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SOME HISTORICAL TRENDS IN THE RESEARCH AND DEVELOPMENT OF AIRCRAFT

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SUMMARY

A survey of some trends in aircraft design was made in an effort to determine the relation between research, development, test, and evaluation (RDT and E) and aircraft mission capability, requirements, and objectives. Driving forces in the history of aircraft include the quest for speed which involved design concepts incorporating jet propulsion systems and low drag features. The study of high speed design concepts promoted new experimental and analytical research techniques. These research techniques, in turn, have lead to concepts offering new performance potential. Design trends have been directed toward increased speed, efficiency, productivity, and safety. Generally speaking, the research and development effort has been evolutionary in nature and, with the exception of the transition to supersonic flight, little has occurred since the origin of flight that has drastically changed the basic design fundamentals of aircraft. However, this does not preclude the possibility of dramatic changes in the future since the products of research are frequently unpredictable. Advances should be expected and sought in improved aerodynamics (reduced drag, enhanced lift, flow field exploitation); propulsion (improved engine cycles, multimode engines, alternate fuels, alternate power sources); structures (new materials, manufacturing techniques); all with a view toward increased efficiency and utility.

INTRODUCTION

Man's dream to fly like a bird began many centuries ago. The Chinese Emperor Shun was supposed to have built himself an air chariot in 2500 B.C. Somewhat later, serious thinkers began to study the properties of air. Aristotle conceived that air had weight, and Archimedes discovered the principle of buoyancy or floating in a fluid. Other men of science probing the mysteries of air and flight included Galileo, Bacon, Pascal, and da Vinci. Around 1490, da Vinci invented a spiral screw which could raise (or pump) water or, in air, could potentially sustain flight. He correctly deduced that the flow of air over the wing of a bird provided lift and the faster the flow of air the greater the lift. Numerous pioneers--Watts, Giffard, Otto, Cayley, Daimler, Henson, Stringfellow, Moy, Phillips, Ader, Maxim, Lilienthal, Langley, Chanute, Herring and others--brought about better understanding of propulsion; wing curvature or camber; balance and control; and so on. At the turn of the 20th century, the Wright brothers began to make a mark on the history of manned-powered flight and man's conquest of flight began to catch hold in earnest.

DISCUSSION

The Beginnings

Wright Brothers.- The first officially acknowledged controlled and sustained flight of a powered, man-carrying, heavier-than-air airplane occurred at Kitty Hawk, North Carolina, on December 17, 1903, when Orville Wright flew the Wright brothers' Flyer I for 12 seconds over a distance of 120 feet at a ground speed of about 7 miles per hour and an altitude of 8-12 feet. Substantial progress in airplane performance has since been made. In fact, on the first day of powered flight, the Wright brothers were able to extend the performance on the fourth flight to a distance of 852 feet and a time of 59 seconds. Curiously enough, the accomplishments that the Wright brothers attained in less than 2 hours had been preceded by years of planning

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through the study and analysis of the work of other experimenters through wind-tunnel tests and through prototyping with kites and gliders.

World War I.- Airplane development preceded rapidly around the world in the early 1900's--European countries, Italy, Russia--but development in the U.S. moved in a a somewhat more restrained manner. During World War I, the airplane became an effective weapon of war with the major technology growth directed toward increased utility, mission needs, or lethality, rather than in improved performance in terms of speed, altitude, range, or maneuverability. Most of the development of these airplanes was accomplished by the European countries with the major event in the U.S. being in the creation of an aircraft industry to aid in production.

Creation of NACA.- Although other countries had seen the value of aeronautical research and development, it was not until March 1915 that the U.S. Congress passed a resolution that created the National Advisory Committee for Aeronautics (NACA) which, in 1958, became the nucleus of the National Aeronautics and Space Administration (NASA). The sum of $5000 was appropriated for the first year's operation and the Committee embarked on the task "to supervise and direct the scientific study of the problems of flight, with a view to their practical solution." Construction work for the NACA began at Langley Field, Virginia in July 1917. Construction for the first of many wind tunnels began in the spring of 1919. On June 11, 1920, the new wind tunnel was operated for the first time and the Langley Memorial Aeronautical Laboratory (now Langley Research Center) was formally dedicated. The laboratory was not established in time to impact the military aircraft of World War I but in the early 20's, through innovative wind-tunnel test techniques and through full-scale flight test work, NACA did begin the conceptual process of improving the aerodynamic characteristics of existing aircraft and their components. New unique facilities were continually developed such as the variable-density wind tunnel; propeller research tunnel; full-scale tunnel; spin tunnel; low-turbulence tunnel; high-speed tunnel; ice tunnel; free-flight tunnel; hydrodynamic test tanks; structures test equipment, supersonic, hypersonic, and transonic tunnels; thermal tunnels; dynamic and flutter tunnels; and so on.

Some of the events of significance during the 1920's and 1930's included the engine supercharger; initial high-speed airfoil design; the NACA cowling that increased cooling and decreased drag for radial engines; basic NACA airfoil research; drag clean-up studies; stressed-skin construction; wing flap studies; cantilever wings; retractable landing gear; enclosed cockpit. These developments were directed toward increased speed; increased efficiency; increased safety and comfort; increased utility or productivity.

Speed

One of the inherent features of movement through air is the possibility of attaining high speeds. With speed, there are economic advantages possible in time-savings and the potential for increased productivity exists. For military purposes, other possible advantages include rapid response, negating defenses, and increased survivability.

Compressibility.- A major problem of high speed flight, however, resulted from the fact that air is compressible such that, for a given shape moving through the air at increasing speeds, a point can be reached where the compressed air creates a drag in excess of the thrust. For airfoil shapes, a change in pressure distribution may occur that tends to cause stability and control changes and, in some cases, a diving

tendency exceeding the control recovery capability could result. These problems of compressibility challenged the researcher for many years. Diving tendencies for airplanes such as the P-38 were overcome by the development of an undersurface dive flap that, when deflected, created a nose-up pitching-moment to aid in the dive recovery.

Test Techniques.- In the case of compressibility, the press of aerodynamic advancement gave impetus to the researcher to develop new test techniques with which to study the phenomena. The resulting test techniques included free-fall drop models; free-flight rocket models; wing flow; transonic bumps; and the slotted-throat transonic test section. The look ahead to supersonic flight also influenced the research airplane flight test program (X-series), and the further development of supersonic and hypersonic wind tunnels and engine test facilities.

Propulsion.- An additional limiting factor to the speed progression was the use of conventional propellers--popular since the Wright Flyer. Rotating propeller blades also suffered from compressibility effects and thus eventually reached a point where the airplane speed was limited by the ability of the propeller to accelerate the airstream. A major technological change in aircraft design then occurred with the incorporation of reaction propulsion systems such as rocket motors and jet engines. Rocket powered aircraft were produced by the Germans in the mid-30's. Jet propulsion was also being developed in Germany (von Ohain) and in Great Britain (Whittle). The increased speed attainable through jet propulsion now presented other challenges--principally that of reducing drag.

Airframe Considerations

Swept Wings.- At the end of World War II, the work of German scientists on the use of wing sweep for achieving higher flight speeds became available. An example is the work of Dr. Adolf Betz on airfoil theory published in 1935. The basic theory for swept and yawed wings as developed by Betz is based on the concept that only the component of velocity normal to the wing leading edge determines the chordwise pressure distribution. Thus, by increasing the sweep angle, the normal component of flow is reduced and the critical Mach number at which the drag rises due to compressibility is increased. The use of wing sweep was to have a pronounced effect on the design of airplanes and missiles for years to come. Wind-tunnel tests and theoretical studies of swept and yawed wings (including swept-forward wings) were underway at NACA in the mid '40's. The first operational swept-wing fighter in the U.S. was the jet propelled P-86 which first flew on October 1, 1947. The airplane began its life in 1944 as a straight-wing Navy jet (XFJ-1 Fury). As German data became available, the design evolved to the 35-degree swept-wing airplane.

In the same time period following World War II, the U.S.S.R. began the development of a jet-propelled swept-wing fighter, the MiG-15. In the case of the Soviet Union, they not only acquired the German data but they also acquired the German scientist, Dr. Betz himself, to assist in the development of the swept wing fighter. Through diplomatic skills, the Soviets acquired the British Rolls-Royce Nene jet engine and used it to power the MiG-15. The MiG-15 had a tremendous impact on air warfare in Korea where it initially gained a tactical edge over the slower P-51's, F-80's, and F-84's. But in late 1950 when the F-86 arrived in Korea, the balance of air power swung back in favor of the U.S. fighter.

Other air powers along with the U.S. and the U.S.S.R. have continued to exploit the advantages of wing sweep with fighters, bombers, and commercial aircraft over the

years. A research airplane, the Bell L-39, which was a P-63 modified to incorporate a swept wing, was flight tested at NACA-Langley in 1947 as an aid in the studies of swept wing design. Bell subsequently built the X-5 research airplane which was capable of changing wing sweep in flight as a further aid in the studies of sweep. Some of this work was used in the development of variable-sweep aircraft which will be discussed later.

Delta Wings.- The delta planform offers another approach to speed capability through the use of a highly-swept leading edge and the achievement of a low-thickness ratios. The concept has an origin traceable to Germany where Dr. A. Lippisch developed the tailless Me. 163 Komet rocket airplane and did research work on delta wing designs. Lippisch continued his work with the U.S. Air Force following the war and, working in cooperation with Convair, the tailless delta-wing XF-92A was conceived and first flew on June 8, 1948. A follow-on development, the F-102, proved inadequate for supersonic flight and, in modifications designed to reduce its drag, the transonic area rule was applied for the F-102A. A successor airplane (F-106) had no difficulty in attaining M = 2 flight and is still in limited service as an interceptor today. Many other delta-wing type aircraft were subsequently developed around the world and this configuration was destined to leave its mark on aircraft design history. The U.S.S.R. acquired the German delta wing data and proceeded to exploit the design. Several Soviet aircraft make use of the concept with perhaps the most notable example being the MiG-21, a fighter having M = 2 capability, that was flying by 1955. The Soviet delta wing designs generally use aft-tail controls as opposed to the tailless configuration. It is reasonable to assume that the use of the aft-tail control gives good control effectiveness; makes provision for wing landing flaps; and does not detract from the wing lift-drag ratio. The effectiveness of the MiG-21 in an air combat role was recognized in Vietnam and partly led to the decision for the U.S. to design a "MiG killer" that was to become the F-15.

Trapezoidal Wings.- Still another approach for high speed was through the use of razor-sharp, thin, low aspect ratio wings. A classic example was the F-104. While achieving low drag and high speed, the F-104 had some stability problems and load carrying limitations. Many F-104's were built and used primarily in foreign countries but the basic concept was not to become a hallmark of fighter design.

Variable Sweep.- U.S. studies in the late 1940's by the Bell Company, based again on German data, suggested the possibility of combining the low-speed advantages of low sweep with the high-speed advantages of high sweep into one airframe having a variable wing sweep capability. The concept resulted in the X-5 variable sweep research airplane that partly lead the way to other operational aircraft. In the late 1950's and early 1960's, NASA variable sweep programs included various research models; a configuration for the Navy CAP mission; configurations for the Air Force TAC mission; and provided support of the multimission TFX concept. Later, the concept was to reappear in the U.S. in the form of the B-1 strategic supersonic penetrating bomber and the Navy F-14 fleet air defense fighter. Several Soviet variable-sweep airplanes ranging from fighters to bombers have been produced. The French have flown a variable-sweep Mirage, and the multinational (Britain, Italy, Germany) variable-sweep Panavia Tornado is in service.

Commonality.- In February 1961, Robert McNamara directed the Navy and the Air Force to combine their separate plans for a new tactical aircraft. Thus began the TFX (Tactical Fighter Experimental) program that was to emerge as the F-111. Although the services opposed the program, DOD persevered and a joint development for a common aircraft proceeded--F-111A for the Air Force and F-111B for the Navy. What began as the symbol of a new order in defense acquisition was, several years later,

to become a symbol of the failure of that order. The Navy never procured any B models and, after cancelling out of the program in 1968, proceeded to develop its own shipboard fighter, the F-14. The Air Force acquired only a third of the planned number of F-111 aircraft (less than 500) and subsequently preceded to develop its own tactical fighter, the F-15. By the end of the '60's, this effort to achieve bi-service use of a single aircraft--to achieve commonality--had failed. The reasons for this failure, which revolve around weight and size limitations that were incompatible with the multimission performance requirements, are not to be considered in detail in this paper. It is the purpose of this discussion to point out that the research, development, and acquisition of "common" bi-service aircraft was not new with the TFX program nor is commonality necessarily inherently doomed to failure. Some examples of successful commonality include the Boeing P-12 (Army)/F4B (Navy). This highly successful design was first delivered beginning in 1929 with 366 going to the Army as P-12's and 188 going to the Navy as F4B's. The Navy version was operational from the carriers Lexington, Langley, and Saratoga beginning in 1929 and was one of the forerunners of modern carrier fighters. A somewhat more recent example of commonality is the F-4 which originally was developed as a Navy shipboard fighter (F4H-1) and was later procured by the Air Force. Until the advent of the F-15, the F-4 was the mainstay of the Air Force tactical fighter fleet. Other examples could undoubtedly be found but suffice it to say that bi-service use of a "common" design is achievable.

Research Airplane

The quest for research to keep pace with performance potential lead to the creation of a manned flight research airplane program in the mid 1940's that was to explore concepts including straight wings, swept wings, delta wings, variable sweep, swept tailless, canard-delta, rocket and jet propulsion, and VTOL. Much was learned from the program that would assist in the development of future airplanes with regard to aerodynamics, stability and control, handling qualities, structures, propulsion, and so on. The program resulted in airplanes to first exceed M = 1 (X-1); M = 2 (D-558-II); M = 3 (X-2); M = 6 (X-15); first manned outer space and reentry flight (X-15); exploration of low altitude penetration flight (X-5); and many other highlights. It would appear that the research aircraft program was a worthwhile venture that contributed substantially to the advancement of airplane design.

Century Series

The conquest of supersonic flight lead to a rash of designs in the 1950's that reflected almost all types of configurations. It was the era of the "Century Series" airplanes in which some problems were exposed and, in most cases, corrective measures were applied by the experimentally developed "fix" rather than by any innovative technological development. Most of these airplanes experienced stability problem. Fixes included increased vertical tail area or the addition of ventral fins to improve the directional stability characteristics of such airplanes as the F-100, F-102A, F-104, F-105, F-106. The original F4H (Phantom II) was modified after wind tunnel testing to include increased tail anhedral, a leading edge extension, and wing tip dihedral.

Area Rule

The F-102 exhibited transonic drag problems that lead to the application of area-rule techniques that would influence the design of many aircraft to follow. The area rule simply reiterates a fundamental problem associated with compressibility--that the drag of a vehicle moving through air is directly related to the extent of the disturbance imparted to the air. For a vehicle of a given volume, it is desirable to have the overall area or volume distribution from nose to tail as small and as smooth as possible in order to reduce the disturbance to the air and, hence, reduce the drag. Early designs to adopt the principle were the F-102A, F-106, F-105, and F11F-1.

Computer Aided Design (CAD)

With the advent of computer techniques, it became possible to more easily examine and adjust the volume distribution for the reduction of drag at zero lift. The techniques have continually been improved to include the drag due to lift; to design optimum wing planforms, camber, and twist; to design cambered wing-body combinations for self-trim and drag reduction; to extend into the supersonic regime (supersonic area rule); to calculate sonic boom pressures; examine interference flow fields; and so on. The computer aided design techniques have resulted in the conception of near-optimum designs and have permitted the rapid turnaround time required to examine aerodynamic trade benefits early in the design stages. The general use of computer aided design techniques has become one of the most important design tools of the last two decades.

Programs that have made extensive use of CAD have been the SCAT supersonic transport; the continuing supersonic cruise programs; the VFAX (Navy) and FX (Air Force) fighter programs; the Lightweight Fighter Prototype program; the super-critical airfoil program; laminar flow airfoils; and so on.

RDT and E Role

Research Approaches.- Research approaches in the U.S. are varied. Often a systems problem arises and research is undertaken to provide solutions. Basic research sometimes reveals new potential capability and suggestions for systems to exploit that capability may follow. Research is not centralized in the U.S. but is independently conducted by government, military, industrial, academic, and private sources. Communication between various research groups can be a problem. It is possible that some problems may get little attention whereas, at the same time, some solutions may develop for which there is no problem.

Team Studies.- There have been team studies wherein groups of researchers that represent various government, military, and industry organizations work together on a given project. Some examples of this type have been the SST, TFX, FX, VFAX, and LWF programs. The technological accomplishments of such groups has generally been excellent but the utility of the studies has sometimes been dictated by factors other than technology--economics, mission constraints, political environment, and so on.

U.S.S.R. Approach.- The history of Soviet aircraft development is both an example and a contradiction of the political system. Designs are generated within the Council of Ministers and thus reflect the needs of the state and are controlled by the highest levels of a centralized government. However, the design bureaus, like U.S. firms, exist in a highly competitive environment with special rewards for

success. Soviet designs are judged by performance, simplicity, maintainability, and ease of manufacture. Low cost and simplicity are generally emphasized over innovation and sophistication. Among the rewards for success may be years of continued production with modified versions or new generations of aircraft derived from previous proven designs. Features of the Soviet system are:

- Highest government levels support the aircraft industry
- Separation of design and production
- Research institutes supply handbooks that control approved aerodynamic designs, structural methods, and available materials
- Emphasis on competition at all levels including prototyping
- Simplicity, commonality, and continuity predominate

The Last 40 Years

Military Aircraft Trends.- Some trends in U.S. jet propelled military developments over the past forty years are shown in figure 1. This figure shows the cumulative total of combat aircraft that were built and flown although not all reached an operational status. With minimal exceptions, only pure jet aircraft are included.

U.S. jet aircraft began with the Bell XP-59 in 1942--the same year that the Boeing B-29 bomber flew. The first operational jet, the Lockheed XP-80 followed in 1944. A rapid series of jet types soon followed. The swept wing jet was introduced with the North American P-86 in 1947 and a rash of designs continued into the early 50's. Following the experimental transonic and supersonic research airplane flights of the late 40's and early 50's, the first operational supersonic jet fighter--the North American F-100--appeared in 1953. Now a new surge of supersonic designs of various types followed through the 50's. In 1962, the Lockheed A-11, forerunner of the YF-12 and SR-71, first flew and M = 3 operational capability became a reality. At about that point, the prolific design trend began to slow. The next USAF fighter, which came in 1963, was the McDonnell F-4C and was an adopted Navy design from the mid 50's. Then the era of commonality produced the General Dynamics F-111A in late 1964. The next new fighter for the Air Force did not appear for eight years when the McDonnell Douglas YF-15 flew in 1972. The General Dynamics F-16 lightweight fighter subsequently flew in 1974.

Bomber development has been less than spectacular. The Boeing B-52, introduced in 1952, is still the mainstay of the bomber force. In the interim, the Convair B-58 M = 2 bomber was in and out of the inventory in the mid 50's to 60's; the M = 3 North American B-70 was successfully developed in the mid 60's and then cancelled; the Rockwell International B-1 variable sweep airplane flew in 1974 and successfully demonstrated high altitude cruise, low altitude penetration, and M = 2 flight by 1976, but was cancelled in 1977 and then reinstated in 1981.

U.S./U.S.S.R. Trends.- A similar figure in which U.S.S.R. military aircraft have been added permits some observations on development trends within the two countries (fig. 2). The cummulative number of U.S.S.R. types may be somewhat low because of the manner in which Soviet aircraft are modified. The MiG-21, for example, is shown only at its initial entry date in 1955. However, about ten substantially revised versions of the MiG-21 have been developed through 1976.

The first Soviet jet fighters, MiG-9 and Yak-15, appeared in 1945-46 and both became operational in about the same time period as the U.S. P-80. The production of these airplanes was speeded up considerably through the use of German jet engines.

The MiG-15 followed closely in 1947 thus introducing the swept-wing jet fighter in the U.S.S.R. in the same year that the P-86 was introduced in the U.S. The production of the MiG-15 was greatly accelerated through the use of the British Rolls-Royce Nene jet engine. Several other lesser-known jet fighters were built in the late 1940's--the Yak-17, Yak-23, Yak-30, Yak-50, and the La-15. A version of the La-15 with a 45-degree swept wing and a Rolls-Royce Derwent engine broke the sound barrier in December 1948. The MiG-17, a better known follow-on to the MiG-15, broke the sound barrier in February 1950. The MiG-19 appeared in 1953 and demonstrated M = 1.3 capability--the same year that the YF-100 was demonstrating the same capability in the U.S. The MiG-21 followed in 1955 and demonstrated M = 2 capability in about the same time frame that the U.S. demonstrated such capability. The Soviets have followed with M = 3 capability demonstrated in the mid 1960's with the E-266--again in the same time frame as similar developments were occurring in the U.S. In 1967, the Soviets unveiled several new aircraft in the Foxbat, Flogger, Flagon, Fitter B, Faithless, and Forehand indicating advances or growing interest in fighters, interceptors, variable wing sweep, STOL, VTOL. In 1969, the variable-sweep Backfire bomber appeared; in 1974, the shipboard Forger VTOL; in 1976, the variable-sweep Fencer fighter-bomber; and into the 1980's with at least five new fighters including the improved Flogger J, Foxhound, Fulcrum, Flanker, and Frogfoot; as well as the Blackjack bomber and other possible developments of new interceptors, transports, and bombers. In any event, the preponderance of aircraft types displayed by the Soviets should cause one to closely examine the balance of power between the East and the West.

Miscellanea

Firsts Are Hard to Find.- It is difficult to attribute a "first" to any design feature. The following is a partial list of recorded events, to help illustrate the problem of "firsts:" Air screw (propeller and helicopter) and flying machines, da Vinca, 1490; jet-powered delta wing, 1867; cambered airfoils and tandem wings, 1890; canard, early 1900's; swept-wing tailless, 1910; wing tip vertical tail, 1911; circular wing, 1911; enclosed cabin, streamline wheel covers, monocoque fuselage 1912; engine cowling, spinners, 1913; all-metal airplane, 1916; stressed-skin, 1919; retractable gear, 1921; variable camber wing, 1921; wing fillets, 1921; etc. To some extent, current research on multibodies; spanloaders; and blending are also reflected in the past. Do not be discouraged if you are told there is nothing new.

Stray Dogs.- While "stray dog" designs abound, only a small sampling will be mentioned. In 1939, Curtiss, in an effort to perpetuate the P-36 and P-40 series produced several airplanes for test. The YP-37 introduced the new Allison inline engine to the P-36 airframe with some increase in speed. The XP-40Q used a full-bubble canopy and clipped wings adapted to the P-40 airframe for some increase in speed. The XP-42 introduced more streamlining attempts and an all-moving horizontal tail was installed. The XP-46 was based on fighter pilot experience in Europe and incorporated automatic leading-edge slats similar to those on the Messerschmitt 109. Curtiss proposed the XP-46 to the Army and the Army then drew up a requirement around the proposal. Although each of these Curtiss airplanes were built and flown, none actually entered the inventory. A few other stray dog designs resulted from Army competitions in 1939-40 seeking new fighter designs in anticipation of involvement in World War II. One was the Vultee XP-54 Swoose Goose, a pusher-propellor design with twin-tail booms that flew in 1943. The XP-54 had an articulating nose section that could be tilted upwards to permit lobbing shells to achieve maximum range from its two low-muzzle velocity 37 mm cannons. At the same time, two .50 caliber machine guns, with higher muzzle velocity, were depressed downward. The XP-54 had a unique

engine cooling system with air being drawn in at the wing leading-edge root, passed over the engine radiators and exited through a slot in the landing flap trailing edge. A small flap was mounted on the landing flap for controlling airflow in flight. The XP-54 also had a hinged door beneath the cockpit that dropped downward and lowered the pilots seat for entry. The bottom door could also be used for emergency, in-flight, downward ejection to clear the propeller.

The Curtiss XP-55 Ascender was a 30-degree swept-wing, tailless, pusher with a canard trimming surface that first flew in 1943. The airplane used outboard vertical tails and wing-tip "trailerons" outboard of the vertical surfaces. Four .50 caliber guns were mounted in the nose and the all-up weight of the airplane was only 7300 pounds. Three were built, but stability problems and engine cooling problems led to cancellation by the Army in late 1943.

A third pusher-type was the Northrop XP-56 Black Bullet. The XP-56, which was flying in 1943, was a true flying wing based on previous Northrop work with flying wing designs. The aircraft was designed with split flaps on the outboard trailing-edge to provide yaw control. A later modification included wing tip venturi tubes with valves to create yaw through differential drag.

While these radical fighter designs and several other proposals were being evaluated and rejected, the British had approached North American Aviation in April 1940 in search of a new fighter for the RAE. As a result, the NA-73 was turned out in 117 days and first flew in October 1940. Subsequently, the airplane which was designated the P-51 Mustang (or A-36 dive bomber), was adopted for U.S. operational use in 1943 and became one of the outstanding fighters of the war. The P-51 used the newly-developed NACA laminar-flow wing and had a radiator ingeniously positioned beneath the body for low drag. The P-51 was not a stray dog but the manner in which it strayed into the U.S. inventory by way of the British and not by way of the Army competition is interesting.

Lightweight Fighters.- With no criteria for defining a "lightweight fighter," a few designs that might qualify will be mentioned. In 1939, Douglas proposed to the Army a small, high-altitude fighter designated XP-48. Gross weight was 3400 pounds, aspect ratio was 11, maximum wing loading was 37 pounds per square foot. The airplane was never built.

The Tucker XP-57, proposed in 1940, weighed 3000 pounds loaded. The engine was located behind the pilot with the propeller drive shaft passing between the pilot's legs. With a fully loaded wing loading of 25 psf, the airplane was expected to be highly maneuverable but it was never completed.

The Bell XP-77 gross weight was 3583 pounds with a maximum wing loading of about 35 psf. With a view toward saving critical wartime materials (1942), the airplane made extensive use of plywood. Two airplanes were eventually built, the first of which flew on April 1, 1944. The second airplane was lost in an inverted spin in October 1944 and the program was cancelled in December 1944.

Before Their Time.- The Northrop XP-79A was begun in 1942 as a unique rocket-propelled flying-wing fighter design following the pattern of the German Me 163 Komet. Although the rocket version was eventually cancelled, a rocket propelled flight was made on July 5, 1944. Further development was done with a jet-powered XP-79B that flew, and was destroyed in a crash September 12, 1945. The unusual magnesium airframe was totally consumed by fire. The airplane was only 14-feet long

and incorporated a prone position cockpit which would have permitted the pilot to withstand 21 g's. Wing-tip bellows were used to provide yaw control and a four-point gear was installed.

The Republic XF-91 Thunderceptor design was begun in 1946 as a supersonic daytime interceptor. The airplane was fitted with a jet engine and four rocket motors to provide rapid acceleration and climb capability. The airframe had a unique 35-degrees swept wing with adjustable incidence to provide the most effective angle of attack for take-off, cruise, and landing. In addition, the wing had inverse taper which, in conjunction with leading-edge slats, was intended to reduce the tendency of wing tip stall at low speeds. The jet version flew in May 1949. In December 1952, the airplane with combined jet and rockets, reached 50,000 feet in 5.5 minutes at M = 1.7. While this performance could not be matched by contemporary jet interceptors, further development was halted and the interceptor role was subsequently filled by the Convair F-102A.

The Republic XF-103 design was one of the winning entries of the advanced interceptor program initiated in 1949 to provide a new interceptor capable of exceeding M = 1 at greater than 50,000 feet and to be operational in 1954. The XF-103 design had a dual-cycle turbo-ramjet engine which was intended to achieve about M = 4 at 80,000 feet with a combat radius of about 430 miles. The engine, to be developed by Wright, was to be a conventional turbojet with an afterburner designed to serve the dual purpose of a ramjet engine. Other advances in state-of-the-art included titanium construction, high temperature hydraulics, downward ejection escape capsule, retractable ventral fin, and periscope forward vision (no canopy). A metal mock-up was constructed but after a nine-year development program and some problems with titanium procurement and fabrication, engine development, and funding, the project was cancelled in September 1957. It is interesting to note, however, that many of the features of the XF-103 design were used later on the Lockheed YF-12, including the concept of the dual purpose afterburner/ramjet system.

The North American F-107A was a ground attack fighter-bomber design of 1953 that was in competition with the Republic F-105. Although the F-107 lost the competition, three airplanes were built and extensive flight tests were conducted. The F-107 had no difficulty in achieving M = 2 flight in 1956 and demonstrated several features such as the top-mounted inlet, all-moving vertical tail, and spoiler roll controls.

Another USAF program began in 1955 to develop a long-range intercepter. North American received a contract in 1957 for the XF-108 Rapier design which was to be an all-weather, two-man, two-engine, long-range interceptor with a combat speed of at least M = 3 at 70,000 feet with a 1000 nautical mile range and 5 minutes of M = 3 combat. In addition, the airplane was to cruise at M = 3 for 350 miles with 10 minutes of M = 3 combat. Finally, there was a requirement for M = 3 cruise for 280 miles with a one-hour loiter time followed by a high speed target intercept 750 miles away. The XF-108 was similar to the B-70 delta wing-canard design but had twin horizontal-ramp side inlets, a centerline vertical tail, and two wing-mounted vertical surfaces for added directional stability. The Air Force believed that the F-108 would be a good mobile missile launcher to intercept enemy aircraft far from their intended targets, and in 1957 had programmed for about 480 aircraft to become operational by 1963. A mockup was built by early 1959 but the airplane was never to be built and the program was cancelled September 23, 1959 due to funding problems. (Note that was 24 years ago and today we are still studying aircraft designs with similar, or less, capability.)

The degree of success that might have been achieved with these various cancelled designs remains speculative. However, it is fair to say that, had these designs become operational, we would have had building blocks that could have undoubtedly resulted in far more advanced designs than we have today.

EPILOGUE

This paper, being historical in nature, does not permit definite conclusions or recommendations. However, based on the historical record, some observations related to the research and development of aircraft seem relatively clear:

- The research and development of U.S. aircraft since 1903 has been more evolutionary than revolutionary.
- The most radical changes in aircraft design occurred with the advent of jet propulsion and the conquest of supersonic flight.
- Many advances in design are brought about through "technology transfer"--a notable example being the German influence following World War II.
- Many advances have occurred through urgent necessity brought on by war, for example.
- Experimental flight programs have been major contributors to aircraft design.
- Many design features have occurred as "fixes" to unexpected problems although some problems have undoubtedly been prevented through advanced research.
- The exploitation of the "area rule" and advances in computer-aided design have been significant contributors to aircraft design.
- Research is not centralized in the U.S. and can lead to communication problems that inhibits maximum application of research capability to effective utilization.
- Cancelled programs, while contributing to the learning curve, have probably resulted in a lesser current military capability than could have been achieved otherwise.

The possibility of dramatic changes in future aircraft design is not precluded, however, since the products of research are frequently unpredictable. Advances should be expected and sought in improved aerodynamics (reduced drag, enhanced lift, flow field exploitation); propulsion (improved engine cycles, multi-mode engines, alternate fuels, alternate power sources); structures (new materials, manufacturing techniques); all with a view toward increased efficiency and utility.

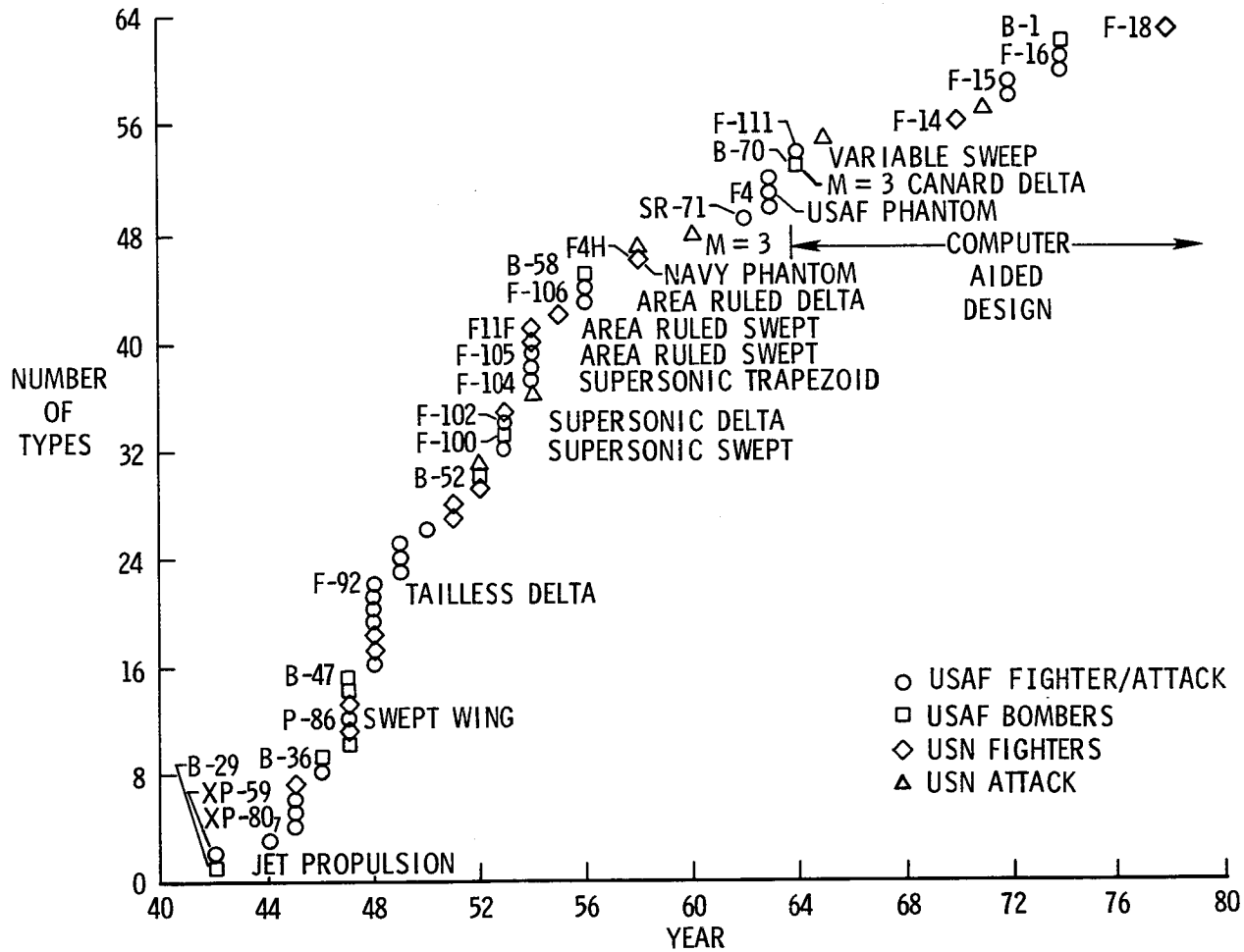

Figure 1.- U.S. military aircraft trend.

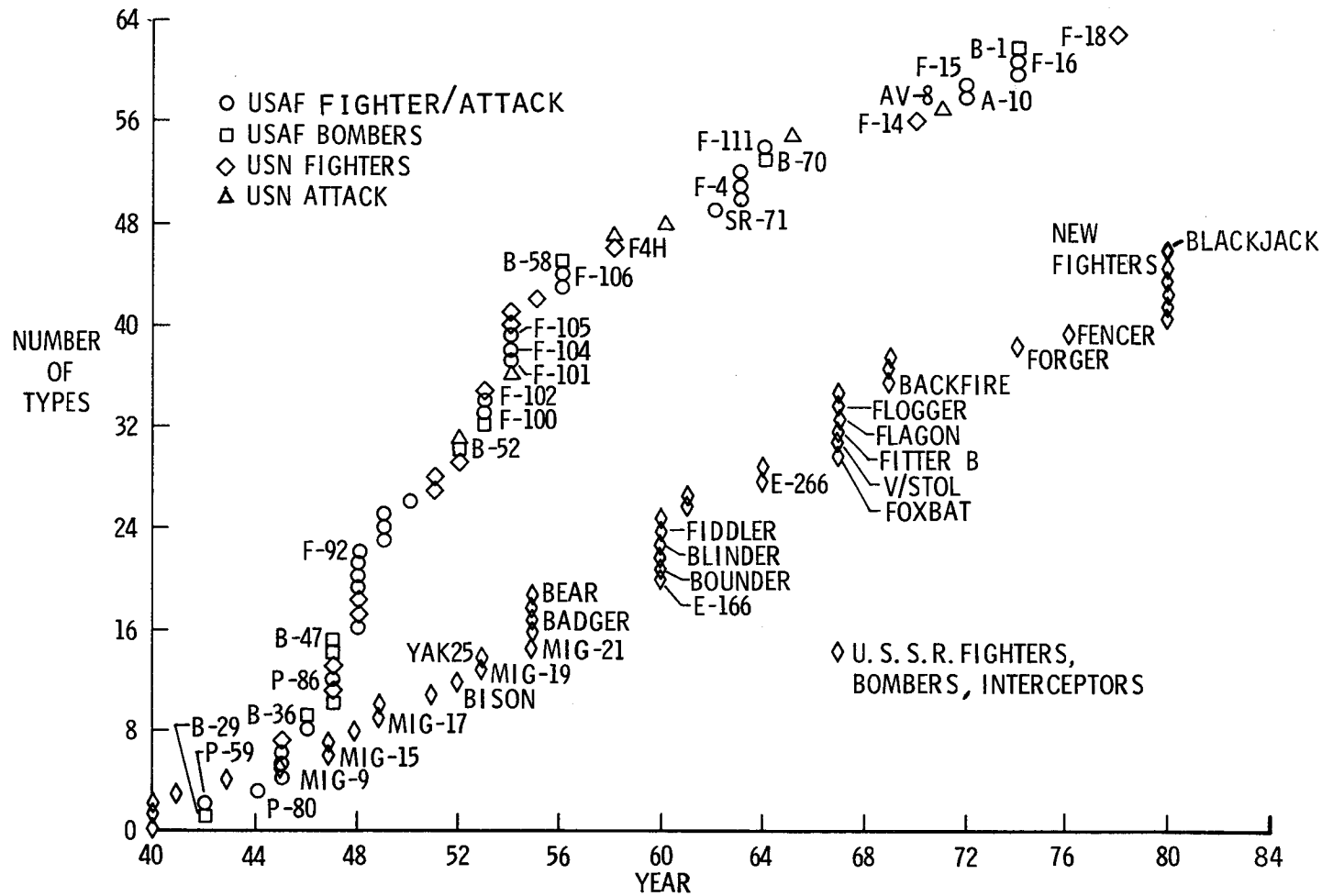

Figure 2.- U.S. and U.S.S.R. military aircraft trend.

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16. Abstract

A survey of some trends in aircraft design was made in an effort to determine the relation between research, development, test, and evaluation (RDT and E) and aircraft mission capability, requirements, and objectives. Driving forces in the history of aircraft include the quest for speed which involved design concepts incorporating jet propulsion systems and low drag features. The study of high speed design concepts promoted new experimental and analytical research techniques. These research techniques, in turn, have lead to concepts offering new performance potential. Design trends have been directed toward increased speed, efficiency, productivity, and safety. Generally speaking, the research and development effort has been evolutionary in nature and, with the exception of the transition to supersonic flight, little has occurred since the origin of flight that has drastically changed the basic design fundamentals of aircraft. However, this does not preclude the possibility of dramatic changes in the future since the products of research are frequently unpredictable. Advances should be expected and sought in improved aerodynamics (reduced drag, enhanced lift, flow field exploitation); propulsion (improved engine cycles, multi-mode engines, alternate fuels, alternate power sources); structures (new materials, manufacturing techniques); all with a view toward increased efficiency and utility.

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