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THE ORIGINS OF THE CRUISE MISSILE: A CASE STUDY IN TECHNOLOGICAL INNOVATION (U)

Leonard Weinstein

April 1980

Classified by: DD FORM 254, MDA 903 79 C 0018 (OUSDRE)
(DoD-IDA MANAGEMENT OFFICE), 24 OCTOBER 1979
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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO. AD-A[illegible]	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) THE ORIGINS OF THE CRUISE MISSILE: A CASE STUDY IN TECHNOLOGICAL INNOVATION (U)		5. TYPE OF REPORT & PERIOD COVERED [illegible] Final; July 1979
		6. PERFORMING ORG. REPORT NUMBER IDA Paper P-1[illegible]
7. AUTHOR(s) Leonard Wainstein		8. CONTRACT OR GRANT NUMBER(s) Independent Research
9. PERFORMING ORGANIZATION NAME AND ADDRESS Institute for Defense Analyses 400 Army-Navy Drive Arlington, Va. 22202		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS OUSDRE (Director, Program Control & Admin.) The Pentagon, Washington, D. C. 20301		12. REPORT DATE April 1980
		13. NUMBER OF PAGES [illegible]
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) SECRET
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE Declassify on 12/31/[illegible]
16. DISTRIBUTION STATEMENT (of this Report)		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Cruise missiles; Research and development; Guidance systems; Propulsion systems		

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This study investigates the technological origins of the current U.S. cruise missiles. It identifies the sources of the component technologies and the purposes for which they were originally developed, examines the way these component technologies were synthesized through R&D programs into weapon systems, and identifies major technical and nontechnical factors that conditioned system development

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during the period from 1967 to 1974.

While R&D on long-range cruise missiles was marked by a discontinuity from the end of the 1950's until the end of the 1960's, cruise missiles as a class have been in service since the early 1950's. There has been almost continuous work by the U.S. military R&D community and defense contractors on various aspects of cruise missile technology. In addition, technology developed primarily for other purposes also proved to be applicable to cruise vehicles. By the time interest in long-range cruise vehicles revived, these technologies had evolved to the point that it became feasible to undertake the development of an effective longer range cruise missile capability.

The several technologies involved in the new generation evolved independently--airframe, propulsion system, fuels, guidance and warhead. It was guidance and propulsion which provided most problems. The first step in synthesizing these technologies occurred in the SCAD project (1968-77) that laid the system technological basis for the later Air Force and Navy cruise missile programs. The technical problems encountered in the SLCM and ALCM programs were similar to those encountered previously in SCAD, although the separate air and sea applications presented certain unique problems.

The cruise missile case may be viewed as a good example of opportunistic R&D, wherein technologies designed originally for other purposes were married to a military concept and synthesized into a weapon system. However, the process was neither unambiguous nor successful as early as had once seemed likely. There appear to have been three significant factors in the cruise missile programs: the perceived military need; the development environment, which comprehended the degree of acceptance of and support for the systems and the political climate of the time; and the state of the technologies involved. The interaction of these factors conditioned the course of development.

The main technical issues involved in developing the cruise missile were the optimization of component performance and system integration. Because of the evolutionary development of the component technologies, it was the overall system integration that presented the main technological challenge of the cruise missile and produced the main technological innovation.

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IDA Independent Research Program

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PREFACE

(U) This study, conducted during August and September 1978, reviews the technological origins of the current cruise missile programs. Its purpose is to trace the component technologies to their sources, to examine how these technologies were synthesized into weapon systems, and to identify major technical and non-technical factors that conditioned system development.

(U) It is not a program history as such, nor does it deal at length with the broader strategic issues that were involved in cruise missile development. The period covered runs from about 1967 to early 1974, the cutoff date representing the time when both the air-launched and sea-launched cruise missile programs were underway. By 1974 the technology issues had long since been confronted, and, while all problems had by no means been solved, development was continuing on a steady evolutionary basis.

(U) Chapter I deals with the earlier experience of the United States with cruise missiles up until the later 1960's and with the reasons for a revival of interest in unmanned vehicles. Chapters II through VII describe the development of the several component technologies from their immediate origins to the end of the period covered. Chapters VIII and IX deal with the subsonic cruise armed decoy (SCAD) program and with the Navy sea-launched cruise missile (SLCM) and the Air Force air-launched cruise missile (ALCM) programs, in the course of which the independently developed component technologies were integrated into weapon systems.

(U) Much useful data were gathered from discussions with persons who were involved with the cruise missile development or analysis at that time. Where opinions on some issues and recollections of points of fact have varied, often markedly, between equally knowledgeable persons, both points of view have been reflected in the text. The following persons were interviewed:

Andrew Borden, Center for Naval Analyses
Harry Davis, formerly Deputy Undersecretary for Electronic Systems, USAF
David Heebner, formerly ODDR&E
John A. Englund, ANSER
Alexander H. Flax, formerly Assistant Secretary of the Air Force for Research & Development
Lt. Gen. Glenn Kent, USAF (Ret.), formerly AFSC
Albert Latter, RDA, formerly with the Defense Science Board
Melvin Laird, formerly Secretary of Defense
Paul Nitze, formerly Secretary of the Navy and member of SALT Negotiating Team
Stuart Rubens, OSD/PA&E
George Schubert, Technical Director, Joint Cruise Missile Project Office
Carl Tross, DIA, formerly with Navy Cruise Missile Project Office
Alton Quanbeck, CIA, formerly with OSD/Systems Analysis
Samuel Williams, Williams Research Corporation
Archie Wood, formerly USAF SCAD Program Manager
Maj. Gen. Jasper Welch, USAF, formerly AFSC

(U) In addition, group discussions were held at the following organizations with personnel involved in early cruise missile development or analysis:

RAND Corporation
Lockheed Missiles and Space Company
Boeing Aerospace Company
SRI/International

(U) I am also indebted to Robert Oliver, Robert Swanson, Ronald Finkler, Arthur Krinitz, and Donald Dix, my colleagues at IDA, for their technical assistance.

SUMMARY

(U) This study reviews the technological origins of the current U.S. cruise missiles. It identifies the sources of the component technologies and the purposes for which they were originally developed, examines the way these component technologies were synthesized through R&D programs into weapon systems, and identifies major technical and nontechnical factors that conditioned system development during the period from 1967 to 1974.

(U) Postwar U.S. cruise missile development produced a surprising number of operational systems.[1] The most successful of these were tactical and air defense systems, some of which provided long service. Efforts to develop a long-range strategic cruise missile, however, were not marked by similar success. For one thing, by the late 1950's improvements in ballistic missile technology promised more effective intercontinental weapons. Furthermore, the longer range cruise missiles all shared three fundamental characteristics: large, heavy warheads, inaccurate and weighty guidance systems, and relatively inefficient heavy turbojet or ramjet propulsion systems. High-altitude flight was required to achieve range objectives, and this made these cruise vehicles highly vulnerable to air defenses.

[1](U) For the purposes of this study, a cruise missile will be defined as an unmanned, self-propelled, air-breathing guided vehicle that sustains its flight through aerodynamic lift over most of its course. The latter qualification covers rocket assisted launchers. The definition does not include vehicles with pure rocket propulsion.

(U) While R&D on long-range cruise vehicles was marked by a discontinuity from the end of the 1950's until the end of the 1960's, cruise missiles as a class have been in service since the early 1950's. There has been almost continuous work by the U.S. military R&D community and defense contractors on various aspects of cruise missile technology. In addition, technology developed primarily for other purposes also proved to be applicable to cruise vehicles. By the time interest in long-range cruise vehicles revived, these technologies had evolved to the point that it became feasible to undertake the development of an effective longer range cruise missile capability.

(U) The revival of interest in cruise missiles can be dated to about 1967, with the surfacing of the concept of a SCAD (subsonic cruise armed decoy). The concern that underlay SCAD--the need to solve the increasingly difficult problem of how to penetrate hostile air space with a manned bomber--was a reflection of wider concerns on both the tactical and the strategic level. The tactical experience of the war in Southeast Asia, considerations of cost, and the growth of technology had all combined to make unmanned air attack vehicles attractive for a variety of missions. In the late 1960's the Air Force and the scientific community began to reexamine the potential of both cruise missiles and remotely piloted vehicles. This led first to the efforts of the Air Force to develop the SCAD and then, in the early 1970's, to the Navy sea launched cruise missile and the Air Force air launched cruise missile.

(U) The several component technologies involved in the new generation of cruise vehicles evolved independently. Of these components--airframe, propulsion system, fuels, guidance system, and warhead--the technology of the airframe posed the fewest problems. The warhead also caused little difficulty. It was the guidance system first and the propulsion system second that represented the component technological challenges of the new generation of cruise missiles.

(U) It was development of the lightweight turbofan engine with a low specific fuel consumption (SFC) and thrust-to-weight ratio that has made possible the small, long-range cruise missile of today. The desirable qualities for a propulsion system had been established in early efforts: low SFC, lightness, and minimum production of observables. While small turbojets had been made as early as 1945, a truly efficient miniature fanjet that fulfilled these requirements did not appear until the Williams WR-19 engine was developed in the later 1960's for an ARPA Flying Belt project. This engine was the father of a family of engines that has since been developed for cruise missile use.

(U) In the period up to 1974, the engine was not seen as risk-free. Considerable skepticism existed as to whether it could indeed achieve the necessary fuel economies to reach the objective ranges. Furthermore, the high-energy, high-density fuels that had to be used in order to achieve those ranges posed the possibility of reduction of engine efficiency through fouling. The viscosity of the fuels at the low temperatures that an air-launched missile would encounter also represented a technical risk, since measures to resolve the viscosity problem meant loss of energy content and hence lessened vehicle range.

(U) Of the component technologies of the cruise missile, however, the guidance system has probably been the most difficult to develop. The basic system has consistently been inertial navigation with some form of position update device. The Terrain Contour Matching System (TERCOM) grew out of experimental work in 1958 on the supersonic low altitude missile (SLAM) project. By 1968 continuous development had brought it to the point where it was the clear front runner among candidate systems for the new generation of cruise missiles.

However, the system appeared to suffer from serious deficiencies, all of which usually led to its being given a higher technical risk rating than any of the other components. The system had been tested, but not in any structured program nor under operational conditions, and the results tended to be ambivalent. The accuracy and reliability of the system were widely questioned. TERCOM was subject to occasional false fix selection that threw the vehicle off course. The sensor could be affected by the presence of vegetation and snow, which caused foliage and reflectivity errors. The major deficiency, however, was extraneous to the system itself. The necessary data base of digitized terrain profiles of the Soviet terrain did not exist.

(S) Between 1968 and 1974 increased testing developed a larger data base on TERCOM operations, resulting in a [redacted] in it. It also became apparent that with [redacted]

(U) Progress in development and testing of a guidance system was related to developments in terrain-following capability and computer technology. Although terrain following had been studied for a quarter of a century for tactical aircraft application, cruise missile application created special problems and requirements. These in turn involved trade-offs between terrain-following capability and vehicle survivability. A technological breakthrough in the computer field provided the basis for TERCOM in its miniaturized cruise missile mode. The development of semiconductors in the early 1950's led, step by step, to development of the microprocessor around 1970 and then, within another couple of years, to the semi-conductor memory to go with the computer. Along with the technique of Kalman filtering, which permitted optimal use of computer memory space, these two contributions made it feasible to use TERCOM in the cruise missile's confined airframe.

(U) The first step in synthesizing the above described technologies occurred with the SCAD project (1968-73). While the project was ensnared in the politics of the B-1 controversy almost from its inception, progress in developing and integrating the component technologies continued. SCAD laid the system technological basis for the later Air Force and Navy cruise missile programs. The SCAD concept suggested that a very small airframe could achieve considerable range and deliver a respectable warhead with good accuracy.

(U) The Navy interest in a cruise missile can be traced along two separate but obviously interrelated lines. One of these involved development of an antiship missile (Harpoon), beginning in 1967, and the other involved development of a strategic/tactical cruise missile, starting in 1971. As did the SCAD project, the Navy program moved erratically but soon received impetus from considerations deriving from the SALT I agreement. The technologies of the Harpoon and the SCAD were applied to the sea launched cruise missile.

(U) Cancellation of the SCAD program, in July 1973, was followed by the inception of the Air Force air launched cruise missile (ALCM) program. Since then the Air Force and Navy programs have moved not only along parallel technological lines, but also under increasingly common management.

(U) The technical issues encountered in the SLCM and ALCM programs are similar to those encountered previously in SCAD, although the separate applications, air and sea (and especially undersea), presented certain unique problems. The viscosity of high-density fuels, for example, was more a problem for ALCM than for SLCM; on the other hand, the possible toxicity of the high-density fuels represented a serious problem in the confines of a submarine but did not affect the ALCM application.

(U) The cruise missile case may be viewed as a good example of opportunistic R&D, wherein technologies designed originally for other purposes were married to a military concept and synthesized into a weapon system. However, the process was neither unambiguous nor successful as early as had once seemed likely. There appear to have been three significant factors in the cruise missile programs: the perceived military need; the development environment, which comprehends the degree of acceptance of or support for the systems and the political climate of the time; and the state of the technologies involved. The interaction of these three factors conditioned the course of development.

(U) The late 1960's was a period of greater receptivity toward the use of unmanned cruise vehicles for a variety of missions, but there was never any generally agreed-upon military need for a long-range strategic capability. Ranged against the scientific community, OSD, and R&D elements of the Air Force and Navy were the most influential elements of the two Services. The former group wished to exploit the enormous potential they saw in the cruise missile, while the latter, for a number of reasons, preferred that the weapon have a much more circumscribed role. The Air Force either actively resisted a long-range standoff weapon or viewed it at best as a noncrucial penetration aid. The Navy's interests were primarily in anti-ship cruise missiles and only secondarily in a strategic reserve force of cruise vehicles. To both Services, then, the cruise missile was a subsidiary weapon system. The long-range strategic mission was pushed by the scientific community and its DoD supporters.

(U) The controversial nature of the issue of perceived military need in large part shaped the development environment. It seems likely that the environment, rather than technological factors, played the dominant role in the development process. Uncertainty of mission, lack of Service support, Congressional ambivalence, and finally, in 1973, suspicion that the cruise missile was just a SALT pawn always impeded the progress of the program. In consequence, the cruise missile in its early years did not receive either consistent high-level attention or major funding.

(U) A basic premise of this study was that the cruise missile technologies were "available," in the sense that a great deal existed on which to build, when interest in the system revived. While many problems remained in each area, the probability of ultimate success was good, even though the several component technologies were not equally advanced at the outset nor did the development processes move in step.

(U) The technical issues involved in developing the cruise missile were the optimization of component performance and system integration. Because of the evolutionary development of the component technologies, it was the overall system integration that presented the main technological challenge of the cruise missile, and produced the main technological innovation.

GLOSSARY

AAA	Antiaircraft artillery
ABRES	Advanced Ballistic Reentry System
AFSC	Air Force Systems Command
ALCM	Air launched cruise missile
ASD	Aeronautical Systems Division (AFSC)
BTU	British thermal unit
CEP	Circular error probability
ECCM	Electronic counter-countermeasures
ECM	Electronic countermeasures
EMP	Electromagnetic pulse
INS	Inertial navigation system
LACOM	Low Altitude Contour Matching System
MILAM	Multiple independently aimed low altitude missile
MIRV	Multiple independently aimed reentry vehicle
RACOM	Rapid Contour Matching System
RCS	Radar cross-section
ROC	Required operational capability
RPV	Remotely piloted vehicle
SAM	Surface-to-air missile
SCAD	Subsonic cruise armed decoy
SCAM	Subsonic cruise armed missile
SCM	Sea-based cruise missile
SCUD	Subsonic cruise unarmed decoy
SFC	Specific fuel consumption
SLAM	Supersonic low altitude missile
SLBM	Submarine launched ballistic missile
SLCM	Sea launched cruise missile
SRAM	Short range attack missile
SSBN	Ballistic nuclear submarine
SSM	Surface-to-surface missile
SSN	Nuclear submarine
TA	Terrain avoidance
TAINS	TERCOM-Aided Inertial Navigation System
TERCOM	Terrain Contour Mapping System
TERF	Terminal Fix
TERSE	Terminal Sensing Experiment

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TF	Terrain following
TSOFT	Terminal Sensor Overload Flight Test
T/W	Thrust to weight (ratio)

I

CRUISE MISSILE BACKGROUND

(U) For the purposes of this study, a cruise missile will be defined as an unmanned, self-propelled, air-breathing guided vehicle that sustains its flight through aerodynamic lift over most of its course. The latter qualification covers rocket-assisted launchers. The definition does not include pure rocket-propelled vehicles.

(U) The cruise missile programs begun in the early 1970's are the latest manifestations of a long-term American interest in the technology of unmanned powered aerial vehicles. This interest can be traced back to the First World War when (in 1917) experiments were undertaken with robot aircraft that could be flown a few miles. This work continued for some 15 years, and while no military application resulted, there was some indirect payoff in terms of the development of the autopilot and instrument landing systems. Then, in the late 1930's, the Navy made plans to use TV-guided assault drones with a range of 200 miles.

(U) Between 1938 and 1940, the Army Air Corps devised an updated version of the 1917 drone aircraft, called the "Bug," that had a 200-mile range, but development was halted in 1943 as the craft was no longer considered competitive to manned aircraft. (Development efforts were not pursued because the technology of the time did not promise an early achievement of goals.) In 1944, to counter the first successful cruise missile, the V-1, the United States on several occasions used bomb-laden drone

B-17's that were crashed into the heavily defended launch sites, thus using one unmanned vehicle against another.[1]

A. INITIAL PROGRAMS

(U) In the period immediately following the war, the United States attempted to develop a missile capability. The technology of both ballistic and cruise missiles was in its infancy, but the focus was rapidly put on cruise missile applications because of apparent commonality with conventional aircraft systems and because the United States had inherited the V-1 and V-2 technology along with some of the scientists who had created the weapons. (German experience with the V-2 had illustrated that there was a greater technological problem associated with the development of ballistic missiles.) Although hard-pressed to show an application for such a weapon, the Air Force undertook to copy the V-1 immediately after its appearance in the summer of 1944. By the time the war ended, more than 1,300 copies of the V-1 had been built, the American version being called the JB-2.[2]

(U) The problem with the cruise missile efforts lay in the difficulty of adequately replacing the human input to the aircraft system (guidance, target acquisition, mission programming, flexibility), as relatively little exploitable technology was available. Nevertheless, the desire for a missile capability pushed the United States toward development of cruise missiles,

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[1](U) J. A. Englund, *Advanced Missiles--Technology and Applications: The Cruise Missile--What Is It? What Might It Be?* (Arlington, Va.: ANSER, April 30, 1978), p. 2, SECRET.

(U) It should be noted that the V-1 was not a true cruise missile in the classic sense, since it had no on-board guidance system. It was pointed in the direction of its target and its engine automatically cut out after the time designated as required to put it over its target.

[2](U) R. Perry, *System Development Strategies: A Comparative Study of Doctrine, Technology, and Organization in the USAF Ballistic and Cruise Missile Programs, 1950-1960*, RM 4853PR (Santa Monica, Calif.: RAND, August 1966).

which appeared to be the course of least resistance. In short order the desire for a rapidly acquired cruise missile capability outran existing technology. Both the Air Force and the Navy initiated programs, with the first operational weapons becoming available in the mid-1950's.

(U) By 1960, cruise missiles for both strategic and tactical applications had been developed by the Air Force and Navy. Table 1 lists most of the cruise missile programs begun since the late 1940's. Their diversity is surprising. There was the Navy Regulus, mounted on submarines and surface ships; the intercontinental Snark, which was designed to fly at a 5,000-ft altitude at Mach 0.94 for 5,500 nm and deliver a 4-Mt warhead; the tactical Mace and Matador; the air defense Bomarc; the air-to-surface Pascal and Hound Dog; and the bomber penetration decoys Goose and Quail.[3]

(U) Some of these missiles had a long and useful life. Bomarc, with its nuclear warhead, was one, and Hound Dog, Talos, and Quail are others. Some had brief lives. The first Snark missile was placed on alert in March 1960 at Presque Isle, Maine; the full 702nd Strategic Missile Wing was declared operationally ready in March 1961; the Wing was inactivated as obsolete in June 1961.[4]

(U) Perhaps the most exotic of the programs was the SLAM (Supersonic Low Altitude Missile), initiated in August 1958 by Chance-Vought under Air Force contract. The intention was to develop a nuclear-powered, low-altitude intercontinental (unlimited range) missile capable of carrying a nuclear warhead anywhere in the world. While the missile program itself was cancelled by 1960, work was continued on some of the components,

[3](U) Headquarters, USAF, DCS/Plans and Operations, *Cruise Missile Study* (Draft) (April 20, 1976), p. 111, SECRET.

[4](U) Headquarters, Strategic Air Command, *The Development of Strategic Air Command, 1946-1973* (Offutt AFB: September 19, 1974), p. 85.

Table 1 (U). U.S. CRUISE MISSILES AND PROGRAMS AS OF 1975

System	Application	Propulsion	Max. Range (nm)	Speed (Mach)	Weight (lbs)	Guidance	Initial deployment
Regulus I	SSM	Turbojet	575	0.9	14,500	Radio command[a]	1956
Regulus II	SSM	Turbojet	1,200	>2.0	26,000	Inertial[b]	--
Navaho	SSM	Ramjet	5,500	3.0	300,000	Inertial (SINS)	None[c]
Snark	SSM	Turbojet	6,300	0.9	55,000	Inertial/celestial	1958[d]
Matador	SSM	Turbojet	600+	0.9	13,000	Radar command	1953[e]
Mace	SSM[f]	Turbojet	1,200	0.9	14,000	Inertial/map matching	1959
Quail	Decoy	Turbojet	345	0.9	1,200	Autopilot-timer programmed	1960[g]
Hound Dog	ASM	Turbojet	600+	2.0	10,000	Inertial/star-track	1961[h]
SLAM	ASM/SSM	Nuclear	Global	>3.0	3,600	--	None
Harpoon	SSM	Turbojet	50+	<1.0	1,500	Active radar	In test
Talos	SAM	Ramjet	65+	2.5	7,800	Semi-active radar	1959
Bomarc	SAM	Ramjet	420	2.7	16,000	Radio command	1961
SCAD	Decoy/ASM	Turbofan	700	0.5	2,200	Inertial	None
SLCM (STRAT)	SSM	Rocket/turbofan	1,500+	<1.0	3,000	Inertial/TERCOM	In dev.
SLCM (TAC)	SSM	Rocket/turbofan	300+	<1.0	2,400	Inertial/active radar	In dev.
ALCM	ASM	Turbofan	700+	<1.0	1,900	Inertial/TERCOM	In dev.

[a] Launch from conventional SS or ship.
[b] Launch from nuclear SS or ship.
[c] Cancelled 1957.
[d] Operational 1960, retired 1961.
[e] Replaced by MACE, 1962.
[f] Converted to drones.
[g] Last delivery 1962.
[h] Last delivery 1963.

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specifically the nuclear power plant and a guidance system. The latter was to become particularly significant. As Jane's put it in 1963:

> Under further USAF contracts, Chance-Vought have developed an advanced self contained guidance sub-system capable of directing missiles, including SLAM, with unprecedented accuracy. Simple but relatively inexpensive, this system was flight tested in a Convair T-29 in 1961.[5]

Thus was the Terrain Contour Mapping (TERCOM) system born.

(U) By the late 1950's, as a number of cruise missiles were beginning to enter service, interest in a strategic mission for them declined. For one thing, improvements in ballistic missile technology promised development of effective intercontinental weapons. Soviet scientific successes with Sputnik and the first Soviet ICBM had inspired the United States to all-out efforts in this field. U.S. resources and efforts were directed henceforth into the ballistic weapons.

(U) The other major reason for cessation of the long-range cruise missile efforts lay in the technical problems related to them. While several of the programs had produced actual operational systems by 1960, the longer range weapons all shared certain characteristics: large and heavy warheads, inaccurate and weighty guidance systems, and inefficient, heavy, turbojet or ramjet engines. Further, they had at best inaccurate rudimentary means of obtaining location information to correct their guidance systems during flight. To compensate for these inadequacies, high-altitude flight was required in order to achieve range objectives. This meant the subsonic vehicles were vulnerable to air defenses.[6] Consequently, the cruise missile became

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[5](U) L. Bridgman, ed., *Jane's All the World's Aircraft, 1963-64* (New York: McGraw Hill, 1963), p. 430.

[6](U) Englund, *Advanced Missiles*, p. 8, SECRET.

non-competitive and its functions were assigned to either ballistic weapons or manned aircraft.[7]

(U) That the Navy had second thoughts about having missed opportunities to utilize the early postwar strategic missiles in a tactical role was illustrated by an exchange during a Senate Committee on the Armed Services hearing in March 1971. The Deputy Chief of Naval Operations for Surface Warfare stated that "we had a missile called the Regulus some time back, which we dropped, that turns out to be similar to the missile the Soviets now have against us in the cruise missile category." In answer to a question as to why we dropped it, he stated that it was decided that with the arrival of Polaris the Regulus, which was considered a strategic missile, seemed superfluous. "We felt we had stepped beyond it. We were not smart enough to move that missile into a tactical application and we should have."[8]

(U) By "we" the Deputy Chief was of course referring specifically to the Navy, since the Air Force Matador and Mace were tactical weapons. The failure of the Navy to pursue a tactical application has been traced to the fact that beginning in 1947, early development contracts for proposed Navy cruise missile programs no longer included ships as target options. This restriction of U.S. target options may have been a primary influence on the development of guidance technology and was a main difference between U.S. and Soviet efforts. Since the Soviets lacked carriers and the air support carriers provide to other ships, they compensated by developing antiship missiles as a means of increasing the firepower of both surface ships in

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[7](U) K. Tsipis, "Cruise Missiles," *Scientific American* 236 (2), p. 20.

[8](U) U.S., Congress, Senate, *Hearings Before the Committee on Armed Services, Fiscal Year 1972 Authorization for Military Procurement, Research and Development, Construction and Real Estate Acquisition for the SAFEGUARD ABM, and Reserve Strengths*, 92d Cong., 1st sess., March 26, 1971, p. 981.

particular and also submarines. The Soviets did not ignore land targets, but rather concentrated their efforts on attacking targets at sea at relatively modest ranges, a mission for which the technical requirements were less demanding.[9]

B. REVIVAL OF INTEREST IN UNMANNED VEHICLES

(U) Revived interest in cruise-type missiles can be dated to about 1967, when the concept surfaced of a subsonic cruise armed decoy, or SCAD (with links to the Harpoon), the development of which will be described later. The concern underlying SCAD--the need to solve the increasingly difficult problem of how to penetrate hostile air space with a manned bomber--reflected a wider spread concern with regard to both tactical and strategic operations. By the later 1960's, a particular set of circumstances made unmanned vehicles look more attractive and both remotely piloted vehicles (RPV's) and cruise missiles were again being discussed. These circumstances resulted from the tactical experiences of Vietnam, considerations of cost, and the growth of technology.

(U) Combat in Southeast Asia had demonstrated that disproportionate cost benefit ratios often marked manned aircraft operations against targets that were heavily defended with combinations of missiles, conventional radar-guided AAA, and defensive fighters. As a result, means of eliminating the human factor in certain operations came under examination.

(U) Eliminating the necessity of having a human present in an attack system carried many advantages. It could mean the elimination of life support equipment, which would reduce structural size and weight, and this in turn would reduce both initial and operating costs. Unmanned vehicles could further operate at altitudes, speeds, and acceleration regimes that would be too dangerous or unbearable for a human. Such a

[9](U) F.A. Tatum, *Evolution of US and Soviet Cruise Missile Technology* (Santa Monica, Calif.: RAND, July 1978), p. 5, SECRET.

system could be a one-way system, meaning more range and payload for the same weight, and would thus be expendable and need not be constructed of high-quality, long-lived materials or components. The absence of features external to the main airframe, such as stores or cockpit, would mean a reduced radar cross-section and thus greater penetration capability.

(U) On the other hand, there were obvious disadvantages to unmanned attack vehicles. The absence of man meant the system would be inflexible. Moreover, one-way systems had to be very inexpensive to justify their use. Data links could be not only expensive, but also unreliable and vulnerable to ECM, and overall reliability had to be high or low confidence in the weapon would create a need for multiple vehicles per mission, thus increasing the original low cost.[10]

(U) The development of new interest in cruise missiles paralleled that for RPV's.[11] As a reflection of this growing interest, the Air Force Systems Command and the RAND Corporation sponsored a major symposium, from May to June 1970, to review the feasibility and practicability of RPV's. Technical papers established a base for the several technologies that could contribute to development of RPV's, and the Report of the Symposium stressed the fact that individual technologies had attained development levels such that they could be incorporated into remotely piloted systems with little or no attendant technical risk. The Report also emphasized that one significant advantage of RPV's was that they made possible a new approach to low-cost vehicles. In the past, as missions and defenses

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[10](U) Englund, *Advanced Missiles*, p. 7, SECRET.

[11](U) An interesting combined use of RPV and cruise missiles is reported in *Aviation Week*, June 20, 1977, p. 81. The magazine reports that the Naval Air Systems Command plans to proceed soon with its program to develop a small RPV for use on nonaviation ships to detect, locate, and classify potential targets for antiship weapons such as the McDonnell-Douglas Harpoon and the General Dynamics Tomahawk.

had become more sophisticated, it had been necessary to build more complex aircraft to ensure operational superiority or even basic survival in such an environment. As aircraft became more complex to build, they became extremely costly per unit. Budget constraints forced the Air Force to buy fewer units and this in turn drove unit cost higher. The Report pointed out that for a decade the Air Force had been caught in an ever-widening spiral of higher costs and fewer aircraft. RPV's seemed to offer a means of breaking this pattern.[12]

(U) In writing of RPV's in 1971, the Defense Science Board pointed out that in several environments, some already experienced and some forecast for the future, the need for alternative systems to complement the capability of manned aircraft was apparent. For some tasks manned aircraft could be too expensive to procure and operate, even without allowing for attrition from enemy defenses. Overflight by manned aircraft of enemy or neutral territory could be politically unacceptable. Finally, the increasing capability of air defenses could result in high attrition rates--high enough to preclude sustained operations and prevent achievement of the military objective--or excessive cost in human and material resources.[13]

([redacted]) Furthermore, cruise missiles could be [redacted] Experience with [redacted]

[12](U) RAND Corporation, *Report of the Proceedings of the AFSC/RAND Symposium of May-July 1970*, Vol. 1 (Santa Monica, Calif.: RAND, July 1971), p. ii, SECRET.

[13](U) Office Director Defense Research and Engineering, Defense Science Board, *Interim Report of the Panel on RPVs* (July 1971), p. 3, SECRET.

[redacted] This was in spite of the [redacted][14]

(S) Presumably, another factor present in the considerations of the late 1960's was the fact of the [redacted]

(U) Finally, technology applicable to cruise missiles had been developing steadily throughout the 1960's. Work on information processing, propulsion, navigation, guidance, and sensors showed the potential of all these systems to improve the reliability and accuracy, increasing range and penetration

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[14](U) Center for Naval Analyses, Naval Warfare Analysis Group Study 67, *The Future Role of Sea-Based Strategic Cruise Missiles* (August 1971), p. 57, TOP SECRET.

[15](U) Defense Intelligence Agency, *Land and Air Launched Cruise Missiles (Current and Projected--Eurasian Communist Countries)*, DST-1330S-014-76 (June 25, 1976), p. 3, SECRET.

[16](U) J. Olmstead, A. Bien, and R. Keenby, *Cruise Missile Submarine Operations: An Information and Tactics Study* (Menlo Park, Calif.: Stanford Research Institute, December 1971), p. 24, SECRET.

capability, and decreasing size and costs of cruise missiles. New composite materials had also appeared for use as aircraft components that were to improve aerodynamics, and to permit more freedom in design contours. This in turn resulted in lower radar cross-sections and more efficient airframes.[17]

C. CRUISE MISSILES: A CONTINUUM

(U) As indicated in Table 1, cruise missiles as defined have really been part of the American arsenal since the early post-war years. Because the successful ones tended to be air defense or tactical range missiles, they never received much public attention. Nevertheless, the U.S. military research and development community and contractors were working almost continuously on some aspect of cruise missile technology. While it is true that R&D on long-range strategic cruise missiles as such was not continuous during the period from the end of the 1950's to the late 1960's, the technologies needed for those systems continued to evolve. By the time interest in cruise missiles was revived, these technologies had developed enough to enable an immense improvement in cruise missile capability.

(U) By tracing the origins of the several technologies in the next several sections, the stage can be set for an examination of how those technologies were woven into systems at the turn of the 1970's. Since it is infeasible to describe both component development and system development analyses in a chronological framework, without overlap, some repetition was unavoidable.

[17](U) Englund, *Advanced Missiles*, p. 13, SECRET.

II

PROPULSION SYSTEM DEVELOPMENT

(U) The desirable qualities for a propulsion system for a cruise missile had been established in the early efforts. They included efficient propulsion (low specific fuel consumption) and the minimum production/generation of observables (the acoustic signature and infrared signature) to minimize the probability of detection. In addition, the need to avoid detection through sonic boom on overland flight segments meant that the missile was restricted to at most a high subsonic velocity, which had to be slow enough to prevent significant transonic drag rise and yet fast enough to maintain the time of flight and the inertial unit requirements at reasonable levels. Cruise missiles were essentially restricted to use of engines that produced speeds of Mach 0.8 to Mach 0.85.

Underlying the modern cruise missile was the development [redacted] Development of the [redacted]

(U) U.S. cruise missiles before the current generation were all powered with turbojet or ramjet engines, except for three or four short-range missiles that were rocket powered. The engines used were simply versions of those that had been developed for aircraft. The current U.S. program represents a change, since an effort is being made to apply the technology of the small turbofan engine specifically to the cruise missile.

(U) Use of the small turbine engine is not unique to the present cruise missile. A recent survey of the subject points out that in 1945 Westinghouse produced a jet engine 9.5 in. in diameter, which was fitted to the first missile to be powered by a turbojet, the U.S. Navy Gorgon, in August 1945. Flying at 10,000 ft, the 560-lb missile attained a speed of over 420 mph, and carried enough fuel for a 2-hr flight. The T/W ratio was only about half that of the current engines, and specific fuel consumption was a great deal higher. The Navy cancelled the small engine program because the engine apparently had no other application and was deemed too costly to be developed only for missile research.

(U) There were also foreign contributions to small turbojet engine technology. The French began gas turbine work in 1947 that eventually produced a series of what were relatively small engines, compared to standard aircraft engines. In 1955, Turbomeca developed an engine 22.5 in. in diameter producing 1,450 lbs of takeoff thrust at a T/W ratio of about 4 and specific fuel consumption of about 1--a performance close except in terms of size and thrust to current cruise missile engine performance. By 1960 another French firm, Microturbo, had developed small turbojets for sailplanes and target drones, some as small as 12.5 in. in diameter with 175-lb thrust. Other small engine contributions have been made by English firms and by Fairchild in the United States.[1]

(U) The large turbofan engine was introduced in the late 1950's and quickly swept the commercial market because of its added fuel economy, efficiency, and lift capacity. When considered for use in the cruise missile, the fanjet has several important advantages over the regular turbojet. The fanjet

[1](U) F. Tatum, *US and Soviet Cruise Missile Technology*, pp. 11-13, SECRET.

produces much less acoustic signature, since it has a higher mass flow rate and a lower exhaust velocity. Also, the fanjet emits less infrared radiation from hot engine parts or from the jet exhaust plume than the turbojet because cooler air from the fan bypass flow mixes and cools the core exhaust jet. The fanjet thus has the advantage in both infrared and acoustic signature.

(U) In the matter of radar cross-section (RCS), the fanjet is at a disadvantage. The inlets necessary for air-breathing engines are normally efficient radar scatterers and tend to enhance the RCS of the vehicle. Good design that takes advantage of shadowing or uses radar-absorbing materials can counteract this somewhat. However, the fanjet requires a larger air mass flow rate, which in turn requires a larger inlet.[2]

A. THE WILLIAMS ENGINE

(U) The major American developer of small engines was the Williams Research Corporation of Walled Lake, Michigan, organized in 1954 for the specific purpose of developing small gas turbine engines. Samuel Williams had been employed at Chrysler, where he had worked on a Navy turbojet project and on an automotive gas turbine. After his company was formed, work for the automobile companies developed a technology base for eventual work on aircraft engines. Williams' first engines were for automotive and marine applications, and in 1956 he produced the first successful small turbine engines for these purposes. The first Williams aircraft turbojet was built in 1960 and flew in 1962. The WR-2 first ran at a design thrust of 70 lbs in 1962 and was developed into industrial and automotive engines of 75, 150, and 500 shaft horsepower. The WR-2 was fitted to the Canadian AN-USD-501 high-performance battlefield reconnaissance

[2](U) R. E. Reichenbach, *Long-Range Cruise Missile Study*, IDA P-958 (June 1973), p. 34, SECRET RD.

vehicle and a derivative, the WR-24-6, powered the Northrop NV-105 target drone.

(U) In April 1964, the Bell Aerospace Company and Williams proposed to the AGILE Program of ARPA that a "Flying Belt" be developed for infantry use, to be powered by a tiny fanjet. The resulting contract called for development of a propulsion system for the Bell Flying Belt, an individual flight system or lift device to enable a man to fly 10 mi at speeds up to 60 mph, using only engine power for lift, propulsion, and all control functions. Williams research on the engine using company funds had begun in 1964, and the joint Bell-Williams program began in 1965.[3]

(U) In the spring of 1965, ARPA requested IDA to examine the engine, which was found adequate to meet the requirements of the Flying Belt. The latest version of the engine was capable of providing substantially more thrust than the 425 lbs of standard day sea-level static thrust proposed originally. Furthermore, the IDA analyst could foresee no serious technical or production problems.[4]

(U) Initial engine testing was completed in 1967 and the WR-19 engine development and a 50-hr Preliminary Flight Rating-Test were concluded in 1969. The WR-19 at this time was a twin-spool bypass fanjet, 24 in. long, 12 in. in diameter, weighing 61 to 68 lbs (depending on accessories), and producing 430 lbs of thrust. The specific fuel consumption was less than 0.7 lbs/hr/lb. The engine burned standard JP-4 fuel. At the time, both the Williams turbojet and fanjet were only about 10 percent as large as the next largest engines in their classes.

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[3](U) Williams Research Corporation, *Company Background and Related Experience* (Walled Lake, Mich., 1973), p. 3.

[4](U) K. Campbell, *The Williams WR-19 Fan-Jet Engine for a Proposed Jet Flying Belt*, IDA P-196 (July 1965), p. 31.

(U) The WR-19 was the father of the family of engines that has since been developed. When the current revival of interest in the cruise missile began, with the Air Force's Bomber Penetration Study in 1967, there was controversy as to whether a SCAD, a subsonic cruise unarmed decoy (SCUD), or a subsonic cruise armed missile (SCAM) was the preferred approach. Whatever the final role of the missile, however, the Air Force would have expected a long-term, high-risk development of a small air-breathing engine for it. The major engine manufacturers were pessimistic that an engine of the small size required would be efficient. However, the Air Force learned then that the Williams engine existed and might serve as a technological base.[5]

(U) The Williams people recognized the limitations of the existing engine for some applications. A Williams engineering report prepared for Lockheed Missiles and Space Company in July 1968 on the feasibility of a SCAM stated that "within the present state of the art, no engine design appeared to be capable of 2000-nm range at sea level Mach 0.85 within the established vehicle size, and when proper allowance was made for the space requirements of payload, guidance, and control systems." The report stressed that the use of high-energy fuels would be required for maximum range, pointing out that Shelldyne appeared to offer the best chance because of its combustion characteristics, which were similar to those of JP-4. Shelldyne also promised a 30-percent greater range. Therefore, the use of high-energy fuels to go with the engine also had to be considered a development objective.[6]

[5](U) Interview with Mr. Samuel Williams, Williams Research Corporation.

[6](U) Williams Research Corporation, Engineering Report prepared for Lockheed Missiles and Space Company, *Engine Study for a Subsonic Cruise Armed Missile* (July 15, 1968), p. 3, CONFIDENTIAL.
(U) Later testing was to show that the original expectation in regard to the range benefit from Shelldyne was 30 percent too high.

(U) It was not until 1972 that the Air Force funded wind tunnel tests of the Williams engine, and not until late 1972, in competition with the engine industry, that Williams was given the contract to provide prototype engines for the SCAD program. The F-107-WR-100 design that resulted was basically derived from the WR-19 family of engines. The engine was a small, lightweight turbofan with special provisions for high-altitude starting.

(U) After the SCAD program was well underway, the Navy became interested in a SLCM. All four competitors for the project in early 1973 chose the Williams engine, but a second competition was demanded with Williams against Teledyne. Again Williams was selected. However, the Navy elected to use two engines, the Teledyne engine, which came from the Harpoon, for the tactical version of the SLCM and the Williams engine for the strategic version. In mid-1973, when the SCAD program was cancelled and the ALCM program begun, the Williams engine was selected by the Air Force for their new long-range cruise missile system.

(U) There was clearly some concern over the degree of technical risk involved in using the Williams F-107-WR-100, the advanced version of the WR-19. It had not yet been proven that such a small engine could achieve the necessary fuel economies in order to reach the objective range. Furthermore, by the spring of 1974 the Williams SCAD-derivative engine had still not flown in a missile. The Navy attempted to spread the technical risk for the strategic missile by continuing development of the long-range Teledyne engine that had lost out in the SCAD competition.

(U) The strategic version of the SLCM thus was to use one or the other of the turbofan engines designed originally for the SCAD, while the tactical version would use a modified Harpoon turbojet. The decisive factors in the tactical case were the lower cost of the turbojet, the shorter range requirements, and the need for higher thrust to engage a moving target.[7]

(U) At this time both variants of the strategic missile engine had yet to be run on high-density fuels. There was concern that the high-density fuels might create smoke plumes or, through fouling, reduce the efficiency of the engine. The Williams engine had been tested early in the SCAD program using the new fuels, and fuel viscosity (as a result of low temperatures at altitude) had been a problem, with the fuel tending to stick to the walls of the fuel container. The Williams engine had a slinger, which atomized the fuel and distributed it equally in the combustor. This innovation was derived from Williams' experience with truck engines using heavy Diesel fuels, which tended to react to low temperatures in the same manner as the new high-energy aviation fuels. This experience gave Williams the technological base from which to attack the viscosity issue. Fortunately the smoking engine problem did not develop as feared.[8]

B. THE ENGINE EXPERIENCE

(U) The development of the engine technology needed for the cruise missile was straightforward and evolutionary, typical of the engine business. Once an operating engine has been developed, large advances can be made on it. The initial breakthrough was the Flying Belt engine, which achieved a high-pressure ratio in a very small engine without undue complexity. After that, no major issues of engine technology were at stake. Many improvements have been made, but no major changes. As an engine is itself a composite of many interrelated technologies--pumps, combustors, materials--improvements in several specific

[7](U) U.S., Senate, Committee on Armed Services, *Hearings, FY 1975*, 93d Cong., 2d sess., April 12, 1974, p. 3668.

[8](U) Interview with Mr. Samuel Williams.

areas contribute to the overall success of the engine. Such improvements have included the development of solid turbine wheel castings, or design which demanded that a single part do several jobs, reducing both complexity and weight.

(U) Innovations in the use of materials were also attempted, although the alloys utilized were the same as those utilized in large engines. Experiments were made in employing ceramic coatings for combustors and rotor blades while research efforts to increase the maximum gas temperature for the WR-19 and its derivatives were continuous. The temperature actually used at the turn of the 70's was about 1,750° F., with the materials in use (Haynes 31 cobalt-base alloy for inlet guide vanes, Inco 100 for first-stage turbine blades, and Inco 713 for other hot parts) having a potential limited to about 1,950°. Despite the mechanical difficulties involved in working on such small components, with the turbine rotor disc and blades cast as single units, Williams continued to experiment with air-cooled turbine rotor blades, with the goal of developing an engine to operate at a gas temperature higher than 2,000° F.[9]

(U) For both SCAD and ALCM/SLCM, the engine development experience was the same. The major problems were related to packaging the engine as part of the overall weapon system; system integration rather than engine technology per se was the issue. Relatively modest improvements were made to the basic small turbofan engine, but these still allowed conservative operating conditions and thus permitted a large area of potential engine development.

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[9](U) J. W. Taylor, ed., *Jane's All the World's Aircraft, 1971-72* (London: Jane's Yearbooks, 1971), p. 715.

III

FUELS DEVELOPMENT

(U) It is generally accepted that the two technological advances key to the development of the current generation of cruise missiles are micro-electronic devices, which led to improved guidance accuracies by several orders of magnitude, and the development of the small, efficient fanjet engine that for every hour of flight consumes no more than (and preferably less than) one pound of fuel for every pound of thrust. Another crucial, although less publicized factor in the development of the propulsion system has been the creation of a new generation of jet fuels. These are synthesized liquid hydrocarbon fuels that increased the range of the cruise missile by as much as 19 percent over the range possible when conventional commercial and military aviation fuels are used.

(U) Before the development of the Navy Talos at the end of the 1950's, the only fuels available for turbine-powered aircraft or missiles were JP-4 and JP-5. For Talos, the Navy chose to use a specially synthesized liquid hydrocarbon fuel called RJ-4; since then both the Navy and Air Force have continued to develop fuels with increasingly higher densities. (Air Force and Navy fuel requirements differ somewhat because of the operational characteristics of their vehicles.)

(U) The difference between the BTU/gal of standard aviation fuels (JP-4 and JP-5) and the BTU/gal of the newer high-density fuels developed in the 1960's and 70's is marked:

Fuel	BTU/gal
JP-4	11[illegible],000
JP-5	125,000
RJ-4	140,000
JP-9	142,000
JP-10	142,000
RJ-5 (Shelldyne H)	161,000

Use of these newer fuels has resulted in increased range and (due to experimentation and development during the last 10 years) the desirable low-temperature operational characteristics associated with JP-4 and JP-5.[1]

(U) One of the earliest of the high-density fuels was Shelldyne. It was developed experimentally in the early 1960's as a high-energy fuel for use in volume-limited vehicles using air-breathing engines. The fuel had a low freezing point, a high specific gravity, and a calorific value per unit volume then believed to be some 30 percent higher than that of conventional aviation fuels. It could be mixed with existing fuels to increase overall calorific value and was thought to be compatible with all materials likely to be used in the construction of supersonic air vehicles.

(U) Shelldyne was not prepared from crude oil by the conventicnal process used to make gasoline, kerosene, and widecut fuel types, but rather was specially prepared from specific petrochemical intermediates.[2] The process for developing Shelldyne was independently originated in the Shell laboratores. Synthesis was first carried out on a batch laboratory and pilot plant scale in England, Germany, and Holland, and by the end of the 1960's the fuel was being produced in California. Shelldyne was found to be unstable in storage in regard to gum formation. The hydrocarbon was hydrogenated and in this form, renamed

[1](U) G. W. Burdette, H. R. Lander, and J. R. McCoy, *High Energy Fuels for Cruise Missiles* (paper presented at the AIAA Aerospace Meeting, Huntsville, Ala., January 1978), pp. 3-4.

[2](U) Shell International Petroleum Company, *Shelldyne*, Report 59F (London: Shell, April 1965), p. 2.

Shelldyne H, the fuel proved to be chemically and thermally stable.[3]

(U) By the beginning of 1973, extensive U.S. tests of Shelldyne indicated that the high-density hydrocarbon fuels did indeed burn with high efficiency in jet-type engines. However, the viscosity of the fuel at low temperatures was a continuing problem. It had been recognized early at Shell that the viscosity of the fuel was higher than that of conventional fuel, but with adequate mixing no combustion problems were encountered on rig tests. Nevertheless, in 1969, during work on the SCAD program, it was found that at the low temperatures at which a carrier aircraft would fly, the fuel tended to adhere to the walls of the fuel container.[4] This was more a problem for the ALCM than the SLCM, which, however, had its own set of problems with high-density fuel.

(U) In the early 1970's the Air Force Aero Propulsion Lab, Shell, and Sun Oil were carrying out extensive research in an effort to reduce the viscosity of the high-energy fuels. Various blends were tried that reduced viscosity but at the expense of energy content. The viscosity of several blends is as follows:

Type	Blend Component	Viscosity (centistokes at -65° F)
JP-4	--	--
Shelldyne H	--	1,000
Shelldyne H	Methyl cyclohexane 50/50 by weight	12
Shelldyne H	Methyl cyclohexane + TH-Dimer (52/33/15)	50

[3](U) J. R. Fultz and H. R. Lander, *RJ5 (Shelldyne H) Type Fuels as Propellants for Volume-Limited Air Breathing Missiles* (paper prepared for JANNAF Propulsion meeting, November 1972), p. 504, CONFIDENTIAL.

[4](U) Interview with USAF Program Manager, SCAD Program.

Since a viscosity of 12 cs at -65° F was required, unblended Shelldyne's viscosity at the time was a serious problem. Alternative solutions considered included preheating the fuel and using new fuel nozzles.[5]

(U) Other exotic fuels were available when interest in the cruise missile was renewed, such as fuels using metal slurries and/or metallic compounds. The ideas for such fuels had been around for years, but the fuels were not considered for cruise missiles, although they may have had extremely high-energy/high-density characteristics. In general, the exhaust plumes they created contained solid metal oxide particles, which would have enhanced the visual signature of the vehicle. Since the great virtue of the cruise missile was an on-the-deck penetration capability, a visible exhaust signal would have done much to increase vulnerability. Furthermore, it had been found that slurries tended to cause contamination of engine turbine blades and other engine parts, which in turn reduced engine efficiency.[6]

(U) By the time both the Air Force and Navy cruise missile programs were underway in 1974, the high-energy fuels had been much improved, but there were still operational problems that only lengthy testing under operational-type conditions could resolve. The Navy had decided by 1973 to use TH-Dimer in the SLCM, but the Air Force did not definitely choose high-energy fuels for the ALCM until early 1977.

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[5](U) David J. Welch, *Cruise Missile Technology Study*, TR-4600-001 (RDA, October 1973), p. 3-2, SECRET.

[6](U) R. Heichentach, *Long Range Cruise Missile Study*, p. 37, SECRET.

IV

GUIDANCE SYSTEM DEVELOPMENT

(U) Of the several major components of the cruise missile, it is the guidance system that has probably been, over the years, the most consistently difficult to develop. In the earlier cruise missile years, the United States employed several types of ground-based radio guidance systems (Shoran, Shanicle) that used World War II technology; a radar map-matching system in the Mace (1960) for range extension; and several variations of inertial and stellar-inertial systems. There has been research on other techniques as well. However, since the immediate post-war years, inertial guidance systems, either alone or in combination with supporting systems that provided position updates, have been under continuous development. Some form of inertial system was either already a component of or was under consideration for every cruise missile under development.

(U) The inertial systems of the earlier period were large, cumbersome, inaccurate, and expensive. Their weight and volume could only be accommodated in a sizeable vehicle. The major operational problem was drift, which after many miles could seriously affect accuracy. U.S. experience with relatively long-flight-time, low-acceleration aerodynamic vehicles had been that the gyroscope random drift rate was the crucial element in system performance. Developing the technology to reduce the drift rate has been the pacing requirement.

(U) Improvements in inertial systems technology over the last 20 years have led to a reduction in gyroscope random drift rate. Advances in gyroscope technology led to a reduction in short-term drift rate from 0.03 degrees/hr in 1958 to 0.001 in 1971.

(U) The other major component in an inertial system is the computer. In the early programs the computer and associated elements accounted for as much as one-half to two-thirds of the total inertial system weight, even with the relatively heavy inertial system components then used. The first transistor computers with magnetic disc memory elements appeared about the middle of the 1950's and were both bulky and heavy, weighing up to several hundred pounds and occupying several cubic feet. Ten years later, microcircuit computers with solid state memories made major weight reduction feasible. Reduction in the weight of the computer was paralleled by similar reductions in the weight of the inertial components. This was accompanied by an enormous increase in computational capability. Total system weight dropped from about 300 lbs in 1960 to 20 lbs in 1977.[1]

A. DEVELOPMENT OF TERRAIN CORRELATION PROGRAMS

(U) Perhaps because it represents the most problematical technology involved in the current cruise missile program, the area of guidance system development seems to have received a greater degree of historical attention than has the development of other components. The section that follows is drawn in large part from two chronological summaries of the development of TERCOM, one by the Naval Air Systems Command and the other by the Aeronautical Systems Division, Air Force Systems Command.[2]

(U) To solve the problem of gyroscope drift in an inertial system, a variety of position updating techniques had been considered in the early 1950's. A high-altitude supersonic 1,500 nm missile called the Triton was to have used an

[1](U) F. Tatum, *Cruise Missile Technology*, pp. 20-30, SECRET.

[2](U) Naval Air Systems Command, Cruise Missile Project Office, *TERCOM For Cruise Missiles* (September 1975), SECRET. Also USAF, AFSC/ASD, Directorate of Systems Engineering, *Terrain Contour Matching (TERCOM) Primer*, ASD-TR-77-61 (August 1977).

area-map-matching technique based on radar reflectivity measurements, and the Mace cruise missile was eventually equipped with such a system. These update systems attempted to locate the vehicle with respect to the ground over which it was flying. The most successful of the techniques and the one that has survived is the TERCOM, which measures terrain elevation, not radar reflectivity.

(U) In simple terms, a TERCOM system matches sequences of terrain elevation measurements to stored terrain profiles and determines geographic location by finding the best fit. TERCOM operates on the premise that selected geographic sites on the land surface of the earth are uniquely defined by the vertical contours of their terrain (the analogy to the human fingerprint was recognized early). Like fingerprinting, TERCOM requires previous mapping of terrain contours for the area over which the vehicle carrying it is to fly. Stored terrain profiles (digitized maps or matrices) are prepared from the aerial photographs, and the resulting reference map is then stored in a computer carried aboard the missile. During operational flight, the TERCOM system measures the vertical contour of the terrain along its flight path, using a radar altimeter to measure ground clearance and using primarily a barometric altimeter to provide a reference. By subtracting instantaneous ground clearance from the reference altitude, TERCOM determines the terrain contour. Then the system searches its computer memory to find the stored terrain contour which most nearly matches the measured one. Since the coordinates of the stored terrain contour are known, this serves to fix the vehicle position in geographic coordinates.

(U) TERCOM requires only standard avionics equipment and an expanded digital computer capacity. The radar altimeter measures ground clearance and the barometric altimeter measures the altitude above sea level. The inertial measurement unit measures the missile position in order to (1) navigate the missile between TERCOM matrices, (2) activate the TERCOM system at the appropriate time, (3) maintain the missile on the correct heading over the TERCOM matrices, and (4) space the TERCOM measurements to conform to the appropriate cell size. Also, the vertical accelerometer in the inertial system is typically used to complement the barometric altimeter signal. The digital computer performs the TERCOM and navigational computations and stores the reference terrain elevation data.[3]

(U) The idea that a terrain profile is unique and that that uniqueness can be used for a fix-taking technique that updates an inertial navigation system was originally developed at Chance-Vought (LTV-Electrosystems, Inc.) in 1958 for use with the Air Force nuclear-powered SLAM. The terrain contour matching system was first called Fingerprint. The SLAM program itself was cancelled in 1959, but Chance-Vought continued research on the navigation system using company funds. During that year, Chance-Vought instrumented a Twin Beechcraft aircraft and flew over three test areas: one near Fort Bliss, Texas; one near San Saba, Texas; and one near Omaha, Nebraska. The overall CEP achieved by the guidance system was 370 ft, based on 64 runs. The reference data were prepared from U.S. Geological Survey maps.

(U) The potential for using this fix-taking technique in long-range, low-altitude cruise missiles was recognized by personnel at the Air Force Systems Command Aeronautical Systems Division, Wright-Patterson AFB, and in April 1960 a year's contract was given LTV-Electrosystems, Inc. for continued research in the field. The objective of the resulting program, known as TERCOM, was to demonstrate the feasibility of using terrain contour matching to determine vehicle geographic position. Emphasis was placed on a flight-test demonstration of

[3](U) Naval Air Systems Command, *TERCOM for Cruise Missiles*, pp. 1-1, 3-1, SECRET.

the system's fix-taking performance using an off-the-shelf radar altimeter and performing the correlation function post-flight. Tests were conducted over a wide range of altitudes, a wide spectrum of terrain characteristics, and during various types of weather and seasons of the year.

(U) As part of the test program, a T-29B aircraft was instrumented and flown over 24 different sites at various altitudes (ranging from 500 to 20,000 ft) in various regions. Three different radar altimeters were evaluated. The terrain of the matrix areas ranged from flat (Chesapeake Bay, and Washington, Indiana) to extremely rough (Bryce Canyon, Utah, and Saranac Lake, New York). A total of 105 post-flight TERCOM fixes were made. Accurate fixes were made in all cases where measurement and instrumentation equipment was functioning properly. The scale of the USGS maps used ranged from 1:24,000 to 1:125,000, with cell sizes of 400 to 6,000 ft. The CEP's achieved ranged from 160 to 2,400 ft over these extremes. Test results on TERCOM showed that if one could get within the correct cell of the matrix, the CEP would be 0.4 the size of the cell.

(U) From 1963 to 1965, LTV-Electrosystems, Inc. conducted further research into terrain contour mapping, the objective of this program (known as LACOM, for low altitude contour matching) being to design and develop a complete fix-taking subsystem usable with a family of guidance systems for low-altitude aircraft. Another product of the program was the development of a semi-automatic technique for preparation of the digitized reference matrix that is stored on board the vehicle and used in the terrain contour matching process.

(U) Flight testing of the LACOM subsystem was carried out in late 1964 and early 1965 in a T-29 aircraft. The system exhibited an overall CEP of 165 ft for 75 fixes in the Fort Worth and Lano, Texas, and Hillsboro, Ohio areas.

(U) From 1963 to 1966, LTV-Electrosystems, Inc. performed work for the AF Avionics Laboratory Research & Technology Division, AFSC on the rapid contour matching (RACOM) program, which sought to develop more rapid computational methods and increase system accuracy. In a brief flight test, a small GE laser ranging unit was flown by helicopter over the Dallas area and data were gathered at 50-ft intervals. These data were matched against a 1:5,000 scale map with 2-ft contour intervals that had been specially prepared by a local surveying company and against a 1:24,000 USGS map with 10-ft contour intervals. In both cases the position fix was accurate to within 50 ft (one cell).

(U) The use of a terminal fix system for an experimental maneuverable ballistic reentry vehicle was explored in the terminal sensing experiment (TERSE), terminal fix (TERF), and terminal sensor overload flight test (TSOFT) programs. These programs were conducted as part of the Advanced Ballistic Reentry System program under the USAF Space and Missile Systems Organization.

(U) TERSE (1964-67) determined that (1) the terminal fix sensors could withstand the reentry environment; (2) the radar altimeter would perform satisfactorily provided that the vibration levels were within specifications; and (3) the radar altimeter experienced plasma blackout between 106,000 and 49,000 ft. No TERCOM fixes were made.

(U) TERF was conducted from 1966 to 1968. An F-101-B was flown in a steep dive from 40,000 ft to simulate ballistic reentry. A total of 105 flights were made over the areas of Ellsworth, Kansas, Green River, Utah, and Black Top Mountain, New Mexico using USGS source data. The actual trajectory of the aircraft was reconstructed from tracking radar and onboard camera data. The terminal guidance accuracy was found to be 280 ft (CEP).

(U) TSCFT (1968-71) involved the firing of two Athena missiles with RVTC-29 vehicles into White Sands Missile Range. Post-flight fixing against USGS source data showed a TERCOM fix accuracy of about 300 ft.

(U) Further TERCOM testing included a flight test in 1969 in support of SCAD system studies carried out by the Beech Aircraft Company and IBM, in cooperation. Using reference matrices with 1,200-ft cell size prepared from USGS maps of Flint Hills and Ellsworth, Kansas, a Beech aircraft made 29 passes over 5 different flight courses at altitudes of 500 to 1,000 ft. No false fixes occurred.

(U) In 1968 the SCAD project involved the Boeing Company in an examination of TERCOM for SCAD system studies. Boeing conducted a flight test in 1970-72, flying a Piper Twin Commanche aircraft over six areas in the State of Washington. A total of 12 false fixes occurred in 34 attempts. Although Boeing digitized 1:24,000-scale USGS maps to 500-ft cell size, the indicated magnitude of TERCOM noise was quite large. Also, the terrain was relatively flat. The theoretical results produced by Boeing were similarly pessimistic.

(U) All the above described experimentation was conducted before the formal inception of the Navy and Air Force cruise missile projects in 1973-74.

([redacted]) The initial Navy examination of cruise missile potential in 1971 [redacted]

[redacted]

(U) NAVAIR, in cooperation with the Air Force Aeronautical Systems Division, contracted with Electrosystems, Inc. in mid-1972 to perform a TERCOM-aided inertial navigation system (TAINS) flight test, to feature operational source data and simulated mission flights. The objective of the 2-year test program was mainly to determine the feasibility of using the TAINS for the strategic cruise missile mission and, as a secondary objective, to evaluate the effects of snow coverage on terrain profile acquisition and TERCOM operation. The TAINS flight test demonstrated that TERCOM was a viable concept for cruise missile use if the terrain were properly selected.

(S) Both McDonnell-Douglas and General Dynamics conducted company-funded TERCOM flight tests in [redacted] At this time McDonnell-Douglas was also working on ALCM guidance for the Air Force, and NAVAIR's request for proposals on cruise missile guidance in early 1974 resulted in selection of McDonnell and Electrosystems, Inc. to develop competitively prototype cruise missile guidance sets.

(U) Exhibit 1 and Table 2 summarize the TERCOM development steps and test results.

*(U) A concept similar to TERCOM, called "bottom matching," has been operational on fleet ballistic missile submarines since 1971, having been developed in the 1960's.

Exhibit 1 (U). TERCOM DEVELOPMENT SUMMARY

Project	Sponsor	Period
Fingerprint	Chance-Vought	1958-60
TERCOM	USAF/Aeronautical Systems Division	1960-61
LACOM	USAF/Aeronautical Systems Division	1962-67
RACOM	USAF/AFSC	1963-66
TERSE	USAF/Space & Missile Systems Organization	1964-68
TERP	USAF/Space & Missile Systems Organization	1966-68
TSOFT	USAF/Space & Missile Systems Organization	1968-71
TERCOM	Beech Aircraft Company/IBM	1969
TERCOM	Boeing Company	1970-72
TAINS	NAVAIR/USAF-ASD	1972-74
TERCOM	McDonnell-Douglas, General Dynamics	1973

Source: G. Beck and D. Williams, *First Interim Report--Technical Evaluation of the Terrain Contour Matching-Aided Inertial Navigation System* (Naval Air Test Center, April 16, 1974), p. 4, SECRET.

Table 2 (U). TEST RESULT SUMMARY (U)

CEP NUMBERS ARE CLASSIFIED

Year	No. flights	No. test areas	[redacted]	Cell size (ft)	No. fixes	Program
1959	64	3	[redacted]	--	--	Chance-Vought
1960-61	--	24	[redacted]	400-6,000	105	WADD (USAF)
1964-65	--	--	[redacted]	--	75	LTV-E
1963-66	--	--	[redacted]	50	--	LTV-E
1966-68	105	--	[redacted]	--	--	TERF
1968-71	2	--	[redacted]	--	--	TSOFT
1970-72	34	--	[redacted]	500	--	Boeing
1969	29	--	[redacted]	1,200	--	Beech
1973	16	--	[redacted]	--	--	General Dynamics

B. PROBLEMS AND ISSUES RELATED TO TERCOM

(U) The numerous reports and feasibility studies of the late 1960's and early 1970's that deal with the SCAD, SLCM, and ALCM usually rank TERCOM as the riskiest element of the system. There were marked differences of opinion, however, over how serious the risk was.

(U) While the TERCOM concept had been around for 10 years before the SCAD concept appeared, even in the early 1970's there remained some general concern that the system might be only marginally effective. One expert has expressed that doubt by suggesting that TERCOM was bought for the cruise missile more on faith than as a proved-out system. The main problem was that there had been relatively little structured and consistent testing of the system under operational conditions, and the results of what testing had occurred tended to be ambiguous. Both accuracy and reliability remained questionable.

[redacted]

(S) The Center for Naval Analyses, in its 1971 study on [redacted] Three areas were discussed, the first concerning source data availability. [redacted]

(C) The second problem emphasized by CNA concerned the issue of [redacted]

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[5] (U) Interview with Mr. Carl Tross, DIA (formerly with Navy Cruise Missile Project Office).

[6] (U) Center for Naval Analyses, *Sea-Based Strategic Cruise Missiles*, p. 35, TOP SECRET.

[redacted]

(S) CNA's third area of concern was in regard to [redacted]

(S) It was recognized early that there would be problems with the [redacted]

[redacted]

(U) Thus, improved [redacted]

[7](U) Interview with Mr. Harry Davis.

V

TERRAIN FOLLOWING

(U) Closely related to the development of a guidance system for the cruise missile was the problem of providing the vehicle with a terrain-following capability. The terrain following technique increases the probability of mission success by enabling the missile to fly a low-altitude path that follows the terrain contour, allowing penetration under enemy radar and affording protection from radar detection by local and terrain masking. Studies have been conducted since the early 1950's on terrain following (TF)/terrain avoidance (TA) and have produced a considerable literature. The earlier studies were concerned with manned tactical aircraft missions, with emphasis on forward-looking radar to minimize the probability of clobber. Much of the work was done at the Cornell Aeronautical Laboratory.

(U) TF systems have been in production for a number of years, although by the early 1970's comprehensive design criteria apparently had not yet been developed. Earlier efforts had resulted in unrelated development of technological requirements in related areas such as performance and safety. Because of this, specific but sometimes conflicting requirements were applied to the development of TF. Many techniques were developed to perform TF functions for various aircraft, but until about the time the formal cruise missile programs began, there had been no detailed criteria to specify what TF capabilities were necessary to fulfill strategic and tactical requirements adequately. Performance evaluation measures had varied from one system to another, and meeting specifications did not necessarily result in good operational performance. Comparison and evaluation of systems had been difficult.[1]

(U) Forward-looking TF sets were developed more than 10 years ago for both the B-52 and the FB-111. However, TF for the former was a manually operated system that displayed the terrain immediately ahead. The crew responded when needed. The term "terrain avoidance" was commonly applied to these manual systems. An automatic system was developed for the FB-111 that controlled the aircraft through the autopilot. The first use of terrain following in a missile was in the SRAM, which used a downward-looking set.

(U) The requirements for and operation of a cruise missile TF system differ significantly from the requirements and operation of such a system for manned tactical aircraft. In the first place, because of the cruise missile's mission, navigation is usually more precise (there is greater knowledge of the terrain over which the mission is to be flown). Secondly, the cruise missile is not limited in terms of possible acceleration maneuvers by the need to allow for pilot comfort, which allows more design freedom. Thirdly, since the cruise missile is unmanned, a higher probability of clobber can be tolerated. Fourthly, because of long flight distance and flight time, the probability of detection must be minimized for the cruise missile. This suggests that forward-looking radar may not be desirable due both to the resultant forward emissions and the fact that it increases system complexity and requires space.[2]

(/) While the [redacted] has many advantages, it also has [redacted]

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[1](U) G. Bergmann and G. De Backer, *Terrain Following Criteria* (AFSC, June 1, 197-), p. 1X.

[2](U) Applied Physics Laboratory, Johns Hopkins University, *Cruise Missile Design Studies: Terrain Following Background*, MP-5-88 (January 1974), p. 2-1, CONFIDENTIAL.

[redacted]

(C) Studies have indicated that the probability that a [redacted]

(C) These analyses suggested that the [redacted]

[3] (U) The difference between a cruise missile taking TA actions and a missile flying a straight course at the same average altitude.

[redacted] in the system integration process.

*(U) R. Swanson and S. Musa, *The Impact of Terrain Following Requirements on Cruise Missile Design*, IDA P-1022 (January 1975), pp. 2, 73, SECRET.

VI

COMPUTER DEVELOPMENT

A. MICROPROCESSORS

(U) In the development of cruise missile technology, it is perhaps only with regard to microprocessors that a technological breakthrough can be considered to have occurred. That breakthrough, of course, occurred independent of the cruise missile development process.

(U) While basic semiconductor work dates back to the late 1940's, it was development of the transistor that began the process of miniaturization. Developed by Bell Labs as part of a research program on semiconductors, the transistor was viewed as a replacement for vacuum tubes. By January 1955, the possibility that transistors could be used in place of electron tubes had become increasingly likely. Their apparent advantages over tubes in terms of smaller size, lower heat dissipation, and improved reliability set the stage for the coming of new and smaller mass-produced computers.[1] Bell Labs made their patents freely available and there followed a period of single transistor use.

(U) The idea of putting more than one device (transistor or active element) on a chip surfaced during Fairchild's work on planer devices. Original transistors were three dimensional devices with connections on all three planes. Planer devices had connections from the top only. Development of a successful planer geometry transistor in the early 1960's marked the

[1](U) National Security Agency, *Influence of US Cryptologic Organizations on the Digital Computer Industry* (May 1977), p. 3.

next breakthrough. The next step was to create a means of isolating devices in order to allow for two or more devices on a chip.

(U) At about this time a sizable amount of Department of Defense money began to flow into computer research as part of the effort to put several devices on a single chip and thereby effect dramatic miniaturization. NASA also supported research efforts in aid of its own applications. R&D money came from both the government and industry aimed at the government market. There was also a growing demand for these products for commercial computers. By the late 1950's semiconductors were being used in commercial computers, and by the early 1960's isolation devices were being used for industrial computer applications.

(U) The development process was thus an evolutionary one--planer work, isolation work, inflow of government money. Once several devices were successfully put on a single chip and a vigorous commercial market had been created, increasing the density of devices on a chip was only a matter of further evolution. By 1970 it had become evident that hundreds, if not thousands of units could be put onto a chip.

(U) The first microprocessor was produced around 1970 by a company called Intel by simply putting an entire computer on a chip. The next step, which occurred around 1970-72, was to use semiconductor memories on the chip to go with the computer. The refinement process continued, driven primarily by the commercial market seeking small computers to use for small computations. The calculator and watch markets also became major users of these technological developments, although the commercial computer market did not pick up on the microprocessor until the last two or three years.

B. KALMAN FILTERING

(U) Another major contribution to the cruise missile guidance system was the development of a process of recursive data filtering that saves a great deal of computer memory space.[2] Around 1960 optimal filter techniques based on state-space, time-domain formulations were devised. The approach utilizing these techniques, now known as the Kalman filter after its creator, is ideally suited for implementation with the digital computer and has become the foundation for data mixing in modern multisensor systems.

(U) The problem of data filtering was first encountered as part of the process of determining fire control of antiaircraft guns in World War II and continued to be encountered in air defense, specifically in determining the best radar track from a great mass of data. Kalman provided a generalized theory under which all the smaller cases become specialized cases. He essentially provided an analytical structure for selecting the optimum.

(U) The application of the filter to guidance problems was an obvious one. There are several different navigational systems on an aircraft, with much data coming in from the several sources. Kalman filtering provides a means of collating the mass of data and selecting the best.

(U) The technique (an algorithm or computer software program) has been best described as follows:

> Application of modern estimation techniques to multi-sensor navigation systems began in the mid 1960's, shortly after optimal recursive filter theory was developed and published. Because the errors in a typical navigation system propagate in an essentially linear manner and linear combinations of these errors can be detected from external measurements, the Kalman filter is ideally suited for their estimation. It also provides useful estimates of all system error sources with significant correlation times.... The Kalman filter provides for the optimal use of any number,

[2](U) A recursive solution is one that enables sequential rather than batch processing of the measurement data.

> combination, and sequence of external measurements. It is a technique for systematically employing all available external measurements, regardless of their errors, to improve the accuracy of navigation systems.[3]

(U) The introduction of increasingly sophisticated computers has made it even easier to apply the filtering technique, and it became the keystone of the TERCOM system. A Lockheed analysis in 1969 stated that Kalman filtering "affords substantial trimming of day to day stability errors which previously limited operational accuracy. This reduces the separation between laboratory and operational performance."[4]

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[3](U) The Analytic Services Corporation Technical Staff, *Applied Optimal Estimation*, ed. by A. Gelb (Cambridge: MIT Press, 1974), p. 5.

[4](U) Lockheed Missiles and Space Company, *AGM 86A-SCAD-Design Concept Studies*, Vol. III, *Guidance Systems* (September 1969), pp. 1-6, SECRET.

VII

WARHEAD DEVELOPMENT

(U) While small nuclear warheads were not available in the early post-war years, such weapons were available well before the accurate guidance systems that made their use in cruise missiles desirable. The whole evolution of warheads was aimed toward smaller size and greater yield per pound of weight. That miniaturization of warheads was possible had been demonstrated by the Army's 280-mm gun in the early 1950's and a few years later by the 8-in. howitzer shell. These were low-yield tactical weapons, but by the end of the 1950's similar evolutionary development of the larger yield strategic warheads had occurred.

(U) The necessary technological expertise was essentially available by 1960, with the development of warheads for the Polaris and Minuteman weapon systems. By the end of the 1960's, when interest in cruise missiles was renewed, all that appeared to be required for the warhead was repackaging to fit the configuration--first of the SCAD and then the SLCM and ALCM--and to do so in a nonatmospheric test environment. However, the SCAD was not intended to use an existing warhead, but rather to use an existing warhead as a cost effective starting point. Development work was necessary to produce the specific warhead required for SCAD.[1]

(U) For the cruise missile, the size of the warhead was significant in terms of how it could affect the other elements

[1](U) U.S., Congress, Senate Committee on Appropriations, *Hearings of Subcommittee on Department of Defense Appropriations, FY 73*, 92d Cong., 2d sess., February 21, 1972, p. 807.

of the system. Smallness was necessary both in weight and volume, since the less space taken up by the warhead the more space was available for fuel, while the lighter the payload, the further the fuel could take it. The size of the warhead was dictated by the size of the airframe, which was dictated by the desire to have the smallest feasible radar cross-section.

In the feasibility studies for the SCAM/SCAD system performed in mid-1968, the several contractors agreed on the type of warhead to be used in the armed vehicle. The warheads selected for the several proposed configurations of the vehicle were the [redacted]

(U) The SCAD warhead development effort no doubt benefitted from the SRAM program, which was several years ahead of the SCAD. Development work on the SRAM dated back to 1963, so that by 1969 the warhead had already been built and tested. (The missile was deployed to SAC in August 1972.) Since the SRAM airframe was smaller than the SCAD airframe, being 168 in. long and 17-1/2 in. in diameter, the ability to develop a warhead for the SCAD-size vehicle had recently been demonstrated.

The SLCM concept, with its torpedo-tube-launched missile, created a new technological [redacted] However, the issue of [redacted]

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[2](U) Boeing Company, *Subsonic Cruise Armed Missile (SCAM) Feasibility Study, Final Summary Report* (July 1968), p. 15, SECRET.

[redacted]

(S) This particular study stressed that there would be [redacted]

(S) While [redacted] was a desirable objective, movement toward it seemed slow. In August 1975, DDR&E was still directing the Air Force, Navy, and ERDA to conduct [redacted]

[3](U) J. Luttrell, J. Hesse, and C. Kettenbach, *Submarine Launched Cruise Missile Phase I Study* (White Oak, Md.: Naval Ordnance Laboratory, August 1973), p. 5-1, SECRET RD.

[4](U) Office Director Defense Research and Engineering, *Decision Coordinating Paper for the AGM 86 ALCM Full Scale Development Program*, DSARC II, Preliminary Draft (December 1976), p. 2, SECRET.

VIII

THE SCAD PROGRAM

(U) The year 1967 can probably be designated as marking the beginning of the current cruise missile programs. In that year several studies appeared concerning long-range decoys and standoff weapons and the pressures from several agencies to develop such weapons began to build. Both the military and scientific communities were involved.

(U) Consideration of lightweight decoys in the scientific community had begun at least as early as the previous year, an IDA study on the subject having been published in July 1966.[1] A followup study the next year came to even stronger conclusions on the feasibility of long-range decoys and air-surface missiles. The second IDA study suggested that the state-of-the-art could produce a variety of long-range lightweight turbojet decoy/ASM's capable of carrying radar augmentation and ECM sufficient to saturate fighter defenses and current SAM systems of the Hercules, Hawk, and SA2 types.

(U) The study asserted that nuclear warheads of respectable yield could be carried by decoy/ASM's possibly weighing as little as 400 lbs, thus providing a dual-purpose capability with the offensive function in no way subordinate to the ECM function. High-explosive or chemical warheads could also be employed for an anti-radiation mode or terminally guided missions.

(U) The IDA study stressed the availability of the technology needed to create such decoy/ASM's--the small Williams

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[1] (U) Benson Tucker, *Lightweight Decoys for Aircraft*, IDA P-269 (July 1966).

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turbofan engine, then under development, and an autopilot plus the TERCOM system.[2]

(U) In the same period, scientists at the RAND Corporation were considering ways to solve the bomber penetration problem by using the SRAM.[3] They suggested a scheme to replace the SRAM with another missile of the same size to fit the aircraft rotary rack. Since the missile was volume- and not weight-limited by the rack requirement, it was possible to change the characteristics of the missile significantly. What was suggested was a missile that could fly much further than the SRAM because it flew at the aircraft's subsonic speed rather than at the SRAM's supersonic speed. This increased-range missile was not to be a decoy acting like a B-52, but instead to be a subsonic cruise armed missile (SCAM).

(U) The purpose of the scheme was to put a huge burden on the defense, even though the SCAM's could be shot down. It was not intended that the SCAM be invulnerable. What was intended was a basic transformation. Instead of one aircraft and 20 bombs/warheads, there would now be one aircraft and 20 missiles. It was not that the Soviets would not be able to find any of the missiles, but that they would have to find many of them. This idea, essentially that of Dr. Albert Latter, came to be known as "MIRVing the bomber."

(U) Early in 1967, work began on a Defense Science Board Task Force report on proposed standoff weapons. Published September 15, 1967, the report recommended development of long-range standoff weapons for the Air Force. The report foresaw Soviet employment of acoustic detectors to locate low-flying

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[2](U) Benson Tucker, *Small Long Range Aircraft Decoys and ASMs*, IDA P-358 (August 1967), SECRET.

[3](U) SRAM, AGM 69A, was initiated as a concept by Boeing in December 1963. A USAF request for a weapon system proposal was issued in July 1965. Deployment by SAC began in August 1972.
(U) The SRAM had a range of 30 nm at low altitudes and 70 nm at high altitudes.

bombers and use of SAM's with nuclear warheads to destroy them. It recommended MIRVing the bomber with a long-range cruise missile, an extended range form of Hound Dog. The report also asserted that the effectiveness of the weapon would depend on its being used in large numbers rather than on its speed. It proposed a missile that could fly up to 2,000 nm, with characteristics very similar to those of the cruise missile that eventually appeared in the 1970's. The original name attached to this concept was MILAM (multiple independently aimed low-altitude missile).[4]

(U) The idea of developing a longer range decoy also surfaced in the Air Force that same year as the result of a study at the West Coast Study Facility on bomber penetration. This was a lengthy and comprehensive technical analysis of alternatives. A replacement was suggested for the Quail decoy, which had been designed in the 1950's for use with the B-52 at high altitudes and had become operational in 1962. It had a high-altitude range of 250 nm. The Quail's low-altitude range was quite limited and so it could not carry out the generally accepted tactic of low-level penetration. The study showed that a tenfold increase in decoy miles could be produced by a vehicle with the same volume as Quail.[5]

(U) A variety of sizes were considered for the proposed decoy, allowing for one, two, four, or eight decoys per SRAM space on the aircraft rotary rack. The most interest was evinced in the smaller decoys. Another suggestion made by the West Coast Facility study was for a supersonic missile, ramjet powered with rocket boost, of about the same size as the vehicle that finally emerged as the SCAD. This configuration, called the ASALM, was to be a longer range replacement for SRAM

[4](U) Interview with Dr. Albert Latter, formerly of RAND and member of the DSB.

[5](U) Interview with Lt. Gen. Glenn Kent, USAF (Ret.), formerly head of Development Plans in AFSC.

that could also function as a long-range air-to-air missile for use against Soviet fighters or a Soviet AWACS.

(U) However, the study group viewed a subsonic decoy as a lower technical risk and had more confidence in the availability of the technology to develop one. AFSC, on the other hand, had little confidence in a small turbofan decoy and favored a ramjet.

(U) What the Air Force wanted at this time was a subsonic cruise unarmed decoy, a longer range vehicle than the Quail. As a foolproof decoy could not be achieved, it was proposed that 1 of every 10 decoys be armed with a warhead. The enemy air defenses would thus have to treat all the decoys with respect.[6] The study group decoy was also to carry electronic equipment that, given weight, space, and power limitations, could at least for a few frequencies receive a Soviet radar signal and send back an augmented one.

(U) Once the ideas of the study group began to jell, investigation into the available technology began. The initial and major concern was with the ability to produce a small engine cheaply. Wright-Patterson and the major engine manufacturers reacted negatively. However, precedents were uncovered: a man in California had built a small turbojet to power a glider; the Garett Corporation was found to be building smaller engines for helicopters, not as small as needed and neither cheap nor free of bugs, but still a good deal smaller than the standard engine; the Williams engine was recognized. Thus by late 1967 the study group was convinced that the requisite small turbofan engine could be built.

(U) Examination of TERCOM revealed that the first problem with it was the inability of the patent holding company to test the system properly. The several problem areas that would

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[6](U) Interview with Dr. Alexander Flax, formerly Assistant Secretary of the Air Force for R&D.

continue to characterize TERCOM in the future were also apparent then. Nevertheless, the group believed the system could be made to work.

(U) By the time the study group briefed its report in late 1967, the members were convinced that the proposed long-range decoy could be developed by exploiting the technologies for a basic long-range vehicle.[7]

(U) DDR&E responded very favorably to suggestions from the scientific community that an armed missile be used; and the term SCAM soon supplanted MILAM. The Air Force, however, was generally negative to the armed version of the decoy. General Glenn Kent of AFSC suggested as a compromise both a different name and strategy. His idea was to put into the missile both a warhead and a 20-lb ECM device and to call it a SCAD. This proposal was intended to gain enough support from the Air Force to enable a program to be initiated.

(U) In retrospect, General Kent feels that it was probably unwise to have tried to achieve both objectives with the same program, and that concurrent but separate programs would have been better. While the vehicles to be developed were virtually identical, their functions were completely different. The decoy was intended to simulate the signature of a B-52 and thus to be detected. The armed decoy or SCAM had to avoid detection in order to make its low-level subsonic penetration.

(U) The basic incompatibility of these two objectives was never resolved and led ultimately to the cancellation of the project. Requirements kept shifting from one set of unrealistic specifications to another. Moreover, from the start SCAD was a victim of the politics of the B-1 controversy. The Air Force quickly saw the suggested SCAD as a threat to the sought-after B-1, since the air defense saturation and

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[7](U) Interview with Maj. Gen. Jasper Welch, USAF, formerly with West Coast Study Facility.

penetration potential of a standoff weapon seemed to make the need for a penetrating bomber questionable. In fact, those suspicious that Air Force interests were parochial had interpreted the limitations placed on the SRAM range as reflecting a similar attitude toward standoff weapons of any sort.

A. THE SCAD DEVELOPMENT ROUTE

(U) In early January of 1968, SAC issued a Required Operational Capability (ROC) statement for a replacement for the Quail. The Concept Formulation Plan package/Technical Development Plan was initiated in the Air Staff with a directive calling for an air-launched missile system which could operate as a pure decoy, armed decoy, or attack missile.[8] In March-June 1968, design concept studies were initiated for the air vehicle, propulsion, and decoy electronics. This was followed by advanced development in what the Air Force termed the "higher risk areas of engine propulsion and decoy electronics."[9]

(U) A SCAM feasibility study conducted by Boeing reported in July 1968 that the SCAM/SCAD/SCUD concepts, as defined in their study, were feasible in the 1969 state-of-the-art. Four ranges were examined--500, 1,000, 1,500, and 2,000 nm. The earliest reasonable IOC was determined to be 1972. The study concluded that the development of a suitable fanjet engine would be the pacing factor.[10]

(U) A SCAD Project Office was established early in 1969 at Wright-Patterson, and SCAD feasibility studies intended to

[8](U) Headquarters, USAF, *History of the Directorate of Operational Requirements and Development Plans*, DCS/R&D (January 1, 1969–June 30, 1969), p. 105, SECRET.

[9](U) U.S., Congress, Senate, Armed Services Committee, *Hearings, FY 73*, 92d Cong., 2d sess., February 18, 1972, p. 2366.

[10](U) *SCAM Study*, Vol. III, *Final Report Summary* (Boeing Company, July 1968), SECRET.

provide a weapon system concept were undertaken by Boeing, Lockheed, and Beech Aircraft. However, not long after the establishment of the Project Office, it became apparent that there was fundamental disagreement between AFSC and SAC. SAC wanted a short-range decoy. AFSC wanted an armed decoy capable of longer range flight. Part of the Air Staff supported the AFSC viewpoint. Consequently, in December 1969 the Chief of Staff redirected the program into a two-phase development. There would be a SCAD A--a low-cost, low-risk decoy for use only with the B-52 and with early operational development, and a SCAD B, a modular missile for the B-1, capable of being configured as an unarmed decoy, armed decoy, or attack missile. SCAD A would also have a warhead option.

(U) In an April 1970 Development Concept Plan, the DDR&E, Dr. John Foster, took issue with the Air Force approach, recommending a more flexible program directed toward development of a weapon system that would yield a long-range attack and decoy missile, which would be carried externally and be adaptable for internal carry. A high-performance guidance system would give the armed decoy a good attack capability. The carrying arrangements for the SCAD became part of the political-cum-technical battle that raged between the Air Force and the Office of the Secretary of Defense concerning the SCAD. The Air Force insisted that the SCAD should be carried on the rotary rack of the B-52 and the B-1, along with the SRAM, instead of on wing pylons.[11] This would have constrained the size of the SCAD and thus limited its range potential, which seemed to be in accord with Air Force preferences in regard to standoff weapons.

(U) In June 1970 the Air Force stated that the SCAD would be designed primarily to act as a decoy, and would incorporate

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[11](U) USAF, AFSC, *History of the Aeronautical Systems Division, July 1971-July 1972*, Vol. I, p. 109, SECRET.

only such additional features, at minimal cost, as were needed to satisfy the following requirements: (1) that initial deployment would be of an unarmed decoy that could be armed at a later date, and (2) that the weapon would be equipped with a simple guidance system sufficiently accurate to maintain the penetration corridor.[12]

(U) On July 15, 1970, the Deputy Secretary of Defense endorsed the USAF position on development of a decoy constrained in size for internal carry, currently unarmed but with the alternative of being armed at a future date. Studies toward this end were halted temporarily in December of that year when the Joint Senate/House Conferees denied the entire FY 71 SCAD funding, stating that, while the project had originally been presented only as a replacement for Quail, SCAD had become too expensive and it was not clear what it could do that Quail, Hound Dog, and SRAM could not do.[13] This Congressional action was reversed, however, and in January 1971 a 48-month development program to provide an unarmed decoy by June 1975 was approved.[14]

(U) The objectives of the SCAD program were expressed by Dr. Foster to the Senate Armed Services Committee on March 18, 1971:

> We have decided to concentrate first on means to assist the bomber to penetrate the area defenses and reach the SRAM release point. To do this, we are developing the SCAD initially as a bomber decoy. At the same time, it is being designed with the modular

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[12](U) USAF, Directorate of Operational Requirements and Development Plans, *Semi-Annual History* (January 1, 1970-June 30, 1970), p. 259, SECRET.

[13](U) USAF, Directorate of Operational Requirements and Development Plans, *Semi-Annual History* (July 1, 1970-December 31, 1970), p. 200, SECRET.

[14](U) USAF, Headquarters, Strategic Air Command, *SAC History FY 72*, Vol. II, p. 300, SECRET.

> expansion capabilities I cited; so we are also building a vehicle which, with proper changes, can be used in a long-range stand-off role. It is premature to decide now to put all our eggs in the long-range stand-off missile basket, but our development plan leaves this option open.[15]

(U) Foster explained what seemed to be a withdrawal from his earlier active support of an armed vehicle by stating:

> I happen to agree with the Air Force that the long-lead uncertainty here is the development of the decoy, so I have supported them in pushing that aspect. I personally am somewhat prejudiced toward putting the warhead in all of them rather than some of them, but I do not see any need for arguing that issue at the moment, since they all will be capable of carrying a warhead. It seems to me the thing to do is get some missiles flying and see how they perform, see how much of the current promise can be converted to practice, and then make decisions.[16]

(U) The issue of priority of role, however, continued to dog the SCAD program. In 1971 when the Senate Armed Services Committee recommended refunding the program, it expressed the belief that the Air Force should attach first priority to the earliest possible development of the increased accuracy dual-role SCAD system. When new hearings were held in 1972, the Air Force continued to stress that the first priority should be on the decoy capability.[17]

(U) Additional support was thrown behind the armed version when, in September 1971, an Office of Science and Technology ad hoc panel on strategic long-range standoff weapons concluded

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[15](U) U.S., Congress, Senate, Armed Services Committee, *Hearings, FY 72*, Part I, 92d Cong., 1st sess., March 18, 1971, p. 491.

[16](U) Ibid, p. 420.

[17](U) U.S., Congress, Senate, Armed Services Committee, *Hearings, FY 73*, Part 4, 93d Cong., 1st sess., March 18, 1972, p. 2371

that studies should be undertaken by the Department of Defense on how to adapt standoff weapons for use with the B-1. In February 1972, ODDR&E requested that the Air Force study the concept thoroughly. As a result, alterations were proposed for the SCAD and a program initiated. However, events moved very slowly.[18] The Air Force had never geared the program to be a specific IOC, and in early 1972 the Chief of Air Force R&D told a Congressional committee that by mid-FY 75 sufficient data should accumulate from the flight test program to permit a production decision.[19]

(U) By early 1973, in view of the seemingly irreconcilable differences between the Air Force and the OSD positions, the operational rationale for the SCAD had become increasingly difficult to defend. The Air Force was still adamantly pursuing a decoy for the B-52 with range extension and arming options, but OSD now wanted immediate concentration on a long-range attack decoy equipped with an accurate guidance system instead of the simple system required of a decoy. ODDR&E challenged the Air Force in March 1973 on issues of cost, schedule, and range, as estimated costs were increasing and range was decreasing. Furthermore, in the words of the SAC history, "The DDR&E was also concerned, in regard to the unarmed decoy, about how pressing the need was to ensure bomber penetration."[20]

[redacted] At the end of June 1973, the Deputy Secretary of Defense decided to terminate the full engineering development of SCAD and directed the Air Force to pursue a broader approach

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[18](U) Headquarters, USAF, DCS/Plans and Operations, *Cruise Missile Study* (April 1976), p. 18, SECRET.

[19](U) U.S., Congress, Senate, Committee on Appropriations, *Hearings of Subcommittee on DoD Appropriations, FY 73*, 93d Cong., 1st sess., February 21, 1972, p. 807.

[20](U) USAF, Headquarters, Strategic Air Command, *SAC History FY 73*, Vol. III, p. 503, SECRET.

involving a [redacted]

(U) The history of the SCAD program is outlined below.

SAC ROC	Jan. 1968
Design concept studies	Mar.-June 1968
Advanced development initiated:	
Engine test program/preliminary specifications	Sept. 1968
Engine component development and test	Nov. 1969
Decoy electronics specifications	Mar. 1969
Decoy breadboard and flight test	Dec. 1969
Decoy credibility assurance program	Oct. 1970
Program approval (DCP #74)	July 15, 1970
Temporary Congressional cutoff of funding	Dec. 1970
RFP's for airframe, engine, decoy, navigation, and guidance released	Feb. 1972
Contracts awarded for engine competition	May 1972
Program cancelled	July 1973

B. TECHNOLOGICAL ISSUES IN THE SCAD PROGRAM

(U) It should be noted that despite the political climate surrounding the SCAD program, there was continual progress in developing component technologies and in system integration. According to the documentation available and discussions with personnel from Boeing, Lockheed, and the SCAD Project Office,

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[21](U) D. Welch, *Cruise Missile Technology Study*, p. 1, SECRET.

there is considerable agreement as to what were the technological issues in the SCAD program. The two areas of concern were the effectiveness of TERCOM and the propulsion system. The warhead was never seen as a problem, and neither contractors nor AFSC foresaw major problems with technology. This section will briefly review the technical issues that were found to exist during the 5 or 6 years the SCAD concept was pursued.

[redacted] Neither Lockheed, which bid on the project, nor Boeing, which became the airframe contractor and system integrator, [redacted]

[redacted] The more it was attempted to increase the [redacted]

(U) The Air Force requirement that the SCAD be interchangeable on the rotary rack with the SRAM made engineering

[22](U) Interview with SCAD Program Director, Boeing Company.

solutions difficult. The volume limitations and fact that the shape of the vehicle could not be changed reduced the packaging options available. Furthermore, after a few months, the Air Force relaxed the packaging efficiencies initially required of the ECM work. This soon led to an increase in the volume and weight of the ECM gear, with the consequent loss of fuel storage space and hence reduction in range.[23]

(U) Technical aspects of the airframe, the folding wings and tail, did not represent a major technological problem, nor did launching the missile from wing pylons. These were viewed as engineering problems only.

(U) While most concern probably centered on the TERCOM, there was also a surprising degree of concern over the adequacy of the Williams engine. Several aspects were worrisome, but on the whole there was confidence that the small fanjet could eventually be engineered to do the required job. These engineering problems, however, were not insignificant. For example, the engine had been designed for vertical operation on the Flying Belt, but in the SCAD it would function on a horizontal plane.

(U) Some of the skepticism surrounding the Williams engine was apparently due to the reluctance of the engineers at Wright-Patterson to use the product of a relative unknown in the aircraft engine field (Williams previously had worked in the marine and automotive fields). When the Air Force surveyed the aircraft engine manufacturing community in its first investigations into the SCAD concept, the reaction of the manufacturers was generally that the engine required would be too small to be efficient. Air Force supporters of the Williams engine believed that there was a tendency in AFSC to view the Williams product as "not a real aircraft engine" because it did not fit the

[23](U) Ibid. Also mentioned in interview with Lockheed personnel who worked on SCAD proposal.

technological image of an aircraft engine. Because of its cheap cost and because the concept of a "throw-away" engine was hard to accept, there was a clear prejudice against the engine that resulted in considerable foot-dragging on the engine issue. It proved difficult later even to persuade AFSC to test the Williams engine in a Wright-Patterson wind tunnel.* Supporters of the engine had difficulty getting the engine funded and supported.

(U) Evidence of continuing concern with the engine was reflected in Air Force testimony to Congress in February 1972. At that time it was stated that there was a

> ...medium risk in getting the exact specifics that we have specified for the SCAD's engine. It is quite low because of the earlier efforts which essentially demonstrated the basic feasibility of doing this sort of thing with the light turbofan engine.[24]

(U) One factor in concern over the engine was the issue of fuel. SCAD had originally been intended to use JP-4, the standard aviation fuel. The high-density fuels were attractive, but investigation revealed problems. The low-temperature flow characteristics of the high-energy fuels were not satisfactory. Fuel heating could probably have resolved the difficulty but would have necessitated further weight compromises and thus reduced range once again. The flow problem required changes in metering and the size of the flow channels. It was, in fact, because of these problems, especially with regard to viscosity, that JP-4 had originally been selected. There were other unknowns as well. Shelldyne looked like a good fuel, but its shelf life had not been determined nor had its effects on gaskets and seals. Furthermore, production facilities for Shelldyne at the time were small.

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[24](U) Senate Armed Services Committee, *Hearings, FY 73*, p. 2374.

(U) Despite the fact that the Aeronautical Systems Division of AFSC had supported TERCOM studies and development for the 10 years prior to initiation of the SCAD program, there were apparently questions in some Air Force quarters as to its reliability and accuracy, an attitude that may have been encouraged by the overall Air Force attitude toward the armed version of the SCAD. It is unclear as to whether TERCOM was intended to be put into the pure decoy version, too. All the decoy needed was a simple guidance system adequate to keep it within the bomber corridor, and General Kent, for one, resisted the use of TERCOM in the decoy. The Lockheed team who bid on the SCAD in 1968-69, however, believed the decoy was also to have TERCOM. By 1972 the Air Force was telling Congress that the reason the SCAD was not being developed simultaneously in both armed and unarmed versions was that the unarmed version did not require as sophisticated a guidance system. The implication was that guidance was the element holding back development of the armed SCAD.

([redacted]) There is a marked dichotomy in the views on TERCOM in the period up to 1973. Some connected with the program, like Colonel Wood, the SCAD Project Officer in 1969-70, felt that there were [redacted]

([redacted]) The other point of view suggested that the very [redacted]

[redacted]

(U) Opinions differ as to whether all the component technologies were "available" to build a successful SCAD by the original target date. The program is probably a poor case study to use for exploration of this contentious point, since it was hopelessly entwined with the B-1 issue. What those connected with the program do agree on is that the system technology represented a greater challenge than any of the component technologies. In the confined space of the SCAD, "interface management," as Lockheed called it, was a major area of program concern. The Air Force, too, in February 1972, stated that the risk in the SCAD was essentially in the packaging area, "the actual ability to configure the components in small enough size, weight, and volume to fit in the limited space in the SCAD vehicle."[25] The Air Force at that time called the whole program low-to-medium risk.

[25](U) Senate Armed Services Committee, *Hearings, FY 73*, p. 2375.

IX

THE NAVY AND AIR FORCE CRUISE MISSILE PROJECTS

(U) A curious ambiguity surrounds the origins of the Navy cruise missile program. As early as July 1972, when asked who had initiated the concept of a submarine-launched cruise missile, Dr. Foster stated, "That is going to be hard to trace. It has been talked of for several years."[1] In early 1978 two authorities on naval affairs wrote in an article in the *United States Naval Institute Proceedings* that "TOMAHAWK's origins are obscure."[2]

(U) The Navy cruise missile program can be traced along two separate but obviously intertwined lines of development. One is the development of the antiship missile Harpoon, the other the development of the long-range strategic missile. The two programs began separately but were interactive until 1972. As the Harpoon program started earlier, it may be best to discuss it first. The Harpoon was the first Navy effort in the new cruise missile era and the technical achievements of the program, along with those of the SCAD, laid the foundation for the Navy SLCM program.

A. DEVELOPMENT OF AN ANTISHIP CRUISE MISSILE

(U) On paper the Harpoon antedates the SCAD. Although the Navy had been uneasy for years about the capabilities of Soviet

[1] (U) Senate Armed Services Committee, *Hearings, FY 73*, p. 4353.

[2] (U) N. Polmar and Capt. D. Paolucci, USN (Ret.), "Sea-Based 'Strategic' Weapons for the 1980s and Beyond," *United States Naval Institute Proceedings*, Vol. 104/5/903 (May 1978), p. 9.

antiship cruise missiles, it was the sinking by the Egyptians of an Israeli destroyer in 1967 with a Styx cruise missile that marked the beginning of the Harpoon story. The Navy drew up a broadly written Specific Operational Requirement (SOR) in 1967 for a cruise missile type vehicle, with a range of 35 to 40 nm to carry a 250-lb conventional warhead. In 1969 the SOR was revised to add a requirement for surface ship launch to that for air launch. However, the SOR was not acted on immediately, and not until the end of 1970 was an RFP calling for an air-launched antiship missile sent out to industry. In June 1971 McDonnell-Douglas was chosen as prime contractor.

(U) At this time research was being conducted at the Naval Ocean Systems Center (NOSC) on the bouyant capsule launch of missiles in which a capsule rose to the surface by bouyancy only. NOSC scientists informed Commander (now Rear Admiral) Walter Locke, the Harpoon Project Officer, that underwater launch from a 21-in. torpedo tube might possibly have some application for the incipient Harpoon, and they solicited Locke's support for a feasibility demonstration. With his agreement, McDonnell-Douglas and NOSC worked together on a feasibility demonstration of a boost test vehicle, McDonnell-Douglas defining the missile and NOSC the capsule. In early 1972 the system was tested successfully.

(U) The Harpoon program was now revised to include the submarine-launched variant, the "encapsulated Harpoon." All three efforts--air-, surface-ship-, and submarine-launched--developed in parallel with equal emphasis.

(U) The missile was at this time 180 in. long and 1,350 lbs maximum weight, with a diameter of 13-1/2 in. The capsule was big enough to carry the weapon to the surface at the proper angle, while the booster had enough punch to toss the missile clear before wave action could cause the missile to flip as it exited the capsule. Seeker acquisition had been part of the RFP sent to industry, since there was no in-hand guidance system.

Several systems were proposed, all radar-active. The range of the missile at this time was about 50 nm, but acquisition range was only 13 to 14 nm, which was the line of sight from a 50-ft elevation.[3]

(U) Thus, by early 1972 the Navy had a well-developed ongoing cruise missile program and had in the course of it demonstrated the capability to launch a cruise missile under water from a standard torpedo tube.

B. DEVELOPMENT OF SEA-LAUNCHED STRATEGIC CRUISE MISSILES

(U) The naval strategic cruise missile program grew out of meetings in the spring of 1970 between personnel from OSD/Systems Analysis and the Center for Naval Analyses (CNA). The Systems Analysis people had initiated the discussions to explore the idea of putting long-range cruise missiles into the 10 oldest Polaris submarines, 3 missiles into each Polaris missile tube. They believed that much of the technology required to develop the missile existed as part of the SCAD program.

(U) When Admiral Zumwalt became Chief of Naval Operations in the summer of 1970, CNA delivered to him a list of new ideas that included the idea of a sea-based cruise missile, and requested that they be permitted to do a thorough study of the idea. The study was so directed[4] and was published in September 1971.[5]

(U) This was probably a seminal study in the entire revived U.S. cruise missile effort and deserves detailed coverage. The object was to determine whether sea-based cruise missiles could

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[3](U) Interview with the Technical Director, Joint Cruise Missile Project Office.

[4](U) Chief of Naval Operations, CNO Action Sheet 141-70 (July 6, 1970), SECRET.

[5](U) CNA, *Sea-Based Strategic Cruise Missiles*, TOP SECRET.

usefully be added to U.S. strategic forces. The study examined the role such missiles could play, defined and costed several systems, and laid out alternative plans for their development. The systems were restricted to characteristics that could fore-seeably be achieved with the current technology. Finally, cruise missiles were compared with alternatives of equal cost to determine relative effectiveness.

(U) A covering letter from the Director of Navy Program Planning included with the study stated that the identified high-risk development of TERCOM could be considered an accept-able risk, should the need for such a program be decided upon. Some uncertainties about the engine thrust and volume require-ments also remained and would have to be resolved before a program should be initiated. The latter also stated that the development times suggested by CNA for preprogram efforts, design competition, concept formulation, and proposal evaluation seemed optimistic, in view of past performance.

(U) The CNA study stated at the outset that it grew out of the idea that the technology of the Air Force SCAD could be used to develop a small strategic cruise missile. Two main reasons were offered as to why sea-based cruise missiles (SCM) were of interest: 1) they represented a means of strategic diversifi-cation to improve deterrence, and 2) the current technology could probably provide them with impressive capability at a reasonable cost. Regulus had originally been abandoned in favor of Polaris because ballistic missiles were superior in almost every way--longer range, bigger payload per submarine, greater accuracy, and better penetration of enemy defenses. However, technical advances in the 1960's had reduced the degree of difference. The Soviet ballistic missile defense had become a major concern. At the same time, the means to achieve sus-tained cruise missile flight at very low altitudes had been developed, which with the other characteristics of cruise mis-siles could make penetration much easier. The study stressed the range capabilities achievable with small engines and high-energy fuels, and improved inertial systems and mapping.

(S) The study suggested consideration of several different platforms for launching SCM's: 598/608 Class SSBN's (96 missiles per boat); a new submarine (96 per boat); new or converted merchant hulls (96 per ship); Terrier-equipped ships (up to 40 per ship); and SSN's (torpedo-tube launch--up to 22 per boat). Two sizes of missiles were considered: 20-ft and 16-ft length; 25-in. and 19-in. diameter; 3,200 lbs and 1,800 lbs. The small missile would be launched from the attack submarine or Terrier ship.

(S) CNA reported that a cruise missile with the following characteristics seemed [redacted]

Range at 200-ft altitude: 3,600 mi (1,600 for Terrier or SSN basing)
Speed: Mach 0.75
Altitude: 200 ft

[redacted] for use with new platforms.

(U) The contribution of the SCM was analyzed. In terms of cost effectiveness, SCM's compared favorably with other systems projected to be available in the mid- to late-1970's. While SCM's would contribute to diversification of the strategic arsenal, their principal contribution would be as a hedge against the development of effective threats to the survivability of land-based forces and against the in-flight vulnerability of ballistic missiles and bombers. SCM's could be deployed rapidly on existing platforms once development and tooling were completed, and would also be a hedge against violations of potential SALT agreements.

(S) Potential problems with the [redacted]

(U) In view of their finding that there was substantial risk, CNA recommended that the Navy initiate an R&D program to resolve the principal technical uncertainties associated with the military characteristics of the missile. Prototype development was suggested as the best approach, since development of a successful prototype would provide the technological base for rapid deployment when needed.[6]

(U) CNA was supported in the study effort by Lockheed, which did the feasibility studies. Lockheed apparently put a good deal of effort into the project, pursuing the vehicle approach used in the SCAD program. The study anticipated that no extremely difficult technical problem areas would appear that could not be resolved during development engineering. With regard to TERCOM, the Lockheed study commented:

> While a complete TERCOM system has to date never been demonstrated in an application similar to the cruise missile system's requirements, it was considered necessary for this study to almost categorically assume the credibility of such a system, on the assumption believed valid when compared to the associated state-of-the-art technology, both in component hardware and functionalization techniques.[7]

This suggests that Lockheed was accepting TERCOM as an article of faith rather than as a proven system.

(U) When the CNA report appeared, the Navy generally did not show much interest in strategic cruise missiles, although support and interest were generated in DDR&E and OSD/Systems Analysis. Within the Navy the only real interest was shown by the CNO and to some extent by OP 96 (Office of the Chief of Naval Operations, Systems Analysis Division).

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[6](U) Ibid.

[7](U) Lockheed Missiles and Space Company, *Cruise Missile Study Final Report*, pp. 3-4, SECRET.

(U) The idea of a long-range missile apparently had no particular appeal for much of the Navy, even if what was meant was an antiship missile. There was a simple problem in that the Navy did not really know how to utilize an antiship cruise missile with a 300-nm range. There was the matter of detection of a ship target at such a range and determination of azimuth. For ranges beyond 140 mi, the Navy believed targeting would have to be controlled from a supporting platform.[8]

(C) At this point, however, the possibility of a SALT agreement began to assume significance. In view of the possible [redacted]

(C) Some Navy interest had developed, starting at CNO level, in a [redacted]

[8](U) Interview with Mr. Carl Tross.

[9](U) USAF, Directorate of Doctrine, Concepts, and Objectives, *History* (Jan ary 1, 1972–June 30, 1972), p. 6, SECRET.

[redacted]

(U) To test these [redacted]

(U) Impetus had been provided to this line of development by a [redacted]

[10](U) Interview with the Technical Director, Joint Cruise Missile Project Office.

[11](U) Interview with personnel of the Lockheed Missiles and Space Company.

[12](U) Headquarters, USAF, DCS Plans/Operations, *Cruise Missile Study*.

(C) In response to the Secretary of Defense directive concerning a strategic missile, the Navy authorized five contractor feasibility studies at the end of 1972. These were presumably intended to [redacted]

(C) It should be noted, however, that the emphasis seemed still to be on a [redacted]

(U) On August 14, 1973, and again on December 19, 1973, the Deputy Secretary of Defense directed that the Navy proceed at once with the advanced development of a baseline cruise missile

[11](U) Interview with personnel of Boeing Aerospace Company.

that could be launched from a standard torpedo tube.[14] The August directive was specifically aimed at an antiship cruise missile.[15]

In September of that year, RFP's for [redacted] of the cruise missile went out to industry: the [redacted]

(U) In January 1974, General Dynamics-Vought were given the contract for the airframe and the system integration. The competition for the guidance system and the engine, however, took much longer. Teledyne and Williams competed for the engine, while McDonnell-Douglas and Electrosystems, Inc. bid for the guidance system. A DSARC I review in February 1974 directed the Navy to proceed with the submarine-launched cruise missile, to continue close cooperation with the Air Force, and to address surface-launch modes during prototype validation.[17]

C. THE AIR FORCE AIR-LAUNCHED CRUISE MISSILE

(U) While this process, slow and convoluted as it was, gradually moved the Navy toward development of strategic and

[14](U) Systems Planning Corporation, *Background Paper on Cruise Missile Concepts* (December 1977), p. 2, SECRET.

[15](U) OSD, *Land Attack TOMAHAWK Cruise Missile*, DCP #125 (December 22, 1976), p. 1, SECRET.

[16](U) Naval Air Systems Command, *Anti-Ship TOMAHAWK Cruise Missile*, Program Memorandum #117 (October 28, 1976), p. 1, SECRET.

[17](U) OSD, *TOMAHAWK Cruise Missile*, SECRET.

tactical sea-launched missiles, the old SCAM idea was revived in the Air Force. This renewed interest can be traced to several sources. As mentioned earlier, it has been suggested (with some truth) that OSD inspired and encouraged the Navy strategic cruise missile program as a means of prompting the Air Force to take more forceful action in developing a standoff weapon. Another reason for renewed Air Force interest no doubt was that tentative acceptance of the B-1 program had resulted in less Air Force anxiety over the effect of cruise missiles on the fate of that program. Although the SCAD program had been cancelled, the Air Force had been directed to begin a technology program to keep alive the option of reviving a SCAD and to associate the effort closely with the Navy's cruise missile program.[18]

(U) Another and perhaps crucial factor was a letter from the Assistant to the President for National Security Affairs, Mr. Kissinger, to Deputy Secretary of Defense Clements (June 11, 1973). Mr. Kissinger stated:

> We considered that a long-range air-to-surface missile program made sense strategically and would help SALT. You indicated that you would get a long-range ASM program under way within a week. I would appreciate a progress report on the program.[19]

The Deputy Secretary of Defense replied, on June 22:

> We have two on-going programs which could be adapted to meet the requirement--the Air Force SCAD and the Navy SLCM. The SCAD is in the initial development stage.... SLCM is presently in very early stage as a technology program.[20]

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[18](U) Immediately after the SCAD had been cancelled, the Air Force directed AFSC to inaugurate yet another strategic bomber penetration decoy program.

[19](U) USAF, DCS/Plans and Operations, *Cruise Missile Study*, p. 18, SECRET.

[20](U) Ibid.

(U) Strangely, the full engineering development of SCAD was cancelled 6 days later. Then on July 13, 1973 a formal memorandum from Kissinger to Clements repeated the points of the June letter. On July 20 DDR&E directed the Air Force to begin a program for developing long-range ALCM's compatible with the existing SRAM system.[21] The initial capability was to be evolved from the SCAD. The DDR&E directive specifically urged a "vigorous program to demonstrate the capability to develop and/or deploy an ALCM," an admonition no doubt prompted by the snail-like progress made by the SCAD program.[22]

(U) Kissinger's intervention was to have contradictory effects. On the one hand, it undeniably provided the impetus for developing an ALCM at the very moment when the potential candidate was being killed. On the other hand, Kissinger's actions seem to tie the cruise missile to SALT in a new way. Whether he was serious about an ALCM or whether it was always intended to be a bargaining chip for further SALT negotiations is unknown.[23] What is apparent is that from its inception the weapon was labeled a giveaway. This label, of course, also came to be applied to the SLCM, and there is a body of opinion that ascribes the slow development of cruise missiles and the continuing relative lack of Navy or Air Force interest in them to this belief. It would have seemed pointless to push to develop a weapon that ultimately would be given away by political agreement.

(U) At the end of July, Air Force Headquarters directed AFSC to demonstrate the capability to develop a long-range ALCM.

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[21](U) USAF, AFSC, *History*, Vol. I (January 1-December 31, 1976), p. 200, SECRET.

[22](U) ODDR&E, *Decision Coordinating Paper for the AGM 86 (ALCM) Full Scale Development Program--DSARC II* (Preliminary Draft) (November 1976), p. 2, SECRET.

[23](U) Opinions vary, but it is believed that Kissinger eventually came to support cruise missiles because of their intrinsic military worth.

The initial objective would be to establish the technological base needed for such a missile. The initial capability would evolve from the armed SCAD vehicle. The interim capability would be derived from the Navy cruise missile program. The advanced capability would be established from the technological base of the program.

(U) By mid-August the AGM 86-A office was engaged in preliminary studies of an extended-range armed cruise missile. Operating envelopes and range performances were being determined for a missile configuration that borrowed heavily from the SCAD baseline vehicle. The configuration featured a warhead in the forward section, a belly fuel tank, increased internal fuel capacity, and use of JP-9 high-density fuel.

(U) In mid-October DDR&E requested a preliminary program plan for the development of a cruise missile based on the SCAD concept. The missile would be carried internally in both the B-52 and the B-1 on the SRAM racks and carried externally only on the B-52. There would be no provision for decoy electronics and the missile would employ the SCAD engine. This program was suggested for the bomber force to be considered instead of adopting a Navy cruise missile.

(U) On December 14, 1973 DDR&E recommended cruise missile programs for both Air Force and Navy to the Deputy Secretary. The Air Force was to demonstrate an ALCM, based on the SCAD concept, by mid-1976, with deployment by 1980. The Navy was to demonstrate a SLCM, both tactical and strategic variants, also for deployment in 1980. The Deputy Secretary approved these recommendations on December 19. The Air Force missile would be developed as an adjunct to the bomber force, to be launched in a low-altitude attack outside Soviet defenses, thus improving the penetration capability of the bomber. The missile would utilize SCAD engineering developments for the air vehicle and the turbofan engine. Whereas the SCAD would have depended on ECM, detection of the ALCM would be minimized through low-level flight. The additional space in the vehicle would be used for fuel.

(U) The Deputy Secretary also agreed to the SLCM, with the tactical variant delivering a 1,000-lb payload over 300 nm and the strategic system providing an effective low-level nuclear warhead penetrator from the launch base of the nuclear submarine force. The SLCM would result in a proliferation of the strategic submarine force because every tactical submarine would also become a platform for strategic cruise missiles. The cruise missile was also seen as an effective replacement for forward-based nuclear forces.

(U) The Deputy Secretary pointed out that the technological efforts of both the Air Force and the Navy would have much in common. The Air Force had concentrated on development of a small turbofan engine and high-energy fuels, which were suitable to both systems. The Navy had pursued the development of guidance systems, which were also useful to both developments. The Air Force was thus given the leading role in engine development and the Navy in guidance.[24]

D. TECHNICAL ISSUES IN THE CRUISE MISSILE PROGRAM

(U) We have already touched upon the technical issues encountered in the course of the development of both the SLCM and the ALCM. Both were derivatives of the SCAD, and as has been pointed out, it was the SCAD that showed that a very small airframe could have considerable range and accurately deliver a warhead of respectable size.

(U) The submarine-launched missile did not present any completely new problems to the Navy, nor did it require any major technological advances. There were problems with the

[24](U) USAF, AFSC, *History of the Aeronautical Systems Division*, Vol. I (July 1973-June 1974), pp. 206-208, SECRET.

torpedo tube launch, particularly in ensuring engine start with the firing of a single cartridge. (The Polaris was not an example of this since it carried its own oxidizer.) A number of changes to the SCAD engine were required for the SLCM application: engine performance had to be optimized for sea-level cruise instead of high altitude; the structure/mounting had to be redesigned for high-shock environment; the gearbox was moved from the bottom to the top of the engine; the inlet was redesigned for different distortion characteristics; and the exhaust nozzle was redesigned for a different cant angle.[25]

(U) For the submarine-launched SLCM there was also the problem of the possible toxicity of the high-energy fuels. It was not known how safe Shelldyne or E-Dimer would be if stored in the confines of a submarine for long periods of time. This was crucial, since no toxic substances could be allowed on undersea craft.[26]

(U) The antiship variant of the SLCM (named the Tomahawk by the mid-1970's) was able to make extensive use of antiship technology and hardware developed for the Harpoon. The radar seeker, altimeter, and midcourse guidance unit were transferred directly from Harpoon with little or no change.[27]

(S) In regard to [redacted]

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[25](U) U.S., Congress, Senate, Armed Services Committee, *Hearings, FY 75*, 93d Cong., 2d sess., April 12, 1974, p. 3636.

[26](U) Interview with Mr. Carl Tross.

[27](U) Naval Air Systems Command, *TOMAHAWK Cruise Missile*, p. 1, SECRET.

In April 1974, the Navy Cruise Missile Project Manager told the Senate Armed Services Committee:

> The point not to be missed here is the involvement of the Defense Mapping Agency. The weak link in the 10 years of exploratory development work that was done before is that realistic source data was not used. The cruise missile project office has actually involved the agency that gets the operational maps.

He stated that the DMA task would take 3 to 5 years.[28]

([redacted]) In fact, in 1977 ODDR&E, Air Force Studies and Analysis, and DARPA sponsored a Strategic Penetration Technology Summer Study that asserted that the [redacted] Analysis by the Systems Planning Corporation pointed out that more recent data are sometimes not [redacted]

(U) What did appear to be major new technical requirements in 1974 had to do with [redacted]

[28](U) Senate, Armed Services Committee, *Hearings, FY 75*, p. 3638.

[29](U) Systems Planning Corporation, *Background Paper on Cruise Missile Concepts*, p. 22, SECRET.

There were to be [redacted]

[89] (U) Interview with Mr. Carl Tross.

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AN R&D PERSPECTIVE

(U) Generalizing about R&D processes on the basis of a single case is, at best, risky. Moreover, this study concerns only the beginning of the cruise missile development programs, and ideally a case study should not be made of a system until it is operational and all the problems either solved or accommodated by engineering adjustments. That is still not the situation with regard to the cruise missile. The process has taken longer than is usual for a major weapon system, the time from concept to deployment being typically about 10 to 12 years. The process has already passed the 10-year mark, with the very earliest cruise missile IOC forecast for the end of 1981. Yet here is a system for which little had to be invented, although much was refined and adapted in the integration process.

(U) If the cruise missile case can be characterized as a type of R&D, it could best be termed opportunistic. The combination of a military concept with already existing technologies was ultimately to lead to the development of weapon systems. However, the process of development was both turbulent and surprisingly slow in achieving success.

(U) In the curious history of the cruise missile development three factors, technical and nontechnical, appear to have been significant: the perceived military need; the environment, meaning both the degree of acceptance of or support for the weapon system and the political climate of the time; and the state of the technologies involved. The interaction of these three factors conditioned the course of development.

(U) While in the late 1960's there appears to have been greater receptivity toward, if not indeed general perception of the military need for, newer and better unmanned systems for some functions, there was never any general agreement as to what those functions might be. On one side of the question were the most influential elements in the Air Force and the Navy; on the other were the scientific community and the Office of the Secretary of Defense, with support from Service R&D elements. The latter saw the cruise missile as a weapon with enormous potential; the former preferred that it have a much more circumscribed role. The Air Force, when not openly resisting a long-range standoff weapon, considered the cruise missile merely a useful system, not one really needed in conjunction with a penetrating bomber force. The Navy was interested in the weapon only as a strategic reserve to be deployed on attack submarines or as a longer range Harpoon. The cruise missile, in short, was always seen at best as a subsidiary weapon by the Services for which and by which it was developed. After all, the revived interest in cruise missiles had begun on the Air Force side with a decoy and on the Navy side with a short-range antiship Harpoon. It was the scientific community which had pushed for the long-range strategic mission.

(U) It seems likel that the main pressures originally driving the cruise missile programs were not technological, but rather environmental. This development environment was in large part the consequence of controversy over the issue of perceived military need. From the earliest SCAD/SCAM concept progenitor, the operational concept, desirability, and future of the cruise missile seem always to have been in contention. The lack of a clear mission and of solid Service support from either sponsoring Service seem to have made the system a struggling orphan. Even when support could be mustered, the suspicion, engendered in 1973, that the missile might ultimately be expendable as a SALT negotiating pawn tended to dilute it. As evidence of the ambivalence that has surrounded the program is the fact that as late as January 1977, more than 9 years after articulation of the concept by both the scientific community and the Air Force, neither the ALCM nor the SLCM program was included in the Selected Acquisition Report system, which provides standard comprehensive summaries of the major defense programs to top DoD management.[1]

(U) This development environment undoubtedly had a dampening effect on the development process. The lack of any priority or sense of urgency meant that development efforts did not receive the high-level attention or fiscal support that high-priority strategic missile programs, such as Minuteman or Polaris, had received.

(U) Even the role of the cost factor in cruise missile development seems to have been ambiguous. The anticipated cost of the cruise systems seemed attractive on two bases. The system could use relatively well-developed available technologies, and thus avoid the intrinsic costs of developing these specifically for the program. Secondly, on a comparative basis the cruise missile seemed to offer the capability to execute certain missions more cheaply than alternative systems could.[2] This latter evaluation of the cost of the system was always controversial, however, involving as it did the broad issues of strategy and Service interests. There was less controversy over the intrinsic cost of the overall system, since it initially promised to be astonishingly low. Nor did it seem likely that the price tag on any specific component would delay development of the weapon system. Yet costs continued to rise. By the end of 1970 the SCAD program was already under attack

[1](U) U.S. Government Accounting Office, *Status of Air and Sea Launched Cruise Missile Programs*, PSAD-77-36 (January 1977), p. 2, SECRET.

[2](U) For supporters of the missiles the estimated cheapness of the system was one of its major attractions, since this would permit "proliferation" of the weapon to such a degree that an air defense would be saturated.

for steadily increasing costs and equally steadily declining range.

(U) The third factor significant to the development process was the state of the technologies. The component technologies had been under steady development since the early cruise missile period, although usually for other reasons, and their progress had been evolutionary for the most part (the microprocessor was probably the great "breakthrough"). Furthermore, as has already been suggested, cruise missile development was fairly continuous during the 1950's and 1960's, with cruise missiles of one mission or another always either in service or in development. The advent of the ballistic missile did not cause an abrupt discontinuity, but rather the appearance of one. Even the long-range cruise missile lay dormant for only a few years, from the deactivation of the Snark in 1961 until the appearance of the SCAM/SCAD concept 5 or 6 years later.

(U) A basic premise of this study was that the technologies were available when the cruise missile programs got underway, available meaning (1) the basic knowledge existed of how to build the components, and (2) while all the problems had not yet been solved, the probability of success was high. If technical risk can be solved by the application of enough resources, then there was never more than a medium risk even for TERCOM, which usually got higher marks for risk than the other problem area, propulsion. Yet neither the cruise missile nor TERCOM received major funding in the period under study.

(U) Some of those interviewed for this study stated that the development of a cruise missile was generally felt to be a "piece of cake" technologically. There was even some sentiment that the cruise missile represented a technological step backward. It seems clear in retrospect, however, that the development was not so simple technologically as may have at first been anticipated. The several components of the system were not all equally advanced when interest in the cruise missile revived, nor did their subsequent development occur at the same pace. The fact that the Air Force specifications kept changing certainly did little to improve that situation. TERCOM may well have been delayed by Air Force reluctance to pursue development of a really long-range attack missile. Regardless of the reasons, however, the fact remains that development has continued for a long time of technologies that were widely viewed as virtually "off-the-shelf" at the turn of the 1970's.

(U) Even if all the component technologies had been equally advanced, and development had moved faster, system integration would have continued to pose the problem of determining necessary trade-offs. The requirement for a very small airframe that could fly long distances at very low altitude, navigate with great accuracy, and deliver a respectable size warhead really represented an advancement in the state-of-the-art of integration, if not in the component technologies.

(U) The real technological challenge of the cruise missile was therefore not in component development but in the overall integration of the system. Probably the crucial factor was size. The airframe had to be small to permit large numbers of the weapon to be launched from the carrier vehicle and to reduce the degree of vulnerability derived from the system's subsonic speed. The components had to be small to maximize the fuel-carrying capacity and maximize the range. That the components be small was thus the chief system requirement. The engine was "found" small, the warhead made small, and the TERCOM steadily reduced in weight and volume.

(S) Ironically, the most problematic element in the entire cruise missile system turned out to be one extraneous to the missile itself. The [redacted]

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(U) The technical issues involved in the cruise missile development were thus optimization of component performance and system integration. The former, while not as simple as expected, was less a constraint than the latter. It has often been asserted that weapon systems are assembled, not invented. In the cruise missile case, it would appear that the act of assembling the components was in itself an act of invention.