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REPORT TO THE CONGRESS OF THE UNITED STATES

B-133042

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FINDINGS RESULTING FROM INITIAL REVIEW OF THE BALLISTIC MISSILE PROGRAMS OF THE DEPARTMENT OF THE AIR FORCE

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UNITED STATES GENERAL ACCOUNTING OFFICE

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UNITED STATES GENERAL ACCOUNTING OFFICE

BY UNCLASSIFIED

THE COMPTROLLER GENERAL OF THE UNITED STATES

DECEMBER 1960

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COMPTROLLER GENERAL OF THE UNITED STATES
WASHINGTON 25

B-133042

DEC 27 1960

Honorable Sam Rayburn
Speaker of the House of Representatives

Dear Mr. Speaker:

Enclosed is the report on our findings resulting from our initial review of the THOR, ATLAS, and TITAN ballistic missile programs of the Department of the Air Force. However, the presentation of one of our significant findings on the THOR program, involving its status in the United Kingdom, has been deferred at the request of the Air Force pending review by the State Department, based on an understanding reached with the United Kingdom in obtaining access to its records. This finding will be the subject of a separate report.

As explained in our initial report on this review, released in May 1960, we have been denied access to basic information, records, and reports, and our review has been seriously handicapped. Nevertheless, we have noted certain management weaknesses and activities involving excessive costs. These matters are reported in detail in the enclosed report, and the major findings listed below are summarized in the "Highlights" section beginning on page 3.

1. The adoption of storable fuels in the TITAN program was delayed without apparent justification, and as a result the planned operational date for the first TITAN squadron having significant operational advantages has been postponed 5 months. The limited information made available to us showed that about $163 million would be needed to add storable fuels to this program, and we were told informally that the major obstacle to the program change was the limited fund availability. While the proposed expenditure of such a substantial sum requires careful consideration, it would appear in view of the top priority assigned to the intercontinental ballistic missile program in the defense of this Nation that immediate action should have been taken to provide for obtaining this military capability as soon as responsible organizations had made sufficient tests to determine that adopting this plan was feasible and advisable.

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2. There was an unwarranted delay in providing vitally important captive test facilities for the THOR program.

3. Flight testing of THOR development missiles was attempted more than 1 year prior to captive testing of an assembled missile, with unfavorable results.

4. THOR missiles were shipped to the flight test center prior to incorporation of necessary modifications, with consequent adverse effects.

5. Flight failures of one ATLAS and one THOR caused by turbopump deficiencies could have been avoided without delay in the program.

Air Force comments relating to findings contained in this report have been included in the "Findings" section of the report to the extent pertinent and its general comments on our review are discussed at the conclusion of the report.

Inasmuch as this report is concerned primarily with Air Force management of the programs, we have not requested comments from the various contractors involved.

We regret that in contravention to statutory requirements, the Air Force has denied us access to basic information, records, and reports, including reviews by responsible officials of the progress of the ballistic missile program and the steps taken to identify and correct problem areas and delays in the program. These denials have been made pursuant to policies and procedures of the Departments of Defense and the Air Force, not because of military security reasons but, instead, on the basis that the records contain "privileged" information which could be withheld by the executive branch of the Government. In our opinion, the information, records, and reports withheld from us are essential to the proper performance of our audits and reviews of the operations of the Department of the Air Force in the management of its ballistic missile program. These restrictions impeded the progress of our audit and prevented us from fully discharging our statutory responsibilities to conduct independent and searching examinations in order to report to the Congress and management officials conditions or circumstances which need attention and improvement so as to effectively accomplish the program and prevent the unnecessary expenditure of money, manpower, and material.

Contents

B-133042

Our report is also being sent today to the President of the Senate. Copies of this report are being sent to the President of the United States, to the Secretary of Defense, and to the Secretary of the Air Force.

Sincerely yours,

[signature]

Comptroller General
of the United States

Enclosure

REPORT ON FINDINGS

RESULTING FROM INITIAL REVIEW

OF THE

BALLISTIC MISSILE PROGRAMS

OF THE

DEPARTMENT OF THE AIR FORCE

INTRODUCTION

The General Accounting Office has performed a review of the administrative management of the THOR ballistic missile program of the Air Force and, to a lesser extent, of its ATLAS and TITAN programs. This review was made pursuant to the Budget and Accounting Act, 1921 (31 U.S.C. 53), the Accounting and Auditing Act of 1950 (31 U.S.C. 67), and the authority of the Comptroller General to examine contractors' records, as set forth in 10 U.S.C. 2313(b). The scope of our review is discussed on page 97. (UNCLASSIFIED)

When we began our review of the Air Force ballistic missile programs, the THOR intermediate range ballistic missile (IRBM) program was in a more advanced stage of development than the ATLAS or TITAN intercontinental ballistic missile (ICBM) programs and we, therefore, selected the THOR program for initial review. While we subsequently extended our review to the ATLAS and TITAN programs, this report deals primarily with certain findings in connection with the THOR program. Additional reports dealing with other aspects of these programs will be issued from time to time as our reviews are completed. (UNCLASSIFIED)

The Air Force has reported that significant progress has been made in the ballistic missile program. That there has been progress and that notable accomplishments have been made are not questioned.

HIGHLIGHTS

Our examination of the Air Force programs was directed primarily to those aspects which appeared to warrant particular attention and is not intended to provide an over-all evaluation of the program. As explained in our initial report on this review, released in May 1960, we have been denied access to basic information, records, and reports, including reviews by responsible officials of the progress of the program and the steps taken to identify and correct problem areas and delays in the program. These denials have continued to seriously handicap our review. Nevertheless, based on the limited information made available to us, we noted certain management weaknesses and activities involving excessive costs. These matters are summarized below and are reported in detail in the FINDINGS section of this report.

DELAY IN ADOPTION OF STORABLE FUELS IN TITAN PROGRAM

The planned operational date for the first TITAN squadron to be equipped with a substantially improved missile using storable liquid fuels and having the operational advantages of immediate reaction capability, greater reliability, inertial guidance, and less exposure to enemy attack has been postponed 5 months, evidently due to delay in administrative decision to incorporate storable liquid fuels in the TITAN propulsion system.

Following extensive studies, the Air Force Ballistic Missile Division recommended in March 1959 that storable liquid fuels be introduced into the TITAN program. In April 1959 the Strategic Air Command urged that this recommendation be adopted. However, the TITAN program was not revised as recommended until November 1959, at which time the planned operational date was set back 5 months. The Air Force has refused to make available to us certain records covering the actions taken during the 6-month period between the recommendation by responsible scientific, technical, and operational organizations and the approval by Headquarters, United States Air Force. However, a substantial amount of funds approximating $163 million would be needed to add storable fuels to the TITAN program, and we were told informally that the major obstacle to the program change was the limited fund availability.

We recognize that the proposed expenditure of such a substantial sum requires careful consideration. However, in view of the top priority assigned to the intercontinental ballistic missile program in the defense of this Nation, it would appear that immediate action should have been taken to provide for obtaining this military capability as soon as responsible organizations had made sufficient tests to determine that adopting this plan was feasible and advisable. Furthermore, a Department of Defense representative has testified during congressional hearings that the additional cost of storable fuels would be recovered in a matter of some years of operation through savings in base installation costs, operation, and maintenance. Information made available to us contained no evidence that the delay in decision making will result in any savings in cost; instead, the delay merely postponed the costs for about 5 months. (See p. 20.)

UNWARRANTED DELAY IN PROVIDING CAPTIVE TEST FACILITIES FOR THOR PROGRAM

Our review also disclosed an unwarranted delay in providing captive test facilities of vital importance to the THOR development program. The military departments have emphasized the need in ballistic missile programs to captive test missiles on the ground prior to flight tests in order to minimize the possibility of failures and to conserve costs. Inasmuch as the constructing and equipping of captive test stands require a considerable amount of time and since captive testing of a complete assembled missile cannot be accomplished without the captive test stands, appropriate action should be taken to arrange for availability of such facilities in sufficient time to enable desirable captive tests prior to flight testing. However, availability of captive test stands for the THOR program was delayed 10 months due in part to prolonged negotiations as to whether the Air Force or the contractor would finance the cost of facilities in excess of the amount originally contemplated by the contractor. This delay is particularly questionable inasmuch as the Air Force would have absorbed a substantial part of the cost of these facilities even if the contractor had financed them. (See p. 37.)

EXTENSIVE FLIGHT TESTING PRIOR TO CAPTIVE TESTING IN THOR PROGRAM

Under the original Air Force development plan for the THOR program, flight testing was planned on a "maximum risk" basis to begin 2 months after completion of the first captive test of an assembled ballistic missile, thereby enabling the use of captive test results insofar as possible in preparing for flight tests.

However, the flight test program was accelerated 7 months, and this factor, together with the 10-month delay in availability of captive test facilities, resulted in the attempted flight testing of THOR development missiles more than 1 year prior to the captive testing of an assembled missile with unfavorable results. By contrast, during the same period, the Army captive tested every assembled JUPITER missile before flight testing, and more favorable flight test results were achieved. (See p. 52.)

SHIPMENT OF THOR MISSILES TO FLIGHT TEST CENTER PRIOR TO MODIFICATION

THOR missiles were shipped from the west coast to the flight test center at Cape Canaveral, Florida, without incorporation of necessary modifications, and the missiles were on hand at the flight test center many months prior to launch. The shipment of the missiles prior to modification appears to have been unnecessary and costly and a delaying factor in the program. Extensive modification work had to be performed at the flight test center to incorporate engineering changes and changes in the instrumentation of the missiles made necessary by previous flight and captive test developments. In view of the research and development status of the THOR program at that time, modifications to effect corrections and improvements were to be expected and would have been necessary even if the missiles had been retained at the contractor's plant. However, we believe that such modifications would have been made more economically and more quickly if performed at the factory where facilities, parts, and personnel were available. By contrast, JUPITER missiles required less modification after arrival at the flight test center and were launched within a month after arrival as compared with the average of over 4 months required for THOR missiles. (See p. 62.)

FLIGHT FAILURES OF ONE ATLAS AND ONE THOR
DUE TO TURBOPUMP DEFICIENCIES

A major problem in the ballistic missile programs for both the Air Force and the Army was caused by turbopump deficiencies affecting the flow of propellants into the engines of the missiles. Flight failures of eight ballistic missiles are attributed to the turbopump deficiency, and it appears that two of these (one ATLAS and one THOR) could have been avoided at substantial savings in cost without disruption of flight test programs if the engines had been returned to the contractor's plant for incorporation of modifications that the Air Force had previously approved for application to engines still in production.

We recognize that a decision as to whether the flight program should be delayed for modification of existing missiles involves complex judgments concerning the importance of the modifications and the urgency of the program. However, it seems evident that important modifications which could be made without delaying the program should be made to reduce the likelihood of flight failures. (See p. 76.)

DESCRIPTION OF AIR FORCE BALLISTIC MISSILE PROGRAM

The Air Force ballistic missile program is the largest single military program ever undertaken by the United States. It is managed by the Air Force, with the support of more than 30 major contractors, 200 major subcontractors, and 200,000 suppliers in industries across the Nation, whose joint resources include skills of thousands of scientists, engineers, and technicians. About $7 billion of Air Force funds had been obligated on this program as of May 31, 1960, and the program now involves the expenditure of about $2 billion a year for the research, development, testing, production, and operational deployment of the ballistic missiles. New research and development, test, and production facilities costing hundreds of millions of dollars have been created in support of this program.

HISTORY

The Air Force ballistic missile program originated in 1946, when missile development contracts were signed with North American Aviation, Inc. (NAA), and with what is now the Convair Division of the General Dynamics Corporation. Originally intended for rocket propulsion and long-range missile development, the NAA contract grew into the $700 million Navaho project that was discontinued in 1957. The Convair contract, known as project MX-774, was for study and investigation of missile guidance and control, rocket-engine swiveling, and lightweight missile structures.

Convair continued with research of its own after the 1946 contract was completed in 1948. By 1950, the Air Force felt that study and limited design of an intercontinental ballistic missile were justified and, in early 1951, Convair was awarded a contract for the development of an ICBM, designated as the ATLAS. However, until 1954, the Air Force ballistic missile program suffered from frequent policy changes, funds shortages, major technical obstacles, and low priority.

By late 1952, advances in nuclear weapons technology indicated that production of a small, high-yield warhead was theoretically possible, thus removing what was perhaps the most formidable obstacle to the development of a successful ICBM.

In 1953-54, the RAND Corporation, a nonprofit organization engaged in basic research for the Air Force, conducted a study of the ATLAS program, which then had an expected operational capability dated after 1965, and suggested certain changes which would advance the operational date by at least 5 years. The RAND findings were published in a 38-page report, dated February 8, 1954. The report recommended that some of the very severe performance specifications then existing for the ATLAS be relaxed, such as increasing the circular error probability from about 1,500 feet to 2 to 3 miles. The report suggested certain design characteristics which included a 2-stage vehicle with a conventionally designed structure, and radio-inertial guidance, and stated that an operational missile system of great value should be attainable before 1960. The report stated that, for a missile incorporating these characteristics, there appeared to be no engineering limitation to achieving the schedules shown, since the program was based on almost exclusive use of techniques with which considerable experience had been obtained. Time estimates provided for completion of operational prototype testing by the first or second quarter of 1959. The report concluded that such a revised missile system, if given adequate funding and development effort, could be operational by or before 1960. The operational program envisioned 80 dispersed launching units, with activation of bases completed by the second or third quarter of 1959.

The Strategic Missiles Evaluation Committee (SMEC), composed of outstanding scientists and engineers, issued a less detailed report on February 10, 1954. This report acknowledged aid from the RAND proposals and stated that the beginning of an operational capability was considered attainable in 6 to 8 years; i.e., 1960 to 1962, provided that proper direction and support were given to the program. The SMEC report recommended establishment of a special organization to direct the program. Acceleration of the ATLAS program was a direct result of specific recommendations made by these advisory groups.

ORGANIZATION

In May 1954 the Air Force assigned highest Air Force priority to the ATLAS program and directed establishment of the ballistic missile field office on the west coast. The commander of this office was given authority over all aspects of the program, including the development of the complete weapons system, including ground-support and development of recommended operational, logistic, and personnel concepts, and the Ramo-Wooldridge Corporation (R-W)--now Space Technology Laboratories, Inc. (STL), a wholly owned subsidiary of the Ramo-Wooldridge Corporation--was selected to provide the scientific and engineering effort for this organization. The Air Force ballistic missile field office was established at Inglewood, California, on July 1, 1954, and was designated as the Western Development Division (WDD), currently the Air Force Ballistic Missile Division (BMD).

An Air Materiel Command (AMC) office, currently designated the Ballistic Missile Center (BMC), was established to support the executive agent, BMD, by providing contractual services and advice based upon AMC's broad experience in programing, pricing, production, maintenance, and supply.

A fourth element of the BMD Complex was added early in 1958 when an office of the Strategic Air Command (SAC), designated "SAC-Mike," was organized at Inglewood. The purpose of this element was to provide direct access to each SAC Headquarters staff activity in order to furnish SAC, the using command, with a means for feeding pertinent programing data into the approved channels. This coincided with the transfer of responsibility for the initial operational capability (IOC) to SAC in January 1958.

As a result of recommendations included in an "Air Force Plan for Simplifying Administrative Procedures for the ICBM and IRBM Programs" (known as the "Gillette Report"), dated November 1955, unusual authority was delegated to BMD and BMC in the areas of programing, budgeting and funding, procurement, industrial facilities, military construction, and development of the IOC of the missiles. This authority, in general, removed these functions from intermediate routine reviews and controls and in effect made BMD directly responsible to a newly established Air Force Ballistic Missile Committee composed of the Assistant Secretaries for Research and

Development, Financial Management, and Materiel and the Assistant Chief of Staff for Guided Missiles and chaired by the Secretary of the Air Force.

BALLISTIC MISSILE SYSTEMS

The Air Force ballistic missile program includes three intercontinental ballistic missile systems (ICBMs--ATLAS, TITAN, and MINUTEMAN) and an intermediate range ballistic missile system (IRBM--THOR) which are now in varying stages of development and operation. Beginning with fiscal year 1958, the Air Force provided budgetary support for the JUPITER, an Army IRBM.

The physical and performance characteristics for the individual ballistic missile systems reviewed by the General Accounting Office[1] are described below. The principal contractors for each of the missiles are also shown. With the exception of the JUPITER, Ramo-Wooldridge Corporation/Space Technology Laboratories, Inc., has been the systems engineering and technical direction contractor for all of these programs.

ICBM

ATLAS

The ATLAS ICBM was the first ballistic missile program undertaken by the Air Force. It is a 1-1/2-stage missile, powered by liquid-fueled rocket engines. Two booster engines and a sustainer engine are used simultaneously to launch the missile. At some time during the powered flight the booster engines are shut down

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[1]The MINUTEMAN was in the early stages of development during our field examination and was not included in our review.

and jettisoned, leaving the sustainer engine and fuel tanks to propel the reentry vehicle on toward its destination. Upon completion of its job, the sustainer engine system is jettisoned, allowing the reentry vehicle to become free falling to its destination without power and guidance. The ATLAS weighs in excess of 260,000 pounds and has a range capability in excess of 6,000 nautical miles. The Air Force reported the weapons system to have achieved initial operational capability in September 1959 at Vandenberg Air Force Base, California.

The missile airframe is a nonrigid metallic tank section which is pressurized for structural rigidity. The propulsion system uses liquid fuels and is composed of two booster engines of 165,000 pounds of thrust each, a sustainer engine of 57,000 pounds of thrust, and two vernier engines with thrust of 1,000 pounds each. Radio-inertial guidance is programed initially, but all-inertial guidance is planned at a later date. The nose cone was initially planned as a copper heat-sink but will be changed to an ablation type when these units are available.

Early ATLAS installations are exposed ground-level type and are identified as a soft base configuration. Later ground-level sites are being planned to be constructed with a degree of hardness and dispersal, in order to have some ability to withstand a nuclear attack.

Contractors engaged in the ATLAS program include Convair Astronautics Division of General Dynamics Corporation--airframe; Rocketdyne Division of North American Aviation, Inc.,--propulsion; General Electric Company and Burroughs Corporation--

radio-inertial guidance; American Bosch Arma Corporation--all-inertial guidance; and General Electric Company--nose cone. Convair is also the subsystem integrating and testing contractor for the ATLAS.

TITAN

The TITAN is the second ICBM under development by the Air Force and was originally designed as backup to the ATLAS weapon system. It is a two-stage missile with each stage containing a liquid fueled rocket propulsion system. The initial thrust during launch is provided by the first-stage engines which are shut down and jettisoned at some time during the powered flight. The second-stage engine is then scheduled to start and push the payload-carrying reentry vehicle on toward its destination. Upon completion of its job, the second stage is jettisoned, allowing the reentry vehicle to become free falling to its destination without power and guidance. The missile is approximately 97 feet in length, 10 feet in diameter, and weighs 221,000 pounds, with a range capability in excess of 6,000 nautical miles.

The Air Force originally planned to position and launch TITANs from installations on the ground's surface. However, the program has been modified to provide for positioning TITANs in underground launching sites (silos) and elevating the missile to ground level for launching. These underground launching sites, designed to provide maximum protection against enemy nuclear attack, are classified as hard-base sites. The Air Force is also planning the development of launching facilities capable of launching the TITAN from the below-ground silos.

The missile airframe is composed of a rigid tank section for structural integrity. The propulsion system is composed of 2 first-stage rocket engines capable of 300,000 pounds of thrust and a second-stage rocket engine with 80,000 pounds of thrust. Guidance in the early operational missiles will be radio-inertial; however, subsequent missiles will utilize an all-inertial system. The nose cone originally was to be a copper heat-sink but is now planned to be an ablation type for operational use.

Contractors engaged in the TITAN program include The Martin Company--airframe; Aerojet-General Corporation, a subsidiary of the General Tire and Rubber Company--propulsion; Bell Telephone Laboratories, Inc., and Remington Rand Univac Division of Sperry Rand Corporation--radio-inertial guidance; AC Spark Plug Division of General Motors Corporation--all-inertial guidance; AVCO Manufacturing Corporation--nose cone. The Martin Company is also the subsystem integrating and testing contractor for the TITAN.

IRBM

Early in 1955 consideration was given to the need for a shorter range missile that could be deployed on overseas bases and become operational at an earlier date than the ICBMs. In November 1955 the Department of Defense approved development of IRBMs designed to carry a thermonuclear warhead over a range of 300 to 1,500 nautical miles with an impact circular error probability of about 2 nautical miles.

This action followed a recommendation of the National Security Council stipulating a requirement for an IRBM with development on the highest national priority, provided that it did not interfere with the ICBM program.

Two IRBM programs were authorized. A land-based version, IRBM No. 1 (THOR), was assigned to the Air Force. IRBM No. 2 (JUPITER) was assigned to the Army and Navy jointly, having the dual objective of achieving an early shipboard capability and also providing a land-based alternate to the Air Force program.

The Army's Redstone Arsenal was initially assigned missile system responsibility and the Navy was assigned ship-launched weapon responsibility in the program. To meet the realization of an early operational capability, the development of a liquid propellant missile was undertaken by the Army as being the most expeditious method. The planned utilization of the JUPITER missile placed more exacting requirements upon the weapons system for adaptation to shipboard launching, such as compensation for a moving launcher, additional tail strength, higher take-off acceleration to insure that the missile would not hit the ship after firing, and a special guidance system having freedom in roll to allow the ship to take evasive action.

After a few months of study and research, the Navy decided that a liquid propellant IRBM would not meet its requirements. In the latter part of 1956 the Navy withdrew from the Army program and proceeded to develop a solid propellant IRBM, now known as the POLARIS.

Each of the services was engaged in the development of an IRBM during 1956. The Secretary of Defense assigned operational use of the ship-based IRBM to the Navy and operational control of land-based IRBMs to the Air Force in November 1956. The Army was allowed to continue development of the JUPITER pending further evaluation studies.

In August 1957 the Secretary of Defense appointed an ad hoc committee to critically evaluate the THOR and JUPITER programs. This was undertaken in an effort to decide which of the two was the better weapons system or how the two could be combined into a single missile system. This ad hoc committee was unable to agree on the selection of a single IRBM and, following the Soviet demonstration of missile strength in October-November 1957, the Secretary of Defense ordered both the THOR and the JUPITER missiles into production even though development of both missiles was still in progress.

THOR

The THOR is a single-stage intermediate range ballistic missile. The missile is approximately 65 feet in length, 8 feet in diameter, and weighs 110,000 pounds. It is designed for launching in a vertical position from above-ground launch sites. During flight, the reentry vehicle separates from the missile and becomes free falling to its destination.

The missile airframe is composed of a rigid tank section for structural integrity. The propulsion system is liquid fueled and is composed of a main engine capable of 150,000 pounds of thrust and two gimballed vernier engines of 1,000 pounds thrust each. Guidance is accomplished by an airborne all-inertial system. The missile utilizes a copper heat-sink nose cone.

The THOR IRBM is an outgrowth or a by-product of the ATLAS ICBM which was under development when the THOR program was initiated. The inertial guidance, nose cone, and propulsion systems from the ATLAS were utilized in the THOR in addition to many hardware components which were also shared.

The Ballistic Missile Division of the Air Research and Development Command is responsible for the development of the THOR weapons system. Contractors engaged in the THOR program include the Douglas Aircraft Company, Inc.--airframe; Rocketdyne Division of North American Aviation, Inc.--propulsion; AC Spark Plug Division of General Motors Corporation--guidance; and General Electric Company--nose cone. The Douglas Aircraft Company is also the subsystem integrating and testing contractor for the THOR.

An agreement to furnish United States IRBMs to the United Kingdom for use by British forces was consummated in February 1958. THOR missiles were deployed under this agreement beginning in September 1958, and a force of 4 squadrons consisting of 15 missiles each is being established. British units of the Royal Air Force have operational control of the THOR, but the nuclear warheads are in the custody of and controlled by the United States Air Force.

JUPITER

The JUPITER IRBM is an outgrowth or second generation of the Army's Redstone missile. It is approximately 60 feet in length and 9 feet in diameter and weighs 110,000 pounds. It is designed for launching in a vertical position from above-ground launch sites. Launching and separation of the reentry vehicle are similar to the THOR. Although present plans contemplate fixed launch emplacement, the Army has maintained that the weapons system is capable of a high degree of mobility.

The missile airframe is composed of a rigid tank section for structural integrity. The propulsion system is liquid fueled and is composed of a main engine of 150,000 pounds of thrust and one vernier engine of 500 pounds of thrust. Guidance is accomplished by an airborne all-inertial system and the missile utilizes an ablative-type nose cone.

The Army Ballistic Missile Agency (ABMA), established in February 1956, was responsible for development of the weapons system. Contractors engaged in the JUPITER program include Chrysler Corporation--airframe; Rocketdyne Division of North American Aviation, Inc.,--propulsion; Ford Instrument Division of Sperry Rand Corporation--guidance and control; Goodyear Aircraft Corporation--nose cone.

The JUPITER program provides for a total strength of three squadrons. It is reportedly in an operational status and is scheduled for deployment to allied countries.

FINDINGS

PLANNED OPERATIONAL DATE FOR ADVANCED TITAN SQUADRON WITH IMMEDIATE REACTION CAPABILITY AND OTHER OPERATIONAL ADVANTAGES HAS BEEN DELAYED 5 MONTHS EVIDENTLY DUE TO DELAY IN ADMINISTRATIVE DECISION TO INCORPORATE STORABLE FUELS

The planned operational date for the first TITAN squadron to be equipped with a substantially improved missile (hereinafter referred to as TITAN II) using storable liquid fuels and having the operational advantages of immediate reaction capability, greater reliability, inertial guidance, and less exposure to enemy attack has been postponed from October 1962 to March 1963, evidently due to delay in administrative decision to incorporate storable liquid fuels in the TITAN propulsion system. [redacted]

The Scientific Advisory Committee, Office of the Secretary of Defense, has strongly recommended since early in 1958 that storable liquid propellants be introduced in the TITAN program in replacement of the liquid cryogenics[1] propellants currently used, in order to simplify operations and to increase reliability. Following an extensive research and test program, the Air Force Ballistic Missile Division recommended to Headquarters, United States Air Force (USAF), in March 1959 that additional funds promptly be provided to equip the seventh and subsequent TITAN squadrons with storable fuels. The Strategic Air Command, assigned operational responsibility for this weapon, concurred with BMD's recommendation

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[1]Cryogenics are liquefied fuels and oxidizers which must be kept cooled to very low temperatures or carefully insulated because of the great rapidity with which they boil away at normal temperatures. (UNCLASSIFIED)

in April 1959, strongly urging that funds be provided in view of the expected advantages in performance, reliability, manpower, annual operating cost, growth potential, and simplicity. The views of these organizations received consideration at Headquarters, USAF, on May 3, 1959, in preparation for recommendations to the Secretary of the Air Force by May 30, 1959. However, the recommended change in the TITAN program was not approved until November 1959, at which time the planned operational date for the first squadron to be equipped with the advanced TITAN missile containing storable fuels and other operationally advantageous features was revised from October 1962 to March 1963. (SECRET)

The Air Force has refused to make available to us certain records covering the actions taken during the time period between March 1959, when the recommendation was made by BMD that storable fuels be introduced into the TITAN program, and late 1959, when this recommendation was adopted. Our limited review disclosed that a substantial amount of additional funds approximating $163 million was estimated by BMD as required to add storable fuels to the TITAN program, and we were told informally at Headquarters, USAF, that the major obstacle to the program change was the limited fund availability. However, a Department of Defense representative testified during congressional hearings in March 1960 that the additional cost of introducing storable fuels in the TITAN program would eventually be offset by savings in personnel, equipment, and maintenance costs. (UNCLASSIFIED)

The limited information made available to us did not disclose any justification for this delay in decision making. The delay in

(UNCLASSIFIED)

approval of the revised TITAN plan evidently did not cause any savings in costs but instead postponed incurrence of such costs for about 5 months. Had prompt decision been made to approve the recommendations of responsible scientific, technical, and operational organizations, it appears that the strategic advantages of immediate reaction capability, greater reliability, inertial guidance, and reduced exposure would be available sooner without any additional cost. (UNCLASSIFIED)

<u>Storable liquid propellants have significant advantages over propellants used in ATLAS, THOR, JUPITER, and TITAN missiles</u>

The liquid propulsion system utilized in the TITAN I, as well as the propulsion systems of the ATLAS, THOR, and JUPITER, is complex and has certain operational drawbacks which would be eliminated if storable liquid propellants were used. (UNCLASSIFIED)

A mixture of two liquid components is required in the propulsion systems: (1) the fuels and (2) the oxidizer, which supports combustion when in combination with the fuel. Liquid oxygen (LOX) is used as the oxidizer in the systems now employed. Liquid oxygen must be refrigerated as it has a low critical temperature and a high vapor pressure at nominal temperatures. Storage of LOX for extended intervals introduces severe complications; all equipment employed in handling and utilizing it must be scrupulously clean in order to avoid explosive reactions. Consequently, the missile launching area must have special facilities of a permanent nature, including on-site LOX generating plants. (UNCLASSIFIED)

Because of the damaging low temperature action of cryogenic fuels, TITAN I missiles cannot be kept in a fueled, ready state except for very short "hold" periods during the countdown. (~~CONFIDENTIAL~~)

Storable liquid (noncryogenic) propellants are reported to have significant advantages over the cryogenic liquid propellants. A storable (noncryogenic) propellant is defined as a liquid propellant which can remain in the missile tankage with the missile in a "ready-to-launch" condition for at least 1 year without maintenance. Many fuels are considered storable, but the number of attractive oxidizers considered storable is relatively small. Selection of the combination of fuel and oxidizer considered as comprising the optimum storable propellants depends on the extent of serviceability, reliability, economy, and performance desired to carry out the assigned mission.

The advantages ascribed to the use of storable propellants in the ballistic missile program include:

1. Decrease in reaction time[1] from 15 minutes to 30 seconds. Inasmuch as the total amount of time reportedly required for enemy ICBMs to reach this country is estimated at some 30 minutes, the 15-minute reaction time programed for the THOR, JUPITER, ATLAS, and TITAN I missiles allows only about 15 minutes for detection of the enemy launching, decision as to the action to be taken, and execution of the order. In view of the significance of such decisions, the opportunity to almost double the amount of time available for decision making would seem of crucial importance.

2. Increase in reliability of the missile system through elimination of certain steps in the operational cycle. For example, loading of storable propellants would be accomplished far in advance of the countdown and thus any problems which might arise during loading could be corrected without affecting the launching, whereas problems arising in the loading of cryogenic propellants during the countdown could nullify the launching. Similarly, elimination

[1]Reaction time is the elapsed time between the time the site operations officer receives the command to fire and the time the missile lifts off the launcher.

of the need for other equipment such as igniters, heaters, and rapid-fill valves also adds to the reliability of the system by reducing the possibility of error. Furthermore, the absence of extremely low temperatures and the absence of the need to dispose of boil-off vapors provide greater reliability for systems using storable fuels.

3. Savings through reduction of equipment and manpower requirements. On-site LOX generating plants would not be required and such equipment as igniters, heaters, and rapid-fill valves would be eliminated. This in turn would reduce personnel requirements, simplify logistic support, and cut future maintenance costs.

4. Higher performance than cryogenic propellants, such as an increase of 400 miles in the missile's range.

Storable liquid propellants are toxic and personnel will therefore be required to wear protective clothing. However, we understand that this is not considered to be an important handicap inasmuch as it has been successfully overcome in other weapon systems using corrosive chemical propellants, such as the CORPORAL, NIKE-AJAX, and BOMARC.

Storable liquid propellants also are reported to have certain advantages over solid propellants. As stated by the Assistant Secretary of the Air Force (Research and Development), during congressional hearings in February 1959:

> "The storable liquids in a rocket engine offer a better capability for response time, readiness, and minimizing logistic problems, than the cryogenic liquids. They are not so good as solid propellants from those points of view. On the other hand, they are better than solid propellants usually from the performance point of view. A general statement can be made that storable liquids offer better performance than solid propellants."

<u>Scientists recommended R&D effort on storable fuels beginning in August 1957</u>

In August 1957, the Bacher Panel, composed of a group of scientists assembled by the Air Force to review the progress of the ballistic missile program, recommended that research and development (R&D) be initiated in several areas in order to take advantage of possible improvements in first-generation ballistic missiles and to prepare for major changes in second-generation missiles. The Panel pointed out that failure to initiate research might result in delay and in much greater future costs. With respect to propulsion systems, the following comment was made:

> "For historically good and sufficient reasons the present Air Force Ballistic Missile effort is based wholly on liquid fuel systems with the attendant problems of cryogenics, propellant storage, and questionable reliability. The propulsion systems of Thor, Atlas, and Titan differ only as to engineering details. They duplicate each other in principle of operation. Some improvements in range and payload will result from engineering product improvements, but a real research effort is needed to realize major advances in operational characteristics of ballistic missiles. A propulsion system of improved simplicity and reliability is operationally essential. Considering the present state of the art, diversity in the principle of operation is also desirable. Accordingly, it is believed essential to initiate R. & D. work aimed at the acquisition of storable oxidizers for liquid propellant systems of high specific impulse."

<u>Program to replace nonstorable liquid propellants of TITAN with storable propellants recommended by Scientific Advisory Committee in January 1958</u>

In its report to the Secretary of Defense, dated January 31, 1958, the Scientific Advisory Committee suggested that a program be undertaken to replace the present nonstorable (cryogenic) liquid propellants of the TITAN with storable propellants, specifically recommending "a more vigorous exploitation of the potentialities of storable liquids."

This recommendation was brought to the attention of the Secretary of the Air Force by the Director of Guided Missiles, Office of the Secretary of Defense, on February 26, 1958, requesting that the Air Force "*** review the effort being carried on in storable liquid propellant R&D in view of providing a capability in the TITAN missile as early as feasible. ***." (UNCLASSIFIED)

Feasibility of utilizing storable propellants reported by propulsion contractor in February 1958

The contractor responsible for research, development, and production of propulsion systems for the TITAN released a report on February 15, 1958, concerning the potential use of storable propellants in the TITAN. The report stated that a study had been conducted to determine a storable propellant combination which would result in no missile payload or range penalties and minimum redesigning or modification of existing hardware. The study showed that storable propellants could be substituted for the liquid propellants in the TITAN, with equivalent missile performance and with minimum hardware modification and redesigning. (UNCLASSIFIED)

Further studies made by Air Force as to desirability and feasibility of incorporating storable fuels in TITAN system

On May 22, 1958, the Commander, BMD, advised Headquarters, USAF, that an extensive research and test program was under way to obtain a high performance combination of liquid fuels which have good stable combustion characteristics and are easily and safely handled and adapted to long-term storage. In addition, he advised that study was being made of the change which would be necessary to the TITAN system to convert it to the use of noncryogenic propellants. [redacted]

In August 1958, BMD advised Headquarters, USAF, that not enough information was known concerning storable fuels and

(UNCLASSIFIED)

recommended that additional studies be performed, advising that recommendations would be submitted in March 1959. (UNCLASSIFIED)

<u>Repeated recommendations by Scientific Advisory Committee for use of storable propellants in TITAN</u>

The Scientific Advisory Committee, for the Office of the Secretary of Defense, made repeated recommendations that storable propellants be incorporated in the TITAN missile. (UNCLASSIFIED)

In its March 15, 1958, report, the Committee commented, in part, as follows:

> "With regard to the incorporation of storable propellants in the TITAN missile, the Committee recommends that the Air Force be directed to provide immediately for the development of the components required for this purpose. The propellants should be selected on the basis of minimum modification to the present component design, and the objective should be the earliest possible deployment of storable propellant TITANS in hard bases. However, the currently-planned LOX-JP[1] components should be continued in development, and provision for cryogenic propellants at the initial hard-base installation should continue to be incorporated until sufficient confidence has been acquired in the new components to permit dropping the cryogenic components from the program. The development status of the storable liquid power plant should be followed closely so that a decision may be made as early as possible relative to eliminating the LOX-JP TITAN power plant." [redacted]

The next report of the Committee, dated May 21, 1958, reaffirmed this position, stating that liquid propellant engines for the TITAN test program should continue to be produced but product improvement funds should be reassigned to the storable propellant program. (UNCLASSIFIED)

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[1]LOX-JP is the abbreviation for liquid oxygen-jet propulsion. (UNCLASSIFIED)

The September 25, 1958, report of the Committee stated that:

> "(4) It is presently planned that a decision regarding the replacement of LOX-JP with storable propellants will be made early in 1959 as a result of studies and experiments now being actively pursued." [redacted]

The January 14, 1959, report of the Committee, referring to the studies in process on replacement of liquid propellants with storable propellants, stated that: "The potential importance of a switch to such propellants seems even greater now than it did some months ago." (UNCLASSIFIED)

The March 31, 1959, Committee report recommended that the Air Force modify the TITAN development program promptly to incorporate storable fuels and "that a schedule be established to provide missiles with storable propellants to the fifth operational squadron instead of to the seventh operational squadron at a later date." However, as explained subsequently in this report, this recommendation was revised to apply the change to the seventh operational squadron based on a proposal by BMD to retain essentially the initial TITAN configuration for the first six squadrons, and then introduce a number of major modifications with the seventh squadron. (UNCLASSIFIED)

The May 29, 1959, report of the Committee stated, in part, as follows:

> "<u>STORABLE LIQUID PROPELLANTS</u>
>
> "The Committee in several recent reports has made strong recommendations relative to an acceleration of the development and application of storable liquid propellants. At the current meeting the Army Ordnance Missile Command presented plans and proposals for intensive efforts in this field. The Committee endorses increased effort in this field but reiterates its strong belief that the most urgent and important application of storables is to the TITAN missile. Immediate authorization

(UNCLASSIFIED)

> and funding are essential if the introduction of storable liquid propellants into the seventh and succeeding TITAN squadrons (as appears highly desirable) is to be accomplished." (UNCLASSIFIED)

<u>BMD recommended in March 1959 that storable liquid propellants be introduced in TITAN program</u>

By March 1959, BMD had satisfied itself that introduction of storable propellants in the TITAN was not only feasible but desirable. Briefings were presented by BMD at Headquarters, USAF, on March 25, 1959, recommending that a program to provide noncryogenic propulsion in the TITAN be approved. The briefing charts showed that the improved TITAN system incorporating storable fuels could be operationally available by October 1962. (SECRET)

As stated previously, the Scientific Advisory Committee recommended in March 1959 that "a schedule be established to provide missiles with storable propellants to the fifth operational squadron instead of to the seventh operational squadron at a later date." As explained in the March 31, 1959, report of the Scientific Advisory Committee:

> "Subsequent to the preparation of the above report three Committee members (Bode, Kistiakowsky, and Millikan) spent three days (April 1-3) at Martin-Denver and the Ballistic Missiles Division discussing in detail the TITAN program. Two additional Committee members (Hyland and McRae) participated in the discussion on April 3. The group was informed of a proposal to retain essentially the initial TITAN configuration for the first six squadrons, and then introduce a number of major modifications with the seventh squadron. These modifications would include inertial guidance, in-silo launch, and storable non-cryogenic propellants. Although the group still believes strongly in the desirability of changing TITAN to storable propellants at the earliest possible date, it was convinced that the proposed plan of including this change with the other major modifications in the seventh squadron is probably the most desirable one from an over-all point of view. Accordingly, this group

> would alter the Committee's earlier recommendation in this respect. It is believed that the other Committee members would, in the light of the information given the smaller group, also concur in this change." [redacted]

At that time (April 1959) the fifth TITAN squadron was scheduled to be operational in June 1962 and the seventh squadron was scheduled to be operational in October 1962. Thus, the Scientific Advisory Committee evidently felt that a delay of 4 months was warranted in view of the related benefits that would be obtained. [redacted]

<u>Strategic Air Command recommended in April 1959 that storable fuels be incorporated in TITAN program as soon as possible and that other SAC weapons systems not be cut back to provide funds for this change</u>

Following the briefings at Headquarters, USAF, on March 25, 1959, at which BMD recommended that a program to provide storable fuels in the TITAN be approved, the Vice Chief of Staff directed SAC on April 7, 1959, to submit its recommendation on this matter. SAC was instructed, in the event it recommended that storables be incorporated in the TITAN program, to "cite those programs of lesser priority which could be cut back in order to fund such a proposal." The Vice Chief of Staff also directed the Deputy Chief of Staff (Operations) that the SAC recommendation on storable fuels should be presented to the Air Council through the Air Force Weapons Board so that recommendation could be made to the Secretary of the Air Force by May 30, 1959. (UNCLASSIFIED)

In reply dated April 23, 1959, the Commander in Chief, SAC, recommended that storable fuels "be incorporated in the TITAN weapon system at the earliest possible date." He stated that: (UNCLASSIFIED)

> "It is understood that many questions remain to be answered prior to the attainment of a full operational capability with non-cryogenics. However, the potentially great payoff in the areas of performance, reliability, manpower, annual operating cost, growth potential, and simplicity dictate that the non-cryogenics program must be funded. This decision will stand on its own merit. *** SAC does not concur that lesser priority SAC weapon systems should be reduced in scope to provide these funds." (UNCLASSIFIED)

Further briefings were held at Headquarters, USAF, in April and May 1959 as to the desirability of providing storable propellants in the TITAN program. These briefings, along with the March 1959 briefing, pointed out the numerous operational benefits to be derived by using storable fuels, as well as advantages in space programs, and pointed out that it would not be possible to fund this change through use of funds already programed for ballistic missiles. The briefings reported that the incremental cost of the research and development for this program change would be $199 million for the last 5 squadrons of the 11 squadrons then planned, less minimum savings of $7.2 million per squadron, or a net cost of $163 million. Additional savings of an unspecified amount also were expected through manpower reductions of at least 46 men per squadron, lower operational costs, and savings in the training area. These briefings showed that the revised TITAN system could be operationally available by October 1962 and recommended that additional funds be requested from the Office of the Secretary of Defense to introduce storable funds in the seventh and subsequent squadrons. ~~(SECRET)~~

Approval of program to include storable propellants in TITAN program in November 1959, accompanied by delay in planned operational dates

Prior to November 1959 the approved TITAN development plan provided for 11 squadrons. The 7th through the 11th squadrons were planned to be dispersed in a new 1x9 configuration presenting 9 aiming points to the enemy and to be equipped with the TITAN I missile which would use an in-silo launcher, an inertial guidance, and cryogenic fuels. (UNCLASSIFIED)

In October 1959, Headquarters, USAF, requested that a development plan be prepared providing for operational activation of 14 squadrons. Headquarters, USAF, directed that the 7th through 14th squadrons be equipped with storable propellants and all-inertial guidance, deployed in a new configuration, and capable of being launched underground. (UNCLASSIFIED)

The new TITAN development plan was approved in November 1959. Air Force records show that the planned operational dates for the 7th through the 14th squadrons were set back in conjunction with the change in program as follows: [redacted]

	TITAN squadron No.		Planned operational activation dates: Prior to November 1959	Planned operational activation dates: November 1959
	1		June 1961	August 1961
	2		November 1961	December 1961
	3		February 1962	February 1962
	4		April 1962	April 1962
	5		June 1962	June 1962
	6		August 1962	August 1962
Equipped with advanced TITAN missile	7		October 1962	March 1963
Equipped with advanced TITAN missile	8		December 1962	May 1963
Equipped with advanced TITAN missile	9		February 1963	July 1963
Equipped with advanced TITAN missile	10		April 1963	August 1963
Equipped with advanced TITAN missile	11		May 1963	October 1963
Equipped with advanced TITAN missile	12	(These were not programed previously)	-	November 1963
Equipped with advanced TITAN missile	13	(These were not programed previously)	-	January 1964
Equipped with advanced TITAN missile	14	(These were not programed previously)	-	February 1964

Thus, prior to the November 1959 revision in the TITAN development plan, the planned operational activation date for TITAN missiles equipped with all-inertial guidance, using the in-silo launcher, and dispersed in a less vulnerable configuration was October 1962. The only additional technical feature introduced in the TITAN program when the operational activation dates for the 7th through 11th squadrons were postponed was storable fuels. [redacted]

<u>Air Force refusal to furnish records of actions taken leading to decision to incorporate storable fuels in TITAN program</u>

In view of the apparent delay in implementing the recommendations that storable fuels be introduced into the TITAN program, we inquired in June 1959 as to the action being taken by the Air Force in this matter. We were informed that this matter was under consideration by the Air Force Ballistic Missile Committee and, therefore, could not be made available to us. We were told that the major obstacle to such a program change was limited fund availability arising from budgetary considerations. (UNCLASSIFIED)

As stated previously, the TITAN program was revised in November 1959 to provide for introduction of storable propellants in the seventh squadron. We subsequently requested access to the records showing the actions taken between the dates of the recommendations in March to May 1959 that storable fuels be included in the TITAN program, and the adoption of this recommendation in November 1959. We were informed that several of the documents involved were considered to be of a privileged nature and therefore were not available to us. The records denied to us include minutes of

(UNCLASSIFIED)

the Air Force Ballistic Missiles Committee[1] and minutes of the Air Force Weapons Board[2] which advises the Chief of Staff, through the Air Force Council,[3] on all matters concerning weapons systems. (UNCLASSIFIED)

We discussed this matter in August 1960 with the Secretary of the Air Force Ballistic Missiles Committee, who had been designated as the individual from whom we could obtain authoritative information on the ballistic missile program. We pointed out that, based on the information made available to us, both the Ballistic Missile Division and the Strategic Air Command had been firmly convinced by April 1959 that introduction of storable propellants in the TITAN program was advisable and that squadrons equipped with TITAN missiles using storable fuels could be operational by October 1962. We pointed out further that, when this recommendation was approved late in October 1959 and the formal development plan was approved in November 1959, the operational activation date was changed to March 1963 and, therefore, the only logical conclusion from the information made available to us is that the [redacted]

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[1]The Air Force Ballistic Missile Committee is composed of the Assistant Secretaries for Research and Development, Financial Management, and Materiel and the Assistant Chief of Staff for Guided Missiles and is chaired by the Secretary of the Air Force. (UNCLASSIFIED)

[2]The Air Force Weapons Board is an advisory body providing a formal method for applying the collective judgment and experience of senior Air Staff officers in the selection and/or management of weapons systems, support systems, and advanced systems. (UNCLASSIFIED)

[3]The Air Force Council is composed of the Vice Chief of Staff, the Deputy Chiefs of Staff, and the Inspector General, USAF. (UNCLASSIFIED)

delay in approving the recommendation was responsible for the delay in the planned activation date. We commented to the Air Force representative that it was obvious that a program change involving some $163 million would require deliberation, but nevertheless, in view of the top priority of the program and the significant operational advantages to be gained, the delay seemed questionable. The Air Force representative made no comment with respect to this matter and offered no explanation of the delay. [redacted]

Agency comments and our conclusions

The Air Force comments on our revised draft of the report did not furnish any specific information or documentation. The Air Force reply contends that, in criticizing the time required for reaching the decision to introduce storable propellants in the TITAN program, we "exhibit an unawareness of the magnitude of the issues [the Air Force] faced, not only in relation to TITAN itself, but as concerns the total pattern of our strategic deterrent forces." (UNCLASSIFIED)

The limited information made available to us did not disclose any justification for the delay in the decision to revise the TITAN program to include storable liquid propellants. We recognize that the proposed expenditure of some $163 million requires careful consideration before it can be approved. However, in view of the top priority assigned to the intercontinental ballistic missile program in the defense of this Nation, it would appear that immediate action should have been taken to provide for obtaining this military capability as soon as responsible scientific, technical, and operational organizations had made sufficient tests to

(UNCLASSIFIED)

determine that adoption of this plan was feasible and advisable. This decision was reached by April 1959, but the revised program was not approved until November 1959, evidently causing the planned activation date for the first squadron with storable liquid fuels and other important operational features to be postponed 5 months.

While authorization for expenditure of a substantial sum was necessary in order to add storable liquid fuels to the TITAN program, a Department of Defense representative testified during hearings in March 1960 before a subcommittee of the Committee on Appropriations, House of Representatives, that the additional cost of the storable fuels would be recovered "in a matter of some years of operation" through savings in base installation costs, operation, and maintenance. Information made available to us contained no evidence that the delay in decision making will result in any savings in costs. Instead, the delay merely postponed the costs for about 5 months. If prompt action had been taken to approve the recommendations made by responsible organizations in March and April 1959 instead of deferring this decision to November 1959, the strategic advantages of immediate reaction capability, greater reliability, inertial guidance, and reduced exposure probably would be available some 5 months sooner without additional cost.

UNWARRANTED DELAY IN PROVIDING
VITALLY IMPORTANT CAPTIVE TEST FACILITIES
FOR THE THOR DEVELOPMENT PROGRAM

The military departments have emphasized the need in ballistic missile programs to captive test missiles on the ground prior to flight tests in order to minimize the possibility of failures and to conserve costs. Inasmuch as the construction and equipping of captive test stands require a considerable amount of time and since captive testing of a complete assembled missile cannot be accomplished without the captive or static test stands, appropriate action is necessary to arrange for availability of such facilities in sufficient time to enable desirable captive tests prior to flight testing. However, availability of these test stands for the THOR program was delayed 10 months due in part to prolonged negotiations as to whether the Air Force or the contractor would finance the cost of facilities in excess of the amount originally contemplated by the contractor. The necessity for and the appropriateness of the delay in obtaining facilities are particularly questionable in view of the fact that the Air Force would have absorbed a substantial part of the cost of these facilities even if the contractor had financed them.

As described subsequently in this report, unfavorable results occurred in the flight testing prior to the first captive test of an assembled THOR. In view of the importance of captive testing, it is evident that the THOR development program would have been further advanced and substantial costs far in excess of the cost of the captive test facilities would have been avoided if appropriate steps had been taken promptly by the Air Force for construction and equipping of required captive test facilities.

Importance of captive testing of missiles
prior to flight tests
emphasized by Air Force and R-W/STL

Captive testing involves an operation in which the complete airborne system is erected on a test stand and prepared and checked out, the rocket engines are ignited, full thrust is built up, and all the various subsystems are operated in a manner and in a sequence approximating as closely as possible that encountered in a flight.

The importance of captive testing is brought out in the Air Force Ballistic Missile Development Plan, quoting the following statement by the Commander, ARDC, in March 1955:

> "Guided missiles are highly complex systems comprising many complex subsystems, the failure of any of which results in failure of the entire missile. All these systems are in series as regards the overall reliability. No flight test of a manned aircraft is contemplated prior to an exhaustive series of static and dynamic tests of components, subsystems, and the complete system. Because of the fact that no modification or fix can be made in flight, it is necessary that even more exhaustive and comprehensive test be conducted on components, subsystems, and systems for guided missiles, particularly rocket ballistic missiles. Further, in the field of rocket ballistic missiles, the thrust developed is very high and the duration of powered flight is very short, so that full-scale captive testing becomes very important and necessary. Flight tests with expensive missiles cannot be justified until reasonable assurance of success has been obtained from captive operations of the complete weapon systems.
>
> "The present practice of relying primarily on flight testing has been demonstrated to be incapable of providing the necessary data on which to base needed improvements in missile design. Simulation of potential difficulties and the development of reliability must be done on the ground prior and in addition to flight testing. This must be done by extensive and exhaustive laboratory, bench, simulation, and full-scale testing of each component, subsytem and system. It is in this connection that the utility of full-scale testing under

captive conditions becomes apparent. It is contemplated that through use of a suitable test stand, subsystems can progressively be added to the basic propulsion unit until the complete integrated system is tested. While it is recognized that this does not provide complete simulation of free flight, by careful planning, it can be used to eliminate many possible causes of potential failure for later flight tests.

* * * * *

"On the basis of this inspection of the factors involved, certain conclusions are apparent.

"a. Primary dependence on flight testing for rocket ballistic missiles is inadequate and extremely expensive.

"b. A comprehensive ground test program is a prerequisite to flight testing of rocket ballistic weapons.

"(1) Captive testing can be effective and economical.

"(2) The cost of missiles lost in flight test through inadequate pre-flight testing can greatly exceed the cost of facilities required for a comprehensive ground test program.

"(3) The ground test program should include program insurance and growth potential."

The advantages of captive testing over flight testing have also been described by a representative of R-W/STL, the Air Force contractor for the systems engineering and technical direction of the ballistic missile program, as follows:

"Captive testing allows for extensive system development in the integration of the various subsystems by means of a simulated flight sequence for the entire missile. In addition, a completely realistic reproduction of the flight operation up to actual lift-off is created, which makes possible significant results in the support systems area. As a special development tool, captive testing has definite advantages compared with flight testing, such as better controlled conditions and instrumentation. Rather than a test failure leading to total loss, as in flight, there is generally the chance for repair and reuse of the missile and equipment. Another major advantage of captive testing is the flexibility of rescheduling and the quantity of testing possible as compared with flight test.

"The fundamental limitation of such captive testing is, of course, the absence of effects associated with the missile's motion through space. With regard to simulation of the vibration environment for airborne equipment, this may still be of a quality and magnitude so as to represent meaningful vibration testing, even though not exactly the same as for flight. Also, captive testing is directly applicable to many problems of subsystem interaction simply because of its basic ground on laboratory test nature and not because of flight simulation features.

"To sum up, the salient feature of an effective captive test program is that it accomplishes a large part of the development test effort under well controlled engineering laboratory conditions and frees the flight test program for investigation of true flight problems."

Availability of captive test facilities delayed 10 months due in part to prolonged negotiations as to whether Air Force or contractor would finance cost of facilities exceeding contractor's estimate, much of which cost would have been absorbed by the Air Force even if financed initially by the contractor

The first captive test stand for the THOR program was scheduled in the original Air Force plan of November 18, 1955, to be available in March 1957. However, this stand was not available until January 1958. The 10-month delay in availability of facilities was caused, in part, by extensive negotiations between the Air Force and the airframe contractor as to which would finance the cost of constructing the facilities. As a result, the first captive firing which had been scheduled for May 1957, 2 months before the initial planned flight attempt, was not accomplished until May 1958.

Prolonged negotiations prior to award of architect-engineering contract

The initial development plan prepared in November 1955 by the Air Force with the assistance of its systems engineer and technical director, R-W/STL, provided for four captive test stands and one battleship test stand for the THOR program. Two of the captive stands and the battleship stand were indicated as contractor facilities; the remaining two captive stands were to be located at an unidentified Air Force base. The Air Force did not inform the three airframe contractors that were being considered for the THOR development contract of the facility requirements included in the development plan, inasmuch as the Air Force wanted to obtain their independent estimates. However, the Air Force specified that launch facilities and assembly buildings at the Air Force Missile Test Center (AFMTC) would be Government furnished.

Proposals submitted by these contractors on December 8, 1955, differed widely with respect to captive test facilities. One contractor proposed to do initial captive testing on the launch stand at the Air Force Missile Test Center, Cape Canaveral, Florida, with later requirements for an unspecified number of Government-furnished hot-firing sites at Santa Susana, California. Another contractor proposed a 3-stand complex in the Sacramento area at an estimated cost of $14 million, of which the contractor would finance $2 million and the Government $12 million. The third contractor orally advised that it would supply "all required facilities to do the job," and its written proposal stated as follows with respect to facilities:

> "All facilities required for the accomplishment of this project are now available except a rocket static test site. This latter will be available in Southern California for continued work on the project after about 1 January 1957. ***."

The THOR Evaluation Board, in commenting on the facility proposals, pointed out that:

> "One of the key factors in a crash program is the ability of the contractor and the government to furnish facilities. This applies not only to those facilities spelled out by the various companies, but also to those additional facilities that are known to be necessary as a result of previous WDD(BMD) experience."

The proposal of the third contractor was considered by the Board to be the most attractive facilities proposal for the Air Force and more definite and all inclusive than facility proposals of the other two contractors. On December 13, 1955, the Board rated this contractor first in order of preference, after consideration of various factors including the facilities proposal. On the following day, the contractor and BMD officials held a conference to clarify the statements made by the contractor concerning facilities. After an enumeration by the Air Force representatives of the type of facilities required which included battleship test stand, associated supporting and land facilities, static stands, and launch stands at the launch facility, the contractor advised the Air Force that only certain of these items would be furnished, "including a test stand (probably a dual-position stand)," all at an estimated cost to the Air Force of $1,500,000 to $2,000,000. Although this statement was inconsistent with the previous proposal, it was accepted by BMD officials with the qualification that "if the Air Force requires extensive testing in excess of that envisioned by [the contractor], additional facilities will have to be provided in some fashion." The extent of testing envisioned by the contractor was not indicated in the record of the meeting.

In a meeting at Headquarters, USAF, on December 23, 1955, attended by the Deputy Secretary, Assistant Secretary (Research and Development), and others, the selection of the airframe contractor for the THOR program was considered and certain limitations of expenditures were discussed. Decision was made at this meeting to select the contractor recommended by the Evaluation Board but to observe the following limitations:

> "a. That the fund limitations to the program be held at $4 million to begin with.
>
> "b. That the Air Force would prepare a letter contract with [the contractor] within the next 90 days.
>
> "c. That we were not to let the contractor know that we had made the $4 million limitation at this point.
>
> "d. That the program was to be planned so that there would not be any extensive industrial facilities planned or provided by this company. The holding back of this contractor in the building of back-yard type facilities[1] should be continued until the contractor lets the Air Force know that he is strapped and that his program was being delayed from lack of these facilities, at which time the Air Force would consider these requirements and make the appropriate decisions.
>
> "e. We were not to advise the contractor of the above facts other than to let him know that we are negotiating this letter contract within the next 90 days."

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[1]A backyard facility is a local proving ground test facility for use by a missile airframe contractor in missile system checkout and static firing.

The letter contract for the THOR weapon system development, dated December 27, 1955, provided as follows with respect to the facilities to be furnished by the contractor:

> "With the exception of tooling peculiar to the IRBM, and facilities at Air Force test stations, the contractor shall provide all facilities for this program. It is recognized that this agreement is based upon the program envisioned in the Contractor's proposal of 8 December 1955. Should the Air Force require extensive testing in excess of that proposed by the contractor, any additional facilities required will be negotiated. ***."

On January 3, 1956, the contractor contacted another firm to initiate engineering services for flight test stands at Patrick Air Force Base and a propulsion test facility at Edwards Air Force Base. A subcontract for this work was awarded to this firm on February 17, 1956. As provided in the letter contract, the Air Force was responsible for the cost of this work.

The contractor also initiated an arrangement with the same firm in January 1956 to lease land at Sacramento, California, for construction of captive test facilities. However, the contractor did not request a proposal for design of the proposed facilities pending further discussions with the Air Force during March 1956 as to whether the Air Force or the contractor would finance the cost of facilities exceeding the amount contemplated by the contractor, as previously discussed with the Air Force on December 14, 1955. During the March discussions, the Air Force pointed out that a single-position stand was necessary, in addition to the dual-position stand planned by the contractor, in order to avoid disruption of the program if the dual-position stand was damaged extensively during the tests. A cost-sharing agreement was orally made whereby the contractor would furnish nonseverable items[1] for the two stands and the Air Force would furnish the severable items with a unit value in excess of $500.

On April 9, 1956, the contractor requested a proposal from the architect-engineering firm for design of the proposed facilities. On May 3, 1956, the contractor advised the Air Force, by letter, that it would supply the two firing pads, control and assembly buildings, roads, and general utility items if the Air Force would provide the tooling, test equipment, and handling equipment, including servicing towers and propellant servicing and pumping equipment. On the same date, the architect-engineering firm submitted its proposal covering design of two stands, and the subcontract was awarded to it on May 14, 1956.

Thus, in the case of facilities to be located at Air Force installations where the Air Force had accepted responsibility for the cost of constructing and equipping the facilities, the contractor awarded a subcontract for engineering services on February 17, 1956. However, the subcontract for design of captive test stands to be located on contractor property was not awarded until 3 months later, after agreement had been reached that the Air Force would finance a portion of the cost. The Air Force states that the major factor in the delay in awarding the subcontract was the time required to determine specific design criteria applicable to the

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[1] A facility item will be considered "nonseverable" when, upon removal, its loss of value plus damage to the premises where installed may reasonably be anticipated to exceed 50 percent of the installed cost of the facility item (AFPI 13-406 b).

test facility. However, the award of the subcontract was made much more quickly for work at Air Force bases where financing was the responsibility of the Air Force, and it seems reasonable to conclude that the subcontract for engineering services for the test stands to be located on contractor property would have been awarded earlier had the Air Force agreed to finance the costs for facilities in excess of those originally proposed by the contractor.

<u>Delay in procurement of long-leadtime equipment for captive test facilities</u>

The contractor's planning report, dated April 9, 1956, included the following facility implementation schedule for THOR test facilities at Sacramento:

> "In order to properly support the DM-18 development test program, the most accelerated facility implementation procedure is needed. The following construction schedules indicate the calendar time allotted for the design, procurement, construction, fabrication and installation for the captive firing test area.
>
> "1. Preliminary design ***
> Begin 21 May, 1956 - Finish 20 July 1956
> "2. Detail design ***
> Begin approximately 6 August 1956 -
> Finish approximately 2 November 1956
> "3. Construction time including procurement, fabrication and installation.
> Begin 27 August 1956 - Finish 28 December 1956
>
> "Notes:
> "1. Construction finish date of 28 December 1956 is to be considered firm."

The notice of award to the subcontractor required that specifications and bidding documents for all material and equipment which must be ordered would be furnished to the contractor not later than July 1, 1956. The bidding and specification documents were completed and forwarded to the contractor on June 17, 1956. The documents provided procurement specifications for long-leadtime items which had to be ordered by an estimated date ranging from 8 weeks to over 6 months in advance of the date required. Thus, prompt procurement action was needed if the required completion date of December 28, 1956, was to be met.

The contractor submitted to the Air Force formal application dated July 18, 1956, for Government-furnished facilities, amounting to $1,305,528, to be located at Sacramento. This application included the long-leadtime type of items on which specifications had been furnished by the subcontractor. The Air Force considered certain of these items, amounting to $252,530, to be nonseverable and, therefore, not to be furnished by the Air Force under existing procurement regulations. The contractor was so advised. Correspondence and discussions between the contractor and the Air Force concerning financial responsibility for these facilities continued during the months of July, August, September, and October 1956.

The Air Force proposed the following alternatives to resolve the problem:

1. That the contractor purchase the nonseverable items. (Had the contractor paid for these items, a substantial portion of the $252,530 cost would have been chargeable to the Government as amortization under the contract.)

2. That Air Force purchase the items if the contractor would agree to buy them upon termination of the contract at a depreciated value. An 80 percent depreciation over a period of 6 years was offered to the contractor, with items to retain a residual value of 20 percent after that time.

3. That the contractor refuse, in writing, to purchase the items.

The contractor refused to purchase the nonseverable items for the reasons that the items would be of no value to it upon completion of the contract, that there was no assurance that the contract would continue for a 6-year period, and that the contractor would be required to contribute $3 million in capital items or twice the amount originally estimated at the time of the award of the supply contract.

On November 2, 1956, the Air Force executed a "finding and determination" under the provision of section 13.406.1(c) of the Armed Services Procurement Regulation, "that it is in the interests of national defense" that the nonseverable facilities be provided on contractor-controlled land, with the Government retaining the right to remove such of the facilities as it elects and to abandon the remainder without obligation in either event to restore the premises to their original condition. Contract AF 33(600)-33941, authorizing the furnishing of facilities in support of the THOR program in the amount of $1,305,528, including the $252,530 for nonseverable facilities, was approved by the Air Force on December 18, 1956.

As shown in the following extracts from the contractor's technical reports, the contractor did not order the long-leadtime items identified by the architect-engineer in June 1956 as being necessary for these facilities until the negotiations for the facilities contract were completed and the contract was approved, and as a result schedule slippages occurred.

October 1956 - "At this time, advance procurement of long-lead time, hardware components of the LOX and fuel and high pressure gas systems could not be accomplished because a USAF Facilities Contract was still under negotiation."

December 1956 - "Final negotiations were completed on the USAF Facilities Contract for Sacramento and Air Force approval was received late in December. This approval will permit advance procurement of long-lead time hardware components of the LOX, fuel and gas systems."

January 1957 - "Some delay is anticipated with the LOX, fuel and high-pressure gas systems because of late approval of the USAF Facilities Contract. The subcontractor for these items is now preparing a procurement schedule for the necessary hardware components."

January to June 1957 - "A major problem area developed with the LOX, fuel, and high pressure gas systems because of late approval of the USAF facilities contract. Due to the short lead-time, procurement difficulties delayed the acquisition of the LOX storage tank and the high-pressure helium compressor. As a relief measure, [the contractor] leased these items for temporary use. As of 30 June, installation of temporary equipment had progressed sufficiently to indicate that it would be operational late in July."

July to December 1957 - "Dual Position Stand
* * * Battleship liquid oxygen and fuel tanks were received in November, * * * The liquid oxygen and fuel systems are being held up for lack of * * * valves."

"Single Position Stand
* * * Checkout of deluge water and nozzles was completed in December, and the fuel system and high pressure gas systems check begun. The liquid oxygen system check will begin in January."

The single-position stand was completed in January 1958 and captive test firing was then started. The first full-duration firing was accomplished in May 1958,[1] a year later than the goal established in the Air Force Ballistic Missile Development Plan of November 1955, and almost 1-1/2 years after the start of the flight test program.

As stated previously, the architect-engineer had provided the contractor on June 17, 1956, with procurement specifications for long-leadtime items which had to be ordered 8 weeks to more than 6 months in advance of the date required to assure availability when needed. However, such items, including components of the liquid oxygen, fuel, and high-pressure gas systems, were not ordered until the facilities contract was approved in December 1956, and they generally were received in the range of 4 weeks to about 7 months. Thus the delay in ordering the long-leadtime equipment was a significant factor in the slippage in completion of the facilities.

Conclusion

In view of the expressed importance of captive testing and the knowledge in December 1955 that the facilities proposed by the contractor did not meet anticipated Air Force development requirements, the failure of the Air Force to arrange for establishment

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[1]A full-duration captive firing of a missile was accomplished at Edwards Air Force Base in March 1958. However, primary objectives of this firing were chiefly concerned with a check of the facility operation. According to contractor reports, captive firing at this location of a complete missile for test purposes was not started until June 1958.

of needed facilities for captive testing in sufficient time to precede flight testing appears unjustified.

As pointed out in the Air Force ballistic missile development plan, utilization of captive testing could "*** eliminate many possible causes of potential failure for later flight tests ***." It therefore seems likely that the program would have been further advanced if captive test facilities had been provided as promptly as possible.

As described in the following section of this report, a number of THOR missiles were lost or destroyed in flight attempts prior to captive testing. Although these failures cannot be directly attributed to the lack of captive test facilities, it seems reasonable to conclude that losses would have been reduced and in all likelihood the monetary savings--apart from the advantages gained in the advancement of the program--would have exceeded the cost of the facilities. In addition, the necessity and appropriateness of the delay in obtaining the captive test facilities is particularly questionable in view of the fact that the Air Force would have absorbed a substantial part of the cost of the facilities even if the contractor had financed them.

DUE TO ABOVE DELAY IN PROVIDING CAPTIVE TEST FACILITIES AND ACCELERATION OF FLIGHT TEST SCHEDULE, FLIGHT TESTING OF THOR DEVELOPMENT MISSILES WAS ATTEMPTED MORE THAN YEAR PRIOR TO CAPTIVE TESTING WITH UNFAVORABLE RESULTS

Under the original Air Force Ballistic Missile Development Plan for the IRBM program, flight testing, which was on a "maximum risk" basis, was not to begin until 2 months after completion of the first captive test of an assembled ballistic missile, thereby enabling the use of captive test results insofar as possible in preparing for flight tests. However, as shown in the preceding section of this report, availability of vitally important captive test facilities for the THOR program was unnecessarily delayed and did not become available until 10 months after the date scheduled in the Air Force Ballistic Missile Development Plan. Also, the flight test program itself was accelerated 7 months. As a consequence of the delay in providing facilities and the acceleration of flight testing, the flight testing of THOR development missiles was attempted more than 1 year prior to the captive testing of an assembled missile, instead of 2 months thereafter, and unfavorable results were experienced. By contrast, during the same period, the Army captive tested every assembled JUPITER missile before flight testing, and more favorable flight test results were achieved.

THOR program originally established on a "maximum risk" basis providing for flight testing of a minimum reliable missile to start 2 months after captive testing, so that captive test results could be utilized in flight test preparations

The initial Air Force plan for development of a medium-range ballistic missile, subsequently designated the THOR IRBM, was prepared by BMD with the technical assistance of R-W, based on the experience gained in the ICBM program, and was forwarded to Headquarters, USAF, for approval on November 18, 1955. This plan pointed out that a "maximum risk program" would be necessary to obtain the missiles within the required time scale. The plan defined a "maximum risk program," as follows:

> "A risk program is one in which, in the interests of early demonstrations, the date of attainment of an eventual, highly reliable operational capability is delayed. A maximum risk program is one in which a minimum requirement is set for the performance of the missiles first flown, and a minimum requirement is set on the reliability of the missiles first flown, in order to insure the earliest possible demonstrations of such a minimum performance vehicle. Obviously, if a risk program could be carried out with no delay in the date of eventual attainment of a reliable, completely operational capability, then that program does not deserve the adjective 'risk,' but is instead merely a logical, optimum program for the attainment of the end objective. By definition, the very use of the word 'risk' implies willingness to compromise the attainment of the end objective for some sort of early demonstration. It also implies that the early demonstration is planned and carried off with considerable degree of uncertainty as to the success of the demonstrations. A risk program is one in which demonstrations are attempted with less backing in the sense of partial, preparatory debugging and reliability testing carried out before the demonstration. When a maximum risk program is agreed upon, it implies that it is better to accept the calculated risk of failure in demonstration than to have that same interim period pass with no demonstration. A maximum risk program directive implies that the urgency in the demonstration of a compromised performance has a higher priority than the urgency in having an eventual, reliable, complete operational capability."

The plan commented that "extremely limited time will exist for the creation of special captive test facilities in time to precede the first flight in the above program." The need for such captive tests had been pointed out previously by the Air Force, stating that "flight tests with expensive missiles cannot be justified until reasonable assurance of success has been obtained from captive operations of the complete weapon system." (See p. 38 of this report.)

The schedules accompanying the initial development plan showed "maximum risk" objective target dates, with tests on captive test stand beginning in March 1957 and captive firing starting May 1957, while the first flight test was to be in July 1957.

<u>Flight test schedule further accelerated 7 months based on contractors' proposals, thus preceding scheduled captive testing by 5 months</u>

Following the presentation of the IRBM development plan to Headquarters, USAF, on November 18, 1955, BMD was directed on November 28, 1955, to proceed with this program. Representatives of three contractors were briefed by Air Force and R-W personnel on November 30, 1955, on the actions taken during the preceding 8 months and on the studies that had been undertaken by various aircraft firms, research organizations, and by the Army Redstone Arsenal leading to the decision to develop an IRBM.

The contractors were notified that development of an IRBM on a "crash" basis was desired and that the early product of the program was to be a demonstrated 1,500-nautical-mile flight. The contractors were not given a schedule of development, but instead were asked to present their version of a maximum risk development schedule based on their past experience.

The contractors submitted proposals for the IRBM on December 8, 1955. The three contractors proposed an early first flight demonstration on September 30, 1956, November 15, 1956, and March 15, 1957, respectively.

Two of the contractors proposed to ship the missiles directly from factory assembly to the launch area with limited checkout firings before launch, while the third proposed to ship from factory assembly to a captive test area and then to the launch area, with more numerous checkout firings. In the evaluation of these proposals by the Air Force and R-W, the third contractor's approach was termed "conservative" and "not in accordance with a maximum risk program." The evaluation board commented that "while the first flight dates estimated by each contractor are probably overly optimistic, there is not much doubt that barring major unforeseen difficulties, each contractor could meet a first flight date well before mid-1957."

Following award of the contract for development and production of the THOR airframe, a flight program was approved providing for flight testing to begin in December 1956, 1 year after award of the contract and 7 months earlier than the flight test program scheduled in the development plan prepared by Air Force and R-W on November 18, 1955.

Thus, although the development plan had been prepared by the Air Force and its systems engineer and technical director based on the experience they had gained during more than 1 year of accelerated activity in the ICBM program and based on special studies made by various organizations during the preceding 8 months, and although this plan was identified as prepared on a maximum risk basis to fly a minimum reliable missile with a minimum performance requirement, the flight testing schedule provided in this plan was further accelerated 7 months, evidently based on the proposals of contractors which the Air Force evaluation board recognized as probably being overly optimistic. As a result of this change in the flight test program, the initial flight test was planned to precede the first scheduled captive test by 5 months, instead of following it by 2 months, and consequently the risk involved in flight testing new ballistic missiles was further increased.

<u>Combination of delay in availability of captive test facilities and acceleration of flight test program led to flight testing preceding captive testing by 16 months with unfavorable results</u>

Although the captive test program was delayed 10 months, the THOR flight test program was advanced 7 months, and as a result, flight tests were conducted for more than a year before full-duration captive testing was completed on an entire missile. Consequently, flight testing of 14 THOR missiles was conducted under "crash" flight test programs during the first 16 months of the flight test program prior to the achievement of a full-duration captive testing of an entire missile, contrary to stated Air Force policy.[1] Of the 14 missiles flight tested, 4 exploded on the launch stand, 2 were destroyed by the Range Safety Officer after launch, 1 broke up in flight, and 7 accomplished their objectives in varying degrees, 3 of these 7 being prematurely terminated.

Although the loss of expensive missiles destroyed in flight attempt during the first year of the flight test program cannot be

[1] In order to minimize the risk of launching missiles without captive testing during this period, however, all THOR missiles, except one, were subjected to flight readiness firings of from 5 to a maximum of 12.5 seconds prior to launch. These firings were conducted at the Air Force Missile Test Center on launch stands which were not designed for captive firings of long duration. The one missile which was not subjected to a flight readiness firing exploded on the launch pad.

directly attributed to the lack of captive testing, it appears that the risks inherent in a flight test program would have been reduced and the number of successful flights might have been increased if aggressive action had been taken to provide for early availability of the captive test facilities.

The results of the flight test program through May 1958, when the first full-duration captive test of an assembled THOR missile was performed, are stated below:

The first launch was attempted on January 25, 1957, and was unsuccessful due to missile explosion on the launch stand, damaging the stand. The stand remained unoccupied for about 2 months. Three additional launches of Series I (propulsion) missiles were attempted between April and August 1957. Of these three attempts, the first missile was destroyed by the Range Safety Officer due to faulty indication on the range equipment after 35 seconds of powered flight; the second exploded on the launch stand; and the third broke up after 95 seconds of flight, when control of the missile was lost. The explosion of the second missile on the launch stand again damaged the stand. The stand remained unoccupied for almost 3 months.

Despite these unfavorable events and without the benefit of captive firings of an assembled missile, a "crash" flight test program was undertaken in September 1957 to accelerate the launch of the remaining four Series I missiles at the earliest possible date, subject only to safety and the probability of a maximum-range flight demonstration. In the first three launches under this expedited program, one missile exploded on the launch stand and the other two accomplished their objectives, although one experienced a turbopump failure after 151 seconds. In the fourth launch, a total of 4,369 pounds of weight was removed from the missile, and the flight achieved a range of 2,400 miles in its lightened configuration.

Emphasis on acceleration of the flight test program was continued through February 1958, and included plans for 3 Series II (guidance) and 2 Series III (nose cone) flight demonstrations. R-W reported on November 1, 1957, that it was "recognized and accepted that all of the normal development program technical objectives may not be accomplished on the crash program time schedule." Previously published detailed test objective documents were revised and a single primary test objective for each of the two series of missiles was established, with other objectives to be accomplished if possible. Additional contractor manpower was transferred to the test center and unlimited overtime was authorized to speed checkout and preparation of missiles for flight.

The 3 Series II missiles, with a primary objective of demonstrating the performance of the all-inertial guidance system, were launched during December 1957 and January 1958 on the crash program schedule. A range of approximately 1,300 nautical miles was to be attained by the flights. The first missile experienced guidance power supply failure after 107 seconds of flight, attaining a range of 200 nautical miles; the second attained a range of 1,150 nautical miles and was considered a success, although a deficiency occurred in the inertial guidance system platform gimball bearing during the last few seconds of the power flight; and the inertial guidance system platform of the third missile became unstable after 95 seconds of flight, and the missile was destroyed by the Range Safety Officer after attaining a range of only 60 nautical miles.

Two Series III missiles, intended to demonstrate nose cone reentry, were launched in February and April 1958. Flight results showed that these two Series III flights failed to accomplish their primary objectives. The first missile experienced engine shutdown after 109 seconds of its intended flight of 154 seconds and attained a range of only 155 nautical miles; the second exploded on the launch stand. A THOR-ABLE flight, intended to demonstrate nose cone reentry in support of the ICBM program, was also attempted in April 1958. Because the special THOR-ABLE reentry flight traveled only 900 of its intended 5,500 nautical-mile range, due to failure of the turbopump, the objectives of this flight were not fully attained. Thus, flight testing was attempted of 14 THOR missiles prior to the achievement in May 1958 of a full-duration captive test of an assembled THOR, with unfavorable results.

<u>During same period Army captive tested every assembled JUPITER missile before flight testing, and more favorable flight test results were achieved</u>

During the same period that the Air Force was conducting its flight test program on a "crash" basis without the benefits of full-duration captive testing, every JUPITER flight test of the Army was preceded by a "full-duration" captive test of the missile. The more favorable results of the JUPITER flight test program appear to show conclusively the value of complete captive testing in advance of the flight test program.

In our limited review of the JUPITER program, we were informed that the Army's development philosophy provides that flight testing of missiles shall be undertaken only after extensive static testing has proved the theory and design of the system and the reliability of the components and that the proper place for shakedown testing of the missiles is at the static test site instead of on the flight test range. The JUPITER program therefore was based on use of a research and development (R&D) static test stand in existence at Huntsville, which had been constructed under earlier missile programs.

On February 2, 1957, the Army conducted a successful, "full-duration" static firing of the first completely assembled JUPITER missile produced by the Army Ballistic Missile Agency (ABMA). We were informed that a static firing of about 25 to 30 seconds' duration was considered by ABMA to satisfy the requirements of a "full-duration" firing for the purpose of checking engine performance and other missile parameters. Subsequent JUPITER R&D missiles were subjected to static firings of this duration at Huntsville prior to shipment to the flight test center for launch.

As discussed on page 38 of this report, basic Air Force policy also subscribes to the importance of captive testing prior to flight test. We were informed that the normal captive firing for the THOR missile would entail a full-duration run of 160 seconds. However, in order to reduce the risk of launching missiles without complete testing, all THOR missiles flight tested prior to May 1958, except one, were subjected to flight readiness firings of from 5 to a maximum of 12.5 seconds prior to launch. These firings were conducted on launch stands at AFMTC, which were not designed for firings of long duration and on which instrumentation was limited, in comparison to an R&D captive test stand. The one missile which was not subjected to a flight readiness firing exploded on the pad during the launch attempt.

The results of the THOR and JUPITER flight test programs through May 1958 are compared below:

Of the 14 THOR missiles flight tested, 4 exploded on the stand, 2 were destroyed by the Range Safety Officer after launch, 1 broke up in flight, and 3 terminated prior to completion of the programed flight. Only 4 full-duration flights were achieved.

By contrast, of the 8 JUPITER missiles launched during this same period, none exploded on the stand, 4 achieved full-duration flights, 2 terminated prior to completion of a full-duration powered flight, 1 exploded after 74 seconds of flight, and 1 broke up in flight.

In addition to the more favorable results in the JUPITER flight program, the completion of captive testing prior to delivery of the missile to the flight test center appears also to have been a significant factor in the ability of the Army to launch JUPITER missiles within a month after arrival at AFMTC, as compared to the average of about 4 months required by the Air Force for THOR missiles.

We are not in a position to compare the over-all effectiveness of the JUPITER program with the THOR program. However, it seems evident that the Army practice of conducting captive tests of JUPITER missiles prior to flight testing is preferable to the practice followed by the Air Force during the early stages of the THOR program.

Conclusion

The decision to advance flight testing 7 months earlier than the date previously established on a maximum risk basis was in direct contradiction to the stated Air Force policy that "flight tests with expensive missiles cannot be justified until reasonable assurance of success has been obtained from captive operations of the complete weapon systems."

This decision apparently was based on estimates prepared by companies competing for the contract for developing the THOR, which estimates were recognized by the Air Force evaluation board as probably being over optimistic. Inasmuch as the November 18, 1955, development plan prepared by the Air Force and R-W on a "maximum risk" basis was evidently based on lengthy consideration of studies made by various organizations during the preceding 8 months as well as the experience gained in the ICBM program, the decision to deviate from this plan by flight testing without captive testing seems to have been questionable. In any event, every effort should have been made to arrange for early availability of captive test facilities to minimize the period of flight testing without captive testing.

SHIPMENT OF THOR MISSILES TO FLIGHT TEST CENTER WITHOUT INCORPORATION OF NECESSARY MODIFICATIONS CONTRIBUTED TO SUBSTANTIAL INCREASE IN COST AND LENGTHY DELAY IN COMPLETION OF FLIGHT TEST PROGRAM

THOR missiles were shipped to AFMTC without first modifying the missiles to a flight readiness configuration, and the missiles were on hand at AFMTC many months prior to launch. The shipment of the missiles prior to modification appears to have been unnecessary and costly and a delaying factor in the program. Extensive modification work had to be performed at AFMTC to incorporate engineering changes and changes in the instrumentation of the missiles made necessary by previous flight and captive test developments. In view of the research and development status of the THOR program at that time, modifications to effect corrections and improvements were to be expected and would have been necessary even if the missiles had been retained at the contractor's plant. However, we believe that such modifications would have been made more economically and more quickly if performed at the factory where facilities, parts, and personnel were available. By contrast, JUPITER missiles required less modification after arrival at AFMTC and were launched within a month after arrival as compared to the average of over 4 months required for THOR missiles.

The contractor originally estimated a cost of $6.5 million to launch 47 THORs by June 30, 1958. Although costs incurred at that date amounted to $9.6 million, only 16 THORs had then been launched. Approximately $10 million more was authorized for this testing through June 1959, and additional costs have been incurred inasmuch as the flight test program for the THOR weapons system was not completed until December 1959. In view of this significant increase in manpower, labor hours, and cost--coupled with the substantial delay in completion of the flight test program--we requested information from Air Force officials concerning actions taken to accelerate the test program. We were informed that all research and development problems were handled on a daily basis, but the earliest evidence made available to us showing action to improve operations at the flight test center was a study of contractor functions and manning at AFMTC completed by a committee comprised of BMD/BMC personnel in September 1958, 20 months after the THOR flight test program started. As a result of this study, the Air Force reported in May 1959 that every effort was being taken between BMD and the contractor to minimize missile modifications at AFMTC and to reduce the time that missiles were at AFMTC prior to launch.

We recognize that estimates made in research and development programs involving new types of weapons are not firm and variances can be expected. However, it seems evident that a portion of the significant increase in cost and the delay in completion of the THOR flight test program would have been avoided if prompt steps had been taken by the Air Force to arrange for incorporation of necessary modifications at the contractor's plant prior to shipment of the missiles to the flight test center. Such arrangements would not have delayed the flight test program inasmuch as a sufficient number of missiles were already on hand at AFMTC for the available test stands. On the contrary, shipment of missiles with all known modifications already incorporated would have minimized the work necessary at the flight test center to prepare for the missiles' launching and therefore should have reduced the time between receipt of the missile and the flight attempt. With the additional facilities at the home plant, the necessary modifications reasonably should have been made in less time at the home plant and therefore the program would have been accelerated.

THOR missiles were assembled at the contractor's plant on the west coast and shipped by airplane to the Air Force Missile Test Center, Cape Canaveral, Florida, for flight testing. The first THOR missile shipped to AFMTC arrived in October 1956, and the inventory of THOR missiles at AFMTC increased to 11 as of December 1958. Three stands were available at AFMTC for flight testing of the THORs. The THOR missiles were inspected upon receipt at AFMTC and placed in storage until space was available in the hangar building for modification and instrumentation preparatory to transfer to the flight test stands for final checkout and launch.

<u>Cost and time required for THOR flight test program increased significantly over original estimates</u>

The THOR airframe contractor submitted a flight test program to the Air Force in June 1956, proposing to flight test 47 missiles with launches beginning in December 1956 and ending on June 30, 1958. The program was accepted by the Air Force and a negotiated estimated cost of $6.5 million plus a fixed fee of $422,500 was established. Our review showed that while flight testing costs of $9.6 million had been incurred at June 30, 1958, the original ending date for the program, only 16 of the 47 missiles had been launched at that time.

Inasmuch as the flight test objectives had not been accomplished within the original time estimate, the program was extended contractually for an additional year, through June 1959, at a negotiated cost of $7.75 million for flight testing the balance of the 47 missiles and about $2.2 million for direct home-plant design and engineering support. The fixed fee applicable to this additional work amounted to $646,360. However, during the negotiations for the extension of the flight test program, $1.25 million of the added cost was regarded by the Air Force as representing an overrun for work which the contractor should have performed on the original contractual flight test schedule. Consequently, the additional fee authorized for the increased cost was reduced by $81,250. The THOR flight test program was again extended and was completed in December 1959, about 1-1/2 years later than originally estimated.

THOR missiles required substantial amount of modification work after arrival at AFMTC, averaging 4 months before launching

Our review of the modification and checkout records for 19 THOR missiles launched during calendar year 1958 showed that an average of 137 calendar days was required to process, modify, and ready the missiles for flight, whereas the contractor had estimated in his flight test program proposal that the missiles would be flight tested within 60 calendar days after delivery to the flight test center. The records also showed that the contractor expended an average of 14,300 direct labor hours per missile, modifying and preparing the missiles for flight, as compared with an estimate in September 1957 of approximately 6,000 hours for accomplishing these functions. The airframe contractor's early proposal included a requirement for 200 persons at AFMTC to prepare missiles and conduct launches during the peak period of the flight test program. The estimate was increased to 250 persons in April 1957, at which time the Air Force reviewed the contractor's manpower and organization at AFMTC. The THOR Program Director reported that the contractor's estimates of personnel build-up were low and stated that a better estimate would be 350 during the peak manpower load. At June 30, 1958, the originally scheduled completion date for the THOR flight test program, the contractor had a total of 528 personnel at AFMTC, and at that date only 16 of the originally scheduled 47 flights had been launched.

STL personnel stationed at the flight test center reported in October 1958 with respect to the modification of missiles, as follows:

> "Modification of missiles prior to grid area checkout[1] requires approximately eight weeks. This length of time is required to complete AOs[2] and EOs[2] on a missile. It is believed that this time could be reduced if most of the AOs[2] were completed at the [contractor's] plant where plant facilities and parts are available."

<u>JUPITER missiles required less modification at AFMTC and were launched within month after arrival</u>

JUPITER missiles shipped to AFMTC for flight testing generally were launched within 1 month after arrival. Under the Army system of development, engineering and design modifications resulting from previous test experience generally were incorporated in the missiles prior to their shipment from Huntsville, Alabama, and consequently relatively little additional modification work was necessary after arrival at AFMTC.

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[1]The final checkout of the missile in which all components function electrically and telemetry recordings are made.

[2]Assembly orders and engineering orders.

The Army employed a system of development which required that flight testing of missiles be undertaken only after extensive laboratory testing had proved the theory and design of each individual missile. After manufacture of each missile was completed, it was checked out and static fired at Huntsville before being shipped to AFMTC for flight testing. Under this system, firing rates were controlled so that as each missile was fired the results of that firing were analyzed to determine and incorporate any necessary modifications in the next missile scheduled for firing and prior to shipment to AFMTC. Thus, extensive modification and instrumentation of JUPITER missiles at AFMTC was not required as in the case of the THOR program, and the JUPITER flight test program adhered more closely to its original flight test schedule.

As stated previously, we did not make an extensive review of the JUPITER program, and we are not in a position to compare the over-all effectiveness of the JUPITER with the THOR program. However, it seems evident that the method followed by the Army in incorporating necessary modifications in the JUPITER prior to shipment to the flight test center is preferable to incorporating modifications at the flight test center.

<u>Delay in action to correct slippage in THOR flight test program not taken for substantial period</u>

The slippage in accomplishing flight tests was apparent early in the program. For example, only three launches had been attempted as of the end of June 1957, compared to the seven originally scheduled. Schedules were revised and flights were deferred into future months, but the revised schedules were not met.

Further schedule revisions and stretch-outs were made, but the new programs were not achieved. In view of these continual slippages and the urgency of the program, vigorous action should have been taken to determine the causes and the necessary corrective actions. However, the earliest report made available to us by the Air Force concerning a review of this matter was issued in September 1958, which was brought to the attention of appropriate officials for implementation in May 1959.

In view of the significant increase in manpower requirements, direct labor hours, and the cost of the flight test program--coupled with the substantial slippage in the flight test schedule--we requested information from Air Force officials as to the actions taken to improve operations at the missile test center. We were informed that all research and development problems were handled on a daily basis. We asked for specific evidence of any studies made or any other actions taken to alleviate the problems at AFMTC which were preventing adherence to the flight test schedule. We were furnished a copy of a survey of AFBMD missile contractor functions and manning at AFMTC completed by a BMD/BMC group in September 1958. Insofar as we could determine, this was the earliest action by the Air Force to formally review this phase of the testing program.

The Air Force survey report contained the following comments concerning the extensive modification work being performed at AFMTC following receipt of THOR missiles:

* * * * *

"Resultant data analysis from flight tests and static tests conducted both at AFMTC and the various static test facilities dictate design configuration changes which must of necessity be made on all subsequent missiles. Most of the instrument changes and all of the design configuration changes must be multiplied by the number of missiles on hand at AFMTC, the number of prepared missiles at the home plant awaiting shipment, plus all of those that have passed the specific point in the assembly line where the change order would be affected.

"A review of records on eight Thor missiles indicates that an average of 876 jobs were scheduled, performed, and recorded for each missile after arrival at AFMTC. The project office estimates that 75% of these jobs were the direct result of missile modifications and instrumentation changes, and only 25% or less were necessary in direct support of routine checkout and test procedures plus changes caused by the immediately preceding flights."

* * * * *

"*** [the THOR airframe contractor] and, to a lesser extent, *** [another contractor] were in effect operating a modification center at AFMTC. Sizable workload reductions will be achieved at AFMTC if known missile modifications are performed prior to shipment. The project offices have control over the date of shipment of individual missiles, but they do not have control over the condition of the missiles. The contractors at AFMTC have built up a capability for modifying missiles and are performing this work largely with premium wages. It is beyond the scope of this committee to determine relative economy between a factory modification line and modification at AFMTC. It seems logical that the modifications could be performed more economically at the point of manufacture."

* * * * *

The conclusion and recommendation of the survey group, as it related to the THOR, was that:

* * * * *

"The amount of modification required on missiles at AFMTC is excessive, particularly on the Thor missiles. This is aggravated by the fact that Thor missiles arrive at AFMTC as much as six months prior to launch, which requires that all changes resulting from flight test or static test findings during this six month period must be performed at AFMTC."

*   *   *   *   *

"2. All known modifications be accomplished on a missile at the place of manufacture prior to shipment to AFMTC. Further, that the backlog of missiles at AFMTC not exceed the checkout capacity necessary to meet the established launch schedule."

*   *   *   *   *

A BMD reply in May 1959 stated that the survey report of the BMD/BMC group had been brought to the attention of all weapons systems directors in order that they might implement the applicable conclusions and recommendations. The reply specifically commented on the recommendation quoted above as follows:

*   *   *   *   *

"*** Both the Atlas and Titan contractors have been directed to make sure that no missiles are shipped to AFMTC with shortages or modifications to be performed unless there are insufficient flight missiles at AFMTC to support the launch schedules. The WS-315 Directorate has discussed this problem with the THOR airframe contractor and every effort is being taken to minimize the modifications to be performed at AFMTC, however, it is felt that the establishment of a separate modification line at Santa Monica would be costly, and due to the necessary tooling delays, would not be available to help alleviate the AFMTC modification workload until the launch program at AFMTC has passed its peak. The lower 'Thor" R&D missile delivery rate coupled with an increased launch rate has reduced the missile backlog at AFMTC to six missiles in the hangars and three on the launch pads.

"4. Due to an urgent overseas requirement several missiles have been reprogrammed from the AFMTC flight program to Emily[1] and this has also been a factor in decreasing the AFMTC backlog."

*   *   *   *   *

In early 1959, the THOR airframe contractor conducted an extensive analysis of its operations at AFMTC, at the request of the

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[1]United Kingdom

Air Force, to "determine what is responsible for the major portion of the workload and to determine the feasibility of a reduction in the preparation time for missiles between arrival and the firing date." Although the report of its analysis indicated that much of the AFMTC modification and instrumentation work was being shifted to the contractor's home plant, it was also pointed out that (1) an average of 10,000 man-hours per missile were still being expended after receipt at the flight center, (2) a large part of the work was at that time principally on missile instrumentation, and (3) it was very doubtful that the time from receipt of missiles at AFMTC to firing could be reduced to the 7-week period desired by the Air Force.

Conclusions

The fact that the original estimates for flight testing the THOR were substantially exceeded does not necessarily demonstrate inadequate management inasmuch as estimates in research and development programs are not firm and variances can be expected. However, the continued shipment of THOR missiles to AFMTC without incorporation of necessary modifications, particularly when sufficient missiles were already on hand at AFMTC to meet flight schedules, evidently was a costly as well as a time-consuming operation and to some degree contributed to the significant increase in cost and the slippage in completion of the flight test program.

Modifications to effect corrections and improvements are to be expected in research and development programs such as the THOR and JUPITER. However, as pointed out by the Air Force survey group, such modifications logically would be made more economically and quickly at the assembly location where facilities, parts, and personnel are available.

Although the survey of contractor operations at AFMTC completed by the Air Force in September 1958 followed by the corrective actions undertaken in the spring of 1959 should reduce missile modification and preparation costs at AFMTC, it should be noted that the THOR program had reached its peak by then and therefore the savings in that program would be relatively small. We believe that substantial savings in the cost of the program could have been effected if prompt steps had been taken by the Air Force to arrange for incorporation of necessary modifications at the contractor's plant prior to shipment of the missiles to the flight test center. We believe that this action would have accelerated the program through minimizing the preparation work at the flight test center prior to launching the missiles.

FAILURE TO DELINEATE RESPONSIBILITIES BETWEEN AIRFRAME CONTRACTOR AND TECHNICAL DIRECTOR FOR CAPTIVE TESTING OF THOR CORRECTED AFTER GAO INQUIRY

The Air Force failed to delineate responsibilities for the THOR captive test program between the THOR airframe contractor and Space Technology Laboratories, Inc. (STL), the systems engineer and technical director. Corrective action was taken by the Air Force after we brought this deficiency to its attention.

The captive test program for the THOR at Sacramento, California, is conducted by the airframe contractor, subject to review and evaluation by STL. The procedures established for conduct of tests did not clearly delineate the respective responsibilities of the airframe contractor and STL. These procedures provided that the basic test-planning document covering the total program test objectives would be prepared by the contractor and approved by STL. However, the test directives covering the operational requirements for a single run or series of runs to accomplish selected objectives from the test plan were not subject to approval by STL for the Sacramento operations. Under these procedures, several tests were performed by the contractor without STL approval while others were reviewed by STL before the tests were performed.

A major reason for the use of a systems engineer and technical director in the ballistic missile program is to coordinate the test programs of the many contractors involved in the various weapons systems and to utilize the accomplishments under one system in furthering the other systems. It thus seems appropriate that proposed captive tests be approved in advance by the systems engineer and technical director. The advantages of such advance review are indicated by the fact that in three instances noted in our review the proposed tests were changed following review of the test directives by STL in advance of the tests.

In October 1958, we discussed this situation with Air Force representatives at BMD, who recognized the necessity for written guidelines. BMD issued a document dated December 31, 1958, entitled "Organizational Responsibilities and Operating Procedures for WS-315A Captive Test Program at Sacramento Including the Propellant Utilization Tests" for immediate implementation by the airframe contractor, STL and BMD. This directive placed upon the BMD/STL field office at Sacramento the responsibility for management control of the test and evaluation program and required that the field office review and approve proposed test directives. It also established documentation and reporting procedures for the Air Force, the Space Technology Laboratories, and the airframe contractor with respect to the Sacramento captive test program.

FLIGHT FAILURES OF ONE ATLAS AND ONE THOR CAUSED BY TURBOPUMP[1] DEFICIENCY COULD HAVE BEEN AVOIDED WITHOUT DISRUPTION OF FLIGHT TEST PROGRAM IF ENGINES HAD BEEN RETURNED TO CONTRACTOR'S PLANT FOR INCORPORATION OF APPROVED MODIFICATIONS

Turbopump deficiencies constituted a major problem in the ballistic missile program during the period from October 1957 to September 1958, both for the Air Force and the Army, causing flight failures of three ATLAS, three THOR, and two JUPITER missiles. The Army delayed JUPITER flight tests scheduled for February and April 1958 following the loss of two JUPITER missiles due to turbopump deficiency. After analysis of the problem and installation of correcting modifications, the Army resumed flight testing in May 1958 and no further turbopump failures were experienced. While the Air Force arranged for modifications of turbopumps in production at the contractor's plant in May 1958, limited modifications were made to the turbopumps on the engines already delivered to the Air Force. The Air Force continued its flight test programs until the failures of one THOR and one ATLAS in August and September 1958, respectively, after which the remaining modifications were made to all of the delivered turbopumps. No further flight failures due to turbopump deficiencies occurred.

We recognize that a decision as to whether the flight program should be delayed for modification of existing missiles involves

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[1]The turbopump is a complex, high-speed mechanism which feeds the propellants into the engine. Engines for the ATLAS, THOR, and JUPITER are manufactured by the same contractor. The turbopumps for these engines are identical except for minor differences in fittings.

complex judgments concerning the importance of the modifications and urgency of the program. However, it seems evident that important modifications which could be made without delaying the program should be made to reduce the likelihood of flight failures. We believe that flight failures of one ATLAS and one THOR might have been avoided without disruption of the flight program if the engines had been returned to the contractor's plant for incorporation of modifications that the Air Force had previously approved for application to engines still in production.

The costs that might have been saved if these flight failures had not occurred cannot be precisely identified due to the research and development nature of the program. The cost of the ballistic missile itself depends on such factors as the quantity of missiles produced, the varying components used in the particular missiles, whether the cost of research and development is included, and whether the cost of related equipment such as test facilities and ground support is included. In testimony before a subcommittee of the Senate Appropriations Committee in March 1960, the Air Force reported the typical production cost of individual ballistic missiles, showing $1.9 million for the ATLAS and $.7 million for the THOR.

Flight failures caused by turbopump deficiencies beginning in late 1957

During static tests of THOR engines made by the propulsion contractor in mid-1957, the first indications of marginal turbopump design appeared in the form of bearing walking in the gear box. This condition was discovered during the teardown inspection of the test engines used in the static tests, which disclosed evidence of bearings having moved axially within their mountings in the turbopump case. The contractor's detailed examinations at the time indicated that this was an undesirable characteristic. The Air Force and STL directed the contractor to investigate means of preventing recurrence of the bearing-walking condition.

The engine of THOR missile 108 shut down prematurely during its flight test on October 11, 1957. The specific malfunction was not identified at the time, although it was believed that a gas generator or mechanical failure of the turbopump had caused the engine shutdown. Subsequently, it was determined that the malfunction occurred in the turbopump but the specific nature of the malfunction was not identified.

The flight test of JUPITER missile AM-3A, launched November 26, 1957, was not completely successful because of premature loss of engine thrust after 101 seconds of flight. Since the evaluation of flight-test data indicated a mechanical failure of the turbopump, instrumentation and additional equipment were installed on JUPITER missile AM-4 to isolate the specific area of malfunction within the turbopump. JUPITER missile AM-4, launched December 18, 1957, failed after 117 seconds of flight under similar conditions to those experienced by JUPITER missile AM-3A. After analyses of test data, the malfunction was traced to a breakdown in the turbopump gear box.

ATLAS missile 13A, fired on February 7, 1958, failed to complete its planned flight course. BMD concluded that, while there was some indication of turbopump difficulties, it was established with reasonable certainty that lubricating oil exhaustion had occurred and comparison with data on the two JUPITER unsuccessful flights showed no similarity.

On the basis of the static engine tests which gave the first indication of a bearing problem in mid-1957, the contractor, on February 7, 1958, submitted a proposal to incorporate improved bearing retainers in the turbopumps of certain undelivered THOR engines. We were informed that this proposal had been returned to the contractor by the Air Force Plant Representative without BMD approval since the proposal was not accompanied by substantiating test data necessary for evaluation of the proposal.

<u>JUPITER flight test program, postponed in February 1958 pending correction of turbopump deficiency, was resumed in May 1958 and no subsequent failures due to turbopump malfunction occurred</u>

In view of the failures of JUPITER missiles AM-3A and AM-4 due to turbopump deficiencies, the Army postponed scheduled launchings of two missiles. JUPITER missiles AM-5 and AM-6, scheduled to be launched in February and April 1958, respectively, were rescheduled for launching in May and July 1958 in order to allow the Army Ballistic Missile Agency time to evaluate the flight-test results of missiles AM-3A and AM-4, to perform laborabory tests, and to install correcting modifications to the turbopumps.

Because of the similarity of failure of missiles AM-3A and AM-4 and the telemetry indications that a malfunction in the turbopump gear box could have been the cause of the engine malfunctions, a gear-box test program was initiated on February 13, 1958, at ABMA's High Altitude Test Facility at Huntsville, Alabama. The testing program was under the over-all supervision of ABMA with personnel of the propulsion contractor participating in the actual testing.

The contractor reported that certain laboratory tests had indicated that gear-box performance was affected by low pressure and that tests made at its Field Propulsion Laboratory, simultaneously with the ABMA's High Altitude Test Facility, showed conclusively that low pressure at altitudes above 90,000 feet had caused lubricating oil foaming, resulting in bearing failure.

Based on the number of successful vacuum tests at ABMA's High Altitude Test Facility in which bearing retainers were employed to prevent bearing walking and the number of failures in vacuum testing using the standard unretained bearings, ABMA decided on March 17, 1958, to incorporate bearing retainers into JUPITER engine production and to modify all delivered JUPITER turbopumps, including missile AM-5, with bearing retainers. Since this modification was a factory operation, delivered JUPITER turbopumps were returned to the contractor. Our review of the contractor's records indicated that the average time required at its plant to modify these turbopumps with improved bearing retainers was approximately 16 days.

Several other significant modifications also were made to JUPITER turbopumps during the period flight tests were suspended. These modifications consisted of pressurization of gear boxes, strengthening of quill shafts, use of heavy lubricating oil, and insulation of lubricating oil tanks and lines. The modified JUPITER missile AM-5 was successfully flight tested on May 18, 1958, and no failures attributable to turbopump malfunctions occurred in 10 subsequent JUPITER flight tests through June 1959.

Air Force failed to incorporate modifications in turbopumps that could be made without delaying the flight test program

The Air Force decided in May 1958 to continue the ATLAS and THOR flight test programs without incorporating all approved turbopump modifications. Modifications that could be made without returning the turbopump or engine to the contractor's plant were made in the field, but approved modifications that required the return of the turbopumps to the contractor's plant were not authorized on the basis that significant delays in the flight test programs would result and there was insufficient evidence of potential failure. Our examination disclosed, however, that these modifications could have been made to missiles scheduled for launching in July 1958 and later without delaying the program. Relative to the evidence of potential failure, we recognize that this involves matters of technical evaluation. However, it is of interest to note that the Army considered it of sufficient importance to justify modification of all of its missiles even though its flight schedule was delayed. After the failures due to turbopump deficiency of THOR 127 in August 1958 and ATLAS 6B in September 1958, the Air Force returned all turbopumps and/or engines to the contractor for modification.

Air Force continued flight testing while Army postponed JUPITER flight tests

As reported previously, the Army postponed flight testing of JUPITER missiles from February to May 1958 pending identification of the turbopump deficiencies and installation of modifications.

During this period the Air Force continued its flight test program and on April 9, 1958, arranged to equip flight-missile turbopumps with a gear-box pressurization system and to use a type of lubricating oil which exhibited better antifoaming properties at altitude conditions. This modification did not require return of engines or turbopumps to Rocketdyne.

Six flights were attempted by the Air Force during February to April 1958, all of which failed to achieve the planned flight duration. The propulsion system of one missile shut down prematurely, but loss of telemetry made the exact cause indeterminable; one failure was attributed to oil exhaustion, another to premature engine cutoff due to loss of LOX, and another was suspected of having a restriction of the fuel feed system. On April 5, 1958, the flight of ATLAS 15A was prematurely terminated after 105 seconds of flight when a booster-engine turbopump failed, causing a complete propulsion shutdown. THOR missile 116, in which the pressurized gear box was incorporated in the turbopump, was launched on April 23, 1958, and failed to complete a number of full-range flight objectives as the result of a premature loss of engine thrust due to a turbopump malfunction. The contractor reported that further examination showed that turbopump movements, because of engine frame distortions under flight loads, caused a high axial and radial load on the turbine assembly. Simulated loading tests were made by the contractor. To correct the distortion under flight loads, the turbine exhaust duct bellows assemblies and quill shafts of missiles scheduled for flight test were modified.

Air Force arranged in May 1958 to modify turbopumps on engines in production line to incorporate improved bearing retainers but decided not to apply this modification to missiles already produced

On April 4, 1958, the contractor submitted two proposals, each applicable to a different turbopump shaft, to incorporate improved bearing retainers in the turbopumps of THOR engines in production. On the basis of the static engine test data submitted by the contractor, BMD approved one proposal on April 21, 1958, and the other on May 8, 1958, and requested issuance of covering Contract Change Notification requests by BMC. On May 13 and 16, 1958, BMC requested the Air Force Plant Representative at the contractor's plant to issue Contract Change Notifications covering installation of improved bearing retainers in designated undelivered THOR engines. On April 7, 1958, the contractor submitted a similar proposal for modifying the turbopumps of ATLAS engines in production. BMD approved the proposal on April 24, 1958, and BMC requested issuance of a Contract Change Notification on May 16, 1958. BMD decided that the retainer modification would be made only on undelivered engines because the return of all turbopumps to the contractor for modification would result in significant delays in the flight test programs. However, inasmuch as the time required for these modifications was about 1 month, the modifications could have been applied to missiles scheduled for flight testing in July 1958 or later without delaying the program and thereby the failures of two missiles in August and September 1958 might have been avoided. We were informed by an official of the contractor that plant capacity considerations were not the basis for deferral of the retainer modification program.

On May 1, 1958, the Army informed the Department of Defense (DOD) that the turbopump problem had been analyzed and modifications had been established to correct the weaknesses. A meeting of all persons concerned with the turbopump problems in the JUPITER, THOR, and ATLAS missiles was held to review the ABMA test-program data and the corrective actions taken. The meeting was held on May 12, 1958, at ABMA and was attended by representatives of the National Advisory Committee for Aeronautics, of DOD, BMD, ABMA, STL, and the contractor. During the meeting the THOR flight test program for succeeding missiles was described as consisting of instrumented flights to obtain additional measurements in the turbopump area. Bearing retainers were not included among the "fixes" to be incorporated in future THOR missile firings. The JUPITER flight test program outlined for the succeeding three missiles included, among other "fixes," turbopumps with bearing retainers.

The turbopump gear boxes used in the ATLAS, JUPITER, and THOR missile engines were identical, and BMD had conducted an extensive investigation of ATLAS and THOR engine turbopump bearing reliability. The BMD investigation disclosed that the engine data obtained from flight tests of JUPITER missiles AM-3A and AM-4 exhibited characteristics similar to those obtained during the static test program at the contractor's plant where bearing failure was experienced due to loss of gear-box lubricating oil. During the contractor's static-test program, over 117 hours of turbopump operating time was accumulated with no history of bearing failure where the lubricating system functioned properly.

The review of bearing designs with bearing consultants resulted in suggestions to incorporate bearing retainer rings to prevent bearing walking and to add an antifoaming agent to the lubricating oil. These suggestions were based on the results of the ABMA laboratory tests where foaming of the lubricating oil, with resultant reduction in cooling capabilities, was noted under simulated altitude conditions. At this time, BMD had determined to incorporate bearing retainers into Air Force engine turbopumps scheduled for future delivery and was undertaking investigations of antifoaming agents.

Further, BMD concluded that:

1. Evidence of critical bearing reliability was inconclusive.
2. Differences in configuration and operating procedures existed among the ATLAS, JUPITER, and THOR.
3. Improvements in turbopump bearing designs to assure greater reliability were desirable, and action had been taken to incorporate the most promising of the improvements into production of engine turbopumps scheduled for future delivery.
4. There was no evidence of turbopump bearing failure having been experienced during the ATLAS and THOR flight-test programs up to the time of the investigation.

BMD considered that it would be an error to suspend flight tests, thus delaying attainment of an operational capability, unless there was strong evidence that an unusually high percentage of failures could be expected. The results of the investigation were not considered to have furnished such evidence, and the flight-test programs were continued as planned.

Following the flight failure of THOR 116 on April 23, 1958, the Air Force had 10 consecutive flight tests without a turbopump failure. The duration of 6 of these tests exceeded the number of seconds of flight in which previous turbopump failures had occurred.

<u>After two additional flight failures due to turbopump deficiencies, the Air Force arranged to return all turbopumps and/or engines to plant for modification</u>

On August 17, 1958, THOR missile 127, which had been designated for the first lunar probe, failed due to a turbopump bearing malfunction. Early in September 1958, the THOR 127 turbopump was recovered from the ocean with a sufficient number of parts intact to indicate the source of failure. On September 18, 1958, ATLAS missile 6B also failed due to turbopump deficiencies. Although these missiles contained certain turbopump modifications which had been retrofitted in the field, they did not carry the turbopump bearing retainers and improved bearing.

As a result of the analysis of the recovered turbopump and the failure of ATLAS 6B, the Air Force decided to retrofit all delivered ATLAS and THOR engines scheduled for flight testing. Retrofits included turbopump bearing retainers and improved bearings. Based upon an STL presentation to a DOD group on September 22, 1958, the opinion was expressed that bearing retainers and improved bearings could be incorporated in delivered THOR engines with little or no delay in existing schedules.

Our review of contractor records indicated that for the retrofit of THOR engines, an average of about 31 days was required for rework and reinstallation where the entire engines were returned to the contractor's plant with 42 days being the longest lapsed time required to complete this operation. An average of 10 days was required for the first three units modified where only turbopumps were returned. The first three ATLAS engines, on which retrofit was accomplished (in October 1958), required an average of 32 days for rework and reinstallation. No further turbopump failures were experienced after incorporation of the bearing retainers.

Agency comments and our conclusions

The Air Force comments with respect to this finding were confined to the statement that,

> "*** with an assurance that our finest scientists and technicians could not give, your [GAO] auditors find that this occurrence could have been avoided by certain modifications to correct high altitude turbopump deficiencies. ***"

The Air Force had approved modifications to currect turbopump deficiencies in the ATLAS and THOR missiles. Modifications that could be made without returning the turbopump or engine from the test site to the contractor's plant were made at the site. However, other modifications approved by the Air Force for installation in engines under production were not installed in those turbopumps and/or engines that had been delivered inasmuch as it would have been necessary to return them to the contractor's plant.

According to official records, the reasons for not modifying the turbopumps and/or engines that had been delivered were that (1) such action would cause significant delays in the flight test programs and (2) there was insufficient evidence of potential failure. We found, however, that these modifications could have been made to missiles not scheduled for launching in the immediate future without delaying the program. While the question as to evidence of potential failure involves matters of technical evaluation, it should be noted that the Army considered this question of sufficient importance to justify modification of all of its JUPITER missiles using the same turbopump even though the JUPITER flight scheduled was delayed, and the Air Force returned all turbopumps and/or engines to the contractor for modification following the subsequent failures due to turbopump deficiency of one THOR and one ATLAS.

Inasmuch as the modification involved a vital element of the missile and could be made without delay of the program, we believe that the modification should have been performed rather than needlessly risking additional failures. Had such arrangements been made, it appears likely that the flight failures of the first lunar probe (a THOR missile) and an ATLAS missile would have been avoided with substantial savings in costs.

AGENCY'S GENERAL COMMENTS AND OUR POSITION

The Air Force disagreed with the findings reported in our preliminary draft of this report but did not furnish any detailed comments. During the course of our review, the Air Force refused to make available to us certain essential information, records, and reports, and, consequently, we were unable to assure ourselves that all pertinent information was made available to us for consideration in arriving at our conclusions. We pointed out this situation to the Air Force in transmitting our preliminary draft for comment, and we, therefore, requested that the Air Force include in its reply any additional facts, appropriately documented, pertinent to the findings discussed in the report. The Air Force did not furnish any specific information or documentation in its reply, and, in view of the provisional nature of certain findings and conclusions, we have confined this report to those findings on which sufficient data could be obtained to warrant reporting to the Congress. In view of the significant changes that had been made in certain portions of the report as a result of program developments or information obtained subsequent to the preliminary draft, we transmitted the revised draft to the Air Force for comment, but again the Air Force did not furnish any specific information in refutation of the findings contained in the report.

Air Force comments relating to findings contained in this report have been included in the findings sections of the report to the extent pertinent and Air Force general comments on our review are discussed in pertinent part below.

prevented us from fully discharging our statutory responsibilities but also impeded the progress of our audit.

Even though we have been precluded through denial of access to records from fully accomplishing our audit objectives, we consider it proper and useful to develop and report to appropriate authorities any significant information available to us covering any aspect of the program and the manner in which it has been conducted.

COVERAGE OF ATLAS AND TITAN PROGRAMS

The Air Force points out that our report confines discussion of the ATLAS and TITAN programs to a single incident in each of these programs, and the Air Force therefore concludes that these programs have been found by us to be free of major deficiencies and major problems. This conclusion, however, is unwarranted.

Our examination disclosed that there had been many significant slippages in these ballistic missile programs and that many of the goals were not being met as planned. The denial to us of access to records covering the reviews of these programs by responsible officials precluded effective consideration of whether steps had been taken to overcome the problems involved. Consequently, we are confining our reporting on these programs to two significant aspects on which sufficient information was acquired to warrant reporting to the Congress. This, however, does not connote that other aspects of these programs were found to be free of major deficiencies or problems.

COMPLEX SCIENTIFIC AND TECHNICAL QUESTIONS

The Air Force contends that our auditors render judgment of complex scientific and technical questions which are not within their province and that such ventures "are difficult, at best, to reconcile with the inherent and traditional confines of GAO cognizance."

The primary purpose of our reviews is to make for the Congress independent examinations of the manner in which Government agencies are discharging their financial responsibilities. A proper evaluation of the agency's financial management cannot be made without studying the agency's policies, procedures, and practices. The fact that an activity involves scientific and technical operations does not, in itself, remove the activity from the purview of our examinations. While we do not evaluate the scientific and technical aspects of these activities, our examinations frequently disclose serious deficiencies in the financial management of these activities. Our examinations also disclose delays in management decisions which seriously impair the activities irrespective of the merits of the technical decisions ultimately made. They may also disclose that a preponderance of technical opinion is not accepted for an extended period with no apparent reason. We report on the effect of such activities where, from the information obtained in our examination, it appears that they conflict with the prudent expenditure of funds or the intent of the Congress.

To illustrate, in the case of the ATLAS failure due to turbopump deficiencies discussed previously, we did not attempt to determine whether the proposed modifications were technically sound. This certainly would be outside our sphere of competence. The very fact that these modifications had been approved by the Air Force for application to all new production seemed reasonable evidence that such modifications would have been beneficial for those turbopumps and/or engines that had already been produced and were awaiting flight testing, at least those that could be modified without delaying the program.

Recommendations for corrective action

The Air Force contends that the draft report is not constructive but instead "is devoted to closed incidents and devoid of recommendations for corrective action."

As stated previously, it is our practice, in carrying out our reviews of the operations of Government agencies, to bring to the attention of appropriate authorities any areas found to require correction or improvement and to make recommendations for corrective action to the extent practicable. Although the restriction on access to records hampered our activities and prevented us from fully accomplishing our objectives, we nevertheless made constructive recommendations insofar as possible during the course of our review.

In those instances where we noted that undesirable conditions currently existed, we brought such conditions promptly to the attention of responsible officials so that appropriate corrective action could be taken. For example, as explained on page 73 of this report, we noted a deficiency in the THOR captive test program as a result of the failure of the Air Force to delineate responsibilities between the airframe contractor and the systems engineer and technical director. We brought this matter to the attention of Air Force officials and action was taken to correct this management deficiency.

Similarly, when we noted during the course of our review of the TITAN program that recommendations to incorporate storable fuels had not been adopted for a substantial period of time despite continuous urging by top scientists, we inquired as to the actions being taken in this matter by the Air Force. We were refused access to records covering Air Force considerations of this matter. In view of the fact that the ATLAS and TITAN are first-generation intercontinental ballistic missiles utilizing liquid propellants, and as the urgent need for an operational ICBM was reported by the Air Force as having been met by the ATLAS in September 1959 while the TITAN was not scheduled to be operational for some time, we recommended to the Air Force and the Department of Defense on December 4, 1959, that an appropriate evaluation be made to determine whether the TITAN should be converted to storable propellants at the earliest practicable date. We subsequently learned that the Air Force had actually approved the incorporation of storable propellants into the TITAN program during November 1959.

In certain instances, we noted serious deficiencies of a nonrecurring nature. In such instances, no remedial action could be taken but nevertheless our statutory responsibilites require that the matters be reported to the Congress. For example, the unwarranted delay in providing urgently required facilities for the

GAO AUDIT APPROACH

The Air Force states that our review was begun in April 1958 with the objective of developing and identifying "the major deficiencies and major problems in all aspects" of the ballistic missile program and that our report admittedly is "directed primarily to those aspects which appeared to warrant particular attention and is not intended to provide over-all evaluation of the program." The Air Force contends that this approach is not appropriate in a program of this importance.

It has been the customary practice of this Office, in carrying out its reviews of the operations of Government agencies, to place particular emphasis on any aspects suspected to require correction or improvement and on the means to accomplish it and to report findings and related recommendations to appropriate authorities and to the Congress. Our experience has repeatedly shown that this approach has led to a better understanding and recognition of problem areas and has resulted in highly significant improvements in Government activities.

Our review of the administrative management of the Air Force ballistic missile program was undertaken in this manner. However, the refusal by the Air Force to make available to us basic information, records, and reports has seriously handicapped our review. As stated in our initial report to the Congress on May 19, 1960, on this program, beginning on page 107, the Air Force denied us access to basic information, records, and reports, including reviews by responsible officials of the progress of the ballistic missile program and the steps taken to identify and correct problem areas and delays in the program. These restrictions not only

THOR captive test program described on page 37 of this report had a significant impact on the program and obviously warrants reporting to the Congress. Nevertheless, as the facilities have been made available, no recommendation for corrective action in this case is necessary.

Whether or not specific recommendations are made, we believe that the reporting of significant weaknesses serves a constructive purpose by alerting responsible management to improvements which may be necessary in current or future programs.

REVISION OF DRAFT REPORT

The Air Force commented on the changes between the preliminary draft report and the revised draft, stating that "each and every major finding advanced in the prior draft has been withdrawn."

As stated previously, because of the denial to us of certain essential records, the findings and conclusions in the preliminary draft report, in some instances, were of a provisional nature. These findings and conclusions were included in our preliminary report with the request that the Air Force include in its reply any additional facts appropriately documented. The Air Force did not furnish any specific information or documentation in its reply, and we confined our report to those findings on which sufficient conclusive data had been obtained to warrant reporting to the Congress. All the findings included in the revised draft were originally included in the preliminary draft but some revisions were made in view of subsequent program developments or additional information obtained.

The Air Force reply on the revised draft would have been much more helpful had it commented specifically on the contents of the revised draft rather than criticized the changes between the preliminary draft and the revised draft.

SCOPE OF REVIEW

Our review of the administrative management of the Air Force ballistic missile program was generally confined to the development phase of the THOR, ATLAS, and TITAN ballistic missile programs. We also made a limited review of certain aspects of the Army JUPITER development program. We have not reviewed the most recent major ballistic missile program--MINUTEMAN--or the various space programs associated with ballistic missiles.

When we began our review, the THOR IRBM was in a more advanced stage of development than that of the ATLAS and TITAN ICBMs, and we therefore selected the THOR program for initial review. Our review subsequently was extended to the ATLAS and TITAN programs. Our examination was directed primarily to those aspects which appeared to warrant particular attention and is not intended to provide an over-all evaluation of the program.

As explained in our initial report on this review, our review was seriously handicapped by the denial of access to essential records and the delays in making available to us those records considered releasable by the Air Force. To the extent possible under the conditions imposed, we reviewed the policies established by the Departments of Defense and the Air Force in developing ballistic missiles, the controls exercised at departmental levels, and the procedures and practices followed by the Air Force Ballistic Missile Division of the Air Research and Development Command and the Ballistic Missile Center, Air Materiel Command. We compared the program objectives with the program accomplishments. We also examined reports of congressional hearings concerning these programs. (UNCLASSIFIED)

Our review was directed primarily to the development and procurement of the missiles and did not include personnel-training operations, logistic support, or construction programs at operational bases or training sites. Our review was conducted at Headquarters, USAF; the Ballistic Missiles Complex,[1] Inglewood, California; the Air Force Missile Test Center, Cape Canaveral, Florida; and plants of 15 principal contractors engaged in the missile program. A limited review also was performed at the Army Ballistic Missile Agency located at Huntsville, Alabama. (UNCLASSIFIED)

Our review began in May 1958 with an audit of the THOR missile program. Early in 1959, we expanded our efforts to include the ATLAS and TITAN missile programs and a limited review of the JUPITER program. Although the major portion of our field work was completed in June 1959, we performed additional work in further consideration of questions raised in our field work and on related subsequent program developments. (UNCLASSIFIED)

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[1]Comprising BMD, BMC, SAC-Mike, and STL.

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