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SOME FIGHTER AIRCRAFT TRENDS

M. Leroy Spearman

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National Aeronautics and
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Langley Research Center
Hampton, Virginia 23665

SUMMARY

Some basic trends in fighter aircraft are traced from the post World War II era. Beginning with the first operational jet fighter, the P-80, the characteristics of subsequent fighter aircraft are examined in terms of performance, mission capability, effectiveness, and cost. Characteristics presented include such items as power loading, wing loading, maximum speed, rate of climb, turn rate, weight and weight distribution, cost and cost distribution. In some cases, the characteristics of U.S.S.R. aircraft are included for comparison.

The results indicate that fighter capability is dependent on many factors and extreme caution should be used to assure that conclusions are not based on any preconceived obvious indicators to the exclusions of some less obvious and possibly conflicting indicators. U.S.S.R fighter trends have, for the most part, been similar to U.S. fighter trends. The future challenge in fighter technology is to reduce the size and weight while retaining, or improving mission capability. These challenges are in such areas as manufacturing, structures and materials, as well as in improved aerodynamics and propulsion.

INTRODUCTION

Integral parts of the U.S. Air Force and the U.S. Navy are those aircraft classically identified as fighters. In a broad sense, these aircraft include air-superiority fighters, close air-support-attack/fighters, as well as dedicated interceptors. Some of the better known and more widely used U.S. jet fighters of the past four decades are shown, drawn to the same scale, in figure 1. These are the P-80 Shooting Star (about 1945), the F-86 Sabre (about 1948), the F-100 Super Sabre (about 1954), the F-4 Phantom II (Navy, 1958; USAF, 1963), the F-15 Eagle (about 1972), and the F-16 Falcon (about 1974). These fighters, together with many others, will be reviewed in the present paper for the purpose of depicting fighter trends over the past 40 years and to provide some rationale for past, present, and future fighter design trends. It is not presumed that this paper could possibly cover all aspects of fighter design technology. It is the purpose of this paper, however, to highlight some diverse features of fighter concepts and to at least illuminate to some extent the complexity of considerations required in arriving at a fighter concept.

SYMBOLS

M	Mach number
S	reference wing area
T	thrust
W	weight

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DISCUSSION

Historical Background

U.S.A.F. Fighters.- A chronological depiction of Air Force fighter types (fig. 2) begins with the first U.S. jet fighter, the Bell XP-59A Airacomet, in the early 1940's. The "P" designation for "pursuit" was in use through the era of the United States Army Air Force (USAAF). When the United States Air Force (USAF) was created in 1947, the pursuit designation was changed to "F" for "fighter." Hence, for a period of time, some service aircraft carried both designations, such as the P-86 (F-86) and P-84 (F-84). Shown in figure 2 are the Air Force fighters that have been built and flown over the past 40 years, although not all reached operational status. All were jet-propelled with the exception of the propeller-driven P-82 twin Mustang and the P-81 with a combination of turboprop and turbojet propulsion. The advent of jet propulsion produced quite a flurry of fighter prototypes from the mid-1949's through the mid-1950's. Beginning in the late 1950's, however, USAF fighter prototypes have been relatively few and far between.

U.S.N. Fighters.- A similar depiction of Navy fighters (fig. 3) shows the same rapid development of prototypes in the mid-1940 to mid-1950 time period. Following the F4H in 1958, however, new Navy fighters have been extremely rare.

Composite U.S. Military Aircraft Trend.- A composite view of all U.S. military aircraft types since 1942 is shown in figure 4 together with some development highlights. The P-59, of course, represented the beginning of U.S. jet propulsion. The use of wing sweep was a highlight of the P-86. The F-92 introduced the use of the tailless delta concept that was extended to supersonic speed with the F-102 and F-106 interceptors and the B-58 bomber. The F-100 introduced the supersonic swept-wing concept. Other supersonic swept-wing concepts with the added use of the area rule for drag reduction were the F-105 and F-11F. The F-104 introduced the use of a thin, low-aspect-ratio, trapezoidal wing. The F4H introduced a slightly compromised wing planform having a relatively large leading-edge sweep angle but with a large root chord that resulted in a low trailing-edge sweep angle. The F4H design also incorporated twin jet engines--a departure from many preceding classic fighter designs. Some other twin jet designs had previously been developed, however, including the first jet (P-59), the XF-83, the XF-88, the F-89, the XF-90, the F-101, the F-5, the F3D, of which the principle operational types were the subsonic F-89 and the supersonic F-101.

Mach number 3 flight was achieved in the mid-1960's with the SR-71 (YF-12) aircraft and with the XB-70 bomber. The XB-70 also represented a different U.S. design type with its aft delta wing and canard control surface.

In the mid-1960's, the operational use of variable wing sweep appeared on the F-111 design. Previous development of variable wing sweep had been done with the X-5 and the XF10F. Variable wing-sweep concepts to follow later in the 1960's and early 1970's were the F-14 and the B-1. Other than the Air Force F-111 and the Navy F-14, no other U.S. fighter-type aircraft that employs variable sweep has been produced. Subsequent fighter designs such as the F-15, F-16, and F-18 employ fixed wings with essentially trapezoidal planforms and aft tails. The X-29 experimental aircraft currently being developed employs a fixed forward-swept wing and a canard control surface.

The many concepts developed during the period from about 1942 to the mid-1960's relied heavily on experimental data--both wind tunnel and flight. Beginning in the mid-1960's, computer-aided design techniques were developed that could greatly reduce the design time and permit rapid turnaround time in examining design changes and in making trade studies. Although these techniques are available for increased design capability and have been used in numerous design studies, the capability has not been reflected in many new flight articles over the past 20 years.

U.S. and U.S.S.R. Military Aircraft Trends.- The U.S. military aircraft trend is repeated in figure 5 and the U.S.S.R. military aircraft trend has been added. The U.S.S.R. trend does not show the early rapid growth of types followed by a tapering-off as occurred in the U.S. Rather, the U.S.S.R. trend has been steady and persistent with an influx of new types appearing at fairly regular intervals up to the present time. It should be pointed out that the U.S.S.R. trend does not reflect the extensive modifications that are made to some designs. For example, the MiG-21 Fishbed and the MiG 23 Flogger are each shown as single points, whereas, in reality, modifications to such designs have resulted in a larger family of sometimes dramatically different aircraft types.

Some other observations relative to the U.S.S.R. trend are:

- o Exploitation of jet propulsion (such as MiG-9) followed closely to U.S. developments.
- o Swept-wing jet, MiG-15, in same time period as P-86, subsequently improved with MiG-17.
- o First supersonic jet, MiG-19, in same time frame as F-100.
- o M = 3 flight, E-166 and E-266, achieved in same time frame as SR-71.
- o Configuration types have included early straight wings; swept wings; delta wings with aft tails; trapezoidal wings; variable-sweep wings.
- o Variable sweep development (Fitter B, Flogger) in same timeframe as F-111.
- o Extensive use of variable sweep, being used on the Fitter B and Flogger fighter families, the Fencer fighter-bomber, and the Backfire and Blackjack bombers.
- o Exploitation of V/STOL with direct-lift engines and vectored nozzles and deployment of Forger VTOL in same timeframe as AV-8.

Performance Characteristics

Thrust-to-Weight and Speed Trends.- The maximum thrust-weight ratios and the approximate maximum Mach number for several U.S. and U.S.S.R. fighter aircraft are shown in figure 6. It would be unwise to expect a compilation of data of this type to lead to definative conclusions since the consideration of many other factors precludes any necessarily direct correlation between T/W and M. However, in general, it would be expected that an increase in T/W would provide for increased speed, or conversely, that an increase in M would require some increase in T/W. Such a general trend is displayed for the various fighters shown. There is no question that some aircraft have been underpowered and thus restricted in speed. Others may be overpowered for the maximum speed with the excess power being dictated by such considerations as improved take-off performance, improved acceleration or climb rate, improved maneuverability, and so on. However, there is still the possibility that some relation exists between the speed and power factors and the aerodynamic drag of the airframe. In addition, the type of inlet becomes a factor--normal shock inlets, for example, may impose speed limitations sooner than a variable geometry inlet.

The U.S. fighters follow a fairly linear trend from the early subsonic jets through the more recent supersonic jets. Major departures are the AV-8, which falls above the general trend, with the higher T/W being used for the V/STOL capability, and the F-111 and F-14 aircraft, which fall below the trend, with the higher speeds presumably resulting from lower drag due to the high wing sweep and the larger size airframe which should permit a more favorable area distribution.

The F-15 has an indicated speed capability that is about the same as the F-111 and F-14 although the maximum T/W is about twice as large. This may be due, in part, to excessive T/W in the F-15 for other purposes and, in part, to lower drag for the F-111 and F-14 due to wing sweep and better area distribution.

A tentative assessment of the U.S.S.R. aircraft indicates a general trend of T/W versus M that is slightly better than the U.S. trend. That is to say that generally higher speeds are indicated at lower levels of T/W. For example, the MiG-21, MiG-23, MiG-25, MiG-31, SU-15, SU-27, and MiG-29 family all indicate speeds equal to, or greater than the F-18, F-16, and F-15 family with the same, or less, T/W values. This difference reflects the probability of lower drag due to more slender area distributions and, in the case of the MiG-23, some added benefits of wing sweep. The Yak-36 operates with a lower T/W than the AV-8 presumably because of the utilization of direct lift engines to aid the V/STOL capability. The TU-28 which operates at about the same speed as the F-16 and F-18 but with half the T/W, is an extremely large, long-range interceptor, which should have a better area distribution than the small fighters. The SU-24 which, in many ways, is physically similar to the F-111 and F-14 has T/W and M characteristics that are also similar.

It cannot be overemphasized that conclusions drawn from this type of comparison must be kept in context with other considerations that enter into speed and thrust values. Some of these additional considerations will be discussed subsequently.

Performance Capability.- Another measure of performance can be presented in the form of maximum takeoff thrust-weight ratio and combat wing loading (about half fuel). This kind of measure (fig. 7) indicates that, in general, as T/W increases and W/S decreases, a tendency toward increased agility should result--more power with which to move and less weight to be moved. As the wing loading increases, a tendency toward increased endurance generally occurs since the increased weight usually results from an increase in fuel. A large number of U.S. aircraft and U.S.S.R. aircraft can be placed within bounds that largely overlap. If anything, the U.S.S.R. boundary indicates a slightly greater tendency toward agility whereas the U.S. boundary shows a slight tendency toward increased endurance. Falling outside the region of reasonably similar boundaries were the U.S. F-15, F-16, F-18. These aircraft indicate increased agility due to high-thrust loadings while maintaining low wing loading. Although parameters for the U.S.S.R. MiG-29 and SU-27 are not sufficiently defined, it is reasonable to speculate that they would be well outside the U.S.S.R. boundary shown and would probably be in the direction of increased agility similar to the F-16 and F-18. The U.S. F-111 and the U.S.S.R. SU-24 are well outside the boundaries in the general direction of greater endurance. The U.S.S.R. TU-26 bomber is also shown as an example of an aircraft that would be expected to maximize on endurance with less concern for agility.

Agility Potential.- Using data such as that on figure 7, another way of looking at the implications is simply to divide the maximum thrust-weight ratio by the combat wing loading for specific aircraft and arrive at a factor defined as the agility potential. The higher the ratio of T/W to W/S, the greater the potential for agility. This kind of measure is shown in figure 8 for a number of aircraft over the years from the mid-1940's. Again it is recognized that a number of other factors enter into agility, but taken in context this kind of measure can provide some useful insights.

It is apparent that over the years a number of U.S. fighters having various measures of thrust, weight, and size, resulted in agility potentials not vastly different. Notable exceptions are the F-102 and F-106 in the late 1950's that, primarily because of low values of W/S (large wing area), displayed substantial higher values of agility potential than what might be considered a nominal average. In fact, by this form of measurement, the F-102 agility was not exceeded until the F-15 was produced some 20 years later and subsequently was about equaled by the F-16. In the same timeframe as the F-102 and F-106, the F-104 is an interesting example. Originally intended as an air superiority fighter, based on the experience of Korea, the F-104 was expected to reach combat altitude quickly and to be able to fight at high altitudes. Accordingly, the airplane had a high T/W for its time but also a high W/S (small wing area) and the result was again only an average value of agility potential. A comment made by Kelly Johnson in 1954 concerning the F-104 is of interest--with airplanes such as the F-101, F-102, F-105, and F-106 in mind he said ". . . . what we have done is bring an end to the trend toward constantly bigger, constantly more complicated, constantly more expensive airplanes."

The F-5 airplanes, while moderate in size and cost, indicate an agility potential about the same as that for the F-104 or the F-86. The mainstay for many years, the F-4 is about the nominal average in agility. The F-16 and F-15 represent substantial improvements in this measure over the F-4. The U.S.S.R. MiG-21, Mig-23, and SU-15 are about equal to, or slightly better than, the F-4 but substantially below the F-15 and F-16. Again, it might be expected that the MiG-29 and SU-27 will be about the same as the F-16--an improvement over previous U.S.S.R. fighters.

Sea Level Climb Rate.- Another performance gauge is the rate of climb at sea level, which is shown for various aircraft in Figure 9 as a function of Mach number. These data, within the accuracy that is available, show a reasonably linear progression of increasing sea-level climb rate with increasing maximum speed capability. In general, U.S. fighters appear to be somewhat better performers in this measure than U.S.S.R. fighters. In early jet fighters, some advantage was evident for the MiG-17 compared to the F-86A and for the MiG-19 compared to the F-100. The F-86D, however, performed better than the MiG-17. Some other observations are:

- The F-106 indicates a marked improvement over the F-102.
- The F-104, with advantages of lightweight and attendant possible lower cost, exhibits a climb rate that is about the same as the F-101 and F-106.

- The F-4D represented an improvement over previous U.S. tactical fighters and most U.S.S.R. fighters--exceptions being the MiG-23 and MiG-21N.

- The MiG-21N, with increased thrust, has a substantially higher climb rate than the MiG-21F and, in fact, is about comparable to the F-16.

- The F-16 and F-15, both with high T/W, indicate the highest climb rates.

Insufficient data precludes the inclusion of the MiG-29 and SU-27 but it might be expected that these aircraft would be comparable to the F-16 and, perhaps, the F-15.

Maneuvering Parameter.- A maneuvering parameter has been developed in the Langley Differential Maneuvering Simulator. This parameter includes, not only T/W and W/S, but also takes into account the lift-drag ratio and the maximum attainable lift. The maneuvering parameter corresponds directly to the time-on-advantage for one-on-one fighter combat. The maneuvering parameter is directly proportional to thrust-weight, lift-drag, and maximum lift, and is inversely proportional to wing loading. The parameter is shown in bar-graph form in figure 10 for various U.S. fighters. The F-104 and F-4C appear at the lower end of the spectrum partly because of high wing loadings. The F-4E is measurably better than the F-4C because of better lift characteristics. The F-15 and F-16 indicate dramatic maneuver performance improvements because of the high thrust-to-weight and the low wing loading. Insufficient data again precludes U.S.S.R. fighters but intuitively it might be expected that some versions of the MiG-21 and MiG-23 would have respectfully high maneuver parameters, and that the MiG-29 and SU-27 may be in a class with the F-15 and F-16.

Turn Rate.- Turn rates, instantaneous and sustained, are shown for several fighters at M = 0.9 and an altitude of 15,000 feet in figure 11. The F-16 and F-15 represent improvements over the predecessor F-4E, particularly in sustained turn rate, and also indicate better turn characteristics than two operational U.S.S.R. fighters--the MiG-21 and MiG-23. However, some reported values for the newer U.S.S.R. MiG-29 and SU-27 turn-rate performance are considerably better than preceding U.S.S.R. fighters and superior to the U.S. F-16 and the F-15.

The F-5E is included to indicate the comparability with the MiG-21 and MiG-23. This is one of the reasons that the F-5 has been utilized by aggressor squadrons.

Some Other Mission Considerations

Again, it would be presumptuous to think that all factors that enter into mission capability could be addressed in this paper. However, a few observations will be offered for consideration on some mission characteristics.

Supersonic Flyout. Some results based on a type of analysis that has been done by Riccioni (fig. 12) show the mission radius as a function of average outbound speed (from 0 to M_{max}) for several U.S. fighters performing a supersonic flyout from take-off with an optimum cruise back. Internal fuel only is used except where noted. Obviously, other values of radius would result for other conditions, particularly where subsonic segments are included in the flyout. The purpose of these data, however, is to attempt a comparison of supersonic efficiency by indicating about how far out you might fly (radius) as a function of the time (speed) utilized in reaching that distance. The desired results would be those in the upward and outward directions, of course. There is a general tendency toward reduced efficiency (less radius) with increasing average outboard speed as the fighter-types progress from the F-100D, to the F-5E, the F-104, the F-4E, and the F-15A. Exceptions are the F-104 with tip tanks (additional fuel) which goes considerably farther than the basic F-104 but at a lower average speed; the F-106, which has the greatest radius on internal fuel only and flys out at the same average speed as the F-4E, thus reflecting a cleaner design; and the F-16A, which reflects better efficiency in that the radius is about equal to, or greater than, the F-5E, F-104, and F-4E, but at a higher average speed. The F-15A indicates a decrease in efficiency since the radius drops rapidly with increased average speed.

One familiar message from this type of comparison is that the efficiency of supersonic-capable fighters needs to be improved. Or, put more simply, if a supersonic flyout radius greater than 100 nautical miles is required, then the maximum average outbound speed capability of the F-15A cannot be utilized. In comparison, an F-106 using an average M of 1.5 would fly out 150 nautical miles. The main considerations here are simply: "How far do you need to go?" and "How quickly do you need to get there?"

Supersonic Air-to-Air Potential. Another mission consideration is shown in figure 13 for the same fighters illustrated in figure 12. This consideration has to do with the air-to-air potential capability--or what you potentially can do after reaching the supersonic combat radius. The supersonic flyout radius is shown in bar-graph form and the air-to-air ordnance carried is tabulated for each airplane. Observations that can be made from this figure are:

- The F-100 at about 150 nautical miles would operate with guns only.
- The F-104 with a range from 140 to 180 nautical miles could use a gun and could fire two missiles.
- The F-106, also at a range of about 150 nautical miles, could fire five missiles, one of which was a Genie, and carried no gun.
- The F-4 at a lesser range of about 120 nautical miles could fire four missiles and also use a gun.
- Both the F-5 and the F-16, with nearly comparable ranges of about 130 nautical miles could fire only two missiles and use a gun.
- The F-15, with the shortest range of about 100 nautical miles, could fire eight missiles and also use a gun.

This kind of information poses some questions, such as: "Is a shorter radius of action with more firing opportunities a fair trade for a larger radius of action with less firing opportunities?" The extremes, of course, are to have tremendous firepower capability but not to be able to take it anyplace, or to have a tremendous range capability but no firepower. The answer lies somewhere between and must be given serious consideration with the ultimate goal of having tremendous firepower at a tremendous radius.

Internal Fuel and Maximum Ordnance Trends.- The data presented in figure 14 is intended to suggest another consideration in the assessment of fighter mission capability trends. These data show the internal fuel capacity and the maximum ordnance load (including air-to-ground) for various fighter aircraft over the past

40 years. These data interrelate the vehicle size and volume with the potential lethality. Early jet fighters were quite small and hence had relatively small quantities of internal fuel and relatively low maximum ordnance load capability. A general trend toward increased size over the years has resulted in increased internal fuel capacity and increased load-carrying capability.

Some observations are:

- Some supersonic designs remained small, such as the F-104 and F-5, with little growth in internal fuel capacity, but with some increase in ordnance load for the F-5E.

- The F-101 and F-106 were large airplanes with large internal fuel capacity. The ordnance load was low, however, since the primary weapon was air-to-air missiles.

- The F-105, although having little growth in internal fuel capacity compared to preceding aircraft, did show considerable growth in maximum ordnance load because of the number of air-to-ground weapons carried externally.

- The F-4 provided further growth in load carrying capability through the addition of externally carried air-to-ground weapons.

- The F-111 is a large airplane with an exceptionally large internal fuel capacity and a large ordnance carrying capability. The internal fuel capacity of the F-111A is a little over 5000 gallons compared to about 400 gallons for an F-80 or F-86 and about 1800 gallons for an F-15.

- The F-14 has a large internal fuel capacity (about 2500 gallons) and a large ordnance load comprised mainly of large air-to-air missiles.

- The F-15, F-16, and F-18 are all good load carriers with a mix of air-to-air and air-to-ground weapons. The F-18 appears to be an exceptionally good load carrier for its size.

Some Weight Factors

Combat Weight.- The trend in combat weight as a function of Mach number is shown in figure 15 for several U.S. fighters. For these data, the airplanes are configured for air-to-air missions and the combat weight is composed of the empty weight, half fuel, full gun ammunition, and air-to-air missiles. The general trend is an increase in combat weight as the maximum Mach number increases. There is a lower bound of what might be considered lightweight fighters including the F-5, F-104, and F-16.

For some aircraft, such as the F-111, F-18, and A-7, the combat weight is dictated more by the large fuel capacity rather than by munition weight. For the F-14, both a larger fuel capacity and a large munition load are contributing factors. At the highest Mach number, the large difference in combat weight for the F-15 and F-111 reflects a design emphasis for air superiority with the F-15 and a design emphasis for multipurpose ground attack and long range with the F-111. Hence any attempt to compare fighter capability in terms of combat weight should be done with great care because of the many factors included.

Operating Weight Empty.- The trend in operating empty weight with Mach number is shown in figure 16 for U.S. and some U.S.S.R. fighters. The empty weight includes all fixed equipment but no fuel or munitions. The trend is again toward an increase in weight with increasing Mach number. These data also reflect the influence of aircraft size with the smaller aircraft on the lower bound and the larger aircraft on the upper bound. In general, the U.S.S.R. fighters appear to be slightly better than the U.S. fighters in terms of empty weight and speed. Exceptions are the TU-28, an exceedingly large interceptor for which there is no U.S. counterpart, and perhaps the Yak-36 with its direct-lift engines.

To some extent, the empty weight provides a measure of cost--the larger, heavier aircraft being more expensive than the smaller, lighter aircraft. The cost, however, must also be tempered by other factors such as the complexity.

Fighter Weight Distribution.- The distribution of the empty weight for various basic U.S. fighters over the past 40 years (fig. 17) provides an interesting pattern. The percent of empty weight allotted to structure, propulsion, auxiliaries, avionics, and fixed weapon equipment is shown for each airplane. The following observations are made:

- With little exception, the percent of empty weight allotted to each category has remained about constant since the days of the F-80.
- The largest single part of the empty weight is the structure. Thus, the possibility for meaningful reductions in empty weight lies in the areas of manufacturing and structural techniques and in the area of materials.
- Reductions in the weight of propulsion systems and various auxiliary mechanisms offer the possibility of large payoffs in weight reduction.
- The percent of weight allotted to avionics has remained relatively small.
- The percent of weight allotted to the fixed equipment necessary for weapons carriage is almost insignificant.

A general observation regarding the distribution of fighter weight is that a large amount of equipment (almost 90% in structures, propulsion, and auxiliaries) is required in order to provide support for the primary purpose of the fighter--the carriage and delivery of weapons. Hence, very careful attention should be given to improving the cost effectiveness of fighters by reducing the complexity and the cost of systems used simply to get the weapons airborne.

DCPR Weight.- The Defense Contractor Planning Report (DCPR) weight is, perhaps, more nearly related to the structural cost. This weight is comprised of the structural airframe including the necessary fixed wiring, tubing, and controls but does not include the engine, wheels, or instrumentation. The trend in DCPR weight for fighters over the last 40 years (fig. 18) again shows a progressive increase in airframe weight for most fighters primarily due to size. Those airplanes that have remained relatively small (F-104, F-5, F-16) show little change in airframe weight over the years. The F-111 weight, which seems to be exceptionally high, is partly due to weight associated with the variable wing-sweep structure. It is reasonable to assume that the manufacturing cost will increase with increasing DCPR weight. Hence, a clear message to detect--although challenging to implement--is to reduce the size and weight of fighters while retaining, or improving, the mission capability. The challenges are in such areas as manufacturing technology, materials technology, and improved aerodynamics to reduce volume and thrust requirements.

Some Cost Factors

Quantity and Cost Trends.- The trends in U.S. fighter/attack aircraft procurement and flyaway cost from 1968 to 1982 (fig. 19) shows a decrease in quantity and cost immediately following Vietnam, but, since the early 1970's, the quantity of fighter/attack aircraft accepted has been more or less constant while the flyaway cost has risen significantly. This is a picture of a fundamental problem today--can we afford what we believe to be needed, or can we expect to maintain an adequate defense with what we believe we can afford? Indeed, this is an easy problem to state, but a quite difficult one to answer.

Flyaway Unit Costs.- The flyaway unit cost for several fighter/attack aircraft procured in 1981 is shown in figure 20. As might have been expected from some of the previous discussion on aircraft size and capability, the F-14 and F-15 are relatively expensive, and the F-18 is, as yet, quite expensive. Other factors, such as complexity, also must be considered. Questions that may be asked--"Are you getting what you are paying for?" or "Do you need what you are getting?" are easily asked but, again, difficult to answer.

Lot Average Cost.- The lot average cost of several airplanes in 1981 dollars over the years from about 1950 is shown in figure 21. These average costs reflect the total number of aircraft procured and the number of years during which they were procured. Although the numbers change slightly when averaged in this manner, the general trend in cost increase is unchanged.

Lot Average Cost Distribution.- The distribution of lot average cost for several current fighters is shown in bar-graph form in figure 22. Although the amounts vary considerably, some general observations can be made:

- o The largest amount is applied to the airframe as might be expected from previous discussion of the weight distribution.
- o Propulsion is the second largest expense.
- o The airframe cost appears to be, by far, the largest cost item for the F-18--exceeding the total cost of the F-15, for example.
- o The avionics cost for the F-18 seems surprisingly low compared to the total F-18 cost, as well as in comparison to the avionics cost for the other airplanes.

Flyaway Cost Distribution.- The distribution of flyaway cost for various basic U.S. fighters over the past 40 years is presented in figure 23. Again, the airframe is shown to be the largest cost factor, averaging about 60 percent of the total flyaway cost over the years. The second largest cost contributor is generally the propulsion system. The beginning of the era of avionics in the 1960's is evident by the increase in percent cost devoted to avionics--becoming about the same as that for propulsion. The same results are shown in bar-graph form in figure 24 for the more recent fighters (past 20 years). The cost fraction for each item shown is dependent upon a number of factors such as the number of units built, the complexity of the item, variations in manufacturing techniques, and so on.

CONCLUDING REMARKS

It has been the purpose of this paper to review some fighter aircraft trends over the past four decades in order to illuminate some of the factors to be considered in assessing the relative merit of fighter aircraft. Where possible, comparisons were made between U.S. aircraft and U.S.S.R. aircraft. While it is not presumed that specific conclusions could be drawn from this trend study, some pertinent observations are made.

- The assessment of fighter capability is dependent on many factors and extreme caution should be used to assure that conclusions are not based on the use of any preconceived obvious indicators to the exclusion of some less obvious and possibly conflicting indicators.
- Some fighter aircraft tend to excel in air-to-air capability and some in air-to-ground capability--the true multipurpose fighter still appears to be elusive.
- For the most part, U.S.S.R. fighter trends have been quite similar to U.S. fighter trends.
- The latest U.S. operational fighters are apparently superior to U.S.S.R. fighters, however, this may be offset by U.S.S.R. fighters currently being readied for deployment.
- The empty weight distribution of U.S. fighters has remained relatively constant over the past 40 years, with the largest contributing factor being the structure.
- Generally speaking, about 90 percent of the empty weight (structures, propulsion, auxiliaries) is required to support the mission of weapon carriage and delivery.
- Since the early 1970's, the quantity of fighter/attack aircraft accepted has been essentially constant, whereas the total flyaway cost has tended to rise.
- The largest cost item is that due to the airframe structure.
- The challenge to fighter technology is to reduce the size and weight of fighters while retaining, or improving, the mission capability--these challenges being in such areas as manufacturing, structural design and materials technology, and in improved aerodynamics that reduce the volume and thrust requirements.

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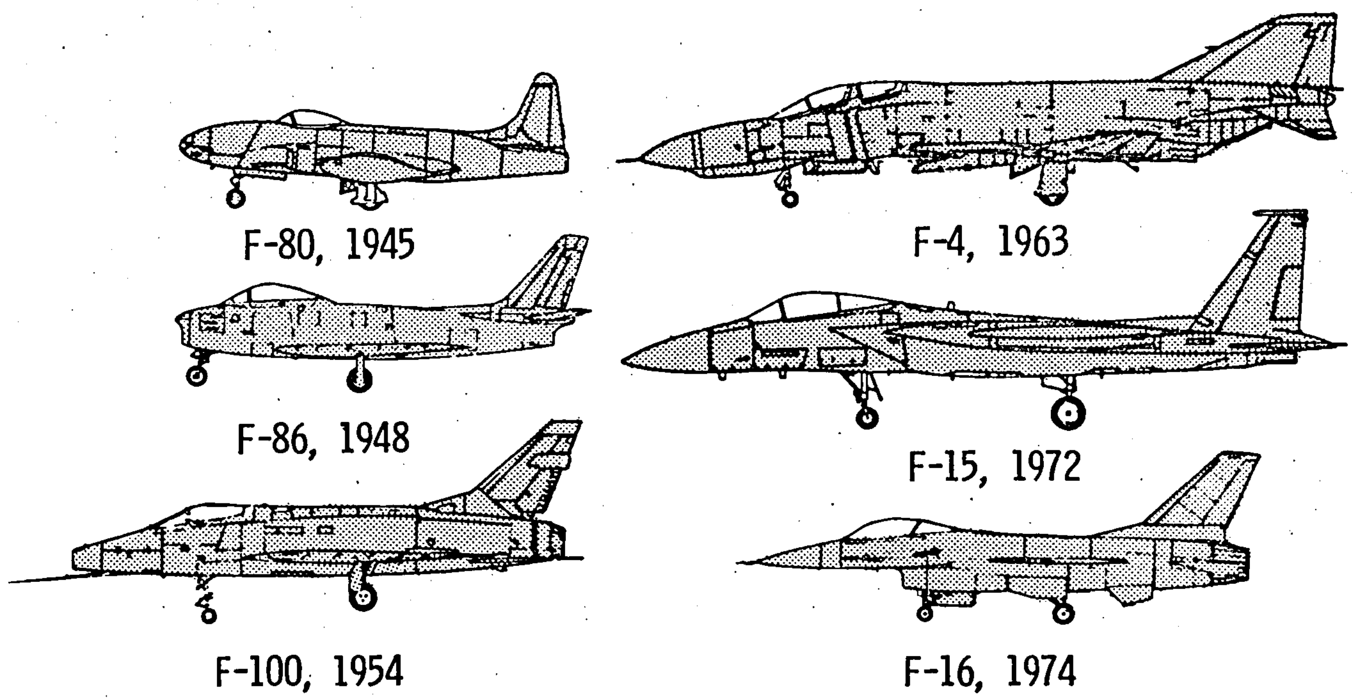

Figure 1.- Some U.S. fighters.

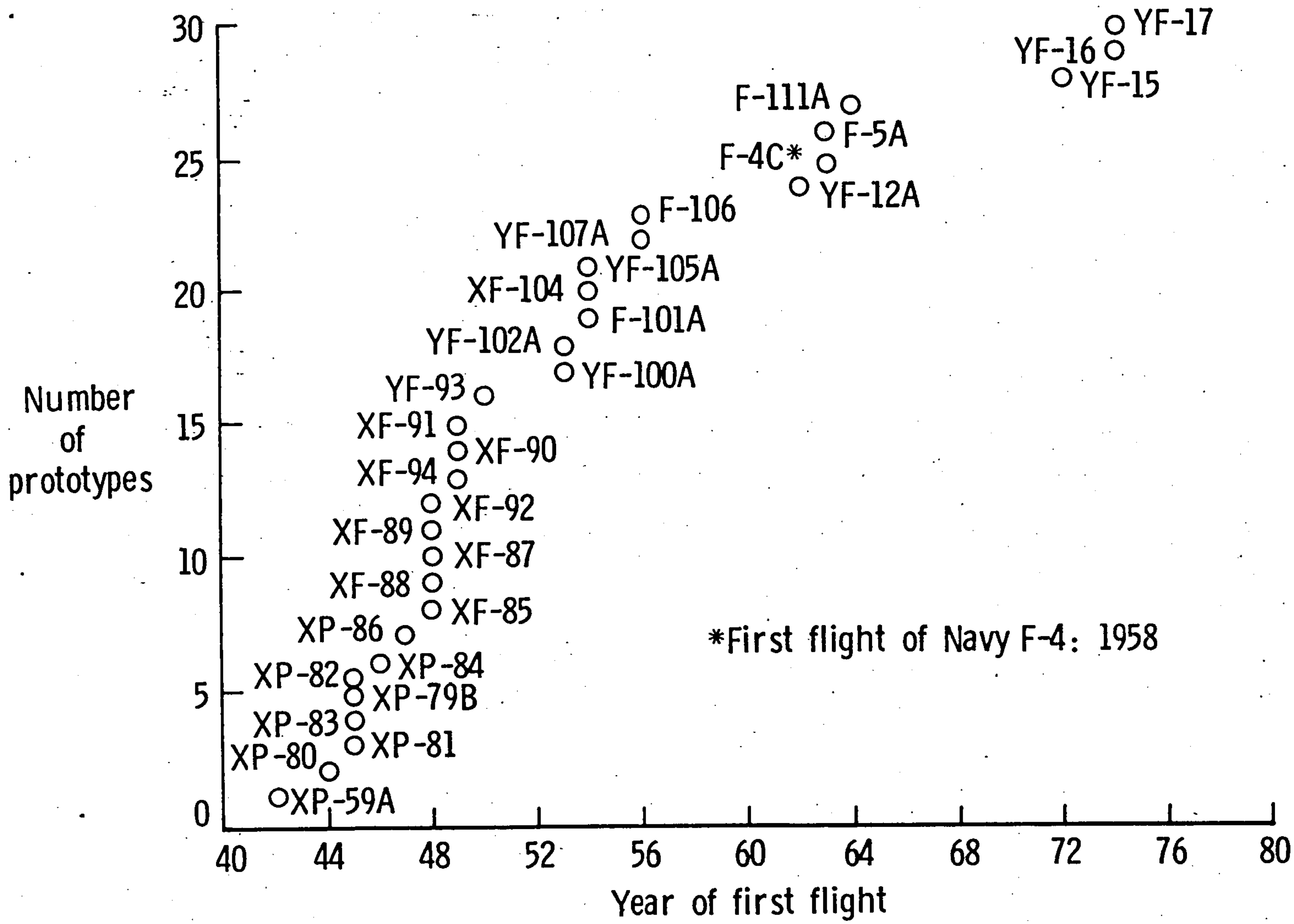

Figure 2.- Chronology of U.S. Air Force fighters.

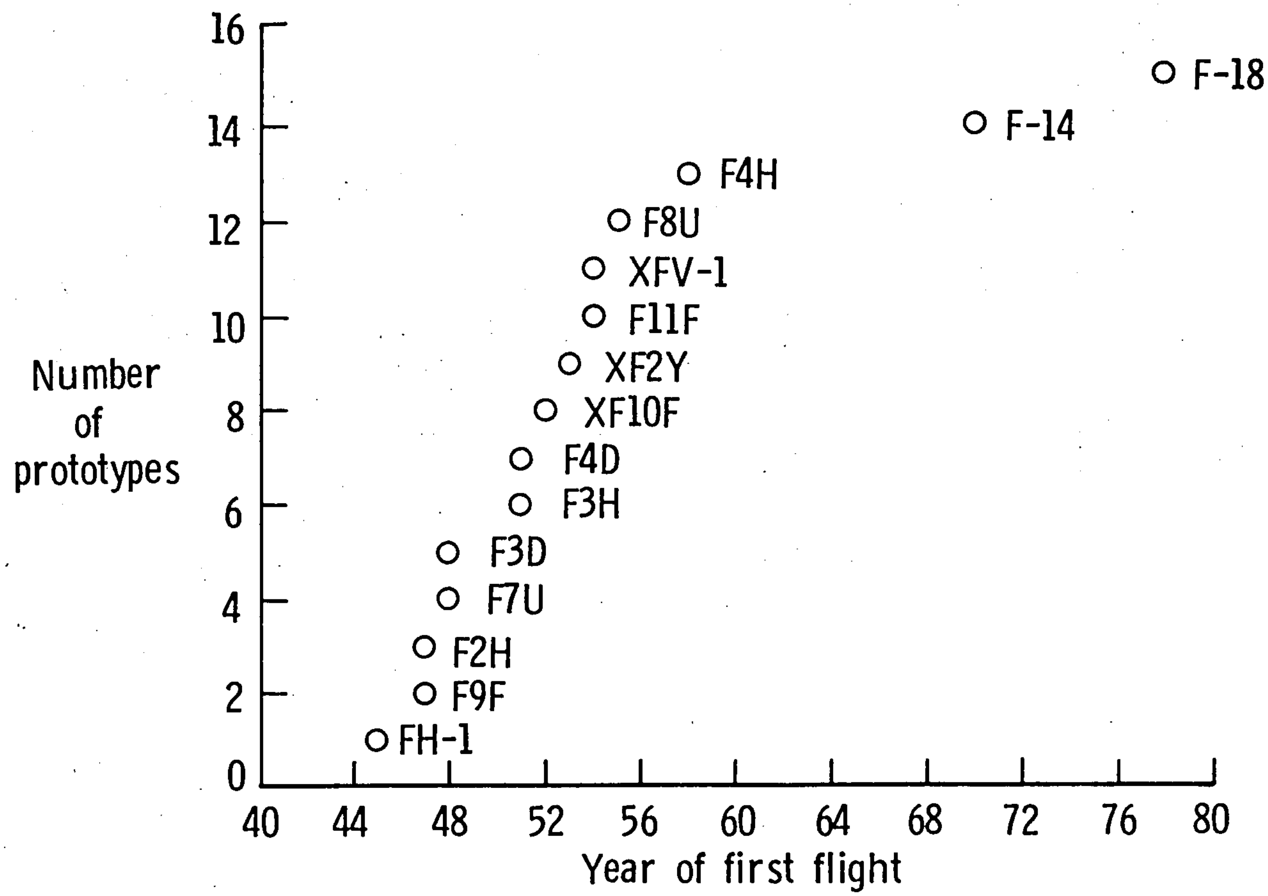

Figure 3.- Chronology of U.S. Navy fighters.

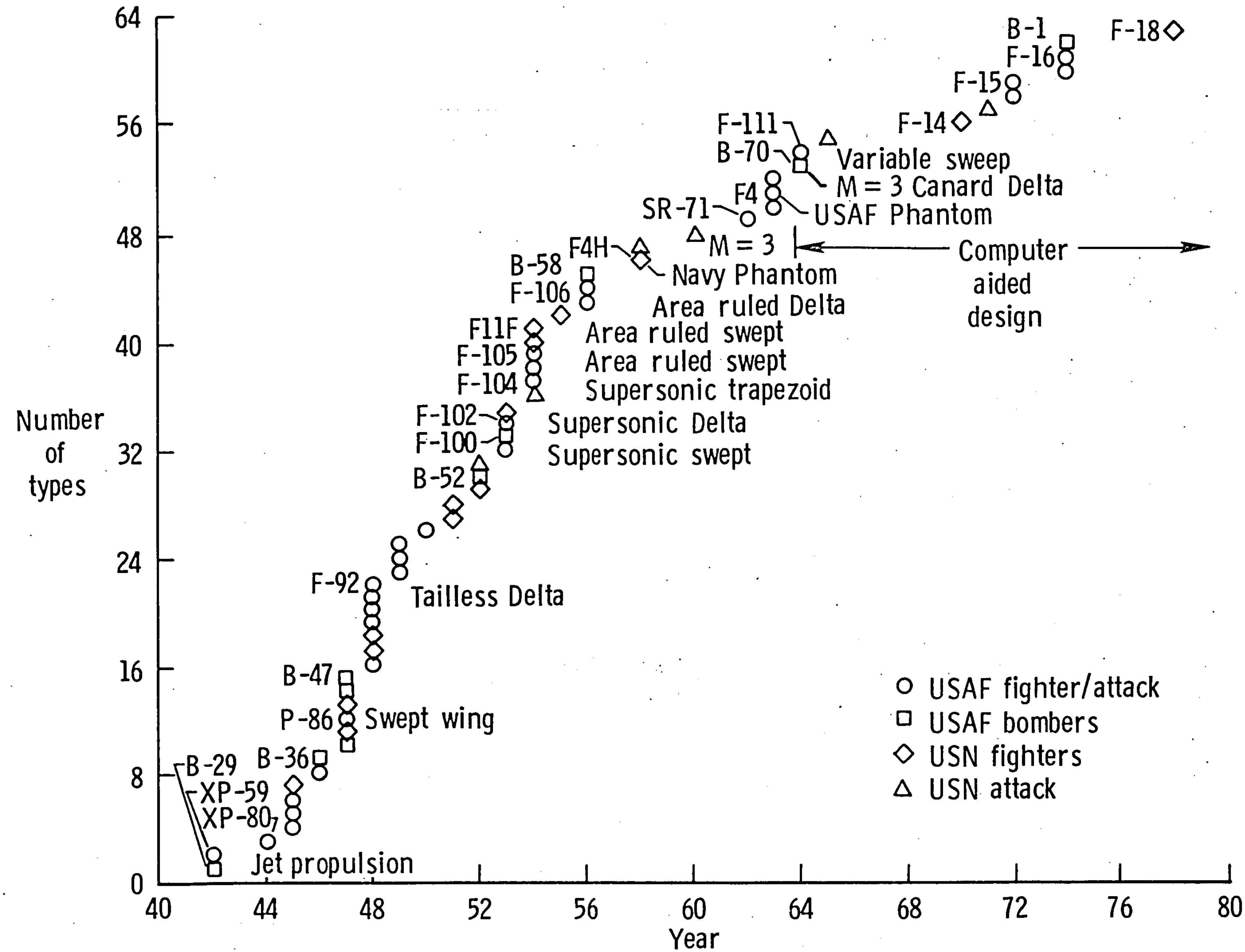

Figure 4.- Chronology of U.S. military aircraft developments.

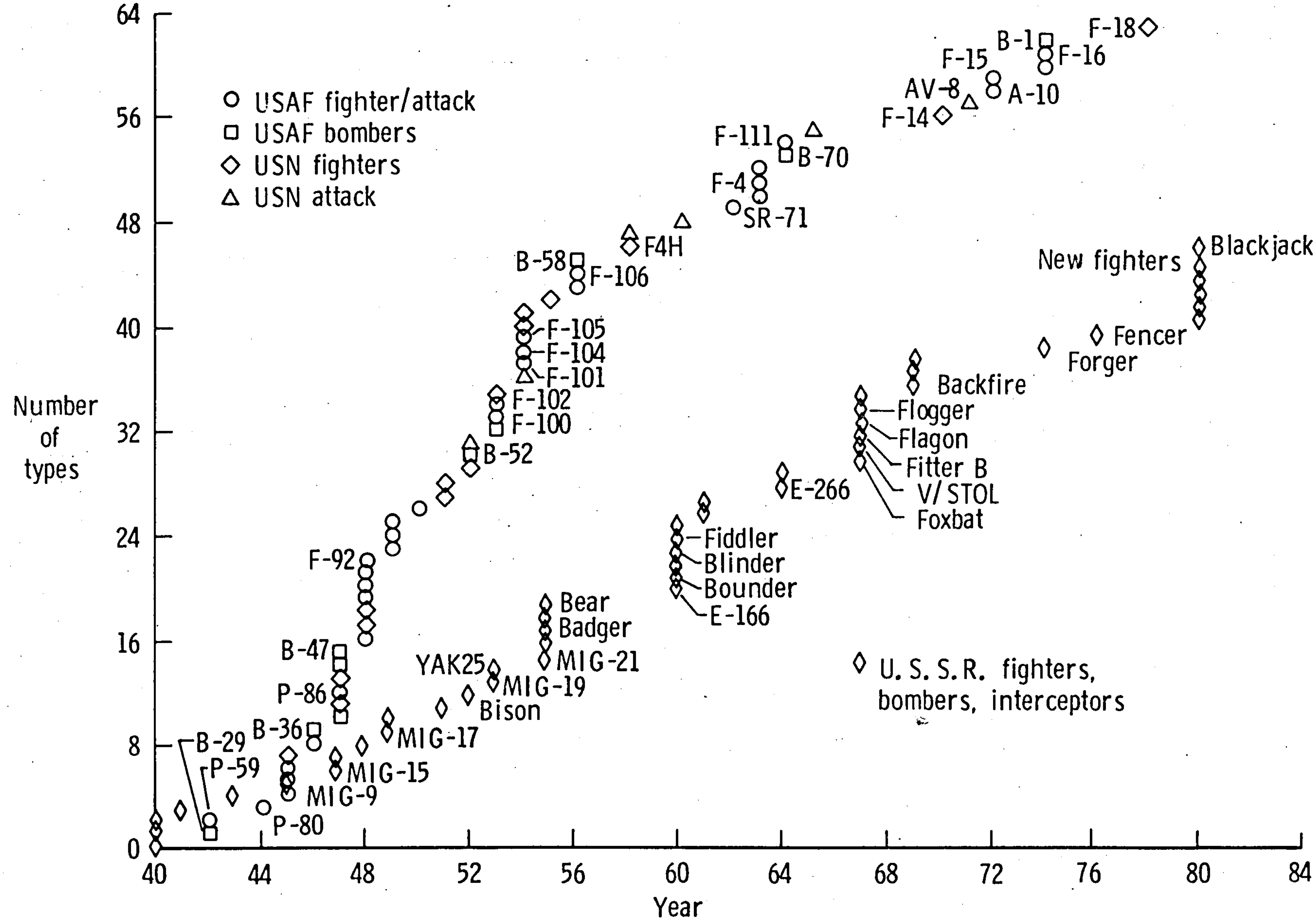

Figure 5.- Chronology of U.S. and U.S.S.R. military aircraft trends.

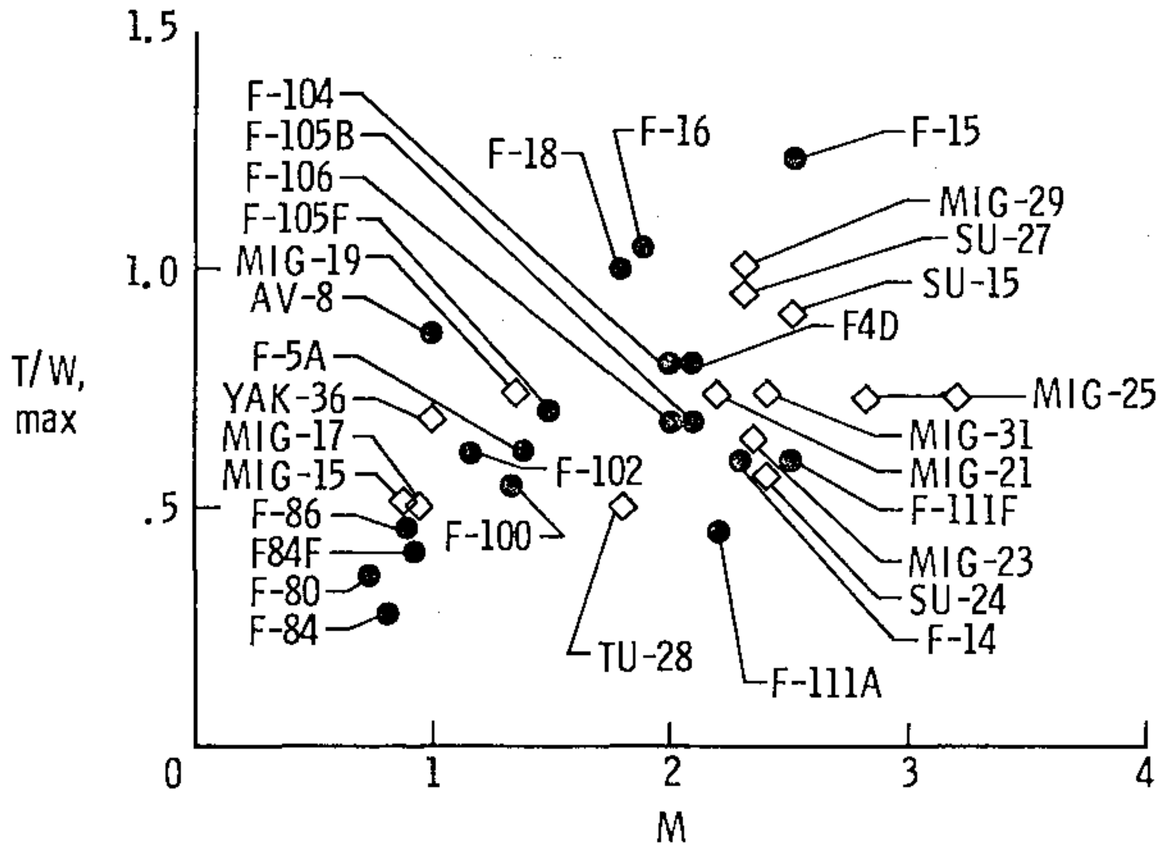

Figure 6.- Thrust-to-weight and maximum Mach number trends, U.S. and U.S.S.R. aircraft.

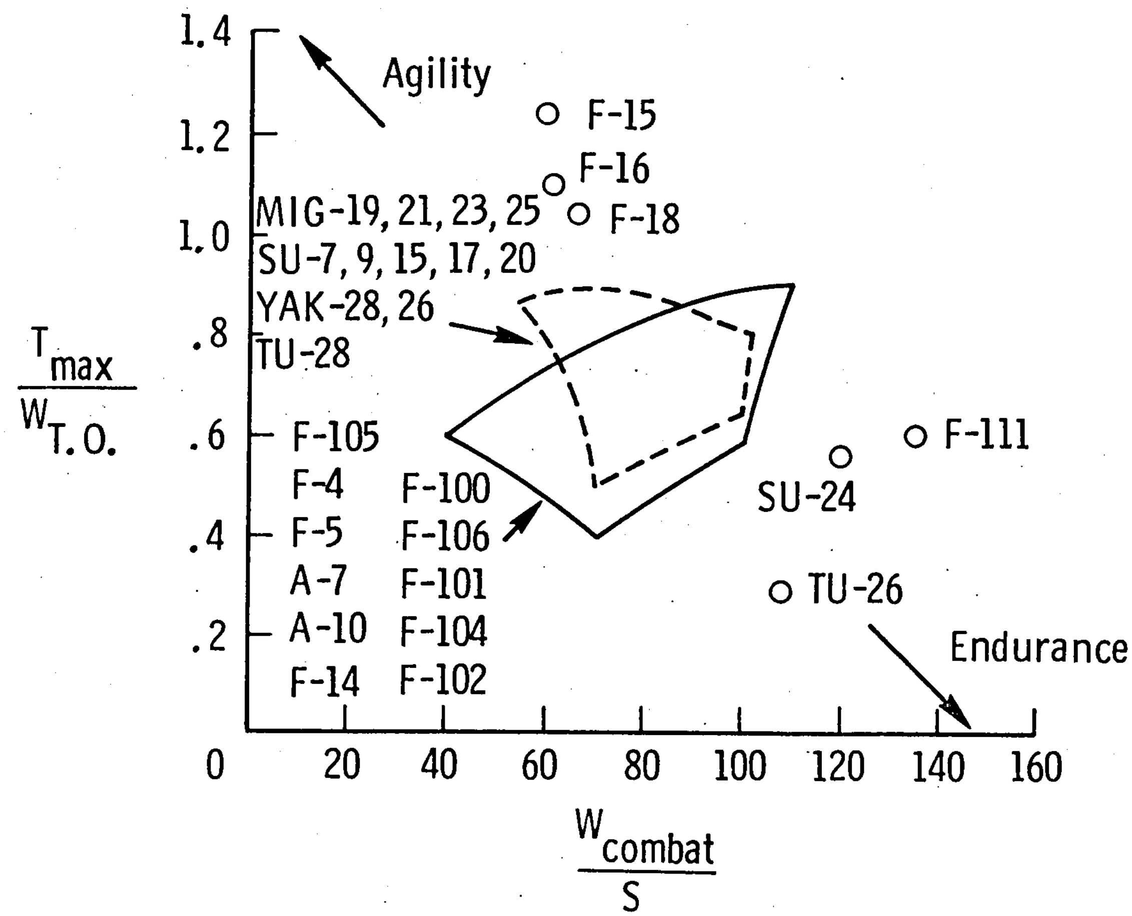

Figure. 7.- Thrust-to-weight versus combat wing loading for U.S. and U.S.S.R. aircraft.

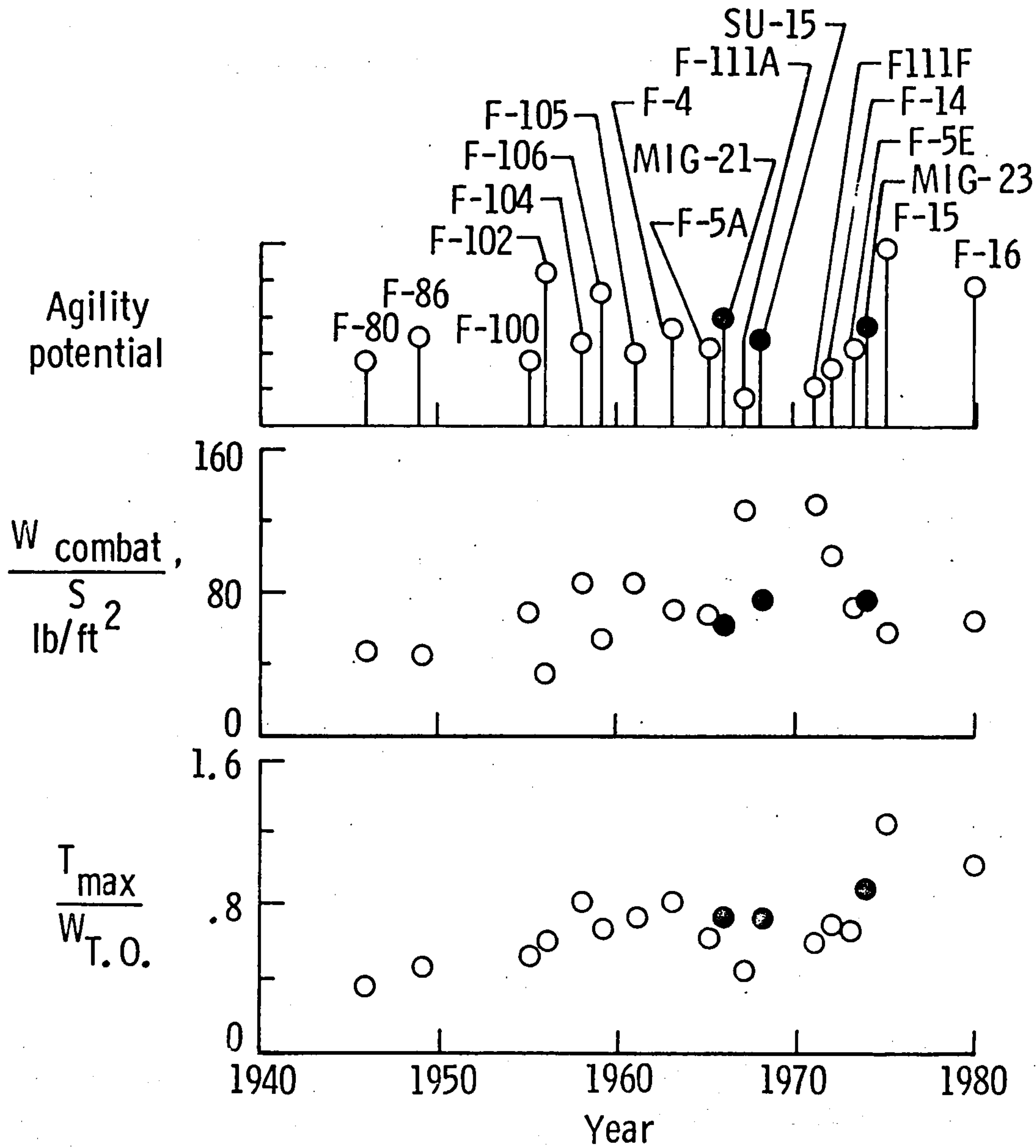

Figure 8.- Agility potential for U.S. and U.S.S.R. aircraft.

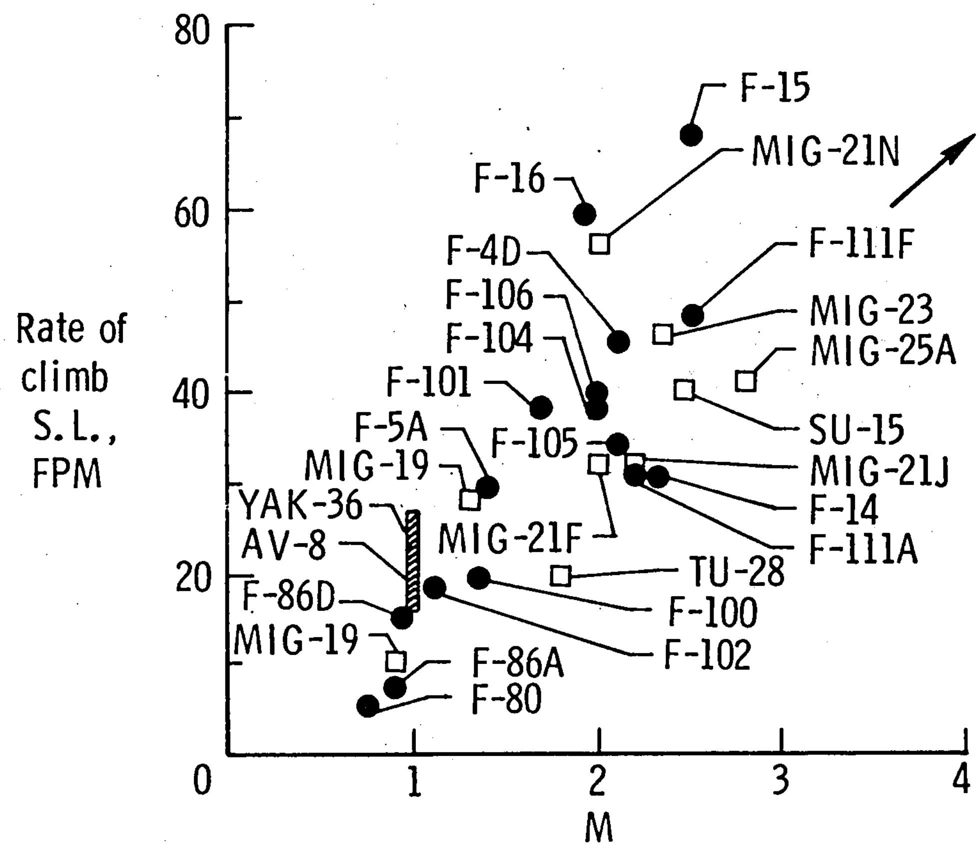

Figure 9.- Sea-level rate of climb versus Mach number for U.S. and U.S.S.R. aircraft.

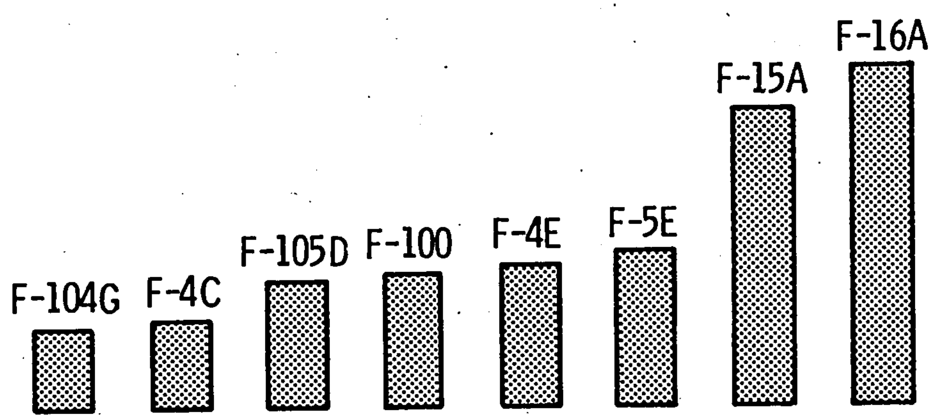

Figure 10.- Aerodynamic maneuvering parameters.

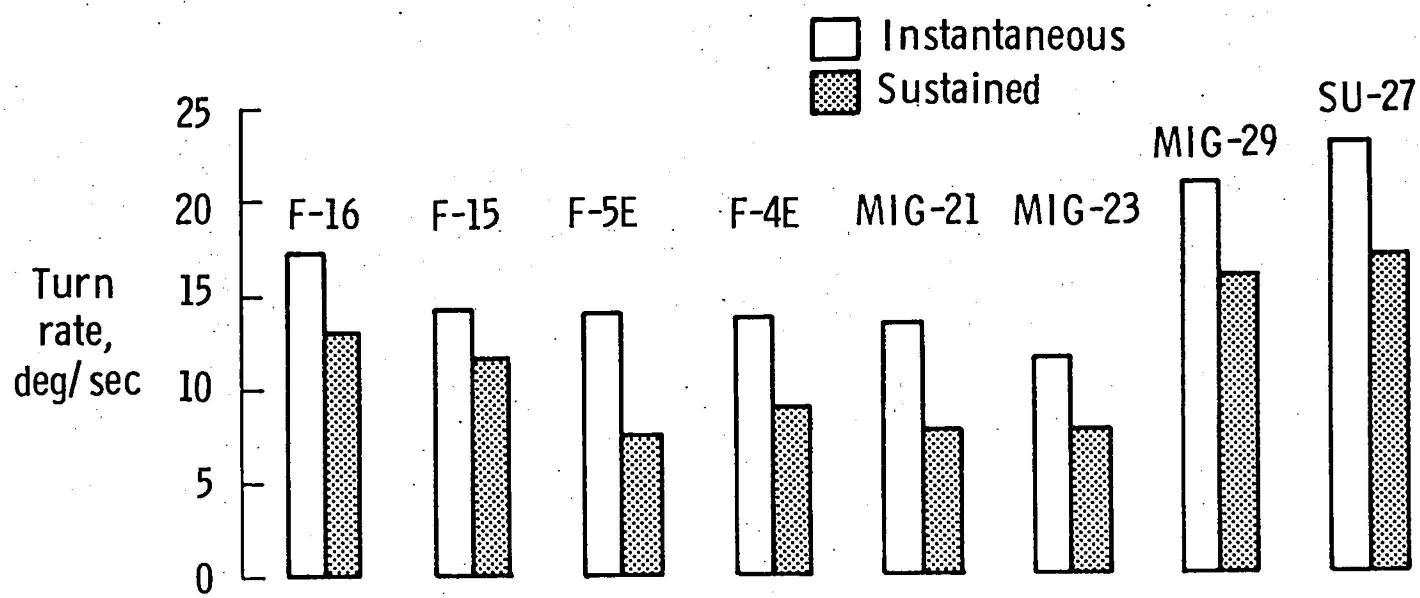

Figure 11.- Turn rate for U.S. and U.S.S.R. aircraft, M = 0.9 at 15,000 feet.

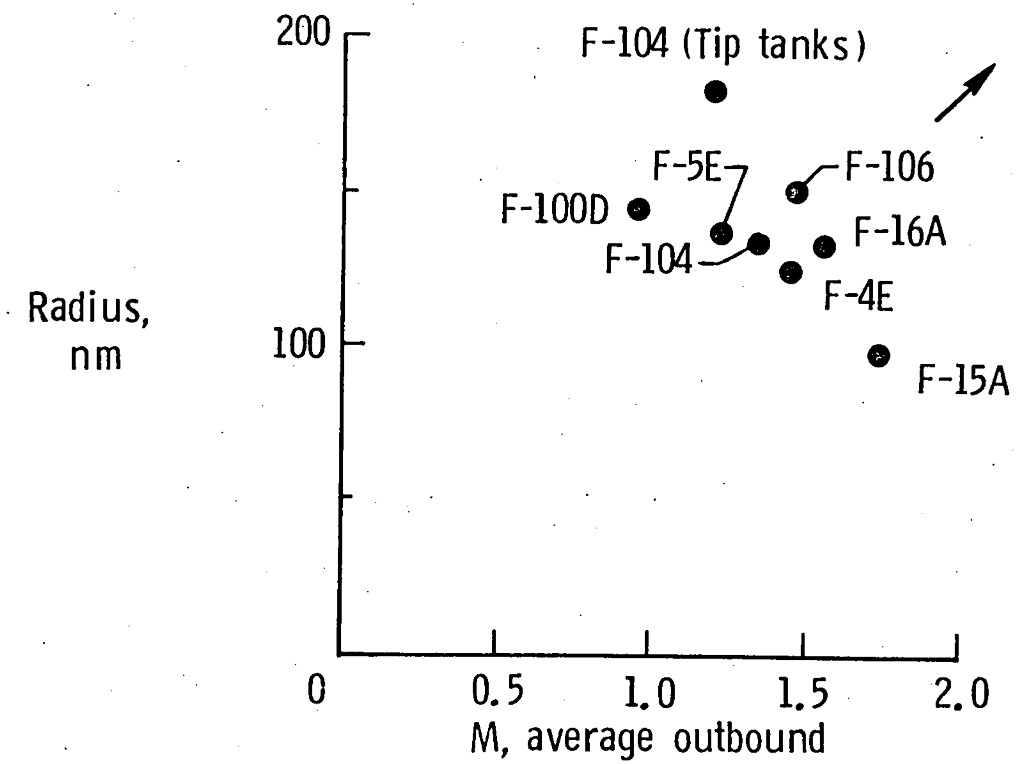

Figure 12.- Supersonic flyout mission.

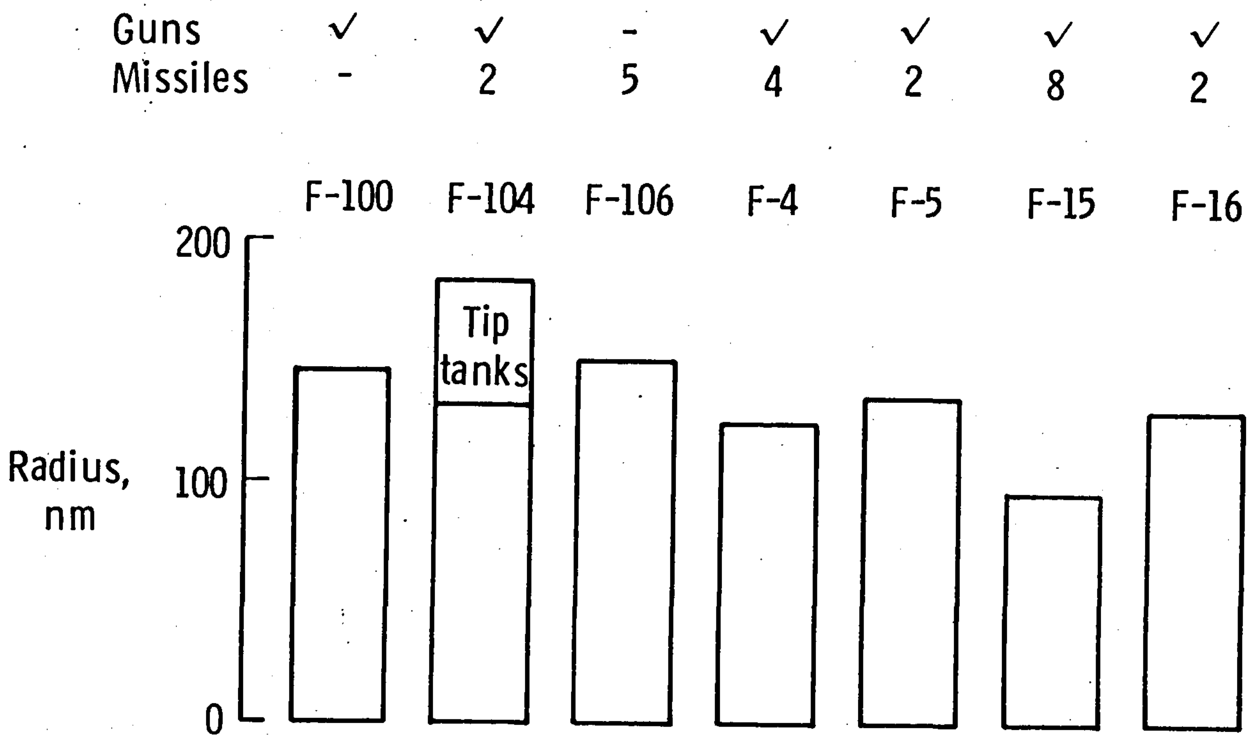

Figure 13.- Air-to-air combat potential for supersonic flyout mission.

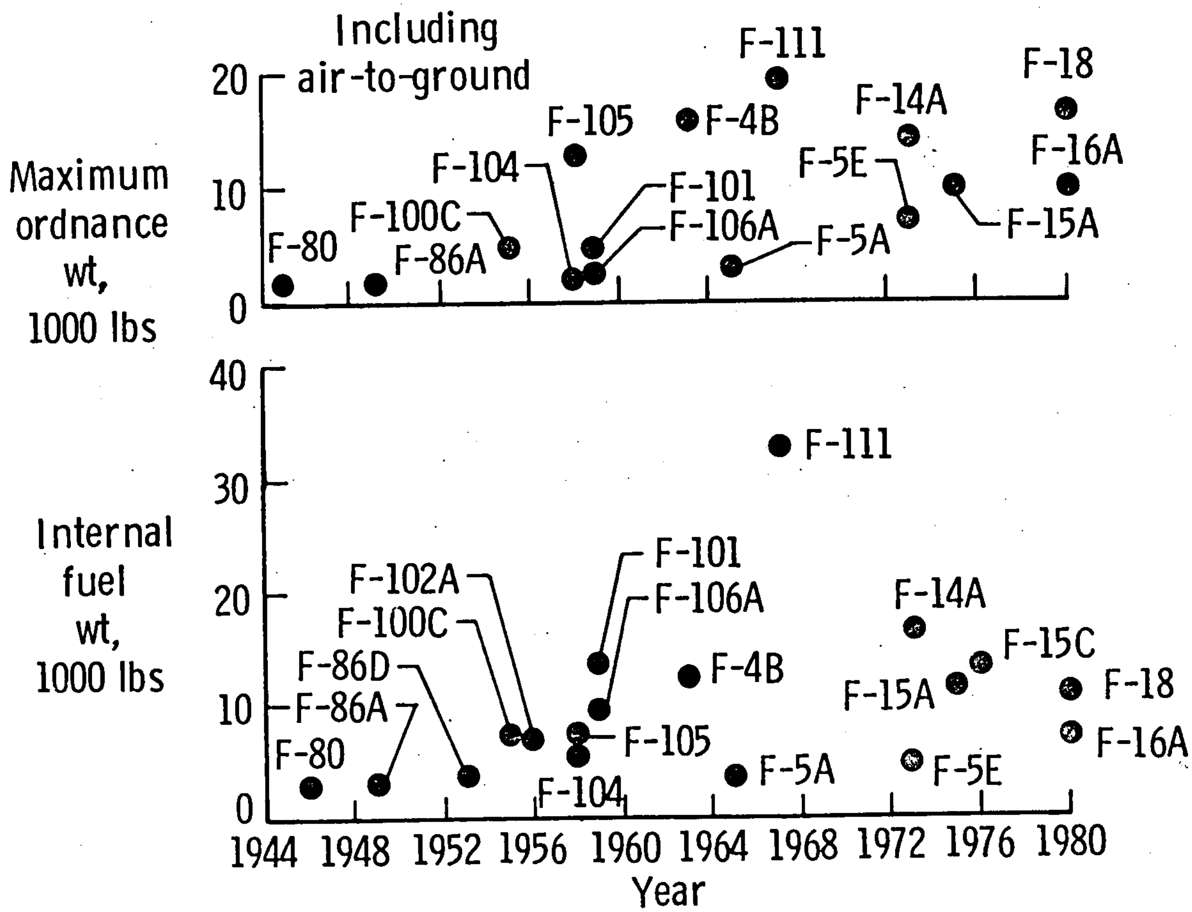

Figure 14.- Internal fuel and maximum ordnance trends.

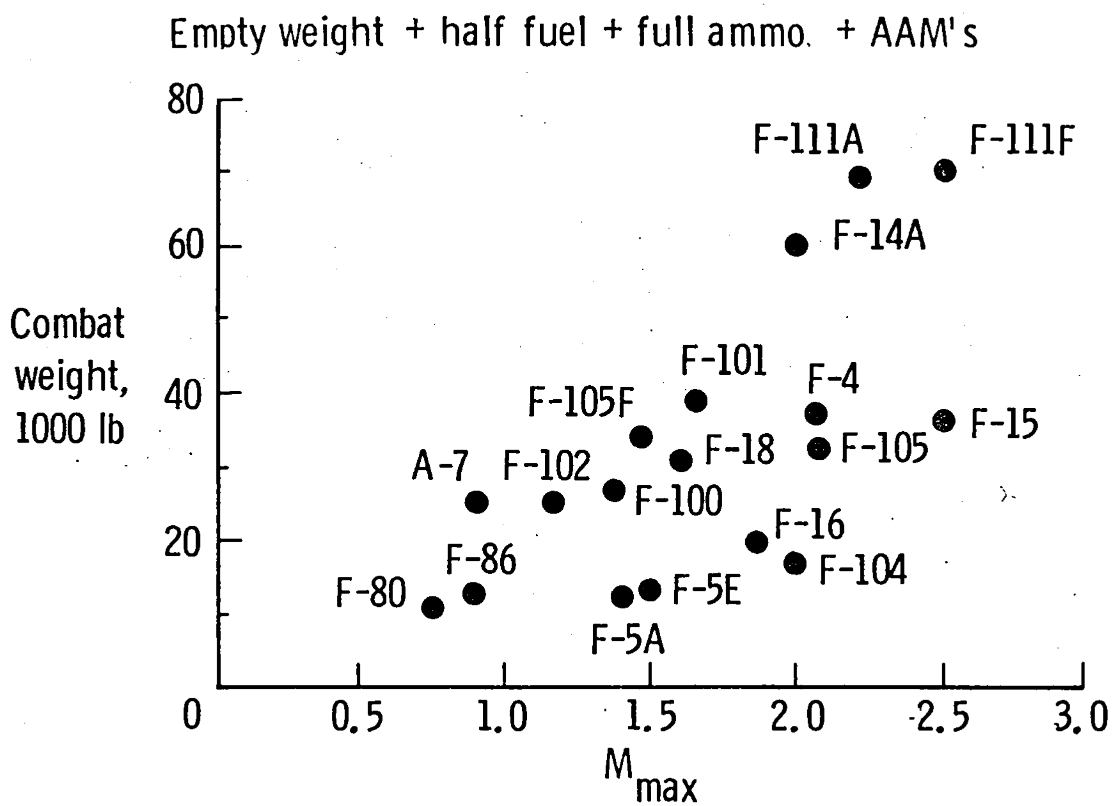

Figure 15.- Combat weight versus Mach number.

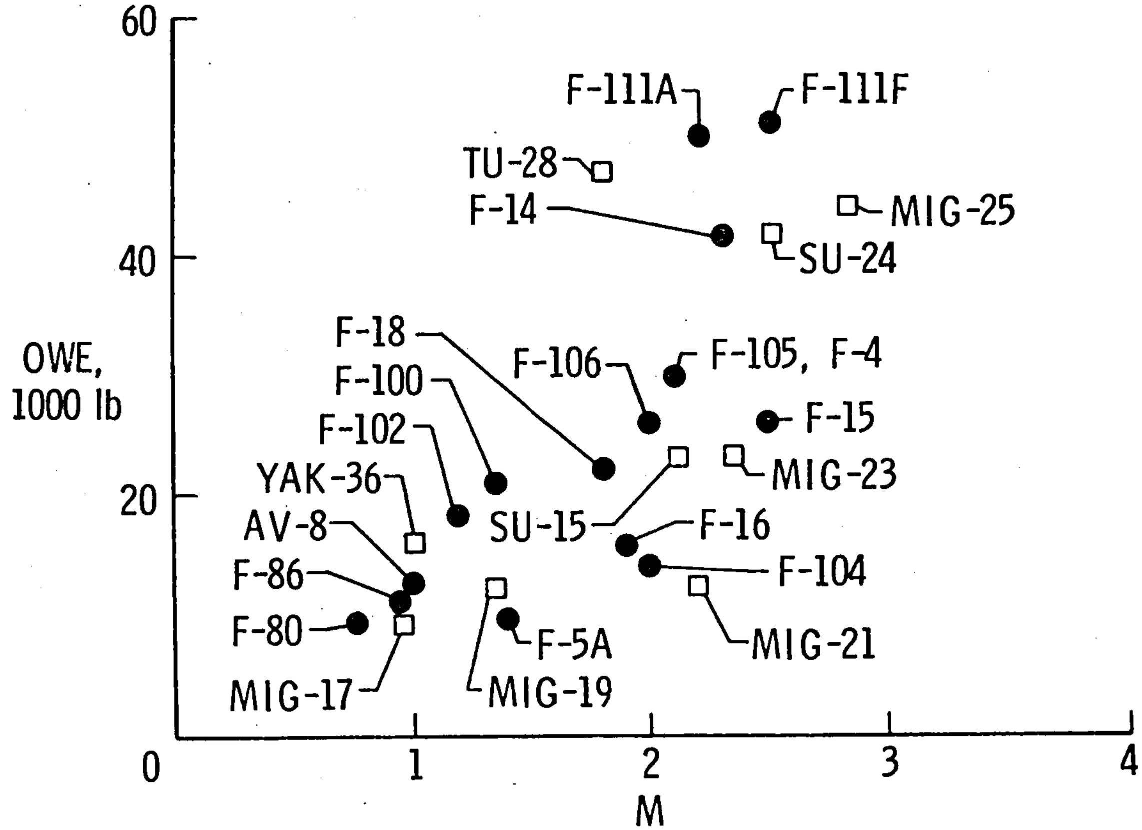

Figure 16.- Empty weight trends versus Mach number for U.S. and U.S.S.R. aircraft.

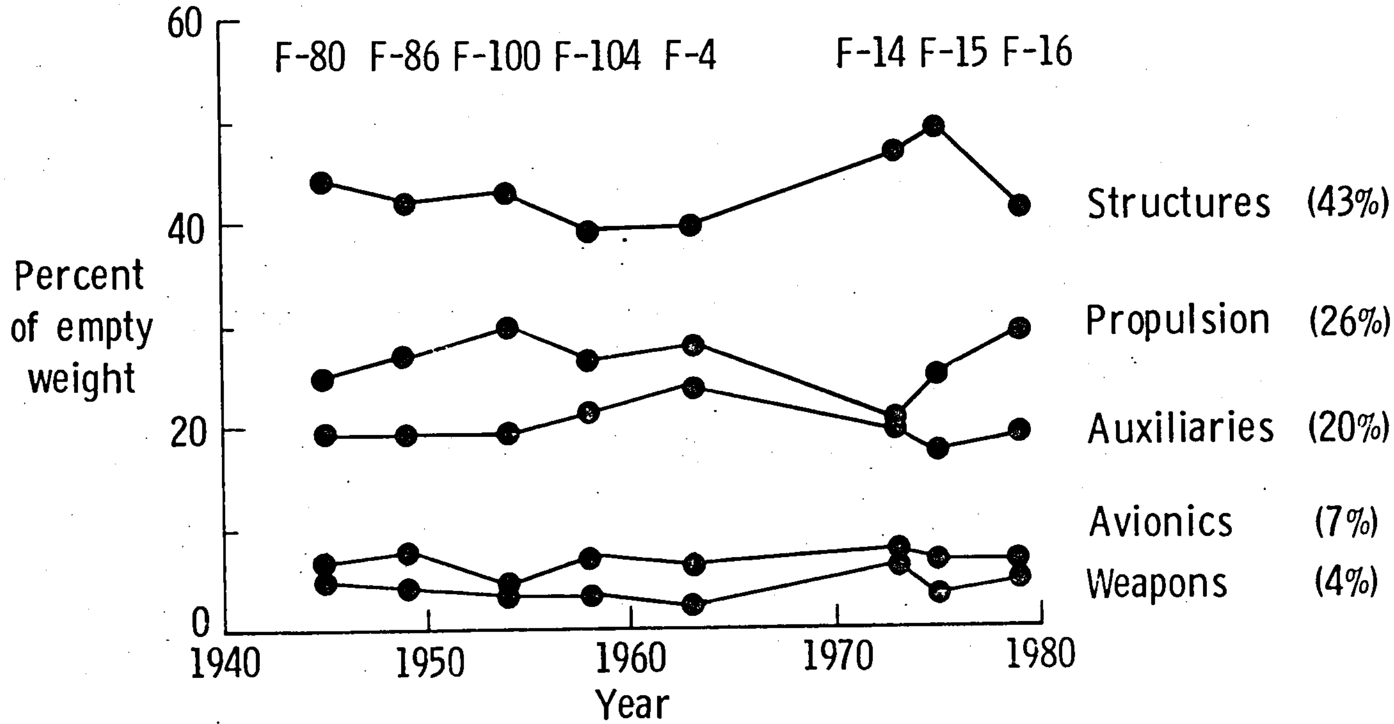

Figure 17.- Distribution of empty weight for various U.S. fighters over the past 40 years.

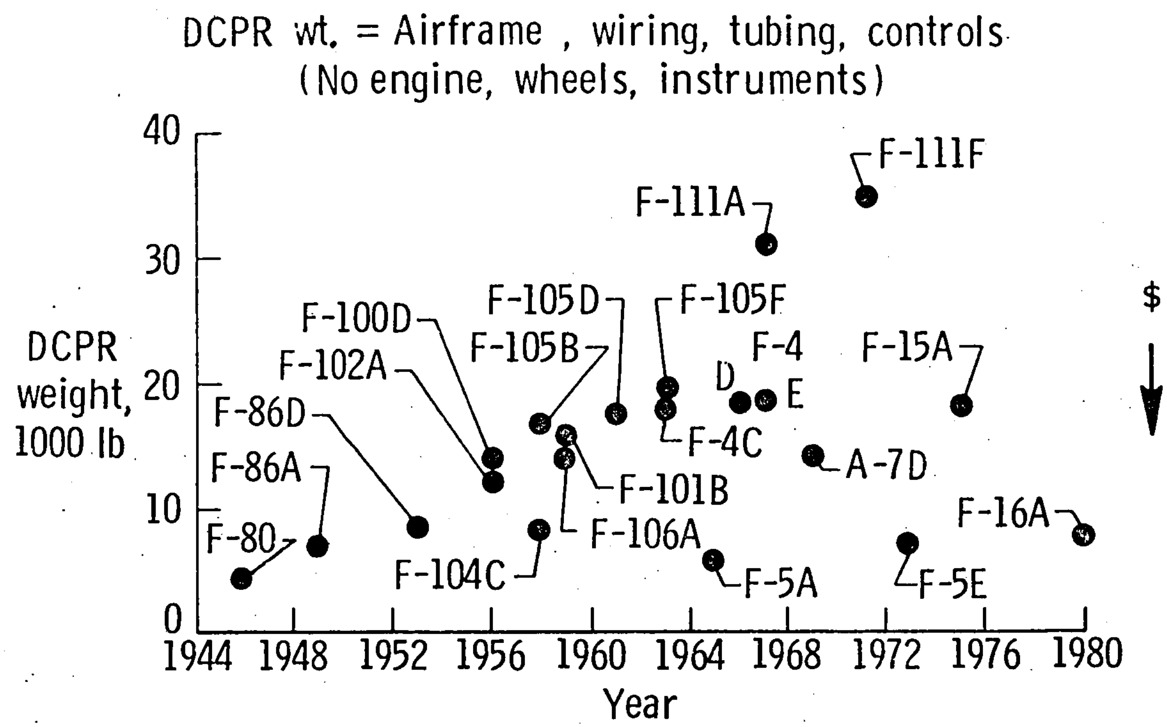

Figure 18.- The DCPR weight trends for U.S. fighters.

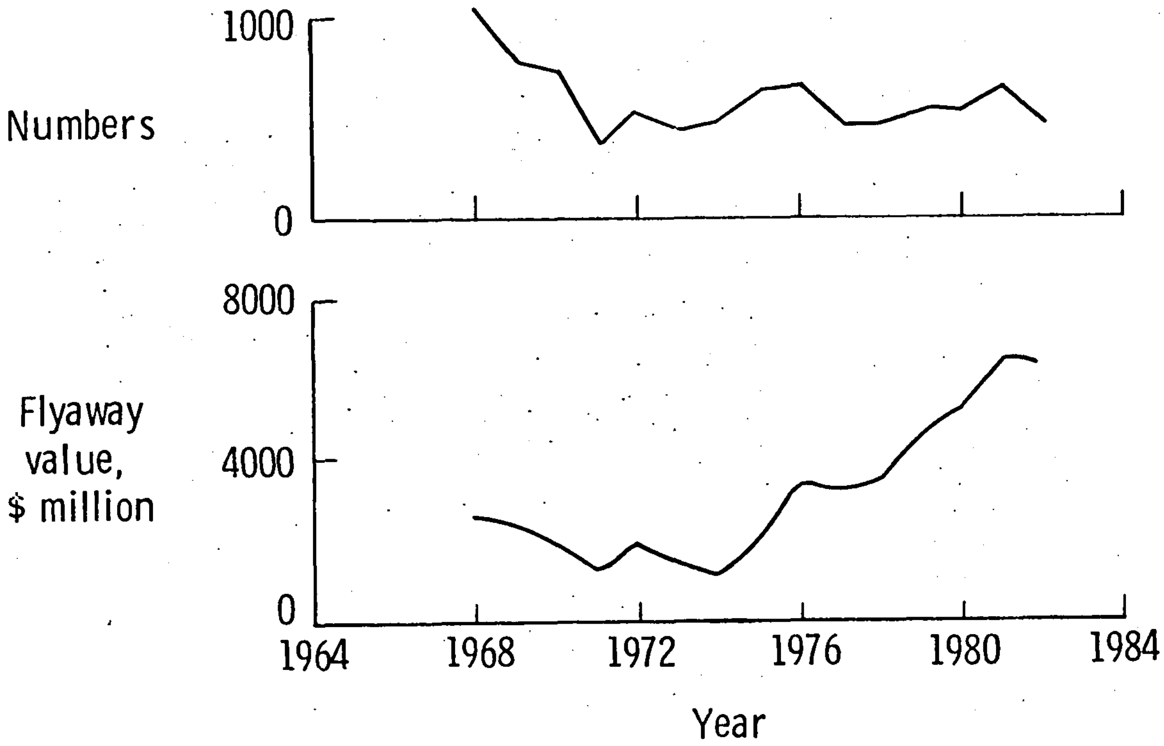

Figure 19.- Trend in quantity procured and total flyaway cost for U.S. fighter/attack aircraft, 1968 to 1982.

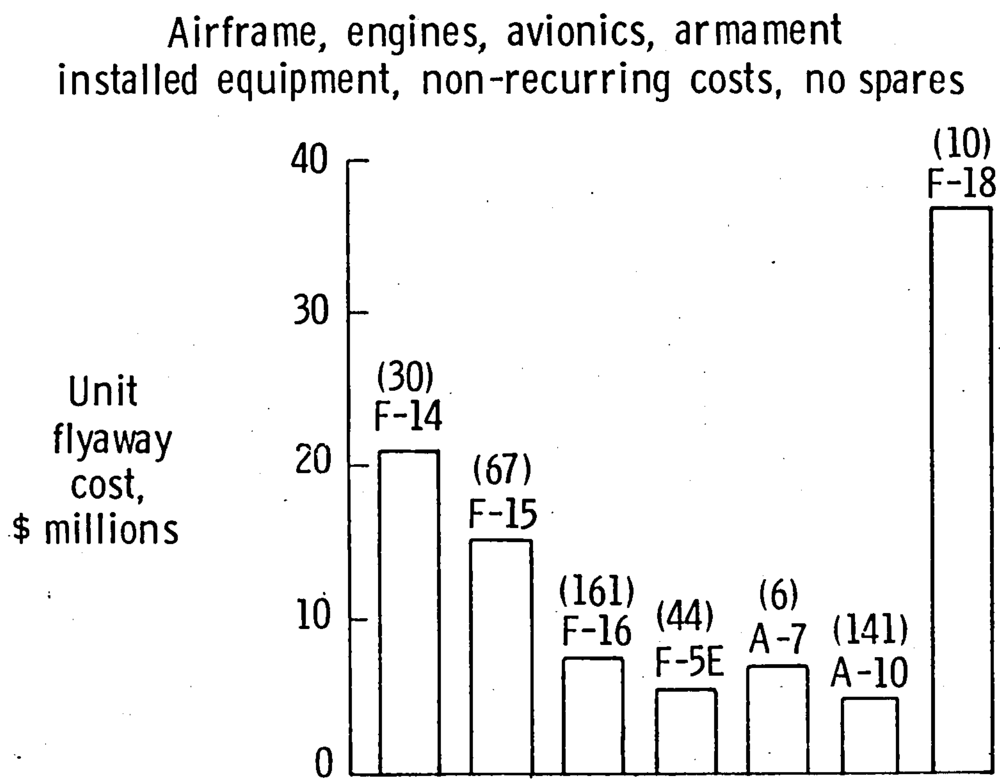

Figure 20.- Flyaway unit cost, U.S. fighter/attack aircraft, 1981.

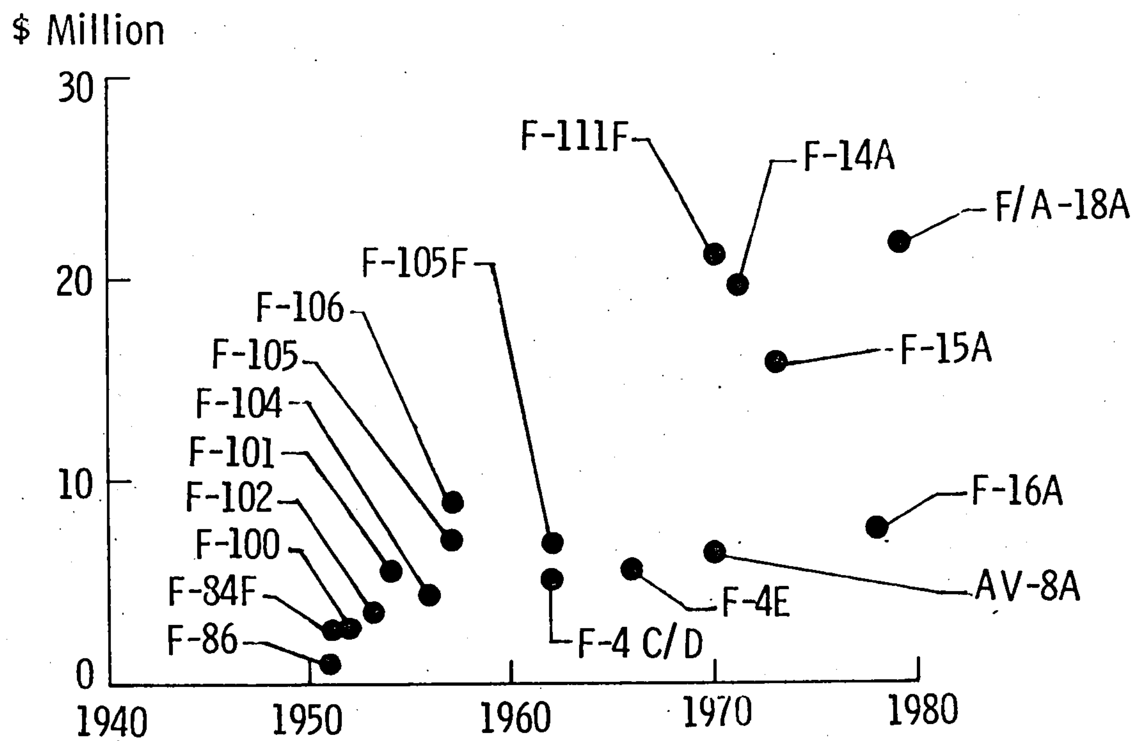

Figure 21.- Lot average cost for several U.S. fighters since 1950 , 1981 dollars.

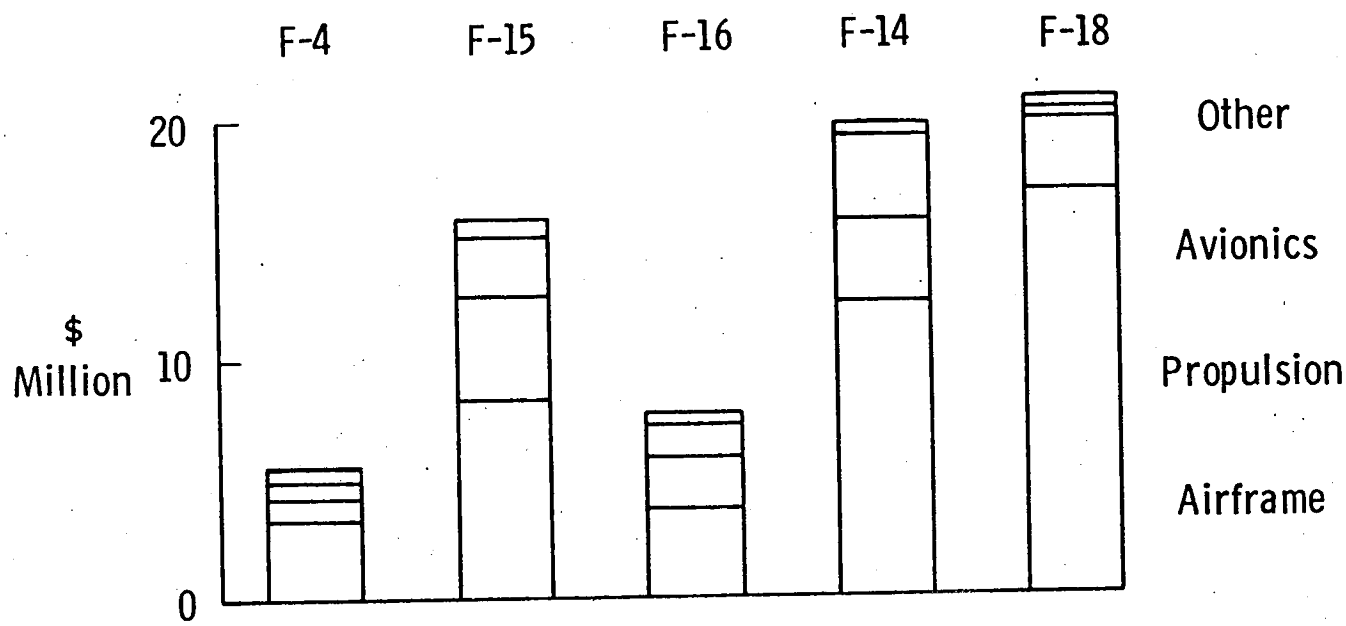

Figure 22.- Distribution of lot average cost for current fighters, 1981 dollars.

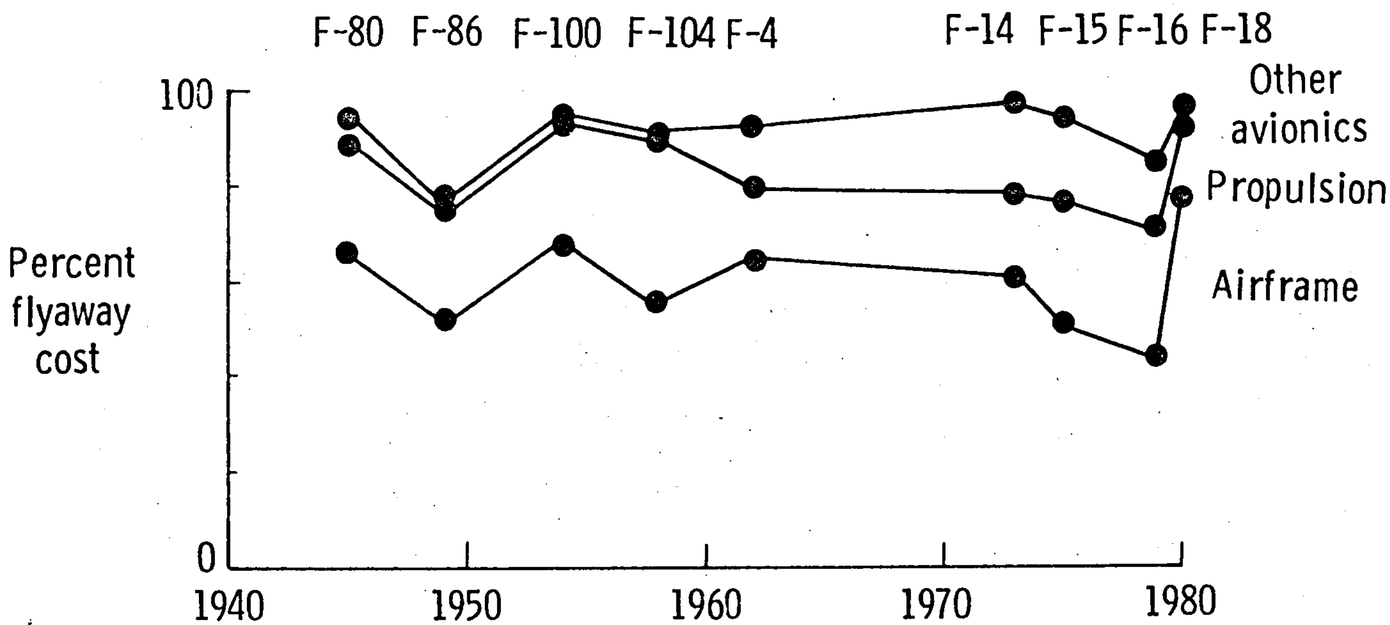

Figure 23.- Distribution of flyaway cost for various U.S. fighters over past 40 years.

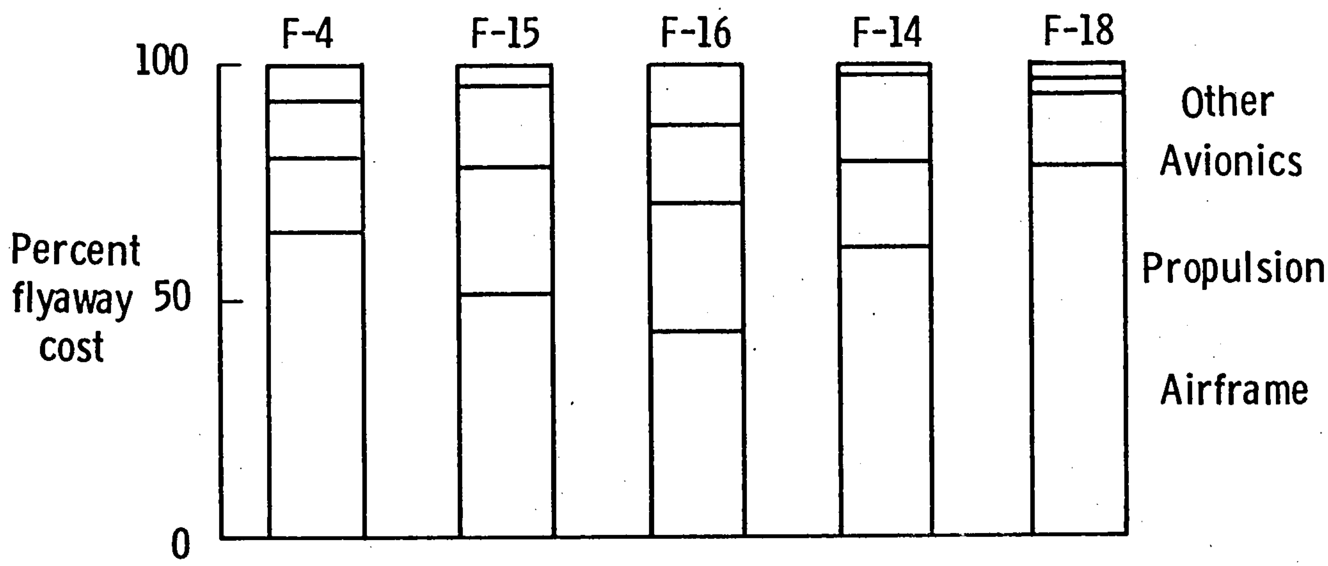

Figure 24.- Percentage distribution of flyaway cost.

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15. Supplementary Notes

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16. Abstract

Some basic trends in fighter aircraft are traced from the post World War II era. Beginning with the first operational jet fighter, the P-80, the characteristics of subsequent fighter aircraft are examined in terms of performance, mission capability, effectiveness, and cost. Characteristics presented include such items as power loading, wing loading, maximum speed, rate of climb, turn rate, weight and weight distribution, cost and cost distribution. In some cases, the characteristics of U.S.S.R. aircraft are included for comparison. The trends indicate some of the rationale for certain fighter designs and indicate some likely characteristics to be sought in future fighter aircraft designs.

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