THE MX MISSILE TEST PROGRAM

AND ALTERNATIVES

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NOTE

Unless otherwise specified, all costs are expressed in current dollars. All dates, except those related with costs, refer to calendar years. Dates related with costs refer to fiscal years.

PREFACE

Most of the MX missiles the Air Force plans to buy are earmarked for the test program, which establishes and monitors system capability and reliability over the system life. Thus, though the Congress halved the planned deployment of MX, the total system's size--and hence its cost--has not fallen in proportion. As requested by the House Budget Committee, this paper analyzes the basis for the planned test program--determined largely by statistical guidelines established by the Joint Chiefs of Staff--and illustrates the risks and savings associated with a curtailed test program. This paper builds on an earlier study. In accordance with the Congressional Budget Office's mandate to provide objective analysis, the paper makes no recommendations.

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SUMMARY

The MX, a highly accurate intercontinental ballistic missile (ICBM) carrying ten nuclear warheads, has long been a source of contention. Debate centers on the 195,000-pound missile's production, basing, and cost. These issues have been put to rest, at least temporarily, with fiscal year 1986 Congressional action specifying that no more than 50 MX missiles be deployed (in Minuteman silos) at any one time. Twelve MX missiles were authorized for fiscal year 1986, bringing the total number authorized thus far (including 20 research and development test missiles) to 74--enough to complete the deployment.

Though the planned deployment of MX has been numerically halved, from 100 to 50, the total purchase of missiles--and hence the system's cost--has not been cut by a proportionate amount. The reason for this disparity is that the program for testing the MX missile is not subject to change as the planned deployment decreases. Of the total 193 MX missiles that have been or will be bought (including Research and Development missiles), 143 are designated for testing. All 119 missiles still to be bought are earmarked for the test program. Specifically, the Congress provided that from 12 to 21 missiles be procured for this purpose in fiscal year 1987.

In this paper, the Congressional Budget Office examines the basis for that test program, which will consume about three-fourths of all MX missiles purchased. The study focuses on Operational Testing and Evaluation (OT&E), which constitutes the largest segment of the test program and is to proceed in two phases:

- Phase I of OT&E follows Research and Development (R&D) testing and is designed to establish an estimate--with a high degree of confidence--of the accuracy and reliability of the system. This baseline estimate is important both for operational and target planning, and for monitoring the MX system's capability over time. The Air Force program calls for 24 missiles to be tested over three years (1988-1990) for Phase I.

- Phase II of OT&E, designed to monitor degradation in system performance and reliability, then tests on a yearly basis over the remaining system life. A total of 84 missiles, or about seven per year, are planned to be tested over the 12 years (1991-2003) of Phase II.

Analysis of Current Plans

The Joint Chiefs of Staff have established general guidelines for weapons systems included in the strategic nuclear war plan--also known as the Single Integrated Operational Plan (SIOP)--designed to ensure an acceptable level of testing. These guidelines form the foundation for the sizing of a ballistic missile test program. They specify annual testing to maintain the statistical level of confidence required in each service's estimate of weapon system reliability. However, the guidelines leave the statistical analysis and details of the test program to the individual services. The services often prefer to test to more strict criteria than specified by the JCS, especially in Phase II where the guidelines are less stringent.

The CBO analysis finds that the 24 missiles allocated by the Air Force for Phase I testing might not suffice to meet the statistical guidelines set out by the JCS and the Air Force's Strategic Air Command (SAC). Assessment based on the Air Force's assumptions and Classical statistical techniques indicates that at least 36 missiles would be needed. The Air Force rationale for using only 24 missiles for Phase I testing, however, rests on experience with land-based missiles and a judgment that, in light of constraints on the total test program, additional test missiles should be shifted to Phase II of the program.

The seven missiles per year allocated to Phase II slightly exceed numbers necessary to meet JCS guidelines as interpreted by the Air Force: about six missiles per year would suffice. The Air Force wants more Phase II missiles, because it believes JCS guidelines for Phase II are not demanding enough, and also because the Air Force wants flexibility to meet diverse needs. Extra test missiles would be needed, for instance, if the MX remained in service longer than the 15 years currently planned--as has happened with past generations of U.S. land-based missiles--or if the MX at some point requires a major modification. Minuteman II missiles have been deployed for about 20 years, and although there are only 26 test missiles remaining, the Minuteman is likely to remain deployed through the end of this century.

Given the objectives of a ballistic missile test program, when Phases I and II are considered together, the MX test program seems modest in size. Phase I is actually too small as judged by Classical statistical techniques; the extra missiles in Phase II might be needed if the MX stays in the inventory for more than 15 years. The MX test program is also modest in size compared to test programs for other U.S. ballistic missiles.

Alternative Test Programs

Nonetheless, the test program will consume 74 percent of all MX missiles purchased, including those designated for R&D. In light of the small planned deployment of the MX, the Congress might consider options that provide less testing--hence less confidence in system performance--in order to hold down costs. The options examined here focus on Phase II of the Operational Test program, the portion that accounts for the bulk of operational test missiles.

Option I would reduce Phase II testing to about six missiles per year, thus reducing the remaining purchase of MX missiles by 12 from 119 to 107. This option would not meet the more stringent criteria for Phase II testing that the Air Force prefers. Nor would it provide as much of a hedge as do current plans against a possibly longer service life or other contingencies. If, for example, the history of the Minuteman missile were repeated and MX service life were extended, there would be even fewer test assets than under the current plan to accommodate an extension. This reduction in the test program would also eliminate flexibility for additional testing. The need for additional testing could arise as a result of unforeseen degradation of some components, requiring replacement or modification. Or it could arise from a need to test later improvements to the missile's capability to preserve its utility in the face of improved Soviet abilities.

This option would, however, meet JCS guidance standards. Moreover, depending on how it was implemented, the option could save from 0.8 to $1.8 billion. (See Summary Tables 1 and 2). Assuming a baseline program of 21 missiles per year, cutting the missiles from the end of the baseline buy would yield total savings of $1.8 billion. 1/ However, this method would not yield any savings over the five years 1987-1991, and would actually increase costs relative to the baseline in 1991 in order to end the program efficiently. On the other hand, proportional reductions in the program over the same period as in the baseline would mean purchase of 19 missiles per year, and would yield savings of about $0.6 billion over the next five years, with total savings of about $0.8 billion. Proportional reductions in the options would not affect deployment; nor would it slow the test program. However, this method would increase unit costs, owing to less efficient production rates, and thus lower the total savings.

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1. Since the Congress, in 1986, specified purchase of "from 12 to 21 missiles" for the test program in 1987, this baseline assumes continued annual procurement of 21 missiles per year through 1992.

SUMMARY TABLE 1. PROCUREMENT RATES UNDER CURRENT BASELINE AND OPTIONS (Fiscal years 1985-1992)

	1985 and prior	1986	1987	1988	1989	1990	1991	1992	Total
Current Baseline a/	42	12	21	21	21	21	21	14	173
Meet Minimal JCS Guidance for Phase II (test six/year)									
Option I									
Cut from end of buy	42	12	21	21	21	21	23	0	161
Reduce rate immediately	42	12	19	19	19	19	19	12	161
Meet JCS Guidance for Phase II every other year (test three/year)									
Option II									
Cut from end of buy	42	12	21	21	21	9	0	0	126
Reduce rate immediately	42	12	12	12	12	12	12	12	126
Minimal Testing									
Option III									
Cut from end of buy	42	12	21	21	5	0	0	0	101
Reduce rate immediately	42	12	12	12	12	11	0	0	101

SOURCE: Congressional Budget Office.

a. Assumes continued procurement rate of 21 missiles per year, the maximum specified by the Congress for 1987. Doesn't include 20 Research and Development test missiles.

SUMMARY TABLE 2. OPTIONS FOR MX TESTING

Reduction in Number of Test Missiles	Savings Relative to Current Baseline a/ (in millions of 1987 dollars): Continue at Current Rate - Cut from End of Buy: 1987	1987-1991	Total	Reduce Rate Immediately: 1987	1987-1991	Total
Meet Minimal JCS Guidance for Phase II (test six/year)						
Option I						
12	0	-110 b/	1,820	100	640	760
Meet JCS Guidance for Phase II every other year (test three/year)						
Option II						
47	0	3,360	5,290	600	2,970	3,000
Minimal Testing						
Option III						
72	0	6,010	7,940	600	4,920	6,850

SOURCE: Congressional Budget Office.

a. Assumes continued procurement rate of 21 missiles per year, the maximum specified by the Congress for 1987.

b. This option would purchase 23 missiles in 1991--two more than the baseline rate--in order to end the program efficiently.

Option II, testing three missiles per year, would not meet current JCS guidelines requiring that certain levels of degradation in reliability be detected within a year. It could, however, meet JCS guidance every two years by following a practice, now standard for the Air Force, of pooling sample data from both years. This detection method increases risk, of course, but since the Strategic Air Command has not, over the years, experienced any sudden, drastic reductions in missile reliability, the added risk in detecting changes only every two or three years might be tolerable. Further, Option II offers even less flexibility than does Option I to accommodate such a possibility as an extended service life. Nor does it satisfy the more stringent reliability criteria the Air Force prefers.

In return for this added risk, Option II would eliminate 47 missiles from the test program and thus allow total savings of between $3.0 and $5.3 billion, again depending on how the option was implemented. Savings over the next five years, and total savings, would be higher if reductions occurred at the end of the baseline MX purchase. There would be no savings, however, in 1987 under this method. Proportional reductions to 12 missiles a year would provide savings of $0.6 billion in 1987, but total savings of only $3.0 billion due to unit cost increases.

Option III allows for minimal testing of the MX, purchasing only 36 missiles for both Phases I and II of Operational Testing--72 fewer than are now planned. The Air Force could allocate these missiles to Phase I or Phase II, or both, depending on its judgment. For instance, if R&D testing now under way were considered successful and provided enough data to establish baseline parameters, then all missiles could be used for Phase II to monitor for losses in reliability. This would allow testing of about three missiles per year, and it would be similar in effect to Option II. Conversely, if the original plan for 24 missiles in Phase I were considered absolutely necessary, then there would only be 12 missiles available for Phase II. In this case, the Air Force might wish to forgo flight testing for degradation unless its annual Aging and Surveillance monitoring indicated potential deterioration. If they did, there would be a small reserve for flight testing of modifications. Training benefits from flight testing could probably be accomplished without actual launch of a real missile; all actions up to the actual launch could still be practiced, perhaps with the launch itself simulated.

Substantial risk is obviously inherent in this option. Military planners would be much less certain of the reliability of the system over time. Should a serious problem necessitating major changes develop with the MX, there would be few missiles available to test the changes. This could be of even greater concern, because the rest of U.S. land-based missiles--Minuteman II and III--are already old, and have few test missiles remaining.

Moreover, from a policy perspective, this option could reduce the deterrent value of the system if the Soviet Union perceived the system to be weakening. Because production of the missile would stop soon, there would also be less opportunity to expand deployment, should Soviet actions prompt an expanded U.S. response.

This option would, however, be consistent with a decision that the limited deployment of the MX does not warrant the expense of heavy testing, especially in light of constrained defense budgets and the slowing of other modernization programs. Arguably, the deterrent value of the MX system is already low, since its contribution to U.S. warheads capable of surviving an attack and retaliating is very small--in most cases, less than 1 percent. Further loss of deterrent capability because of minimal testing and the resulting uncertainty may be of belated importance. Moreover, having a system deployed for many years without testing is not without precedent: the Titan missile was deployed for more than 15 years without a flight test, and some Minuteman missiles may be in a similar situation before the end of the century.

Through radical reductions in the test program, this option would save from $6.9 to $7.9 billion. Savings would begin in 1989 if reductions occurred from the end of procurement, with $6.0 billion in savings through 1991, and $7.9 billion in total savings. If instead the annual number of purchases were reduced to 12, the five year savings would be $4.9 billion, including $0.6 billion in 1987, and total savings would be $6.9 billion.

SECTION I. WEAPONS SYSTEM TESTING

Why Test?

Any weapons sytem will undergo certain expected and other unexpected degradation over time. The general objective of a test program is to establish and monitor a system's capability and reliability--that is, its ability to perform with the precision, speed, and aim that its operators count on in planning. To assure a weapon's continued reliability, continued monitoring is necessary. Ancillary benefits of a system's test program include crew training and however much deterrent effect might result from public demonstrations of confidence in the system's effectiveness.

A test program is organized in segments or phases. Research and Development testing generally consists of controlled testing of specific components and capabilities. Operational Testing and Evaluation, the largest segment, involves flight tests that closely simulate the operational environment; these test the viability of the overall system. Aging and Surveillance testing involves extensive ground testing to detect stress and age-related defects before they might impede performance.

None of the objectives of a test program is affected by the number of missiles to be deployed. Under each of the formal plans for MX deployments--ranging from as many as 200 missiles to as few as 50--the size of the test program has remained constant.

How Much Testing is Enough?

There is no objectively "best" amount of testing. Significant costs are associated with testing. And ballistic missile testing is in some sense paradoxical. Since a ballistic missile is destroyed in the testing process, the missiles that remain operational are obviously not those that have been tested. Thus no amount of testing can assure how a system would perform. Testing, however, should be sufficient to give planners confidence in the statistically predicted reliability and performance of an overall system.

To make this process less vague, the Joint Chiefs of Staff establish minimum guidelines for operational testing of strategic systems employed in a nuclear war plan, also known as the Single Integrated Operational Plan (SIOP). These guidelines, explained in more detail in the next section, are designed to ensure that the services maintain an acceptable level of statistical confidence in their estimate of system reliability. Thus, they

form the foundation for the sizing of a test program. However, the guidelines leave the statistical analysis and details of the test program to the individual services. Furthermore, these guidelines are described as lower bounds for confidence and reliability; the services might impose more stringent criteria for testing than specified by the JCS.

SECTION II. THE AIR FORCE'S MX TEST PROGRAM

Each of the three segments in the test program for the MX missile has specific objectives, but all are intended to establish and monitor the capability and reliability of the system. The test program involves monitoring the operational ground equipment, airborne equipment, and warhead. Included in these systems are numerous subsystems, such as the booster, post-boost vehicle, arming and fuzing mechanisms, guidance subsystem, and flight-control subsystem.

RESEARCH AND DEVELOPMENT TESTING

Testing starts while a weapons system is still at the R&D stage. The goal is to develop a missile that meets specified performance standards for such features as range and accuracy. Now under way, the MX missile's R&D test program includes 20 flight tests. Objectives in this phase evolve from limited early developmental testing through fully integrated operational testing. To date, ten MX flight tests have been conducted, with the latest two carried out from a modified Minuteman silo at the Vandenberg, California, test range. The current plan calls for completion of 16 flights before Initial Operational Capability (IOC) of the system in December 1986, with the remaining four flight tests leading into the Operational test phase of the program. 2/ According to a recent report by the General Accounting Office, the MX's flight test program to date has shown good performance. 3/ Problems that have occurred have centered on the third-stage extendable nozzle exit cone (ENEC), which gives the missile an important increment of range. This mechanism failed the first, third, and seventh flight tests. Later modifications appear to have solved the problems.

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2. Initial Operational Capability for the MX is defined as deployment of the first ten missiles.

3. General Accounting Office, "Status of the Intercontinental Ballistic Missile Modernization Program (GAO/NSIAD-85-78)," July 8, 1985, p. 17.

OPERATIONAL TESTING AND EVALUATION

After successful R&D testing, Operational Testing and Evaluation proceeds in two phases over the life of the system. These tests are designed to simulate as closely as possible what the Defense Department terms "the operational environment" in order to ascertain the missile's ability to deliver its payload reliably and accurately. The United States does not test ICBMs from actual, operational silos, however, but rather, from launch facilities at test ranges--such as Vandenberg--designed to represent the operational silos.

Phase I

The first phase of OT&E is primarily concerned with establishing a statistical estimate, with a high degree of confidence, of the system's accuracy and reliability. 4/ This estimate serves for both operational and target planning, and it establishes an accurate baseline against which to measure any future degradation. When problems are uncovered in a missile test, they are corrected, if possible, before the next missile flight test. Although this does not make for an ideal statistical sample, it is an operational reality.

Owing to reductions by Congress in planned procurement rates, and a decision to maintain the initial deployment in December 1986, Phase I Operational testing for MX will not begin until fall 1988--more than a year after completion of R&D. The planned Phase I OT&E program for the MX will test 24 missiles over a three-year period (1988-1990).

Phase II

On successful completion of Phase I, the second phase of the Operational Test program begins with annual testing over the life of the system to monitor degradation in performance and reliability. 5/ A sample of missiles

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4. Weapon system reliability refers to the proportion of successful launches--with success defined as the launch, completion of flight, and delivery of the warhead. Accuracy of the weapon is measured by its Circular Error Probable (CEP). CEP is defined as the size of a circle (its radius) centered on the target within which the warhead has a 50 percent probability of impacting.

5. If there are unexpected difficulties in Phase I, it may be extended and some planned Phase II missiles used for additional Phase I testing.

is randomly selected--and replaced--from the deployed force each year, taken to the test range at Vandenberg--along with a task force of technicians and crews from each missile's home base--and flight-tested there. A total of 83 missiles, about seven a year, are planned for testing during Phase II of the MX program.

Aging and Surveillance

The Aging and Surveillance component of the test program proceeds at the same time as OT&E testing, and it is designed to detect any aging and deterioration of components before the system shows signs of actual degradation. This is accomplished by extensive ground testing. The MX test program calls for one Aging and Surveillance missile a year.

In the past, Aging and Surveillance testing has been instrumental in the early detection of age-related defects. For example, the deterioration of the bonding material between the motors and casing of Minuteman II, Stage 2, and Minuteman III, Stages 2 and 3, currently being corrected, was discovered this way. The program has also been instrumental in confirming that Stage 1 of both missiles is sound.

Most of Phase II OT&E and Aging and Surveillance testing is conducted after production of the missile has been completed. Thus, significant deterioration problems might require the manufacture of new components or sub-components.

Even though the MX is similar in many ways to current U.S. ICBMs, it will still need thorough testing. Many of the missile components that have deteriorated and caused reliability trouble with the existing Minuteman missiles have completely new counterparts with the MX, and they might or might not be the source of new problems. For instance, the missile guidance system, the component causing the greatest reliability flaw with the aging Minuteman missiles, is a new advanced system for the MX using inertial reference. The motor casing for the second and third stages is a new graphite composition that might wear exceptionally well with time, or might suffer from unexpected brittleness. These types of problems are difficult to predict. Eight components on the MX were not used on previous ICBMs.

- Stages I-III Kevlar Motor Case
- Stage II and III extendable nozzle exit cones
- Stage IV surface tension propellant tank
- AIRS guidance system

- o Unique Signal Device
- o MK21 Reentry Vehicle
- o Solid state radar fuze
- o Aluminum/composite "aeroshell" reentry vehicle structure

THE SIZE OF THE MX TEST PROGRAM COMPARED TO OTHERS

Compared to the size of test programs for five other U.S. ballistic missiles, the MX program is modest in scale (see Table 1). The number of missiles designated for the MX test program is at or very near the lowest of any of the test programs. 6/ Flight testing during Phase II of Operational testing for the MX is set at about seven missiles a year, as compared, for example, with 12-16 for the Trident II.

The MX test program might be considered especially modest in size if, as has been the case with past ICBMs, their actual service life has exceeded the Air Force's initial estimate for the system (see Table 1). The Minuteman II only has 26 test missiles remaining and might be deployed through the end of the century. The last operational test of a Titan missile was carried out in 1969, yet the last of these missiles is not to be retired until 1987.

THE JOINT CHIEFS' STANDARDS FOR OPERATIONAL TESTING

Though comparisons can help judge the magnitude of the MX test program, a key test of adequacy is the ability to meet guidelines issued by the Joint

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6. The Navy's test programs for the Trident I (C-4) and planned Trident II (D-5) are much larger than the other test programs. Navy test programs have additional considerations that might make direct comparisons misleading, such as the assumption of a 30-year service life, the use of multiple--"ripple"--launches to test crew and submarine adequately, and the necessity to examine missile performance over a broad spectrum of ranges and azimuths. These issues are examined in more detail in a CBO companion analysis of the Trident II test program. The Army test program for the Pershing missile would provide a better comparison, but the Army has classified its numbers.

TABLE 1. COMPARISON OF TEST PROGRAMS FOR SIX BALLISTIC MISSILES

	Numbers of Missiles					
	MX	MMI	MMII	MMIII	Trident I	Trident II
Total Test Missiles	143	290	205	284	263	418
Research and Development Tests	20	56	20	25	25	30
Operational Tests	108	210	171	242	208	356
Aging and Surveillance Tests	15	24	14	17	30 a/	30 a/
	Year Ending					
Original Projected Service Life	2003 b/	1969	1980	1985	1998	2029

a. In the case of the Navy, these are "pipeline" missiles; missiles that are in the process of being inspected and redeployed as submarines are overhauled. They include so-called Service Life Evaluation missiles that are similar to Aging and Surveillance missiles.

b. Service life is technically measured from Initial Operational Capability. However, in the case of the MX, the 15-year Operational Test program was delayed two years to 1988. Thus, Operational Testing is planned to extend over the period 1988-2003 versus 1986-2001. According to the Air Force, then, the MX system will likely be deployed beyond its technical service life of 15 years.

Chiefs of Staff. This section examines Operational Testing--the largest segment of the test program--to which JCS guidelines pertain. (This section does not examine other phases of testing. Research and Development testing is well under way, and the missiles for those tests have already been purchased. No statistical requirement exists for Aging and Surveillance test missiles; from a practical perspective these missiles have been instrumental in detecting age-related problems, and so devoting one missile a year to this type of testing might be reasonable.)

The CBO has analyzed the test program for the MX that would meet JCS guidelines--which focus specifically on the missile's reliability--in the two phases of Operational Testing. Testing will also establish the accuracy of the MX, but the JCS guidelines do not explicitly deal with accuracy; hence, testing for accuracy does not explicitly influence the size of the MX test programs. 7/

Phase I

The JCS guidelines require a high degree of confidence in the baseline estimate of overall system reliability developed during Phase I. Specifically, the JCS requires 90 percent confidence (in statistical terms) that overall system reliability be within 10 percentage points of the reliability observed in the sample tested. Reliability refers to the proportion of missiles that would be successfully fired; that is, missiles that would launch, complete all phases of flight, and deliver their payload. For example, if the Air Force tests 30 missiles with 25 successful results (reliability of 83 percent in the sample), it would have to demonstrate by statistical analysis that, 90 percent of the time, it would be correct in stating that the system's true reliability was at least as good as 73 percent. 8/

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7. With Navy missiles, test requirements imposed by the Navy for accuracy do affect the size of the program.

8. Note that this guideline makes sense only for reasonably high degrees of reliability. At 10 percent reliability, for example, the criterion is met but is not meaningful. But ballistic missile reliability is assumed to be well above 50 percent.

For a given standard of reliability, the larger the sample size observed to meet that standard, the higher the confidence one can have that the observation accurately reflects overall system reliability. An example might clarify the principle. In five tosses of a fair coin, the probability of getting "heads" four times is about 16 percent--that is, about one-sixth of the time, one would be mistakenly led to predict that one has an 80 percent probability (four out of five) of getting "heads." But in ten tosses, the probability of getting "heads" a comparable eight times is only 4 percent--making it much less likely that one would be led to the same erroneous conclusion.

Thus, for a given observed reliability, only certain sample sizes can provide the level of confidence required by JCS guidelines in making a prediction about overall--or "true"--system reliability. The required sample size depends on the expected results. The Air Force most likely assumes, for planning purposes, that the reliability of the sample tested will be around 90 percent. (This is derived from JCS statistical guidelines and the original Air Force plan for 36 missiles in Phase I using Classical statistical techniques. It is also consistent with public estimates of missile reliability.)

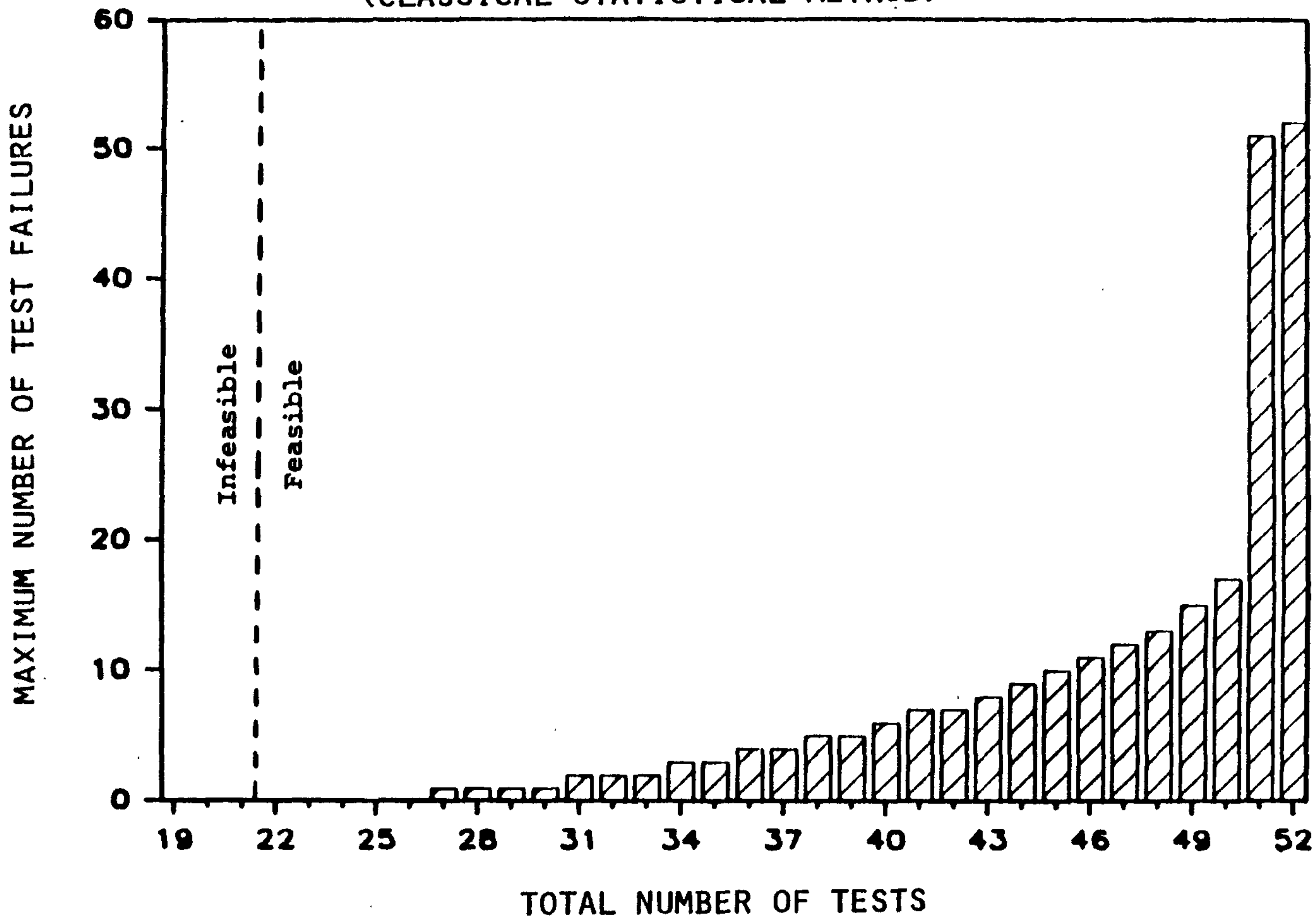
The statistical method that the Air Force chooses to use can also affect the sample size required to meet JCS guidelines. The remainder of this section looks at Phase I test program requirements, first using the "Classical" statistical method, and then using the "Bayesian" statistical method.

Classical Method. For various test sample sizes, Figure 1 shows the maximum number of test failures allowable for a Phase I test program that meets JCS guidelines under the Classical method. The figure illustrates that sample sizes must be larger than 21 missiles to have any prospect of satisfying JCS guidelines. (Again, the guidelines pertain to missiles with fairly high expected reliabilities; more than 50 percent. At very low reliabilities, the guidelines can always be met, but are not meaningful.) For sample sizes of 22 to 26 missiles, it is possible to satisfy JCS guidelines only if every trial is a success, indicating 100 percent reliability. On the other hand, with a large enough sample size--in this case, 51 missiles--one can always be confident that the success rate in the sample accurately represents the system's true reliability. In this case, one always meets JCS guidelines regardless of what the success rate is.

With the assumption that reliability of the sample will be around 90 percent, the smallest sample size that offers a chance of meeting JCS

FIGURE 1. MEETING JCS GUIDELINES FOR MISSILE TESTING

(CLASSICAL STATISTICAL METHOD)

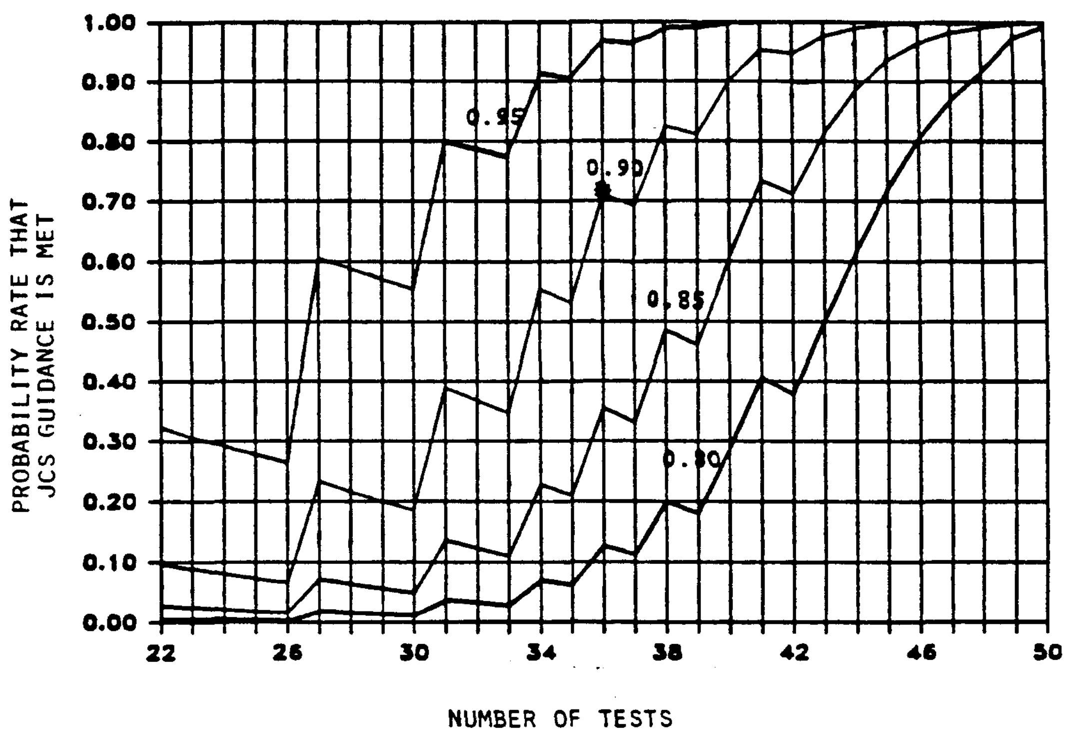


This graph displays the maximum number of failures that can occur in a Phase I missile flight test program that meets JCS guidance:

-- below 22 missiles, it is not possible to meet JCS guidance
-- at 40 missiles, 6 or fewer failures satisfies JCS guidance
-- above 50 missiles, any number of failures satisfies JCS guidance

guidance for Phase I is 36 missile tests with 32 successes. This minimum of 36 missiles exceeds the Air Force's plan for 24 missiles in Phase I. Moreover, a sample of 36 missiles does not guarantee meeting JCS guidelines. That only happens if, when the 36 missiles are tested, at least 32 are successful. But even if the overall system (true) reliability were around 90 percent, the particular sample tested would have at least 32 successes only about 70 percent of the time. Thus, even with a sample size of 36 test missiles, the Air Force would implicitly be accepting about a 30 percent risk of not meeting JCS guidelines. Figure 2 illustrates the probabilities, with different sample sizes, of meeting JCS guidelines given overall system reliabilities of between 80 percent and 95 percent.

FIGURE 2. PROBABILITY OF MEETING JCS GUIDELINES
(GIVEN TRUE RELIABILITY = 0.8...0.9)



* Even with a sample size of 36 missiles, the Air Force is implicitly accepting a 30 percent risk of not meeting JCS guidelines.

Bayesian Method. To justify a choice of 24 test missiles for Phase I in light of these results, the Air Force has applied a Bayesian statistical analysis. Bayesian analysis provides a formal framework for incorporating information other than sample information into a model for making inferences about the characteristics of a population--in this case, the overall MX system. By Classical analysis, only the sample results would be formally considered, although experience might still temper statistical prescriptions.

To illustrate the use of Bayesian statistics, consider an example in which a technician tests a sample of ten light bulbs from a large shipment, and finds five to be defective; this implies a 50 percent rate of defective bulbs. How would his assumption change if, in addition to the sample information, he knew that all past shipments of bulbs had been of extremely high quality, with an overall defective rate of only 5 percent? With this information, a technician using Bayesian statistics would develop a second--or "prior"--probability distribution based on the information about prior shipments, and essentially multiply it with the probability distribution from the sample data. The resulting distribution is a weighted compromise of the two and, according to a Bayesian, represents the best information at hand. The less sample information one has, the greater the relative weight or influence of prior information, and vice versa. In a case of a Bayesian analyst's not having prior information--hence, no empirical data to apply--results as would be expected are similar to the Classical method.

With constraints on test resources, the Air Force's apparent decision to incorporate prior information into a Bayesian framework, and thus reduce the sample size necessary in Phase I, seems reasonable. Prior information in the case of the MX could include performance data from R&D tests, engineering estimates, and data from component tests.

The Air Force did not, however, explicitly incorporate prior data into its Bayesian analysis. Instead, it used a mathematically-based prior distribution that heavily weights the probability of obtaining outcomes near 100 percent reliability in the sample and thus reduces the requisite sample size to meet JCS guidelines to 24 missiles. 9/ The prior distribution used by the Air Force does not appear to reflect actual, empirical information about MX or about earlier missiles.

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9. The application of a mathematically-based prior is a subject of controversy even in the theoretical literature, and the CBO has not been able to find any practical justification that would be consistent with this case.

Although statistical justification for the Air Force's use of 24 missiles in Phase I is thus lacking, the decision reflects an operational judgment that might be reasonable. Based on its substantial experience with ICBMs, the Air Force believes that JCS guidelines for Phase II are not sufficiently demanding, and do not provide any additional flexibility for contingencies such as a longer service life. (This is discussed in more detail in the following section.) Given a limit on the total number of test missiles, the Air Force believes that added risk in Phase I is justified in order to shift additional missiles to Phase II.

Phase II

Air Force testimony indicates that for Phase II, JCS guidelines are less stringent than for Phase I and would allow a significant degradation in capability to go undetected. Moreover, the JCS guidelines do not provide sufficient detail to unambiguously interpret Phase II test requirements. Unlike Phase I, Phase II testing is concerned with detecting a change in system reliability. The Strategic Air Command has interpreted JCS guidelines for Phase II as: Test enough missiles to have a specified probability of observing at least one flight test failure caused by a specified degradation in reliability. 10/

According to Air Force testimony, six missile tests a year would be sufficient to meet minimal JCS requirements for Phase II. However, because the Air Force has never experienced as large a reliability degrade as covered by these guidelines, it has imposed a more stringent requirement for testing. The requirement is to test enough missiles to have a 90 percent probability of observing a failure associated with a force degrade of 10 percent or more over a three-year period. Based on this requirement, the Air Force plans seven missile tests a year and will pool the sample data over three years. Testing six missiles a year would provide a 90 percent chance of observing a degrade of 12 percent within three years.

But for several reasons the Air Force feels that the extra missiles are required for an acceptable Phase II program. First, as noted, the JCS guidance might not be sufficiently demanding, and the Air Force is concerned about detecting much smaller declines in reliability. Moreover, the Air Force wants some flexibility in case the MX remains in service longer than is currently planned, or in case of some necessary modifications later on. As stated earlier, the Air Force now plans to keep the MX about

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10. The model is expressed as $P=1-(1-D)^N$ where P is the probability of detecting a failure, D is the amount of reliability degrade, and N is the number of missiles tested.

15 years, but Minuteman II has been in service about 20 years and might remain through the end of the century. If the MX should remain in service five more years than planned, then the currently planned buy of missiles for Phase II would provide about five missiles each year, or just under the minimum required to meet JCS guidelines.

As the above discussion suggests, the current MX test program is modest in scale by many standards, including JCS guidelines and in comparison with other test programs for ballistic missiles. Even in Phase II, for which the current plans do exceed JCS guidelines, there are reasonable arguments for the larger number.

SECTION III. OPTIONS TO REDUCE THE TEST PROGRAM

On the other hand, the Congress might be concerned that--under current plans to deploy only 50 MX missiles--fully 143 of all 193 missiles to be bought (or 74 percent) will go to the test program. Given the small deployment now planned and the budgetary constraints now drawing increasing attention, the Congress could choose to accept the risks of a smaller test program to reduce costs. Several options, entailing modified levels of procurement (see Tables 2 and 3), define the range of the choices. The options focus on Phase II, because it constitutes the bulk of the test program.

OPTION I. LIMIT FLEXIBILITY BY REDUCING PHASE II TESTING

Though this option wold allow the Air Force to meet JCS guidelines, it would limit any hedge against a longer service life for the MX. If the Air Force's history with the Minuteman II were repeated with the MX, there would be even fewer test assets to accommodate an extended service life. This reduction in the test program would also virtually eliminate flexibility for additional testing. The need for such additional testing could arise as a result of unforseen degradation of some components, or it could arise from a requirement to test later additions to the capability of the missile to preserve its viability in the face of increased Soviet abilities.

This option would, however, meet JCS guidelines. Moreover, it is not far from meeting the higher standards desired by the Air Force. Pooling sample data (as the Air Force already does) over three years would yield a 90 percent probability of observing a test failure associated with a 12 percent decline in reliability--rather than 10 percent as the Air Force would prefer. Thus, even if JCS guidelines were not considered demanding enough in Phase II, it is possible to test to higher confidence levels every three years.

This option would allow a 12-missile reduction in the test program's present size. Depending on how the option was implemented, it could yield savings from $0.8 to $1.8 billion. Assuming a baseline program of 21 missiles per year, cutting the missiles from the end of the baseline purchase would yield total savings of $1.8 billion, all accruing in 1992. However, costs in 1991 would actually increase slightly compared to the baseline in order to end the program efficiently. On the other hand, proportional

TABLE 2. PROCUREMENT RATES UNDER CURRENT BASELINE AND OPTIONS (Fiscal years 1985-1992)

	1985 and prior	1986	1987	1988	1989	1990	1991	1992	Total
Current Baseline a/	42	12	21	21	21	21	21	14	173
Meet Minimal JCS Guidance for Phase II (test six/year)									
Option I									
Cut from end of buy	42	12	21	21	21	21	23	0	161
Reduce rate immediately	42	12	19	19	19	19	19	12	161
Meet JCS Guidance for Phase II every other year (test three/year)									
Option II									
Cut from end of buy	42	12	21	21	21	9	0	0	126
Reduce rate immediately	42	12	12	12	12	12	12	12	126
Minimal Testing									
Option III									
Cut from end of buy	42	12	21	21	5	0	0	0	101
Reduce rate immediately	42	12	12	12	12	11	0	0	101

SOURCE: Congressional Budget Office.

a. Assumes continued procurement rate of 21 missiles per year, the maximum specified by the Congress for 1987. Doesn't include 20 Research and Development test missiles.

TABLE 3. OPTIONS FOR MX TESTING

Reduction in Number of Test Missiles	Savings Relative to Current Baseline a/ (in millions of 1987 dollars)					
	Continue at Current Rate - Cut from End of Buy			Reduce Rate Immediately		
	1987	1987-1991	Total	1987	1987-1991	Total
Meet Minimal JCS Guidance for Phase II (test six/year)						
Option I						
12	0	-110 b/	1,820	100	640	760
Meet JCS Guidance for Phase II every other year (test three/year)						
Option II						
47	0	3,360	5,290	600	2,970	3,000
Minimal Testing						
Option III						
72	0	6,010	7,940	600	4,920	6,850

SOURCE: Congressional Budget Office.

a. Assumes continued procurement rate of 21 missiles per year, the maximum specified by the Congress for 1987.

b. This option would purchase 23 missiles in 1991--two more than the baseline rate--in order to end the program efficiently.

reductions in the program over the same period as in the baseline--with purchase of 19 missiles a year--would have the advantage of saving $0.6 billion over the next five years (1987-1991), but would mean lower total savings of $0.8 billion because of inefficiencies in production rates.

OPTION II. MEET JCS GUIDELINES EVERY OTHER YEAR

This option would buy enough missiles to test three a year in Phase II (or a total of 36, compared to 84 under current plans). Testing three missiles a year could meet JCS guidelines for six missile tests every other year by pooling sample data. Since SAC has not, in its extensive experience with land-based missiles, sustained any sudden and dramatic reductions in reliability, the risk in detecting changes only every two years might be tolerable.

This option would not, however, allow testing to the more stringent levels the Air Force prefers. Testing three missiles would provide, over a three-year period, 90 percent probability of observing only a larger decline in force reliability of 23 percent, versus detecting a 10 percent decline as is preferred by the Air Force. This option would also virtually eliminate flexibility for testing over an extended service life or because of unexpected degradation leading to modifications.

In return for increased risk, this option would allow a reduction of 47 missiles, producing total savings of between $3.0 and $5.3 billion, again depending on how the option was implemented. By cutting off the end of the planned purchase, larger savings would accrue both over the five years 1987-1991 and in total. However, this method would not yield any savings in 1987. With proportional annual reductions, which would maintain the annual level of procurement at 12 missiles, almost all savings would occur over the five fiscal years, but total savings under this method would be lower, by more than $2.0 billion, because of unit cost increases.

OPTION III. MINIMAL OPERATIONAL TESTING

This option would provide 36 missiles for all phases of Operational Testing, rather than the 108 missiles now planned by the Air Force. The Air Force could allocate these missiles to Phase I or Phase II, or both, depending on its judgment. For instance, if R&D testing were considered successful, and if it provided enough data to establish some baseline parameters, then all missiles could be used for Phase II to monitor declines in reliability. This would allow testing of about three missiles per year and would be similar in effect to Option II. Conversely, if the original plan for 24 missiles in Phase

I were considered absolutely necessary, then only 12 would be available for Phase II. In this case, the Air Force might wish to forgo flight testing for declines in reliability unless the annual Aging and Surveillance monitoring indicated deterioration. In that event, a small reserve would be available for flight testing. Training benefits from flight testing could probably be accomplished without actual launch of a real missile. All actions up to the actual launch could still be practiced, and the launch perhaps simulated. 11/

There is obviously substantial risk in this option. Military planners would be much less certain of the reliability of the system over time. Should a serious problem necessitating major changes develop with the MX, there would be few missiles available to test the changes. This could be of even greater concern because the rest of current U.S. land-based missiles--Minuteman II and III--are old and also have few test missiles remaining.

Moreover, from a policy perspective, this option could reduce the deterrent value of the system if the Soviet Union assessed the system as less likely to work. Because production of the missile would stop soon, there would also be limited opportunity to expand deployment, should Soviet actions warrant an expanded U.S. response.

This option would, however, be consistent with a decision that the limited deployment of the MX specified by the Congress does not warrant the expense of heavy testing, especially in light of constrained budgets and curtailment of other modernization programs. Arguably, the deterrent value of the system is already low since its contribution to U.S. warheads capable of surviving an attack and retaliating is very small--in most cases, less than 1 percent. 12/ Further loss of deterrent capability following from minimal testing and the resulting uncertainty might be of marginal importance. Moreover, having a system deployed for many years without testing is not without precedent: the Titan missile, as stated earlier, was deployed for longer than 15 years without a single flight test. The Minuteman missiles may be in the same situation before the end of the century.

Through radical reductions in the test program, this option would save from $6.9 to $7.9 billion. The upper bound represents savings that would accrue if reductions occurred from the end of planned procurement, but which would not begin until 1989. If annual buys were reduced to 12, all $6.9 billion in savings would accrue over the next five years, including $0.6 billion in 1987.

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11. In bomber training missions, for example, bombing is simulated electronically.

12. Congressional Budget Office, Modernizing U.S. Strategic Offensive Forces: The Administration's Program and Alternatives, May 1983, p. 46.