von Kármán Lectureship in Astronautics

The Fleet Ballistic Missile System: Polaris to Trident

R. A. Fuhrman
Lockheed Missiles & Space Company, Inc., Sunnyvale, California

Nomenclature

A1	1200-naut-mile Polaris missile
A2	1500-naut-mile Polaris missile
A3	2500-naut-mile Polaris missile
AX	development Polaris missile
A1X	preproduction A1 test missile
A2X	preproduction A2 test missile
A3X	preproduction A3 test missile
B3	large-diameter, 2500-naut-mile missile
C3	Poseidon missile
C4	Trident I missile
FBM	Fleet Ballistic Missile
ICBM	intercontinental ballistic missile
IRBM	intermediate range ballistic missile
Nobska	name of point of land near Woods Hole
Polaris	generic name for A1, A2, A3 systems
Poseidon	generic name for C3 systems
SINS	ship's inertial navigation system
SSBN	ship, submersible, ballistic (nuclear powered)
ULMS	Undersea Long-Range Missile System
Trident I	generic name for C4 system

I. Introduction

Prologue

The history of the Fleet Ballistic Missile (FBM) System is a story of national, program, and technical challenges; of Polaris-Poseidon-Trident systems; of their marriage with nuclear-powered submarines; and of their enduring role as a survivable and effective sea-based strategic deterrent. The FBM history is also a story of extraordinary leadership, management, team dedication, imagination, and ingenuity; and is an important example of the cooperative efforts of the government, industry, and independent research laboratories; of efficient utilization of available resources; and of outstanding achievement.

The Polaris concept was created in an atmosphere of growing alarm over an imminent Soviet strategic threat. The program began to take shape in 1955 in response to a sense of national urgency and the resulting directives to develop and produce a sea-based Strategic Weapon System. Early candidates included the Army's liquid-fueled Jupiter missile on surface ships and submarines. Critical warhead, propulsion, and inertial guidance technological projections pointed to a Polaris missile drastically reduced in size and weight and with the potential for launch from submerged submarines. During an usually brief time span (January 1957 to November 1960), the Polaris program proceeded from preliminary design to operational deployment at sea. The FBM System became operational on November 15, 1960 when the USS George Washington (SSBN 598) departed Charleston, S.C. on its first patrol with sixteen 1200-nautical-mile (n.mi.) Polaris A1 missiles.

The basic Polaris development and acquisition program was essentially completed when the forty-first (and last) FBM submarine (the USS Will Rogers, SSBN 659) departed on patrol on October 3, 1967 loaded with sixteen 2500-n.mi. Polaris A3 missiles. Thirty-one of the original forty-one submarines have since been designated for conversion and redeployment with Poseidon missiles. Currently, with the first Trident submarines under construction and the Trident I (C4) missile in development, the era of the Polaris and Poseidon is giving way to the era of Trident.

Robert A. Fuhrman is President of Lockheed Missiles & Space Company, Inc. (LMSC) and Senior Vice President, Lockheed Corporation. He was appointed a Fellow of the AIAA in February, 1978 and was awarded the von Kármán Lectureship in Astronautics. He joined the Missile Systems Division of LMSC in 1958 as technical staff head of Polaris System development. He advanced through positions of increasing responsibility and in 1969 became General Manager of the Missiles Division and a Corporate Vice President. He next served, successively, as President of The Lockheed-Georgia Company and The Lockheed-California Company. He returned to LMSC in 1973, and assumed his present position in 1976. Before joining Lockheed he was with Ryan Aeronautical Company, first as chief aerodynamics engineer and later as chief technical engineer. Mr. Fuhrman was in the Navy V-12 Program and was commissioned an ensign after graduating from The University of Michigan with a B.S. in aeronautical engineering. He also holds an M.S. in fluid mechanics and dynamics from The University of Maryland, and he attended the Executive Management Program at Stanford. He is a member of The National Academy of Engineering and The Space Engineering Board of the Academy's Assembly of Engineering, and is a director of The American Defense Preparedness Association and The Santa Clara County Manufacturing Group. Other memberships include The Cosmos Club, The Alabama Space and Rocket Center Science Advisory Committee, The National and American Management Associations, The Navy League (life member), Air Force Association, National Alliance of Businessmen (Business Advisory Board), and The Advisory Board for the Schools of Business at The University of Santa Clara.

Presented as Paper 77-355 at the AIAA 14th Annual Meeting, Washington, D.C., Feb. 7-9, 1978; submitted March 6, 1978.
Index category: Missile Systems.

The early progress of our strategic missile systems owes much of its success to extraordinary people. One of these individuals we honor on this occasion, a world-famous authority on the aerospace sciences, a teacher, and a pioneer – Dr. Theodore von Kármán. Dr. von Kármán's contributions during his illustrious career have provided us with research, teachings, and scientific foundations that have served us well and upon which we so heavily depend. His career also included a precursory participation in the FBM programs when, in 1942, he played a leading role in the establishment of Aerojet which later provided the solid-propellant boost systems for early Polaris missiles.[1] Dr. von Kármán played an even larger role in the early ballistic missile programs by leading the Air Force technical mission to Europe in 1945 to gather information on German aeronautical and missile achievements. By the end of 1945, he had produced the report, "Toward New Horizons," which served as a basis for Air Force research. He was also Chairman of the USAF Scientific Advisory Board in 1949 and 1950 when the Air Force was progressing toward the development of the Atlas missile.

In 1952, as a junior Navy representative, I had the opportunity to participate in a NATO Advisory Group for Aeronautical Research and Development meeting in Rome under the leadership of Dr. von Kármán. I was impressed by that meeting and recall with pride that occasion and my brief association with Dr. von Kármán.

There are, of course, thousands of people who contributed greatly to the success of the FBM program. Each deserves praise. Each sees the history of the FBM System a little differently from his vantage point. Each is part of a vast array of talents which come from many branches of the government, the military services, industry, and the intelligence-scientific-academic communities. Among them, too, are the officers and men of the FBM submarine crews – a special group to whom we owe tribute.

It has been personally gratifying for me to have had the opportunity to be a member of the team participating in the development and deployment of the FBM System. For over sixteen of these past twenty-plus years, I have had direct technical and management involvement in the program at Lockheed. My participation has ranged from establishing the early requirements as one of the systems engineers to directing those functions; from serving as a member of the Missile Committee of the FBM Steering Task Group to being a member of the Steering Task Group itself; and from being Chief Engineer and Poseidon Program Manager for Lockheed, to other management assignments. My own sense of appreciation for the accomplishments of this exceptional team comes from first-hand experience.

Genesis of the FBM

The era of the FBM began in early 1955 as the result of an evaluation by the National Security Council of the potential of the United States to retaliate if attacked by the Soviet Union. In its report, published in February 1955, the Council stressed the urgency of the intercontinental ballistic missile (ICBM) program.[2]

In addition, it recommended development of an intermediate range ballistic missile (IRBM) to be launched from overseas land bases and from the sea. Because of the compressed development time scale, it was believed that the many severe problems associated with long-range intercontinental missiles, particularly the difficult guidance and re-entry requirements, would be more readily solved with missiles of shorter ranges. Initially, potential sea-based deployment concepts primarily focused on surface ships, with applications to submarines as a secondary consideration.

In conformity with the 1948 "Key West Agreement" on service roles in nuclear warfare, ICBM's had been assigned to the Air Force.[3] The Army was authorized to develop the 1500-n.mi. IRBM Jupiter in competition with the USAF Thor. The Navy at this point had no defined role in ballistic missiles, although a V-2 had been launched from the deck of the aircraft carrier USS Midway in September 1947.

But in the summer of 1955, the "Killian Report" (following the earlier National Security Council paper) suggested, and the National Security Council recommended, that part of the IRBM force should be sea-based.

Consequently, the Navy was directed to design a sea-based support system for the liquid-fueled Jupiter missiles.[4] The Secretary of Defense directed the Army and Navy to proceed jointly with the development of IRBM No. 2 (Jupiter) and also established the Joint Army-Navy Ballistic Missile Committee. The Department of Defense further proposed that the IRBM program be assigned a top priority equal to the ICBM program and that all aspects of the program move forward with urgency.[5]

On November 17, 1955, the Secretary of the Navy defined the Navy's role and created the Special Projects Office to handle the problems associated with the ship-launched weapon system.[6] Development responsibility for the missile which would satisfy both Army and Navy requirements remained with the Army Ballistic Missile Agency. Shortly thereafter, the Secretary of the Navy reaffirmed the Navy's highest priority for a sea-based IRBM, subsequently referred to as the FBM System, and established the Navy Ballistic Missile Committee.

Thus, the Special Projects Office, previously charged with the development of the ship installation of the Jupiter missile, was then given responsibility for development of the entire sea-based system and installation of the Jupiter missile.

II. National Challenge

- Military Need and National Commitment
- Revolutionary Weapon System Concept
- Innovative Management Approach

National Objective

The objective was to develop an intermediate range (1500-n.mi.) surface-to-surface ballistic missile system which would be an offensive Naval weapon system for use against land targets. The Jupiter missile was to be the basis for the program. Future applications to submarines were to be considered. The initial surface ship-launched version of this system was to be available for operational evaluation by January 1, 1960. A submarine-launched version was to be ready for operational evaluation by January 1, 1965.

Management Concept

New bold approaches were clearly necessary in view of the national priority and commitment, the urgency, the ambitious goals, and the immensity of the task. The need for delegated authority, management innovation, adequate funding, technological advances, and inspired people was recognized as essential to early and sure success.

Rear Adm. W. F. Raborn Jr., USN, was selected on December 2, 1955 to command the Special Projects Office and he was given the broad responsibility and top priority to develop an FBM System. Rear Adm. Raborn was to report directly to the Secretary of the Navy; his "orders" were contained in a classified letter outlining his authority and the guidelines for accomplishing his task.[7] His instructions were to "move fast," recommend courses of action to the Chief of Naval Operations relative to the need for money and people, generate support for the program, and provide weekly progress reports (because the President of the United States expected monthly reports). From that point on, it was "all ahead flank." This authority, combined with the full personal backing of the Secretary of the Navy and the Chief of Naval Operations, the sense of national urgency, and the unqualified support of the government-industry team, were the prime contributors to the success of the FBM program.

The basic management concept established during the first year and effectively adhered to throughout the entire program was based on nine firm principles: 1) vertical organization, 2) compact team, 3) clearly understood responsibilities, 4) sharp interface definition, 5) detailed planning and coordination, 6) uninhibited communications, 7) independent evaluation, 8) centralized financial control, and 9) management by objective. With these principles and a "hand-picked" organization with a ceiling of forty officers, "Red" Raborn directed the team whose methods, authority, and ultimate achievements were to become outstanding in Navy history.[8]

A Navy Concept

The Navy's initial task was to integrate the Army's liquid-fueled Jupiter IRBM into a shipboard weapon system with as little change to the land-based system as possible. The Navy expressed concern over the missile's original envelope of about 90 feet in length and 95 inches in diameter and countered with a proposed 50-foot length and a 120-inch diameter. Secretary of Defense Charles Wilson worked out a compromise for a missile of about 58 feet in length and 105 inches in diameter. However, the Navy also recognized that the logistic, safety, launching, and operational problems inherent in large liquid-fueled missiles might be the Achilles' heel in its opportunity to deploy a strategic ballistic missile system. In addition, the Navy was particularly concerned with two significant operational features. The first was that cryogenic liquid-fueled missiles could not be fueled much in advance of firing and the fueling process was a long and complicated one. Also, the interval between the firing command and actual launch could be hours or as much as one day. The second was that relatively slow missile acceleration at liftoff from a moving ship in various sea states could cause significant problems. Therefore, in the Navy's view, liquid-fueled systems were contrary to the objective of a "ready" missile – simple, rugged, and reliable, or as Raborn said, "like a cartridge in a gun."

The Special Projects Office began to formulate an approach which it hoped would convince the von Neuman Committee (Secretary of Defense Scientific Advisory Committee) and the Secretary of Defense Ballistic Missile Committee that the Navy should develop an alternate solid propulsion system. Rear Adm. Raborn called upon his former Bureau of Ordnance associates and the solid-propellant community to prepare the "case" for solids.

Propulsion experts developed the conceptual solutions, preliminary designs, tradeoff analyses, and plans to support a full-fledged solid-propellant motor development program in preparation for this proposed change in direction. Thrust vector control and thrust termination had never been demonstrated for the application to solid propellants in IRBM's, but were resolved, at least on paper. Studies of clustered motors, staging ratios, and advantageous trajectories for a solid-fueled missile had been conducted. The Navy's background in solid propellants and projections of the state-of-art gave further support to the readiness of solid-propellant technology. The results of these studies were successively presented to the decision makers at many levels within the Navy and the Department of Defense. Finally, in March of 1956, approximately four months after Special Projects Office initiation, the Navy was authorized to proceed on a solid-fueled "back-up program," which received the designation Jupiter S. Two deployment modes were contemplated: a surface ship-launched system to be ready for operational evaluation by January 1, 1960, and a submarine-launched system to be available five years later.[9]

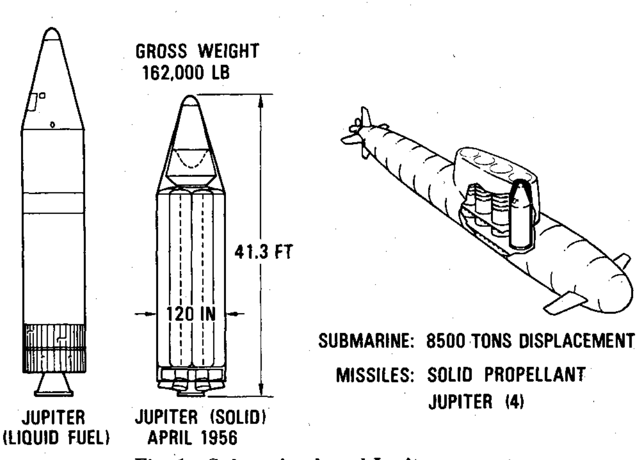


Fig. 1 Submarine-based Jupiter concept.

At this time, Capt. Levering Smith reported for duty with the Special Projects Office to direct the development of the missile and the solid-propellant boost propulsion system. Capt. Smith, as one of the Navy's leading propulsion experts, played a key coordination and integration role in the evaluation of total system problems and in the utilization of these rapidly developing technologies.

Applying the proven solid-propulsion technology of 1956 to deliver a 3000-pound payload 1500 n.mi. resulted in an extremely large vehicle. The "solution" was a two-stage missile, in which the first stage was a cluster of six motors, each 40 inches in diameter, surrounding a similar single motor of the same dimensions which served as the second stage. It was known that this staging ratio (6:1) was inefficient, but the motor size selected represented the largest available at that time. The overall diameter of the missile was 120 inches and its weight was estimated to be about 160,000 pounds.[10] Although shorter than the liquid-fueled Jupiter, the solid system exceeded the liquid in both diameter and weight. Preliminary design studies based on this solution showed that a reasonable submarine configuration of 8500 tons could carry only four missiles (see Fig. 1).

The Polaris Missile Concept

During the summer of 1956, several study groups were convened to analyze the key operational and development issues. Two noteworthy efforts included a National Academy of Sciences study (Project Nobska), sponsored by the Office of Naval Research, and a study by the Weapons Planning Group at the Naval Ordnance Test Station at China Lake (now the Naval Weapons Center). Project Nobska was to consider ways of defeating a Soviet nuclear submarine threat by first estimating the characteristics and capabilities that the Soviets could plausibly build into their future nuclear-powered submarines, including the potential for ballistic missiles. The objective of the China Lake study was to postulate what damage capability would accomplish deterrence and what characteristics and technologies could be projected for a more efficient second-generation (post-Jupiter) missile. Synthesizing the findings of these two study efforts led to projections of potential Soviet nuclear submarines and submarine-launched ballistic missiles. As a consequence, U.S. submarines and solid-propellant missiles were also characterized. At Nobska, Dr. Edward Teller from the Atomic Energy Commission asked a simple and vital question – "Why are you designing a 1965 weapon system with 1958 technology?" He predicted dramatic reductions in warhead weight for an acceptable yield, and presented historical data to support those predictions. The potential of a warhead, whose weight and volume were a fraction of the Jupiter system, was sufficiently enticing to cause a preliminary missile design to be created. The specific impulse of future propellants and the weight of an advanced all-inertial guidance system, combined with the critical warhead and re-entry body characteristics, resulted in a two-stage solid-propellant missile configuration in the 30,000-pound class.[11]

In the meantime, the Secretary of Defense's Scientific Advisory Committee, by mid-July 1956, had recommended 1) a full-fledged solid-propellant missile program, and 2) cancellation of instructions that the Jupiter nose cone, guidance, and control components be used with the solid-propellant vehicle – because their suitability to this application was questionable.

Performance projections for this 30,000-pound class missile were provided to the Chief of Naval Operations, Adm. Arleigh A. Burke, immediately following the transmission of Dr. Teller's warhead predictions on September 4, 1956. Adm. Burke requested that the Atomic Energy Commission certify the warhead projections. In parallel, Capt. Levering Smith was asked to provide, within two weeks, in conjunction with contractor support from Lockheed and Aerojet, an assessment of the missile size and weight. A preliminary estimate (which turned out to be within 10% of the Polaris A1 actual weight) was provided in one week. At the same time, the Atomic Energy Commission responded with unconditional support. Encouraged by the study results and performance projections, the Scientific Advisory Committee recommended that the Navy solid-propellant IRBM program be assigned top priority and that its final objective be the development of a missile in the 30,000-pound class capable of a range of 1500 n.mi. in the mid-1960's time period. Rear Adm. Raborn named it Polaris and the program was underway before the more formal envelope and performance estimates were derived.

A study group was assembled in October 1956 to develop the plans and identify the tradeoffs required to select the envelope parameters necessary to enable concurrent development of the submarine and the weapon system. The study group included key executives from Navy, industry, and academic organizations. Each individual was authorized to commit his parent organization without lengthy referral to higher management. The actual selection of the parameters and resultant systems was to be accomplished by a Special Task Group six months later.

This study supported the initial estimate that a 30,000-pound configuration would deliver the postulated warhead to a range of 1500 n.mi. if a two-stage solid-propellant configuration with the projected performance characteristics could be developed (see Fig. 2).

Armed with the optimistic projections of the Special Projects Office, the Secretary of the Navy recommended, in November 1956, that the Navy terminate participation in the Jupiter program and concentrate its efforts on Polaris.[12]

This recommendation was approved by the Secretary of Defense on December 8, 1956, signifying the official beginning of the Polaris development program.

III. Program Challenges

- An Interim 1200-n.mi. Capability by Late 1960
- A Fully Operational 1500-n.mi. System by Mid-1962
- A 2500-n.mi. Missile by Late 1964

Basic Plan

The original directives had specified the development of a surface ship capability to be delivered for evaluation by January 1, 1960 and a submarine version by January 1, 1965.

As redefined by the Special Projects Office in May 1957 (five months after development go-ahead), the program called for an interim submarine capability by January 1, 1963.[13] The interim system was to provide a 1200-n.mi. missile range, a surface launch, and provisions for adaptation to a surface combatant ship. The fully operational submarine system was to provide a 1500-n.mi. missile range and a submerged launch capability by January 1, 1965. In June 1957, the Chief of Naval Operations approved the recommendations of the Special Projects Office's Special Task Group for both surface and underwater launch capabilities. However, funding for the surface ship application was deferred and never restored.

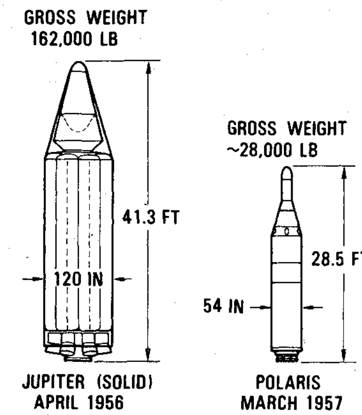


Fig. 2 Evolution from Jupiter to Polaris.

Growing Alarm and Program Acceleration

Continuing evidence of Soviet missile and nuclear weapons progress had created a growing demand for acceleration in the development of U.S. missiles. The Russian launching of Sputnik I on October 4, 1957 also increased pressure on the U.S. space effort and the Polaris program. Thus, the program was again redirected in late October-November 1957 emphasizing an accelerated and augmented Polaris program. The interim capability was advanced two years and the operational system availability date of the Polaris Model B was advanced one and one-half years to June 1963. The interim capability was designated as the Polaris A1 with production missiles to be deployed in June 1961. Submarine application and submerged launch were required.[14,15] Later directives specified deployment of the 1000-n.mi., or greater, A1X test missile by April 1960 if emergency measures were invoked; and deployment of Polaris A1 was adjusted to November 1960.

In February 1959, objectives for future systems specified that the deployment of the 1500-n.mi. Polaris A2 (previously known as the Polaris B) be accelerated to April 1962. The directives also introduced the requirement for an advanced operational capability of a new generation 2500-n.mi. missile. This 2500-n.mi. capability was originally referred to as a "C" missile and later redesignated as Polaris A3 with deployment planned for mid-1964.[16,17]

In summary, the Polaris A1, A2, and A3 systems were rescheduled, delivered in less time than originally allocated to the first generation, and met all their respective program and performance objectives (see Fig. 3).

IV. Management and Technical Challenges

- Submarine-Launched 30,000-Pound Solid-Propellant Missile to 1200 n.mi. in Less Than Four Years
- Ship-Installed Launcher, Fire Control, and Navigation Equipment to Meet Submarine Construction Schedule

Weapon System Goals

The challenge was set by the simple statement of the FBM System operational requirement specified in February 1957: "provide an all-weather capability to deliver from ships to strategic land targets at intermediate ranges, with minimum susceptibility to countermeasures, a weapon which will provide the required damage probability." In addition to the numerous challenges implicit in the selected submarine approach in terms of volume constraints, special environments, and access limitation, specific technical challenges were also issued as performance objectives, warhead yield, and system accuracy. Fire control and launching readiness, and reaction-

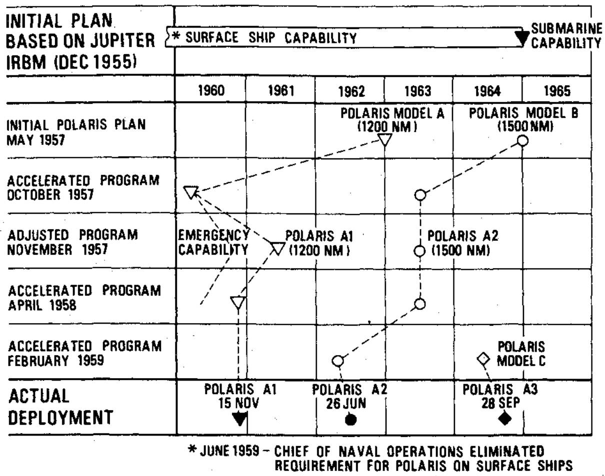


Fig. 3 Polaris milestones.

time goals were defined. More general goals for cost, simplicity, and reliability were also stated.[18,19]

Strategic Weapon System

Developing all elements of the Strategic Weapon System concurrently on a schedule compatible with the new submarine presented a significant program management challenge. It also presented a major technical challenge, calling for early definition and commitment of many physical and functional interfaces. Functional subsystems of the Strategic Weapon System were established to clearly defined interfaces which also defined the organizational structure of the Special Projects Office. They remain so to this day. Within the Special Projects Office (circa 1957) the technical branches included Launcher, Missile, Fire Control and Guidance, Ship Installation, Navigation, and Operations & Test. The Special Projects Office organization and supporting contractor team is basically the same today (see Fig. 4).

Operational Concept

The operational concept was straightforward – submerged patrol for approximately sixty days (originally from the continental U.S.) with a full complement of missiles which could be launched from the submerged position toward specified targets within a defined time interval following receipt of the order to fire. Operational support between patrols would be provided by "dedicated" submarine tenders. In order to maximize time on patrol and be consistent with human endurance for such specialized and demanding submarine operations, two crews (Blue and Gold) would alternate manning the ship for successive patrols. This concept was borrowed from the British system of alternating full crews on ships assigned to Asiatic stations and was modified for FBM applications. The concept continues on current operations.

Technical Concept

The operational concept gave rise to several key elements of the technical approach which, in turn, generated significant subsystem challenges: 1) in order to maximize missile performance in the constrained volume permitted by the submarine, missile design-limit loads would derive from underwater or atmospheric flight loads while ship and launcher shared the burden of maintaining an environment compatible with this approach; 2) to maintain the missiles in a dormant state, they would be isolated from any source of significant power until the final stage of "readiness to launch" when the muzzle hatch would be opened and the missiles launched by ejection; 3) motor ignition would be delayed until well clear of the submarine to maximize submarine safety; 4) missile readiness testing and limited access for selected package replacement aboard the submarine would be provided to assure system operational readiness during the sixty-day patrol; 5) because the launch platform would be constantly moving, navigation would continuously feed initial conditions to fire control and fire control would continually update missile guidance for accuracy until the moment of launch; 6) to minimize missile inert weight and increase reliability, nothing would be calculated in flight that could be calculated aboard ship by fire control; and 7) finally, because a submarine requires weight and buoyancy control to stay submerged, the lost weight from launched missiles would be replaced by backflooding the empty launcher[20] (see Fig. 5).

Missile Challenges

Development of a missile that would meet the objectives established by the Special Task Group in the spring of 1957 together with the planned operational concept required that responsible government agencies and contractors jointly commit to significant advances in many technical areas. Among these were:

1) Development of a missile configuration which would be compatible with the handling, stowage, launch, and flight environment (both underwater launch and aerodynamic loads which coincidentally were about equal), and which could attain controlled aerodynamic flight after the air-water-air transitions of launch ejection, underwater travel, and surface broach prior to motor ignition.

2) Development of large high-performance solid-propellant rocket motors which could vary and control the direction of the thrust vector (flight path control) and terminate forward thrust with precise timing (velocity control).

3) Development of a compact, lightweight, and accurate inertial guidance system which would be compatible with techniques for erection, alignment, and initialization on a constantly moving platform.

4) Development of missile electrical and electronics systems for power distribution, flight control, ignition events, stage separation, and safety functions which would also include missile-borne instrumentation and range safety provisions critical to understanding the behavior of the unmanned and nonrecoverable missile using so many new technological applications.

5) Development of an efficiently small and relatively lightweight warhead and re-entry system applicable to IRBM ranges which could be dependably and accurately separated from the missile when forward thrust was terminated.

Weapon System Challenges

Development of a Strategic Weapon System incorporating the Polaris missile presented innumerable technical challenges to the team of subsystem designers. Included were:

1) Developing techniques for handling and protecting the missile during "strikedown" (lowering) of the missile into the launcher and rotationally indexing it to assure alignment of accesses, umbilical connections, and optical paths.

2) Developing environmental conditioning for major equipment as well as the missile, including controlled temperature, pressure, humidity, acceleration, vibration, and shock extremes, up to the potential shock levels from antisubmarine depth charge attack.

3) Determining the orientation of the sixteen separate missile-guidance inertial platforms with respect to the ship's navigational reference frame to support accurate fire control computations.

4) Acquiring and maintaining accurate navigation data needed to prepare missiles for firing, based on knowledge of the submarine's position, heading, and velocity, even after being submerged for long periods.

5) Preparing the missile for launch and assuring, with confidence and safety, a properly functioning missile prior to launch.

6) Maintaining a controlled (dry) missile environment in the launcher throughout the launch readiness phase including

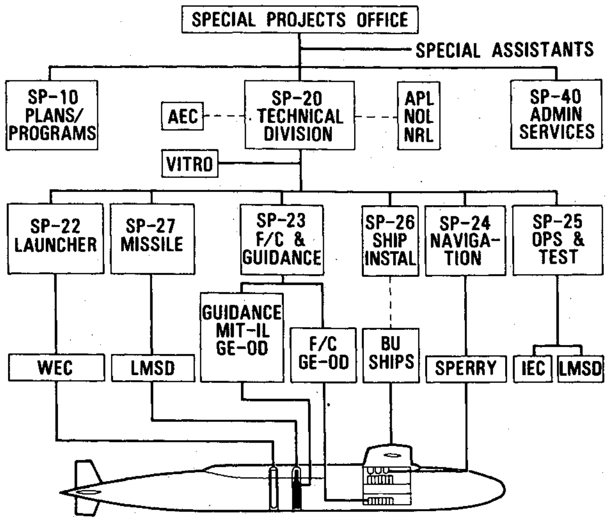


Fig. 4 Special Projects Office organization—1957.

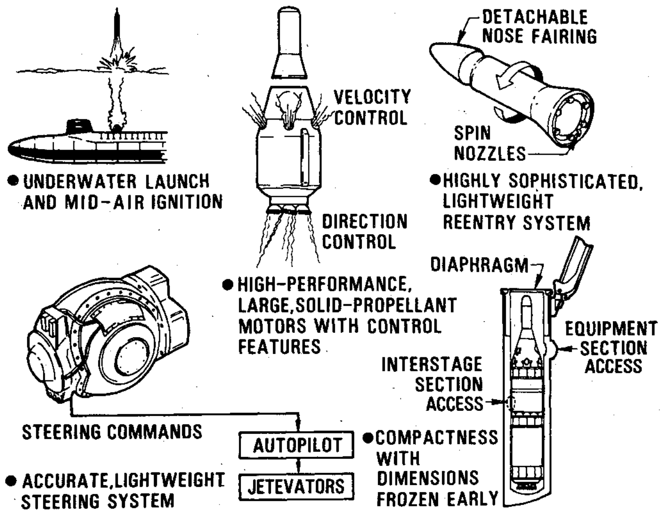


Fig. 5 Polaris areas of technical creativity.

"muzzle hatch open" until the ejected missile enters the water as it emerges from the launcher.

7) Controlling the launch eject pulse within flight-derived design limit structural loads and propelling the missile from launch depth through the water and into the air above, prior to ignition and self-controlled flight.

8) Developing equipment and procedures for preparing missiles for firing, for verifying missile condition, for determining proper trajectories and required thrust termination velocities, and for firing sixteen Polaris missiles at up to sixteen selected targets at varying ranges within a period of minutes.

9) Providing weapon system level instrumentation which could acquire and record system performance data aboard the submarine during installation and operational performance tests without introducing bias into the critical function.

10) Maintaining interface compatibility to assure interchangeability of the Polaris missile into any launcher in any FBM submarine.

11) Developing compatible communication techniques to make it possible to stay in constant touch with a submerged submarine on-station anywhere in the world's oceans.

Design Concepts

The management and design philosophies evolved during the early Polaris program were probably unique in that they contributed significantly to the creation of Polaris by 1) setting minimum performance goals and target values based on specific missile envelopes and predicted technological growth, and 2) encouraging the flexibility to tradeoff underachievement in one system with overachievement in another area. This was particularly true, for example, in trading-off propellant specific impulse with missile inert weight and in trading-off missile, fire control, and navigation error contributions for an overall system accuracy.

Missile

The basic missile concept was primarily described as a submarine-launched (by ejection) solid-propulsion ballistic missile. The missile was to be maintained within a controlled environment, would be essentially dormant until prepared for launch, and would be maintainable at sea.

Under the technical direction of the Missile Branch of the Special Project Office, Lockheed was responsible for providing design, engineering feasibility demonstrations, concept verification, models and mockups, and plans for the engineering development of the Polaris missile system (less guidance), including the re-entry system and the missile test and readiness equipment.

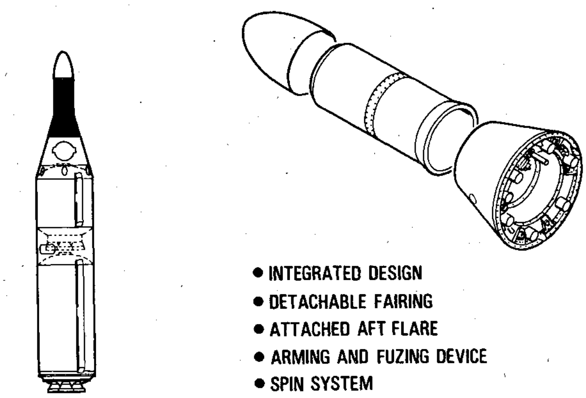


Fig. 6 Polaris A1 re-entry system.

Re-entry Body

The re-entry body, containing the warhead, was to separate from the equipment section on command from guidance with separation occurring at the re-entry body aft flare and equipment section interface. The ejected re-entry body was to continue on a ballistic trajectory and detonate at a predetermined height over the target (see Fig. 6).

It was apparent from the outset that an integrated warhead re-entry body design approach offered the only hope of achieving a Polaris goal of a re-entry body weight which was 30% of the weight of the 3000-pound Jupiter payload. Polaris adopted the then-unique and unconventional approach of integrating the design of both Atomic Energy Commission and Department of Defense components. Designs and materials were selected for their compatibility with dual use, such as for structural integrity and thermal protection. This approach led to weights and volumes consistent with the original predictions and a re-entry body weight of less than 900 pounds. The vital program was directed by Lt. Robert Wertheim, Head of the Reentry Section of the Missile Branch of the Special Projects Office (now Rear Adm. Wertheim, Director of the Strategic Systems Project Office). Integrating the re-entry body design and development was another excellent example of the principals working together. Under the technical direction of the Special Projects Office, the re-entry body design by Lockheed, the arming and fuzing by the Naval Ordnance Laboratory, White Oak (now the Naval Surface Weapons Center), and the warhead by the Livermore Laboratory of the Atomic Energy Commission (supported by the Sandia Corporation, Albuquerque) verified Dr. Teller's earlier projections.

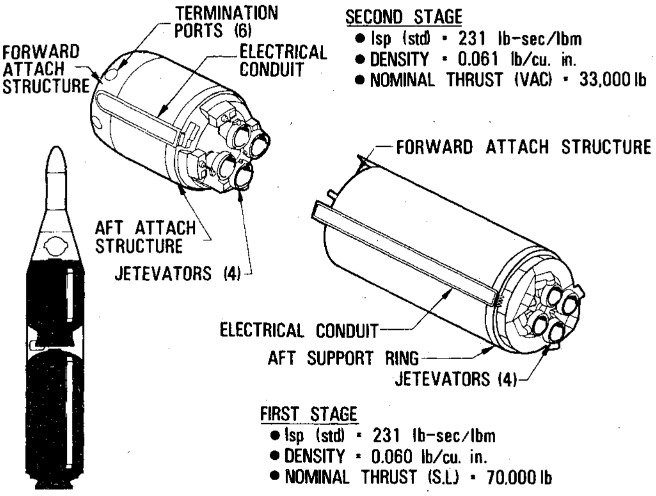


Fig. 7 Polaris A1 propulsion system.

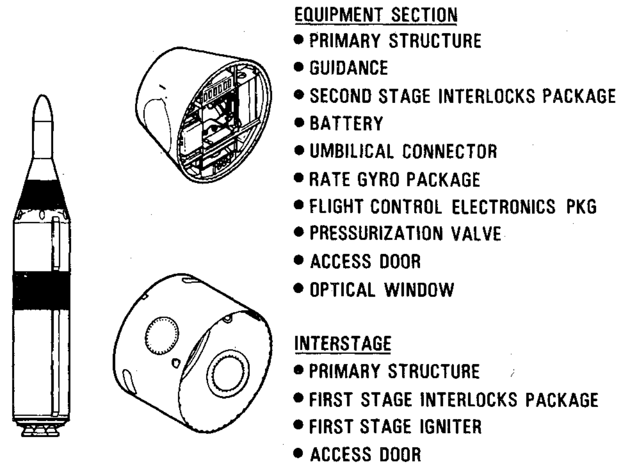


Fig. 8 Polaris A1 structures.

Propulsion

The propulsion system was to consist of first and second stage solid-propellant rocket motors mounted in tandem and fired sequentially. In additon to providing thrust to the missile, the motors were to serve as primary structural members in the overall missile body. Each stage was to include a motor chamber, case-bonded solid propellant, four nozzles with jetevators for thrust vector control, an igniter assembly incorporating a safety and arming device, and an igniter adapter to make the motor initially nonpropulsive, as well as structural provisions for attachment to the missile. Early development was to concentrate on high-energy propellants with satisfactory ballistic and mechanical properties; reduced inert weights; a jetevator vector control installation; and reliable thrust termination, ignition, and safe-arm concepts (see Fig. 7).

Missile Guidance

The missile was to utilize an all-inertial guidance concept which was to supply pitch, yaw, and roll attitude references, steering commands to the flight controls, an in-flight safety signal for arming and fuzing initiation, and a re-entry body ejection signal when the proper missile velocities were achieved.

The initial design of the missile guidance system was performed by the Instrumentation Laboratory of the Massachusetts Institute of Technology (now the Charles Stark Draper Laboratory) with industrial support from General Electric - Ordnance Department (now General Electric - Ordnance Systems). The digital guidance system proposed by Dr. Charles Stark Draper was an extension of ballistic missile inertial guidance technology developed for Atlas and Thor missiles. The proposed system was appreciably lighter than the Jupiter system (by a factor of six), smaller than those then existing, and fundamental to the feasibility of the Polaris concept.

Implicit guidance formulations were selected to reduce the complexity of in-flight computations and were mechanized to direct a predetermined missile flight path to minimize aerodynamic loads as a function of time from launch. The first-stage flight path was also selected to minimize angle of attack, control, and structural problems at stage separation. The relatively simple guidance mechanization controlled pitch attitude by Z-dot (dz/dt) steering equations during first-stage flight, stage separation, and early second-stage flight, for a total of about 72 seconds. This concept resulted in the AIAA Sperry Award for its Lockheed inventor.

Once safely out of the atmosphere, guidance equations were switched to velocity-to-be-gained cross product steering which used a vector cross product implementation to derive an angular velocity command signal proportional to the angle between the indicated thrust acceleration and the velocity-to-be-gained vectors. The command signals were sent to the flight control electronics (autopilot) and on to the thrust vector control to loft or deloft the missile and drive all components of the velocity-to-be-gained toward zero, causing a command to terminate thrust and separate the re-entry body.

Missile Structures

Missile structures were to include the first- and second-stage ballistic shells and the nose fairing. The first, or interstage section, was to be located between the first- and second-stage rocket motors. The second, or equipment section, was to be located between the second-stage motor and the re-entry body. The nose fairing was to cover the forward face of the re-entry body (see Fig. 8).

Design Solutions

Novel concepts applied to the missile required verification before preceeding with development. Among others, these included the following:

1) Stowage/launch adapters were appended to the missile in three circumferential rows to serve as missile guides when lowering (strikedown) or launching the missile and to provide lateral shock support of the missile in the launch tube. The bottom row also provided a seal to prevent "blowby" of ejection pulse gases during launch.

2) Efficient utilization of the lightweight equipment section, interstage, and rocket motor chambers as primary structures had to be compatible with all assembly, stowage, launch, and flight conditions.

3) A basically unstable hydrodynamic missile configuration had to be ejected with sufficient velocity over a range of launch depths to reach the surface of the ocean (without booster ignition or active controls) within acceptable pitch/pitch rate and axial load factor limits.

4) Adequate thrust vector control deflection and angular rate, following booster ignition, were required to "capture", stabilize, and control the missile.

5) A one-atmosphere airspring for ejecting the separated re-entry body from the booster at the moment of forward thrust termination and structural separation in conjunction with an airtight equipment section with relief valve pressure control was provided to accommodate pressure differences of submerged or surface launch.

6) Venting of rocket motors and some structures and equipment to the ambient allowed lightweight designs in a pressurized (and pressure changing) environment. Provisions for venting were such that water ingress during underwater travel would be minimal and not detrimental.

7) The unshrouded (except for the hydrodynamic/aerodynamic shaped nose fairing) re-entry body was an integral part of the missile external contour. The nose fairing, taped on to provide re-entry body nose protection during handling as well as for basic fluid dynamic reasons, was ejected by airspring in space after the tape burned off during exit heating and the dynamic pressure dropped sufficiently.

8) A structural flare section was attached to the aft end of the re-entry body to provide aerodynamic damping at re-entry and stabilization during descent.

9) Unique electrical connector designs precluded water shorting of the umbilical pins when exposed to sea water during launch.

10) Pyrotechnic cutting (primacord) of the interstage and re-entry body aft flare provided for accurate stage separation.

Fire Control

By mockup, simulation, and full-scale demonstration, the General Electric - Ordnance Department verified selected approaches to its two most significant problems which involved 1) sufficiently accurate geo-ballistic trajectory computations to meet system accuracy goals within available shipboard space and operational time, and 2) accurate determination of the azimuth relationship between the missile guidance pitch axis and the ship's navigation reference system to make possible guidance alignment during missile launch preparations.

Fire control was caught between two extremes since 1) real-time computation based on continuously changing navigation inputs involved an excessively large computer (with the technologies of the late 1950's) with the risk of excessive down time, and 2) direct input of precomputed initial conditions based on a very fine patrol area grid system without onboard intermediate computation involved a punched card library that would not fit the submarine. However, a happy compromise was reached when a fairly coarse grid of patrol area launch squares was used with precomputed card inputs for the center of each square followed by computer interpolation for the exact submarine position and heading within the square. This system fit the submarine and worked very well.

An optical system provided a stable optical path between the ship's reference and a prism mounted in each missile guidance system. Using autocollimation and rail-mounted travelling optical carts that could be positioned to observe the missile guidance porro prism through the optical glass windows in each missile mount tube and in each missile, the system proved it could accurately measure the critical axis relationships between the widely separated ship's inertial navigation system (SINS) and guidance system.

To provide the trajectory computations, fire control also required earth and atmospheric models, and target information. The target data was generated ashore at the Naval Proving Ground, Dahlgren (now the Naval Surface Weapons Center) and was brought aboard the early submarines in the form of punched cards.

Navigation

As early as 1951, Sperry Gyroscope (now Sperry Systems Management) had conducted studies of advanced versions of the Mk 19 gyrocompass and Dr. Charles Stark Draper of the Massachusetts Institute of Technology had begun development of a self-contained inertial navigation system. By September 1956, Sperry, later chosen as industry manager for Navigation Systems, had delivered an experimental SINS, based on the Massachusetts Institute of Technology design, for engineering tests aboard the surface ship USS Compass Island.

At-sea testing demonstrated the potential of both the Sperry version of SINS and an alternate design by NAA Autonetics to meet the critical navigational requirements. The Special Projects Office decided to install three SINS in each submarine with a computer monitoring and evaluation capability to preserve the critical navigation function in the event of equipment malfunction or system disagreement.

Because of inevitable gyro drifts, periodic updating of SINS was necessary and a variety of techniques and external aids would have to be utilized—including star tracking, radiometric sextants, various radio navigation systems, and later the Navy Navigation Satellite System (TRANSIT) developed by the Applied Physics Laboratory of the Johns Hopkins University.

With this concept of multiple fix sources and a continued drive to improve the critical inertial navigation system, the FBM submarine would be able to navigate anywhere submerged. With systems similar to the FBM SINS, the submarines USS Nautilus and USS Skate were guided on their historic voyages beneath the polar ice in 1958 and the USS Triton on her eighty-four day underwater cruise around the world in 1960.

Launcher

Underwater launch and transition through the ocean's surface was unique to Polaris. Many alternative launch concepts were evaluated and tested. Participants included the Naval Ordnance Test Station, Lockheed, David Taylor Model Basin (now the Naval Ship Research and Development Center), Aerojet at Azusa, and Westinghouse Electric Corporation. Westinghouse, under the technical direction of the Launcher and Handling Branch of the Special Projects Office, developed the full-scale experimental and prototype launchers for surface tests at the San Francisco Naval Shipyard, Hunters Point, and for submerged launches off San Clemente Island.

Launcher experiments moved rapidly from scale models to full-scale launch of redwood logs into San Francisco Bay from the "Peashooter" test facility at the San Francisco Naval Shipyard. Initially, inert test vehicles provided by Lockheed were also launched into the bay to be recovered and refurbished for additional testing. To differentiate between missile damage which could have occurred during launch, such as failures of base-mounted hardware or tipoff contact with the launcher muzzle lip, and damage resulting from fallback into the bay, an overhead crane with an aircraft carrier arresting system, "Skycatch", was developed. This system reeled up slack in a missile tether and arrested missile fallback in mid-air. Pulse characteristics, plenum chamber requirements, and environmental compatibility with the missile were all explored to confirm the selected compressed-air blowdown ejection technique.

Underwater launch testing began at the "Popup" test site of the Naval Ordnance Test Station's underwater test range near San Clemente Island. Here, environmental simulation approached the real thing. The ability to preserve the dry in-tube environment with an open muzzle hatch was demonstrated with a diaphragm seal across the launcher muzzle and a small positive differential between internal tube pressure and external sea water pressure at launch depth. A floating crane, appropriately referred to as "Fishhook", provided a capability to arrest and retrieve test vehicles. Originally capable of fixed submerged launch, the facility later provided a moving submerged launch capability. Missile response to sea states and surface waves at broach was confirmed through the courtesy of Navy-cruiser generated waves over the test site on request. Validation of the launching concept was proved by the launch of a Polaris launch test vehicle. The launch test included a cut-grain (short burn time) first-stage motor which successfully ignited and established flight control prior to burn out.

A "ship-motion simulator", built by Loewy Hydropress, was installed at Cape Canaveral to duplicate the pitch, roll, and heave of a range of surface launch conditions and sea states. A missile launch tube was installed in the ship-motion simulator and launches were conducted to demonstrate

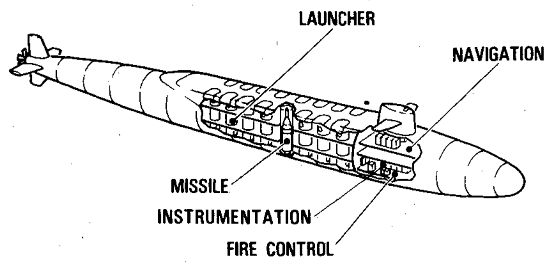


Fig. 9 Polaris submarine.

missile behavior in a surface environment. Since underwater launches from an SSBN were less affected by such environments, use of the ship-motion simulator was discontinued in the later programs.

Instrumentation

Test instrumentation installed aboard the submarine was used for acquiring, processing, and recording weapon system performance data and for checking out missile equipment during installation and performance tests of the FBM System. Primary functions included verifying the operation of missile-borne telemetry, flight safety transponders, and beacons prior to launch, and acquring missile telemetry data, as well as data related to fire control, ship, launcher, navigation, and missile test and readiness equipment functions during countdown. The desirable attributes included real-time monitoring, remote signal sources throughout the submarine, "quick look" capability, autocalibrations, self-test, and provisions for automatic alarms.

The Submarine

One major decision which required the resolution of a number of conflicting claims concerned the number of missiles per submarine. The preliminary design effort had already shown that submarine cost was quite insensitive to the number of missiles up to thirty-two. The principal effect of more missiles was to make the submarine longer, and more difficult to maneuver. More missiles per submarine would reduce the system cost per warhead as well as reduce operating costs, but putting "more eggs in fewer baskets" affected target coverage and system survivability. With considerable technical tradeoffs, many operational considerations, inputs from the Special Task Group, and a dash of intuition, Rear Adm. Raborn recommended sixteen missiles per submarine (see Fig. 9).

The Navy had been proceeding with the design of the USS Ethan Allen, the lead ship of the 608 class, which was designed from the keel up to carry the Polaris missile. Navy plans also called for a more advanced design, to become known as the USS Lafayette 616 class.

However, the need for an interim deterrent capability demanded an interim submarine. Five Skipjack nuclear attack submarines were designated for redesign and for deployment as the 598 class Polaris SSBN's. The first (the USS George Washington) was created from a keel already laid at the Electric Boat Division of General Dynamics Corporation at Groton, Conn., for the submarine USS Scorpion. A 130-foot missile section was inserted amidships and provided the compartment that became known aboard ship as the "Sherwood Forest" (see Fig. 10).

The FBM submarine characteristics were approved by the Chief of Naval Operations on June 18, 1957, approximately six months after initiation of the Polaris program and about two months after the Special Task Group recommendations. The USS George Washington (SSBN 598) was ordered on December 31, 1957 and deployed on November 15, 1960 with Polaris A1 missiles. On November 22, 1960, the USS Ethan Allen (SSBN 608) was launched, and on May 8, 1962, the USS Lafayette (SSBN 616) was launched. The forty-first, and last,

	598 CLASS (5 SUBMARINES)	608 CLASS (5 SUBMARINES)	616 CLASS (31 SUBMARINES)
LENGTH	380 FEET	410 FEET	425 FEET
BEAM	33 FEET	33 FEET	33 FEET
SUBMERGED DISPLACEMENT	6,700 TONS	7,900 TONS	8,250 TONS
PROPULSION	STEAM TURBINES POWERED BY WATER COOLED NUCLEAR REACTOR		
CREW	10 OFFICERS 100 ENLISTED	12 OFFICERS 100 ENLISTED	14 OFFICERS 126 ENLISTED
MISSILES	16 POLARIS A1 OR A3	16 POLARIS A1, A2 OR A3	16 POLARIS A2, A3, C3 OR C4
LAUNCH SYSTEM	AIR EJECT	AIR EJECT	GAS STEAM GENERATOR
NAVIGATION	SINS	SINS	SINS

Fig. 10 Polaris FBM submarine characteristics.

FBM SSBN (the USS Will Rogers, SSBN 659) was deployed on October 3, 1967.

Under the leadership of Adm. H.G. Rickover and the guidance of experts in the Navy Bureau of Ships, the Electric Boat Division broke all shipbuilding precedents in building the nuclear submarine USS George Washington, and its twin, the USS Patrick Henry, in record time. The launching of the USS George Washington on June 9, 1959 was exactly on the schedule established months before, a shipbuilding feat vital to meeting the advanced operational date. The Electric Boat Division also set another record when the USS Ethan Allen was launched just fourteen months after her keel was laid.

Other FBM submarines were built by the Newport News Shipbuilding and Drydock Company, Mare Island Naval Shipyard, and Portsmouth Naval Shipyard. The Naval Shipyard at Charleston, S.C., contributed by converting the "moth-balled" tender, the USS Proteus (AS-19), into the Fleet's first Polaris submarine tender.

Evolving Program Management Philosophies

The schedule necessitated concurrent development of missile, guidance, navigation, fire control, and launcher. It called for sharply defined interfaces, and continuing physical-functional interface coordination. Vitro Laboratories provided support to the Chief Engineer of the Special Projects Office and played an important role in weapon system interface coordination, system safety, and systems planning. Development planning had to include provisions for flexibility, contingencies, fallback positions, and "work-around" schedules. Similarly, the test programs had to include concurrent and parallel testing.

Although weapon subsystems development and testing were conducted concurrently, it was necessary to demonstrate missile and launcher compatibility prior to missile launch from the submarine.

The missile flight test schedule could not support a serial test program and therefore required multiple demonstrations and objectives on each flight.

Within the missile, concurrent development and testing of propulsion, structures, electrical and electronics systems, and the re-entry body were also necessary and required new management techniques, early definition of correlated interfaces, aggressive systems engineering and integration, and relentless coordination.

The technical teams faced unique engineering problems without the lessons of precedent, but they were able to draw on management, engineering, scientific, and academic backgrounds. Against this background, they applied initiative, ingenuity, common sense, and "trial and error." Flexibility within the program also gave room for compromise solutions and the teams were free to seek the course that solved the problem.

Throughout the weapon system, alternative solutions to problems were many. Each had its supporters and opponents.

To its credit, the management of the program avoided premature elimination of alternatives while recognizing the need for critical decisions to meet the schedule. Program flexibility was retained as long as possible so as to adopt major changes arising either from over-optimistic projections or from operational constraints not originally appreciated.

Polaris A1 Development

During the period since the Navy role was defined in late 1955, the Special Projects Office had directed the development of the sea-based Jupiter system; had built the "case" for a solid-propellant version; had initiated a "backup" propulsion program; and had sponsored the effort leading to the Polaris concept. It had also established the basic goals and interfaces, characterized the systems, and directed the critical validations and advanced developments. Based on the preliminary definitions of the weapon system and the submarine, development of the Polaris A1 could begin.

V. The Polaris A1

- Envelope Parameters Established by April 1957
- Concepts Validated...Technologies Advanced
- Deployment in November 1960

Basic Elements in Place

By January 1957, the Navy had all the basic elements to begin the development of a Polaris Strategic Weapon System. The ingredients included Rear Adm. Raborn and his management team, Capt. Smith as Technical Director, an onboard technical team, a Polaris system concept, and a mandate to design, build, deliver, and support an operational strategic system for the Navy.

Special Task Group

By Special Projects Office directive, a Special Task Group was formulated to 1) recommend the optimum Polaris-submarine weapons sytem by March 1957, and 2) monitor and sponsor the contingent development program.[21] The Special Task Group consisted of separate committees, one for each of the major subsystems, the Operational Requirements Committee, and a Steering Group.

At its first meeting on January 7, 1957, the Special Task Group established an organizational structure and identified the proposed FBM System envelope parameters that were required by March 1957. After three months of concentrated work, the Special Task Group came up with the answers and preliminary definitions of a new weapons sytem which took advantage of the projected state-of-the-art. Keeping in mind that the size of the Polaris would dictate the size of the submarine (the most costly part of the FBM System), the Special Task Group concluded that Polaris must be patterned to the estimated size and weight of components several years hence. Rather than set a fixed range for Polaris, the Special Task Group fixed missile envelopes and set target range goals. Thus, for any selected time period, the Polaris performance would be in line with the most modern components.

The parameters selected included the missile diameter (54 inches), the missile length (28.5 feet), the missile weight (approximately 30,000 pounds), and the launch tube dimensions which included an extra 3 feet to accommodate ancillary launcher equipment and possibly longer missiles in the future. The earliest Polaris was to achieve its minimum target range, but later Polaris missiles, under the system of predicting future state-of-the-art, would have ever-growing capabilities that would increase target coverage, operating area, and sea room of the FBM System.

The Special Task Group, later renamed as the Steering Task Group, has continued for over twenty years to provide a valuable forum for review, direction of, and information exchange on the Polaris, Poseidon, and Trident programs.

Re-entry System Development

Re-entry body tests numbered in the thousands, including scale model tests to select shape and materials, and hardware testing to establish structural reliability. Radiant heat, vibration, shock, acceleration, and structural tests demonstrated that components and subassemblies could survive and function in the most severe environment. Scale models of re-entry bodies were flight tested on the early experimental vehicles and full-scale bodies were subsequently flown on the prototype test missiles.

Lockheed had been conducting atmospheric re-entry body tests for the Air Force for some time using the solid-propellant three-stage X-17 test vehicle. The Navy benefited from this activity in an excellent example of cooperative effort and redesignated the X-17 as the FTV-3 for continuing Polaris re-entry experiments. The vehicle, nicknamed Polaris Jr., was a three-stage re-entry vehicle wherein two stages were ignited in sequence during the ascending part of the trajectory. The last stage was ignited on descent and a re-entry body was driven into the atmosphere at a very high Mach number. One-third scale Polaris re-entry body models were flown on some of these flights.

Propulsion Development

Background

Solid-propellant rocket development by the Navy had started at the Naval Powder Factory, Indian Head, Md. (now the Naval Ordnance Station) in 1942. Several generations of aircraft-launched unguided missiles resulted which were used by all military services. As the Navy's research and development program for solid-propellant technology expanded, Navy contractors and in-house laboratories at Indian Head and at the Naval Ordnance Test Station, China Lake pioneered the development and application of both composite and double-base propellant systems. Many of the solid-rocket weapons and solid-propellant applications, such as "jet-assisted takeoff" (JATO) and cartridge-actuated devices developed for use in World War II and the Korean conflict, trace their lineage back to these fundamental investigations. Subsequent work placed more emphasis on increasing specific impulse and reducing weight of inert components.

Tests at the Naval Ordnance Test Station in 1955, which were confirmed by the Atlantic Research Corporation in 1956, demonstrated a significant increase in specific impulse obtained by the addition of finely divided aluminum to the propellant. The projected gains in specific impulse and reductions in inert weights supported the Polaris performance objectives and preliminary missile sizing estimates. By mid-1957, large-scale tests at Aerojet, the Polaris boost propulsion developer, reconfirmed these expectations and assured that booster contributions to the performance goals could be achieved.

Thrust termination and thrust vector control concepts were also being investigated. One thrust vector control concept had already successfully completed several tests based on a "jetevator" design adapted by Dr. Willy Fiedler of Lockheed from his own previously patented control system. Fiedler, a veteran of the German V-1 program, had developed his control principle while working for the Navy at the Pt. Mugu Naval Air Missile Test Center.

Polaris Applications

The development of solid-propellant propulsion systems for Polaris A1 was carried out between 1957 and November 1960 and included static and flight testing of 339 motors.[22,23]

Propulsion development presented its share of technical challenges. In addition to those associated with propellants and potential safety hazards, there were problems related to nozzles, thrust vector control, thrust termination, and the missile configuration. Second-stage thrust termination for precise velocity control had to be developed and demonstrated. Long-term submarine stowage and short-term launch and flight environments were unique. First-stage ignition at a safe distance from the submarine was a "must". Weight, total impulse, burn rate, and staging ratios were critical.

Several thrust vector control alternatives including jet vanes, tabs, jetevators, and movable nozzles were evaluated. Of these, a molybdenum jetevator vector control was selected for initial Polaris test and production configurations. Fore-end venting of the second-stage motor to achieve thrust reversal was selected for velocity (range) control.

The propulsion development program led to heavyweight static test vehicles with approximately the dimensions of the early Polaris flight test vehicles. The most frequent problem encountered in the first series of tests was the loss of the carbon throat and exit cone liners from the nozzles. A redesigned version incorporating molybdenum inserts backed by a graphite heat sink and molybdenum liners offered greatly improved performance.

Polyurethane composite propellants containing aluminum were selected for both the first- and second-stage motors. A propellant and liner configuration was defined for the flight test missiles.

The initial chambers and closure were of heavy, thick-walled construction designed for static testing only. Later, flight-weight chambers were of the same configuration, but of lighter gauge steel. After several failures in hydrostatic tests, an improved steel was selected and eventually used in the early flight test and Polaris missiles.

Polyurethane liners, along with other insulation materials, were utilized to protect inert components from the extremely high flame temperatures that resulted from aluminum additive propellants.

Prior to the start of Polaris flight testing, the outstanding development problem encountered during static tests of the first-stage motor was the failure of the thrust vector control device (the jetevator) which had performed so well in the earlier test vehicle series. As first designed, the jetevator was simply a solid ring with a spherical inside surface. The jetevator was mounted so that it could be rotated past the rim of the nozzle and into the exhaust stream. Between the spherical inside surface of the jetevator and the mating spherical surface at the end of the nozzle, was a blow-back seal which prevented exhaust gases, directed forward when the jetevator was immersed, from passing between the jetevator and the nozzle and impinging against the aft end of the motor. An evaluation of several prospective materials led to the selection of molybdenum as the jetevator material. The molybdenum available in 1958 was brittle at temperatures below 400°F and the massive one-piece jetevators tended to crack early in a firing, either from ignition shock or from the mechanical and thermal shock of the first immersion into the exhaust stream. Also, the jetevator bearings tended to overheat. A redesign was developed that would better absorb the thermal stresses and structural loads to which the jetevators were subjected. The blow-back seal was later eliminated when it was found to cause sticking due to collection of aluminum oxide, and external insulation was required to prevent both jetevator blow-back and aerodynamic base heating. This series of problems plagued static motor tests and delayed the start of the flight program about two months.

The Polaris A1 boost propulsion consisted of a redesigned AX (experimental flight test vehicle) first-stage motor and a lightweight second-stage motor. Second-stage chamber weights were reduced by improved technology in rolling and welding chambers from high-strength steel, by reducing the weight of other inert parts, and by reducing the weight of insulation. Aerospace Material Specification M-255 and M-256 steels were selected for chamber construction.

Four jetevators on the first-stage used steel housings and four second-stage jetevators used lightweight titanium housings. To terminate the thrust of the second-stage motor, six thrust reverser port assemblies were located at 60-degree increments around the forward head of the chamber. Propellants in both stages were an aluminized polyurethane formulation, although the ratio of aluminum powder to ammonium perchlorate oxidizer differed. Standard specific impulses were about 230 lb_f-s/lb_m with densitites of 0.060 to 0.061 lb_m/in.[3]

Underwater Launch

A big share of the Polaris development was centered in Sunnyvale, Calif. This was headquarters for the Lockheed Missiles & Space Division, the Polaris Missile System Manager, and site of the Westinghouse Electric Corporation plant which developed and produced the launching system. One outstanding example of teamwork on the Polaris program was the series of tests involving Navy, Westinghouse, and Lockheed engineers to prove the feasibility of underwater launch and recovery.

One-fifth scale tests of underwater launch with simulated wave motion began on January 2, 1958 in the Lockheed underwater missile facility at Sunnyvale. These tests simulated realistic sea conditions for over 3000 dummy launches to provide data on hydrodynamic performance. This unique facility provided for subscale submerged (static or translational) launch, tow carriage capabilities, atmospheric pump-down, Froude scaling, wave action, optically clear water for underwater photography, and many types of instrumentation.[24]

A full-scale launch test dummy vehicle further confirmed the concept of underwater missile launch from a submerged platform off San Clemente Island during March 1958. The first attempt to launch a missile from a submarine-type launching tube (the land-based ship-motion simulator) and ignite the first stage about 60 feet in the air was a complete success. The same test from the USS Observation Island (the EAG-154, a surface ship) was also successful. On March 23, 1960, the first full-weight dummy missile launched from the USS George Washington demonstrated proof of an underwater launch from an actual submarine (see Fig. 11).

The first underwater launch of a live missile (cut-grain first stage) off San Clemente Island on April 14, 1960 decisively proved the underwater launch concept with a full-scale test vehicle.

Test Progress

As the development and ground test program progressed, several key missile, warhead, and launcher test demonstrations met their objectives and satisfied the prerequisites for a flight test program. One of these demonstrations included the highest total impulse achieved to date in this country by a solid-propellant rocket motor. An experimental static firing of a Polaris-type motor on March 28, 1957 by Aerojet attained a total impulse of about 3.5 million lb-s with an average thrust of 60,000 pounds. Another key demonstration occurred in July 1957, when the Atomic Energy Commission detonated an experimental device which confirmed the previous projections of a Polaris warhead. Tests of the launcher and missile-launcher compatibility were also successful.

The results of the subsystem developments were coalesced into a comprehensive and very visible flight test program, a program which would demonstrate performance in the actual flight environments to be experienced by the operational missiles. The early Polaris flight tests, from January 1957 to mid-1958, using available boosters, demonstrated the feasibility of solid motor thrust termination for velocity control, jetevators for attitude control, and investigated reentry thermodynamics. Special flight test vehicles (referred to as the FTV series) were used for a total of twenty-two flights.

The initial series of tests investigated thrust reversal at low altitude and then, using a two-stage vehicle, demonstrated effectiveness at high altitude. An existing single-nozzle motor

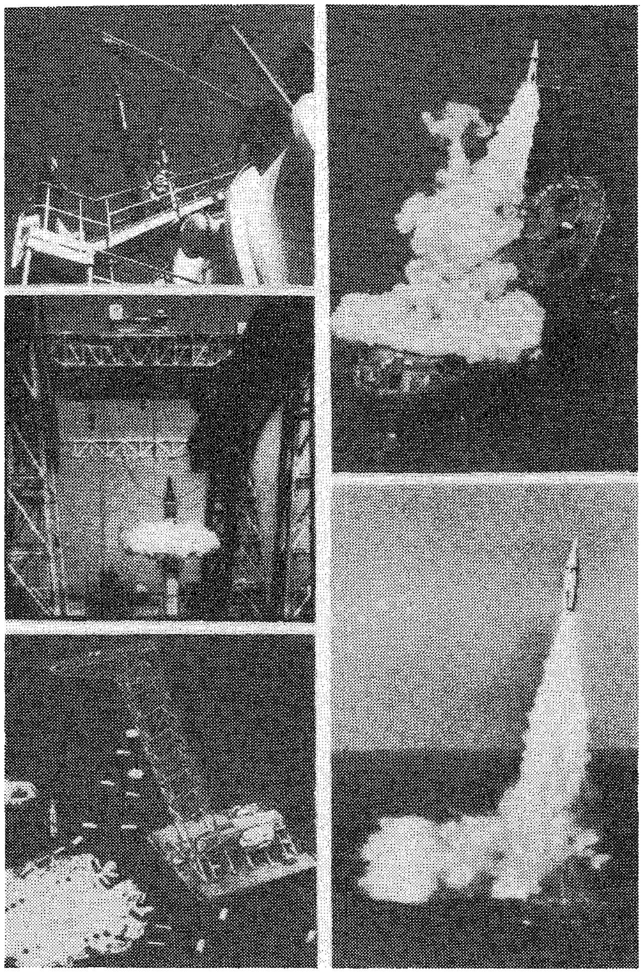


Fig. 11 Polaris test demonstrations.

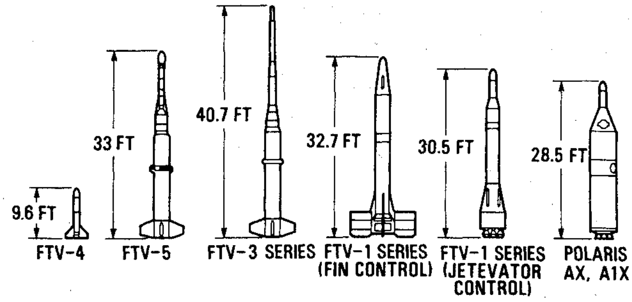


Fig. 12 Flight test and prototype development vehicles.

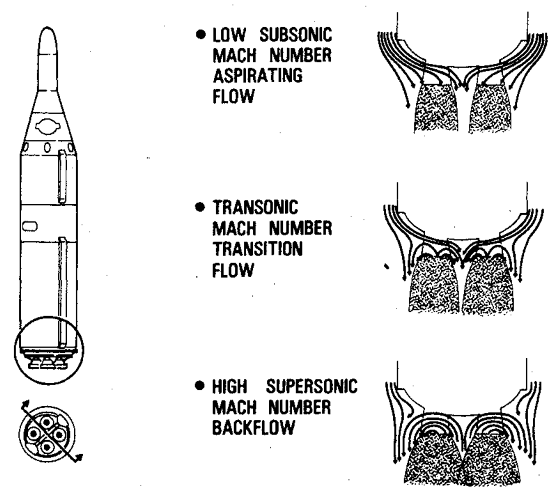


Fig. 13 Characteristic heat flows.

was modified to carry a plenum chamber and four nozzles to simulate the proposed Polaris geometry. It carried jetevators and demonstrated thrust vector control of the aerodynamically unstable missile. Another vehicle, the three-stage FTV-3 (derived from the X-17 vehicle), concentrated on payload re-entry, nose cones, surface roughness effects, and the ability of materials to withstand the re-entry environments (see Fig. 12).

Flight testing of Polaris prototypes began at Cape Canaveral on September 24, 1958, with the launching of the Polaris AX-series of flights. One year later, Polaris A1X flight tests were to demonstrate performance with configurations more representative of the production missile.

The record of successful flights in the AX-series was not spectacular. The first AX flight made a beautiful takeoff, and a very stable flight—straight up. The malfunction was attributed to the autopilot programmer used in lieu of a guidance system. The Range Safety Officer initiated the command destruct system at 27 seconds and that worked with great success.

The second flight (AX-2) had a perfect programmer, but an imperfect ordnance system. The first stage ignited, but "chuffed" at both ends and never left the pad. AX-3 and AX-4 developed more sophisticated troubles during first-stage flight which resulted in loss of control and erratic flight. Electrical wiring on the base of the first stage had failed from heating levels greater than predicted. "Operation Hotfoot" investigated the base flow heating, ascertained the problem, and "Operation Phoenix" took the appropriate corrective action, which worked.

These special investigations are ones I remember well. I directed the "Operation Hotfoot" task force in the search for an understanding of the phenomenon, a definition of the engineering problem, and corrective action. The scope of the investigation included diagnosing telemetry data from flight tests, exhaustive thermodynamic analysis, and special tests and measurements on the AX-5 through AX-8 flights, which continued even though, for some time, we did not fully understand the basic nature of the phenomenon being experienced.

We enlisted the help of every laboratory and expert. Through a combination of sled tests with rocket motors configured to simulate the four-nozzle design, hot and cold flow wind tunnel tests, static test firings, and a tremendous analytic effort by numerous laboratories, the nature of the problem was better understood. We determined that at low altitudes and subsonic Mach numbers, the four nozzle exhaust plumes acted in an aspirating fashion, bringing in the outside air and, in fact, cooling the base region. But at higher altitudes and transonic Mach numbers, the expanding exhaust gases tended to block this aspiration. At even higher altitudes and Mach numbers, a back flow of hot gases actually occurred and caused a concentration of heat flux at the center of the motor base and adjacent equipment (see Fig. 13).

Limited data derived from the AX-1 flight test had already indicated base heating to be higher than previously anticipated. The jetevator investigations were expanded to include reverse gas flow on a multiple nozzle rocket configuration under various environmental conditions. Such places as the Naval Ordnance Test Station at China Lake, Edwards AFB with its long sled tracks, and the Arnold Engineering Development Center at Tullahoma with its high-altitude chambers were all utilized in a coordinated program to obtain basic data. Actual measurments were also obtained on the AX-3 and AX-4 flights. Corrective measures on AX-5 were apparently successful, but one sticky jetevator caused loss of control and the missile was destroyed after about 35 seconds of flight (see Fig. 14).

The "Operation Phoenix" corrective actions consisted of putting fiberglass flame shielding, supplemented with silicone rubber, over the hydraulic packages, cabling, and motor dome in order to form a barrier to flame and hot gases. More sophisticated solutions were applied to later missile designs. By the time of AX-6, we were apparently cured of this ill. The AX-6 was the first fully successful flight and was flown on April 20, 1959.

Seventeen AX test vehicles were flown between September 1958 and October 1959. Demonstrations included structural integrity, stage separation, jetevator control, re-entry body hardware, and functions out to ranges of 430 n.mi. by April 1959. Demonstrations also included the autopilot, thrust termination, and arming/fuzing to about 700 n.mi. one month later.

In September 1959, the first of forty A1X flight tests began. During the next ten months, thirty of the A1X models were flown at the Atlantic Missile Range (now the Air Force Eastern Test Range). New hardware was introduced. Structures and controls were redesigned for reliability and for ease of maintenance and repair. From A1X-14 on, the test missiles were substantially the same as the production design except for the added instrumentation and range safety provisions.

LOCATION	STAGE	SCALE	ALTITUDE (FEET)	EXTERNAL FLOW VEL (M)	SOURCE OF EXHAUST GAS
EDWARDS AFB SLED TRACK	1ST	0.38	11,000 TO 24,000 (SIMULATED)	0.9 TO 1.6	SIDEWINDER MOTORS (SOLID)
AEDC TULLAHOMA PROPULSION WIND TUNNEL	1ST	0.25	SEA LEVEL TO 60,000	0 TO 1.6	HIGH-PRESSURE AIR (COLD)-(TO 950 PSI)
	1ST	0.20	SEA LEVEL TO 60,000	0 TO 1.6	AGC 10KS2500 MOTORS (SOLID) POLARIS PROP.
AEDC TULLAHOMA ENGINE TEST FACILITY	2ND	0.63	40,000 TO 100,000	NONE	AGC 10KS2500 MOTORS (SOLID) POLARIS PROP.
	1ST	0.20	60,000 TO 75,000	3.0	AGC 10KS2500 MOTOR (SOLID) POLARIS PROP.
AEROJET GENERAL CORPORATION	1ST	FULL	SEA LEVEL	NONE	POLARIS STATIC FIRING

Fig. 14 "Operation Hotfoot" special tests and measurements.

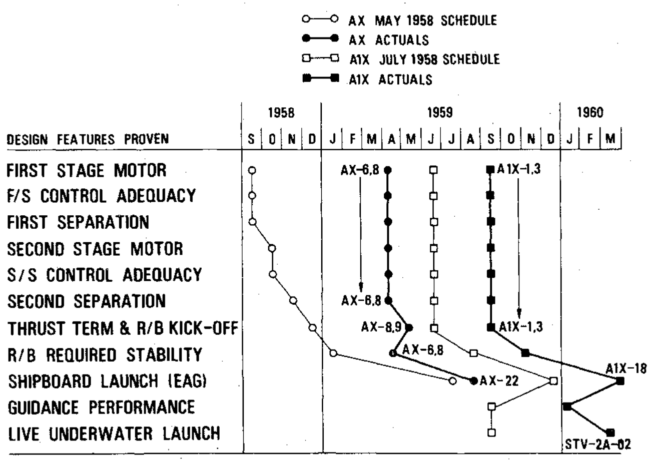
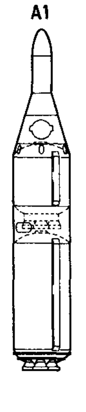


Fig. 15 Polaris AX and A1X accomplishments.

A1



- AN INTERIM CAPABILITY
- 1200 NAUTICAL MILES
- 54-INCH DIAMETER
- 28.5-FOOT LENGTH
- 28,500-POUND WEIGHT
- DEPLOYED 15 NOVEMBER 1960

Fig. 16 The Polaris A1.

In January 1960, flights began under the control of the smallest all-inertial guidance system developed at that time. This guidance system replaced the Lockheed autopilot created for the early experimental and prototype missiles. The A1X flight test program was considerably more successful (70% complete successes) than the AX.

Technical Accomplishments

As of April 1960, the composite achievements, as primarily demonstrated by the AX and A1X flight tests, included the first stage, second stage, and re-entry body structural integrity; the adequacy of the jetevator controls; the autopilot; first- and second-stage separation systems; overall performance including predictable/repeatable range, thrust termination, and re-entry body separation; the stability and thermodynamic characteristics of the re-entry body; arming and fuzing functions; surface tube launch; shipboard launch; full guidance performance; payload; and live underwater launch[25-27] (see Fig. 15).

In the schedule-oriented Polaris program, testing philosophies emphasized early, multiple objective (and relatively large) experimental and preprototype flight test programs. Although schedule-oriented, no tests were made simply to meet a schedule. To a large degree, ground test facilities for simulating flight environments did not exist or were of limited capability. The selection to fly missiles at a level of acceptable risk, rather than the time-consuming alternative of developing comprehensive ground test and simulation facilities, was made since the missile had to ultimately demonstrate performance in the actual flight environment. There were risks and consequently there were failures. Of the seventeen AX flights, five were successful, eleven were partially successful, and one was a complete failure. Of the forty A1X flights, twenty-eight were successful, eleven were partially successful, and one failed.

The Big Test

The submarine-launched missile demonstration was planned for July 1960 with some concern. With a less-than-desirable AX flight test record and the A1X program only partially completed, the first test firing of the A1X-31 from a submerged submarine drew the attention of many anxious people. On July 20, the first functional Polaris missile was launched from the USS George Washington for a successful full-range demonstration. With the flush of success and a gambling spirit, a second missile was also successfully launched three hours later. With these two "shots heard around the world", the Navy resoundingly entered the Strategic Age (see Fig. 16).

An Interim Sea-Based Deterrent

The Polaris A1 achieved all the performance, envelope, and schedule goals specified by the interim deployment objective.

The missile provided a 1200-n.mi. capability; was within the 28.5-foot length, 54-inch diameter, and 28,500-pound weight constraints; and was deployed on November 15, 1960.

The True Test of the FBM System

"Operation Frigate-Bird", an almost forgotten historical event, took place on May 6, 1962. A Polaris A1 missile was launched from the USS Ethan Allen (SSBN 608) while submerged in the Pacific and its nuclear warhead was detonated at the end of its carefully programmed flight. This is the only time any strategic missile from the United States arsenal has been fired and its nuclear payload detonated. The shot was made during the 1962 atomic tests and hit "right in the pickle barrel."

A Polaris flight test vehicle (FTV-3), launched from the USS Observation Island (EAG-154), had earlier carried the high-latitude Argus nuclear test to a successful high-altitude burst to study the Van Allen radiation belts.[28]

Support Activities

The Polaris development program required considerable support including missile test sites, training facilities, Navy shipyards, an experimental firing ship, and a navigation test ship. Highly specialized facilities within the government laboratory complex also contributed expertise when needed. The primary flight testing was conducted at the Atlantic Missile Range. Supplemental flight tests were also conducted at the Pacific Missile Range.

The USS Observation Island (EAG-154), a post-World War II Mariner class cargo ship, was modified extensively to serve as a missile firing test ship. This ship has since been reassigned for other purposes. A similar ship, the USS Compass Island (EAG-153), is still serving as the navigation system test ship.

VI. The Polaris A2

- Polaris A2 and the SSBN 608
- "Ultimate" Operational Capability

An Evolutionary Approach

The early program plans were revised to produce two missiles. The first, designated A1, had been deployed early but with less than the full 1500-n.mi. range. In April 1958, the program to achieve the 1500-n.mi. range was accelerated, and the full-range missile was designated Polaris A2.

Originally, it had been planned to achieve the 1500-n.mi. range within the Polaris A1 envelope by using higher performance propellants and lighter weight inert components. However, it soon became apparent that maximizing the efficiency of the second stage should be the highest priority. For example, a savings of inert weight in the second stage resulted in a range increment over eight times that of a similar reduction in the first stage. Further, the effects of increased specific impulse were also more significant in the second stage.

Recognizing these potential gains, the Special Projects Office encouraged the government-owned contractor-operated Allegany Ballistics Laboratory to evaluate approaches and components that could yield a higher performance second-stage rocket motor.

It was concluded that a 1500-n.mi. Polaris A2 could be achieved by 1) taking advantage of the alternate second-stage developments; 2) lengthening the Polaris A1 first-stage motor by 30 inches, using the space originally set aside for the launcher's buoyancy compensation tanks; and 3) retaining the proven, reliable propellant developed for the first-stage Polaris A1 motors.

The alternate second-stage effort included the development of a cast-in-case double base (nitrocellulose/nitroglycerin) propellant modified by adding aluminum fuel and ammonium-perchlorate oxidizer. Progress was sufficiently encouraging to permit a full-scale development effort in June 1958.

Another novel approach, that of a glass filament-wound chamber, became part of the effort. Use of such structures as rocket motor pressure vessels for the primary flight load-carrying structure had been pioneered by Hercules Powder Co., the operator of the Allegany Ballistics Laboratory, and had been successfully applied in small upper-stage vehicles.

In the latter part of the 1950's, winding of continuous glass fibers with thermosetting epoxy resins into pressure vessels indicated performance advantages over steel. Significantly higher strength-to-weight ratios appeared likely. Small pressure vessels showed girth strength-to-density ratios of 2×10^6 (150,000 psi girth strength:0.072 lb/in.^{3} density). This compared with a 180,000 psi for steel at 0.283 lb/in.^{3}, or a 0.6×10^6 strength-to-density ratio. An additional apparent advantage was that the motor could be filament-wound to contain both end closures, thus eliminating end joints completely.

Many problems were encountered and overcome in a short time period. The 54-inch diameter chamber development was started in 1958 and the first of these motors was flown in a missile in November 1960. The major problems involved 1) developing a suitable filament winding pattern for the ovaloid chamber domes, and 2) developing adequate reinforcing for the nozzle and thrust termination ports.

In addition to pioneering a new propellant (cast double base) and a new chamber (a filament-wound fiberglass epoxy-resin structure), the alternate approach included the evaluation of thrust vector control alternatives. Objectives included overcoming jetevator problems, reducing inert weights, and minimizing loss of axial thrust. Several movable nozzle concepts were investigated before selecting the rotatable nozzle for the second stage. The rotatable nozzle concept employed a unique feature in that the axis of rotation was set at an angle and produced pure axial thrust when the nozzle was in the null position. When the nozzle was rotated about its axis, the jet stream was deflected relative to the centerline of the motor, thus permitting vector control with a minimum loss in axial thrust. Two opposite nozzles turning together produced a component of side force in the direction toward which they were rotated. If they were rotated in opposite but equal directions, a roll-control torque was produced (see Fig. 17).

The alternate Polaris A2 second-stage motor developments and the longer first-stage motor provided the 300-n.mi. increase in range to meet the 1500-n.mi. objective and, combined with improvements in missile electronics, became the basis for the Polaris A2 (see Fig. 18).

Test Program

Development flight testing began in November 1960, continued in parallel with submarine firings of Polaris A1, and enjoyed a high degree of success. With the advent of the A2X program came the first experience with flame attenuation of radio frequency communications during the boost phase. The new propellant used in second-stage motors contained a high percentage of aluminum which caused ionized particles in the exhaust plume. When this ionized cloud came between the missile and ground-based radio frequency facilities, blackout of telemetry, destruct, and tracking functions occurred. The problem was solved by relying on down-range stations which were in front of the missile and the ionized plume. The first successful submerged launch of an A2 came from the USS Ethan Allen on October 23, 1961 off the Florida coast.

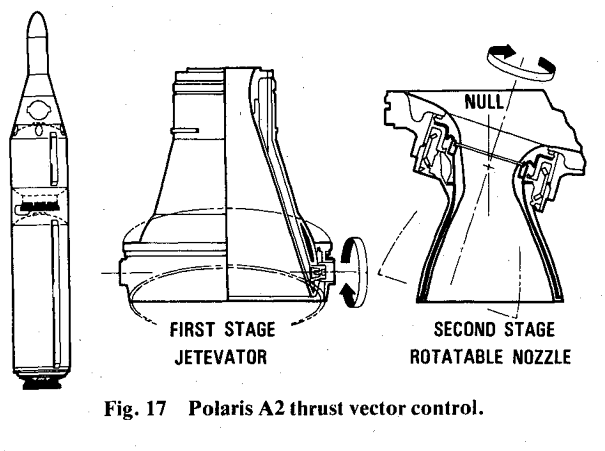


Fig. 17 Polaris A2 thrust vector control.

Beginning in late 1961, a series of A2X missiles were modified to flight test particular subsystems and components potentially applicable to the next generation system.

Operational

The Polaris A2 was deployed in the 608 class FBM submarines and became operational in 1962.

Having met the 1500-n.mi. objective and having gained one and one-half years of operational experience with the Polaris A1, the Special Projects Office increased attention on the operational and logistic support of the growing submarine force. Additional effort was applied to preparing for a potential force of up to forty-one submarines. A worldwide network of training facilities, missile assembly and loading facilities, shipyards, bases, submarine tenders, resupply ships, and fleet support was required. Policies were established assigning "stockpile-to-target" support to prime contractors' responsibilities. A closed-loop feedback circuit was also established to assure the utilization of performance, maintainability, reliability, safety, and test data derived from operational and logistic experience. Data from Demonstration and Shakedown Operations, Weapon System Readiness Tests, Operational Tests, and Follow-On Tests, as well as patrol histories were fed back to the data banks of the FBM team. In addition to the data evaluation by the respective subsystem contractors, the Applied Physics Laboratory of Johns Hopkins University had been assigned responsibilities for overall evaluation of the operational system.

Change of Command

With the Polaris A1 deployed and while the A2 was preparing for deployment, Vice Adm. Raborn was named Deputy Chief of Naval Operations for Research and Development. Rear Adm. I.J. "Pete" Galantin was named Director, Special Projects Office in February 1962.

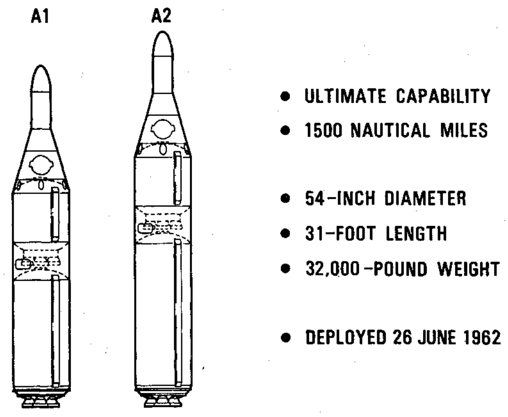


Fig. 18 The Polaris A2.

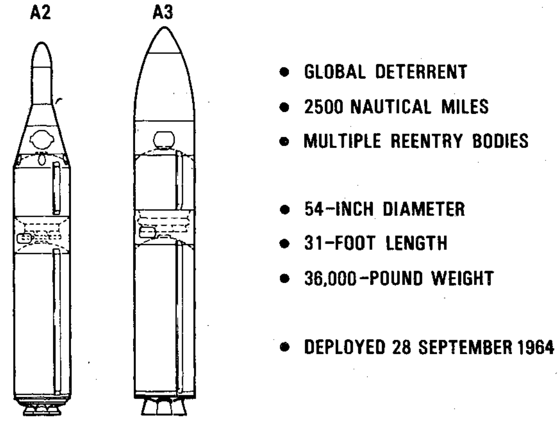


Fig. 19 The Polaris A3.

VII. The Polaris A3

- Exploiting Continuing Technologies
- Multiple Re-entry Body Concept
- An Additional 1000 n.mi.

Examining Alternatives

Strategic Deterrence

Strategic policies had evolved during the late 1950's as strategic systems were authorized and began development. Strategic plans were primarily based on the postulated capabilities of the programs as they were being generated. The programs eventually evolved into the Triad strategic concept—manned bomber, land-based ICBM, and sea-based IRBM. The original aim included the sea-based IRBM role as a deterrent to nuclear attack by providing a second-strike "assured destruction" retaliatory capability. With the deployment of the Polaris A2, the Navy had accomplished its assigned goals and now faced the responsibility of maintaining a survivability factor of one in new environments.

Operational Objectives

Countering the expanding Soviet antisubmarine warfare capabilities and antiballistic missile defenses would require 1) greater sea room and operating area, 2) increased penetrability, and 3) the payloads and accuracy to achieve damage levels from longer ranges.

Advanced Concepts

Weapon system alternatives considered included multiple re-entry body concepts; improved guidance, fire control, and navigation systems; penetration aids; and missile trajectory shaping techniques. New technologies were also considered, since the birth of the Polaris A1 and modifications to the Polaris A2, as well as comparable Air Force efforts, had motivated advancements in propellants, electronics, materials, and thrust vector control concepts.

2500-n.mi. Polaris

Performance estimates supported a 2500-n.mi. range goal for a missile of Polaris A2 size based on technological projections for the 1964-1965 time period.[29]

Polaris A3 Development

By late 1960, the Polaris A1 was ready for deployment, the A2X flight test program had started, many lessons had been learned from the A1 and A2 developments, and the worldwide support network was rapidly building. The SSBN 608 was ready for launch, and the SSBN 616 construction was proceeding according to plan. Integration of the Polaris A3 into the fleet was viewed as a logical extension of Polaris development and highly compatible with the expanding operational and logistic support concept.

Development of the 2500-n.mi. Polaris A3 missile was approved by the Secretary of Defense in September 1960 and funded the following month.

Polaris A3 was a considerably greater advance over A2 than was Polaris A2 over A1. In hardware design, Polaris A3 was approximately an 85% new missile. The Navy-industry team, which developed Polaris A1 and A2, had available the skills of many of the nation's most experienced missile technologists and readily responded to the task of developing a missile with 60% more range with no increase in the overall size of the missile (see Fig. 19).

Recognizing the need for advancements in technology on practically every front to achieve the A3 performance goal, the Navy had previously authorized a series of special pre-A3X flight tests. Their objective was the investigation of new techniques and materials for application to the A3 missile including the demonstration of thrust vector control concepts as alternatives to jetevators.

Two Polaris A1 missiles, A1X-50 and -51, were reconfigured for tests of an advanced thrust vector control system based upon injection of high-density fluid into the nozzles. On September 29, 1961 this system was successfully demonstrated during second-stage flight and, after a second test two months later, was chosen as the baseline thrust vector control system for the A3 second stage. The system was based upon the injection of Freon 114 into the exit cone of the nozzle, creating a shock pattern and causing the main exhaust stream to deflect. The fluid was injected into the exit cone by means of metering valves mounted on the external surface of the nozzle. A fluid management system was developed to insure that in flight excess fluid was jettisoned. The outstanding advantages of the fluid injection system were its low effective inert weight, its insensitivity to the propellant flame temperature, and the negligible constraint imposed on primary nozzle design.

Investigation and evaluation of this technique were typical of the manner in which many unconventional ideas were approached. The early experimental work was accomplished by the Naval Ordnance Test Station, China Lake. Analytical work, optimizing injector locations, injectant selection, and development of the injectors and the expulsion system were carried out by Aerojet, the Allegany Ballistics Laboratory, and Lockheed.

Guidance required significant development with the systems weight and volume allocation set at less than half that allowed in the earlier A1 and A2 missiles. Increased component accuracy was also a requirement at the longer A3 ranges. To demonstrate the effectiveness of the new inertial instruments and a simplified computer mechanization, the proposed system was flown with excellent results on seven special A2 tests during a one-year period starting in November 1961.

An attempt was also made to obtain data on re-entry body materials. A special A2 flight test missile evaluated the nylon-phenolic ablative heat shield which had been selected following an extensive ground test program.

A3 Propulsion Development

The Polaris A3 provided a major gain in performance over the A2, due primarily to substantial improvements in propellants, chamber materials, new thrust vector systems, and alternate velocity control techniques. The first-stage chamber material was changed from steel to high-strength resin-impregnated glass roving, the thrust vector control system was changed to rotatable nozzles on the first stage and to fluid injection on the second stage, and the propellants were changed to formulations with higher specific impulse and density. Development of the first-stage nozzle was one of the most challenging propulsion problems encountered. The final solution involved the use of silver-infiltrated tungsten nozzle throats to withstand the extremely high temperatures and pressures at which the motor operated.

Flight Test

The first A3 flight test was conducted at Cape Canaveral on August 7, 1962. Some less than fully successful flight tests were to be expected. A series of difficulties, each relatively minor, denied the development test crews a complete success until the seventh flight. Extensive static testing and ground tests played an important role in isolating these hardware malfunctions and verifying the soundness of the basic A3 design concept. The A3X-18 (production prototype) flight test was accelerated by several months and successfully demonstrated many production-configured components. During June 1963, the A3X was successfully tested for the first time in a tube-launched firing at sea from the USS Observation Island (EAG-154).

The first launching of a Polaris A3 missile from a submerged submarine took place on October 26, 1963. The missile was launched from the USS Andrew Jackson (SSBN 619) while cruising submerged off Cape Canaveral.

Operational

The Polaris A3 missile became operational on September 28, 1964 when the USS Daniel Webster (SSBN 626) began her inital operational patrol wtih sixteen A3 missiles.

When on December 25, 1964, the USS Daniel Boone (SSBN 629) began the first Pacific Ocean operational patrol, the FBM System became, for the first time, a true global deterrent.

VIII. The Poseidon C3

- New Strategic Objectives
- Increased Diameter Missile
- Revolutionary MIRV Concept

New Challenges

With the Polaris A1 and A2 deployed and the A3 "on the track," Rear Adm. I.J. Galantin, Director of the Special Projects Office and Rear Adm. Levering Smith, Technical Director, turned their attention beyond the Polaris A3 to the growth potential within the FBM System. By reducing the relatively severe shock mitigation requirement imposed on Polaris to balanced criteria and values similar to the other subsystems, additional missile diameter could be obtained within the existing mount tube. Missile diameters as large as 74 inches (as compared with 54 inches for the previous missiles) were possible. Designated as a B-series to denote the larger diameter, a B3 missile concept also denoted a 2500-n.mi. missile range similar to the A3. The increased missile diameter opened up many new opportunities for greater range or payload, larger warheads, or refined guidance systems to maximize mission effectiveness. At that time, antisubmarine warfare projections and forward-based tender support did not warrant a further increase in missile range. Investigations of the performance potential, therefore, focused on increased payload flexibility and improved defense penetration.

One of the payload challenges led to the 1964 AIAA Sperry Award to a Lockheed expert in re-entry thermodynamics and heat transfer theory for his contribution to the advancement of re-entry body nose-tip materials technology.

New Threats

Threat and defense models abounded in an era when antiballistic missile threats dominated antisubmarine warfare concerns. Projections were wide and varied. In general, they predicted a proliferation of mid-course (exoatmospheric) and terminal defenses. The FBM program responded with decoys, chaff systems, electronic jammers, hardening, shielding, circumvention techniques, and trajectory shaping concepts. Hardware was built and tested. In many cases, predictions of antiballistic missile defenses failed to materialize as projected, thereby invalidating many counter solutions.

Potential Roles

The Chief of Naval Operations' interest in a potential hard-target capability was expressed in November 1962. Designs for a multiple-body single-target capability were evaluated for both hard- and soft-target coverage with, and without, penetration aids. Maneuvering deployment platforms for the re-entry system were considered. This concept enabled optimal deployment coverage of undefended targets or optimal spacing (time and distance) for penetration of defended targets. When the hard-target mission was deleted, the B3 was reoptimized, keeping intact the basic essentials of a maneuvering deployment platform.

Coincidentally during 1962, the Air Force generated a requirement for a new re-entry vehicle which would become known as the MK 12. Development of this new payload was authorized in late 1963 with the Director Defense Research and Engineering proviso that it be a joint Navy-Air Force development. Navy applications could be either the Polaris A3, the B3 still in planning, or both. During March 1964, the General Electric Company — Re-entry Systems Division was authorized to develop it for Minuteman and Polaris.

As the B3 design concepts matured, the configuration evolved from multiple Mk 12 bodies to even larger Mk 17 bodies, and then to larger numbers of smaller bodies. In conjunction with the smaller bodies of lower yield, increased accuracy goals led to improved guidance, improved fire control, and improved navigation concepts. However, the Polaris B3 was primarily identified as a single-target weapon of questionable cost effectiveness. Incorporating a multiple-target capability resulted in vastly improved cost effectiveness (low cost per target) and led to a redesignation as C3.

A New Concept

On January 18, 1965 President Lyndon B. Johnson announced in a special message to the Congress that his administration proposed to develop a new missile for the FBM System—Poseidon. Poseidon, designated C3, was to be 74 inches in diameter as compared to the 54-inch Polaris. It was to be 3 feet longer than the 31-foot A3 and about 30,000 pounds heavier. Despite this increase in size, the growth potential of the ballistic missile submarine launching system was to enable Poseidon to fit into the same sixteen mount tubes that carried Polaris; modifications to the launch tubes and a new fire control system for the more complex multiple independently targetable re-entry vehicle targeting problem were to be required. Poseidon was to carry twice the payload of the Polaris A3 with significantly improved accuracy.

The increased accuracy and flexibility of the weapon system would permit its use against a broader spectrum of possible targets and give added insurance of penetration of enemy defenses. As envisioned at that time, the Poseidon was to increase the system and force effectiveness of the FBM System by a factor of eight. The bases for this projection included accuracy improvements, the warhead selection, and the multiple independently targetable re-entry vehicles. This revolutionary multiple target per missile concept changed the course of national policy, strategic force structures, targeting doctrines, and operational planning. It also altered quantitative and qualitative strategic balance.

Plans called for the Poseidon missile to be carried by thirty-one of the Navy's forty-one FBM submarines. (The first ten FBM submarines, including the five USS George Washington class and the five USS Ethan Allen class, would have required extensive and costly modifications and were not retrofitted to Poseidon.) Submarines scheduled for retrofit were assigned to shipyards for modification of launch tubes and outfitting with improved navigation and fire control systems. The first FBM submarine to be converted, the USS James Madison (SSBN 627), made the initial Poseidon deployment on operational patrol in 1971.

On February 16, 1965, shortly after President Johnson's Poseidon announcement, Rear Adm. Levering Smith relieved Rear Adm. Galantin as Director, Special Projects Office (see Fig. 20).

Poseidon C3 Missile

The Poseidon C3 is a two-stage solid-propellant missile with an all-inertial guidance system capable of delivering re-entry bodies to single or multiple targets. The missile has a length of 34.1 feet and a maximum diameter of 74 inches. The post-boost vehicle has a reduced diameter of 72 inches. The launch gross weight is about 64,000 pounds.

The Poseidon introduced a new array of operational concepts and targeting possibilities to the FBM System such as individually targeted re-entry bodies, capabilities for minimum energy to high loft trajectories, and numerous range and payload spacing options made possible by off-loading re-entry bodies.

The Poseidon C3 booster concept is configured similar to the Polaris A3. Here the similarity ended. During second-stage flight, the equipment section with the guidance system and re-entry bodies separates from the booster. The equipment section has a solid-propellant gas generator and an associated steering capability which allows the guidance system to maneuver the equipment section and to eject re-entry bodies into ballistic trajectories to individual aim points.

C3 Propulsion

Development of propulsion for C3 was undertaken by a Joint Venture of Hercules, Inc. and Thiokol Chemical Corp. C3 rocket motors were the first in the FBM program to feature single movable nozzles. These were actuated by a gas generator which also supplied energy for roll control. Both stages have fiberglass cases. The first stage has a composite propellant. The second-stage propellant is a double base. In contrast to the great technological step represented by A3 propellant, C3 represents a conservative approach.

C3 Payloads

In a Director Defense Research and Engineering memorandum of January 13, 1966, provisional approval had been given for a shift in the Poseidon baseline to a multiple small re-entry body configuration. This approval also stipulated that Navy coordination and participation in the Air Force Mk 12 and Mk 17 re-entry vehicle developments continue to insure compatibility and to preserve the option for use on Poseidon. In conjunction with considering a potential hard-target role, initial evaluations of a stellar-inertial guidance system were conducted in early 1966. Advanced developments of a Mk 4 stellar-inertial guidance system were started in 1968.

However, requirements for compatibility with the Mk 12 and Mk 17, for the application of penetration aids and for hard-target accuracy (to be provided by the stellar-inertial guidance), were subsequently dropped. As a consequence, multiple individually targeted small re-entry bodies (known as Mk 3) were selected as the Poseidon payload.

After a twenty-vehicle flight test program, the Poseidon C3 system was first deployed in the USS James Madison (SSBN 627) during March 1971.

IX. The Trident System

- Modernizing SLBM Forces
- Twenty-Four Long-Range, Advanced-Technology Missiles
- Quiet, Efficient Submarine

Submarine for the 1980's

The Undersea Long-Range Missile System (ULMS) was a proposed follow-on to the Polaris-Poseidon ballistic missile fleet. The ULMS program envisaged a more efficient, highly survivable, continental United States based, nuclear deterrent capable of launching missiles with ICBM ranges from quieter submarines of improved hull and propulsion designs. The ULMS concept evolved from the Secretary of Defense "STRAT-X" and Navy long range C3 studies to advanced underwater weapon system concepts and to a revised ULMS concept and program.[30]

During the course of these studies, novel and highly unconventional submarine designs, stowage and launch con-

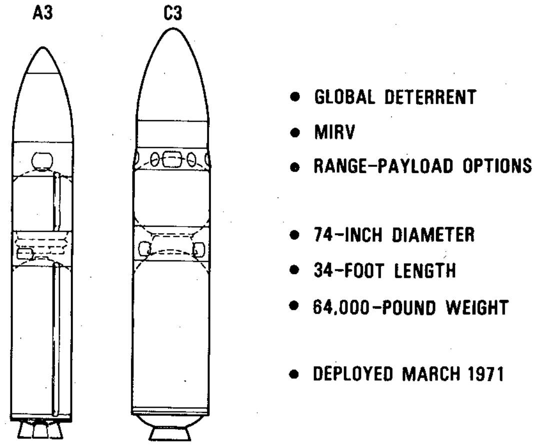


Fig. 20 The Poseidon C3.

cepts, and weapon system architecture were exhaustively evaluated. Every element of the next-generation system was examined in terms of technology, performance, reliability, and cost. Whereas prior systems were highly schedule-oriented in order to fill an urgent operational requirement, no such pressure existed to initiate the next system. Polaris and Poseidon were operational in forty-one boats and were not in immediate danger of becoming a less effective deterrent. There were, however, many potential benefits offered by a new longer range system, a twenty-four launch-tube configuration, and a "quiet" submarine.

With an ICBM-range capability, ULMS would be based in the continental U.S. and would enable the eventual phase-out of the FBM forward bases at Holy Loch (Scotland), Rota (Spain), and Guam.

The ULMS was viewed as the best response to the Soviet submarine fleet expansion and as a modernization and replacement program for our Polaris and Poseidon submarines. The increased Soviet antisubmarine warfare capability caused a re-evaluation of U.S. submarine vulnerability, the need for increased sea room/operating area, quieter operations, and target coverage. The need for eventual modernization was based on a postulated twenty to twenty-five year service life for U.S. submarines which could lead to the retirement of all forty-one FBM submarines by the early 1990's. The need to hedge against the vulnerability of land-based ICBM's and strategic bombers was also considered. And, of course, continental U.S. basing offered a logistic and fleet support cost saving as well as strategic and diplomatic advantages. In short, the threat pendulum had swung from antiballistic missile emphasis to antisubmarine warfare.

ULMS-1 (C4) Go-Ahead

On September 14, 1971 Deputy Secretary of Defense David Packard approved the ULMS program and established the direction for the increased-range missile and submarine concepts. The ULMS program was defined as development of a new, advanced-technology missile featuring greater range and other improvements (optional re-entry system with maneuvering and evasion capability, a new stellar-inertial guidance concept, and improved targetability) as compared with Poseidon. In addition to being compatible with the new ULMS submarine, the missile was also to be compatible with the Poseidon submarines in their existing configuration. The program further defined that prototype testing of the missile could proceed prior to a decision to deploy the ULMS submarine and prior to determining the submarine parameter which would be dependent on missile size and characteristics.

The program objectives were specified and included 1) range essentially double that of Poseidon C3, 2) deployable in the current FBM submarines, 3) traditional FBM reliability and 4) "ownership cost" no greater than Poseidon.

Schedule-oriented program management philosophies on earlier Polaris programs emphasized early and reasonably large experimental and preprototype flight test programs. The philosophies adopted for the more complex and performance-oriented ULMS emphasized extensive and comprehensive ground tests, simulation, preflight confidence testing, and systems tests prior to a more limited flight test program.

Advanced development was begun in December 1971. Early in 1972, the ULMS-1 was redesignated Trident I (C4). Full-scale engineering development and initial production was authorized at the Defense System Acquisition Review Council II in October 1973. Follow-on production was authorized at the Defense System Acquisition Review Council III in December 1976. The first C4X-1 flight test on January 18 1977 was extremely successful and was the forerunner of multiple successes.

The Trident I (C4) Missile

Missile range was established as a critical C4 performance objective and, therefore, required increased energy per unit volume, increased efficiency in energy management, more volume for energy, and reduced inert weight.

The Trident I missile has the same diameter and length as Poseidon and is somewhat heavier. Its range is about twice that of Poseidon with the same payload and with comparable miss distances at the longer range. External changes include an increased nose fairing radius and minor configuration redesign to minimize modification to the SSBN launch tube. In addition to the development and production of the Mk 4 re-entry system, the program has also included the advanced development and highly successful flight test demonstration of the Mk 500 Evader maneuvering re-entry body.

The missile is an all-new, three-stage, solid-propellant configuration with a maneuverable equipment section. The missile guidance sytem is an inertial system. One of the notable differences from the Poseidon design is the introduction of a solid-propellant third-stage booster mounted in the center of the equipment section. Each of the three stages has a boost rocket motor with advanced propellants, improved case materials, and a single lightweight movable nozzle with a thrust vector control system. All thrust vector control systems are of an improved lightweight gas-hydraulic design. Boost velocity control is achieved by burning all boost propulsion stages to burnout, shaping the trajectory to use all the energy, without thrust termination. This method is termed generalized energy management steering. The equipment section is powered by a solid-propellant, post-boost control system. To improve the missile aerodynamic performance, an extendible aerospike is included to overcome the high drag resulting from the blunt C4 nose fairing (see Fig. 21).

Configuration

Overall missile length is slightly over 34 feet. Diameter of the first-stage motor, interstage section, and second-stage motor is 74 inches. The forward skirt of the second-stage motor tapers to 72 inches, which is also the diameter of the adapter section and equipment section. Weight of the missile is greater than 65,000 pounds.

The C4 missile consists of a first-stage motor, an interstage section, a second-stage motor, an adapter section, an equipment section, a third-stage motor, a nose fairing, and a re-entry system. The interstage section connects the first- and second-stage motors, and provides the mounting location for electrical components. The adapter section, third-stage motor, and equipment section attach forward of the second-stage motor. The third-stage motor is mounted through the center of the equipment section and extends into the adapter section and forward of the equipment section.

The missile is divided into functional subsystems which include missile structures, propulsion, flight controls, thrust vector controls, post-boost control system, initiation, ord-

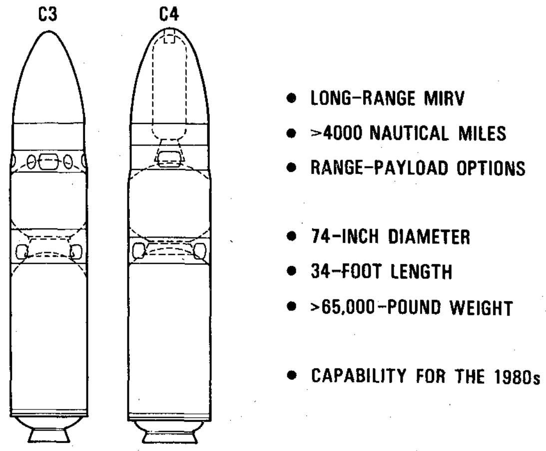


Fig. 21 The Trident I (C4).

nance, command sequencer, re-entry, and electrical power distribution.

Performance Objectives

To achieve the Trident I objectives, design goals included increasing volume available for propellant, improving propulsion performance, improving system accuracy, reducing inert weight, and reducing aerodynamic drag.

Increased propellant volume was primarily achieved by adding the third-stage rocket motor within the nose fairing volume. Miniaturizing and repackaging missile electronic components also contributed to reduced package sizes, weights, and cabling, thereby allowing more volume for propulsion.

Some of the most remarkable technological advancements have been in the missile electronics, particularly in the flight control electronics package and instrumentation. In microelectronics, three technologies existing as separate entities were brought together into a single electronic device. These were beam lead, dielectric isolation, and low-power Schottky transistor-transistor logic.

Improved propulsion performance was achieved by advancing propellant and materials technologies, including high-energy propellants, chamber materials, and lightweight low-erosion nozzles.

Improved system accuracy was achieved by incorporating a stellar-inertial guidance concept; by improving the Navigation and Fire Control systems; by more accurate control of re-entry body separation and deployment based on a dual-pressure level post-boost control system; and by improved software, firmware, and operational procedures.

Inert weights were reduced with structures fabricated from composite graphite-epoxy materials which represent a 40% weight saving compared to similar structures made from aluminum. A concentrated effort to reduce the Mk 4 re-entry body weight also contributed significantly to overall missile performance.

A deployable aerospike, extended shortly after launch, was incorporated to reduce the frontal drag of the C4 nose fairing by about 50%. This unique feature, utilized for the first time on a ballistic missile, was adopted to offset the aerodynamic drag and performance degradation of the unusually blunt nose fairing selected to accommodate the payload and the third-stage rocket motor.

Checkout Equipment

During development, functional tests are conducted on each functional element of the missile before acceptance for assembly. Missile system tests are performed after missile assembly to verify proper manufacturing and assembly. The missile is also checked to verify functional integrity before development flight testing.

The checkout equipment for C4 is basically a set of modified C3 shorebased acceptance checkout equipment and additional C4 peculiar equipment. Some of this equipment is used during development and is also used in the factory for production. Each functional missile segment is tested as a condition of acceptance before assembly or delivery as spares. During the assembly process at the Navy's weapon facilities, production missiles are tested with similar equipment to verify functional integrity before storage or outload to the Fleet.

Modified C3 equipment is also provided for periodic testing during patrol to assess the readiness of each missile for launch, using missile test and readiness equipment functionally compatible with the shorebased equipment.

The Trident Submarine

The Trident submarine was conceived as a stealthy and efficient (from a manapower standpoint) submarine capable of handling large, long-range missiles. It was also conceived as a ship with a thirty-year service life and nine years between overhauls and powerplant recoring. The increase to twenty-four missiles per submarine (from the sixteen in the original forty-one SSBN's) provides a substantial increase in cost effectiveness and could significantly reduce annual operating costs of a smaller submarine force (see Fig. 22).

A series of submarine designs were evaluated during 1971-72, many of which were dependent on projected envelopes for future missile configurations. Ultimately, the Trident I (C4) missile dictated the current launcher configuration with the mount tube interfaces allowing for growth. These factors determined the mount tube envelope and influenced the submarine hull characteristics. The Trident submarine also incorporates new Fire Control and Navigation concepts. The launcher is sized to accommodate the C4 missile whose envelope and access requirements are identical to those of the C3.

Trident Growth Allowance

Establishing a growth allowance in the Trident submarine design stemmed from the successful growth policy originally exploited in developing the Polaris and Poseidon systems. The ability to deploy the Polaris A2 was made possible by an extra 30 inches of length within the same submarine and mount tube. Poseidon was made possible by the 20-inch diameter growth within the same mount tube. Coordinated interfaces for the Trident submarine will allow for missile growth (see Fig. 23).

Trident Ship-Installed Equipment

The launcher and handling concept for Trident I is similar to that of Poseidon but includes a new launcher control group; a new launch tube group, including the launch tube, eject chamber components, tube lateral support, and tube penetration seals; and a new ejector group, particularly the cooling chamber and initiator assemblies. The majority of the handling equipment is also new, including the hoist, liner, and adapter equipment.

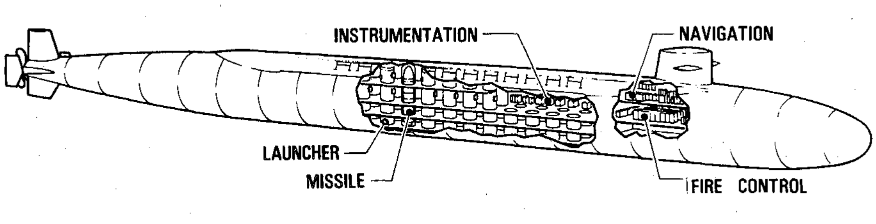


Fig. 22 The Trident submarine.

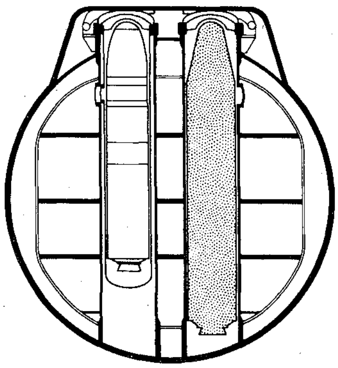


Fig. 23 Trident weapon system growth.

The navigation system is basically the Poseidon navigation equipment except for the addition of an electrostatically supported gyro monitor to provide a significant increase in the allowable interval between external fixes, while maintaining current accuracies.

The Mk 98 Fire Control for Trident I was derived from the Poseidon Mk 88 Fire Control System with minimum modifications except for an increase in computational capability required to support new or expanded functions. A general purpose computer with a 2,000,000-word disk file now provides a significantly expanded onboard capability.

The Instrumentation System for Trident I is derived from Poseidon designs and designated the Data Recording System. The significant conceptual changes for Trident include a permanent test instrumentation core system, provisions for upgrading data quality, built-in test equipment, synchronization of time references, and selective sampling of multiple functions.

X. In Retrospect

Historians of the future perhaps will cite the sense of national urgency and commitment as the foundation for a successful, survivable, and enduring submarine-launched ballistic missile program and strategic submarine force. They may credit a government-industry team that worked together, met the monumental program and technical challenges, and succeeded in achieving the nation's objectives. History is less likely to record the difficulties and early failures, the frantic pace of the early days, or the individual dedication and personal sense of achievement which tend to fade with passing time.

Many of us can readily recall the major program and technical achievements that made an operational FBM System a reality. A multitude of totally new technologies had to be developed, critical engineering problems had to be solved, and a host of management innovations had to be created. In solving some of these problems, the Navy drew on its own experiences with solid-propulsion, navigation, and submarine capabilities as well as benefiting from solid-propulsion and re-entry developments in the Air Force. A key element, an advanced warhead, came from the Atomic Energy Commission.

Three critical technical advances made the sea-based IRBM technically and economically feasible: 1) a warhead of acceptable yield in a re-entry body of less that 30% the weight of the Jupiter payload, 2) solid propellants with specific impulses in excess of 230 lb_f-s/lb_m, and 3) an all-inertial guidance system of about 15% of the weight of the Jupiter system. The development of the smaller missile was made practicable by combining these three elements. In turn, the smaller missile made practical the nuclear submarine as the launch platform and, in combination with SINS, made the submerged launch possible and effective.

Of the many lessons learned during the course of the FBM program, several management issues are worth reiterating. A single management authority and a continuously functioning dedicated team proved to be extremely advantageous. Programs with elements of risk—to be successfully completed in a limited time period—require concurrency in development and initial production. Projecting high confidence cost/schedule/performance outcomes generally requires a conservative approach to management and calls for conducting the program with allowances for contingencies and tradeoffs—expecting the unexpected.

Of course, we have all learned that there are now more rules; that technologies continue to advance; that systems tend to become more complex; that field maintenance grows more difficult; and that it is now more costly to develop, produce, and support these major systems.

Speculating on the initiation of an FBM program in today's environment— instead of 23 years ago—is likely to raise questions about strategic missions, options, acquisition policies, program approval, project management, procurement, development and test regulations, and many other issues.

One major concern to program management is the growing imposition of government policies, directives, and instructions and the increased effort necessary to either support or "ward off" these regulations. Reflecting recently on the history of the FBM System, Vice Adm. Levering Smith, then Director of the Strategic Systems Project Office, observed "that much of what was done was contrary to then current government procedures and regulations. They were set aside then and could be set aside again—if, as it was then, the Administration, the Congress, and the people all saw an all-important need. Together with that support and administrative freedom, we had a group of people with enough experience, knowledge, and ingenuity to devise ad hoc solutions to administrative, engineering, and operational problems as they were uncovered; solutions which fit a well understood overall plan. That is still our method, and it still works."[31]

Since the Polaris A1, payload concepts have grown from single payloads to multiple re-entry vehicles and multiple independently targetable re-entry vehicles. Missile structural materials have progressed from steel and aluminum to filament-wound glass, graphite epoxy, and other advanced composites. Inert weights have been reduced and propellant energies have increased. Missile testing has shifted to more comprehensive simulation and ground testing prior to flight. Systems testing equipment is more capable, thorough, and standardized for all levels of test. Although some missile subassemblies and components have become simpler, most elements have become more sophisticated and complex.

In an era of growing complexity and of highly advanced technologies, great care must be devoted to the practical application of these technologies and their transfer to engineering, manufacturing, quality assurance, and product support disciplines. Performance-oriented and weight-conscious systems tend to result in designs with relatively small safety margins and, therefore, require a more precise knowledge of those margins. These systems are also very sensitive to the engineering data base, manufacturing techniques and controlled processes (controlled manufacturing lines where required), the total test process with precise destructive/nondestructive test measurements, and exacting quality control. In general, as we demand more performance and apply the advanced technologies, the systems become less forgiving.

Current Status

The current FBM forces consist of the forty-one FBM SSBN's equipped with Polaris A3 and Poseidon C3 missiles. The Polaris A1 and A2 missiles were retired some time ago. The Trident submarine is under construction and the Trident 1 (C4) Strategic Weapon System is in development. The Pacific support facilities for Trident at Bangor, Washington,

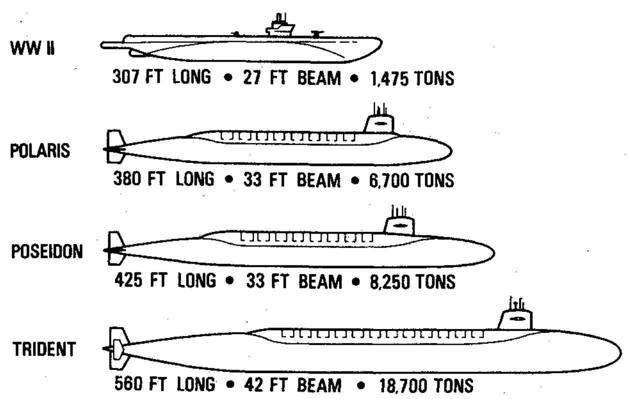


Fig. 24 Submarine comparison.

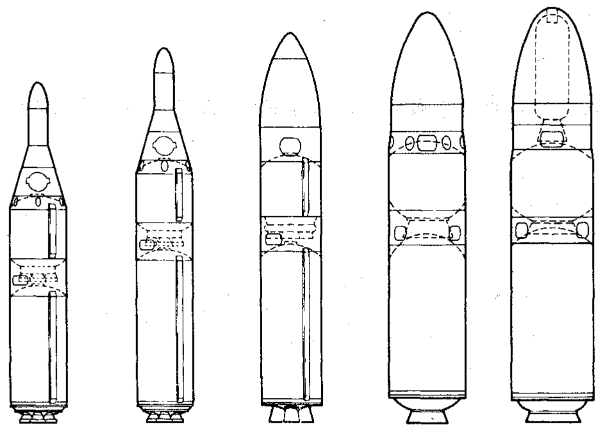


Fig. 25 Fleet ballistic missiles.

are also under construction. Initial production of the Trident I (C4) missile has been authorized and it will be deployed in both Poseidon and Trident submarines.

With the Trident weapon system development well underway, Vice Adm. Levering Smith turned over the reins to Rear Adm. Robert H. Wertheim, as Director of the Strategic System Projects Office, on November 14, 1977 after nearly twenty-two years on the program and over twelve and a half years as its Director.

USS George Washington to USS Ohio

The USS Ohio (SSBN 726), currently under construction as the first Trident submarine, differs dramatically from the World War II non-nuclear and early nuclear FBM submarines.

Ten Polaris submarines are currently operating in the Pacific with Polaris A3 missiles. Five of the submarines are of the 380-foot USS George Washington 598 class. The other five are of the USS Ethan Allen 608 class which are actually 410 feet with a submerged displacement of 7900 tons.

The thirty-one Poseidon submarines are deployed in the Atlantic with Poseidon C3 missiles. Several of these submarines ware designated for backfit to accommodate the Trident I (C4) missiles.

Trident submarines will be initally assigned Pacific deployment with Trident I (C4) missiles (see Fig. 24).

A1 to C4

Today, flight testing of the Trident I (C4) marks the development of the fifth version of submarine-launched ballistic missiles (see Fig. 25).

The Polaris A1 provided the interim 1200-n.mi. capability and was based on revolutionary approaches, concepts, and

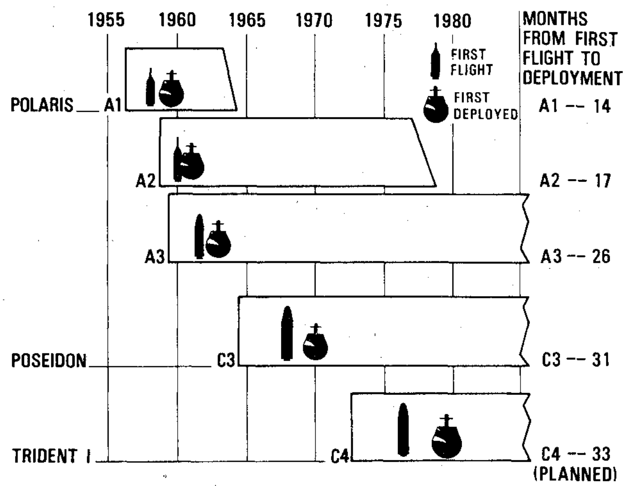


Fig. 26 Fleet ballistic missiles program.

technologies. Similarly, first-of-a-kind launcher, fire control, and navigation systems were conceived.

The Polaris A2 was intended to be an evolutionary growth of the A1. However, it eventually incorporated advancing technologies, particularly in the second stage.

The Polaris A3 was revolutionary with about 85% new subsystems to gain 1000 n.mi. in the A2 envelope. A revolutionary multiple re-entry vehicle concept was also incorporated.

The Poseidon C3 began as an evolutionary system. With the introduction of the multiple independently targetable re-entry vehicle concept, the C3 became a composite revolutionary payload system and evolutionary booster.

The Trident I (C4) is based on highly advanced technologies which essentially double the range of the C3 within the C3 physical envelope while maintaining C3 system accuracy at C4 ranges (see Fig. 26).

A Gratifying Experience

The FBM concept has endured and owes thanks to the many people who contributed so thoroughly to its success. It has been a very gratifying experience for me, and I'm sure for so many others as well, to have had an opportunity to make a personal commitment to this program. I have realized great personal satisfaction in working with a team who conquered the program and its technical challenges, who contributed to a host of Polaris "firsts", who delivered several generations of systems within cost and schedule goals, and who supported our nation's strategic deterrent mission.

XI. Looking Ahead

And so, we find that the FBM submarine-launched ballistic missile concept, the project management approach, the government-industrial team, and the survivability of the operational submarines and Strategic Weapon Systems have stood the tests of time. There seems little reason to doubt that they will ably serve as well in the future.

The future of the Triad strategic force structure is uncertain, as is the role of the submarine-launched ballistic missile. The world environment in the twenty-first century is unpredictable. Defense spending and support for research and development is inconstant. Uncertainties abound in future arms-control policies with potential limitations and bans.

As to the FBM and Trident systems, their future will depend on the Navy's role in strategic policies, on the magnitude and character of the submarine forces, and on the survivability of the submarine platforms. Advanced submarine-launched ballistic missiles with more range and improved accuracy could further exploit the oceans' operating areas, and their natural protective screen, and thus increase the survivability of the strategic submarine forces. So, it seems reasonable to project that strategic submarines and submarine-launched ballistic missile forces will be able to provide a secure, assured-retaliatory capability, and will play a role in national strategic policy. Therefore, they will continue to be viewed as a survivable and effective deterrent to nuclear war.

Acknowledgment

Significant contributions to this paper were provided by O.L. Roske, C.A. Zimmerman, and W.F. Whitmore.

References

[1] von Kármán, T., *The Wind and Beyond*, Little, Brown & Co., Boston, 1967.

[2] "U.S. ICBM Programs," National Security Council Report of February 1955.

[3] Military Service Roles in Nuclear Warfare, "Key West Agreement," 1948.

[4] IRBM Recommendations, "Killian Report," 1955.

[5] "Management of the IRBM No. 2 Development Program," Secretary of Defense Memorandum for the Secretary of the Navy and the Secretary of the Army, Log No. 55-2415, Nov. 8, 1955.

[6] "Fleet Ballistic Missile (IRBM) Weapons System," Secretary of the Navy Memorandum to the Chief of the Bureau of Ordnance, Serial 0031P51, Nov. 17, 1955.

[7] Chief of Naval Operations (Adm. Burke) Directive to Rear Adms. Clark and Raborn, Subject: ICBM-IRBM, Dec. 2, 1955.

[8] Barr J., and Howard, W.E., *Polaris*, Harcourt, Brace and Company, New York, 1960.

[9] Secretary of the Navy Letter to the Chief of Bureau of Ordnance, Subj: Proposed Navy Solid Propellant Program and Minutes of Secretary of Defense Ballistic Missile Committee Fifth Meeting on March 20, 1956, March 22, 1956, Log No. 56-760, April 13, 1956.

[10] "A Preliminary Study, Fleet Ballistic Missile," LMSD 1399, Nov. 1, 1955.

[11] "Review of Project NOBSKA, Final Report," August 5-9, 1957, NRC:cuw: Committee on Undersea Warfare, National Academy of Sciences, Washington, D.C., Nov. 1, 1957.

[12] Secretary of Defense Memorandum for the Secretary of the Navy, Serial 121056-30041, Dec. 8, 1956.

[13] "Fleet Ballistic Missile Technical Development Plan, Special Projects Office," Navy Dept. — BuOrd, May 8, 1957.

[14] SPL Technical Instruction 63-57, Oct. 28, 1957.

[15] SPL Technical Instruction 77-57, Nov. 26, 1957.

[16] Chief of Bureau of Ordnance Special Projects Office Ltr. SP2702-DL:bjg, A1-1/1 Serial 00217SP, April 4, 1958.

[17] Chief of Bureau of Ordnance Special Projects Office Ltr. SP 2702-DL:bjg, A1 Serial 00725SP, Aug. 26, 1958.

[18] Operational Requirement SC-16702, Chief of Naval Operations, Serial 00303P37, Dec. 19, 1955.

[19] Navy Research and Development Plan, Operational Requirement SC-16702, Chief of Naval Operations, Feb. 8, 1957.

[20] "Chronological History of FBM Program," SP Serial 004457, Oct. 25, 1957.

[21] "Special Task Group" structure, objectives and scheduled meetings; Memo from SP-01, Jan. 3, 1957.

[22] "Final Report of the Polaris Model A Propulsion System," Aerojet General Report 3888-31F-A, July 31, 1964.

[23] "Final Report of the Polaris Model A-1 Propulsion System," Aerojet General Report 3888-31F-A1, July 31, 1964.

[24] "Polaris Bare Missile Underwater Launch," LMSD 4428, 1958.

[25] "Polaris Development Report-1960," IAS National Summer Meeting (Los Angeles), June 30, 1960.

[26] "The Polaris Fleet Ballistic Missile Weapons System," Special Projects Office, 1960.

[27] "Chronological History of the Fleet Ballistic Missile Program," Special Projects Office, Serial 001735SP, Dec. 2, 1960.

[28] Sullivan, W., *Assault on the Unknown*, McGraw-Hill, New York 1961.

[29] "Major Changes in FBM Program Requirements," Serial 00781SP, July 17, 1959.

[30] *Trident*, Based on a Case by Barry E. Carter and John D. Steinbruner—Reprinted from Commission of the Organization of the Government for the Conduct of Foreign Policy, June 1975, Volume 4, Appendix K: Adequacy of Current Organization: Defense and Arms Control.

[31] Personal letter from Rear Adm. Levering Smith, DIRSSP to Dr. W.F. Whitmore (Special Projects Office First Chief Scientist), March 1977.

Bibliography

"Polaris Management, Fleet Ballistic Missile Program," Special Projects Office, Sept. 1962 (U.S. Govt. Printing Office).

"FBM Weapons System Master Test Plan," OD 12884, Dec. 9, 1963.

"Fleet Ballistic Missile Project; Navy Department Organization and Responsibilities," SECNAV Instruction 5430.64, Feb. 26, 1964.

"Polaris Development Highlights," LMSC/804325, July 1964.

"Polaris Fleet Ballistic Missile Weapon System Fact Sheet," Special Projects Office, June 1, 1965, and Sept. 1, 1966.

Development Characteristics No. SC-16702-1 to Operational Requirements No. SC-16702, Feb. 20, 1967.

"Highlights of the Polaris Engineering and Manufacturing Effort, July 1964 to July 1968," LMSC D053613.

Sapolsky, H.M., *The Polaris System Development*, Harvard University Press, Cambridge, Mass., 1972.

"Fleet Ballistic Missile System Program History," LMSC 805126L, Dec. 31, 1975.

"An Historical Review of the Polaris Fleet Ballistic Program," PPJ-TR-0162-001 Final Report, Jan. 1977.