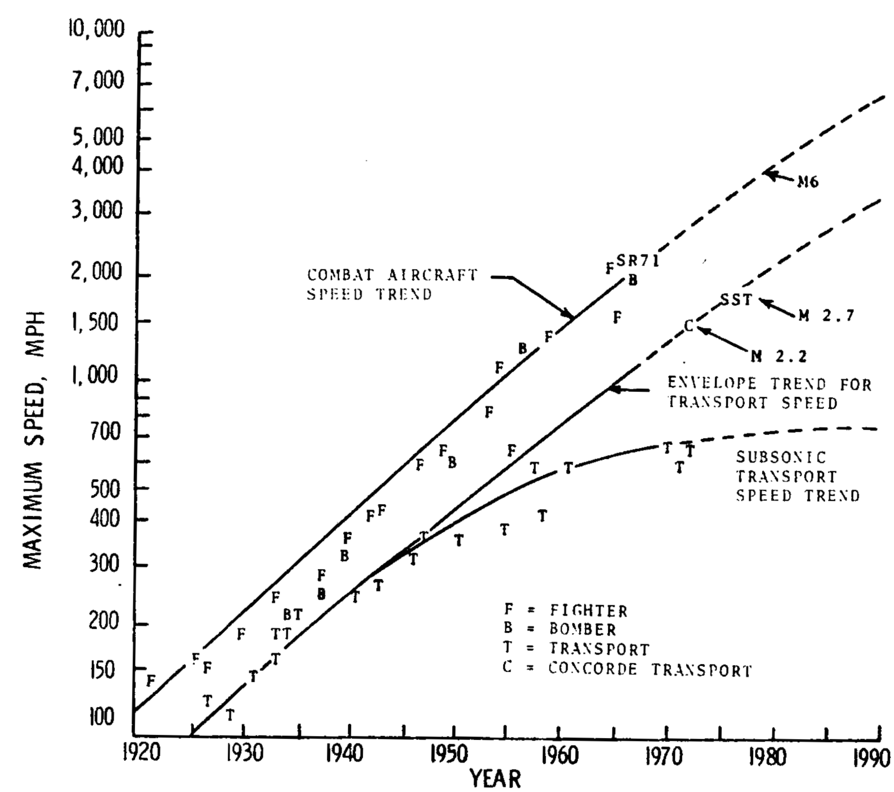

Figure 1 - Speed Trends of Aircraft

As shown in the Figure, as the military quest for faster combat aircraft pushed maximum speeds ever higher, there was an increasing time lag to the attainment of comparable speed by transport aircraft. Not only was the higher transport speed

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* Originally cited by R. C. Lenz, Jr., in "Technological Forecasting," ASD-TDR-62-414, Aeronautical Systems Division, AFSC, June 1962, with revision to include subsonic transport trend data, March 1972.

progressively more difficult and expensive to achieve, but it also was not considered so important a performance parameter to transport aircraft as it was to combat aircraft. The step of using jet engines for transport aircraft in the late Fifties improved the time lag somewhat, but it quickly lengthened again. With the advent of supersonic transports such as the Anglo-French Concorde and the Soviet TU-144, another step change in this relationship appears at hand.

OBSERVATIONS

Several important summary observations can be derived from the foregoing historical discussion of aviation progress and the significant technological advances that have been made in aviation since 1925.

● *First, U.S. aviation really began to grow and prosper during the late Twenties.* A large number of early advances, primarily airframe and engine oriented, were stimulated by civil aviation needs, but nearly all were influenced by the work, research, and experimentation of Government agencies.

● *Second, military sponsorship and first use have characterized most of the significant technological advances that have been made since the beginning of World War II.* This has resulted from the priorities and R&D needs associated with the DoD mission of developing qualitatively superior aerospace systems for the defense of the Nation.

● *Third, military research, development, test, and evaluation usually have provided the basis for the acceptance and use by civil aviation of technological advancement.* The jet airliner is probably the best example of the civilian application of a military sponsored research, development, and production base.

● *Fourth, aviation progress has many contributors.* Several advances have had their basic origins in foreign countries, with the U.S. exploiting them in further development and use. Technical disciplines and sciences in many areas have been involved, such as those in meteorology, human factors, and aviation medicine that are often not considered. In addition, Government non-defense agencies, whether the need has developed from military or civilian aviation sources, have been important contributors to the progress that has been achieved.

● *Fifth, several very significant new factors and considerations are beginning to influence the progress of aviation and the* *technological advances that may be expected.* These include the rapidly rising costs of research and development, the impact of public concern for the environment, the challenge of foreign competition to U.S. civil transport aviation, and a changing and evolving military threat.

- *Finally, recent advances show a trend to total system considerations in growing recognition of the fact that the aircraft itself is only one part of a larger capability problem.* The military has pioneered in this area of integrated system design, and now civil aviation is adopting a similar approach.

SECTION IV

MILITARY RESEARCH AND TECHNOLOGY PROGRAM RELEVANCY TO CIVIL AVIATION R & D NEEDS

This section summarizes civil aviation R&D needs, as identified in the recently completed Joint DoT-NASA Civil Aviation Research and Development (CARD) Policy Study, as well as the current and planned military research and technology efforts that provide relevant contributions to these needs.

CIVIL AVIATION R&D NEEDS

The major problems of civil aviation that require increased emphasis and high priority R&D programs are noise abatement, relief of congestion in areas of high traffic density, and low density short-haul transportation. Additionally, there are other problems that are very important to the future of civil aviation, especially those relating to long-haul transportation, air pollution, air cargo, and the broad technology base supporting all of the needs.

NOISE ABATEMENT

Aircraft noise abatement has been assigned the highest priority because of widespread public concern for the environment and because the success of the noise abatement program will affect the solutions to other problems. The need for noise abatement research and technology will continue until aircraft noise is no longer a matter of military or public concern.

Solution of the noise problem will require balanced and comprehensive R&D programs designed to include research in psychoacoustical phenomena, basic noise generation mechanisms, and quiet engine technology; the reduction of noise generated at the source through improved design of aircraft and engines; the optimization of the flight path of aircraft through use of steep descent and curved approaches; and the development of better planning and control for use of land adjacent to airports.

CONGESTION

Congestion is next on the list of priority problems. It is very complex and involves the airways, air traffic control, and airport *terminals*. Its solution will involve an organized effort directed at air traffic control, runway capacity, ground control of aircraft, terminal processing, access and egress, parking, and airport acquisition and development. The airways system should be upgraded to increase both capacity and safety, as well as to bring rising operating costs under control.

A new short-haul system, separated as much as possible from the present long-haul system, could help relieve congestion at existing airports, especially those in areas of high traffic density. A contender for this new system could be one making use of STOL aircraft. The CARD Study suggested the use of several airports as R&D tools for demonstration and experimental purposes related to alleviating terminal congestion. Areas of emphasis would include off-site passenger and cargo processing, automated passenger processing, aircraft ground control, and alternate procedures to set takeoff and landing priorities.

LOW DENSITY SHORT-HAUL TRANSPORTATION

Although lower in priority than noise and congestion, solutions to the problems of low density short-haul service will be important to the future of civil aviation and to its ability to contribute to the goals of the nation. Increased R&D and other actions will be necessary in order to obtain better solutions to the problems.

Studies should be conducted to examine possible design concepts for low density, short-haul aircraft. A combination of these studies and market experiments could lead to the definition of an aircraft which would have the capacity, economics and performance characteristics to best serve the low density markets.

LONG-HAUL TRANSPORTATION

The long-haul market has long been the backbone of the U. S. civil transport aviation industry. Constant improvements in technology for long-haul vehicles and their propulsion systems are essential to continued U. S. leadership in this field. Included would be programs related to supersonic transports. If R&D can help remove objections to these vehicles, they offer the promise of increased productivity, especially for international routes. Important areas would include research to reduce noise and a sharply focused program to assess upper atmosphere pollution.

AIR POLLUTION

Another area requiring continued attention is pollution from engine exhaust emissions. Jet aircraft produce only about one-seventh of the pollution per passenger-mile when compared with automobiles. With the growth predicted for civil aviaton in the future, however, this level may not be acceptable, and intensified R&D in engine cycles and fuels will be required if this problem is to be alleviated.

AIR CARGO

Although the air cargo area also is important to the future of civil aviation, the Government's role for the present could become primarily one of setting standards and assuring safety. In accepting the responsibility for standards and safety, it would be important for Government to sponsor the R&D necessary to discharge this obligation effectively.

BROAD-BASE TECHNOLOGY

A general finding of the CARD Study was that the varied problems of civil aviation require broad-base programs in research and development, including increased emphasis on non-physical sciences such as economics and sociology.

Such programs would include: (a) systems engineering, simulation, and trade-off studies of new concepts for air traffic control and airport design; (b) improving the accuracy and increasing the applicability of aerodynamic theory; (c) aircraft configurations suitable for both the long- and short-haul markets and incorporating advanced technologies such as new VTOL and STOL concepts and supercritical aerodynamics; (d) improved engine cycles to minimize noise generation, increase thrust-to-weight ratio, and reduce specific fuel consumption; and (e) improved structural concepts, materials, and fabrication techniques to reduce the structural weight fraction and thereby permit greater payloads and longer ranges for advanced aircraft.

Broad-base technology programs would produce the technology necessary to solve the varied problems of civil aviation, to allow civil aviation to achieve its full potential, and to provide options for future developments. As always, research and technology programs would be necessary in several basic disciplines, including avionics, communications, aerodynamics, propulsion, structures, human factors, and applied mathematics.

MILITARY RESEARCH AND TECHNOLOGY PROGRAMS RELEVANT TO CIVIL AVIATION R&D NEEDS

This section summarizes many of the current and planned military aeronautical research and technology programs that relate to the R&D

needs of civil transport aviation described above. Specific references to the programs of other Government agencies are included when such efforts reflect joint programs or when direct interfaces are involved.

As stated previously, the CARD Study report was used as the source document for identification of the needs. Although the CARD Study was accomplished during the period when the Supersonic Transport (SST) was an approved program, and the results and priorities might change somewhat if the CARD Study were updated today, it is not believed that this would affect to any extent the manner in which military research and technology program relevancy has been determined.

However, one significant difference does exist between the structure of the CARD Study of civil aviation R&D needs and the RADCAP discussion of these needs. In the CARD report, high density short-haul transportation was considered part of the congestion problem. In this report, however, the military R&D programs relating to low density and high density short-haul transportation are both treated in an overall review of short-haul transportation.

MILITARY RESEARCH AND TECHNOLOGY RELEVANT TO NOISE ABATEMENT

The DoD has long been active in noise abatement to provide a safe working environment for ground and flight crews, to alleviate the problem of acoustically induced structural fatigue, to reduce the possibility of aural detection during combat operations, and to improve the general community environment around military air bases. Now, as in civil aviation, the DoD is emphasizing consideration for public concern, and the improvement of the noise environment around military air bases, as important tasks in its noise reduction program.

- The Army, Navy, and Air Force are major participants in the Interagency Aircraft Noise Abatement Program under the leadership of the Department of Transportation (DoT). The broad goal of this program is to achieve maximum reduction in aircraft noise by optimizing the noise reduction potential from each element of the system - vehicles, methods of operation, and associated land use strategies.

- In addition, Army development efforts are directed at helicopter noise reduction and quiet propulsion for light aircraft. These programs are considering both engine and aerodynamic noise. Helicopter investigations include the study of rotor noise generation and propagation, and experimentation with alternative techniques for noise elimination and suppression.

• Acoustic efforts within the Navy include quiet propulsion development for V/STOL aircraft. The Navy is also conducting R&D programs related to the noise environment of an aircraft carrier.

• The Air Force is conducting research for determining basic noise generation mechanisms, developing noise suppression techniques and quiet engine technology, and investigating sonic boom propagation. In addition, the Air Force is conducting basic research and developing equipment to aid in evaluating the effects of noise. Related efforts are directed to the effects of noise on surroundings, the development of more refined noise impact criteria, the psycho-acoustic impact of noise, and land use planning techniques. Finally, a planned Air Force development program for the Advanced Medium STOL Transport engine will be directed to meet Federal Aviation Regulation (FAR) 36 noise standards.

• The modification of the aircraft flight path to reduce the noise level in ther terminal vicinity is another method of reducing the aircraft noise impact on noise-sensitive areas. All three of the military services are participants in the National Microwave Landing System (MLS) Program. This system will aid in noise abatement and congestion reduction by allowing new flight profiles, greater traffic density, and more efficient operational procedures.

In summary, DoD efforts in noise abatement are extensive and largely have been directed to the solution of operationally oriented problems. Current programs, however, reflect an increasing attention to public concern over noise and the environment.

MILITARY RESEARCH AND TECHNOLOGY RELEVANT TO AIR POLLUTION

Another environmental problem requiring attention is air pollution. Early military interest in reducing engine exhaust emissions was directed to the elimination of contrails and smoke in order to reduce the probability of visual detection of combat aircraft. Current investigations are concerned with developing solutions that will reduce both visible and invisible pollutant emissions.

• The Climatic Impact Assessment Program (CIAP) was undertaken by several Government agencies under DoT leadership. This program will conduct a complete assessment of the impact of supersonic, high altitude aircraft operations on the atmosphere. Engine testing and the modeling of atmospheric physics will be the primary contributions of the Navy and Air Force.

• The Air Force also has a program with the Atomic Energy Commission to identify and document by high altitude photography the locations, dimensions, and diffusion of atmospheric pollutants. Other

Air Force work includes the development of short length/high heat release combustors, an investigation of the feasibility of using catalytic combustors, and a program to employ laser spectroscopy in developing an instrumentation system which will identify specific pollutants under dynamic conditions on a real-time basis, and be packaged in a mobile unit.

- The Navy has a study of several systems to control emissions from jet engine test cells, and has a prototype system under construction. This system is expected to remove 99 percent of the particulate matter from engine test cell emissions. Navy interest in smokeless operation led to development of smokeless combustor cans which have greatly reduced visible emissions from jet engines. These cans are now being installed by civil transport airlines. By fiscal year 1976, all Naval combat aircraft are expected to be equipped with smokeless combustors.

- The efforts of the Army are directed to the unique problem of small gas turbine combustors. The objective is to determine the best design approach for small gas turbine combustors with low mass emissions.

DoD activities and funding levels relevant to alleviation of the air pollution problem are comparable to those of other Government agencies involved. More significantly, an upward trend in both is perceived, in growing recognition of the environmental problem.

MILITARY RESEARCH AND TECHNOLOGY RELEVANT TO CONGESTION

Congestion, as it applies to aviation, is a very complex problem that requires coordinated efforts directed at both airways and airports. Although the military does not conduct R&D programs specifically aimed at congestion, many of the issues related to airway operations and commercial high density short-haul systems will benefit directly from military research and development programs in flight control, navigation, and landing systems.

Airways Congestion

The crux of all airway operations is the Air Traffic Control (ATC) System that contains surveillance, communications, navigation, and weather service functions. Although military programs are directed to tactical situations, such as forward areas and aircraft carriers, there should be spin-off benefits to civil aviation in both the hardware and operational data areas.

- The National Microwave Landing System development involves all three of the military services, and the final system selected for use is planned to be compatible with both civil and military operations. The effort will not only help to alleviate congestion of airways and terminal areas, but it will also permit optimum curved or steep landing approaches, thus minimizing noise exposure of the population adjacent to airports.

- Present Army research and technology programs relating to airway development include a landing guidance system specifically designed for helicopter operations. This system utilizes a scanning beam of broad coverage which provides for multiple approach paths. Improved distance measuring equipment also is being developed, and the Army Automated Air Traffic Management System Program is composed of tasks on enroute, approach, and departure control, and airborne subsystems. Current priority is being given to the air-ground digital data link and tactical landing tasks.

- A development program is underway to provide an in-flight monitor for the Navy automatic carrier landing system, which employs a microwave scanning beam technique. In association with the developments in the Air Traffic Control Radar Beacon System, the Navy also is developing a Traffic Management System Control and lightweight three-dimensional ground controlled intercept radar giving digital data concerning aircraft at long range and high altitude.

- Current Air Force development efforts for improving the Traffic Control Approach and Landing System include improved methods for tower display of altitude and identity information. The Air Force also has extensive research and technology efforts associated with air traffic control centers. Man/machine interface programs will develop more efficient displays and data handling systems, and determine psychological and physiological tolerance limits for the air traffic controller.

- Navigation and guidance systems receive continuing research and development attention by the DoD. The Air Force is developing an automatic terminal area navigation control concept that includes four-dimensional coordinates for both transports and helicopters, and an Army program provides for the development of a common positioning and navigation system employing LORAN position locators and airborne receivers.

- New air traffic control concepts and operating procedures require much improved communication links. The Air Force Position Locating, Reporting, and Control of Tactical Aircraft System is based on a highly connective, high capacity, and jam-resistant digital communications system. In addition, the Army is currently developing the TRI-TAC System which is a digital transmission and switching system. The digital approach provides for an integrated and totally interfaced system of the type required for future communications.

● Current and planned military communications satellite programs include the Defense Satellite Communication System, Tactical Satellite Communication System, and the new Fleet Satellite Communication System, which will eventually replace the tactical system. The current operational military navigation satellite program is the Navy TRANSIT System. Under the Communication, Navigation, Identification (CNI) Program, the Air Force is accomplishing concept formulation studies and advanced development efforts for an integrated satellite system serving communication, navigation, and cooperative identification functions.

● Several alternate approaches for providing collision warning and avoidance capabilities to future aircraft also are under development and evaluation. A Joint DoT-DoD Program recently has been established to evaluate all competing techniques as a basis for selecting a national standard for a collision avoidance system. Both ground-based and cooperative airborne techniques are being considered. Full collision avoidance systems, which compute and display evasion instructions, and simpler proximity warning devices are included.

● Warm fog comprises 95 percent of all types of fog that occurs in the United States. This type of fog has such an adverse effect on military operations that techniques to dissipate warm fog are being investigated by DoD. Warm fog also causes an estimated economic loss of $75 million annually to civil aviation; therefore, DoD development of warm fog dissipation techniques will have direct economic benefits to civil aviation. In addition, DoD's future plans include programs to: improve the accuracy of terminal area short range weather forecasts; develop improved weather data dissemination systems; decrease the intensity of hurricanes by seeding; and provide automated pilot weather briefings. All of these programs will have spin-off economic benefits to the scheduled airlines.

● Clear air turbulence (CAT) causes passenger discomfort and occasional serious injury or death. In severe instances of CAT, structural damage to the aircraft may occur. Therefore, the need to detect and avoid CAT is important. The Air Force program of experimental investigation is to develop improved techniques for the forecast CAT-prone areas and to establish meteorological bases for the development of airborne devices to detect CAT ahead of the aircraft. A concentrated field observation program of an exploratory nature will be carried out with measurements from radar, aircraft, and meteorological sensors.

Thus, the DoD contribution to the problem of congestion on the nation's airways could be very significant. The DoD research and technology base is extensive, and the relevancy of DoD programs to the civilian R&D needs is high. Major spin-off benefits should result.

Airport Congestion

● Military research and technology programs that contribute to civil aviation include several efforts related to airfield operations. For example, runway operations are a critical problem for both military bases and commercial airports. Military development programs for pavement design and test, and runway clearance, are directly applicable to airport operations. The Air Force is currently involved in a joint runway research program, Combat Traction, which is investigating slipperiness criteria for runways, and developing simulation techniques for determining the stopping characteristics of an aircraft. In addition, the Air Force is responsible for generating runway smoothness standards. This includes development efforts for improving survey and instrumentation methods to determine runway smoothness as a function of time, traffic load, and weather. Also involved are studies of runway configurations.

● Development efforts in base support and life support also are being conducted by the military. Base support items such as aircraft hangars, electrical generation equipment, runway sweepers, heavy equipment, fire fighting equipment, and fuel handling techniques are all applicable to both military and civil operations. Life support items such as protective clothing and acoustical head gear are under continuing development by the military, and problems related to aircraft servicing and accident handling are common to both military and civil aviation

MILITARY RESEARCH AND TECHNOLOGY RELEVANT TO SHORT-HAUL TRANSPORTATION

The short-haul market in civil aviation has not been fully exploited in the past for a variety of reasons. One of the major ones has centered on the absence of a suitable air vehicle - economy of operation, safety, public acceptance, simplicity - for the job. In at least the high density short-haul system, progress in the development of short takeoff and landing (STOL) and vertical takeoff and landing (VTOL) aircraft soon should offer possible applications for the air vehicle part of the system. Military research and technology programs on both STOL and VTOL air vehicles are included in the discussion that follows.

Prototype Developments

● The Army has several current and planned prototype development programs related to V/STOL aircraft. One is for an attack helicopter. Although it will have no direct transport capability, its development technology should be applicable to future vehicles. Second is the prototype development of a Utility Tactical Transport Aircraft System (UTTAS) helicopter. The UTTAS will have a basic weight of approximately 9,500 pounds and be capable of carrying a squad (11) of combat troops and their mission-essential equipment (240 pounds each). The transport will utilize modular components, diagnostic fault equipment, and simplified maintenance procedures. Third, the Army's proposed Heavy Lift Helicopter (HLH) is planned to be useable by all three services. This helicopter will have a gross weight of approximately 115,000 pounds and a payload capability in excess of 20 tons.

- The Navy now has reviewed proposals for a V/STOL Strike aircraft and a longer endurance sensor platform V/STOL aircraft in the 20,000 to 40,000 pound class for the Sea Control Ship. For a ship-to-shore transport, consideration is being given for a major modification of an existing helicopter in the 40,000 to 50,000 pound category. In addition, the Navy is investigating tilt wing, tilt rotor, and lift cruise engine concepts for V/STOL propulsion systems.

- The Air Force has evaluated proposals for the advanced prototype development of an Advanced Medium STOL Transport. This jet STOL aircraft would carry a 15 ton payload, have a mission radius of about 500 nautical miles, and operate in and out of unimproved 2,000 foot airstrips. The objectives of the proposed project are to: (1) design, fabricate, and evaluate a prototype aircraft which will demonstrate in hardware, new technology, which after additional engineering development will provide a medium sized (C-130 class) jet STOL transport; (2) provide a low cost development option for modernization of the tactical airlift force; (3) obtain visibility on costs associated with short field performance; and (4) define STOL operational rules, safety rules, and related design criteria.

<u>Engines</u>

- The UTTAS prototype developments will utilize the GE-12 engine which has a 1,500 shaft horsepower output, and has an increased power-to-weight ratio over previous engines. Other advantages include higher operating temperatures for higher thermal efficiencies and lower specific fuel consumption, and the use of high-pressure ratio sections in front of the engine to help increase power and reduce fuel consumption.

- A 4,000 pound class Garrett three-spool turbofan engine is under development by the Air Force. This engine is expected to have an inherently lower noise level than contemporary engines of the same thrust level.

- An engine development program for a new propulsion system suitable for an Advanced Medium STOL Transport aircraft system also is being considered. The engine is in the 20,000 pound thrust class and will provide significant improvements in performance, thrust/weight ratios, pollution and noise control, simplicity, and maintainability. These improvements would allow an AMST to have significantly improved operating economics and be capable of FAA certification.

- Another engine related development applicable to STOL vehicles is a Teledyne gas generator that features an axial compressor followed by centrifugal compressor, vaporized combustor, and two-staged turbine. This gas generator technology is being developed for use in engines for light to medium gross weight logistics aircraft and lightweight fighters.

- In addition to the prototype development programs, the Army and Navy are conducting several technology development programs applicable to engines for helicopter and V/STOL operations.

  The Army Small Turbine Advanced Gas Generator (STAGG) Program will develop gas generators for a series of small engines in the 1 to 2 and 3 to 5 pounds/second air flow class. These gas generators are to be the "cores" for what eventually will be turboshaft engines for ground vehicles or small rotary or fixed wing aircraft. The approach the Army is using is similar to that of the Air Force in the Advanced Turbine Engine Gas Generator (ATEGG) Program, which results in a technology "stable" upon which engines can later be built for specific applications.

  The Navy advanced V/STOL propulsion project will develop those areas of propulsion technology that are applicable to V/STOL systems and will lead to development of demonstrator systems. The Navy also is conducting high temperature technology under this project.

Equipment

- A major current effort in vehicle equipment is the air cushion landing concept of the Air Force. This revolutionary landing gear would replace conventional wheels, tires and brakes with a cushion of air which is maintained beneath the fuselage. A system is being prototyped on a deHaviland "Buffalo" in a joint effort with the Canadian government.

- The Army has started a program to design, develop, construct, and fatigue test critical components for an advanced technology V/STOL propeller system. The goal of the program is to reduce the weight of an advanced propeller system by one half from present standards, mainly with advanced materials such as composites and design/packaging techniques.

MILITARY RESEARCH AND TECHNOLOGY RELEVANT TO LONG-HAUL TRANSPORTATION

Since the long-haul market provides the economic backbone for civil transport aviation, continuing technological advance in this field is especially important. Although the following discussion includes a number of relevant military "technology" efforts, it is important to note that, in contrast to previous times, there are no currently planned and funded "development" programs for new long range military transport aircraft.

- Supercritical aerodynamics apply particularly to long-haul aircraft and promise improved transonic flight by materially increasing drag rise Mach number. Joint NASA-DoD flight test programs will provide full-scale verification and correlation of the many wind tunnel tests and analysis performed by NASA. Two Navy airplanes, a T-2 and F-8, are presently used, and the Air Force F-111 is planned to be used, to determine the effects of wing thickness, aspect ratio, and wing sweep at varying airspeeds.

- The Air Force Control Configured Vehicle (CCV) Advanced Development Program will develop and validate automatic flight control technology for a large aircraft. The specific control functions to be developed include augmented stability for an aerodynamically unstable aircraft, flutter control, ride control, and maneuver load control. The interactions and compatibility of these control functions will be investigated. The ride control development will provide the first flight experience with a ride system using dedicated miniature control surfaces and will provide the technology base necessary to integrate such capability into other systems performing other structural response control functions. Maneuver load control is the use of control surfaces to provide direct lift (positive or negative) during maneuver on various parts of the wing to minimize bending moments created by the maneuver. This system will begin flight testing in 1973. Presently, a survivable flight control system emphasizing redundant fly-by-wire techniques is in test and evaluation.

- The technology incorporated in the B-1 advanced strategic bomber will have civil aviation applications, primarily in the engine and airframe areas. Engine developments of interest are the use of new materials for compressor blades, a single stage high pressure turbine, and improved turbine cooling technology. Airframe improvements will provide further knowledge of variable sweep, blended wing/body configuration concepts in a large aircraft. Structural mode control will be used to improve ride quality. Structural technology will demonstrate the reliability of various nondestructive testing techniques. Important data on producing and working titanium and highly fracture-resistant materials will be obtained and made available.

● In addition, the Air Force currently has three engine development programs applicable to the transonic/supersonic flight regime. These development efforts are part of the Air Force ATEGG Program previously mentioned. The Detroit Diesel Allison Division is presently running the GMA-100 gas generator. This is a high efficiency, high pressure, variable geometry compressor, with short combustor and two-staged turbines. The General Electric Company is testing the GE14/J1B1. The components include a highly loaded medium pressure-ratio compressor, a carbureting combustor, and a single stage, very high temperature air-cooled turbine. The Pratt and Whitney Aircraft PWA 535 also is currently undergoing cyclic tests. This gas generator incorporates an advanced transonic compressor, and high temperature single stage turbine.

● Important to present and future transports is the use of military ground and flight testing facilities. Large engine test facilities are available at the Air Force Arnold Engineering Development Center (AEDC) and the Naval Air Propulsion Test Center. The recently suspended SST Program was utilizing AEDC engine test facilities. There also are many flight test centers available within DoD. Edwards Air Force Base, California, has long been a major flight test center. Flight testing for the DC-10 and L-1011 is continuing to be conducted there. In addition, the SST Program had planned to utilize this large facility for supersonic flight testing.

● The hypersonic regime is not really a new area of work. Possible programs include an Experimental Cruise Aircraft which would permit the development and validation of hypersonic flight technology. The program would include the propulsion system, propulsion/airframe integration, materials and structures to operate at high temperatures, control and handling criteria at speeds greater than Mach 3, and aerodynamic heating. Preliminary conceptual design studies already have defined the general aerodynamic configurations of vehicles for hypersonic flight. In addition to the above "planned" program, the current Air Force-NASA X-24B Program will demonstrate subsonic, transonic, and supersonic characteristics of a future hypersonic configuration. The Navy Maneuvering Hypersonic Vehicle Configuration design study of lifting reentry also is contributing through the investigation of high heat load structures and attendant thermal protection system designs.

MILITARY RESEARCH AND TECHNOLOGY RELEVANT TO AIR CARGO

Military and civil cargo handling techniques usually are not compatible due to the different nature of the missions, equipment, and facilities. However, some military cargo handling experience relating to airlift operations is transferable to civil aviation.

● The Advanced Medium STOL prototype effort will add to the cargo handling data bank, and the Heavy Lift Helicopter Program will provide improved cargo handling techniques unique to transport helicopter operations.

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● In addition, the Army continues to lead in the development of containerization. The major discrete logistics load for the military currently is the standard shipping container which has dimensions of 8 feet x 8 feet x 20 feet, and a maximum carrying capacity of 22.4 tons. The container will have applications to logistics operations in a multi-modal transportation system concept.

MILITARY RESEARCH AND TECHNOLOGY RELEVANT TO THE TECHNOLOGY BASE

The broad aeronautical technology base available today to a large measure is a result of military research and development. Although the military emphasizes programs relating to superior aeronautical systems for the national defense, the transfer of military technology to civil aviation has been a major contribution to civil aviation progress. In exploiting specific research advances which promise unique or revolutionary defense capabilities ten to twenty years hence, the military must build upon a broad state-of-the-art base that encompasses technologies not only in the basic air vehicle and its subsystems, but in the areas of human factors and meteorological services as well.

Propulsion and Power

Almost every military propulsion research and technology program contributes to the technology base for civil aviation. The requirements for lower specific fuel consumption (SFC), increased thrust-to-weight (T/W) ratios, and lighter engines are not unique to civil aviation. The military states these requirements in terms of mission parameters such as long range, increased maneuverability, and high acceleration rates.

● In the development of advanced propulsion systems, a new approach has been defined to assure the exploitation and transition of advanced propulsion technology at a reduced level of risk, and at a minimum cost. This "building-block" approach is based upon developing advanced gas generator components (compressors, combustors, and turbines) and system responsive components (inlets, fans, controls, exhaust nozzles, and augmentors) which have a high degree of flexibility. These are combined in an advanced technology demonstrator engine to establish the propulsion performance, and structural characteristics required for a class of military systems. More simply stated, the trend is from a "stable" of engines to a "stable" of technology. This approach has been adopted by the DoD and incorporated in the Air Force Advanced Turbine Engine Gas Generator Program (ATEGG), the Army Small Turbine Advanced Gas Generator (STAGG), and the Navy Propulsion Component Technology Program (PCT). There are currently fifteen "demonstrator" engine projects being conducted.

- Related to the technology of propulsion is that of aircraft fire protection. Both the DoD and DoT/FAA have been investigating "safe" fuels for several years in efforts to obtain a less-flammable or non-flammable fuel. If these efforts should prove successful, the payoff, in both military and commercial terms, will be very significant.

Meteorology

The DoD will continue, as in the past, to be the sole agency that provides aerial weather reconnaissance. The data gathered will provide invaluable atmospheric weather observations on an international basis for weather analysis purposes. This data will be especially valuable in locating and measuring the intensity of large storms.

- The Army is developing an Automatic Meteorological System (AMS) to organize available observations within a given geographical area and to process, summarize, and transmit data in near real-time. This will aid greatly in short range (0-3 hr) local weather forecasts.

- Continuing Navy and Air Force support to the National Weather Service on hurricane research is designed to explore the structure and dynamics of hurricanes, improve prediction methods, and examine the possibility of modifying storm intensity.

- In addition, the Air Force is developing techniques and equipment to brief aircrews from a remote centralized weather facility. A combination of computerized weather forecasting, television, and telephone voice links is being used for this briefing system. The Air Force plans to initiate centralized briefing service late in 1973 to ten military air bases. This technique will have direct application to civil aviation, especially in low-density areas.

Avionics

In avionics, the existing technology base is being further expanded by DoD efforts in communications, navigation, control, data handling, and computer technologies.

- For example, the evolution of high capacity, automatic communications and data systems, both voice and digital, will ease the ever-growing communications traffic problems common to both military and civil aviation. This technology base has future application to such proposed programs as the Oceanic Aeronautical Satellite (AEROSAT) Program for air traffic control and communications over broad ocean areas.

● The many DoD efforts involving large scale integrated circuit devices and component developments to meet military requirements have direct application to a broad spectrum of civil aviation use, including computers, and monitoring and test equipment. Other DoD efforts directed at the miniaturization and ruggedization of components have the objective of more compact, lighter weight avionics equipment with greater reliability and reduced maintenance requirements.

Materials

Current and planned DoD programs in materials are directed principally to the general areas of propulsion and structures. Specific application programs may be aimed at certain flight regimes or temperature limits and at a particular class of vehicle, but the largest contribution which military R&D makes to civil aviation in the materials area is the generation of extensive design and engineering data bases.

● Programs for the improvement of propulsion system materials have general objectives to provide suitable properties at increased temperatures and thus permit higher turbine inlet temperatures. Achievement of these goals will result in lighter weight engines or greater thrust-to-weight ratios.

● In structures, military efforts will produce metals with improved structural efficiency, creep resistance, stress/corrosion resistance, and higher operating temperatures. Manufacturing methods for making advanced composites at lower costs as well as advancing the use of composites through prototype structures and service testing will be continued. Improved techniques for non-destructive inspection of metals and composites will be applied. Improved joining methods (adhesive bonding, diffusion bonding, brazing, and glue welding) will be developed and improved to approach 100 percent joint efficiency. The above materials efforts are aimed at producing lighter weight, fail safe structures.

● Other materials research and technology programs relate to improved performance and long life in high temperature insulation materials, seals, and sealants (fuel and pressure), hydraulic fluids, canopies, and windshields. In addition, a new fracture mechanics design and analysis handbook will be completed by the Air Force in the near future.

Human Factors/Aviation Medicine

The military also has extensive research and technology programs in human factors and aviation medicine. Major problem areas *currently under investigation include drug effects on crew performance, time shift effects from long range flights, flight disorientation from inner ear stimulation, and standards for flight physical examinations.*

- Current projects in the field of flight training simulators are centered around the development of improvements in visual simulation of what the pilot sees through his windshield. Other aspects of flight training simulation that receive attention are motion simulation and the measurement of pilot proficiency in a simulator as a means of predicting his proficiency in actual flight. In addition, extensive man/machine interface programs are being conducted for air and ground systems. Some of the possible advancements from these programs are fast decision display techniques for airborne collision avoidance systems, reductions in aircraft accidents caused by human error, and more efficient displays and data handling methods in air traffic control centers.

- Flight training simulation and man/machine interaction developments will have direct application to civil aviation. The general aviation industry also could benefit from new advances in flight simulation and airborne displays.

Air Vehicle Technology

The technology base for air vehicles is supported by extensive military programs in flight mechanics, structures, flight control, vehicle dynamics, and vehicle equipment. Most of the major technological advances in military R&D that benefit civil aviation are found in the air vehicle area.

- In flight mechanics, programs dealing with the compatibility of the jet engine with the air inlet, and improvement in overall integration of the airplane and engine, are expected to result in more efficient airplanes of increased performance. The generalized aerodynamic prediction programs leading to computerized design techniques will shorten, as well as enhance the accuracy of, the design process. Programs in buffet criteria, high-lift and maneuvering devices, advanced airfoil and wing design, and drag minimization are aimed at extending the range and other capabilities of aircraft.

- Advanced development programs in all-metal structures will provide demonstration of the advances recently made in fracture mechanics and in joining techniques which lead to lighter weight structures. Work in structural analysis will lead to optimum designs that satisfy both strength and flutter constraints.

• In flight control, the concepts of CCV, augmented stability, maneuver load control, integrated direct lift control, and elastic mode control will be significant influences on aircraft design. Fly-by-wire control technology will permit greater design flexibility and allow easy incorporation of specialized control functions. Load alleviation, an all-weather landing capability, and an improved pilot-airplane interface are expected to result from this technology.

• In vehicle dynamics, programs in active flutter suppression are aimed at increasing performance envelopes and reducing structural weight. Programs in buffet load research, vibration reduction, the dynamic characteristics of composite structures, and advances in theoretical unsteady aerodynamics will improve flight safety and reliability. Also contributing to design advances are programs in sonic fatigue, particularly those directed to structural elements that are exposed to both high temperatures and noise levels, such as nacelle acoustic treatments and nacelle fairings.

• Vehicle equipment programs involving research in environmental control systems, which provide stable and suitable environment in all compartments of the airplane, are underway. This almost exclusively military supported research area leads to safer, more reliable airplane operations.

ASSESSMENT OF RELEVANCY OF MILITARY AERONAUTICAL RESEARCH AND TECHNOLOGY PROGRAMS TO CIVIL AVIATION R&D NEEDS

The preceding discussions on current and planned military aeronautical research and technology programs clearly show that the relevancy of these efforts to the R&D needs of civil aviation is high, and that this relationship will continue in the future.

It was pointed out, however, that there are differences in degree or extent of relevancy when individual areas of civil aviation R&D need are considered. Thus, as a means for highlighting these variances, specific relevancy assessments have been made. Each area of civil aviation R&D need has been rated according to a scale of three relevancy values: high, moderate and low. The ratings are based on an assessment of the number of military aeronautical research and technology efforts involved, their degree of potential application to the civil aviation R&D need, and the depth and magnitude of the military program. The assessment is summarized in Table 9.

In both noise abatement and air pollution, the military services are major participants in several interagency programs, and separately are conducting a wide variety of fundamental research and technology programs with important spin-off applications. In noise abatement, the military projects are just getting underway, and so the relevancy assessment is "low," with an upward trend indicated. However, the levels of noise abatement and thus the technical solutions that may be required of civil systems may not be compatible with military performance and operational requirements. In air pollution, on the other hand, the military has been active for several years - for perhaps different reasons than today - and so the relevancy assessment is "moderate," with an upward trend also indicated.

Table 9

Relevancy Assessment

CIVIL TRANSPORT AVIATION R&D NEED	MILITARY TECHNOLOGY PROGRAM RELEVANCY
NOISE ABATEMENT	LOW
AIR POLLUTION	MODERATE
CONGESTION	
AIRWAYS	HIGH
AIRPORTS	LOW
SHORT HAUL TRANSPORTATION	HIGH
LONG HAUL TRANSPORATION	MODERATE
AIR CARGO	MODERATE
TECHNOLOGY BASE	HIGH

In the airways aspect of congestion, it is clear that the military services have many important air traffic control, navigation, and communication research and technology programs. Accordingly, a "high" relevancy rating is assigned. Regarding the airport aspect of congestion, however, only military runway efforts seem pertinent to the civil problem. Thus, the relevancy assessment is "low." No change in trend in either case is anticipated.

The degree of compatibility between military research and technology programs and the short-haul transportation R&D needs of civil transport aviation also is clearly "high." The numerous helicopter, STOL and V/STOL efforts of the military certainly will be beneficial to civil aviation.

In long-haul transportation, there are several significant military research and technology efforts, such as the Supercritical Wing and Control Configured Vehicle Demonstrations, hypersonic research, and B-1 spin-off applications. However, only a "moderate" relevancy assessment has been made because it cannot be shown that the military projects are broad-base in nature when all of the possible civil aviation R&D needs in long-haul transportation are considered. In addition, a downward trend is indicated because the military does not have any long range transport aircraft development programs under active consideration at this time. Thus, the extent and number of future military programs in this area could decrease.

In air cargo R&D, very few new military projects are being considered. However, because of past work, and because improvements in cargo handling and containerization still are being made, a "moderate" rating has been assigned.

Finally, the relevancy of the underlying technology base developed as a result of military programs is excellent in all of the disciplines, and a "high" relevancy assessment is the result.

SECTION V

RELEVANCY OF MILITARY AIRCRAFT PROGRAMS TO COMMERCIAL AIRLINER DEVELOPMENT

The preceding section examined current and future military aeronautical "research and technology" programs in relation to the aeronautical R&D needs of civil aviation as identified by the CARD Study. The relationship between aeronautical designs, equipment and hardware generated in military programs and the design, development, and production of civil airliners will now be considered. The nature, timing, and trends of this process are examined with reference to six specific examples. These case studies begin with the Boeing 707 and Douglas DC-8 in the mid-1950s, and continue with inclusion of the Boeing 747 and McDonnell-Douglas DC-10 in the late 1960s. Examples for the future include a Medium STOL Transport (MST) and an Advanced Supersonic Transport (ASST).

OVERVIEW

BACKGROUND CONSIDERATIONS

At the present time the development and production of a large wide-bodied or jumbo jet commercial airliner is a multi-billion dollar venture. The engineering manpower required averages on the order of 5000 personnel for about 30 months during the key portion of the development period, with lesser numbers before and after, and at the peak of manufacturing as many as 10,000 personnel, or more, may be employed. This present requirement for manpower is double the amount previously needed for jet transports such as the Super DC-8 and advanced 707, and four times the amounts for the earlier 707s and DC-8s.

In addition, many large facilities are required, including laboratories, wind tunnels, static and fatigue test facilities, simulators, flight test facilities, and large computer complexes. Buildings are required for manufacturing, subassembly, and final assembly, as well as for the completely integrated vehicle and checkout function. Added to the prime contractor's resources are those of numerous subcontractors. For example, in the case of the 747, Boeing has estimated use of 250 million dollars worth of facilities at subcontractor locations.

A major difference in philosophy exists in the design of military and civilian aircraft. A military aircraft is designed and built to accomplish a military mission, and thus primary emphasis is placed on mission performance. Therefore, some degree of calculated risk is tolerable for the application of new technology for the first time. *Commercial aircraft design, on the other hand, stresses safety, passenger comfort, economy, and long service life.* Therefore, commercial airliner development normally is characterized by the incorporation of only those technological advancements that already have been proven and demonstrated, usually in military systems.

The transfer of technology or hardware also depends, to a great extent, on the mix of military and commercial business in which an aerospace company has been, or is, involved. In the early 1950s, for example, over 50 percent of the Boeing Company's work was in military development and production; today, the amount is about 15 percent. Consequently, the transfer of hardware is less. And, about twenty years ago, the majority of the facilities used by a company, such as Boeing or Douglas, were facilities owned by the Government. Today, the Boeing-Everett Plant, where the 747 is produced, is 100 percent company owned. These observations, on ratio of business and on plant ownership, reflect trends in the hardware transfer process that will be discussed in the case studies later.

BACKGROUND HISTORY

During the 1940s, hardware transfer between civil airliner and military transport developments was almost direct. In some cases, the only differences were in interior arrangements and equipments; in other cases, the chain of improvement was such that it is difficult to determine who sponsored what development. The DC-4/C-54 is one example of this close interrelationship. Designed as a U.S. coast-to-coast airliner, the DC-4's airline use was limited by the war; but over 1,000 flew as the military C-54. This basic design then led to the prototype XC-112A military freighter, from which the C-118, the DC-6, and the DC-7 later evolved.

The military T-29 trainer and C-131 transport were involved in a similar interchange as part of the Convair 240, 340 and 440 airliner developments. The Boeing 377 Stratocruiser was the civilian counterpart of the military C-97 transport, and the C-121 was a military version of the Lockheed 1049 Super Constellation, which in turn had evolved from the earlier military C-69, a version of the original "Connie", the Lockheed 049.

Civil airliner development in the 1940s and early 1950s also benefitted from military sponsored or established plant facilities, *test facilities, manufacturing and production methods, tooling, and design team expertise. The transfer process was a total one, and it continued to the introduction of jet airliner service in 1958.*

The military was the first to undertake the development of jet powered aircraft. By the early 1950s, the rapid advancement made in turbojet engine development and the demonstration of high speed flight already had set the stage for the large aircraft that could be used as commercial transports. Early military jet aircraft - the F-86s, A-3Ds, B-47s, C-135s, and B-52s - proved the technology and were the forerunners of the large jet airliners of today.

The Jet Age of commercial airliners began in 1954, in the United States, with the Boeing Model 367-80 - the prototype predecessor of the 707. The following portions of this section examine further the application and transfer of military R&D and hardware to commercial aircraft development.

SUMMARIES OF AIRLINER CASE STUDIES

Six case studies of airliner development were accomplished as a part of the RADCAP review. Four of the cases relate to the history of modern jet airliners, and two are concerned with projections of realistic but hypothetical future civilian transport aircraft - a Medium STOL Transport (MST), and an Advanced Supersonic Transport (ASST). The primary thrust of the case studies was to examine the relevancy and transfer of military developmental efforts to development of the airliners.

BOEING 707

The Boeing 707 was the first large U.S. jet commercial aircraft designed for high subsonic cruise speeds (0.8 Mach number). The Boeing Model 367-80 was the prototype for the 707, and evolved from Boeing experience with the Air Force B-47 and B-52 programs. The Boeing B-47, which first flew in 1947, was the single most important forerunner to the 367-80, and, in turn, to the Air Force KC-135 jet tanker and the commercial 707. The Boeing 707-120 entered service in 1958, and experience has proved it to be a very successful commercial airliner.

- Configuration

The high aspect ratio, 35 degree swept wing on the B-47 provided Boeing with the extensive aerodynamic and structural design data needed to build a large commercial airplane that could cruise at high speeds and make efficient use of the jet engine. B-47 flight experience also was of vital importance to the 707. The flight data produced new information on the effects of structural flexibility on aileron effectiveness, and emphasized the importance of aeroelasticity. New and improved design methods also were developed based on the B-47 flight results.

In developing the 707, as well as the military KC-135, Boeing attempted to apply all of the lessons learned in the B-47 and B-52 developments. For example, the use of spoilers for roll control and the provision of inboard ailerons came from the B-52. In addition, the problems of the mechanical yaw damper, as experienced on the early military jets, were avoided by using a hydraulically-powered electronic yaw damper. The latter, in turn, transferred back to the late B-52s.

The 707 wing was an advancement over the B-47 wing and had increased thickness near the root, which improved the structural efficiency and thereby reduced the wing weight. The wind tunnel tests accomplished at Boeing on the B-52 wing also provided extensive aerodynamic information on the effects of increased root thickness on lift and drag divergence and made a significant contribution to the 707. In addition, these tests provided considerable information on nacelle placement and pylon design which supplemented earlier tests on the B-47 nacelles and provided design data needed to minimize drag interference between the wing and nacelles. Boeing also found that the stall and stability characteristics of the swept wing were improved by the pylons because they acted like wing fences and helped to reduce spanwise flow, which usually causes flow separation at moderate angles of attack.

- Structures

The interchangeable transfer of major air vehicle sections and components from the B-47 and B-52 to the 707 was low; however, the transfer of equipment and basic design experience from the B-47 and B-52 was high. Between the KC-135 and 707 there was a very high degree of compatibility. Much of the 707 structure is similar to that of the KC-135 with the notable exception of the fuselage design, the use of 2024 aluminum alloy, and improved joint design in the lower wing skins for longer fatigue life.

- Flight Controls

The 707 aircraft flight control system derived from the experiences of the B-47 and B-52 bomber programs. The B-47, with its swept wing, suffered the characteristic Dutch roll oscillation and applied an electronic yaw damper as a corrective measure, a device also used on the 707. The wing-pylon suspended engines, originally causing some configuration and performance concern, also had a beneficial effect, a "docile" stall characteristic of value to the 707. The directional control actuation was accomplished by hydraulics which involved a transfer of technology from high performance fighters.

- Propulsion

The propulsion system for the 707 was a direct transfer of the military J-57 engine, which was the first production engine employing the dual spool concept. This made it possible to apply a higher compression ratio, 11.5 to 1, than other engines of the period. The higher efficiency of the cycle and the engine components produced a 20 percent reduction in fuel consumption compared with single spool, low pressure ratio turbojets. The extensive use of titanium in the rotors and static structure increased thrust-to-weight more than 10 percent. The Pratt & Whitney J-57 engine had been proven on the B-52 and C-135 programs, and its commercial derivative, the JT-3C, was ready for use on the 707. The J-57 and JT-3 engines had a high degree of commonality when the commercial engines were introduced to service. The military program preceded the start of the commercial program by a number of years and uprated models were being developed concurrent with the commercial program. The experience generated was easily applied to both programs.

The Boeing 707-120 made its first commercial flight on October 28, 1958, more than six years after the first flight of the B-52. Development of the military J-57 engine was started in 1949. Thus, prior to the first commercial flight, more than 68,000 hours of engine development testing were completed, and military airplanes had completed more than three million engine flight hours. Approximately 400 million dollars were spent by the military on J-57 engine development.

- Avionics

The direct transfer of avionics equipment from the military was moderate. Boeing procured electronic systems directly from commercial vendors; however, the vendors used basic military designs to produce the equipment. The cost savings were considerable since the vendor did not have to qualify his product to military requirements. The communications radio systems were vendor supplied in accordance with contractor specifications requiring that all vendor produced communications systems be FAA certified in accordance with the applicable ARINC (Aeronautical Radio Inc. - a company sponsored by the airlines to prepare avionics specifications in accordance with FAA requirements) characteristics. About 50 percent of the items of navigation equipment in the 707 were derived directly from military equipments. However, the autopilot and inertial navigational systems (in later models) were direct descendants from military equipment. As with communications systems, the major navigation systems were certified by the FAA to ARINC standards covering that system.

- Summary

In summary, it is clear that the Boeing 707 traces its lineage and ancestry directly to the B-47 and B-52 bomber programs, and that Boeing experience in the military jet aircraft programs was invaluable to the 707 development. The transfer of military technology and hardware, relatively speaking, was very high.

DOUGLAS DC-8

In 1955, Douglas assembled a design team to enter the Air Force jet tanker competition. This team then was prepared to move directly into the design and development of the DC-8 aircraft. By that time, the British Comet was already flying, Boeing had built the Model 367-80 prototype, and Douglas had built such high subsonic speed military jet aircraft as the Navy A-3D, the Navy A-4D, and the Air Force B-66. These aircraft provided some of the technology "know-how" required for the development of a large high subsonic speed commercial transport like the DC-8. Because of time and competition, Douglas undertook the DC-8 program without a direct predecessor or a prototype. The aircraft has proved to be an outstanding commercial airliner and, with some modifications, has led to the Super DC-8, which is one of the largest transports in use today.

- Configuration

The configuration for the DC-8 was conventional. It employed a thicker airfoil section designed by Douglas, based on data from NACA and military R&D programs. The airplane was manufactured and assembled at Long Beach utilizing Air Force plants, as well as two new assembly buildings specifically constructed by Douglas for the DC-8. The DC-8 aerodynamic design was strongly influenced by the competitive thrust of the 707, which threatened to take over the commercial market. Since Douglas did not choose to develop a prototype, a conservative approach was used in many areas.

The 35 degree swept wing on the B-47 had demonstrated that high lift-drag ratios and good stability could be achieved at high subsonic Mach numbers. Douglas established a design goal for the DC-8 to have the same cruise Mach number as the 707 and have better low speed stability and control characteristics. After considerable study and analysis, it was decided to reduce the wing sweep to 30 degrees and to increase the root thickness ratio compared to the B-47 wing. In prior work on the C-74, Douglas had investigated improved airfoil sections for high speed flight. This provided much of the data needed to reduce the wing sweep, increase the root thickness, and retain the same cruise Mach number as the 707.

The DC-8 configuration was developed around the extensive design data that Douglas had compiled from prior military and commercial aircraft development and independent research programs. The double slotted trailing edge flap design was based on extensive design data and wind tunnel tests from the XC-132, C-133, and DC-6 programs. Moderate application of design work accomplished on the A-3D program contributed to the DC-8 wing spoilers. In addition, moderate application from the C-133, and design data from the DC-4, C-54, C-74, and DC-6 aircraft, were used for the fuselage, aerodynamic controls, trim tabs, and aerodynamic balances.

- Structures

The design and development of the DC-8 utilized the procedures and some of the equipment acquired for the structural static and fatigue tests of prior military programs, the A-3D, B-66 and C-133. An airload survey based on military requirements and prior experience was conducted to validate the airloads used in the design. Also, the Government provided the numerically controlled tooling that was employed in manufacturing the aircraft.

- Flight Controls

The flight control system of the DC-8 made maximum use of established technology. The primary controls were mechanical with hydraulic actuation being used only where manual power was insufficient, and then with provisions for manual reversion in case of hydraulic failure. All mechanical and hydraulic components were designed in-house. The autopilot was furnished by Sperry and used accelerometers as the basic stabilization sensors. This was sound in principle but, like all new approaches, required about three years to reach a satisfactory state of service. The problems of rate gyros were avoided by this concept, but the electronics state-of-the-art required by this embodiment was inadequate at that time. Hydraulic leaks and high surge pressure problems that occurred were successfully solved. Douglas engineers estimated that 40 percent of the technology used came from military sources, primarily its own experience with the B-66, X-3 and A-3D aircraft.

6

- Propulsion

The initial DC-8s used the same engine as the 707 - the JT-3, which was the commercial equivalent of the military J-57 engine. Later versions of the DC-8 used the superior JT-4, which was the commercial equivalent of the military J-75 engine. The engine basically is a scaled up version of the J-57/JT-3C twin-spool engine and has a pressure ratio of 12:1. The DC-8-20 transport completed its first commercial flight on March 6, 1960, eight years after the start of development of the military J-75 (1952). More than 32,000 hours of engine development testing and approximately 15,000 hours of flight in military aircraft had been completed prior to the first commercial flight. The military experience, coupled with the technology transferred from the J-57/JT-3C programs, directly benefitted the commercial JT-4 program. Government expenditures on the J-75 engine were approximately $220 million by 1956.

- Avionics

About 60 percent of the avionics equipment incorporated into the DC-8 was derived from commercial equipment. Douglas prepared specifications based on ARINC characteristics to cover the particular equipment being purchased. All avionics systems were FAA certified. The electronics equipment directly transferred from the military were the AN/CRT-3 Rescue Radio Transmitter and the SCR-718 High-Altitude Altimeter.

- Summary

In summary, the major military contributions to the DC-8 program were the technology base, design data, the engine, facilities, some equipment and components, and experience. No similar military jet transport had been produced by the company.

BOEING 747

The Boeing 747 development proceeded from the large background of design data obtained on the KC-135, 707, 727 and other Boeing programs, and the same design team that had been drawn together to work on the Air Force C-5A proposal formed the backbone for continuation of Boeing's large transport design concepts. The extensive analyses and wind tunnel testing on the C-5A proposal aircraft undoubtedly contributed significant design information for the 747, although the final configuration was different. For example, design work for the C-5A competition demonstrated the feasibility of the 16-wheel high flotation main landing gear used on the 747.

- Configuration

The 747 aerodynamic design made effective use of an improved "peaky" airfoil design which provided good lift characteristics at high subsonic speeds. This airfoil section significantly improved the buffet boundary compared to the 707 aircraft. Extensive wind tunnel testing was accomplished by Boeing before the first flight. By the end of 1971, almost 20,000 hours had been logged. A triple slotted flap was developed for the 747 which had its background in the development of the 727. Boeing made extensive use of ground-based simulators to verify the flight handling qualities and stability and control. This procedure combined with the extensive aerodynamic testing in the wind tunnel contributed to the rapid development of the final configuration and the early solution of problem areas.

- Structures

The structural design of the 747 also drew heavily upon the engineering background and technology base assembled by Boeing in designing and developing many large military and commercial aircraft. Their internal R&D programs, particularly in the areas of power spectral density gust design procedures, runway roughness measurements for dynamic taxi loads, fatigue and fracture, and materials applications made significant contributions to the 747 development.

The 747 airframe made extensive use of fiberglass panels and components in many areas to reduce the weight. This was a step forward in structures design. In addition, the large titanium gear extrusion was a significant advancement in landing gear design and also improved the structural efficiency.

The plant facilities for the construction and assembly of the 747 were built by Boeing at a new site, now called the Everett Plant. The first tests for the aircraft were accomplished using both Boeing and military facilities. In addition to Boeing Field and Paine Field, Edwards Air Force Base, Roswell Air Force Base, and Moses Lake were used. And, in producing the aircraft, large titanium forgings were made by Wyman-Gordon using military heavy presses.

- Flight Controls

The control system of the 747 is several-fold more extensive than the system employed in the 707. Four independent hydraulic systems are employed. The control surfaces themselves are divided so that the redundancy extends to the aerodynamic surfaces. The redundancy is so extensive that loss of control performance will not result from a single failure, and even a second similar failure does not cause unacceptable control.

The 747 control system also provides a flight director system which derives its signals from the same signal sources and computers as the automatic control. The pilot may easily monitor the automatic operation, may exercise control in conjunction with the automatic, or may assume the total guidance and control function without loss of orientation and with full understanding of the situation and without switching or control transients. Simplification of operating controls and status monitoring has been widely practiced. Boeing first employed these piloting and instrumentation features in various degrees in the 727 and 737 aircraft. These applications served as prototypes and added confidence to the 747 development.

From Boeing discussions and independent knowledge of Air Force and vendor programs, it is concluded that the origin of the control technology for the 747, including the control configuration and pilot features, derives directly or through other Boeing systems from military sources to the extent of about 50 percent.

- Propulsion

The 747 engine, the Pratt & Whitney JT-9D, was a major advance in turbine engine design, and many of the technical advances incorporated in the JT-9D Program had Government support. A joint military/industry research and development program was begun during the early 1960s with the aim of improving the general turbine engine technology base. The Lightweight Gas Generator Program explored high performance, compact compressors and high temperature turbine design. Technology for this program was incorporated by Pratt & Whitney in a very advanced full-scale demonstrator engine designated the STF-200. This engine became the prototype for a new generation of high-bypass-ratio-engines.

Two major demonstrator engines evolved from the STF-200. One, the Pratt & Whitney JTF-17, was a competitor for the United States Supersonic Transport (SST) Program and the other, the Pratt & Whitney JTF-14, competed for the Air Force C-5A transport program and, although not selected for this application, was redesigned as the JT-9D which was chosen to power the Boeing 747. The JT-9D development began in January 1966 and the 747 first flew in commercial service four years later in January 1970. At that time approximately 5,000 hours of engine development testing had been completed by Pratt & Whitney. Lacking a military counterpart, the opportunity to discover and correct any design problems before commercial use was not present. During the second year of operation, the engine experienced a 0.35/1000 hours inflight shutdown rate with the total flying time of 2,458,343 hours since entering commercial service. Also, during this second year of operation, the engine experienced an unscheduled removal rate of 0.94/1000 hours.

- <u>Avionics</u>

All of the avionics equipment incorporated into the 747 is commercially produced by vendors and is certified by the FAA to applicable ARINC characteristics. However, the component parts in practically all of the vendor items are designed to military standards. In addition, the Omega and Loran navigation systems, the microwave instrument landing system, lightning protection systems, heads-up displays, the multipurpose cathode ray tube displays, warning systems, and integrated instruments were derived from military counterpart equipment.

- <u>Summary</u>

In summary, the Boeing 747 jumbo jet, like the 707, traces much of its technology and development base to R&D activities originally initiated by military needs. Key to the development was the propulsion system, and the high-bypass-ratio-turbofan developed by the Air Force provided the basis for the solution to the propulsion problem.

MCDONNELL-DOUGLAS DC-10

The McDonnell-Douglas DC-10 Medium Range Transport airplane was designed as a 413,000 pound aircraft to transport 270 passengers and 2,240 cubic feet of containerized cargo at speeds of Mach 0.88 between 34,000 and 42,000 foot altitudes for about 3,000 nautical miles. The airplane has a 35 degree sweep, fixed wing and is equipped with three General Electric CF-6 turbofan engines, two enclosed in pylon mounted nacelles beneath the wing and one mounted at the base of the tail fin. The DC-10 was developed around conservative design goals and criteria to minimize risks and shorten development time, and was designed to take advantage of the fuel economy and thrust characteristics of the high-bypass-ratio-turbofan engine.

- <u>Configuration</u>

McDonnell-Douglas designed the DC-10 wing with a "peaky" airfoil section which provides good lift capability at high cruise speeds while reducing shock wave losses and flow separation. The design work done by McDonnell-Douglas in support of its C-5 proposal to the Air Force made a major contribution to the improved airfoil section. The C-5 proposal wind tunnel tests also contributed new design information on nacelle and pylon drag increments. The DC-10 wing design tapers in thickness ratio. The main wing spar has a compound curvature near the root section which permits an optimum variation of thickness ratio in the inboard region of the wing. This advance in structural design technique contributed to good cruise drag characteristics at high Mach numbers.

- Structures

The DC-10 has double-slotted wing flaps of similar design to the DC-8 and earlier Douglas aircraft. This basic flap design goes back to the development of the C-133. Douglas has conducted many two-and-three dimensional wind tunnel tests on the double-slotted flap and now has a large design data base on this type of flap system.

The straight inlet and diffuser of the tail engine on the DC-10 was an improvement in aerodynamic design. This improved the specific fuel consumption because of lower inlet flow distortion.

The nacelle strakes on the DC-10 improve the maximum lift on the wing by preventing flow separation in the mid-span region where the wing is highly loaded. This aerodynamic device generates a powerful vortex which sweeps high energy air above the wing down into the boundary layer and reduces the flow separation at high angles of attack.

The results of Government-sponsored R&D in the areas of non-stationary aerodynamics; low level turbulence measurement, definition and analysis; parametric fatigue analysis; fracture toughness; and structural analysis programming and manufacturing technology were used by the DC-10 design team. In addition, operational experience with the A-3D and B-66, in particular the cold weather sonic fatigue tests conducted in Alaska on the B-66, influenced the detail design of this aircraft.

- Flight Controls

The control system of the DC-10 is a fully powered system. Three totally independent, hydraulic systems provide a high level redundancy. The design approach was based on technology acquired from prior experience and that of others. The studies and experiments, as well as later engineering, that explored and developed these redundancy concepts were military in origin and began about 1959.

The autopilot for the DC-10 provided by Bendix was a derivative of the C-133 autopilot. Although hardware was of necessity tailored to the aircraft and to the customer's required features, about 50 percent of the technology was a direct transfer. In addition to the C-133 experience, which provided Bendix with the first transistorized autopilot, Bendix's work with the B-58 hydraulics actuation system was applied to the DC-10. Similarly, the C-141 redundant yaw damper experience served as background for the DC-10.

- <u>Propulsion</u>

The basic technology of the CF-6 engine, except for the fan system, was the same as the TF-39 engine developed under the military program. The TF-39 engine contract was awarded in 1965. The DC-10/CF-6 made its first commercial flight in August 1971. Prior to the first commercial flight of the DC-10/CF-6, more than 30,500 hours of engine development testing were completed, 27,000 hours as a TF-39 and 3,500 hours in the CF-6 configuration. Additionally, approximately 128,000 engine flight hours had been accumulated in the C-5 aircraft. Because of the similarity, the military experience was of great benefit to the CF-6 commercial engine, as attested to by an inflight shutdown rate of only 0.05/1000 hours after six months of airline service totalling some 38,000 flight hours. During this same time period the premature, or unscheduled, removal rate was 0.21/1000 hours. The Government invested $212 million for the development of the TF-39 engine. A leased B-52 was utilized as a flying test bed for the CF-6 development.

- <u>Avionics</u>

There was very little direct transfer of military avionics equipment to the DC-10. All systems are commercially produced and vendor supplied. However, the electronics system techniques were to a degree derived from the military. For example, the technology of the inertial navigation system used on the DC-10 was initially developed for the Air Force. The C-band altimeter and antennas also derived from military R&D. Examination of the avionics equipment configuration of the Douglas DC-10 airplane reveals that less than 30 percent of the communications and navigation equipments were transferred directly from the military.

- <u>Summary</u>

In summary, the McDonnell-Douglas DC-10 incorporated a moderate to low amount of technology hardware transfer from military

R&D. The primary item of hardware transfer was the propulsion system, the General Electric CF-6 high-bypass-ratio-turbofan. Some modifications to the CF-6 were accomplished to match the flight conditions and operational plans for the DC-10. The engine hardware transfer was significant in saving funds and reducing time to flight operation.

MEDIUM STOL TRANSPORT

The Air Force's request for proposals for the advanced prototype development and test of an Advanced Medium STOL Transport (AMST) of C-130 size was oriented towards a military jet STOL transport that would carry a 15 ton payload, have a radius of action of about 500 nautical miles, operate in and out of unimproved 2,000 foot airstrips, consider the implications of FAR-36 noise standards, and utilize either qualified engines or engines that have been preflight rated. *The size of the military AMST prototype could be comparable to a commercial STOL transport designed for operation in a short-haul high density transportation system. However, a sepcific comparison between the military AMST prototype and a commercial Medium STOL Transport cannot be made at this time since the military prototype is only in the "proposal" stage, and because the characteristics of a possible commercial Medium STOL Transport have not yet been defined.*

- Configuration

Based on limited design data, the proposed military AMST prototype characteristics, and various parameters discussed in the CARD Study, a commercial Medium STOL Transport might have the following general characteristics:

PASSENGERS	90 - 150
GROSS WEIGHT	100,000 - 150,000 pounds
ENGINE THRUST	16,000 - 25,000 pounds
CRUISE MACH	0.8 to 0.85
RANGE	300 - 500 nautical miles
RUNWAY LENGTH REQUIREMENT	2,000 feet
NOISE LEVEL	Meet FAR-36 Noise Standards
IN-SERVICE DATE	1980

Should the military Advanced Medium STOL Transport (AMST) Program be approved and go on contract, the experience gained should be directly transferable to civil aviation. The high mounted wing and associated high lift devices, the turbofan engines, the flight control system, the landing gear, and the cockpit displays should have major application to any future commercial Medium STOL Transport development program that might be undertaken.

- <u>Propulsion</u>

The Air Force also is considering proposals to develop a STOL demonstrator engine. This program will result in the design, fabrication and test of a demonstrator engine in the 20,000 to 25,000 pound thrust range with a bypass ratio in the range of 4 to 8:1, a thrust-to-weight ratio of 7:1, and specific fuel consumption equivalent to the TF-39 and JT-9D engines. Engine testing could begin in 1974, with testing (100 to 150 hours on the demonstrator engine) completed in 1975.

The STOL demonstrator engine would be capable of being adapted to high lift devices such as externally blown flaps. The engine would consider FAR-36 noise criteria, have no visible smoke, and have lower pollutant emissions (carbon monoxide, unburned hydrocarbons, and oxides of nitrogen) than current turbofans. This demonstrator engine could provide the basis for a commercial Medium STOL Transport engine development.

Upon completion of the STOL demonstrator engine test, follow-on activity would include the conduct of a Prototype Preliminary Flight Rate Test (PFRT) by waiving all non-essential specification test requirements until Military Qualification Test (MQT). Upon completion of the prototype PFRT, the engine would be acceptable as a prime propulsion system on experimental aircraft. It is estimated that 1500 to 1900 hours of engine testing and approximately 12 to 20 months would be required to complete the PFRT. Following completion of the prototype PFRT, a formal MQT could be undertaken. The MQT would involve an additional 3,000 to 6,000 hours of engine testing and approximately 22 to 24 months to complete.

- <u>Avionics</u>

The future airborne avionics for short-haul transportation system aircraft will be largely dependent upon results of development programs currently underway within the DoD and other Government agencies. Though the avionics being utilized in these development programs may not be directly utilized, the knowledge and experience gained should provide a high degree of confidence for adapting the test avionics to production configuration.

- Summary

The knowledge and results gained from military development programs now under consideration could significantly reduce the amount of advanced and prototype development necessary to develop and certify a commercial Medium STOL Transport for the short-haul transportation system. The design criteria resulting from the military AMST prototype program, and the hardware, manufacturing technology, tooling, and test results that would be gained from both the AMST prototype and the Air Force STOL demonstrator engine cannot be specifically identified at this time. However, the results could provide a data base and very probably some direct transfers that would be applicable to the development and production of any future commercial Medium STOL Transport.

ADVANCED SUPERSONIC TRANSPORT

Growth in civil air transportation has been provided by new air vehicles incorporating new technology. Utilization of new technology has resulted in productivity increases through the combined effect of increases in aircraft size and speed. *With the projected growth of international travel in the 1980s, a need could exist for a new airplane which would provide an increase in productivity for the 1980s through an increase in speed - an advanced supersonic transport.*

- Configuration

Previous economic studies have shown that a new air vehicle of comparable weight to the Boeing 747, but capable of cruising at Mach 2.7, could provide twice the productivity of the 747. Based on available design and engineering data, the RADCAP Study Team postulates that an Advanced Supersonic Transport (ASST) that would provide desired productivity increases by 1985 could have the following general size, design, and performance characteristics.

PASSENGERS	250 - 300
GROSS WEIGHT	Over 500,000 pounds
ENGINE THRUST	60,000 to 70,000 pounds
MACH NUMBER	2.5 - 3.5
RANGE	4,000 - 5,000 nautical miles
SONIC BOOM OVERPRESSURE	2.0 psi or less
RUNWAY LENGTH REQUIREMENT	12,300 feet or less
MATERIALS	Titanium and Composites
IN-SERVICE DATE	1985
AIRFRAME SERVICE LIFE	40,000 - 60,000 hours
NOISE	Satisfy FAR-36 Noise Standards and EPA Environmental Requirements

To meet a projected in-service date of 1985, a configuration design freeze date would have to occur by 1980, and required advancements would have to be incorporated by the freeze date. Improvements will be necessary in aerodynamics, structures, noise and air pollution reduction, engine characteristics, and materials; and incorporation of sound, practical, and demonstrated advances will be needed to attain a payload-to-design gross weight ratio greater than 8 percent, thereby making it economically viable. Figure 2 reflects a possible program schedule for the development of an ASST.

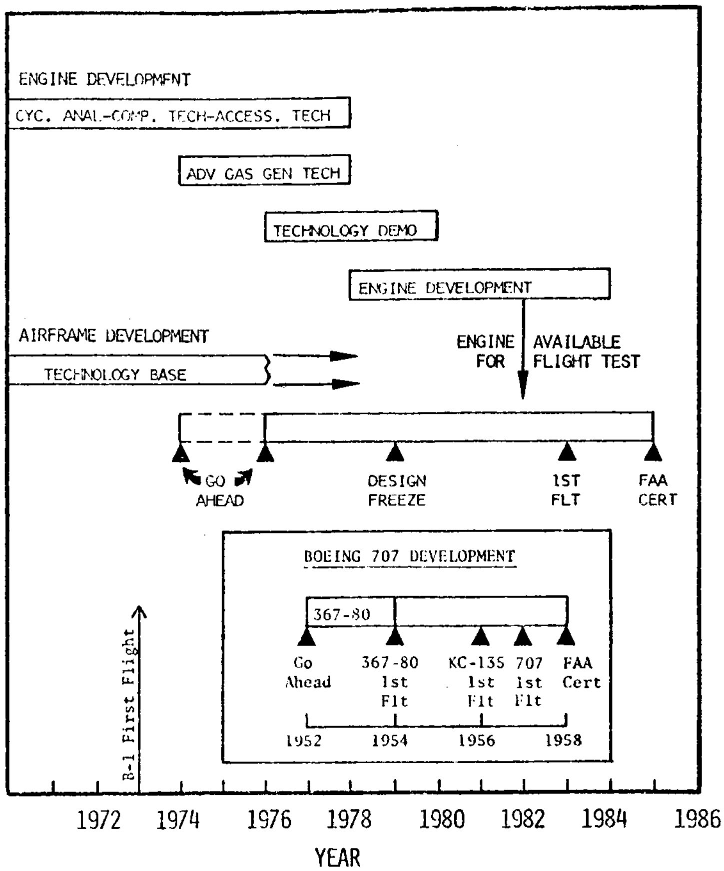

Figure 2 - A Postulated ASST Development Schedule

- **Structures and Materials**

The following areas of military sponsored technology should provide a foundation for significant technological improvements for a supersonic transport:

Advanced Composites

Advanced Metallic Structures

Controlled Configured Vehicles

Airframe/Propulsion System Integration

Improved Titanium Manufacturing Techniques

Microelectronics

The B-1 is one of the military aircraft developments that has relevancy to a future long-haul commercial supersonic transport. The B-1 blended wing/body configuration concepts will provide further knowledge on high speed configuration design. The fluoro-silicone fuel tank sealant was considered as a sealant for the terminated prototype SST and is now being used on the B-1. This basic sealant material could be used and valuable experience obtained in providing initial application until better materials concepts are developed.

One of the military programs that will provide great benefit to a future ASST is the Advanced Composites Program. Significant weight advantages can be attained provided reliable polymer and metal matrix composites are established for the higher temperature requirements of the ASST. The design, manufacturing, and operational use of advanced composites must be continued in order to provide the confidence and know how for the designers to build efficient long life structures. Experience is being gained on the application of composites through military programs.

The use of boron advanced composite materials laminated on longerons of the B-1 will provide a vehicle on which this structural design approach will be tested. This method provides a primary structural application of the material and could be used on the ASST for weight saving. Sonic fatigue design and experience will also be useful to a future ASST.

Even though the B-1 operating temperatures are lower than required for an ASST, they are higher than those for large airplanes presently operating; therefore, design, test and operational experience at these temperatures will be useful to an ASST. Since titanium will be used in critical areas of the B-1 structure, this vehicle will provide a source of continuing advancement in the titanium production, design information, manufacturing methods refinement, and joining techniques.

The first application of a 4,000 psi hydraulic system was incorporated in the North American XB-70 aircraft. Satisfactory operation of this type system was demonstrated. The use of a 4,000 psi titanium hydraulic system was planned for the terminated prototype

SST, and is being used on the B-1. Experience obtained on the XB-70 and B-1 will be valuable for a future ASST.

Structural mode control was planned for the prototype SST. This concept generated from the military program to improve the structural life of the B-52. The program was initiated to improve elastic mode control and rigid body control. From this program the Load Alleviation Mode Stabilization (LAMS) was initiated. This mode control also provides some load alleviation and will assist in reducing structural weight.

- <u>Propulsion</u>

A supersonic transport engine tends to be unique in that it has to accept widely varying inlet conditions and, therefore, must be carefully tailored to the aircraft system. Engine/inlet compatibility is a very important factor to insure engine stability and good performance over the complete flight envelope and provide margins for inlet and engine transients.

The cruise performance is extremely sensitive to exhaust nozzle installation designs. Careful integration of the airframe afterbody and nozzle is extremely important to achieve minimum drag and reduce thrust losses. The noise requirements may cause two approaches: one would be to limit the exhaust velocity to the desired noise level. This approach will cause extremely large engines which will be sized for take off and cause some range loss because they are oversized for cruise conditions. The other would be to install noise suppressors in the exhaust system which will cause some degradation in the nozzle performance. The continuing DoD-sponsored IR&D propulsion program and the Air Force Advance Turbine Engine Gas Generator (ATEGG) Project should provide the components for engine cores required in supersonic flight propulsion.

- <u>Summary</u>

The technology base being generated by military aeronautical R&D, as well as the spin-off benefits that should derive from the B-1 and other military development programs, should be very useful to the development of any advanced supersonic transport aircraft. The application of technology through development, testing and simulation facilities should be moderate, but direct hardware transfer probably would be low. As in the recent past, the major portion of the direct hardware transfer probably would occur in the propulsion system.

DEVELOPMENT RELEVANCY TRENDS AND OBSERVATIONS

The military technology and hardware developed for the post-World War II swept wing jet powered aircraft provided the basis for and means by which the first commercial subsonic jet transports were developed and produced. These aircraft, represented by the Boeing 707 and Douglas DC-8, gained immeasurably from the B-47 swept-wing technology, the Pratt & Whitney J-57 engine, military avionics subsystems, and other military development programs.

A reduction in large military aircraft development beginning in the mid-1950s diminished the transfer of hardware to civil aircraft. The aircraft industry maintained its aeronautical technology base from other military advanced development efforts, independent research and development, and Government laboratory R&D programs.

From the general design point of view, the development of the large "wide body" jet transports required no major new technology other than the large high-bypass-ratio turbofan engine. A closer scrutiny of the design aspects of modern jet transports, however, reveals that the airframe, propulsion, handling qualities, and avionics have incorporated several new features. Many of these design features, such as improved airfoil sections, titanium structures, augmented flight control, and inertial navigation, were derived largely from Government and military R&D.

The recent initiation of DoD prototypes, together with major advancements in R&D, will demonstrate the feasibility and operational performance of new concepts. These activities could provide much of the design data and experience applicable to the development of new commercial aircraft such as the Medium STOL Transport.

The trend in the transfer of hardware and development experience from the military to large long-haul commercial aircraft development has been downward. The future is uncertain, even though much fundamental work in technology is underway. Should an improved subsonic commercial airliner be desired, the transfer could be significant. However, should an operational Advanced Supersonic Transport be desired, particularly by the mid-1980s, development effort would have to be expanded and accelerated.

Tables 10 and 11, together with Figure 3, reflect RADCAP's assessments of the trends in benefits accruing to civil transport aviation from the military "development and production" base. The ratings are high, moderate, and low as described in the preceding section. *Here it is emphasized that the previous section referred*

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to "research and technology" transfer, while this section and the assessments of Tables 10 and 11 and Figure 3 refer to "hardware" transfer - to the benefits from the military development and production base.

In general, and assuming the 1955 period, when direct transfer of hardware was high, as the basic time frame from which the trends are measured, *it can be seen that direct transfer of hardware from the military development and production base has been on a downward trend - from the direct transfer of hardware in the 1955 era to the "bit and piece" transfer of today.*

Table 10 shows that in the 1955 and before time period, by the Boeing 377 example, that direct transfer was high in all areas - the air vehicle, propulsion and avionics. Then, from the 707 of 1958 to the DC-10 of today, the direct transfer process has declined, and overall assessments reflect a downward trend. This applies to everything except the basic engine, where the transfer rating remains high, and where military research and development has been fundamental to all advancements.

Table 10

Development Relevancy/Civil Transport Aviation

	BOEING 377	BOEING 707	DOUGLAS DC-8	BOEING 747	DOUGLAS DC-10	TREND
AIR VEHICLE						↘
Configuration	HIGH	HIGH	MODERATE	MODERATE	MODERATE	
Structures	HIGH	MODERATE	MODERATE	LOW	LOW	
Flight Control	HIGH	HIGH	MODERATE	MODERATE	MODERATE	
PROPULSION						↘
Basic Design	HIGH	HIGH	HIGH	HIGH	HIGH	
Total Engine	HIGH	HIGH	HIGH	LOW	MODERATE	
AVIONICS						↘
Communications	HIGH	MODERATE	MODERATE	LOW	LOW	
Navigation	HIGH	MODERATE	MODERATE	MODERATE	LOW	

Table 11 assesses the probable transfer of hardware to possible future commercial airliner developments. In the Medium STOL Transport development, the transfer process could be high - almost on a par with the decade of the Fifties. This assumes, of course, the continuation of the current military programs in STOL and VTOL research and development. In the Advanced Supersonic Transport development, however, the assessment is that direct hardware transfer possibilities will remain low, even though the benefits from military technology could be high. Thus, the trend - from the 1955 era base - remains downward.

Table 11

Development Relevancy/Civil Transport Aviation

	M S T		A S S T	
	RELEVANCY	TREND	RELEVANCY	TREND
AIR VEHICLE		→		↘
Configuration	MODERATE		LOW	
Structures	HIGH		LOW	
Flight Control	HIGH		HIGH	
PROPULSION		→		↘
Basic Design	HIGH		HIGH	
Total Engine	HIGH		LOW	
AVIONICS		→		↘
Communications	MODERATE		MODERATE	
Navigation	MODERATE		MODERATE	

Figure 3 is the Study Team's overall trend assessment on the hardware, or development base, transfer curve. The spread in the curve for the future reflects the upward trend possibilities in Medium STOL Transport hardware transfer relevancy, as well as the leveling or slightly downward trend possibilities still probable in the long-haul transportation area. *What actually occurs, of course, will depend in a large measure to the success and progress of military R&D programs now in being, or proposed, and to the new commercial airliner programs that might be started.*

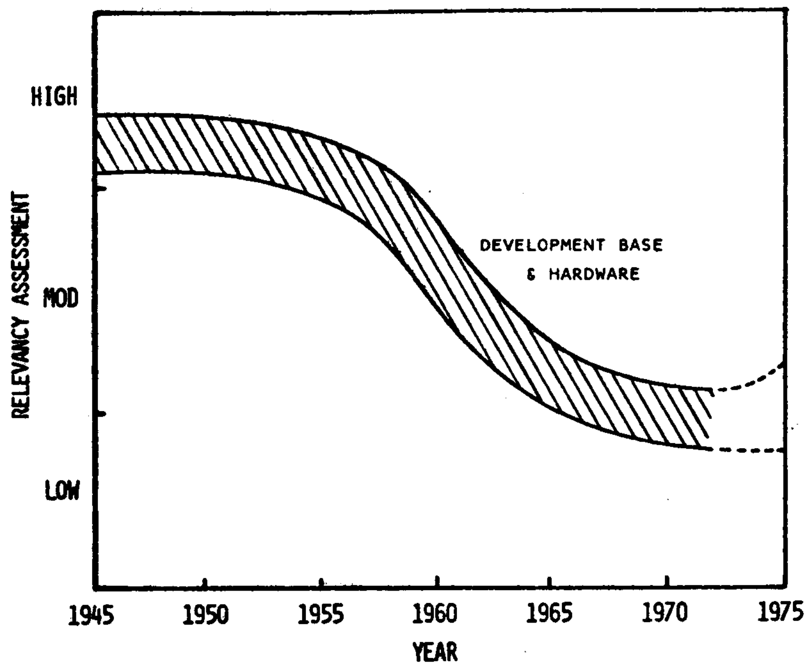

Figure 3 - Military Development Contributions to Commercial Airliners

SECTION VI

AERONAUTICAL R & D FUNDING

This section briefly discusses some of the major funding levels and cost trends in aeronautical R&D. An examination of these levels and trends should help to provide an understanding of the emphasis that has been and is being placed on aeronautical R&D by the various segments of the aviation community.

The R&D dollars reflected herein include basic and applied research funds (referred to herein as research and technology) and development funds, including estimates for the construction of R&D facilities, military and civilian salaries, other support costs, and prototype aircraft development costs, including the construction of full-scale test hardware and complete aircraft, and their test programs.

As used in this section, "Federal defense" funds include those of the Army, Navy, Air Force, Advanced Research Projects Agency (ARPA), the Aircraft Nuclear Propulsion (ANP) Program of the Atomic Energy Commission (AEC), and the R&D funds reimbursed by the Government to industry as allowable overhead charges on procurement contracts. "Federal non-defense" funds include those of the National Aeronautics and Space Administration (NASA) and Federal Aviation Administration (FAA). "Industry" funds include non-reimbursed industry independent research and development (IR&D) and specific development (SD) funds, as well as those funds provided by universities and foundations.

The primary source for the fiscal year funding data used in the RADCAP Study was the Joint DoT-NASA Civil Aviation R&D (CARD) Policy Study, February 1971, as updated by Booz, Allen Applied Research, Inc., in January and February 1972 for inclusion in this report. The funding data reported in the CARD Study as Federal defense funds were obtained from the "Project List" of the Five Year Defense Plan (FYDP), excluding such aircraft projects as bombsights, fire control systems and antisubmarine warfare equipment, and including such missile or space projects as Snark, Quail, Regulus and Dyna Soar. The CARD Study sources for Federal non-defense funds were budget documents available for those organizations dating back through 1945. The CARD Study sources for industry funds were discussions with various military and commercial aircraft, helicopter and engine manufacturers, and a review of Congressional records. Other funding and cost data contained in this report were obtained from the files of various Federal agencies participating in this study, a general literature search, and discussions with several Government and industry representatives.

AERONAUTICAL R&D FUNDING BY SOURCE

The long term trend in total U.S. aeronautical R&D expenditures is upward. The long term trend is also upward for all three elements of the total: Federal defense, Federal non-defense, and industry. Unless there is a complete reversal in national aeronautical goals, the general increase in the number of dollars available for aeronautical R&D is expected to continue, although occasional annual decreases might occur.

Figure 4 shows how the DoD aeronautical R&D funding has increased over the years, with rather sharp rises from 1950 to 1954 and from 1969 to 1973, and a significant rise from 1960 to 1969. During the past decade and into the early Seventies (from 1960 to 1973), Federal defense funding increased by approximately 77 percent, from $1.578 billion to $2.793 billion. The latter figure is also 77 percent of the total FY-1973 anticipated expenditures for aeronautical R&D. *Thus, in interpreting funding trends for aeronautical R&D as a measure of the quality and quantity of the contributions made to aeronautical technology, it can be forecast that DoD contributions to aeronautical R&D will continue to be substantial in the future.*

During the same time period, Federal non-defense funding for aeronautical R&D increased by approximately 445 percent, from $80 million in 1960 to $436 million in 1973. Within this funding category, NASA's aeronautical R&D funding increased by approximately 822 percent, from $32 million to $295 million. *Thus, these trends and increases also should assure that substantial contributions to aeronautical R&D will continue to be made by Federal non-defense agencies in the future.*

Industry funds expended for aeronautical R&D have increased only 22 percent since 1960, from $329 million in 1960 to $402 million in 1973, less than the Federal non-defense total, after reaching a high of $673 million in 1968. From 1968 to 1973, a period of only five years, these industry non-reimbursed funds for aeronautical R&D have decreased by 40 percent. In addition, the IR&D funds reimbursed by the Government to industry as allowable overhead charges on procurement contracts, included as part of the

Federal defense funds discussed above, decreased from $481 million in 1968 to $273 million in 1973, a 43 percent decrease in five years. *Based on industry funding levels and current industry funding trends, it appears that industry will contribute less in the future than it has in the past to aeronautical technological advances.*

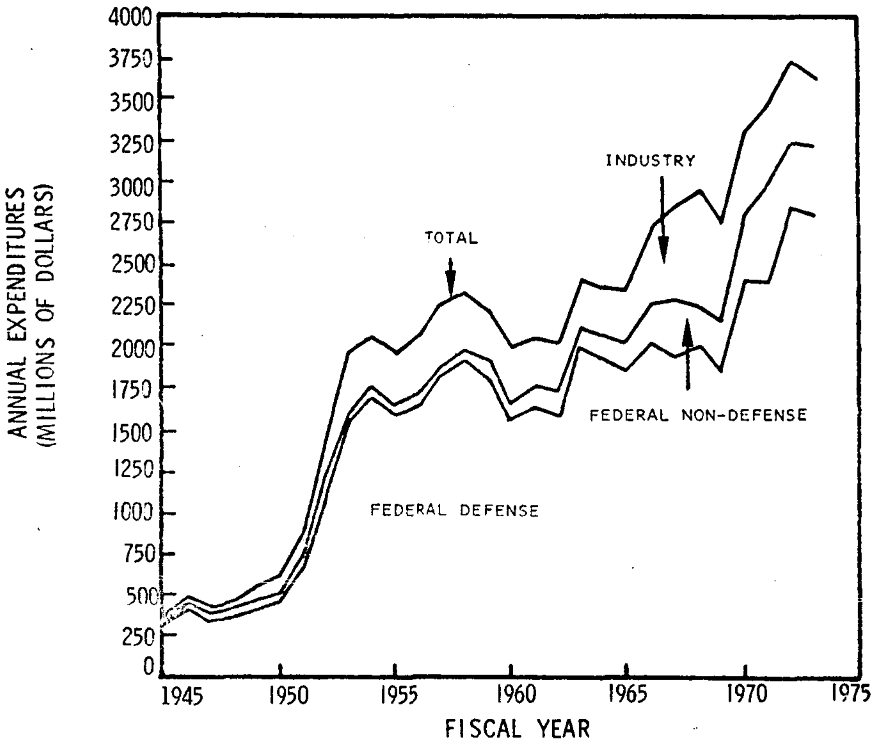

Figure 4 - Sources of Aeronautical R&D Funds (Then Year Dollars)

Economic escalation has had a noticeable effect on the purchasing power of aeronautical R&D funds, as reflected by comparing Figure 5 with Figure 4. Measuring from 1954 (the high point after the rapid build up which began in the late Forties) to the estimated expenditures for 1973, *the trend is still increasing for all funding sources even with economic escalation considered.* The downward trend from 1954 to 1962 has been reversed during the past ten years to where the increasing trends are very noticeable, especially since 1969. These trends indicate that the total aeronautical R&D community and each of its elements have been provided with both increasing funds and increasing purchasing power over the years. Since 1968, however, the industry element has shown a noticeable decrease.

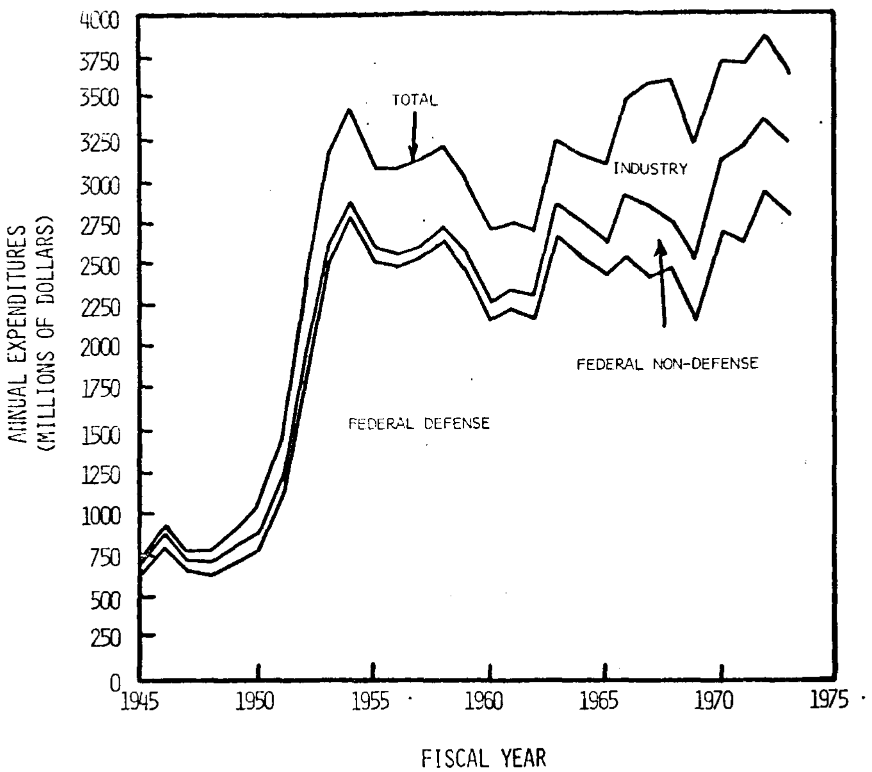

Figure 5 - Sources of Aeronautical R&D Funds (1973 Dollars)

GOVERNMENT AERONAUTICAL R&D FUNDING BY TYPE OF R&D

Figure 6 shows the Government aeronautical R&D funds divided into research and technology and development funds. After the sharp increase in the early Fifties, these funds remained rather stable until 1969, when another upward trend began. The largest portion of the R&D funds reflected on this chart is, of course, for the development of prototype and test aircraft. *Figure 6 highlights the large proportionate share that the Federal defense agencies contribute to both the R&T and development areas. It follows, then, that more technology advancements logically can be expected from the military sponsored programs. As shown earlier, this has occurred.*

It is believed that funds expended for research and technology is one measure of future benefits to be derived in aeronautics. Research leads to advancements in any discipline, and aeronautical research accomplishments lead to hardware development 10 to 15 years after research is completed. *The availability of research and technology funds shows an increasing trend over the years.* Federal defense's proportionate share of the total aeronautical research and technology funds increased from 56.2 percent in 1968 to 65.6 percent in 1973 and Federal non-defense increased from 5.9 percent in 1968 to 11.4 percent in 1973. Although not shown in this figure, industry's proportionate share of the total aeronautical research and technology funds decreased from 37.9 percent in 1968 to 23.0 percent in 1973. Based on these later trends in research and technology funding, it appears that the Federal agencies will provide proportionately more of the significant contributions to advancements in aeronautics in the future.

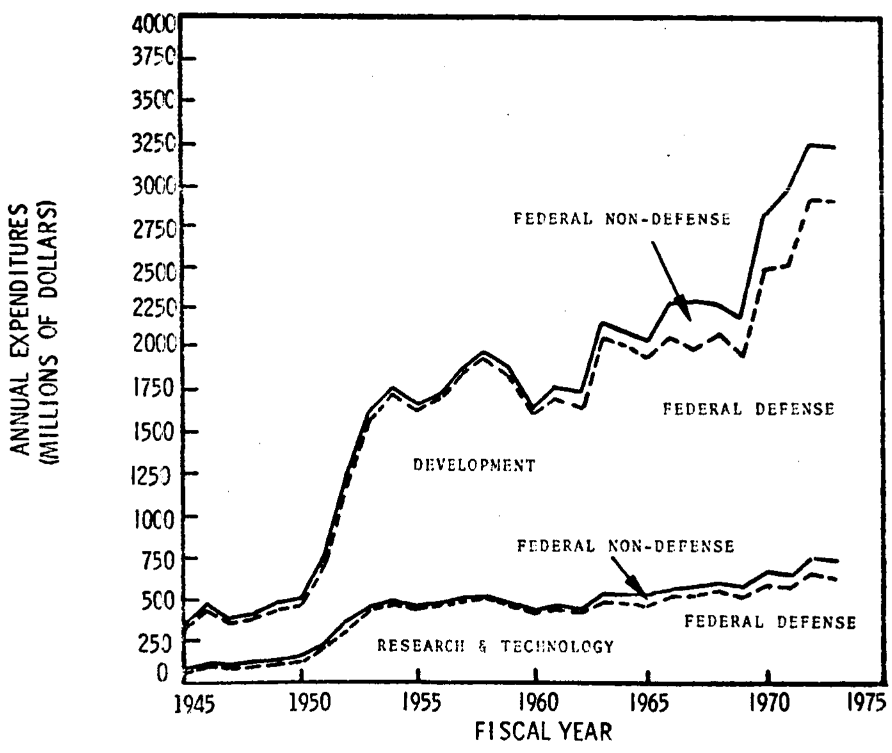

Figure 6 - Government Aeronautical R&D Funding (Then Year Dollars)

Economic escalation has had somewhat of a leveling effect on Government aeronautical R&D, as shown in Figure 7, although slightly upward trends are visible since 1954. Increasing trends are more pronounced during the last five years in "development" funds for both Federal defense and Federal non-defense, and in "research and technology" funds for Federal non-defense. Federal defense aeronautical "research and technology" funds, however, have experienced a slightly decreasing trend during the five year period from 1968 to 1973 due to economic escalation, dropping from $671 million in 1968 to $630 million in 1973. Thus, the purchasing power of dollars available for "research and technology," believed by many to be the basis for the future of aeronautics, has remained almost unchanged, while that available for "development" has slightly increased.

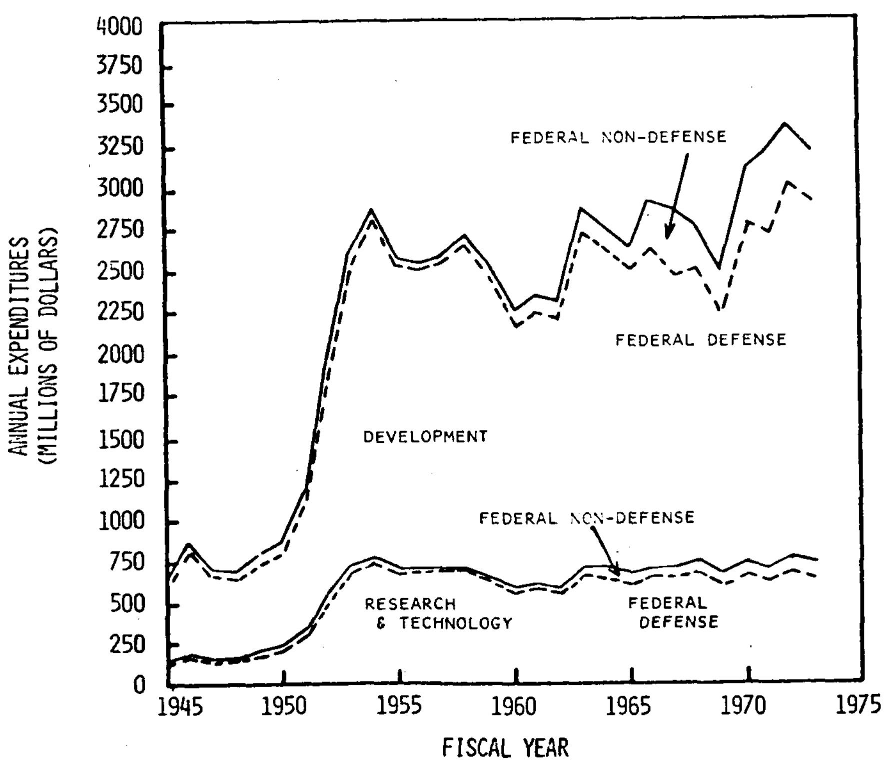

Figure 7 - Government Aeronautical R&D Funding (1973 Dollars)

AERONAUTICAL R&D FUNDING AS A PERCENTAGE OF THE GROSS NATIONAL PRODUCT (GNP)

The Gross National Product (GNP) also has increased each year since 1945, except for the two decreases experienced in 1946 and 1949. *A very significant observation, however, is that the availability of aeronautical R&D funds, taken as a percentage of the ever-increasing GNP, has suffered a severe reversal in the former upward trend.* Since 1954, aeronautical R&D funds have been a sharply declining portion of the total GNP, as shown in Figure 8. President Nixon told Congress, in his January 1972 State of the Union message, that military expenses for fiscal year 1973 will amount to only 6.4 percent of the GNP, down from 9.5 percent in 1968. This percentage decrease will very likely carry over into military R&D and probably into aeronautical R&D, and thus continue the present downward trend of aeronautical R&D as a percentage of the GNP.

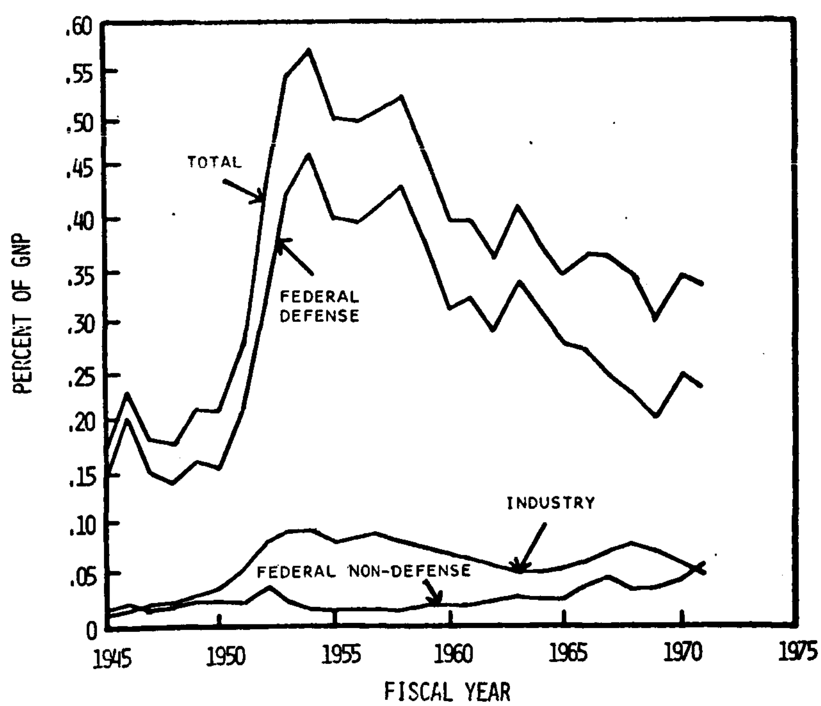

Figure 8 - Sources of Aeronautical R&D Funds (Percent of GNP)

AIRCRAFT DEVELOPMENT AND UNIT COSTS

The cost of developing aircraft has risen dramatically with the advent of increasingly more productive, complex modern aircraft. As shown in Figure 9, the trend for commercial and military transports is steeply upward. Also, Figure 10 shows a rapidly increasing trend in the cost of developing military fighter aircraft. In relatively recent times, it appears that aircraft development costs are about the same - whether it is a transport or a fighter. Around 1955 to 1960 it cost about $100-300 million to develop a transport or a fighter, and in the early Seventies it cost about $1-2 billion. It could be expected that the trends in development costs would differ between the two types of aircraft, and they do, but only slightly. Computing a trend line for only those transports developed since 1955, however, results in a trend very similar to the fighter aircraft development cost trend, being slightly lower but almost parallel to the fighter trend line. In addition to development costs for transports and fighters being approximately equal, it appears that their rates of increase are approximately the same. *Thus, large, complex airframes are nearly synonymous with dense, high performance, complex airframes insofar as development costs are concerned.*

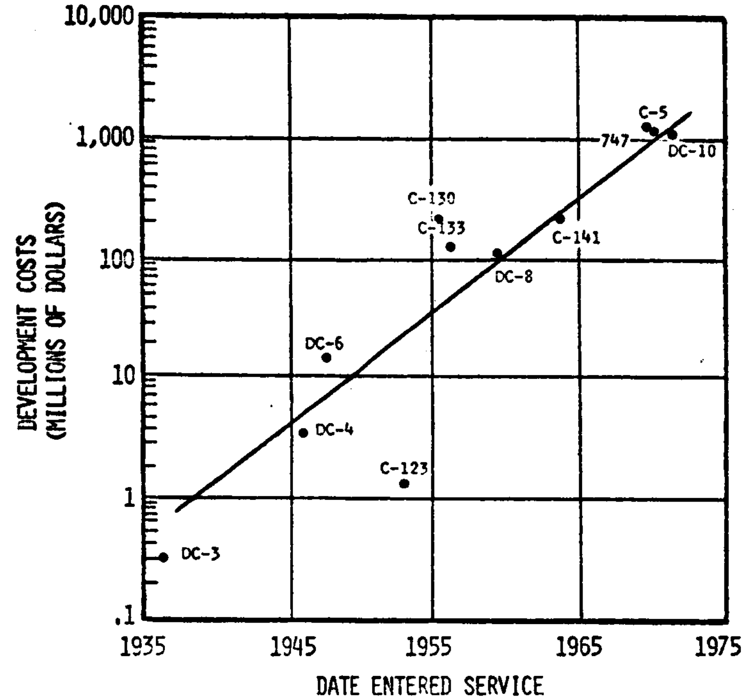

Figure 9 - Transport Aircraft Development Costs

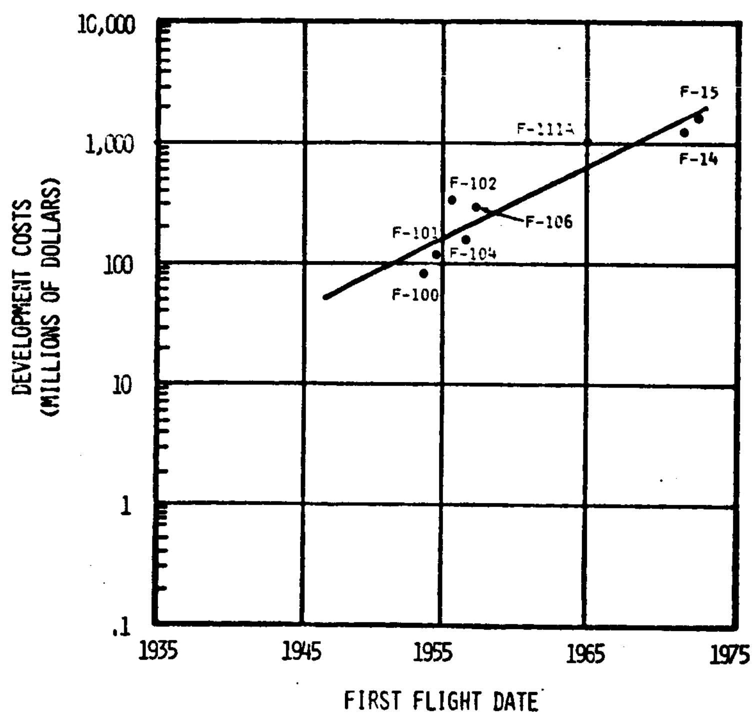

Figure 10 - Fighter Aircraft Development Costs

Figure 11 shows, also in a dramatic way, how the unit price of civil airliners have increased over the years. Unit production price increases are due partially to the increased development costs just discussed that must be prorated to the unit sales that are made.

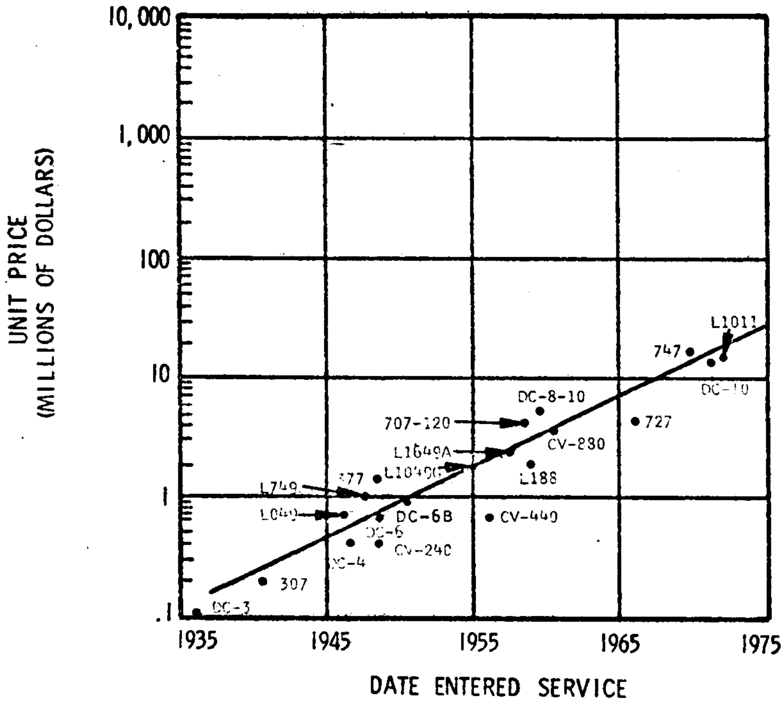

Figure 11 - Civil Airliner Aircraft Unit Price

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COMPARATIVE TRENDS

Figure 12 provides a comparison of some of the most important cost and funding trends that apply to aeronautical research and development. In comparison with the rise in the Gross National Product, the cost of new aircraft development and aircraft unit prices are climbing more rapidly, while the funds available for Federal defense aeronautical R&D are rising more slowly. *This information would indicate that major new aircraft programs will either decrease in number or change significantly in nature, unless some of the trends are altered or reversed. Fewer program starts could result in a significant slowdown in the number of technological advancements made in aeronautics.*

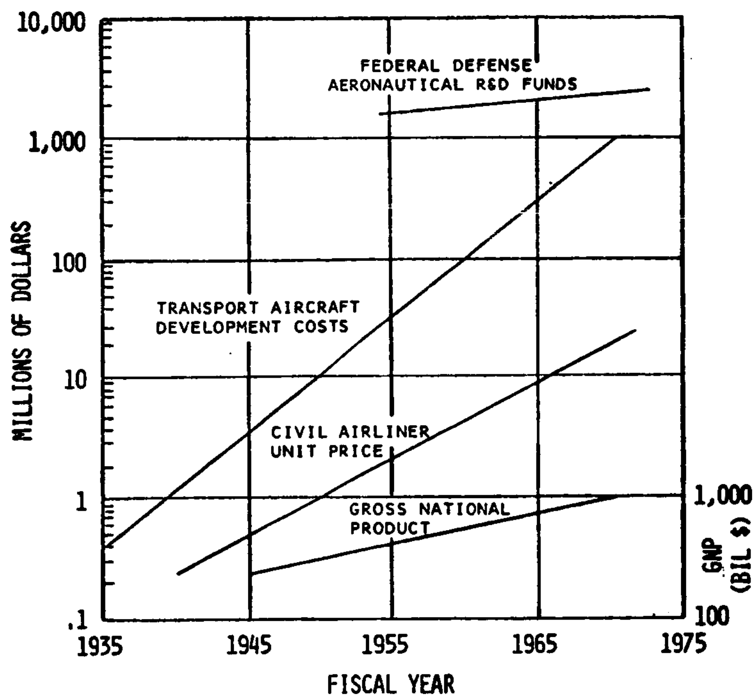

Figure 12 - Summary Comparative Trends

AIRCRAFT DEVELOPMENT STARTS

Related to the general funding picture in aircraft development are the procedures used in development and acquisition. During the 1940s and 1950s, prototyping was the standard procedure for developing and testing aircraft before production orders were placed. In the first jet bomber competition, for example, four companies responded to an invitation to bid on a jet powered bomber capable of a speed of 500 MPH, a service ceiling of 40,000 feet, and a combat radius of 1,000 miles. Four companies responded, and all were accepted. These were the North American XB-45, Consolidated XB-46, Boeing XB-47, and Martin XB-48. Two of these - the B-45 and B-47 - were accepted for production.

Similarly, three prototypes were involved in a penetration fighter competition that was conducted in 1950. These were the McDonnell XF-88, the Lockheed XF-90, and North American YF-93. However, the outbreak of the Korean War diverted attention and funds to other types that were more suitable for quick production, and none of these prototype fighters was produced. The XF-88, though, became the basis for the F-101 ordered two years later.

Use of the prototyping approach began to decline in the 1950s, and in the 1960s very few programs were accomplished in this manner. With the implementation of the "fly-before-buy" concept in the last few years, however, advanced prototyping has been re-initiated as a method of doing business. The number of new military aircraft starts of all kinds, including experimental vehicles, has declined rapidly in the two decades - from an average of about 15 a year in the early 50s, to about 6 a year in the early 60s, and to about 3 a year in the early 70s. What will occur in the future is uncertain, and undoubtedly will depend very much on the military threat that develops.

Figures 13 and 14 illustrate the significant downward trend in the number of new aircraft starts that has been occurring. Figure 13 shows the number of large aircraft, those in the 100,000 pound and over category, that have been developed by the military in the Fifties and Sixties, as well as those known that should first fly in the Seventies. Figure 14 shows the same information on aircraft in the 25,000 to 100,000 pound category. *Many observations on the impact of this trend could be made, but one message is clear - the number of new military aircraft program starts has been sharply declining.*

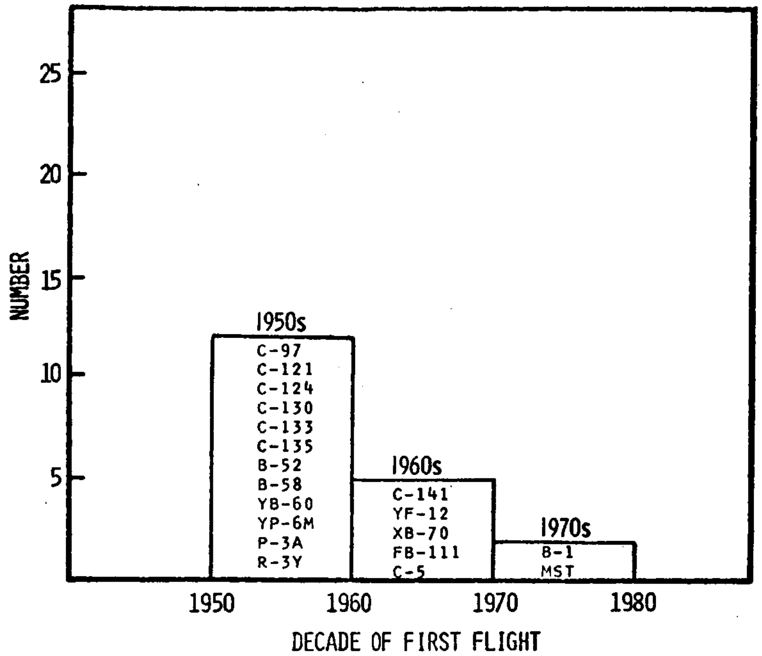

Figure 13 - Military Fixed Wing Aircraft Programs (100,000 Pounds and Above)

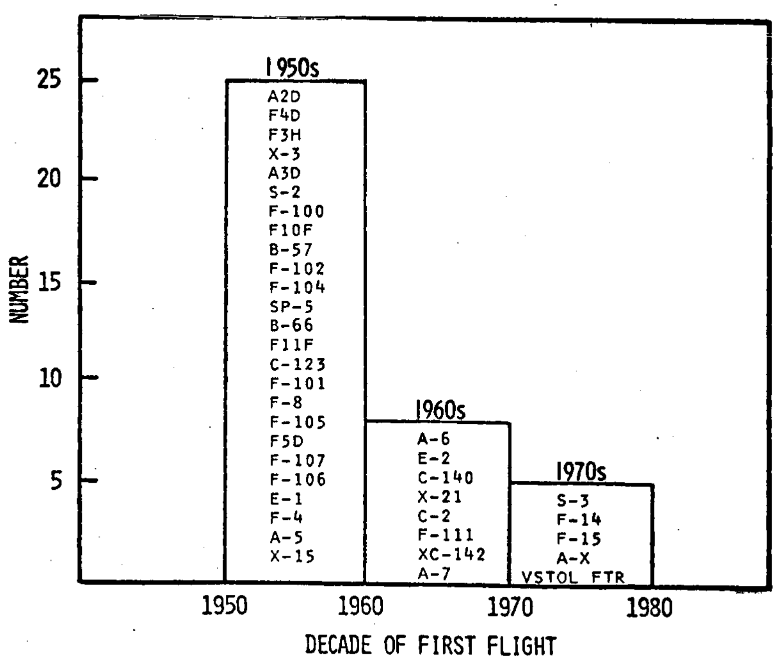

Figure 14 - Military Fixed Wing Aircraft Programs (25,000 - 100,000 Pounds)

AERONAUTICAL R&D FUNDING SUMMARY

The following summary observations on aeronautical R&D funding and the trends associated therewith are derived from the data of the preceding discussion.

- The long term trend in the availability of funds for aeronautical R&D has been upward. This applies to all elements of the total - Federal defense, Federal non-defense, and industry.

- In terms of constant dollars (FY 1973), the trend is still upward over the years, though only slightly for all elements of the total. However, during the past five years, the industry element is experiencing a downward trend.

- In recent years, trends in the availability of industry funds for both research and development, and Federal defense funds for research, have been downward - in contrast to the overall upward trends.

- Development costs of new aircraft have been rising very rapidly - at a rate much greater than trends in the availability of R&D dollars.

- The rate of increase in development costs is much higher, and the rate of increase in the availability of aeronautical R&D dollars is much lower, than the rate of increase in the Gross National Product.

- Trends in development costs and aeronautical R&D funding availability, as well as in new aircraft program starts, indicate that the number of new aircraft programs in the future will continue to decline, unless something very significant occurs in the cost and nature of aircraft development, or in an increased allocation of funds for these efforts.

SECTION VII

STUDY OBSERVATIONS AND FINDINGS

OBSERVATIONS

A number of significant factors now are influencing the relevancy of military R&D to the R&D needs of civil transport aviation. These factors also are influencing aviation progress and the technological advances in aviation that will occur in the future. These points have been recorded as observations of the Study Team.

- *First, aviation has developed in the United States to the point where it now is accepted as a basic ingredient in the American way of life. However, it no longer enjoys the unlimited and enthusiastic public support that marked the glamour and excitement of its spectacular progress, and now must face the challenges of society on a par with other industries and services.* For example, public concern for the environmental factors of noise and air pollution now is having a major influence on the growth of aviation. The importance of these issues on public acceptance of new aircraft and new airports already has been recognized, particularly by civil aviation. The military, though, has carefully observed all that has happened, and military R&D efforts are increasing rapidly in the attempt to reduce the noise and air pollution problems of aircraft operation.

- *Second, the problem of "congestion" on the nation's airways and in airport terminal areas caused by increasing air traffic has impacted significantly on civil airline operations.* Although the military always has been concerned with the many aspects of flight operations in tactical and strategic operating situations, the developing problem in civil airways congestion is adding a new dimension to the total problem of air traffic control. The need for a joint approach in achieving its solution should further enhance coordination between military and civil aviation in undertaking work on other problems of common interest.

- *Third, modern aircraft, whether military or civilian, have become increasingly complex and sophisticated in the drive for improved performance and higher productivity. This, in turn, has led to parallel increases in cost and acquisiton time.* As a result, and because the availability of development funding has not risen at the same rate, the trend has been to fewer new aircraft programs. Unless the availability of development dollars is substantially increased, or unless performance demands on new aircraft are substantially changed, it is expected that this trend will continue. Planning for new aircraft development must accommodate the realities of increasing cost, longer acquisition schedules, and a reduction in the number of new aircraft program starts.

● *Fourth, the amount of aeronautical R&D funding is substantial and has been rising steadily over the years. When economic escalation factors are applied, a slight rise in purchasing power is still evident, though not as great.* However, whenever aeronautical R&D funding is compared to the Gross National Product, to total expenditures for Government R&D, or to increases in aircraft development and production costs, the trends are unfavorable, and the proportionate balances are not maintained. Aeronautical R&D funding, as a percentage of the GNP or as a portion of total Government funding for R&D, is on a downward trend.

● *Fifth, there now are major military interests in short-haul transport development, both in the STOL and VTOL areas.* The Advanced Medium STOL Transport prototype, the planned Heavy Lift Helicopter, the demonstrator and prototype engines, and related research and development programs are manifestations of these interests. These military programs, providing they continue, should yield many spin-off benefits to civil aviation in the aircraft portion of the short-haul transportation system.

● *Sixth, the current absence of a firm military need for a new long-haul transport, either high subsonic, transonic, or supersonic, could significantly impact the technology and development base that historically has existed in the long-haul area.* Although the military "research and technology" base is being maintained, the depth, relevancy, and capability of the "development" base in long-haul aircraft could erode and decline.

● *And finally, any decrease in the current relevancy of military aeronautical hardware to the needs of civil aviation could add even further to the already increasing costs of civil airliner development.* As shown in this report, these costs have risen dramatiically, and cannot help but be major considerations in any new airliner development and production programs that are undertaken.

FINDINGS

The findings of the RADCAP Study are listed below:

● *Government sponsorship, primarily military, has provided most of the significant technological advances that have been made* *in U.S. aviation.* During the time period covered by this report, from 1925 to 1972, the military has provided the funding support for about 70 percent of the technological advances assessed as being most significant by the Study Team. Government civilian agencies have funded about 20 percent of them, and the private sector has supported the remainder.

- *Early military application of technological advances in accomplishing the defense mission has provided the basis for their acceptance and use in civil aviation.* The military was first to use about three-fourths of the advances discussed in this report. This reflects an emphasis by the military on aircraft mission performance and a willingness to accept some risk in achieving this performance. It also reflects the stress of civil transport aviation on safety and passenger comfort, as well as the tendency to use new hardware and equipment only after it has been proven and demonstrated in military aircraft systems.

- *Other bonus effects, or spin-off benefits, of military aeronautical R&D have been extensive - manufacturing technology and techniques, production methods, tooling, and plant and test facilities.* The availability and use of military ground and flight test facilities, for example, have been very important to growth and progress in civil aviation.

- *The military aeronautical R&D program, in support of defense objectives, will continue to be substantial.* This is reflected in the military aeronautical R&D funding and program discussions of this report. The question of the "adequacy" or "sufficiency" of this program, however, for either military or civilian aviation R&D needs, was not addressed in this study.

- *The research and technology generated by the military R&D program will continue to be available for civil aviation application, essentially as in the past.* With the possible exception of large, long range, transonic and supersonic cruising aircraft, the relevancy of the military aeronautical technology base to the R&D needs of civil transport aviation is high, and the spin-off benefits of military technology should continue to be important and significant.

- *The benefits accruing to civil aviation from the military sponsored development and production base, however, have decreased in both relevance and importance.* As a result of the decrease in the number of new military aircraft development and production programs, particularly in those of the large transport and large bomber categories, the "direct" transfer of hardware and equipment from military to civil application that marked the early and mid-Fifties has changed to the "bits and pieces" transfer process of today.

- *In short-haul transportation, however, the downward trend in the hardware transfer process should reverse, and relevancy should begin to improve.* This assessment is based on the relatively large number of military R&D activities now in progress in this area, and assumes that the current programs, particularly the prototype aircraft and engine programs, will continue to completion.

- *In long-haul transportation, little change to the current relevancy status is forecast.* Unless something new or significant should occur, the transfer of hardware and equipment probably will remain at the low-to-moderate levels of today.

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RADCAP VOLUME II REPORT

APPENDICES LISTING

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