PAST TRENDS IN PROCUREMENT OF AIR INTERCEPT MISSILES
AND IMPLICATIONS FOR THE ADVANCED MEDIUM-RANGE
AIR-TO-AIR MISSILE PROGRAM (AMRAAM)

STAFF WORKING PAPER

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PREFACE

The U.S. Navy and Air Force have been developing and procuring guided missiles to be used by aircraft to attack other aircraft for more than three decades. In recent years, there has been concern in the Congress that increasing costs of these Air Intercept Missiles may be jeopardizing the ability of the services to procure sufficient quantities. Currently, much of this concern is focused on the Advanced Medium Range Air-to-Air Missile (AMRAAM), which entered full-scale development in early 1982.

The Research and Development Subcommittee of the House Committee on Armed Services has requested this CBO study of topics related to the development and procurement of Air Intercept Missiles in order to aid that Subcommittee in deciding about the future of the AMRAAM program. This paper, which examines the history of procurement of AIM systems, is a partial fulfillment of that request. This study was undertaken to ascertain what lessons, if any, could be derived from history which would be useful to the Congress in judging AMRAAM. In accordance with CBO's mandate to provide objective and impartial analysis, the paper offers no recommendations.

The paper was prepared by Alan H. Shaw of CBO's National Security and International Affairs Division, under the general supervision of Robert F. Hale and John J. Hamre. It was reviewed by Dr. John Transue and received internal CBO review. The cooperation of the U.S. Navy and Air Force in supplying data is gratefully acknowledged. The assistance of external reviewers and of the Air Force and Navy implies no responsibility for the final product, which rests solely with CBO. Francis Pierce and Robert Faherty edited it; Janet Stafford typed it.

October 1982

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SUMMARY

Soon after World War II, the Navy and the Air Force began development of guided missiles to be used by fighter aircraft in attacking other aircraft. Compared with the guns used by fighters up until that time, such air intercept missiles (designated AIM) offer greater range, greater accuracy, and the opportunity to engage an enemy aircraft over a greater range of relative positions. Although air intercept missiles entered the inventory too late to be used in the Korean War, they were used extensively in the Southeast Asian conflict. This paper examines the history of AIM procurement in order to provide a framework to aid the Congress in making decisions concerning the Advanced Medium Range Air-to-Air Missile (AMRAAM), currently under development.

INTRODUCTION TO AIR INTERCEPT MISSILES

Beginning in the mid-1950s, the Navy introduced two families of missiles, the AIM-9 Sidewinder and the AIM-7 Sparrow, and the Air Force produced the Falcon missile (designated AIM-4 and later AIM-26). In the 1960s, the Air Force began to buy Sidewinders and Sparrows, and terminated Falcon production. In 1971, the Navy initiated procurement of the long-range AIM-54 Phoenix missile. The Phoenix, Sparrow, and Sidewinder remain in production, the latter two having undergone several model changes.

The Sidewinder is carried on all currently operational U.S. Air Force, Navy, and Marine Corps fighters and interceptors. With a maximum range of about four miles, it is the principal weapon for engagements within visual range. The missile homes on the infrared emissions of the target aircraft. The missile seeker acquires the target prior to launch; once launched, the missile is independent of the launch aircraft. The 25-year evolution of the Sidewinder has resulted in numerous improvements. The principal ones have been increased seeker sensitivity to allow the missile to detect the target from any angle (all-aspect capability), the ability to detect a target not directly in front of the launch aircraft (off-boresight capability), and greater capability to detect the target in the presence of other infrared signals (operations in clutter). The major limitations of the Sidewinder are its range and the degradation of seeker performance under certain weather conditions.

Engagement range is extended by the 25-mile Sparrow carried on F-4, F-14, F-15, and F/A-18 aircraft. The Sparrow is a beyond-visual-range missile that homes on the radar signal broadcast by the launch aircraft and reflected from the target. Operating the Sparrow requires the pilot to illuminate the target continuously with his radar from the time the missile is launched to the time of impact. Like the Sidewinder, the Sparrow has gone through a progression of model improvements since it was introduced in 1957.

The long-range Phoenix missile (maximum engagement range about 100 miles) is carried only on the Navy's F-14. For part of its flight, the Phoenix is guided the same way Sparrow is. For the last part of its flight, however, it uses its own on-board radar for guidance, freeing the launch aircraft from further interaction with the missile. This active terminal homing, plus features of the F-14 radar, allow the F-14 to engage several targets simultaneously

Experience has shown that there are some fundamental problems associated with operating the Sparrow that stem primarily from its mode of guidance. Operating the Sparrow restricts the flight path of the pilot during missile flight, making him vulnerable to counterattack by his target or by another aircraft. A pilot attacking a target can fire several Sparrows at that target, but cannot engage another target while his attack is still in progress. Finally, the Sparrow is not compatible with the F-16, which will be the most numerous U.S. fighter.

In order to overcome these deficiencies, the Air Force and Navy have been developing a new Advanced Medium Range Air-to-Air Missile as a successor to the Sparrow. AMRAAM will employ active terminal homing similar to that used on the Phoenix to allow it to operate autonomously after launch. It will be operational on all modern U.S. fighters and interceptors: F-14, F-15, F-16, F/A-18. The Phoenix itself would not be a viable substitute for the Sparrow since it is twice the weight and about six times the cost of the Sparrow, and requires a very costly radar on the launch aircraft in order to achieve long-range performance.

AMRAAM entered full-scale development in early 1982, and is expected to enter production in the mid-1980s. The current program calls for an $800 million development program followed by the production of 20,000 missiles at $190,000 each (in fiscal year 1982 dollars), approximately one-half more than the unit cost of the most recent Sparrow model, AIM-7M.

SCOPE

Progressive improvements in AIMs have been accompanied by significant increases in unit costs. There has been concern in the Congress that, no matter how effective AMRAAM is, it may be ultimately too costly to buy in the quantities necessary to supply U.S. forces adequately. Congressional decisions regarding AMRAAM will be made against the backdrop of several widely held perceptions. These are:

- As time has progressed, the procurement of AIMs has consumed an increasing share of the defense budget while the number procured has decreased;

- Actual unit costs of AIM systems are always much more than initial estimates;

- This has led to difficulties in achieving inventory goals.

The implications of these hypotheses for AMRAAM seem clear: if they are true, the actual unit cost of AMRAAM will be much greater than that of the Sparrow, either increasing the impact of AIM procurement on the defense procurement budget, slowing progress toward reaching inventory goals, or both. This paper uses the history of AIM procurement to test these hypotheses and to ascertain what can be learned from history that may be useful to the Congress in judging the AMRAAM program. In particular, the paper examines:

- Long-term trends in the number of AIMs procured and the impact of that procurement on the defense procurement budget;

- The pattern of changes in the estimated costs of AIM systems as they have proceeded through full-scale development and into procurement.

LONG-TERM PROCUREMENT TRENDS

Contrary to some perceptions, DoD has not been devoting an ever increasing share of its procurement dollar to a diminishing number of AIMs. While it is true that compared to the early years of AIM procurement DoD is spending about the same fraction of its budget for one-fourth as many missiles, since about 1970 both

numbers and budget share have increased at about the same rate. During the 1960s, the cost of missile improvements was absorbed by buying fewer missiles, while during the 1970s it was accommodated by increasing the budget share devoted to AIMS. This is illustrated in Summary Figure 1. In addition, the budget share allotted to procuring the Sidewinder and the money allotted for the Sparrow (not shown in the figure) have individually followed the same general trend as the aggregate.

Two main causes underlie the divergence of the trends in numbers and costs. First, the constant-dollar unit cost of the AIM-9 Sidewinder, which has usually been procured in greater numbers than the AIM-7 Sparrow, increased fivefold from the early 1960s to the late 1970s. Second, there has been a gradual shift toward buying fewer Sidewinders and proportionately more Sparrows. The Sparrow missile, although its cost has been more nearly constant over time, has always been more expensive than the Sidewinder. In addition, the introduction of the very costly AIM-54 Phoenix is responsible for a large share of cost growth, as indicated in the figure.

If a long-term linear trend can be discerned over the more than two decades that AIMs have been procured, on the average, the impact on the defense budget of expenditures for AIM procurement has been roughly constant. If history is any guide, the budget share devoted to AIMs is not likely to change much in the near future. Therefore, cost control in AMRAAM becomes an important consideration.

GROWTH IN DEVELOPMENT AND PROCUREMENT COSTS

While history cannot predict the future costs of AMRAAM, it can yield an important perspective. Cost growth in development and procurement for six air intercept missile programs (AIM-7E, AIM-7F, AIM-7M, AIM-9L, AIM-9M, AIM-54A), as reported in constant dollars in the Defense Department's Selected Acquisition Reports (SARs), has been analyzed and compared to growth for all the programs reported in recent SARs. Growth in development cost is of interest both of itself and because of its possible utility as an indicator of procurement cost growth.

Development Cost Growth

Development cost growth for these six AIM systems followed a rather irregular pattern. Three showed no growth; two showed

extremely high growth of 300 percent to 400 percent, which is seven to ten times the average for all the systems reported in recent SARs (that is, 40 percent); and one (AIM-54A) grew at just over the average rate for all current SAR systems. The two that showed very high growth represented, in general, greater technical departures from their predecessors than did those that showed no cost growth, while the AIM-54A program developed an entirely new missile--clearly a technical departure.

The data suggest a pattern with implications of AMRAAM, but are not conclusive. Development cost growth is qualitatively correlated with degree of technical departure. One possible interpretation of the data is that the cost of AIM developments that involve important technical departures, such as AMRAAM, are wildly unpredictable. Another is that the cost of such developments are likely to be several hundred million dollars, as AIM-7F, AIM-9L, and AIM-54A were, and that the AMRAAM estimate of $800 million for development is likely to be a realistic one. The data provide no statistical basis for choosing one interpretation over the other. While the AIM-54A program seems closest to AMRAAM based on degree of technical departure and the magnitude of the initial estimate of development costs, a single data point has no statistical significance.

Unit Cost Growth

Unlike development cost growth, the growth in unit cost for the originally planned quantities of the six systems was distributed in a manner consistent with all current SAR systems. The lowest growth in unit cost of the AIM systems was 10 percent and the highest was 90 percent; the average of 43 percent is very close to the average for all SAR systems. The fact that the unit cost increases displayed by so many systems follow a fairly well-defined distribution indicates a reasonable likelihood that future programs will follow the same pattern. Without a detailed understanding of the mechanisms that produce this cost growth, it is not possible to predict what the growth of any particular system will be.

Furthermore, there is an apparent correlation between unit cost growth and development cost growth. The average unit cost growth for the three systems with no development cost growth was 28 percent, while the average for the other three was about 56 percent. An examination of all systems in the current SARs as well as the historical AIM data indicates that unit cost increases

are generally correlated with development cost increases. Indeed, it can be generally concluded that increases in development cost almost always mean increases in unit cost, though a lack of increase in development cost does not guarantee low unit cost increase. Development cost growth appears to be an indicator of unit cost growth to come.

The unit cost growth of systems with the same development cost growth typically shows a wide variation, however, making a precise numerical prediction of one from the other fairly meaningless. While the data do not support an accurate prediction of unit cost growth from development cost growth, the data are more strongly supportive of a minimum value of unit cost growth as a function of development cost growth. The data strongly support a minimum value of unit cost growth of 25 percent or half of development cost growth, whichever is lower.

The data confirm intuitive expectations. Since the earliest estimates of development and procurement costs published in a SAR are made at the same time, whatever factors operate to produce a low estimate of one would be expected to produce a low estimate of the other. The competition for funds provides an incentive to err on the low side of the region of uncertainty of both estimates.

IMPLICATIONS FOR AMRAAM INVENTORIES

History presents no hard and fast conclusions that can be applied directly to AMRAAM. It does, however, provide a useful framework for examining the program.

On the basis of historical precedent, AMRAAM is a good candidate for growth in both development cost and unit cost, but history provides no firm prediction that AMRAAM costs will grow. Based on past experience with AIMs and current SAR systems, unit cost growth on the order of 50 percent would not be surprising. Unit cost growth of less than 10 percent or more than 100 percent would be surprising, but is certainly not impossible. As time progresses, it may be possible to form a better judgment of what unit costs are likely to be by monitoring the development program.

There are currently shortfalls in inventories of both Sidewinders and Sparrows, especially in the later models. There has been concern in the Congress about the rate at which the inventory objectives for the newest missiles, especially the AIM-7M, will

be approached. If past patterns of funding continue in the future, AMRAAM, which is currently estimated to cost about 50 percent more than AIM-7M, would be procured at rates less than or equal to its predecessor. If AMRAAM unit costs are ultimately significantly greater than currently predicted, either the impact of AIM procurement on the defense budget will have to be increased beyond what it has traditionally been, or AMRAAM will have to be procured at a lower rate than the AIM-7M it is due to follow. In this regard, it is important to note that reductions in buy rates below those planned in a program cause further cost increases and yet further rate reductions.

In making decisions regarding AMRAAM, other important factors need to be considered. The program is not being pursued in a vacuum. The program management has 25 years of service experience in developing AIMs and other missiles to draw upon, and has introduced several management initiatives to control development and production costs. Finally, cost is not the only factor in procuring defense systems. If the system is really needed, its procurement should be seriously considered despite any cost problems which may arise. In doing so, however, the Congress (and DoD) ought to keep in mind that significantly increased costs and constant or rising inventory objectives cannot be easily accommodated within a relatively constant share of the budget, and that procuring a system under these circumstances will have important implications for the rate at which it is procured and the funds available for other defense procurement.

CHAPTER I. INTRODUCTION

The U.S. Navy and Air Force have been developing and procuring air-to-air missiles for about 30 years. These missiles, which carry the designation AIM for air intercept missile, are designed to be launched from an airplane in order to destroy another airplane, thereby extending the engagement range of the launch aircraft beyond the effective range of its gun.

As the complexity and operational capabilities of these missile systems have increased, costs have also increased leading some in the Congress and within the Department of Defense (DoD) to express concern that rising unit costs could, in the near future, jeopardize the maintenance of sufficient inventories. A particular reason for concern is that a new missile system differing in design from its predecessors in some fundamental ways is entering full-scale development, and cost growth in the future could make it prohibitively expensive.

As a practical matter, the Congress will have to decide on a year-to-year basis whether or not to fund continued development of this Advanced Medium Range Air-to-Air Missile (AMRAAM). The decision will be based in part upon how the Congress views the likelihood that the program will meet its cost and performance goals.

The AMRAAM development program is estimated to cost $800 million. About $200 million has been appropriated through 1982 and $212 million is requested for 1983. The current plan is to buy 20,000 missiles at an average of $190,000 each (in fiscal year 1982 dollars), beginning in the latter half of the 1980s. AMRAAM is a joint Air Force/Navy program, with the Air Force as lead agency.

SCOPE

This report provides a historical perspective within which the costs of AMRAAM may be judged. In particular, it presents long-term trends in costs and numbers of missiles procured, and a brief analysis of growth in their development and production costs.

After a brief history of AIM developments presented in Chapter II, Chapter III examines long-term trends in the number of air intercept missiles procured, the fraction of the DoD procurement budget devoted to that procurement, and unit costs. This analysis was conducted in order to examine the contention that over the years DoD has been spending increasing amounts on air intercept missiles, but has been getting fewer of them. The analysis also provides an understanding of how changing costs associated with successive model improvements have been accommodated in the past, and a context within which to judge what may happen if the AMRAAM costs significantly more to procure than its predecessors.

Chapter IV analyzes past cost growth during selected missile programs. This analysis makes no projection of AMRAAM cost growth, but provides a framework within which an informed judgment may be made regarding possible cost growth as the program progresses through full-scale development into procurement.

The paper examines only topics related to costs and cost growth. Whatever the ultimate cost performance of the AMRAAM program, decisions to proceed with development and procurement will also depend upon the capabilities of the system, the availability and relative attractiveness of alternatives, and, on balance, its contribution to U.S. defense capabilities.

CHAPTER II. BACKGROUND

During World War II, fighter aircraft attacked enemy aircraft exclusively with guns. In the late 1940s, the U.S. Air Force and Navy initiated the development of air-to-air guided missiles that would provide aircraft with weapons of substantially greater range than the gun. In the mid-1950s, the Navy began production of the short-range AIM-9 Sidewinder, an infrared homing (heat seeking) missile, and the medium-range AIM-7 Sparrow, which employs semi-active radar homing. 1/ These two missiles are still in production, having undergone numerous modifications in the intervening years. From 1954 to 1963, the Air Force produced the Falcon missile (designated AIM-4 and AIM-26), in both infrared and semi-active radar models. 2/

Since the mid-1960s, Sidewinder and Sparrow have been employed by both services and by many foreign nations. In addition, the Sparrow is employed from a shipboard launcher as the RIM-7 Sea Sparrow, and a variant of the Sidewinder is used in the Army's Chaparral surface-to-air missile system. 3/

The Sidewinder is carried on all currently operational U.S. Air Force, Navy, and Marine Corps fighters and interceptors. With a maximum range of about four miles, it is the principal weapon for engagements within visual range. The missile homes on the infrared emissions of the target aircraft. The missile seeker acquires the target prior to launch; once launched the missile is independent of the launch aircraft. The 25-year evolution of the Sidewinder has resulted in numerous improvements as shown in Figure 1 and Table 1. The principal ones have been: increased seeker sensitivity to allow the missile to detect the target from any angle (all-aspect capability), the ability to detect a target

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1/ The launch aircraft illuminates the target with its radar, and the missiles home on the energy reflected from the target.

2/ This period also saw the production of unguided air-to-air weapons, which are not discussed in this report.

3/ Neither Sea Sparrow nor Chaparral is included in this study.

FIGURE 1. SIDEWINDER MISSILE HISTORY

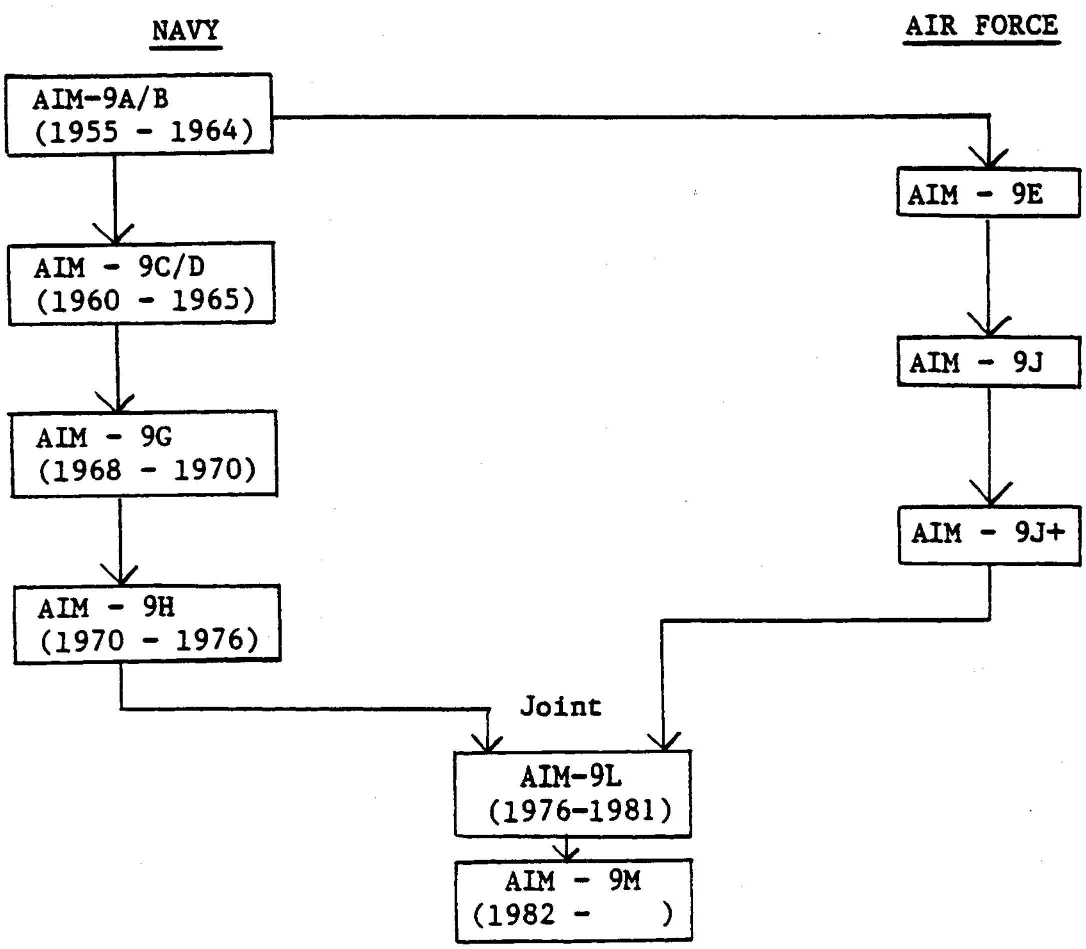


TABLE 1. THE SIDEWINDER MISSILE

Model	Major Changes from Earlier Models
AIM-9A	Prototype.
AIM-9B	First production model.
AIM-9C	Semi-active radar version of AIM-9B (only SAR AIM-9).
AIM-9D	Higher speed; greater range.
AIM-9E	Modification of AIM-9B for USAF: improved seeker for better low altitude performance.
AIM-9G	Off-boresight target acquisition.
AIM-9H	Better close-range "dogfight" capability; solid state electronics.
AIM-9J	Conversion of AIM-9B/E for better "dogfighting," better maneuverability.
AIM-9P (or JP)	Improved AIM-9J.
AIM-9L	Developed for "dogfighting": increased seeker sensitivity for all aspect target acquisition; greater maneuverability.
AIM-9M	Improved performance in presence of countermeasures and clutter; reduced smoke motor.

SOURCES: Jane's Aircraft 1980-81, Jane's Weapon Systems 1980-81, Jane's Weapon Systems 1979-80.

not directly in front of the launch aircraft (off-boresight capability), and greater capability to detect the target in the presence of other infrared signals (operations in clutter). The major limitations of the Sidewinder are its range and the degradation of seeker performance due to certain weather conditions.

Engagement range is extended by the 25-mile Sparrow carried on F-4, F-14, F-15, and F/A-18 aircraft. The Sparrow is a beyond-visual-range missile that homes on the radar signal broadcast by the launch aircraft and reflected from the target. Operating the Sparrow requires the pilot to illuminate the target continuously with his radar from the time the missile is launched to the time of impact. Like the Sidewinder, the Sparrow has gone through a progression of model improvements since it was introduced in 1957, as shown in Tables 2 and 3.

TABLE 2. SPARROW MISSILE HISTORY

Model	Approximate Production Dates	User
AIM-7C	1957 - 1959	USN
AIM-7D	1959 - 1962	USN/USAF
AIM-7E	1963 - 1970	USN/USAF
AIM-7E2	1969 - 1973	USN/USAF
AIM-7F	1974 - 1982	USN/USAF
AIM-7M	1982 -	USN/USAF

TABLE 3. THE SPARROW MISSILE

Model	Major Changes from Earlier Models
AIM-7C,D,E	Basic Sparrow semi-active radar missile.
AIM-7E2	Better maneuverability for improved "dogfighting."
AIM-7F	Solid state electronics, larger motor for greater range and speed, greater reliability and lethality, increased launch and attack volumes, and improved lock-on in presence of look-down clutter.
AIM-7M	Improved seeker for better performance in presence of countermeasures and look-down clutter.

SOURCES: Jane's Aircraft 1980-81, Jane's Weapon Systems 1980-81, Jane's Weapon Systems 1979-80, Air Force Magazine (May 1981).

The long-range Phoenix missile (maximum engagement range about 100 miles) is carried only on the Navy's F-14. For part of its flight, the Phoenix is guided the same way the Sparrow is. For the last part of its flight, however, it uses its own on-board radar for guidance, freeing the launch aircraft from further interaction with the missile. This active terminal homing, plus features of the F-14 radar, allow the F-14 to engage several targets simultaneously.

Experience has shown that there are some fundamental problems associated with operating the Sparrow, stemming primarily from its mode of guidance. Operating the Sparrow restricts the flight path of the pilot during missile flight, making him vulnerable to counterattack by his target or by another aircraft. A pilot attacking a target can fire several Sparrows at that target, but cannot engage another target while his attack is still in progress. Finally, the Sparrow is not compatible with the F-16, which will be the most numerous U.S. fighter.

In order to overcome these deficiencies, the Air Force and Navy have been developing a new Advanced Medium Range Air-to-Air Missile as a successor to the Sparrow. AMRAAM will employ active terminal homing similar to that used on the Phoenix to allow it to operate autonomously after launch. It will be operational on all modern U.S. fighters and interceptors: F-14, F-15, F-16, and F/A-18. The Phoenix itself would not be a viable substitute for the Sparrow since it is twice the weight and about six times the cost of the Sparrow, and requires a costly radar on the launch aircraft in order to achieve long-range performance.

CHAPTER III. HISTORICAL TRENDS IN MISSILE COSTS AND QUANTITIES PROCURED

This chapter examines trends exhibited over the past three decades in the costs of air-to-air missiles and in the numbers procured. While the most relevant data are for the past ten years (1973-1982), those for earlier years lend important perspective, as the figures will show. The data from 1973 forward are complete; the earlier data are not. In particular, data for Sidewinder models produced exclusively for the Air Force by modifying existing missiles (AIM-9E, AIM-9J, and AIM-9JP) were not available from the Air Force. All Navy procurement and all Air Force Sparrow procurement appears to be accounted for in data supplied by the program offices. Future projections are also based upon program office data, corroborated and augmented by other sources. In the case of some of the early models, total costs have been calculated from partial or complete hardware costs by applying scaling factors derived from more modern models.

AGGREGATE TRENDS FOR TOTAL AIM PROCUREMENT

Numbers Procured

Figure 2 shows the number of air intercept missiles bought each year from 1973 to 1982, with projections to 1986 (based on program office estimates). A steady decrease in 1979-1981 is evident, with a planned correction in the near future as the M models are procured. However, this decline follows a much longer increase beginning in the early 1970s. Therefore, the seemingly sharp decline is actually a temporary and relatively small fluctuation following a long rise.

Figure 3 shows the same information extending back to 1954. From this, it is clear that the early 1970s represented the culmination of a period of tremendous decline that began about ten years earlier, a decline only partially reversed by the steady increase which followed. Even allowing the removal of Falcon from the total buy, the decrease in AIM-7 and AIM-9 procurement was a factor of roughly 10. The Phoenix accounts for only a small fraction of the total buy, and its inclusion does not affect the general trends.

FIGURE 2. THE NUMBER OF AIR INTERCEPT MISSILES PROCURED EACH YEAR

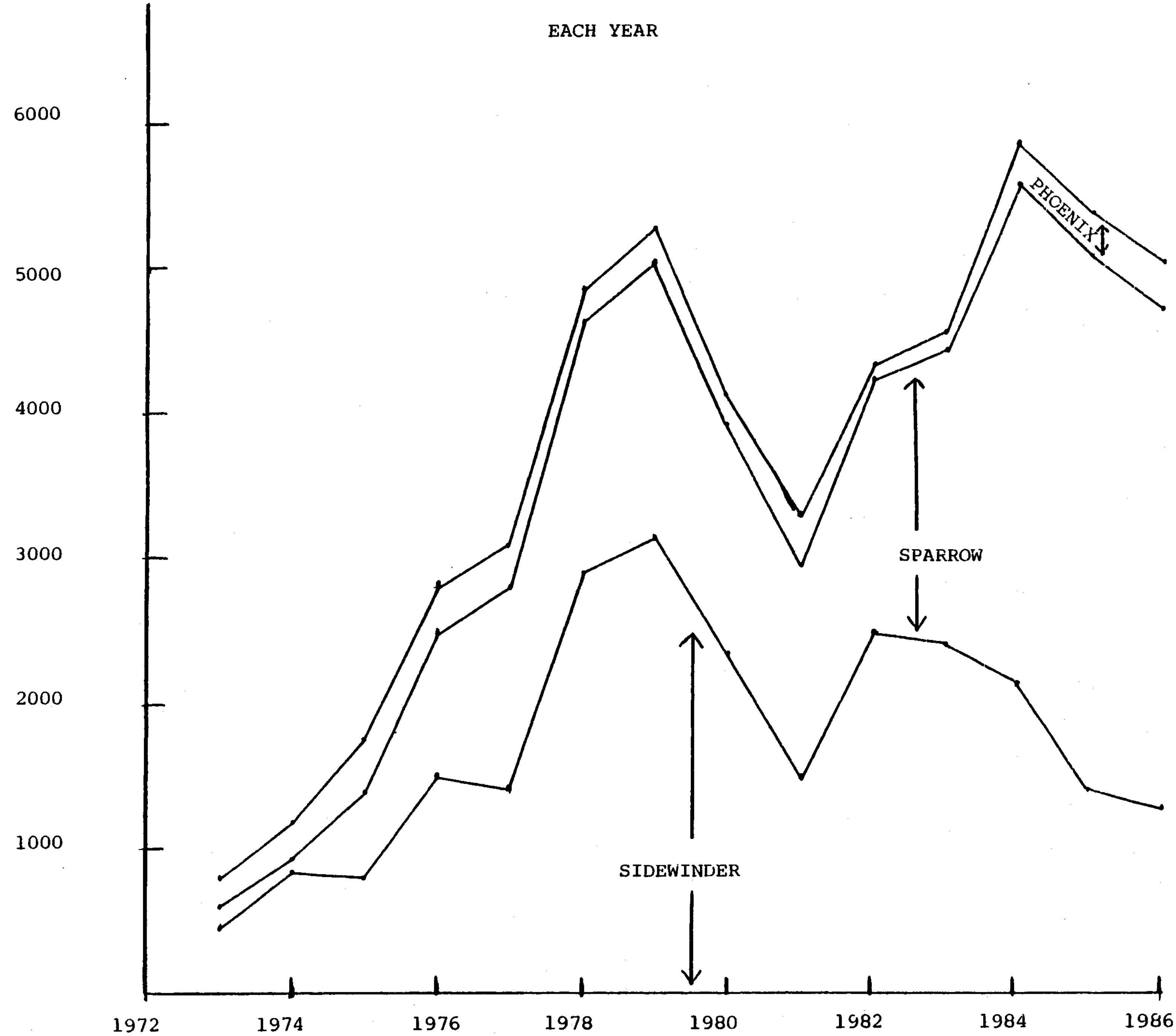
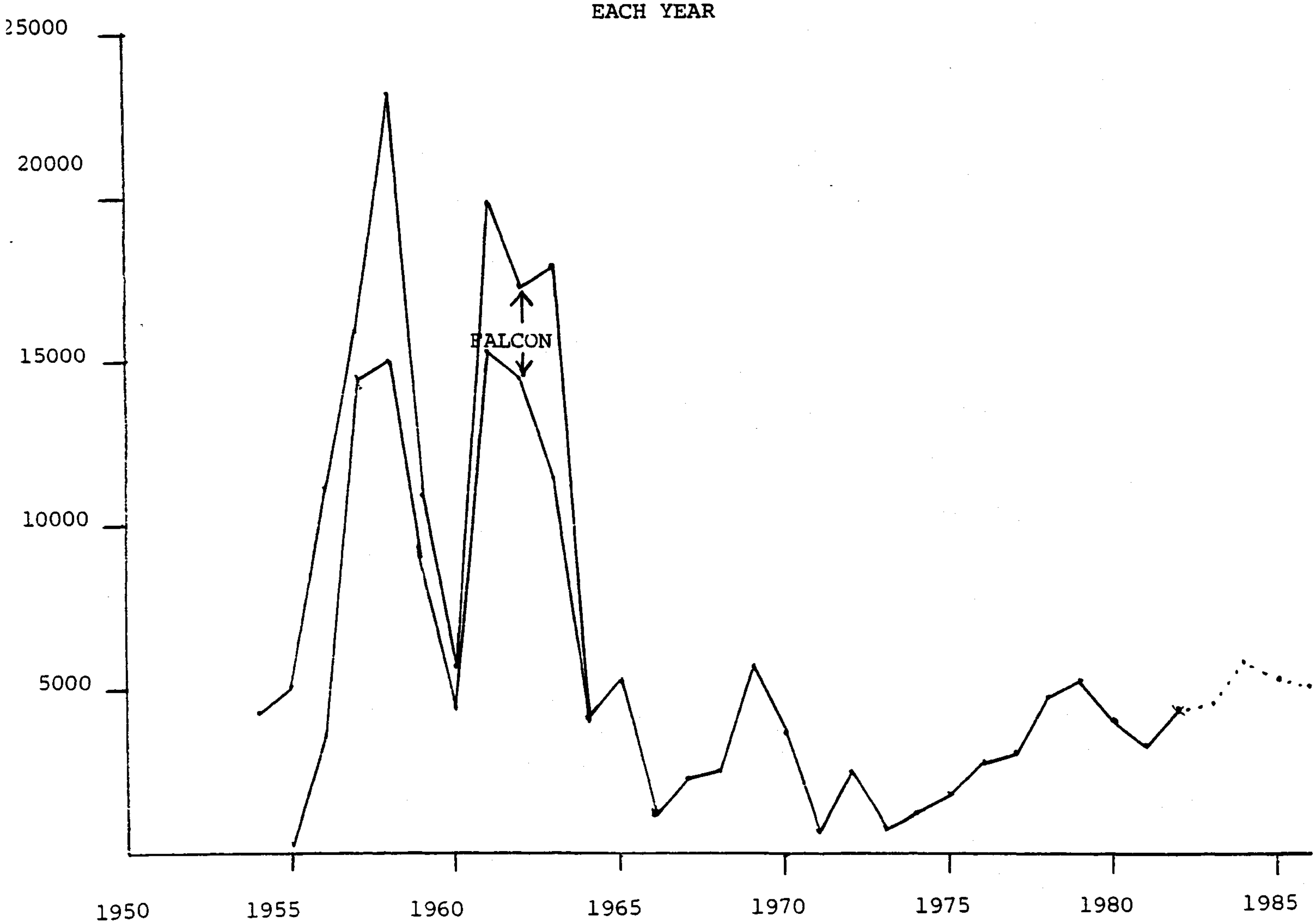


FIGURE 3. THE NUMBER OF AIR INTERCEPT MISSILES PROCURED EACH YEAR



Between the mid-1960s and the late 1970s, about 5,000 Air Force AIM-9Bs were modified to become AIM-9Es, and were subsequently remodified along with 9,000 more AIM-9Bs to the AIM-9J configuration. Inclusion of these modifications in Figures 2 through 4 will alter the data in detail, but not the trends displayed. 1/

Figure 2 also shows that most of the total buy and most of the growth from 1973 to 1979 consisted of Sidewinders; this was even more so in the preceding two decades. However, the projected increases in 1982-1986 are predominantly in Sparrows; roughly three times as many Sparrows as Sidewinders will be procured in 1984-1986. This partially reflects the extent to which the inventory objectives for the various Sidewinder and Sparrow models have been met. It also indicates a shift in tactics to greater reliance on the longer-range radar missiles and less emphasis on the Sidewinder. This trend will tend to increase the cost of fulfilling overall inventory objectives, since radar missiles are more costly than infrared missiles.

Total Costs

Figure 4 displays the fraction of the total DoD procurement budget expended each year on air intercept missiles. This measures DoD's commitment to procuring these systems each year in terms of its impact on the procurement budget. The steep decline in numbers procured is mirrored by a decline in expenditures. The rise in numbers during the 1970s is also reflected in a rise in budget share. However, since numbers of missiles procured are only about one-fourth of earlier levels, the investment growth reflects dramatically higher unit costs of more sophisticated later models.

TRENDS EXHIBITED BY SIDEWINDER AND SPARROW INDIVIDUALLY

The overall trends in procurement of air intercept missiles clearly indicate that average unit costs have been increasing, and are well above what they were during the first decade of production of these systems. Furthermore, the mix of Sidewinder and Sparrow missiles is shifting away from a preponderance of

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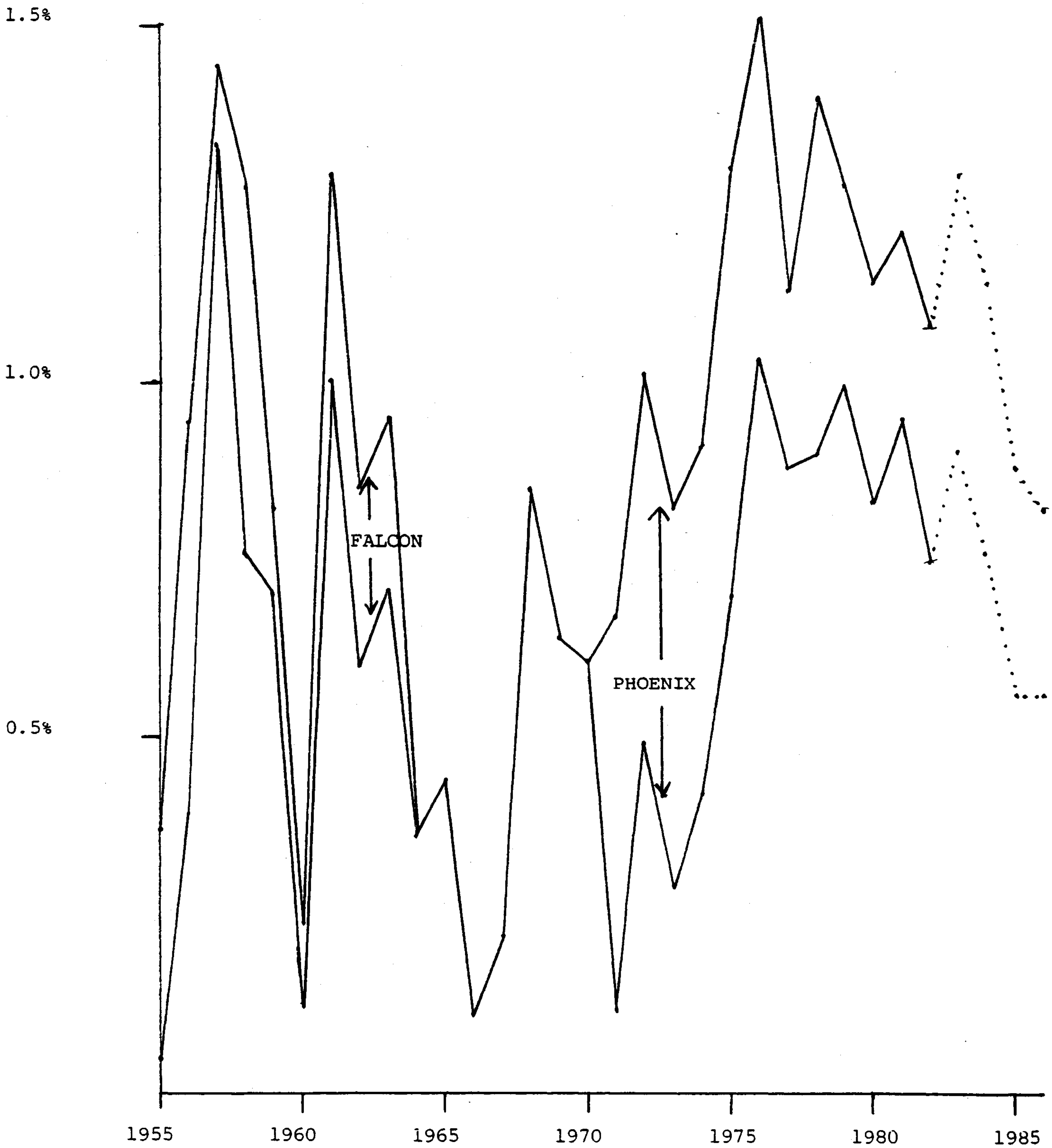
1/ Jane's Aircraft 1980-81, Jane's Weapon Systems 1980-81.

FIGURE 4. FRACTION OF THE DEFENSE DEPARTMENT PROCUREMENT BUDGET SPENT ON AIR INTERCEPT MISSILES



Sidewinders and toward more Sparrows than Sidewinders. These trends are illuminated by examining the two missile programs separately. Doing so also permits a clearer examination of unit costs.

Sidewinder

Figure 5 shows the basic trends of the AIM-9 Sidewinder program. The bottom figure shows that the numbers procured fell rapidly in the 1960s, and then remained on the average generally unchanged until the present, with some increases in 1974-1979. The fraction of the DoD procurement budget going to this program, however, after peaking very early stayed on the average unchanged, with some overall increase in the late 1970s followed by a distinct decline. The increases in the late 1970s would appear much more substantial were the figures to show only data beginning in 1973.

The relation between the trends exhibited in these two graphs is shown in the upper graph, which exhibits average yearly unit costs in constant fiscal year 1982 dollars. The same number of missiles were bought in the early 1960s as in the late 1950s, but at a substantial reduction in budgetary impact. This is a reflection of unit cost reductions. A steady, large rise in unit costs from the early 1960s to the late 1970s is responsible for the fact that, while average expenditures have remained generally constant since 1959, numbers declined until the 1970s.

The unit cost fluctuations are explained by Figure 6. Successive introduction of new models with higher unit costs produced a steadily rising curve with "spikes" superimposed on it. As each model proceeded into production, unit costs fell.

Figure 7 removes the "spikes" by displaying the average unit costs for each model plotted at the year at which that model achieved initial operational capability (IOC). The line serves only to connect the points and guide the eye. The upward trend in costs is clear: more than fivefold since the first models. The fact that the costs decrease from AIM-9L to AIM-9M indicates the potential of modern manufacturing techniques for reducing costs while improving the missile.

Sparrow

The basic trends in the history of the Sparrow are exhibited in Figure 8. Compared to the Sidewinder, the average number of

FIGURE 5. SIDEWINDER PROCUREMENT HISTORY

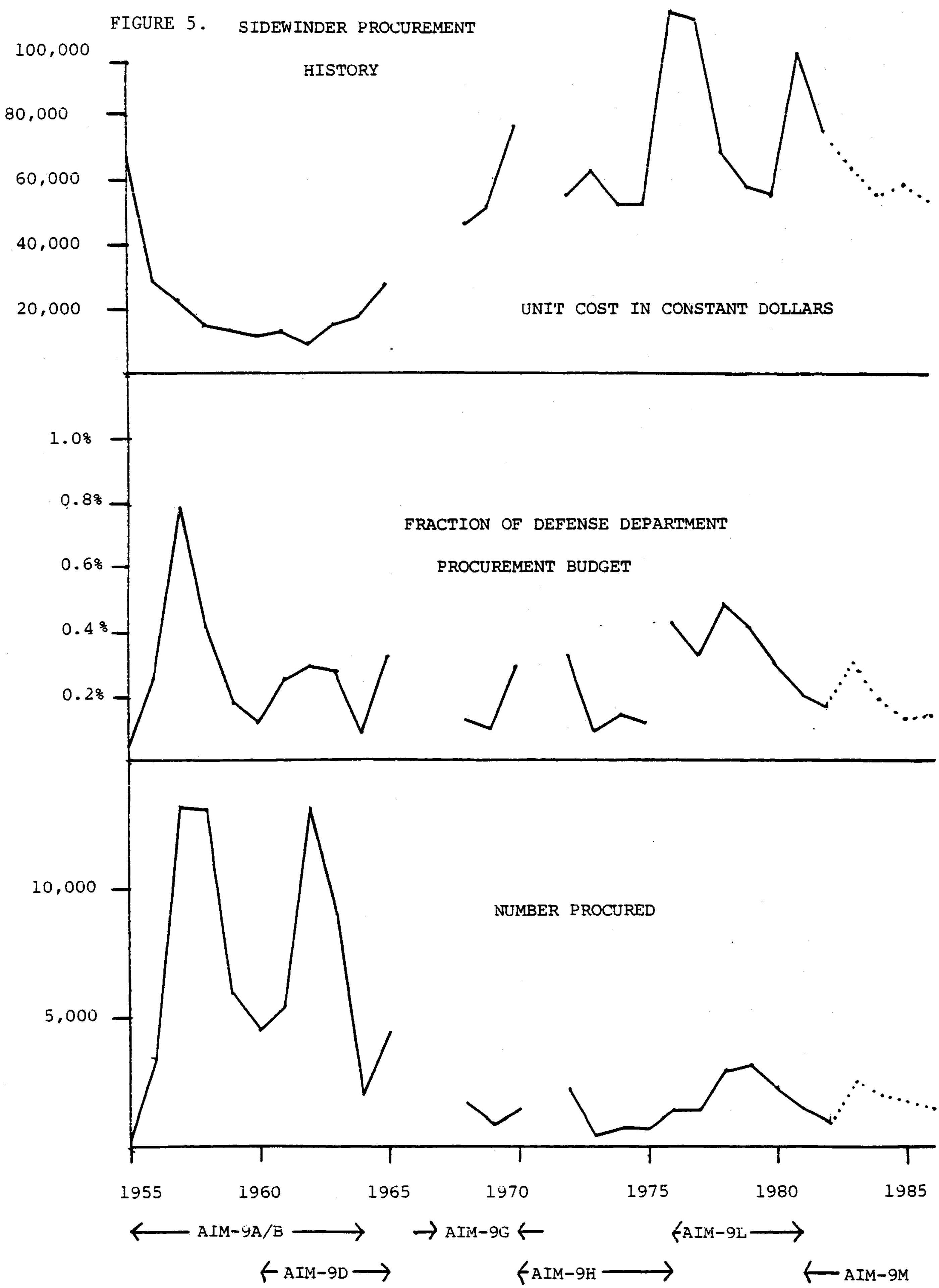


FIGURE 6. UNIT COSTS OF AIR INTERCEPT MISSILES (THOUSANDS OF 1982DOLLARS)

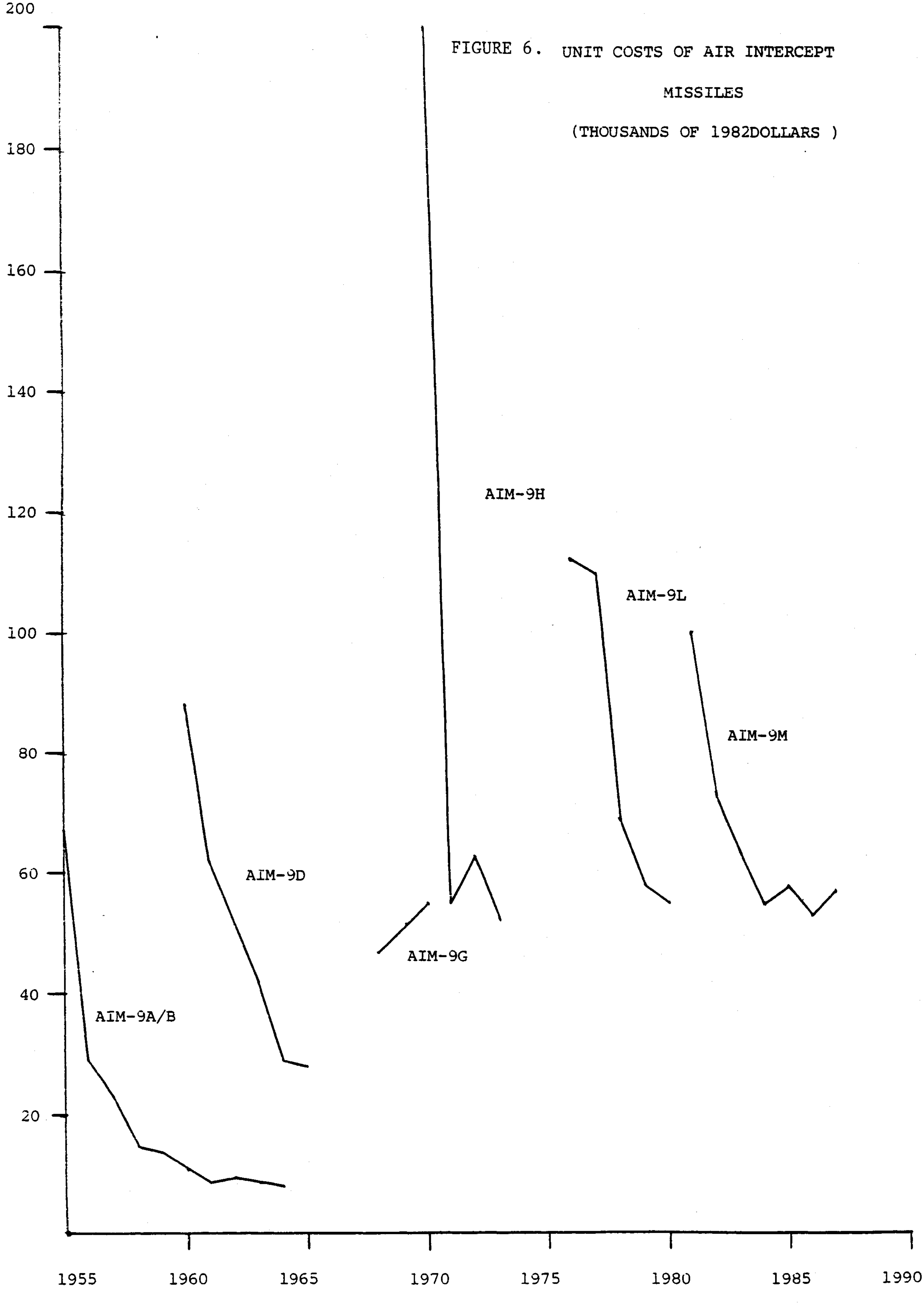


FIGURE 7. AVERAGE UNIT COST OF EACH SIDEWINDER MODEL IN THOUSANDS OF 1982 DOLLARS

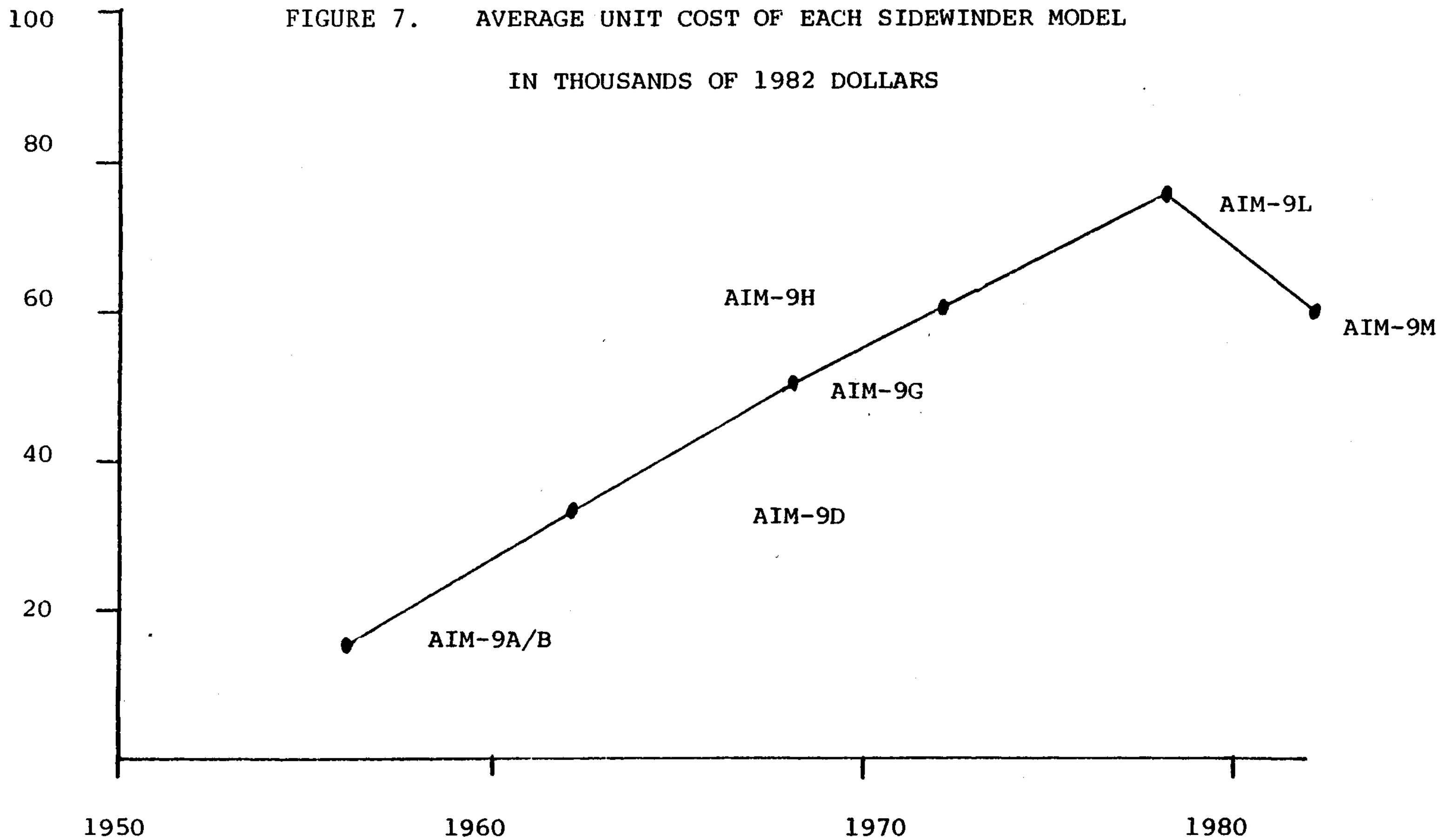
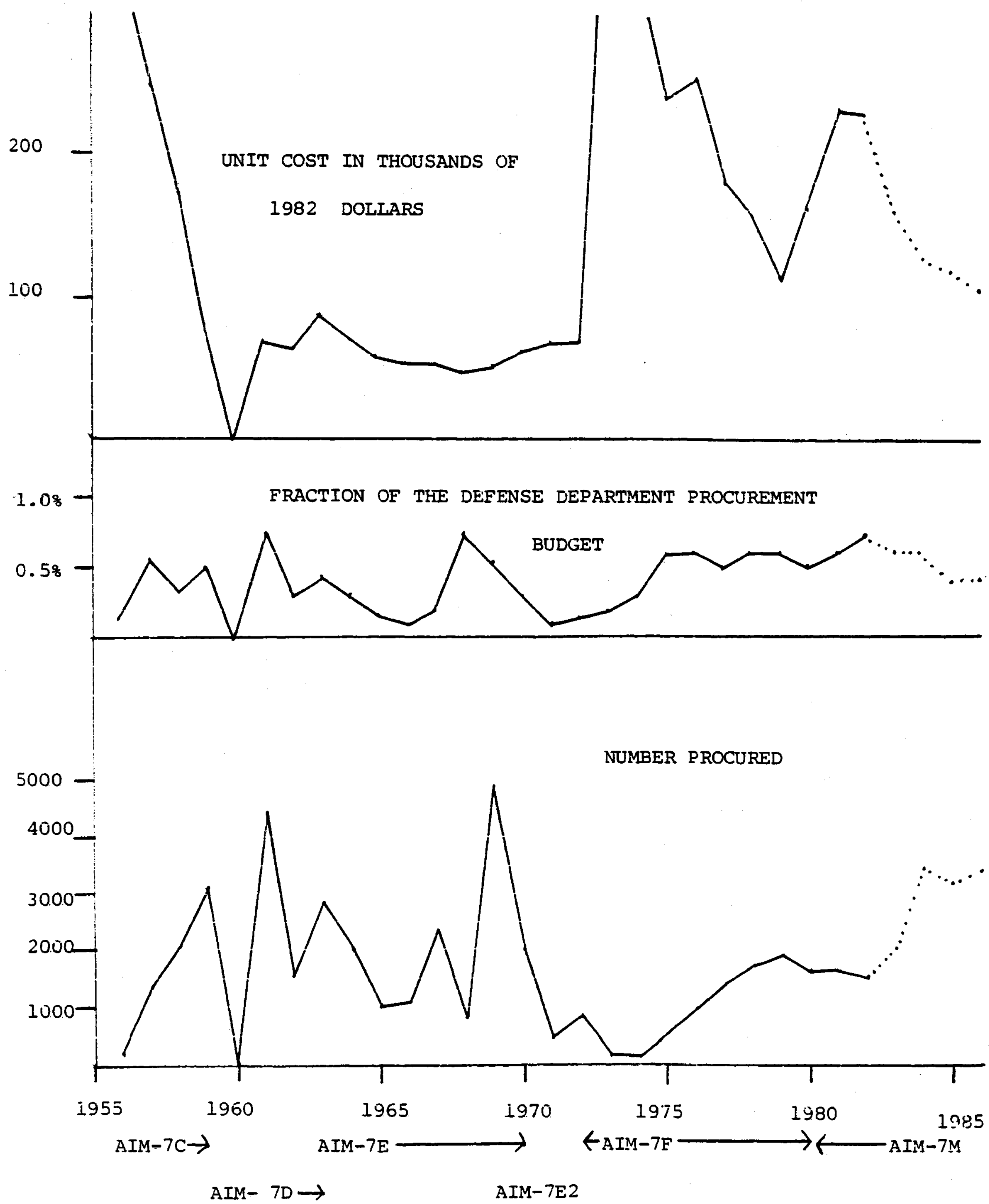


FIGURE 8. SPARROW PROCUREMENT HISTORY



Sparrows procured has remained more nearly constant over time, except for the big dip in the early 1970s. The fraction of the DoD procurement budget devoted to the Sparrow has also remained broadly constant; it is somewhat higher in recent years than it was in the early years of the program.

After the high unit costs associated with starting the Sparrow program, unit costs stayed relatively constant until the mid-1970s. The reasons for this are illustrated by Figure 9. AIM-7C, AIM-7D, AIM-7E, and AIM-7E2 all involved successive relatively small modifications. This resulted in little increase in unit cost every time a new model was introduced, equally little decrease as it entered full production, and therefore little overall variation in unit cost. This pattern is indicative of an evolution of one missile system rather than successive introductions of new models. AIM-7F, however, represented a departure as was shown in Table 3, and its introduction caused a large increase in unit costs followed by a sharp decrease, as is generally the case in the introduction of a new system. 2/ The introduction of AIM-7M resulted in a similar trend.

Figure 10 shows average unit costs for each model displayed at IOC. The line only serves to connect the points. In constant dollars, AIM-7F and AIM-7M cost about twice what the earlier D, E, and E2 models cost. Surprisingly, AIM-7F and AIM-7M cost about as much per unit as AIM-7C, the first model.

INTERPRETATION OF TRENDS

Changes in requirements and the incorporation of performance improvements have caused the average unit costs of AIMs to increase over the years. This was apparently accommodated during the 1960s by reducing the number of AIMs procured and in the 1970s by increasing the share of the budget devoted to procuring AIMs until it was back to the level from which it had declined during the 1960s. The major changes that have taken place have been the large rise in the cost of the Sidewinder from the early 1960s to

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2 Typically, when a new system is introduced, unit costs in the first year are much above average for that system. Few are produced, the line must be started, and the workers are unfamiliar with the particular product. As time goes on, the company "learns," becomes more efficient, and costs come down.

FIGURE 9. UNIT COSTS OF SPARROW MISSILES IN THOUSANDS OF 1982 DOLLARS

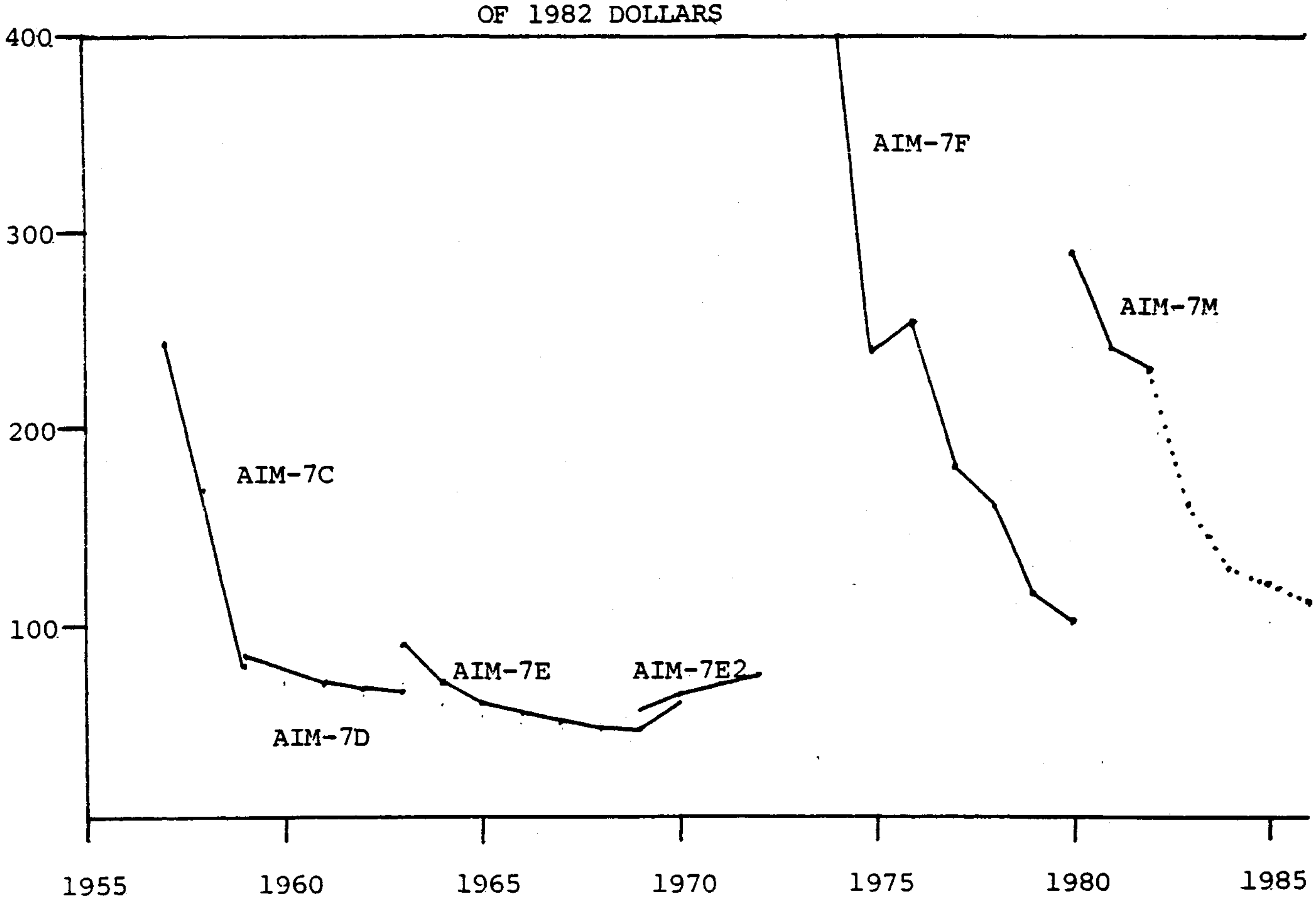
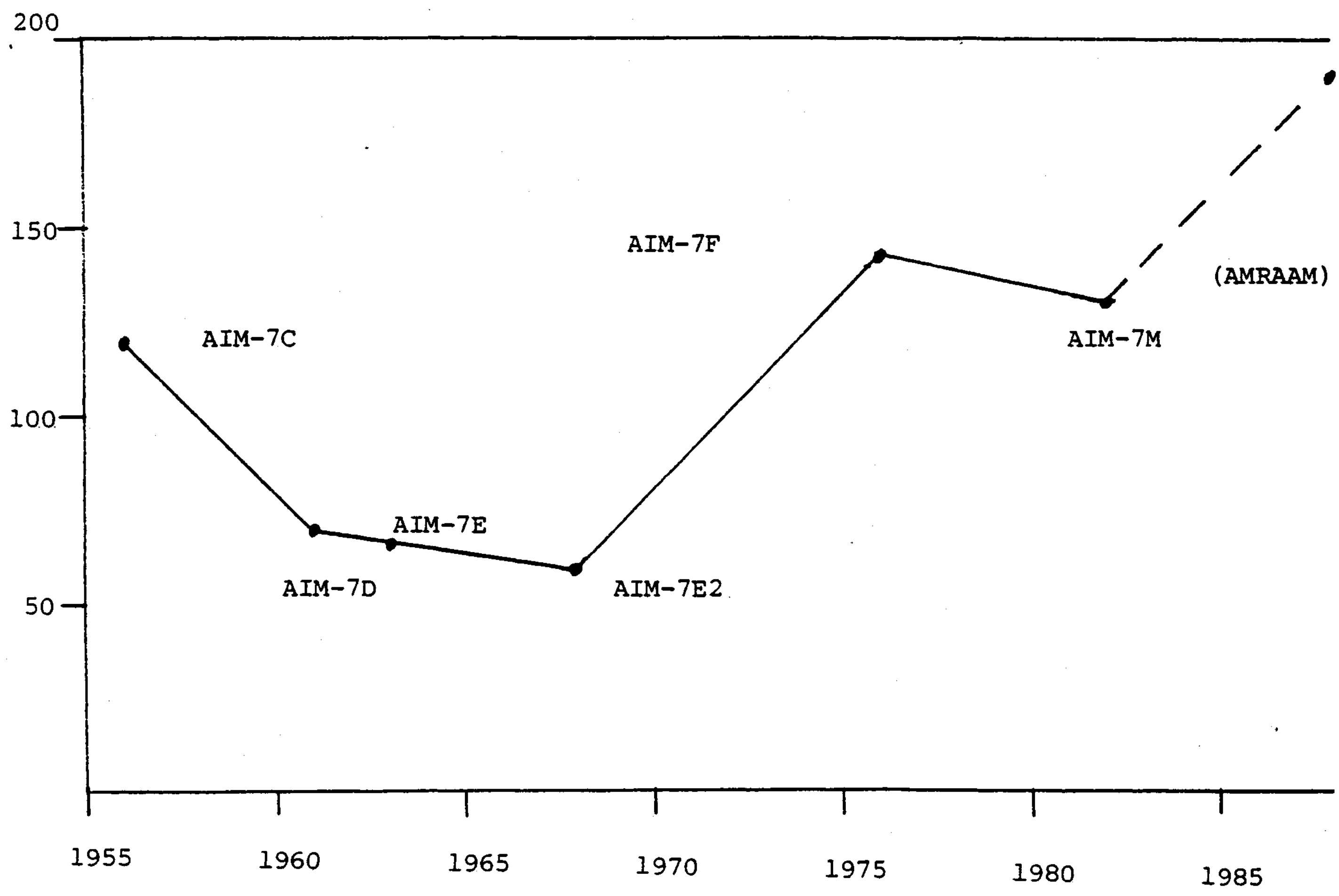


FIGURE 10. AVERAGE UNIT COSTS OF SPARROW MODELS AND AMRAAM IN THOUSANDS OF1982 DOLLARS



the mid-1970s, the introduction of the Phoenix in 1971, and the doubling of Sparrow unit costs with the introduction of the AIM-7F in the mid-1970s.

This trend does not mean that missiles have only become more expensive over the years. They have also become more capable. In the realities of the budget process, however, the price for increased capability reflected in higher average unit costs has been a large reduction in the overall numbers procured due to limitations on resources allocated.

In replacing a missile with a newer model, the choice of missile design is at least partially based upon "cost/effectiveness"--that is, on cost in relation to some measured value of performance. In theory, a very costly missile could be a better buy than a much less costly one if it is more effective, justifying procurment of smaller numbers. Other factors, however, also limit a choice. Inventories are not based only upon effectiveness. There ought to be at the very least, enough missiles to load up the aircraft, or enough to shoot two at every target aircraft allowing for the fact that the distribution of missiles to units cannot be based upon perfect knowledge of where the enemy will be. For example, the AMRAAM programmed buy of 20,000 exceeds the AIM-7M Sparrow buy by several thousand. Furthermore, while no law limits the budget share allotted to AIMs, in the past it has remained remarkably constrained.

CHAPTER IV. GROWTH IN DEVELOPMENT AND PROCUREMENT COSTS

This chapter examines the growth in the costs of air intercept missile programs for those six systems for which Selected Acquisition Reports (SARs) exist. Cost growth in these systems is compared with cost growth in other SAR systems, and the reasons for growth as identified in the SARs are discussed.

In December 1981, a competitive selection was made of a single contractor to proceed with development and, ultimately, production of AMRAAM. 1/ Concurrently, the program moved from advanced development to full-scale development. Typically, the estimate of program costs--both development and procurement--that is made at about the beginning of full-scale development is called the development estimate. If a SAR is written for the system, it contains the development estimate. Each quarter, an updated SAR is written and sent to the Congress. It contains the development estimate and a current estimate. The current estimate is updated each quarter and the changes documented; the development estimate is never altered. This development estimate then becomes a critical benchmark for measuring future cost growth or "overruns." Cost estimates that precede the development estimate are called planning estimates. These are not reported in the SAR. The first SAR for AMRAAM is anticipated in the fall of 1982. The AMRAAM costs listed in this report are program office estimates formulated in Spring 1982.

This chapter uses the terms "current estimate" and "final estimate," sometimes interchangeably. Final estimate, which is a term not used in the SAR, means the current estimate that appeared in the last SAR for a particular system. For example, the current Sparrow SAR refers only to the AIM-7M; the final estimate for the AIM-7F comes from the last SAR that reported on the AIM-7F.

This chapter deals with the AIM-54A Phoenix, the AIM-7E (including the AIM-7E2), AIM-7F, and AIM-7M Sparrows, and the

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1/ Following the precedent of recent AIM programs, a second procurement source has been selected to competitively produce the missile designed by the prime contractor.

AIM-9L and AIM-9M Sidewinders. Development is complete for all of these programs and procurement is complete for all except the AIM-7M and AIM-9M.

REPORTED COST GROWTH IN AIM-7E, AIM-7F, AIM-7M, AIM-9L, AIM-9M, and AIM-54A

Tables 4 and 5 show the reported growth in the development and unit procurement costs of five Sidewinder and Sparrow models and the AIM-54A Phoenix. The tables show the percent increase of the constant dollar final estimates (or current estimates in the case of the M models) over the development estimates.

TABLE 4. COST GROWTH

	Development Cost (in millions of 1982 dollars)		Unit Procurement Cost (in thousands of 1982 dollars)	
System	Development Estimate	Final or Current Estimate	Development Estimate	Final or Current Estimate
AIM-7E/E2	72	67 a/ b/	67	88 a/ b/
AIM-7F	67	283 a/	108	151 a/
AIM-7M	78	79	112	135
AIM-9L	32	157 a/	47	71 a/
AIM-9M	54	55	69	66
AIM-54A	314	484 a/	630	850 a/ c/
AMRAAM	800 d/		190 d/	

a/ Final estimate.

b/ Selected Acquisition Report was prepared before reporting in constant dollars was instituted. Constant dollar conversion was estimated. However, inflation was low during years in question.

c/ Data taken from December 31, 1977, SAR corrected for presence of AIM-54C.

d/ Planning estimate. SAR not yet available.

TABLE 5. COST GROWTH

System	Milestones: Begin Development	Milestones: IOC a/	Percent Change: Development	Percent Change: Unit Procurement	Percent Change: Unit Procurement for Constant Quantity b/
AIM-7E/E2	1960	1963/68	-5	30	10
AIM-7F c/	1965	1976	320	40	45
AIM-7M	1978	1982	0	20	55
AIM-9L c/	1971	1978	400	50	90
AIM-9M	1976	1982	0	-5	20
AIM-54A c/	1962	1973	55	35	35
Average					43

a/ Initial Operating Capability.

b/ Unit procument costs for constant quantity removes the unit cost distortion caused by amending inventory objectives in the course of the program.

c/ Reflects large technical departure from predecessors.

The unit procurement cost reported in the SAR is the total procurement cost divided by the number of production units. It is affected by both changes in costs and changes in quantity. While the change in the unit procurement cost indicates how well the average unit cost over the entire program conformed to the initial estimates of that cost, the change in unit procurement for constant quantity (that is, the quantity originally specified) shows more directly how well that program was managed, without benefit of an alteration in buy size. For example, the AIM-7E buy size was drastically reduced from that which was originally planned, and the unit cost increased well beyond what would have been the case had the program not been adjusted. The size of the AIM-7F buy was essentially unchanged throughout the program. The others all had buy sizes significantly increased, which reduced overall unit cost growth. Unless otherwise specified, unit cost

growth discussed in the report will be growth in unit cost for constant quantity.

Development Cost Growth

The most striking feature of Tables 4 and 5 is the very large growth in AIM-7F and AIM-9L development costs. Indeed, all those systems that showed cost growth in development programs (AIM-7F, AIM-9L, and AIM-54A) represent substantial technical departures from their predecessors. This is of particular interest because AMRAAM, which will have an active seeker and other features similar to Phoenix, will be quite different from Sparrow.

Chronology lends an important perspective to these anomalous development growths. The AIM-7E/E2 were part of a slowly evolving missile system that began with the AIM-7C (see Chapter II). This is supported by Figure 9, which showed that the yearly unit costs of AIM-7C, D, E, and E2 follow a pattern of unit costs indicative of one missile rather than four successive introductions. It is therefore not surprising that AIM-7E/E2 development costs were well controlled. The AIM-7F, on the other hand, incorporated major technical departures from the preceding models, becoming both a missile for close-in maneuvering air combat (dogfighting) and a medium-range missile that could acquire a target from any direction including above. However, the original estimate of the cost of developing the AIM-7F was about the same as for AIM-7E. The result was a very large development cost increase. After the experience of AIM-7F, the development costs for AIM-7M were well controlled.

Similarly, AIM-9L, developed specifically for dogfighting with an all-aspect seeker, represented a large departure from previous Sidewinders. The development program was seriously underfunded. The succeeding program to develop AIM-9M as an incremental follow-on to the AIM-9L was much more successful in controlling development costs.

The AIM-54A Phoenix development program resulted in an entirely new type of missile, yet its increase in cost--about 50 percent--was much less than the growth in AIM-7F and AIM-9L development programs. This program, however, began with a development cost estimate about five times that of AIM-7F and 10 times that of AIM-9L.

Although AMRAAM will be very different from the AIM-7M it will replace, it is less dissimilar from current missiles than

Phoenix was from the missiles existing when it was developed. Phoenix is much larger and has a much longer range and different guidance mode than any AIM that then existed. AMRAAM will be somewhat smaller than Sparrow with about the same maximum range, and will have the same type of terminal guidance as Phoenix.

The two missiles with very high cost growth may or may not be good predictors for AMRAAM. Both were originally estimated to require development at levels about equal to the less ambitious development programs, well below $100 million in fiscal year 1982 dollars, and eventually grew to several hundred million dollars. The AIM-54A program, originally funded at $300 million in 1982 dollars, grew only 50 percent. AMRAAM is funded at about $800 million and would seem to come closest to the AIM-54A in character when estimated funding and degree of technical change are considered.

These data are inconclusive. One possible interpretation is that costs of developments involving important technical departures are wildly unpredictable. Another is that such developments are all likely to cost several hundred million dollars so that the AMRAAM estimate is likely to be a realistic one. The data provide no statistical basis for choosing one or the other.

Unit Cost Growth

The increases in unit costs for constant quantity are more regularly distributed. All are between 10 percent and 90 percent, with an average of 43 percent and a median of 35 percent to 45 percent. If the 10 percent and 90 percent points are dropped (as a check for consistancy), the average becomes 39 percent and the median is unchanged.

While Table 5 shows no obvious separation on the basis of technical changes, the average cost growth for the three systems representing the greater technical departures from their predecessors (with substantial development cost growth) was twice that of the other three systems (56 percent compared to 28 percent). Similarly, there is no clearcut correlation with chronological sequence. Table 5 shows that Sparrow unit cost increases have grown from AIM-7E to AIM-7F to AIM-7M, while AIM-9M shows a much smaller increase than its predecessor, the AIM-9L. The relation between changes in development costs and changes in unit costs is addressed in a later section.

COMPARISON OF AIM COST GROWTH WITH THAT OF OTHER WEAPONS SYSTEMS

There are currently 44 SAR programs (that is, programs for which Selected Acquisition Reports exist). Figure 11 shows the distribution in growth of the development and unit procurement costs of those systems reported in the September 1981 SARs (updated with data from the March 1982 SARs in those systems in which significant changes occurred in the interval) and indicates where the six AIM systems listed above fall on these distributions. This figure is a "snapshot in time" in the sense that the 44 systems are in various stages of development from initiation of full-scale development to completion of procurement. Not all represent the same level of maturity; some will experience no further cost growth, while others could exhibit significant future growth. Historical evidence leads one to anticipate that, were this data to be compiled when all these programs had reached maturity, the distributions would be shifted toward higher cost growth. 2/

Tactical missile systems reported in the SARs display average growth not significantly different from that of all systems. The distribution of growth in unit procurement costs of the six air intercept missiles is similar to the distribution for all current SARs. The average for these missiles is identical to the average for all SAR systems. Only the AIM-9L exhibits inordinate unit cost growth, roughly twice the average.

Considering the distribution of growth in development costs of air intercept missiles, the average would be a fairly meaningless number. AIM-7F and AIM-9L development cost increases are many times greater than the average for all systems, and well above the growth for any system reported in these SARs. AIM-9M, AIM-7M, and AIM-7E are well below the average, but have the same growth as several systems reported in the SARs.

As noted above, the growth indicated for AIM-7E, AIM-7F, AIM-9L, and AIM-54A comes from the final SARs for those systems

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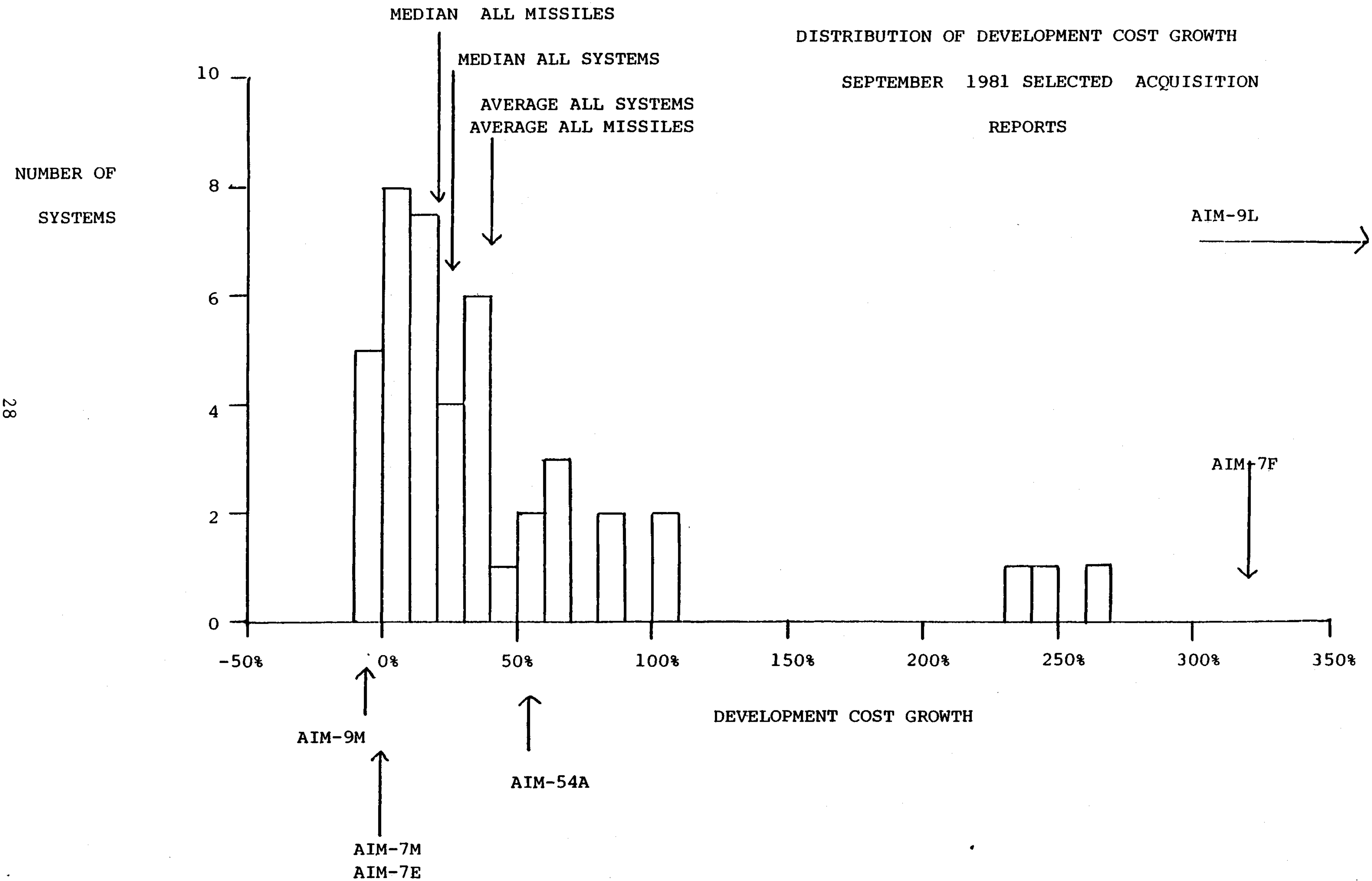
2/ A 1979 Rand Corporation report observed that for 31 SARs examined the total growth (development and procurement corrected for quantity) had a mean value of 1.20 and a median of 1.06, but that mature systems in the sample had an average growth of 1.34 and a median of 1.24. Edmund Dews and others, Acquisition Policy Effectiveness: Department of Defense Experience in the 1970s (October 1979).

FIGURE 11A.

DISTRIBUTION OF DEVELOPMENT COST GROWTH

SEPTEMBER 1981 SELECTED ACQUISITION REPORTS



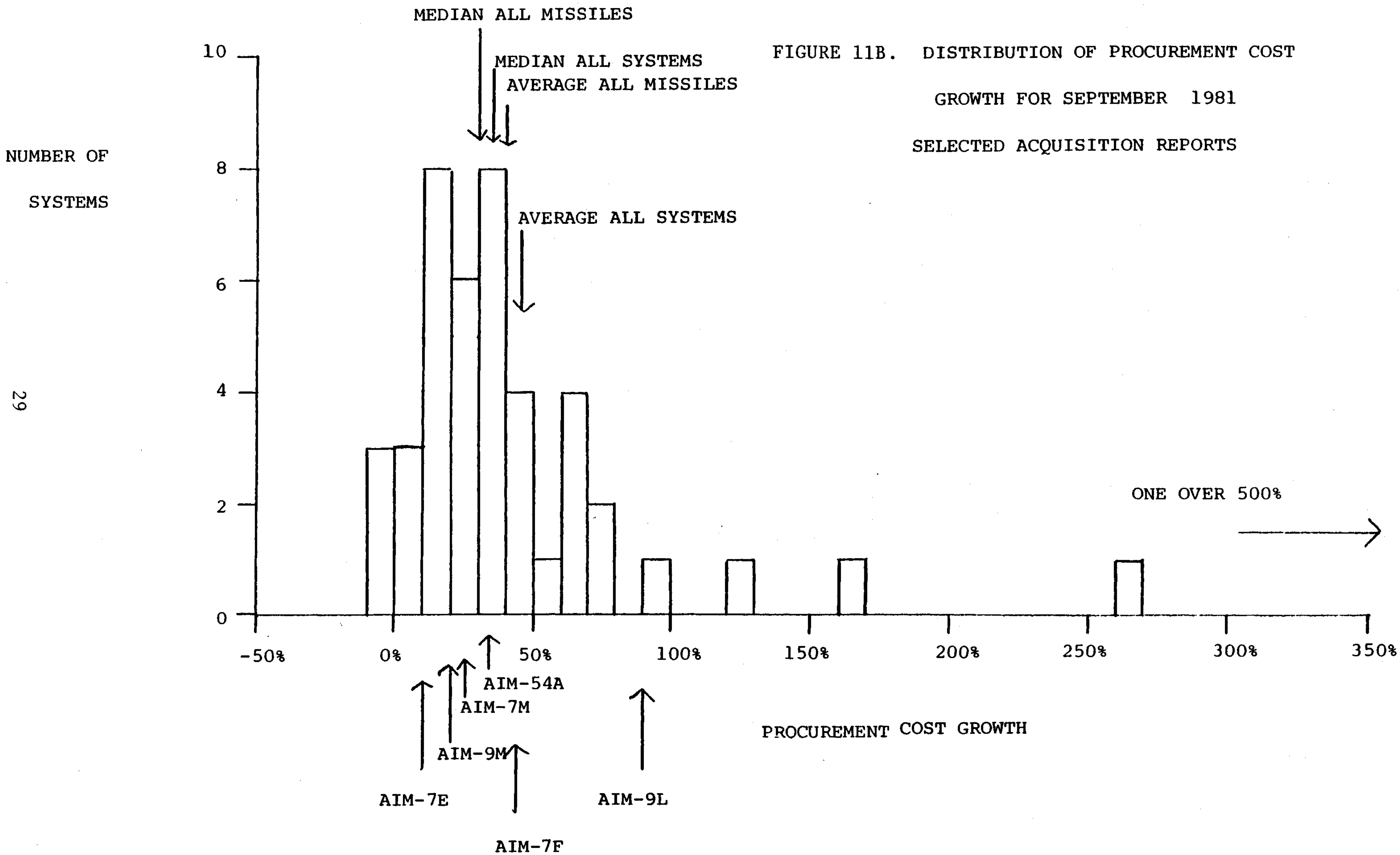


FIGURE 11B. DISTRIBUTION OF PROCUREMENT COST GROWTH FOR SEPTEMBER 1981 SELECTED ACQUISITION REPORTS

(all of which predate September 1981), and can be considered final, reliable numbers. By contrast, AIM-9M and AIM-7M growth figures are the current estimates from the most recent SARs. All of the development funds for these two systems will have been spent prior to fiscal year 1982. Therefore these estimates of development costs and development cost increases are not likely to change and can be considered final. However, procurement, in both cases, has only just begun, with IOC scheduled for late 1982 and early 1983 for AIM-7M and AIM-9M, respectively. A 1980 IDA study determined that there is little cost growth after IOC; most cost growth occurs two to four years after the development estimate. 3/ AIM-7M is three to four years past development estimate; AIM-9M is five to six years beyond development estimate, but both are short of IOC. Similarly, a study by Management Consulting and Research, Inc., reported that the majority of cost growth occurs between development estimate and approval for production (basically the same conclusion). 4/ However, the unit costs of AIM-7F and AIM-9L continued to rise significantly for about one year following IOC. On this basis it is difficult to ascertain whether or not AIM-7M and AIM-9M will sustain further growth in unit costs. Indeed, between September and December 1981, AIM-7M cost growth nearly doubled to its present value, while AIM-9M growth remained essentially unchanged.

CORRELATION OF DEVELOPMENT COST GROWTH WITH UNIT COST GROWTH

Development cost growth provides a simple, relatively unambiguous, observable parameter of a program. If development cost growth can be correlated in a meaningful way with unit cost growth, monitoring development cost growth may provide a useful tool in controlling costs, or at least reducing the risk of large cost increases. In most programs, most of the money is spent in procurement, and not development. For example, in Sidewinder and Sparrow programs, development costs have been only a few

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3/ N.J. Asher and T.F. Maggelet, On Estimating the Cost Growth of Weapons Systems, Institute for Defense Analyses; Cost Analysis Group (June 1980).

4/ Management Consulting and Research, Inc., Analysis of DoD Weapon System Cost Growth Using Selected Acquisition Reports, prepared for Director of Cost and Economic Analysis, U.S. Department of Defense (February 27, 1981).

to 10 or 12 percent of the entire program cost. 5/ Most development funds are spent before large-scale procurement begins, so an estimate of development cost growth is usually available before a large fraction of the money for the program has been spent.

Figure 12 shows the relationship of unit cost growth to development cost growth for the six AIM systems addressed in this chapter. The dashed line is a least squares fit of a straight line to the data. This is discussed in Appendix A. The figure suggests that based only on the six AIM programs discussed here:

- there is no exact relationship between unit cost growth and development cost growth;
- on the average, unit cost growth of about 25 percent is to be expected if development cost growth is low, and low or zero development cost growth is no guarantee of low unit cost growth;
- although the data indicate that higher development cost growth means higher unit cost growth, the correlation of the two is not very strong.

These trends are based on a small data sample, and while suggestive are certainly not definitive. They would be more convincing were they supported by a larger data set. Figure 13 shows a similar plot for all current SARs. The solid line is a least squares fit of a straight line to the data points. The dashed line recreates the dashed line in Figure 12. The figure indicates:

- a precise prediction of unit cost growth from development cost growth would be impossible;
- low development cost growth does not guarantee low unit cost growth;
- higher development cost growth is indicative of higher unit cost growth.

5/ Current estimates for AMRAAM indicate that development will be about 17 percent of the total cost.

FIGURE 12. CORRELLATION OF DEVELOPMENT COST GROWTH WITH UNIT COST GROWTH

FOR SIX AIR INTERCEPT MISSILE MODELS

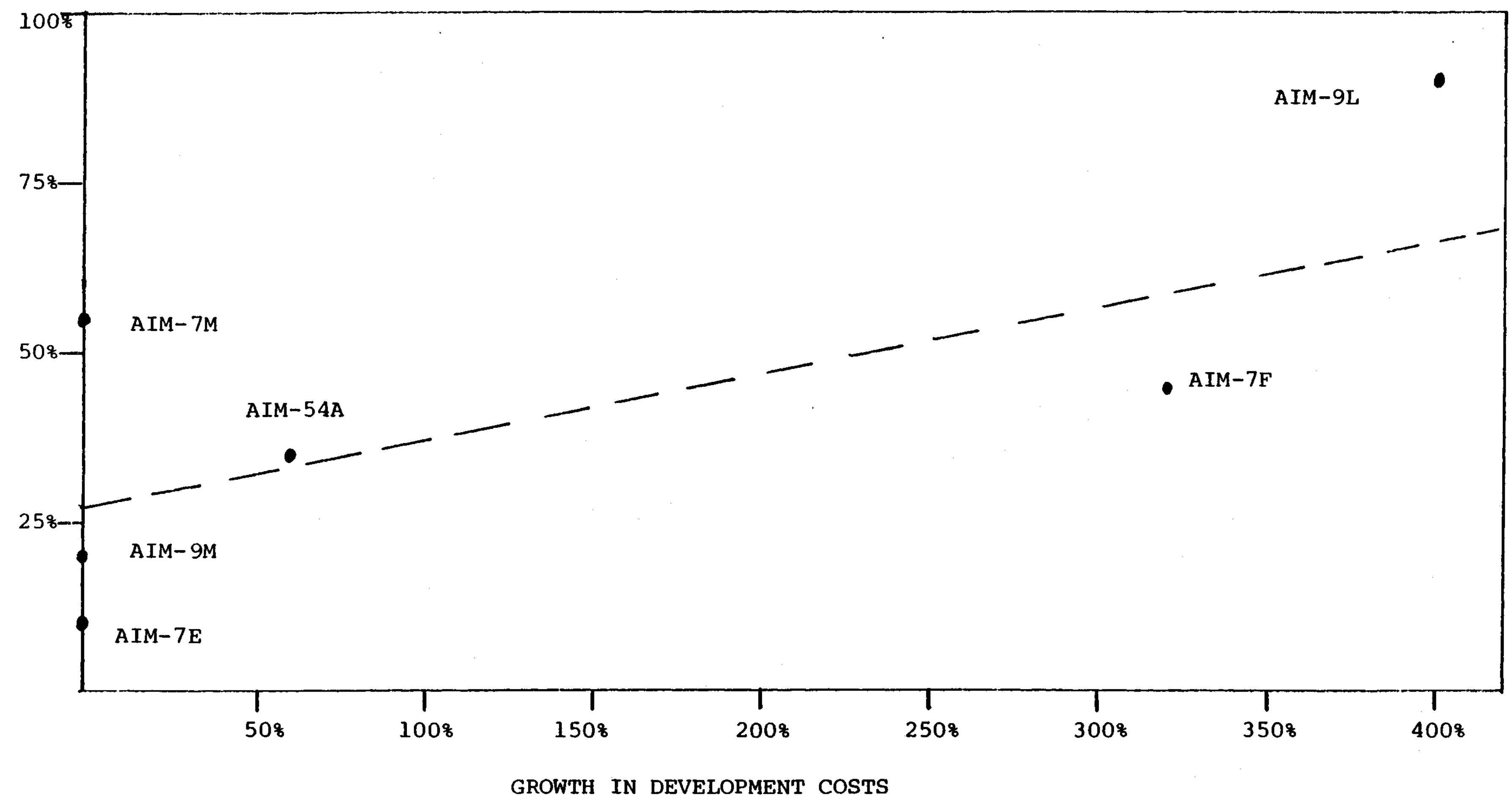
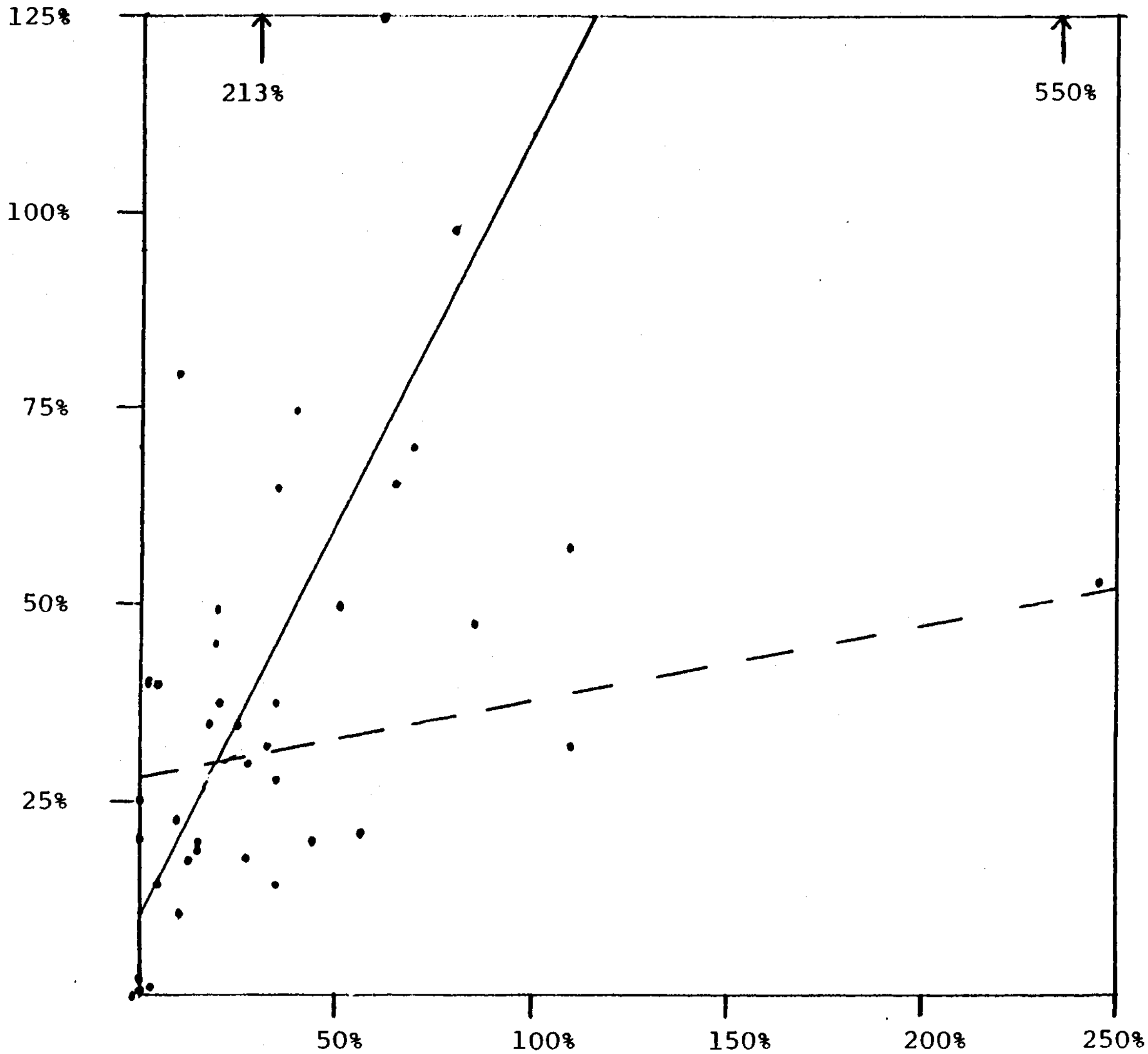


FIGURE 13. COREELATION OF DEVELOPMENT COST GROWTH WITH UNIT COST GROWTH FOR SEPTEMBER 1981 SELECTED ACQUISITION REPORTS

UNIT COST GROWTH



DEVELOPMENT COST GROWTH

The two figures yield significantly different values of average unit growth for low development growth, and very different trends for the variation of unit growth with development growth. It seems clear that these data cannot be used to predict unit growth from development growth with any certainty. However, using the data in both figures, it is possible to define a value of minimum growth in unit cost as a function of growth in development cost that is consistent with essentially all the data. For development cost growth less than 50 percent, unit cost growth is at least half development cost growth. For development cost growth in excess of 50 percent, minimum unit cost growth appears to be 25 percent plus about one-tenth of the amount by which development cost growth exceeds 50 percent.

The data confirm intuitive expectations. Those factors that operate to produce a low estimate of development cost could be expected to influence a low estimate of procurement cost. Furthermore, the competition for funds provides an incentive to report estimates on the low end of regions of uncertainty.

COST GROWTH BY CATEGORY

The Selected Acquisition Report breaks down cost changes into several categories:

- Economic--basically unanticipated inflation. Since this study considers only changes in a program reported in constant dollars, economic changes will not apply.

- Quantity--changes in cost due to changes in the number procured. Since this study looks at cost growth for a constant quantity, this category will also not apply.

- Schedule--cost changes due to changes in scheduling the program. This can arise from factors internal to the program such as a contractor failing to meet the agreed-upon schedule, or external factors, primarily service, OSD, or Congressional decisions to add or delete funds in any particular year.

- Engineering--cost changes due to re-engineering.

- Estimating--correction of a previous estimate. As a program progresses more and more detailed information accrues, and cost estimating becomes a more exact art.

- o Other--reasons not in the above categories, except:
- o Support--changes in costs of required support.

In practice, these categories are not mutually exclusive, and decisions must be made when preparing the SAR as to what categories to assign which changes to. These decisions are guided by precedent and by a requirement to consider the categories in the order listed above, but similar changes appear to be assigned to different categories when several SARs are compared.

Growth in Development Program Costs

AIM-54A, AIM-7F, and AIM-9L provide examples of programs that exhibited noticeable cost growth in development. Phoenix cost growth, 54 percent, was somewhat greater than the average for all recent SAR systems, but the other two exhibited growth in excess of 300 percent, which is very atypical.

In all three cases cost estimating changes are a minor source of change. The AIM-7F and AIM-9L SARs list engineering changes and associated schedule changes as the major sources of growth. Almost all the AIM-54A cost growth reported in the SAR was ascribed to contract cost growth, attributed to increased contractor development costs, and related schedule changes. "Contract cost growth," however, is not one of the currently recognized growth categories. It appears from the description in the SARs that, in all three cases, problems in the development phase required more engineering and other development work which, not unexpectedly, caused the schedule to slip.

In a broad sense, all of these increases could be said to arise from inaccuracy in estimating the cost of the development of the missile at the time of the Development Estimate. However, "estimation" changes are defined as changes due to corrections in preparing an estimate which are not attributable to quantity, engineering, schedule, or support changes. That is, the changes listed as estimation changes are only those that cannot be ascribed to any other cause.

Growth in Unit Costs

AIM-54A Nearly all the growth in Phoenix unit costs is assigned to schedule changes associated with the cancellation of

the F-111B, the originally designated carrier for the Phoenix, and the re-orientation of the program to the F-14A, the current platform. This seems clearly a change beyond the control of the program manager. Removing this source of growth, AIM-54A cost growth has been modest (about 5 percent).

AIM-9L. Roughly one-half of the procurement cost growth exhibited by AIM-9L was attributed to estimation changes associated with redefining costs as the missile went into initial production.

AIM-7F. In this case estimation is a minor change. The majority of growth is assigned to the schedule category for "rescheduling and repricing to best estimate."

AIM-7M. About half of the change is assigned to estimating, and revising procurement quantities in fiscal years 1983 to 1987. The other half is ascribed to repricing as the missile entered production.

AIM-9M. In this case nearly the entire change is assigned to the schedule category, but for "revising the annual procurement profile."

Summary of Unit Cost Growth. From this information, it appears that major parts of unit cost growth in AIM-7F, AIM-7M, and AIM-9M are due to revising the procurement profile. However, in each case, the growth is assigned to a different category. These changes could represent changes dictated from outside the program (that is, by the Navy or Air Force, the Office of the Secretary of Defense, or possibly the Congress) or response to internal factors, or some combination of both.

AIM-9L seems to be a clearcut case of poor estimation of production costs. It was not until the missile actually entered production that the true costs became known, at nearly double the original estimate. About half the growth in AIM-7M appears to be for the same reason. It is not clear what happened in the case of AIM-7F. However, the description implies that this case was similar to that of the AIM-9L; estimates of price and schedules were revised sharply upward as empirical information became available which proved the old estimates inaccurate.

CHAPTER V. IMPLICATIONS FOR AMRAAM

The most obvious lesson from history is that nothing can be said with any certainty concerning a future program by examining the progress of past programs. Nothing obviously constrains future funding patterns to follow past funding patterns or dictates that cost control in future programs will follow that exhibited in the past. If past performance had followed very strong and well defined patterns, a case could be made with some confidence that the prospects were good that those patterns would continue. In reality, however, past performance, while following generally discernible trends, does not display strongly defined behavior. Therefore, almost nothing can be said with any certainty regarding what may happen in the AMRAAM program based upon what has transpired in the past.

Nevertheless, the general trends of the past can be used as clues to bound expectations as to what is likely to occur in the future.

In principle, several factors ought to determine whether or not AMRAAM is procured: the anticipated threat, the performance advantages it offers, and how it compares in "cost/effectiveness" to available alternatives, among others. Ideally, if the system is needed, it ought to be accommodated in the defense budget whatever the cost. A missile that is much more cost/effective than its predecessor although more costly per unit ought to be less costly overall since fewer would be needed to accomplish the same mission.

In reality, cost/effectiveness alone does not determine procurement levels, and the budget may not be elastic enough to accommodate a needed system in sufficient numbers if the cost is too high. The AMRAAM procurement objective exceeds the total AIM-7M buy now planned. This makes sense: more aircraft types will use AMRAAM than will use AIM-7M; both the Navy and the Air Force plan to expand their fighter inventories; and threat improvements will probably add to missile requirements. In the past, the budget share allotted to AIMs, while often fluctuating greatly from year to year, has not changed dramatically on a sustained basis. Extrapolating past trends into the future (and assuming some real growth in defense procurement), it is possible

to envision that there will be sufficient funds available to procure AMRAAM at about the same rate that AIM-7M will be procured assuming that AMRAAM will cost 50 percent more per unit than AIM-7M, as is currently estimated. On the other hand, an assumption of no real increase in AIM funding by the late 1980s may be seen as not inconsistent with historical patterns.

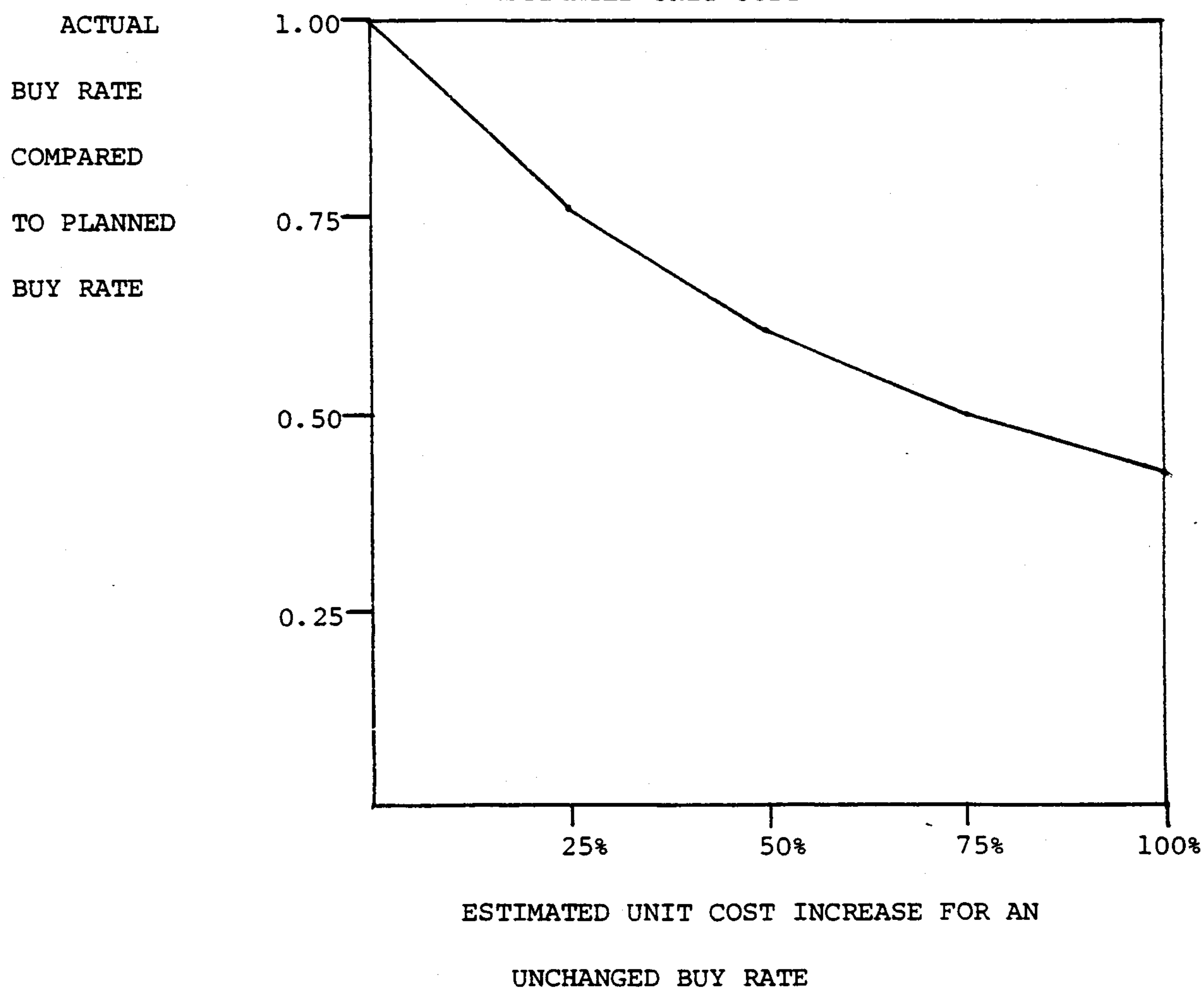
If funding levels are not increased to take account of the higher cost of AMRAAM relative to Sparrow, AMRAAM will be procured at a slower rate than Sparrow has been. There are currently shortfalls in the Sparrow inventory, especially in the inventories of the newer AIM-7F and AIM-7M. 1/ The relatively slow rates at which these missiles have been procured in recent years has caused long delays in reaching inventory objectives. Still lower AMRAAM procurement rates would slow progress toward achieving these objectives still more.

These considerations indicate the importance of cost control in the AMRAAM program. If unit costs exceed current estimates and funding levels are not adjusted accordingly, buy rates will have to be reduced below planned levels. However, reducing buy rates would cause still further cost increases. An estimate of the reduction in buy rate as a function of cost increases is shown in Figure 14. 2/ For example, applying this methodology, a 50 percent increase in the estimated unit cost when combined with a constant funding level would result in a reduction in buy rates to 67 percent of the planned level. However, if the buy rate is reduced, the unit cost is increased still further so that a 50 percent increase actually becomes a 64 percent cost increase and the buy rates are reduced to 60 percent of those originally planned.

1/ Congressional Research Service, Air-to-Air Missile Requirements, Inventories and Alternatives: A Brief Analysis (May 30, 1980); DoD Appropriations for 1981, Hearings before the House Committee on Appropriations, Part 9, pp. 280-308.

2/ The methodology applied to estimate the further cost increases due to buy rate reductions is that described in John C. Bemis, "Three Views of the Impact of Production Rate Changes: III. A Model for Examining the Cost Implications of Production Rates," Concepts: The Journal of Defense Systems Acquisition Management, vol. 4 (Spring 1981), pp. 84-94.

FIGURE 14. EFFECT ON YEARLY BUY RATE OF INCREASES IN ESTIMATED UNIT COST



History provides no clear indication of how much AMRAAM unit costs will actually grow between now and the time it enters production. If AMRAAM follows past patterns, unit costs will grow 10 percent to 90 percent, with 30 percent to 50 percent growth most likely. This analysis ignores the fact that the AMRAAM program office has many years of service experience in developing missiles and other systems to draw upon, and has instituted several management initiatives which could very well keep cost under control. It is interesting to note, however, that the six documented AIM programs do not show a pattern of cost growth decreasing from the earlier programs to the later programs.

In monitoring the AMRAAM program, the Congress may find it useful to observe cost growth closely in the development program. Significant growth in development would be a strong indication of growth to be expected in unit costs. On the other hand, lack of growth in the development program would be no indication of good cost control in procurement.

APPENDIX

APPENDIX A. SHORT STATISTICAL ANALYSIS OF GROWTH IN DEVELOPMENT AND UNIT COSTS

SIX AIR INTERCEPT MISSILE SYSTEMS

This section discusses the correlation of unit cost growth with development cost growth for the six AIM systems shown in Table A-1.

TABLE A-1. COST GROWTH IN AIM SYSTEMS

Missile	Percent Growth in Cost of Development	Percent Growth in Cost of Unit for Constant Quantity
AIM-7E/E2	-5	10
AIM-7F	320	45
AIM-7M	0	55
AIM-9L	400	90
AIM-9M	0	20
AIM-54A	55	35

A fundamental concern is whether these data show any correlation between unit cost growth and development cost growth, or are more consistent with these growth categories being two independent variables. If all six values of unit cost growth were found to be consistent with a single probability distribution, it would be an indication that unit growth is independent of development cost growth. Considering only unit cost growth, the four data points other than AIM-7F and AIM-9L have a mean of 30 percent and a standard deviation of 20 (excluding AIM-54A the mean is 28 percent). The probability of a member of this distribution differing from 30 percent by no more than the AIM-7F value does would be about 50 percent. The AIM-7F data are reasonably consistent with the other four; indeed, these five data have a mean of 33 percent

and a standard deviation of 18. However, the probability of a datum which follows this distribution differing from the mean by as much as the AIM-9L datum does is less than 1 percent. Therefore, either the AIM-9L datum is anomalous, or these six data are not consistent with a single distribution. Unfortunately, the absence of further data precludes deciding the case on this basis.

Fitting these data to the linear form:

unit growth = m (development growth) + b

supports the contention that unit growth and development growth are correlated, although weakly. This is illustrated in Table A-2.

All of these fits support a prediction of unit cost growth that is 30 percent plus one-tenth of development cost growth. Although these data are similarly not conclusive, it indicates that the AIM-7F data and not the AIM-9L data may be inconsistent with the rest.

43 SARS

A similar least square fit was performed for 43 September 1981 Selected Acquisition Reports. (One of the 44 SARs showed infinite development cost growth and was discarded.) This resulted in b = .11, m = .99, and R = .61. This indicates that the data are not very consistent with a linear relationship between unit cost growth and development cost growth, and that the best linear fit to these data is very different from the best linear fit to the AIM historical data.

TABLE A-2. LEAST SQUARES FIT OF COST GROWTH DATA

Data Included	b	m	R a/
AIM-7E/E2 AIM-7M AIM-9M AIM-54A	.28	.12	.17
AIM-7E/E2 AIM-7M AIM-9M AIM-54A AIM-7F	.29	.05	.39
AIM-7E/E2 AIM-7M AIM-9M AIM-54A AIM-9L	.28	.16	.85
AIM-7E/E2 AIM-7M AIM-9M AIM-54A AIM-7F AIM-9L	.27	.12	.75

a/ R is the regression correlation coefficient, which has a value $-1 \leq R \leq +1$. R = ± 1 for a perfect fit.