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AN OUTSIDER'S VIEW OF THE
PHOENIX/AWG-9 WEAPON SYSTEM

by

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AN OUTSIDER'S VIEW OF THE PHOENIX/AWG-9 WEAPON SYSTEM

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ABSTRACT

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

TABLE OF ABBREVIATIONS

ADR	Altitude Difference Ranging
AIM-54A	Air Intercept Missile No. 54a
AMCS	Airborne Missile Control System, associated with the F-111B
ASG-18	Airborne Special Fire Control System No. 18, associated with the F-108 and the YF-12
AWG-9	Airborne Armament Fire Control System No. 9
GAR-9	Guided Air Rocket No. 9
GHz	GigaHertz (1,000,000,000 cycles per second)
gpm	Gallons per minute
IF	Intermediate Frequency
IFF	Identification, Friend or Foe
IOC	Initial Operational Capability
kHz	KiloHertz (1000 cycles per second)
LTE	Launch-to-Eject Cycle
MHz	MegaHertz (1,000,000 cycles per second)
NISC	Naval Intelligence Support Center
PRF	Pulse Repetition Frequency
psi	Pounds per square inch
R and D	Research and Development
RF	Radio Frequency
WCS	Weapon Control System, associated with the F-14
XAAM-N-10	Experimental Air-to-Air Missile Naval No. 10
XAAM-N-11	Experimental Air-to-Air Missile Naval No. 11
XAAM-54A	Experimental Air-to-Air Missile No. 54A
YAAM-54A	Prototype Air-to-Air Missile No. 54A

To Uncle Sam, who made all this possible.

Figure 1 - F-14 AND PHOENIX (Courtesy of Hughes Aircraft Company)

I. INTRODUCTION

The United States is an open society. As a result, much information concerning U.S. weapon systems is published in open literature and unclassified sources and is available to anyone, friend or foe. Compared with U.S. defense planners, Soviet planners must have an abundance of information available on which to base their decisions. An important element in defense decision making is the perception of the "threat." "Threat" is the capability to inflict harm. As such, the Soviet perception of the threat from a U.S. weapon system can be equated to the perceived capabilities of that weapon system. Denial of certain types of information (e.g., by classification) about U.S. weapon systems could affect Soviet perception of the threat from the United States and thus alter their reaction to it, i.e., could affect the future development of their weapon systems.

The purpose of this thesis is to conduct an analysis of information available in open literature and unclassified sources on the Phoenix missile system in order to determine how much classified information on this system has crept into the open literature and other unclassified sources. A body of historical and technical data has been gathered and is presented as an unclassified view of the Phoenix missile. It can be assumed that the minimum Soviet knowledge about the Phoenix missile system is detailed in this thesis. One Soviet publication alone on missiles, for example, references many of the sources used in this research project.[1]

The scope of the project was determined by the necessity of completing the thesis in the time allotted, thus the reference materials used were limited to those available in the Naval Postgraduate School library with the exception of *Vectors*, the Hughes Aircraft Company magazine. The following periodicals were the principal sources of information:

1) *Aviation Week and Space Technology*,
2) *Flight International*,
3) *Interavia*, and
4) *International Defense Review*.

Jane's All the World's Aircraft and *Jane's Weapon Systems* also supplied much of the data presented in this thesis. Technical and industrial trade journals were not utilized because the Naval Postgraduate School library did not contain the journals this researcher needed. Unclassified sections of three classified sources were used because it was felt that people who read these documents would be less hesitant to talk about the unclassified sections. Someone, somewhere had made the determination that the items in these sections should be "Unclassified."

The thesis is organized as follows: first, the development history of the Phoenix missile is discussed; second, the Phoenix missile system security classification guidance is outlined; third, the Phoenix missile characteristics are detailed by subsystem -- guidance, armament, propulsion and control; fourth, the AWG-9 Weapon Control System characteristics are detailed -- antenna, radar modes, infrared sensor and data link; and fifth, the Phoenix missile modes of operation are described. In the final chapter recommendations are made on how to use the data that has been compiled in this thesis.

Figure 2 - F-14 AND SIX PHOENIX MISSILES (courtesy of Hughes Aircraft Company)

II. DEVELOPMENT OF THE PHOENIX AIR-TO-AIR MISSILE

A. EAGLE AND FALCON

The AIM-54A Phoenix air-to-air missile and AWG-9 Weapon Control System did indeed "rise from the ashes," specifically those of more than one cancelled defense program. The Phoenix was the direct descendant of the Navy's Eagle/Missileer program and the indirect descendant of the Air Force's F-108/GAR-9 fighter and YF-12A/AIM-47A interceptor programs. "The AWG-9 AMCS is related to the AN/ASG-18 developed by Hughes for the YF-12A Mach 3 interceptor, and it is believed that considerable similarity in concept and technology exists between the two systems."[2]

In 1953 the U.S. Navy contracted Bell Telephone Laboratories to study the increasing complexity of the air intercept problem. Aircraft were being built with much higher speeds, so high that the existing fire control systems could not handle the tracking loop at the extremely fast closing speeds between interceptor and target. The Bell study suggested that the Navy build a slower airplane and build the high performance into the missile and its fire control system. This study was the origin of the Eagle concept.

Eagle was an expression of faith in the belief that it is better to put performance into the missile rather than into the carrier aircraft. Missileer was the name for the subsonic platform that was to carry the Eagle missiles.

Adm. R. B. Pirie, Deputy Chief of Naval Operations for Air, explained the philosophy behind the Eagle/Missileer concept:

> The present combination of fast fighters carrying short-range missiles comprises the airborne portion of our task force defense against air attack. Intercepts must be made at relatively short range with little time available.
>
> With missile and radar development what it is, why must we tore supersonic holes in the air for air defense? A follow-on fighter concept is the answer. This concept exploits sophisticated long-range detection devices. It depends more and more on the high Mach speed ability of missiles to make the kill of attacking bombers.
>
> [A Missileer aircraft] would be a virtual heavy cruiser of the air. It would track more than one target and control more than one missile at a time. It could stand off the enemy from many directions with its missiles.[3]

In support of this argument it was stated that the Soviet Union had already turned to the "slow plane" concept in the development of interceptor aircraft. It was also stated that the Soviet Union was developing a 75 mile range air-to-air interceptor missile to supplement their current inventory of air-to-air missiles.[4]

The U.S. Navy continued with its own internal studies, meeting with opposition from Navy pilots who did not want a slower aircraft and from the Department of Defense because Hughes Aircraft Company was already developing a long-range air intercept missile for the U.S. Air Force. By late 1958 the Navy had convinced the Department of Defense that the Eagle (XAAM-N-10) was needed and that the Hughes/USAF GAR-9 Falcon could not fulfil the Eagle's mission. The GAR-9 was intended for the F-108 Mach 3 interceptor; Eagle was intended for a subsonic aircraft, yet to be built, but which could more easily be configured to carry the fire control system necessary to guide the missiles to multiple targets at long range. A Mach 3 aircraft, for example, would not be able to carry a large enough antenna in its nose radome. The Navy started a design competition after roughing out final operational characteristics: other than the normal limitations required for carrier operations, the Eagle was to be compatible with input data from the Grumman W2F (later redesignated E-2) Hawkeye, a specification carried over to the F-14 program. Complete systems designs were to be submitted by the contractors.

Bendix Systems Division was selected as prime contractor, Bendix Pacific Division was to develop guidance and control and Grumman Aircraft Engineering Corporation was to build the missile airframe. System characteristics included the following for the Eagle:[5]

Length:	12 to 15 feet
Weight:	About 1300 lbs.
Diameter:	14 inches without booster; 16 inches with booster
Warhead:	About 100 lbs.
Body geometry:	Cylindrical body, ogival nose cone with flared-skirt afterbody
Controls	Four highly swept, truncated delta surfaces reminiscent of the Hawk planform, and a finned booster
Propulsion:	A two-stage solid propellant, to be developed by Aerojet-General Corporation and the rocket motor cases to be fabricated by Solar Aircraft Company
Guidance:	Airborne radars on both the Eagle missile and the Missileer aircraft to be developed by Westinghouse Air Arm Division; airborne tactical computer to be developed by Litton Systems, Inc.; initial and mid-course guidance to be developed by Bendix Research Laboratories Division; terminal guidance to be developed by Sanders Associates,

	Inc. (a coherent, pulse Doppler radar with extremely high resolution -- this system was designated in the original contract proposals)
Radome:	To be developed by Goodyear Aircraft Company
Power:	Auxiliary power unit tc be provided by AiResearch Manufacturing Company.

Systems capabilities included:

Range:	100 nautical miles (conflicting statements ranged from 30 to 200 nautical miles)
Altitude:	Up to 100,000 feet
Speed:	Up to Mach 4.

The Eagle would have a preprogrammed launch and command mid-course guidance with two modes of terminal guidance: fully active and home-on-jam. Its trajectory was based on a boost-glide-boost design.

The slow plane/high performance missile concepts were developed in parallel but requirements for the aircraft were not finalized until the parameters for the Eagle were set. Missileer was to be built around a three-man crew: pilot, co-pilot and missile operator. It was to be subsonic (about Mach 0.9), cruise from four to six hours, operate about 150 nautical miles from the task force and carry six Eagle missiles as primary armament. The Missileer air intercept radar was designed to be a C-band (4.0-8.0 GHz, later redesignated as G and H bands), pulse Doppler radar with a 100 nautical mile detection range against medium and high altitude targets and slightly less against low altitude targets. The radar dish was five feet in diameter and was a hydraulically powered, two-axis antenna; it had a wide look angle and was rate-gyro stabilized. In the track-while-scan mode the system was to acquire and attack six targets simultaneously (this specification was carried over to the Phoenix/AWG-9 program). The guidance law was based on "constant true bearing navigation," in which the missile is aimed at such a point ahead of the target that both the missile and the target will reach that point at the same instant, i.e., the line-of-sight does not rotate relative to the missile.

When the Eagle idea was announced in 1958, the GAR-9 was already being developed for the U.S. Air Force. The GAR-9 was further along in development because it was an advanced version of the Falcon missile and was originally intended for use on the North American F-108 Rapier interceptor. The Eagle and GAR-9 were to have similar capabilities but the Navy contended that the Hughes missile would not fit the Eagle's intended mission: the fire control system in the F-108 would not be able to support the Eagle as well as the fire control system in the Missileer -- the F-108 could not fit a five foot antenna dish in its nose radome and still maintain a Mach 3 speed. The Navy also stated that the Eagle's <u>active</u> radar guidance "would enable such a missile to be directed at different targets in a widely dispersed attack" while the GAR-9's <u>semi-active</u> radar guidance "requires the interceptor to keep its radar aimed at [the] target until the missile strikes, making it better suited to a single-shot supersonic interceptor rather than for [the] Navy's planned 'slow plane' missile platform aircraft."[6] As will be seen later, when Hughes Aircraft Company became the prime contractor for the Phoenix missile, the follow-on to the Eagle, the mid-course guidance mode for the new Navy missile was <u>semi-active</u>. At the end of 1958 the Navy won its battle with the Department of Defense and was able to continue the development of the Eagle.

In 1959 the U.S. Air Force cancelled the F-108 long-range interceptor but Hughes was able to continue the development of the AN/ASG-18 fire control system and the GAR-9 air-to-air missile. The fire control system originally was to be reconfigured to fit the Convair B-58 Hustler. The Air Force continued the development of the GAR-9 because the missile had been developed too far to stop. Meanwhile, the Air Force continued to search for an interceptor to fill the void left by the F-108 cancellation. In 1964 the Air Force revealed the YF-12A, a fighter/interceptor version of the Lockheed A-11/SR-71. The YF-12A was equipped to carry and launch the Hughes AIM-47A, a larger derivative of the Falcon family which began life under the designation GAR-9. It followed traditional Falcon principles, but was entirely different from its smaller predecessors in that it employed both infrared and coherent pulse Doppler radar guidance. Characteristics of the AIM-47A/GAR-9 were:

Length:	12 to 13 feet
Weight:	About 800 lbs.
Diameter:	13 to 14 inches
Range:	About 200 miles
Speed:	Up to a peak of Mach 6
Propulsion:	Package liquid propellant by Lockheed.

The dimensions were basically equivalent to those of Eagle, although the method of propulsion was different.[7] The ASG-18 fire control system consisted of a pulse Doppler fire control radar and infrared sensors at the front of each fuselage side fairing; the YF-12A interceptor was designed to carry eight AIM-47A missiles, with a multiple launch capability but only at single targets.[8]

As the Eagle concept matured, other missions were added to its orignal limited mission of long-range interception.

Among the missions for its new <u>multi-purpose</u> role were fleet air defense and protection of Marine landing forces in the period before antiaircraft defenses were set up ashore. Also considered were long-range ground attack and antisubmarine warfare roles.

The Eagle/Missileer was formally cancelled in 1961. Money was needed for other programs and there was stiff government and military opposition to the idea of paying for the development of an aircraft that offered no increase in performance. Fighter pilots opposed it because of an ingrained belief that superior speed wins fights.[9] The concept of separate fighters for the different services also came under fire when Robert S. McNamara became Secretary of Defense in 1961.

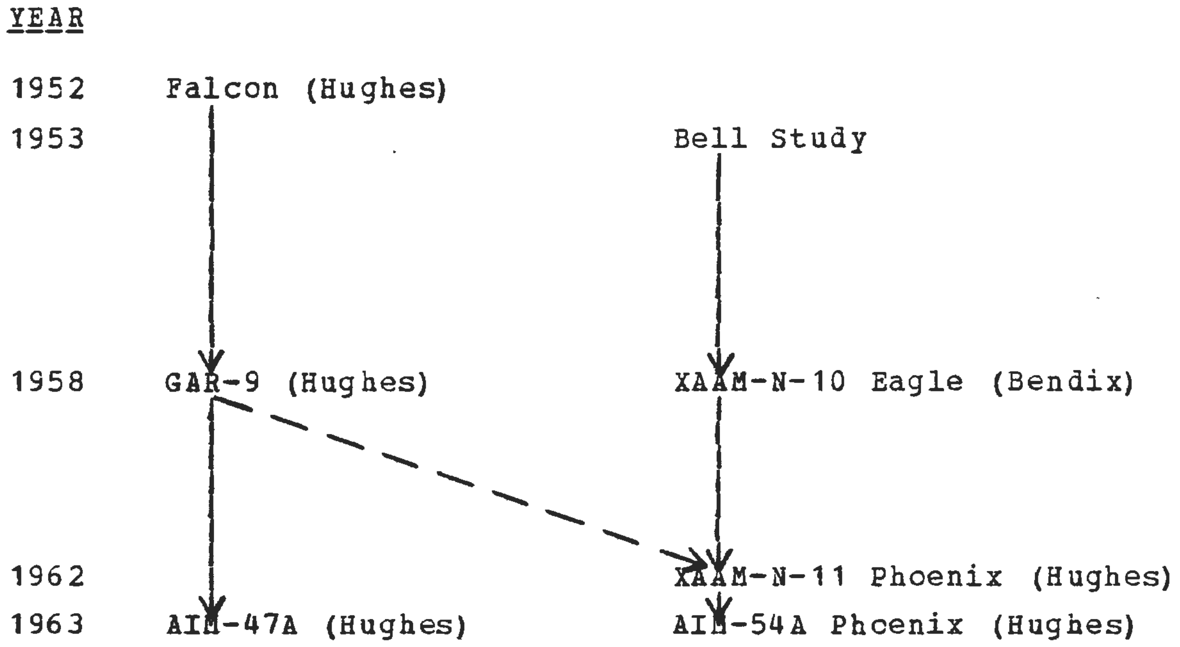


Figure 3 - PHOENIX ANCESTRY

YEAR	EVENT
1958	Need for Eagle established, DOD approval
1959	Bendix selected as prime contractor, design begun
1961	Eagle cancelled TFX (F-111B) proposals
1962	Need for Phoenix established Hughes selected as prime contractor Phoenix R and D begun
1965	Phoenix test flights begun
1966	First guided firing, prototype testing
1968	F-111B cancelled
1969	AWG-9 capabilities expanded F-14 R and D begun
1970	AWG-9 reconfigured for F-14
1971	First Navy Preliminary Evaluation F-14/Phoenix test flights begun First Phoenix procurement contract
1972	Second Navy Preliminary Evaluation First two F-14A squadrons formed (IOC)
1973	Bureau of Inspection and Survey trials begun
1974	First Phoenix deployment
1976	Phoenix Improvement Program

Figure 4 - PHOENIX DEVELOPMENT HISTORY

B. PHOENIX, TFX AND F-14

In February, 1961, Secretary of Defense Robert S. McNamara initiated a study that examined the possibility of combining all service requirements for a tactical fighter into one multi-purpose tri-service aircraft. After study, the Army's requirement for a relatively low performance close-support aircraft was separated out; the Air Force and Navy were to develop a tactical fighter jointly. Requests for proposals from industry were sent out in September with December 1, 1961, as the deadline for submission. Service requirements had to be compromised since the Air Force wanted a heavy (90,000 lb.) aircraft with a long unrefueled ferry range, long loiter time on station, long cruise distances at low altitudes, low level dash capability at Mach 1.2 and a high altitude retreat. The Navy version was to be carrier-based, perform long-range interdiction with an Eagle-type missile and provide interdiction and close-support for the Marines.[10] It would have been hard enough to develop one plane to satisfy only one set of requirements; it was impossible to satisfy the requirements of both services with one aircraft, especially since the Air Force version was basically a fighter-bomber and the Navy version was an interceptor.

The Navy's version of TFX (F-111B) had a requirement for a long-range missile; the Air Force version (F-111A) had no missile requirement. Since the Navy wanted to keep the Eagle alive it suggested that a transformed Eagle be considered -- the first stage of the Eagle would be strengthened and the second (booster) stage be eliminated while retaining the same guidance system.[11] Requests for proposals from industry for the new missile were sent out in February, 1962, and proposals from four companies -- including Bendix, the prime contractor for the Eagle missile; Grumman; Hughes, the developer of the Falcon and GAR-9 missiles; and Raytheon, the developer of the Sparrow missile -- were received in April.[12] By mid-May the Navy Evaluation Committee had narrowed the selection down to two contractors, Hughes and Raytheon. In August Hughes was selected to develop the long-range air-to-air missile and its associated fire control system for the Navy version of TFX. The missile was renamed "Phoenix" because it had "risen from the ashes" of the Eagle/Missileer program. In November Flight International reported that the GAR-9, which was originally conceived by Hughes for the F-108, was being resurrected in "two much modified versions" for the F-111A and F-111B. The new weapon was to take the place of the "100-mile Eagle" that was cancelled earlier. The "real" predecessor is obscured. Conceptually the Phoenix owed much to the Eagle but physically owed more to the GAR-9, especially since the same contractor developed both the GAR-9 and the Phoenix. But the AWG-9 missile control system owed much more to the Eagle/Missileer concept.[13]

As the F-111A (USAF) and F-111B (USN) programs developed special problems arose with the Navy version. The F-111B could not be satisfactorily adapted to carry six Phoenix missiles and still maintain its weight low enough for carrier operations. It was the requirement that the F-111B must carry the Phoenix, which demanded extra structural strength, and hence weight, over the Air Force version, which led to the F-111B's inability to operate from aircraft carriers. The F-111B and Phoenix development continued until late 1968 when the the F-111B was cancelled; McNamara's concept of "commonality" was defeated.

The Navy and Air Force were free to pursue their own designs for tactical fighters. The Navy developed the VFX, which became the F-14, and the Air Force developed the FX, which became the F-15. The F-14 was designed to fulfil three operational requirements:

1) escort, gain and maintain air superiority,
2) fleet defense, knock out airborne and some types of surface threats, and
3) interdiction and close support.[14]

The second requirement necessitated a long-range Phoenix missile and AWG-9 Weapon Control System. The advanced Phoenix missile and AWG-9 fire control system were the principal justification for the Navy's commitment to the variable geometry, bi-service aircraft and the same weapon system became the main justification for accepting the cost of the F-14 aircraft.[15]

The development of the Phoenix and AWG-9 was long and uneven because it had to be designed for three different aircraft --Missileer, F-111B and F-14 -- with different technologies available before the weapon system was finally operational. As the Eagle, the missile used a two-stage propulsion system because rocket technology was not advanced enough to build a single-stage solid propellant that would boost a missile over 100 miles. The original model of the Hughes Phoenix for the F-111B was also a two-stage weapon.[16] By the time the design was finalized, the Phoenix had a single-stage, solid propellant rocket motor and its physical characteristics were similar to those of the GAR-9/AIM-47A. Vectors, the Hughes Aircraft Company magazine, stated:"Over the years the basic aerodynamic configuration of the [Hughes] missiles has remained fairly constant, only the lengths, girths and fins change for different mission profiles. Also, all the Hughes missiles are tail-guided."[17]

Hughes Aircraft Company initially contracted with Litton Systems for fourteen fire control computers for the AWG-9 Weapon Control System. The first digital computer that Litton delivered to Hughes was oversize, overweight and failed to meet the contractual environmental requirements. Although this system was used in the early flight tests aboard the A-3A test aircraft, which began in January, 1965, Hughes initiated a back-up fire control computer effort with a dual competition between Control Data Corporation and Univac Division of Sperry-Rand. In September, 1965, Hughes ordered two Univac 1830 computers as part of its continuing evaluation of a computer manufacturer to replace Litton Systems, which was separated from the Phoenix program in August, 1965. But in April, 1966, Hughes selected Control Data Corporation to supply the fire control computers (CDC 5500 series computers) for the AWG-9 Weapon Control System, with Univac as the alternate source. The weapon control system for the F-111B was designed for a side-by-side configuration; Hughes was able to adapt the weapon control system to fit the F-14's tandem configuration and reduce system weight from 1650 lbs. to 1320 lbs. and the volume from 31 cu. ft. to 28 cu. ft. as a result of applying many electronic component and packaging advances of the late 1960s.[18]

At the other end of the Phoenix development program, the prime propulsion contractor for the Phoenix was North American Aviation's (now Rockwell International Corporation) Rocketdyne Division. Rocketdyne developed Flexadyne, an improved solid propellant based on an advanced polybutadiene fuel-binder, and experienced vibration and temperature problems, with the propellant burning through its rubber insulation. Hughes conducted a back-up competition among Aerojet-General (the original propulsion contractor for Eagle), Lockheed and Thiokol. In August Aerojet-General was selected as the alternate source for the rocket motor, even though Rocketdyne had solved its propellant problems successfully.[19]

C. PHOENIX FLIGHT TEST HISTORY

This section details the flight test history of the Phoenix missile and the AWG-9 Weapon Control System. The date of each event is given and each event is described. The footnctes indicate the date and source of the first published report concerning each event, i.e., the first report that the researcher found.

Date	Event
January 1965	The first airborne separation of the Navy's Hughes Phoenix missile for the F-111B was successfully conducted in the sea test area off Pt. Mugu, California. An unpowered dummy-version of the missile was separated safely from the A-3A test aircraft and maintained stable altitude during descent (no date given).[20]
August 1965	"Tests of the Phoenix missile fire control system are expected to get underway soon."[21] A specially modified A-3A aircraft equipped with an F-111B radome, missile pylons attached to the fuselage under the wings and a special 20 KVA gas turbine power system will be used. Early flight tests were conducted using the overweight and oversize Litton fire control computer because of ample

Date	Event
	capacity aboard the modified A-3A. "But the missile is slated for flight tests under conditions more closely resembling F-111B specifications, requiring the computer to fit a tactical form factor and to meet military specifications."[22]
April 1966	The Phoenix air-to-air missile completed its first powered flight at the end of April in a test conducted by Hughes Aircraft Company from a Navy/Douglas A-3A Skywarrior near San Nicolas Island off the California coast.[23]
12 May 1966	The first guided firing of the Phoenix (G-4) missile occurred on 12 May at the Pacific Missile Range. The unarmed missile made a direct hit on a BQM-34 drone aircraft controlled from Pt. Mugu.[24] A photograph of the launch shows the pronounced nose-down attitude of the missile that is characteristic of launches when missiles are forcibly ejected from the launch aircraft.[25] (See Figure 5).
8 September 1966	A Phoenix missile launched from an A-3A intercepted a Firebee drone over the Pt. Mugu testing grounds on September 8 (picture of launch).[26]

Figure 5 - PHOENIX LAUNCH FROM A-3 (Courtesy of Hughes Aircraft Company)

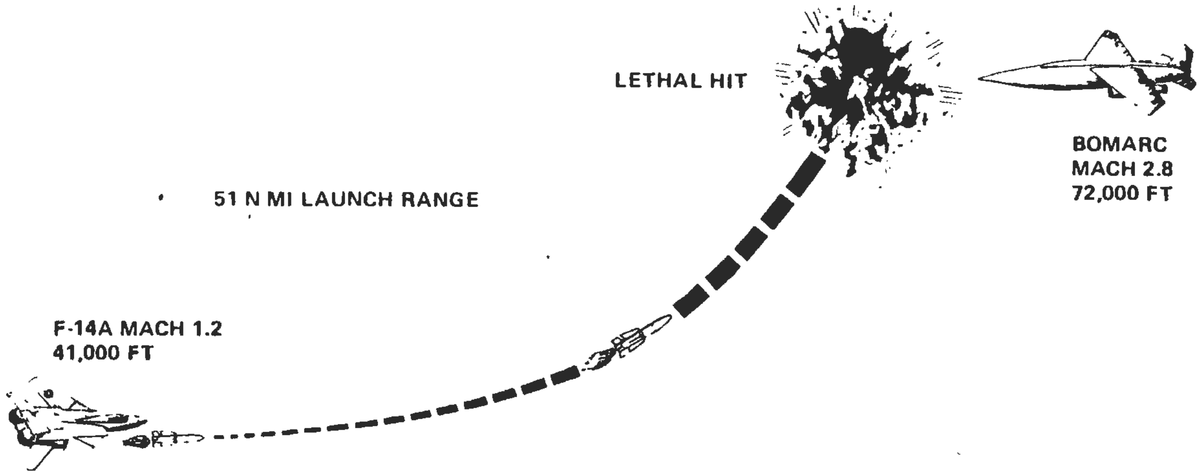
Date	Event
November 1966	The first live separation and powered flight from an F-111B was made by the Phoenix 30 days ahead of schedule.[27]
17 March 1967	The Phoenix missile scored a hit on March 17 in its first guided launch from the F-111B. The test firing was conducted off the California coast near the Naval Missile Center at Pt. Mugu. The Phoenix radar (AWG-9) located a small jet drone, locked on the target at long range and hit it. A picture of the test missile (G-9) is shown; the numbers stenciled on the side of the missile are visible.[28]
11 September 1967	First long *Aviation Week and Space Technology* article describing the Phoenix program. Four guided test flights are identified: three from the A-3A and one from the F-111B. The first described was the 12 May 1966 firing; the second and third were "successful exercises of the semi-active and then the combination of semi-active and active guidance systems"; the fourth was the 17 March 1967 firing from the F-111B.[29]
January 1968	The first successful track-while-scan shot as well as the first supersonic launch from the F-111B that had been planned for December slipped into January because of delays caused by adverse weather, technical adjustments and the presence off the California

Date	Event
	coast of Russian trawlers which might have had the airborne tests under electronic surveillance.[30] The track-while-scan test was announced in advance,[31] which might have accounted for the Russian trawlers.
April 1968	The Senate Armed Services Committee voted to cancel the F-111B program and the Navy expected to begin a contract definition of the carrier-based VFX-1 (F-14A) interceptor in June. Unlike the F-111B, the VFX-1 would also have an air superiority mission.[32]
11 September 1968	An F-111B operated by Hughes in a checkout of Phoenix missile avionics crashed off the California coast on September 11. The crash site was 90 miles west of Pt. Mugu and 20 miles north of San Miguel Island. No survivors were found.[33]
December 1968	The Navy cancelled the F-111B program.
January 1969	The Navy decided to expand the capability of the Hughes AWG-9 fire control system to handle a wider variety of air-to-air missiles plus fixed guns as well as the advanced Phoenix missile. Other missiles would be the Raytheon Sparrow and late-model Sidewinders.[34]
February 1969	The Navy and Grumman signed an F-14 Research and Development contract.

Date	Event
March 1969	The simultaneous attack capability was demonstrated when two drones were successfully engaged by an F-111B.[35]
April 1969	The Navy and Hughes had a final review of all specifications for the Phoenix and AWG-9 Weapon Control System.
May 1969	A formal mock-up review of the F-14A was held at Grumman Aircraft Engineering Corporation.[36]
August 1969	The first Phoenix missile system trainer was "recently" delivered to the Navy at the Naval Missile Center; it will be used to train missile control officers for the F-14A fighter. The trainer simulates a complete mission profile, from target acquisition to lock-on and missile launch.[37]
March 1970	The first Phoenix/AWG-9 Weapon Control System, reconfigured for the F-14A, was delivered to the Navy "recently" by Hughes. Its weight had been pared from 2000 lbs. to less than 1400 lbs.[38]
25 May 1970	Second long <u>Aviation Week and Space Technology</u> article on the Phoenix/AWG-9. The weapon system was described in more detail and the test flight history to date was summarized: of 29 Phoenix missiles fired from F-111Bs and A-3As, 22 had scored direct hits, passed within kill distance of aerial targets or otherwise met their objectives. Longest

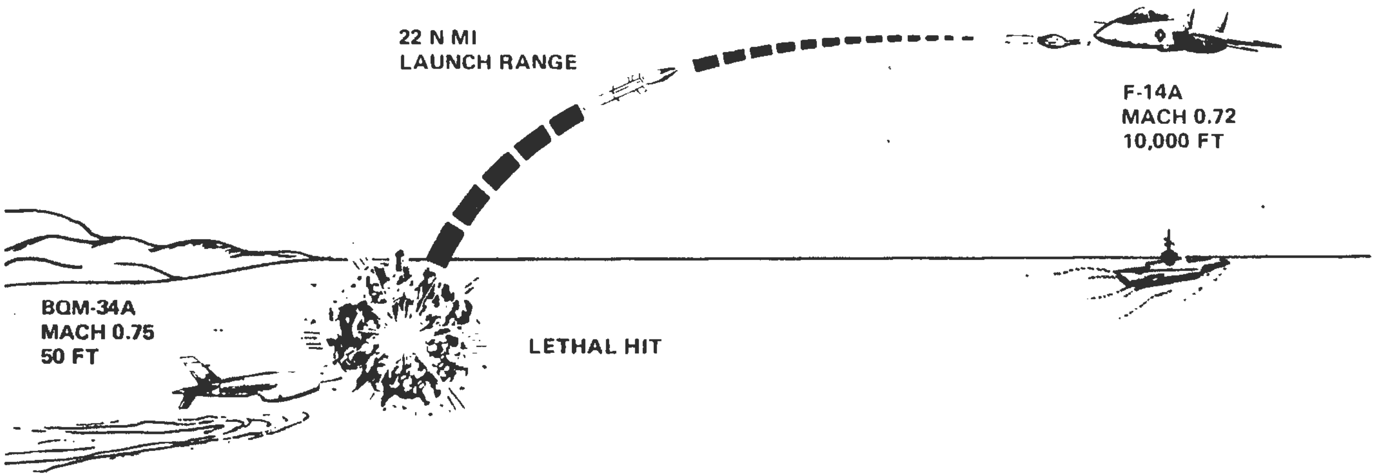
Date	Event
	missile firing to date was 78 miles. In March 1969 two missiles were simultaneously fired and successfully directed against targets separated by 10 miles.[39]
August 1970	A Phoenix missile destroyed an F-9F Cougar jet fighter converted into a target drone in the "recent" first test of the missile with a live warhead. The Phoenix was launched at a range "described as much greater than that of any existing operational air-to-air missile."[40]
August 1971	The first Navy Preliminary Evaluation (NPE) of the Hughes AWG-9 fire control system for guidance of the Phoenix missile in August-September, 1971, showed 10 deficiencies.[41]
October 1971	Hughes Aircraft Company received a $72.4 million negotiated contract for pilot production of Phoenix air-to-air missiles. The contract superceded a $40 million letter award disclosed last year. Hughes also received a $137.1 million award for Phoenix AWG-9 fire control systems and associated ground support equipment.[42]
October 1971	F-14A No. 4 arrived at Pt. Mugu to be outfitted with the AWG-9 and Phoenix weapon system.[43]
December 1971	Hughes received its first production and

Date	Event
	procurement contract for the Phoenix missile.[44]
January 1972	The first two evaluation flights of the F-14A with an AWG-9/Phoenix missile system operating have been completed.[45]
June 1972	First launch of the Phoenix missile from an F-14A was demonstrated against a target drone simulating a MIG-23 (now MIG-25) Foxbat. The drone was flying at an altitude "well over 70,000 feet"; the F-14 was flying at 40,000 feet at a speed of Mach 1.2. The range between the target and F-14 was 35 to 40 miles. Miss distance was less than 20 feet; lethal radius of the Phoenix warhead is 25 feet.[46] (See Figure 6). A photograph of the launch is shown on the cover of another issue of Aviation Week and Space Technology.[47] The Phoenix and AWG-9 also demonstrated a "look-down" capability when the missile was launched from a test aircraft at 10,000 feet at a cruise missile target flying at 800 feet.[48] (See Figure 7).
6 July 1972	The second Navy Preliminary Evaluation of the Phoenix started on July 6.[49]
12 October 1972	The F-14 entered Navy service on October 12 with the formation of two F-14A squadrons at NAS Miramar.[50]



This launch mission demonstrated the ability of Phoenix to destroy sophisticated high altitude, high speed targets. Such targets are capable of flying at speeds and altitudes that make them essentially immune to any other weapon. A BOMARC missile drone was augmented to simulate the radar cross section of an actual aircraft and was flown at Mach 2.8 at 72,000 feet altitude. A single Phoenix was launched from an F-14 51 nautical miles away, flying straight and level at Mach 1.2. The missile climbed more than 5 nautical miles vertically and scored a lethal hit on the BOMARC. Phoenix has performed such interceptions four times, including a direct hit and a warhead kill.

Figure 6 - HIGH ALTITUDE, HIGH SPEED TARGET (Courtesy of Hughes Aircraft Company)

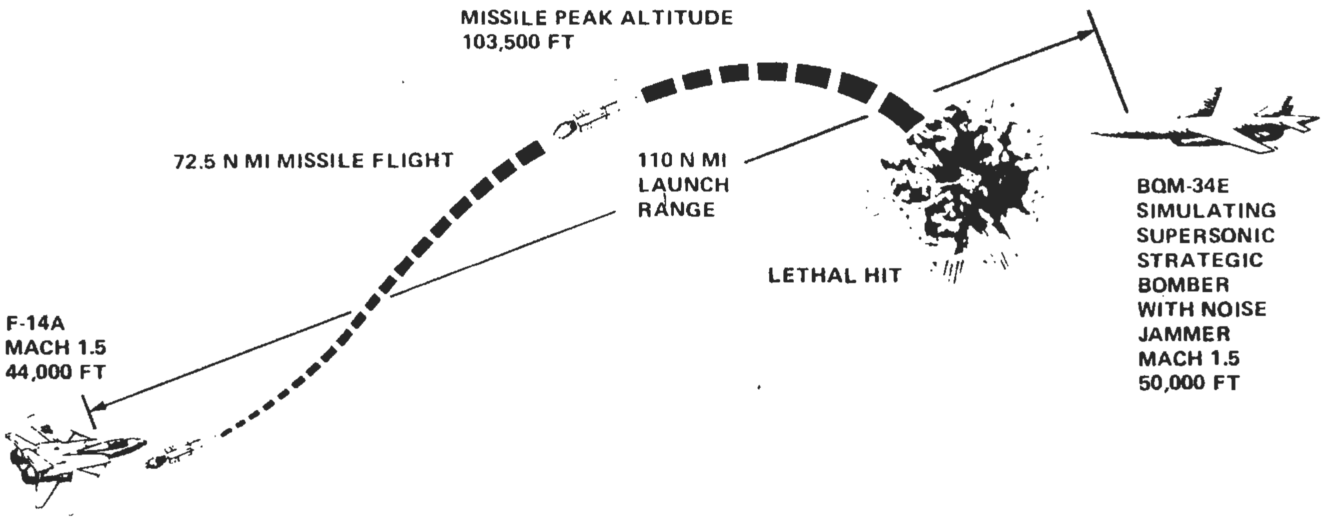


Cruise missiles are a serious threat to surface ships. These weapons, which are launched from aircraft, surface ships, or submarines, can fly just above the surface of the water to avoid radar detection and interception by defensive weapons. Cruise missile vulnerability to Phoenix-armed F-14s has been demonstrated in many low altitude target attack missions. For example, the mission illustrated was a Phoenix shootdown attack on a very small simulated cruise missile target, a BQM-34A drone under remote operator control, which was flying 50 feet above the surface of the sea on a simulated anti-ship cruise missile attack. One Phoenix missile was launched from an F-14 at an altitude of 10,000 feet and a range of 22 nautical miles. The missile scored a lethal hit by passing the target within the Phoenix warhead lethal radius and by having the warhead fuze (target detecting device) trigger on the target.

Figure 7 - CRUISE MISSILE TARGET (Courtesy of Hughes Aircraft Company)

Date	Event
20 December 1972	An F-14 scored near simultaneous hits on four target drones with Phoenix missiles on December 20 in tests of the multiple firing and guidance capability of the AWG-9 fire control system. The F-14 was at 30,000 feet; the five drones were flying at four mile separation at altitudes between 20,000 and 25,000 feet. The AWG-9 detected the targets at more than 60 miles, began tracking them at more than 50 miles in the track-while-scan mode and launched four of its full load of six Phoenix missiles in 45 seconds at a range in excess of 30 miles.[51] Announcement of this test was made earlier.[52]
12 March 1973	Third long <u>Aviation Week and Space Technology</u> article on the Phoenix; special reports on "F-14 Systems Capabilities" and "F-14 Weapon Control System." The capabilities of the AWG-9 were described in detail and the flight test history was again summarized to date --39 of 57 Phoenix firings had met their objectives.[53]
March 1973	Navy Bureau of Inspection and Survey (BIS) trials began in March.[54]
April 1973	To date the Phoenix missile had been fired 59 times, including 15 firings from the F-14, with an overall success ratio of 76% and a success ratio of 86% from the F-14.[55]

Date	Event
12 April 1973	The longest known successful air-to-air guided missile intercept occurred on April 12 when a Phoenix fired from an F-14 intercepted a simulated Backfire supersonic bomber at a range of 110 nautical miles. The target was flying at 52,000 feet at a speed of Mach 1.55; the AWG-9 track-while-scan radar began tracking the target at 132 nautical miles while the F-14 was traveling at Mach 1.45 at 45,000 feet. The aircraft released the missile at 110 nautical miles; the missile followed a trajectory that reached an altitude over 100,000 feet before passing the target at 75 nautical miles within lethal radius (5 feet) of the warhead. The target used an on-off blinking noise jammer but was not successful in jamming the Phoenix radar system.[56] (See Figure 8).
13 August 1973	Summary of some of the more important Phoenix test flights.[57]
27 September 1973	First long article about the F-14 and the Phoenix in <u>Flight International</u>. A two-page cutaway drawing of the F-14 was shown and the AWG-9 was described in detail. Some Phoenix test flights were described.[58]



Another air threat is the supersonic strategic bomber. This bomber was simulated by a BQM-34E supersonic target drone augmented to represent the radar cross section of the bomber. As would be expected in a real attack, the target was using an on-off blinking noise jammer to confuse radar defenses. The target flew toward the F-14 at an altitude of 50,000 feet and a speed of Mach 1.5. The F-14 began tracking the approaching bomber with the AWG-9 system in the track-while-scan mode at 132 nautical miles and launched a single Phoenix at 110 nautical miles. During flight, the Phoenix reached a high point in its trajectory of 103,500 feet. No other known air-to-air missile has ever flown so far and high and intercepted its target.

Figure 8 - LONG RANGE CAPABILITY (Courtesy of Hughes Aircraft Company)

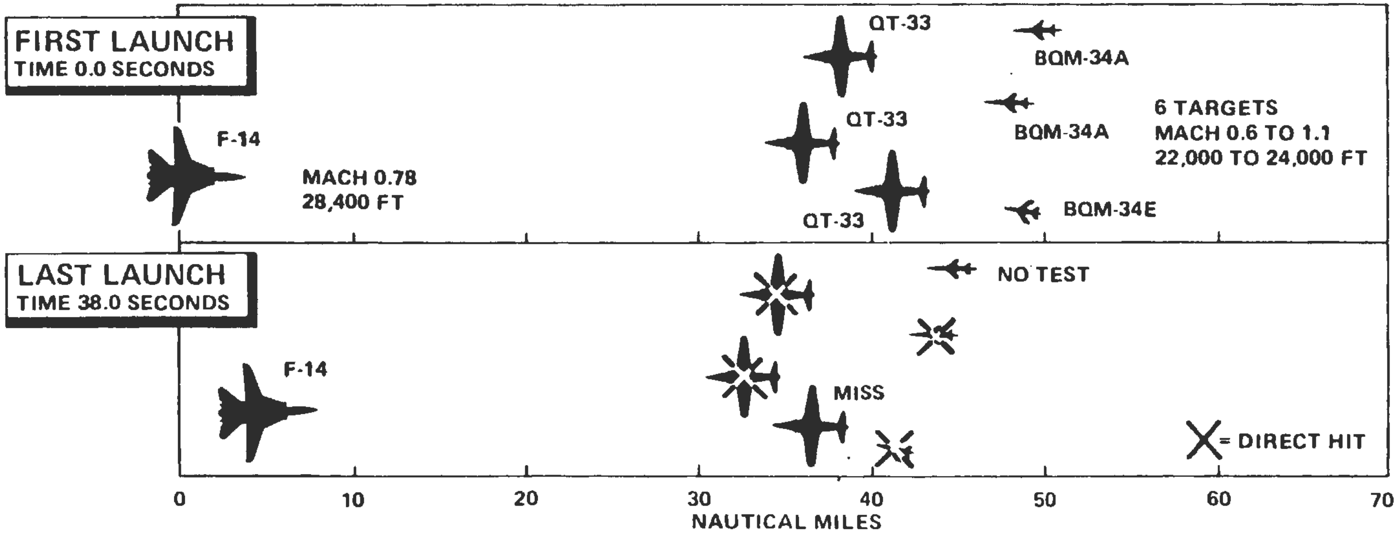
Date	Event
21 November 1973	Six Phoenix missiles were near-simultaneously launched from an F-14 on November 21 and successfully intercepted four target drones at a range in excess of 50 miles. One missile had a hardware failure and one drone veered off course, leaving a radar signature insufficient for tracking at that range. The missiles were launched within an interval of 37 seconds, with two missiles fired in a 3 1/2 second period.[59] This test was announced in advance.[60] (See Figure 9).
September 1974	First deployment of the F-14/Phoenix to WESTPAC on the USS Enterprise.
December 1974	Interavia article on the F-14/Phoenix describing the AWG-9 capabilities in detail.[61]
December 1974	In a test in December a drone pulled a 6g, 174° turn four seconds after a Phoenix had been launched at it in an attempt to break the radar lock of the missile and AWG-9 fire control system. The AIM-54A responded with a 16g maneuver and scored a lethal hit. (See Figure 10). Of the first 76 Phoenix missiles launched from the F-14, 57 were counted as hits and 11 as no-tests, giving a success ratio of 88%.[62]
November 1975	There have been 124 Phoenix missiles fired in tests, 80 from the F-14 with an 85% success ratio from the F-14.[63]

Date	Event
November 1976	*Aviation Week and Space Technology* article on Sixth Fleet modernization detailing F-14/Phoenix capabilities.[64]

The Navy is currently in the formative stages of a Phoenix Improvement Program in which identified areas of work include:

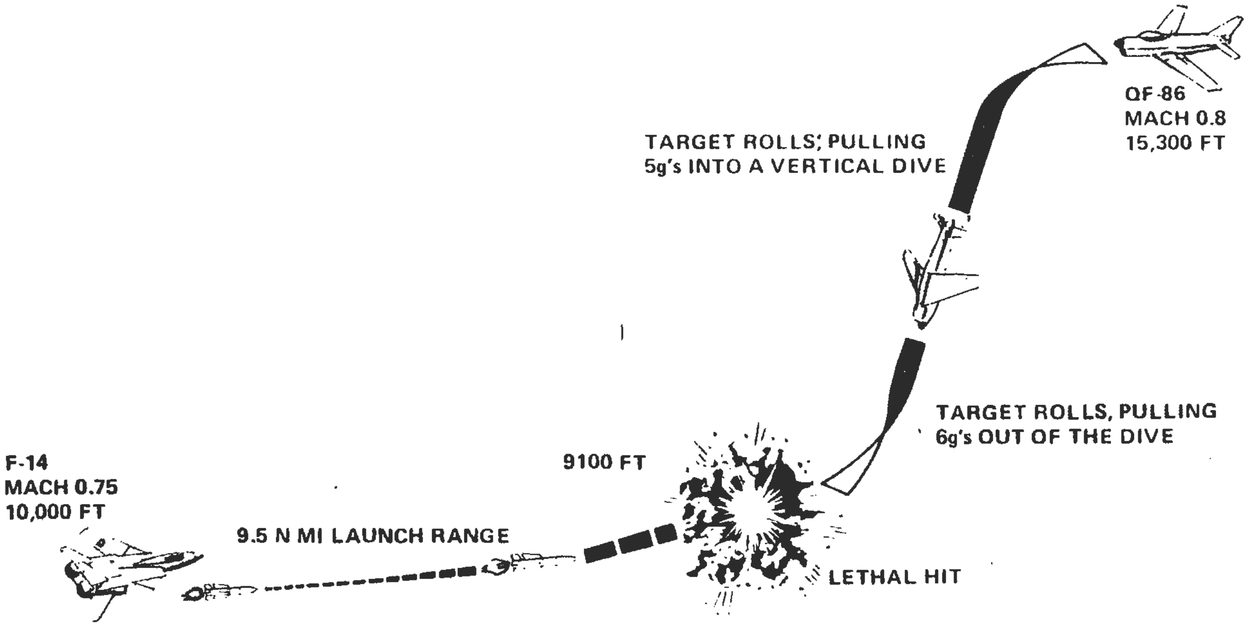
1) redesigning the Phoenix missile's present analog electronic unit into a digital unit with a reprogrammable digital processor, resulting in greater precision, flexibility and speed,
2) replacing the transmitter's klystron with a solid-state transmitter, yielding a transmit-receive unit with greater reliability, better tracking capability, easier maintenance and easier production, and
3) changing the target detecting device.

Increased technology makes these improvements possible.[65]



This launch mission objective was to demonstrate the AWG-9 and Phoenix missile capability to track and attack six targets simultaneously. Six Phoenix were launched in rapid sequence against a six target drone raid that was being tracked by the AWG-9 in its unique track-while-scan (TWS) operating mode. At the time of first launch, the fighter was at 28,400 feet altitude and Mach 0.78. The targets were flying toward the fighter in two rows of three at approximately 23,000 feet altitude and at various speeds. Three unaugmented drone QT-33s were in the forward row and two BQM-34As and one BQM-34E in the rear row, all augmented to 10 square meters. Launch ranges varied from 31 to 50 nautical miles. All missiles were launched within 38 seconds and flight times of the four successful launches were between 78 and 107 seconds. Of the six missiles launched, four were direct hits, one was a no test, and one was a miss. The miss was caused by a missile antenna control loop failure. The no test score was due to a loss of target augmentation which caused the missile and AWG-9 to lose track on the target. This condition, which cannot occur in a real attack, is a consequence of simulating hostile targets with remote-controlled drones.

Figure 9 - SIMULTANEOUS SIX TARGET ATTACK (Courtesy of Hughes Aircraft Company)



While not intended as a dogfight missile, Phoenix has greater capability against maneuvering targets than any other air-to-air missile. For example, in the illustrated launch mission, a QF-86 drone attempted to break AWG-9 and Phoenix track by violently maneuvering in the vertical plane 16 seconds after missile launch. The drone pulled 5g's going into a 6200 foot dive and 6g's coming out. Phoenix scored a lethal hit on the drone just as it pulled out of the dive. In other evasively maneuvering target launches, Phoenix has pulled as many as 16g's to hit the target.

Figure 10 - VIOLENTLY MANEUVERING TARGET (Courtesy of Hughes Aircraft Company)

Figure 11 - F-14 CLOSE-UP (Courtesy of Hughes Aircraft Company)

III. PHOENIX MISSILE SYSTEM CLASSIFICATION GUIDANCE

The United States is an open society. As a result, much informaticn concerning U.S. weapon systems is published in open-source literature and is available to anyone. In order to keep some control over vital areas of information, security classification guidance is provided for most weapon systems. NAVAIRINST 5511.4B (26 December 1972) prcvides security classification guidance for Naval Air Systems Ccmmand missiles and weapons. Guidance for each system is detailed on separate charts: across the top of each chart are listed areas of information; on the side of each chart is a breakdown of each missile by major components.

Chart H details the security classification guidance for the Phoenix missile system[66] while Chart T details guidance for all rocket motors, including the MK 47 and MK 60 versions of the Phoenix rocket motor.[67] Guidance is provided for the following major components (among others):

1) Complete missile,
2) Guidance system,
3) MK 11 Mod 0 electronic assembly, fuze,
4) MK 42 Mod 0 antennas, fuze,
5) MK 334 fuze,
6) MK 82 Mod 0 warhead, and
7) AWG-9 Weapon Control System.

This chapter will discuss each of these components and the applicable areas of information.

The AWG-9 areas of information that are classified

"Secret" are:

1) AWG-9 counter countermeasures capability -- information on the design features which are intended specifically to overcome enemy interference,
2) Specific frequency -- exact frequency within the numerical frequency band at which the radar is designed to operate; or a limited number of exact frequencies at which the radar is designed to operate; or the exact frequency set in at any one instance,
3) Coding -- means by which the missile guidance can discriminate between signals received, and
4) Vulnerability to countermeasures --susceptibility to defeat by the enemy.

Areas of information which are classified "Confidential" are:

1) Accuracy -- precision with which detection, acquisition, tracking and fire control are performed,
2) Resolution -- ability to analyze characteristics of targets and to distinguish between them,
3) Numerical frequency band -- electromagnetic band in which the radar system is designed to operate,
4) Sensitivity -- ability to receive signals,
5) Detailed performance characteristics,
6) Technical advances in the state of the art,
7) Classification of the end item -- this is not an area of information but a determination of how the component or assembled item should be classified, taking into consideration all the areas of information that concern that component; this determination primarily governs the manner in which

the component is handled, stowed and shipped, and

8) Pulse outputs and IFF interrogate control lines A and B -- all other information related to IFF is "Unclassified."

All components of the AWG-9 are "Unclassified" except the following, which, as end items, are classified "Confidential":

1) Radio frequency master oscillator,
2) Hydraulic radar antenna,
3) Infrared receiver, and
4) Detail data display assembly.

See Table I for a summary of this information.

The end item classification of the MK 82 Mod 0 warhead is "Unclassified" although two areas of information are classified "Confidential." They are:

1) Lethality and critical effects -- description of the specific degree of damage to the target including miss distance, which is the maximum distance from the target in which the warhead is effective, and
2) Terminal ballistics -- effects and action of a missile when it impacts or bursts at the target.

See Table II.

No areas of information about the MK 334 fuze are classified.

The specific frequency of the four MK 42 Mod 0 fuze antennas is classified "Secret." Alphabetical band and numerical frequency band are classified "Confidential." The classification of the end item is "Confidential." See Table

The following areas of information about the MK 11 Mod 0 fuze electronic assembly are classified "Secret":

1) Counter countermeasure capability,
2) Specific frequency, and
3) Vulnerability to countermeasures.

As with the fuze antennas, alphabetical band, numerical frequency band and end item classification are "Confidential." Also classified "Confidential" is the maximum range at which the fuze electronic assembly can receive signals, i.e., can sense the target. See Table II.

The following areas of information about the MK 47 Mod 0 and MK 60 Mod 0 rocket motors are classified "Confidential":

1) Details on ignition capabilities,
2) Formulation of materials -- propellant chemical composition and proportions,
3) Propellant processing,
4) Consumption rate,
5) Specific binders of the propellant,
6) Burn time -- time required to consume propellant,
7) Thrust,
8) Total impulse,
9) Specific impulse,
10) Motor firing duration,
11) Exhaust characteristics, and
12) Missile performance parameters -- range, Mach number, etc.

No areas are classified "Secret." See Table III.

The following areas of information about the missile guidance system are classified "Secret":

1) Counter countermeasure capability,
2) Specific frequency,
3) Ccding, and
4) Vulnerability to countermeasures.

The following areas are classified "Confidential":

1) Accuracy,
2) Maximum range -- maximum distance from the target at which the missile guidance system is designed to function and control the missile, i.e., the terminal guidance envelope,
3) Resolution,
4) Numerical frequency band,
5) Sensitivity,
6) System capacity -- maximum number of operations which the guidance system can perform simultaneously in carrying out its design functions,
7) Technical advances in the state of the art, and
8) End item classification.

See Table IV.

The following areas of information about the complete missile are classified "Secret":

1) Counter countermeasure capability,
2) Lethality and critical effects, and
3) Vulnerability to countermeasures.

The following areas of information are classified "Confidential":

1) Accuracy,

2) Maximum and optimum launch altitudes,
3) Resclution,
4) Detailed performance characteristics,
5) Effectiveness against specific future threats,
6) Technical advances in the state of the art, and
7) End item classification.

See Table V.

The following three chapters relate information found in open-source literature to the Phoenix Missile System security classification guidance described in the previous section. First, the Phoenix missile will be described in detail; second, the AWG-9 Weapon Control System will be described; third, the Phoenix modes of operation will be discussed. The information contained in these chapters is derived from unclassified materials.

Table I - AWG-9 SECURITY CLASSIFICATION GUIDANCE

Area of information	Classification
Coding	Secret
Counter Countermeasures Capability	Secret
Specific Frequency	Secret
Vulnerability to Countermeasures	Secret
Accuracy	Confidential
Detailed Performance Characteristics	Confidential
End Item	Confidential
Numerical Frequency Band	Confidential
Resolution	Confidential
Sensitivity	Confidential
Technical Advances in the State of the Art	Confidential
Alphabetical Band	Unclassified
Reliability	Unclassified
System Capacity	Unclassified
Maximum Range	Unclassified

Table II - WARHEAD SECURITY CLASSIFICATION GUIDANCE

A. MK82 Mod 0 Warhead

Area of Information	Classification
Lethality and Critical Effects	Confidential
Terminal Ballistics	Confidential
End Item	Unclassified
Reliability	Unclassified
Type of Warhead	Unclassified

B. MK 42 Mod 0 Fuze Antennas

Area of Information	Classification
Specific Frequency	Secret
Alphabetical Band	Confidential
End Item	Confidential
Numerical Frequency Band	Confidential

C. MK 11 Mod 0 Fuze Electronic Assembly

Area of Information	Classification
Counter Countermeasures Capability	Secret
Specific Frequency	Secret
Vulnerability to Countermeasures	Secret
Alphabetical Band	Confidential
End Item	Confidential
Numerical Frequency Band	Confidential
Maximum Range	Confidential
Reliability	Unclassified

Table III - ROCKET MOTORS SECURITY CLASSIFICATION GUIDANCE

Area of Information	Classification
Burn Time	Confidential
Consumption Rate	Confidential
Details on Ignition Capabilities	Confidential
Exhaust Characteristics	Confidential
Formulation of Materials	Confidential
Missile and Rocket Performance Parameters	Confidential
Motor Firing Duration	Confidential
Propellant Processing	Confidential
Specific Binders	Confidential
Specific Impulse	Confidential
Thrust	Confidential
Total Impulse	Confidential
Chamber Pressure	Unclassified
End Item	Unclassified
Grain Configuration and Geometry	Unclassified
Type of Propellant	Unclassified
Weight of Propellant	Unclassified

Table IV - GUIDANCE SYSTEM CLASSIFICATION GUIDANCE

Area of Information	Classification
Coding	Secret
Counter Countermeasures Capability	Secret
Specific Frequency	Secret
Vulnerability to Countermeasures	Secret
Accuracy	Confidential
End Item	Confidential
Maximum Range	Confidential
Numerical Frequency Band	Confidential
Resolution	Confidential
Sensitivity	Confidential
System Capacity	Confidential
Technical Advances in the State of the Art	Confidential
Alphabetical Band	Unclassified
Reliability	Unclassified

Table V - OVERALL SECURITY CLASSIFICATION GUIDANCE

Area of Information	Classification
Counter Countermeasures Capability	Secret
Lethality and Critical Effects	Secret
Vulnerability to Countermeasures	Secret
Accuracy	Confidential
Detailed Performance Characteristics	Confidential
Effectiveness against Future Threats	Confidential
End Item	Confidential
Maximum and Optimum Launch Altitudes	Confidential
Resolution	Confidential
Technical Advances in the State of the Art	Confidential
Altitude Capabilities	Unclassified
Launch Speed	Unclassified
Maneuverability	Unclassified
Maximum Range	Unclassified
Maximum Speed	Unclassified
Reliability	Unclassified
Trajectory	Unclassified

Figure 12 - XAIM-54A PHOENIX BEING READIED FOR LAUNCH (Courtesy of Hughes Aircraft Company)

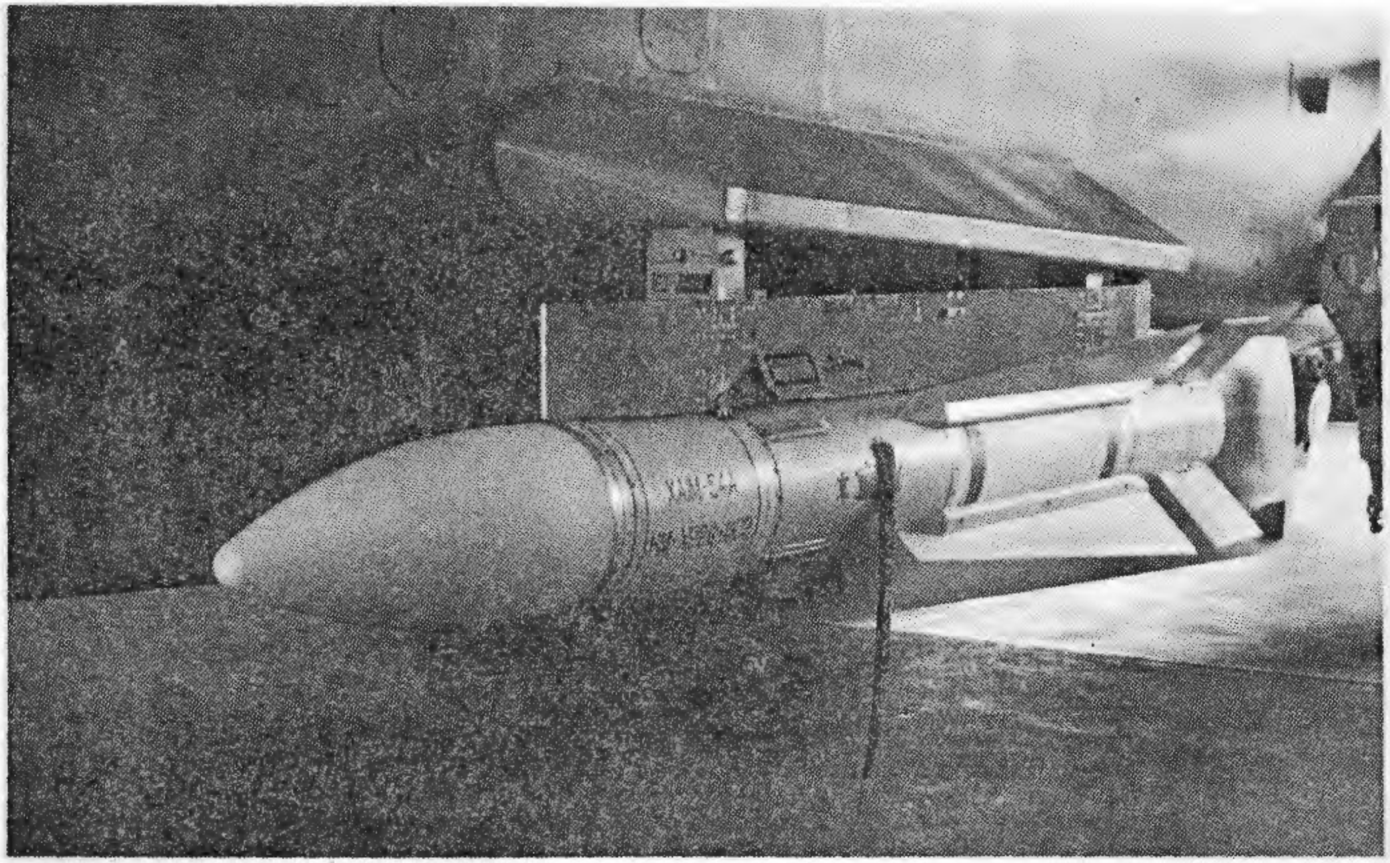


Figure 13 - XAIM-54A PHOENIX READY FOR LAUNCH (Courtesy of Hughes Aircraft Company)

Figure 14 - PROTOTYPE YAIM-54A PHOENIX (Courtesy of Hughes Aircraft Company)

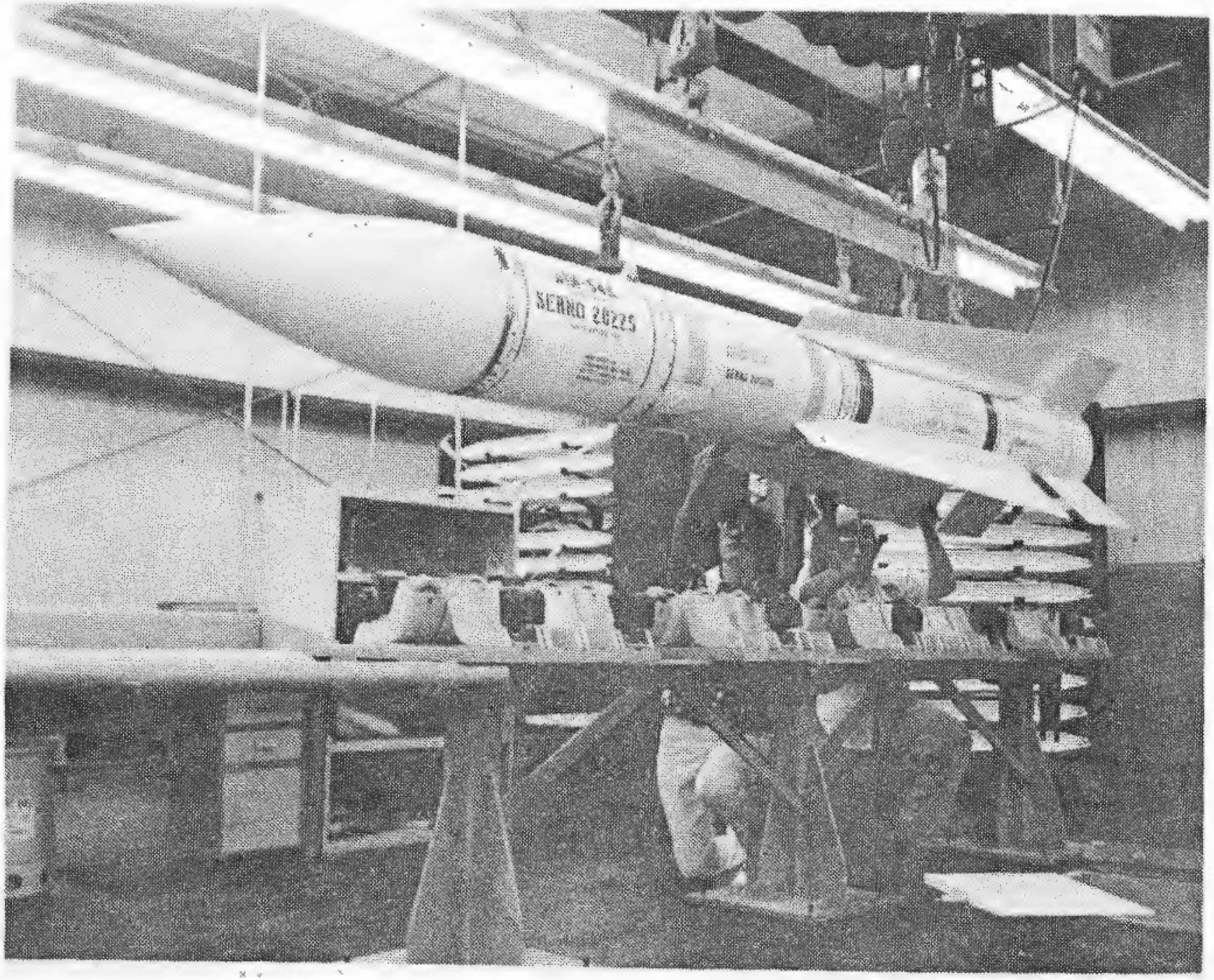


Figure 15 - OPERATIONAL AIM-54A PHOENIX (Courtesy of Hughes Aircraft Company)

IV. PHOENIX MISSILE CHARACTERISTICS

The Phoenix missile is 13 feet long, 15 inches in diameter with a three-foot wing span and weighs 978 lbs. It is powered by a solid propellant rocket motor and carries a 133 lb high explosive warhead detonated by a proximity fuze and/or an impact fuze. The missile has four basic sections: guidance, armament, propulsion and flight controls. Each will be described in more detail (see Figure 16 and Table VI).

It is interesting to note that 978 lbs is the weight of the missile that is listed in the *F-14A NATOPS Manual*[68] and in the *AIM-54A Phoenix Missile*[69] and is unclassified [redacted] The 1976 missile specifications in *Aviation Week and Space Technology*[70] list the weight as 1000 lbs. *Jane's Weapon Systems 1976*[71] states that the weight is 380 kg (838 lbs) but *Jane's All the World's Aircraft 1976-1977*[72] states that the weight is 447 kg (985 lbs) , [redacted] According to the security classification guide, weight information is unclassified. The effectiveness of the security classification guidance is reduced when incongruities, like the one just noted, are encountered.

A. GUIDANCE SUBSYSTEM

The guidance subsystem contains the seekerhead unit, the transmitter-receiver unit, the electronics unit and the rear mixer assembly. The primary function of this subsystem is to provide steering signals to the autopilot by tracking the target in any of the guidance modes.

The seekerhead unit includes the radome, the microwave antenna and associated RF transmission line circuitry, the antenna servo control system and a line-of-sight accelerometer. The radome is made of pyroceram which was devised by engineers at the Naval Air Development Center to reduce rain erosion. The antenna is a high-gain planar array 13 inches in diameter mounted on an inertially stabilized two-axis gimbal structure with freedom of movement in the azimuth and elevation directions. The antenna servo control system includes two rate integrating gyros plus servo amplifiers associated with each gyro; the gyros are mounted on the inner gimbal of the antenna support.

The transmitter-receiver unit operates in X-band [redacted] There are four guidance modes: continuous semi-active, sampled data semi-active, active and home-on-jam. The unit includes a voltage-controlled local oscillator, a transmitter section including power supplies and a receiver section. The voltage local oscillator provides a frequency reference for the active and semi-active modes of operation. The transmitter section provides 75 watts peak power and 25 watts average power (a 1/3 duty cycle factor) to the seekerhead unit.

The electronics unit contains the front receiver, a rear link command decoder, angle tracking circuitry, and velocity tracking circuitry. These and all logic circuits for missile guidance are contained in this unit, which is packaged in a compressed sandwich structure.

Although it is located at the aft end of the missile, the rear mixer assembly is functionally a part of the guidance subsystem. [redacted]

B. ARMAMENT SUBSYSTEM

The armament subsystem consists of the MK 82 Mod 0 warhead, a fuze which contains a safety and arming mechanism and an impact sensing device, a target detecting device and four target detecting device antennas. The purpose of this subsystem is to prevent warhead initiation until the missile has achieved safe separation from the aircraft, to detect the presence of the target and to initiate the detonation of the warhead.

The continuous rod warhead weighs 133 lbs and has an effective radius of 50 feet. "Continuous rod warheads incorporate... a series of rods which are positioned alongside each other around an extremely homogeneous charge and are welded together at alternate ends.... The detonation of the charge provides an impulse of a magnitude exactly sufficient to project the rods radially outwards, the welds at the ends being bent until a ring of rods is formed. . . . [The] initial velocity of the rods is around 1,000 to 1,400 m/sec."[74]

The fuze is mounted on the aft end of the warhead and is electrically connected to the missile guidance system, the target detecting device and the fuze triggering device located on the guidance section bulkhead. Two windows are provided on the botton of the fuze housing, one for determining whether the arming rotor is in the armed or safe position and one for monitoring the arming spring to ensure it is storing no energy. The fuze contains an inertia switch, which senses the high-level shock that occurs upon direct target impact and initiates warhead detonation. When detonation is initiated, an explosive lead transfers the fuze impulse to the MK 60 of MK 47 booster, which amplifies the output to a sufficiently high level to detonate the warhead.

A normal missile launch will occur three seconds after the eject command is initiated. During this three-second period the missile batteries are activated, the fuze solenoid is locked open, the rocket motor igniter solenoid is locked open, the missile flight control unit electronic timer is set to zero and missile functions are transferred to internal power. At the end of the three-second launch-to-eject cycle, the fire signal reaches the launcher circuit to allow ignition of the launcher cartridge by aircraft power. All ordnance is still in the safe position.

The fuze is interlocked to the igniter arming mechanism. This interlock prevents fuze arming prior to launch. Fuze arming requires missile internal power to release its solenoid launch latch; the power is supplied by the missile battery. The igniter arming mechanism transmits an indication of launch. When the rocket motor is ignited, pressure is supplied to a hot gas actuator piston that extends into the fuze and supplies energy for fuze arming.

C. PROPULSION SUBSYSTEM

The propulsion subsystem consists of a rocket motor, an igniter safety mechanism and a rocket motor switch assembly. The purpose of this subsystem is to provide the missile with a long-range capability (over 50 nautical miles); the subsystem was designed to meet the following requirements:

1) Total missile weight of not more than 1000 lbs,
2) Diameter of 15 inches, and
3) Total missile length of 156 inches (13 feet).

The solid propellant rocket motor has a total impulse of approximately 97,000 lb-sec and an average thrust of approximately 4000 lbs with a burn time of more than 25 seconds, depending on the temperature. The Rocketdyne MK 47 Mod 0 rocket motor utilizes an "improved version of Flexadyne, particularly adaptable to Phoenix missile requirements of high volumetric loading, high total impulse and long burning time, to provide the long-range missile operational capability required."[75] The propellant has excellent ballistic and mechanical properties, a five to ten year shelf life and exhaust characteristics that minimize radar attenuation. This information, taken from _Jane's All the World's Aircraft_, [redacted] The effectiveness of the security classification guidance is again reduced because a doubt about the validity of the classification of this item has been placed in the reader's mind. Characteristics of the Aerojet MK 60 Mod 0 rocket motor include a NH_4ClO_4 oxidizer, 1.78 m (70 inches) polyurethane fuel, maximum length, 0.38 m (15 inches) maximum diameter and 199 kg (439 lbs) total weight.[77]

The igniter safety mechanism is designed to arm the ignition system mechanically by an approximate 1.00 inch vertical travel of the positive launch pin resulting from an upward force applied when the missile is launched. The mechanism is a rotor actuated by movement of an arming rod which connects to the launch pin. In the safe position, the rotor blocks off squibs and prevents passage of the gases into the igniter; when the rotor is rotated to the arm position, the passage to the igniter is aligned with the squibs. The design of the igniter safety mechanism includes a dudding feature to ensure that the rocket motor will not ignite when voltage is applied prematurely to the squib circuit of the mechanism.

The rocket motor switch assembly is mounted on the forward rocket motor ring and performs two functions. The first is to switch electrical igniter power to the squibs in the igniter safety mechanism; the second is to switch power to the igniter safety mechanism pull pin unlock solenoid in order to allow the pull pin to actuate the arming rod when the missile is launched.

D. CONTROL SUBSYSTEM

The control subsystem contains the flight control and missile power subsystems. The flight control subsystem consists of the autopilot unit, the rate sensor unit and the hydraulic subsystem. The autopilot unit and hydraulic subsystem are located in the flight control section of the missile and the rate sensor unit is located in the guidance section. The electrical power subsystem consists of the electrical power supply and the electrical conversion unit and is located in the flight control section.

The autopilot unit contains a roll gyroscope and two lateral accelerometers which measure missile motion and stabilize the missile in flight. Steering signals from the guidance section are compared with the measured missile accelerations in the yaw and pitch (lateral) channels; resulting difference signals are processed in the autopilot and applied to the servoactuators to steer the missile to the target. The roll control channel of the autopilot is used to maintain the roll attitude of the missile.

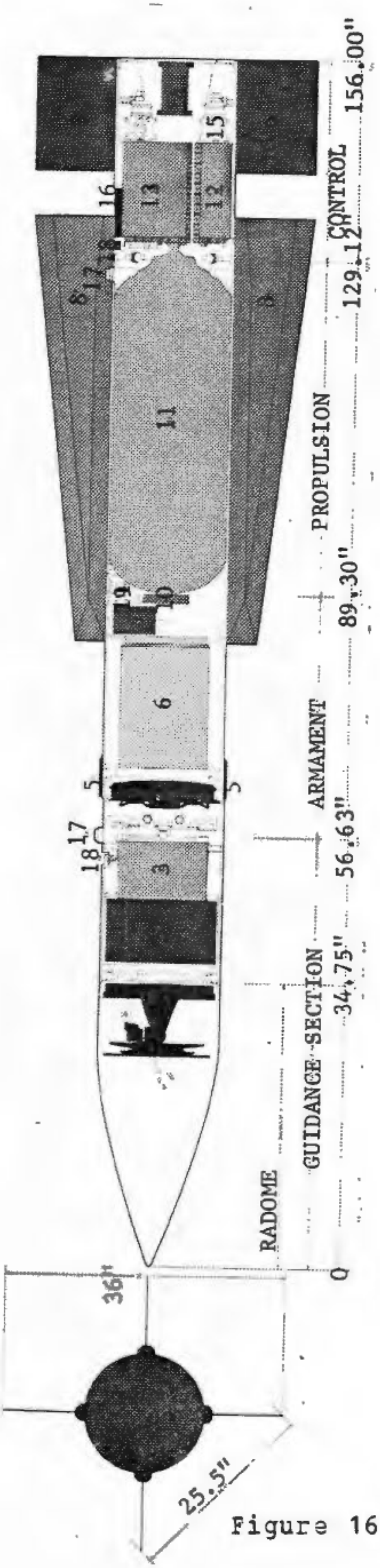
The rate sensor unit is attached to the aft side of the forward ejection bulkhead. It contains two angular rate gyros which sense missile angular velocities about the pitch and yaw axes; these are single-degree-of-freedom gyros and have a dynamic range of ±200 degrees/second.

The hydraulic subsystem major components are the hydraulic power supply, the hydraulic manifold and the four servopositioners, all located in the aft end of the flight control section. The hydraulic system is capable of moving the control surfaces at angular rates up to 120 degrees/second in the absence of opposing aerodynamic loads and provides a stall torque of 1575 in-lb at ±25° servoshaft deflection. The hydraulic power supply is a hydraulic piston pump driven by a 28 volt DC motor with an integral variable volume fluid reservoir. Maximum power consumption at full hydraulic power demand is 4100 watts. The maximum pump out is 1.5 gpm at 3400 psi differential load. The hydraulic manifold is used to direct high-pressure hydraulic fluid from the hydraulic power supply to the servopositioners at flow rates required for rapid missile response. The control surface servopositioners are two-stage servovalves with electrical feedback that drive the missile control surfaces in response to autopilot output signals.

The electrical power supply is a multisection battery: a 28 volt output for the hydraulic pump, a 100 volt output for the active transmitter and a 100 volt output that powers the electrical conversion unit. The 100 volt sections are wired in parallel. The use of separate sections prevents conductive coupling of noise and steering command transients in the high power hydraulic circuit into the low power guidance circuit. All cells of the power supply are activated simultaneously when potassium hydroxide electrolyte in a storage tank is forced into them by a squib triggered gas generator in less than one second. The average power outputs of the battery sections are:

1) Electrical conversion unit 1200 watts
2) Transmitter 400 watts
3) Hydraulic power supply 2100 watts.

In the prelaunch mode the electrical conversion unit converts primary power [redacted] to the required power forms; in free flight it performs the same conversions from missile battery power.



GUIDANCE SECTION

1. Seekerhead Unit
2. Transmitter-Receiver Unit
3. Electronics Unit

ARMAMENT SECTION

4. Target Detecting Device
5. TDD Antennas (4)
6. Warhead
7. Fuze (Warhead Safety and Arming)

FLIGHT CONTROL SURFACES

8. Wings (4)
9. Control Surfaces (4)

PROPULSION

10. Igniter Safety Mechanism
11. Rocket Motor

CONTROL

12. Electrical Conversion Unit
13. Autopilot
14. Rear Mixer Assembly
15. Servopositioners

AIRFRAME AND WIRING

16. Electrical Umbilical
17. Missile Hooks
18. Conditioning Fluid Couplings (2 pairs)
19. Positive Launch Pin

[redacted]

Figure 16 - PHOENIX MISSILE SCHEMATIC

Table VI - PHOENIX MISSILE CHARACTERISTICS

Target Sensor	Active, continuous and sampled data semi-active pulse Doppler radar
Frequency	X-band, [redacted]
Antenna	Planar array
Size	13 inches
Beamwidth	6 degrees
Angle limits	±60 degrees
Doppler filter noise bandwidth	[redacted]
Transmitter power	75 watts peak, 25 watts average
Warhead	Continuous rod
Radius	50 feet
Weight	133 lbs
Propulsion	Solid fuel rocket motor
Total impulse	97,000 lb-sec
Thrust	4,000 lbs
Flight control	Acceleration command, adaptive gain and rate stabilized autopilot
Electrical power	Battery
Power	3700 watts
Duration	160 seconds, minimum
Mass properties	
Prelaunch weight	978 lbs
Guidance section	163 lbs
Armament section	180 lbs
Propulsion section	467 lbs
Control sections	106 lbs
Wings	40 lbs
Control surfaces	22 lbs
Weight at motor burnout	602 lbs
Center of gravity location	
Prelaunch	95.7 inches
Burnout	88.1 inches

[redacted]

V. AWG-9 WEAPON CONTROL SYSTEM CHARACTERISTICS

The AWG-9 Weapon Control System uses a pulse Doppler search, track, acquisition and guidance radar as its primary target sensor and a gimbal-mounted, high resolution infrared search and acquisition sensor to augment and back up the radar. Other equipment included in the AWG-9 Weapon Control System is a high-speed, multi-purpose digital computer and controls and displays for the Naval Flight Officer.

In the track-while-scan mode the AWG-9 can track up to 24 targets simultaneously and can launch six Phoenix missiles against six different targets in order of threat priority as determined by the computer, which maintains up-dated target track files and processes and displays the information on the tactical information display (TID) and the detail data display (DDD). The caption of a photograph describes the inside of the aft cockpit of the F-14:

> [The] large circular cathode ray tube in the center console of the naval flight officer's station in the Grumman/Navy F-14A fighter is the tactical information display. The flight officer receives computer-generated symbology on own-aircraft ground speed, and track, range, bearing, command course, command heading and time to go to selected positions....[He] receives displays of targets as they cross the tactical information display with priorities in target engagement for the missile systems. In the track-while-scan mode, the computer selects the greatest concentration of targets by radar sweeps every 2 sec. The target's last known position is stored in the computer, which estimates where the target will appear next, and computes heading, altitude, speed, launch zones for the F-14A's missiles and firing priorities. Just above the tactical information display is the detail data display providing azimuth and range rate information.[78]

Before the operation of the Phoenix/AWG-9 Weapon Control

System is described, some radar terminology will be explained.

A. BASIC DESCRIPTION OF A PULSE RADAR SYSTEM

Most airborne radars transmit in X-band between 8.5 GHz and 10.68 GHz (now I-band and part of J-band -- see Table VII). The antenna is a limiting factor in the design of an aircraft fire control system. Frequencies used have generally increased since the discovery of radar because higher frequency radars can use smaller antennas. A directional antenna is large compared to the wavelength of the frequency transmitted or received, thus an S-band antenna is generally larger than an X-band antenna. Ku-band (J-band) radars are sometimes used but not in long-range radars since transmissions from these radars (J-band) can be blocked by weather conditions such as rain, snow or clouds.

A pulse radar transmits radio frequency (RF) energy in short, high-power pulses and the echoes are received in short pulses while the transmitter is off (see Figure 17). Radio energy from the stable oscillator is chopped and amplified by a transmitter. This energy is directed by the antenna (in the F-14, a planar array). Target returns in the antenna beam direction are picked up by the antenna and switched to the receiver, which amplifies the signal. The processor then performs a number of functions to extract information about the target for display. Thus pulse-modulation permits the same antenna to be used for transmitting and receiving.

Table VII - SELECTED FREQUENCY DESIGNATIONS

Previous			Current		
Band	Frequency	Wavelength	Band	Frequency	Wavelength
L	1-2 GHz	30-15 cm	D	1-2GHz	30-15 cm
S	2-4 GHz	15-7.5 cm	E	2-3 GHz	15-10 cm
			F	3-4 GHz	10-7.5 cm
C	4-8 GHz	7.5-3.75 cm	G	4-6 GHz	7.5-5 cm
			H	6-8 GHz	5-3.75 cm
X	8-12.5 GHz	3.75-2.4 cm	I	8-10 GHz	3.75-3 cm
Ku	12.5-18 GHz	2.4-1.67 cm	J	10-20 GHz	3-1.5 cm
K	18-26.5 GHz	1.67-1.13 cm	K	20-40 GHz	1.5-.75 cm
Ka	26.5-40 GHz	1.13-.75 cm			

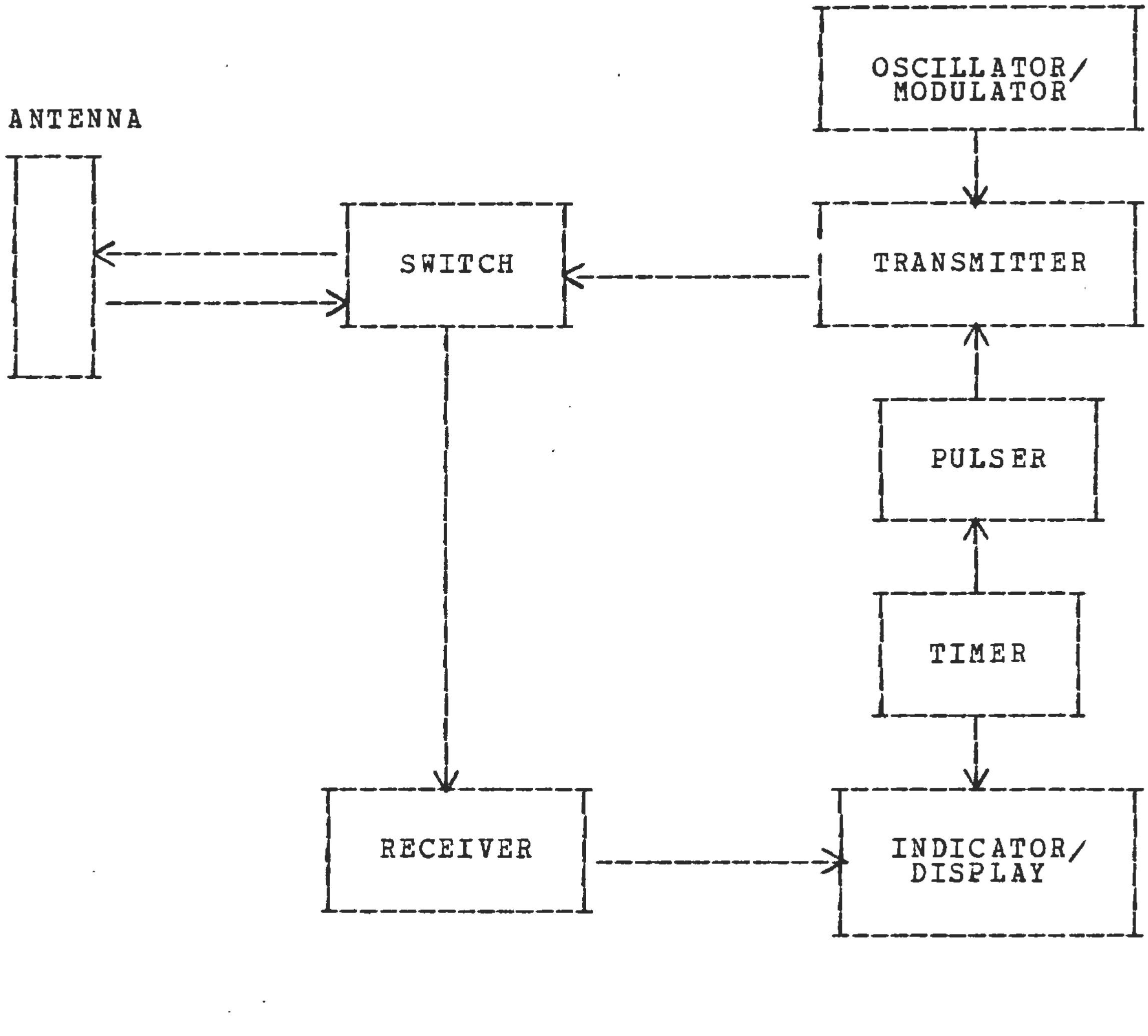


Figure 17 - PULSE RADAR BLOCK DIAGRAM

A coherent radar can separate clutter (radar returns from the ground rather than from airborne targets) and noise (spurious signals generated within the radar receiver and always present in the air) from moving targets. In a coherent radar the pulser periodically interrupts a continuous signal. Direct correlation is possible between the transmitted pulse and the received echo since they are phase-related. Noise is random, so target returns can be easily discriminated from noise.

The speed of any target can be computed by comparing the phase of the return signal directly with the reference signal and calculating the Doppler frequency from the phase shift of a number of successive returns from the same target. The frequency of the returned pulse varies with the speed of the target relative to the radar antenna. Thus moving targets can be easily picked out of clutter returns.

The pulse repetition frequency (PRF) is the rate at which the coherent signal is turned on and off by the pulser. A high PRF is about 300 kHz and enables a radar to extend its range by putting more power on the target. A radar with a high PRF cannot measure target range directly but range data can be derived from Doppler information. A low PRF is about 1 kHz and has reduced range as a result of less effective power of the radar on the target but it enables precise measurement of target range. Doppler shift cannot be readily measured at low PRF and thus it is difficult to distinguish targets from clutter. A medium PRF is about 15 kHz and its advantages and disadvantages depend upon operating conditions since speed and range information cannot be computed directly. Which PRF mode is used depends upon clutter conditions. For a look-up mode, i.e., no clutter, a low PRF might be used; a medium PRF might be selected for a look-down capability to reject ground clutter; and a high PRF might be selected for a long-range requirement.

B. AWG-9 ANTENNA

The transmitting-receiving antenna is a 36-inch (91.44 cm) diameter slotted array, flat plate (planar) antenna housed in the nose of the aircraft. The antenna provides higher gain than an equivalent-sized parabolic dish, is less vulnerable to cross-polarized jamming and lends itself to interrelated use of an interferometer identification, friend or foe (IFF) antenna, situated on the radar's planar array. As a result, the weapon control system computer can correlate angular information derived from the tracking antenna with information obtained from the dipoles of the IFF antenna.[79]

In mid-1969 a series of articles describing new technology phased array antennas were published in Aviation Week and Space Technology. A Hughes Aircraft Company phased array radar antenna called ESAIRA, an acronym for electronically scanned airborne intercept radar antenna, was described in the June 9th issue. The antenna was a 36-inch diameter, planar reflected surface containing 2400 X-band waveguide elements. The reflector surface was illuminated by a four-horn monopulse feed; each radiating element contained a four-step PIN diode phase shifter. "The Hughes antenna is oriented toward application in an intercept aircraft [F-14?]."[80]

The antenna beam was scanned by phasing the signal received at each of the 2400 elements so that the reflected energy from all elements was in phase in the direction of the beam. Beam steering equations were solved in the weapon control system computer which provided commands for the phase shifters. "For the future, Hughes is planning a more advanced antenna in which the drive and logic circuitry would be packaged in a small element together with the phase shifters."[81] The antenna was designed to achieve pointing accuracy with high gain and low sidelobe levels. For a broadside beam at 9.5 GHz, for example, the sidelobes were 21 db down from the main beam.

The antenna was designed to work at high peak and high average powers to accommodate various types of radar. The ESAIRA could handle peak radio frequency power of 375 kw and average radio frequency power of 4.5 kw. A 2.5° beam with an 8.5% bandwidth at X-band could be generated. Gain was 33.5 db and peak sidelobe level was -24 db at broadside and -22 db at ±45° scan. The radar beam could scan ±65° in azimuth and elevation.

The computer that was hooked up to the ESAIRA test antenna determined whether the antenna generated a pencil or shaped beam, changed frequency, and determined azimuth and elevation of the beam. The shape of the beam could be changed almost instantaneously, thus the antenna could function in many modes, such as air-to-air search or multiple-target tracking.[82]

The ESAIRA can be considered to have been the "toy" stage of technology. The antenna in the F-14 has advanced beyond that stage into the "tool" category.

C. RADAR MODES

The AWG-9 Weapon Control System has various radar mode capabilities: pulse Doppler, conventional pulse and transitional. The capabilities of the pulse Doppler mode include:

1) Pulse Doppler search for long-range detection and search out to a 115 nautical mile range.
2) Range-while-search for long-range detection and ranging at a nominal 90 nautical mile range.
3) Track-while-scan for search and detection at 90 nautical miles and multiple-target track and Phoenix launches at a maximum range of 52 nautical miles. The only drawback to the track-while-scan mode is that it can only be used for the Phoenix missiles. In this mode, every two seconds the radar sweeps across and stores the last known position of the target in the computer and estimates where the target will appear next. Heading, altitude, speed, launch zones and priorities in launching missiles are determined by the digital computer.
4) Pulse Doppler single-target track at long-ranges. This mode includes two uses: velocity track out to 90 nautical miles and jam-angle track where the range depends upon the jamming.
5) Pulse Doppler radar slaved for radar illumination and ranging on infrared targets out to 90 nautical miles.

The AWG-9 operates in the conventional pulse mode for short and medium range search and detection. The capabilities of the pulse mode include:

1) Pulse search for short and medium range search and detection and for air-to-ground launches out to 62 nautical miles.
2) Pulse search single-target track at short and medium ranges. This mode includes two uses: range track

out to 49 nautical miles and jam-angle track where the range depends upon the jamming.

3) Pulse radar slaved for radar illumination and ranging on infrared targets out to 49 nautical miles.

A transitional mode is also used for rapid lock-on in the vertical plane or in a manual mode for rapid lock-on to a target located anywhere in the radar field of view with a nominal detection range of 5 nautical miles.[83] Table VIII summarizes the radar mode capabilities of the AWG-9 Weapon Control System.

The AWG-9 radar can transmit pulse Doppler search signals on 19 transmission channels using a broad-band, gridded travelling wave tube. The transmitted frequencies are X-band (I-band in current usage). Six of the channels are used for generating guidance signals for the Phoenix missiles and five are used for guidance signals for the AIM-7F Sparrow missiles. The multiplicity of discrete channels from the travelling wave tube makes possible the minimization of interference from friendly aircraft and from enemy countermeasures and provides adequate frequency margins for semi-active missile guidance.

In the pulse search and track mode, where targets are distinguished by range separation, the target is detected by a pulse mode processor that determines its range. The processor closes a tracking gate around the target. Range rate is found by taking the derivative of range while tracking the single target. Target range is fed into the Naval Flight Officer's detail data display and shown as a function of azimuth. The pulse single-target track angle commands are fed into an antenna controller to keep the antenna centered on the target.

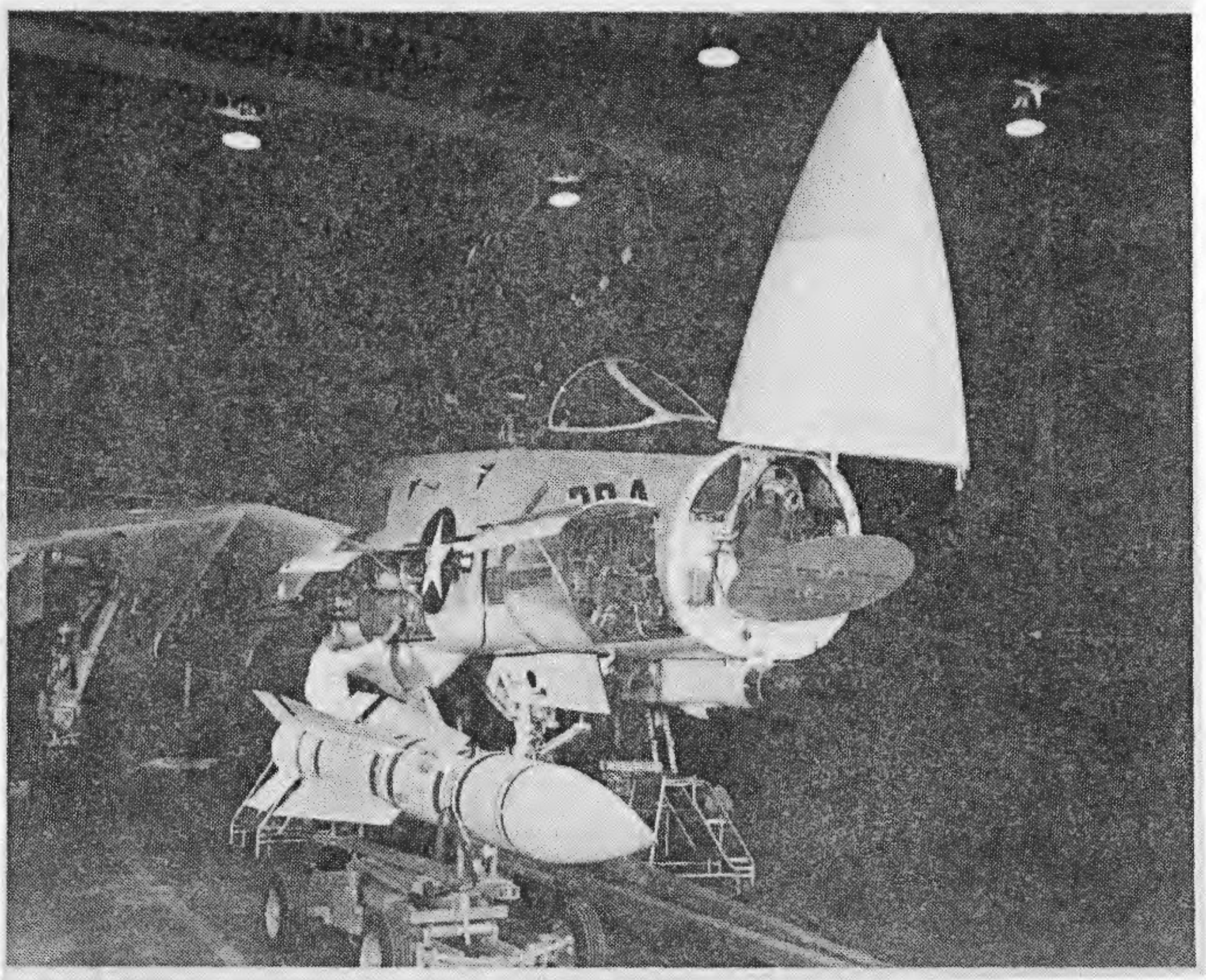


Figure 18 - AWG-9 WEAPON CONTROL SYSTEM (Courtesy of Hughes Aircraft Company)

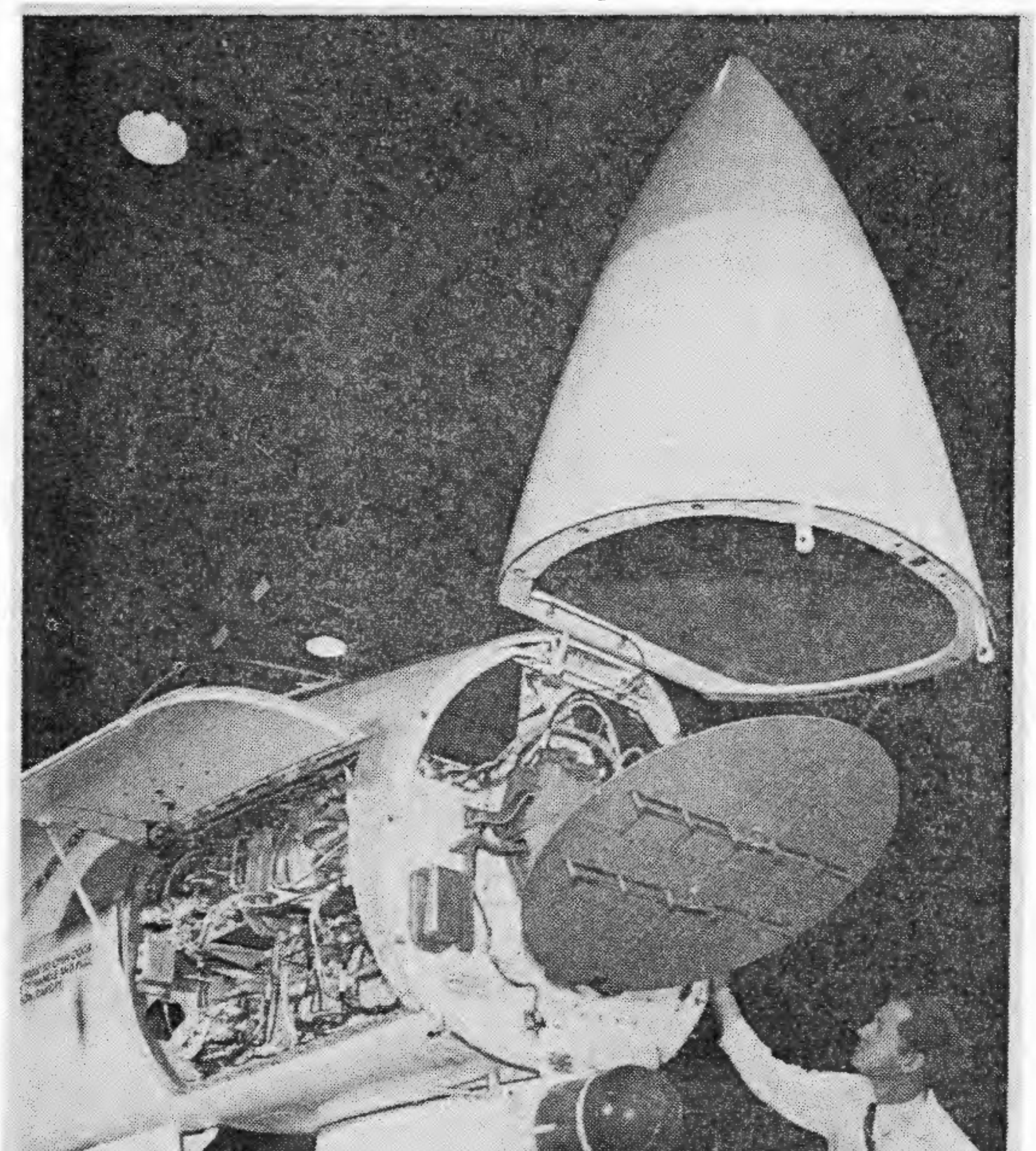


Figure 19 - AWG-9 WEAPON CONTROL SYSTEM (CLOSE-UP)

(Courtesy of Hughes Aircraft Company)

Table VIII - RADAR MODE CAPABILITIES

MODE			PRIME FUNCTION	WEAPONS CAPABILITY	ANTENNA PROGRAM	NOMINAL DETECTION RANGE	TARGET DATA AVAILABLE
PULSE DOPPLER	PD SEARCH (PDS)		LONG RANGE SEARCH AND DETECTION	BORESIGHT MISSILE MODES	±10°, 20°, 40°, OR 65° 1, 2, 4, OR 8 BAR	115 N.MI.*	RANGE RATE
	RANGE-WHILE-SEARCH (RWS)		LONG RANGE SEARCH, DETECTION & RANGING			90 N.MI.*	RANGE, RANGE RATE, AND ANGLES
	TRACK-WHILE-SCAN (TWS)		SEARCH, DETECTION, AND MULTIPLE TARGET TRACK, AND AIM-54 LAUNCH	AIM-54A (MULTIPLE RELEASE) MAX MISSILE LAUNCH - 52 N.MI.	2 BAR 40° OR 4 BAR 20°	90 N.MI.*	COMPLETE TRACK FILE
	PD SINGLE TARGET TRACK (PDSTT)	VELOCITY TRACK (VT)	LONG RANGE SINGLE TARGET TRACKING AND MISSILE LAUNCH	AIM-54A - 63 N.MI. (MAX) AIM-9G - 1.5 N MI. TO 10 N.MI DEPENDING ON ALT/GEOMETRY AIM-7F - 38 N.MI. (MAX)	LOCKON	90 N.MI.*	RANGE, RANGE RATE, AND ANGLES
		JAM ANGLE TRACK (JAT)				DEPENDS ON JAMMING**	ANGLES AND RATES**
	PD RADAR SLAVED (PDRSL)		RADAR ILLUMINATION AND RANGING ON IR TARGET		RADAR IS SLAVED TO IR LINE OF SIGHT	90 N.MI.*	ANGLES, RANGE AND RANGE RATE
PULSE	PULSE SEARCH (PS)		SHORT AND MEDIUM RANGE SEARCH AND DETECTION AND A/G	BORESIGHT MISSILE MODES	+10°m 20°m 40°m IR 65° 1, 2, 4, OR 8 BAR	62 N.MI.*	CONVENTIONAL PULSE RADAR
	PS SINGLE TARGET TRACK	RANGE TRACK (RT)	SHORT AND MEDIUM RANGE SINGLE-TARGET TRACKING, AND MISSILE LAUNCH	GUN A/G STORES AIM-54A (ACTIVE) AIM-7F(CW) - 29 N.MI. AIM-7E(CW) - 18 N.MI. AIM-9 - 1.5 N.MI. TO 20 N.MI. DEPENDING ON ALT/GEOMETRY	LOCKON	49 N.MI.*	
		JAM ANGLE TRACK (JAT)				DEPENDS ON JAMMING**	ANGLES AND RATES**
	PULSE RADAR SLAVED (PRSL)		RADAR ILLUMINATION AND RANGING ON IR TARGET		SLAVED TO IR/TV SENSOR	49 N.MI.*	ANGLES, RANGE AND RANGE RATE
TRANS-ITIONAL	PILOT RAPID LOCKON (PLM)		PILOT INITIATED RADAR LOCKON	NOT APPLICABLE	2.3° BEAM CENTERED ALONG ADL	5 N.MI.*	RANGE AND ANGLE TRACKING
	VERTICAL SCAN LOCKON (VSL)		RAPID LOCKON TO TARGET IN VERTICAL PLANE		VSL HI +15° TO +55° 2 BAR VSL LO −15° TO +25° 2 BAR		
	MANUAL RAPID LOCKON (MRL)		RAPID LOCKON TO TARGET LOCATED ANYWHERE IN RADAR FIELD OF VIEW		± 10° AZIMUTH 1 BAR IN ELEVATION		

* BASED ON 5 m^2 TARGET
** ALTITUDE DIFFERENCE RANGING (ADR) CAPABILITY EXISTS

(Source: Stevenson, Grumman F-14 "Tomcat", p. 79)

In the pulse Doppler mode, targets are differentiated by velocity differences in radar returns. Range rate is found by the Doppler frequency shift in the pulse which is proportional to target velocity along the aircraft's line-of-sight. Extraneous altitude and clutter returns are eliminated by a Doppler clutter processor and range rate is determined by a bank of filters with graduated thresholds. Target range rate is fed into the detail data display and shown as a function of azimuth.

To determine range in the pulse Doppler mode the radar automatically impresses a modulating waveform on a portion of its separate search pulses. Target range can then be calculated from the frequency difference between the modulated and unmodulated portions of the detected pulse returns. Range and range rate signals are passed to the AWG-9 computer, which processes the data for presentation on the tactical information display. To track multiple targets while searching for others, the computer stores antenna angles, range and range rates for each target in a track file. On the basis of several returns from a target, the computer can predict where the target will be on the next radar sweep and where the antenna should point on the next scan.[84]

D. INFRARED SENSOR

As a supplement to the radar, the infrared search and acquisition set passively gathers sufficient information to fire Phoenix or Sidewinder missiles if the radar is inoperable due to malfunction or to effective jamming by an enemy. The Phoenix missile would have to be launched in an active, rather than a semi-active, mode and depend on its own self-contained pulse Doppler radar, which is normally intended for terminal guidance only.

The field of view of the infrared telescope can be slaved independently of the radar antenna so that the sensor can augment the radar by searching an airspace volume in one direction while the radar scans another. The infrared sensor might search high altitudes, where the target-to-background radiation ratio is high, while the radar would scan low altitudes. The infrared field of view can also be driven by the AWG-9 radar antenna or it can drive the radar antenna, depending on the situation. The infrared sensor augments the radar because of its superior angular resolution capability; if the radar detects a group of targets together, the infrared sensor can distinguish each of the aircraft in the group. The infrared capabilities include three modes of operation:

1) Infrared search for infrared search and detection,
2) Infrared track for infrared tracking and missile launch, and
3) Infrared slaved when the infrared is slaved to the radar line-of-sight to the target.

The nominal detection range for each of the modes for a low altitude fighter bomber (without afterburner) is 10 nautical miles in a nose aspect and 46 nautical miles in a tail aspect. For a high altitude supersonic interceptor the nominal detection range is 102 nautical miles in a nose aspect and 179 nautical miles in a tail aspect. The infrared capabilities are summarized in Table IX.

The infrared sensor's detectors are indium antimonide elements that can detect heat generated by exhaust in the 4-5 micron range. The detector array is cooled to operating temperature by the detector refrigerator, which is a self-contained, closed-cycle Stirling cycle refrigerator.[85]

E. DATA LINK

Track data on targets is in a form ready for data link transmission. The automatic two-way data link system in the F-14 permits the fighter to operate in a command data link network. The system provides automatic reception and display of targets outside the radar's range. It in turn permits transmission to a combat information center (CIC) information on targets the F-14 is tracking. Even with the radar turned off in the F-14, the data link system can be used. This enables the F-14 to operate with its radar off and be vectored for an intercept by an E-2C to avoid detection and radar homing missiles. The F-14 radar is turned on immediately prior to launch of a Phoenix or Sparrow missile.[86]

Table IX - INFRARED CAPABILITIES

MODE	PRIME FUNCTION	WEAPONS CAPABILITY	ANTENNA PROGRAM	NOMINAL DETECTION RANGE	TARGET DATA AVAILABLE
IR SEARCH (IRS)	IR SEARCH AND DETECTION	BORESIGHT MISSILE MODES	±6°, 20°, 40°, OR 65° 1, 2, 4, OR 8 BAR	LOW ALT FIGHTER BOMBER (NON A/B): 10 N.MI (NOSE) 46 N.MI (TAIL)	AZIMUTH AND ELEVATION
IR TRACK (IRT)	IR TRACKING AND MISSILE LAUNCH	AIM-54A (ACTIVE) AIM-7E/7F (CW) AIM-9G	±6° GIMBAL SCAN		AZIMUTH AND ELEVATION*
IR SLAVED (IRSL)	THE IR IS SLAVED TO THE RADAR LINE OF SIGHT TO THE TARGET	NORMAL LAUNCH OF AIM-54A, AIM-7E/7F, AIM-9G	SLAVED TO RADAR ANTENNA	HIGH ALT SUPERSONIC INTERCEPTOR: 102 N.MI (NOSE) 179 N.MI (TAIL)	AZIMUTH AND ELEVATION*

* ADR CAPABILITY EXISTS

(Source: F-14A NATOPS Manual, p. 8-9)

VI. PHOENIX MISSILE MODES OF OPERATION

The Phoenix missile has four modes of operation: sample data semi-active, continuous semi-active, active and home-on-jam. These modes will be detailed in this section.

The AWG-9 Weapon Control System radar operates in the track-while-scan mode to support the missile in the sample data semi-active mode. Up to six Phoenix missiles can be launched, supported and guided against six separate targets simultaneously in this mode. There are three guidance phases in this mode:

1) programmed guidance, where the missile performs a timed vertical maneuver in response to prelaunch commands that both allow the missile to avoid the main beam of the radar and provide trajectory shaping that increases the missile's aerodynamic range,
2) mid-course guidance, where the missile utilizes information transmitted directly in messages from the weapon control system, to direct its antenna and control its receiver to receive the semi-active signal and target echo from a designated target as the radar scans the target, derives guidance commands from the sampled return and guides on the target with fixed guidance gain, and
3) terminal active guidance, where the receiver transfers to a different operating frequency on command from the weapon control system, evaluates the spectrum to avoid interfering signals, radiates its own RF signal to illuminate the target,

continuously tracks the target echoes and guides with proportional guidance gain to intercept the target. (See Figure 20).

The switch from mid-course to terminal guidance occurs about 10 miles (16 km) from the target.[87]

The Phoenix missile also performs three guidance phases in the continuous semi-active mode:

1) programmed guidance, which is the same as in the sampled data semi-active mode,
2) mid-course guidance, where the missile receives more messages from the weapon control system than in the sampled data semi-active mode, utilizes message content to position the antenna and turn the receiver on, continuously tracks semi-active target echoes with the receiver except during message transmission, derives continuous guidance signals and guides with fixed guidance gain, and
3) terminal guidance, where the missile continuously tracks the target as in the midcourse phase, but uses proportional guidance. In this mode one missile is fired optimally but up to six missiles can be fired at the same target.

In the active mode the Phoenix missile is launched with its receiver commanded to the active mode, but it receives prelaunch commands when available. The missile attempts acquisition of the target in the active mode with the transmitter radiating shortly after launch. The missile guidance uses an angle-rate memory technique, where the average of the steering signals developed during a clear period are used for tracking and guidance during the following eclipse periods. The aircraft can launch and leave the missile in this mode.

In the home-on-jam mode the missile receiver and guidance passively track noisy electronic countermeasure (ECM) targets on both its active and semi-active frequencies. The missile guidance system locks on the jamming noise. When the jamming is turned off the missile attempts to reacquire the target in either its active or semi-active modes.

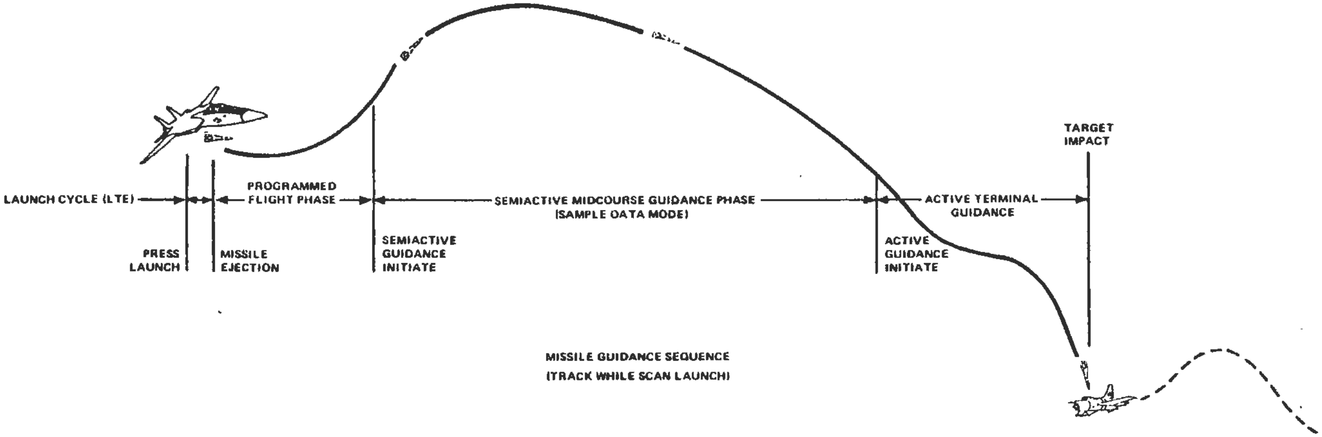


Figure 20 - MISSILE GUIDANCE SEQUENCE

VII. CONCLUSION

(b) (3) (A), (b) (5)

[redacted]

(b) (3) (A), (b) (5)

[redacted]

(b) (3) (A), (b) (5)
[redacted]

(b) (3) (A), (b) (5)
[redacted]

(b) (3) (A), (b) (5)
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(b) (3) (A), (b) (5)

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(b) (3) (A), (b) (5)

[redacted]

(b) (3) (A), (b) (5)

[redacted]

(b) (3) (A), (b) (5)

[redacted]

FOOTNOTES

[1] N.F. Shibayev, Antimissile Warfare, pp. 89-90.

[2] Jane's Weapon Systems 1976, p.666.

[3] Aviation Week and Space Technology, November 10, 1958, p.28.

[4] Aviation Week and Space Technology, September 8, 1958, p. 23.

[5] Aviation Week and Space Technology, February 21, 1961, pp. 50-51.

[6] Aviation Week and Space Technology, November 24, 1958, p. 23.

[7] Flight International, 5 November 1964, pp. 800-803, and Flight International, 4 November 1965, pp. 784-785.

[8] Jane's All the World's Aircraft 1972-1973, p. 334.

[9] Aviation Week and Space Technology, March 13, 1961, p. 132.

[10] Aviation Week and Space Technology, July 9, 1962, p. 26.

[11] Aviation Week and Space Technology, October 9, 1961, p. 24.

[12] Aviation Week and Space Technology, April 2, 1962, p. 13.

[13] Flight International, 8 November 1962, p. 76.

[14] Flight International, 27 September 1973, p. 508.

[15] Columbia Research Corporation, The F-4 and the F-14, p. 74.

[16] Aviation Week and Space Technology, July 8, 1963, p. 19.

[17] Vectors, Vol. XIII (1971), p. 20.

[18] Aviation Week and Space Technology, March 12, 1973, p. 40.

[19] Aviation Week and Space Technology, July 13, 1966, p. 129, Aviation Week and Space Technology, September 11, 1967, p. 63, and Flight International, 9 January 1964, p. 74.

[20] Aviation Week and Space Technology, April 12, 1965, p. 37.

[21] Aviation Week and Space Technology, March 8, 1965, p. 60.

[22] Aviation Week and Space Technology, June 7, 1965, p. 22.

[23] Aviation Week and Space Technology, May 2, 1966, p. 30.

[24] Flight International, 19 May 1966, p. 857.

[25] *Aviation Week and Space Technology*, August 22, 1966, p. 20.

[26] *Flight International*, 29 September 1966, p. 572.

[27] *Aviation Week and Space Technology*, January 30, 1967, p. 13.

[28] *Aviation Week and Space Technology*, April 3, 1967, p. 34.

[29] *Aviation Week and Space Technology*, September 11, 1967, pp. 59-63.

[30] *Aviation Week and Space Technology*, January 1, 1968, p. 18, and *Aviation Week and Space Technology*, January 29, 1968, pp. 22-23.

[31] *Aviation Week and Space Technology*, October 23, 1967, p. 23.

[32] *Aviation Week and Space Technology*, April 8, 1968, pp. 22-23.

[33] *Aviation Week and Space Technology*, September 16, 1968, p. 39.

[34] *Aviation Week and Space Technology*, January 13, 1969, p. 13.

[35] *Jane's Weapon Systems 1976*, p. 172.

[36] *Aviation Week and Space Technology*, June 30, 1969, p. 17.

[37] *Aviation Week and Space Technology*, November 3, 1969, p. 69.

[38] *Aviation Week and Space Technology*, April 6, 1970, p. 92.

[39] *Aviation Week and Space Technology*, May 25, 1973, pp. 51-57.

[40] *Aviation Week and Space Technology*, August 24, 1970, p. 21.

[41] *Aviation Week and Space Technology*, July 24, 1972, p. 18.

[42] *Aviation Week and Space Technology*, October 18, 1971, p. 18.

[43] *Aviation Week and Space Technology*, December 6, 1971, p. 7.

[44] *Aviation Week and Space Technology*, January 31, 1972, p. 19.

[45] *Aviation Week and Space Technology*, January 24, 1972, p. 13.

[46] *Aviation Week and Space Technology*, July 31, 1972, p. 18.

[47] *Aviation Week and Space Technology*, October 16, 1972, cover.

[48] *Aviation Week and Space Technology*, June 5, 1972, p. 42.

[49] *Aviation Week and Space Technology*, July 24, 1972, p. 18.

[50] *Aviation Week and Space Technology*, October 23, 1972, p. 249

[51] *Aviation Week and Space Technology*, January 1, 1973, p. 18.

[52] Aviation Week and Space Technology, September 25, 1972, p. 21, and Aviation Week and Space Technology, November 6, 1972, p. 20.

[53] Aviation Week and Space Technology, March 12, 1973, pp. 31-41.

[54] Aviation Week and Space Technology, March 26, 1973, pp. 46-50.

[55] Aviation Week and Space Technology, April, 2, 1973, pp. 22-24.

[56] Aviation Week and Space Technology, April 23, 1973, p. 24.

[57] Aviation Week and Space Technology, August 13, 1973, pp. 16-17.

[58] Flight International, 27 September 1973, pp. 508-516.

[59] Aviation Week and Space Technology, December 3, 1973, p. 309

[60] Aviation Week and Space Technology, November 19, 1973, p. 9.

[61] Interavia, December 1974, pp. 1203-1207.

[62] Flight International, 23 October 1975, p. 598.

[63] Aviation Week and Space Technology, November 3, 1975, pp. 42-45.

[64] Aviation Week and Space Technology, November 29, 1976, pp. 46-55.

[65] Aviation Week and Space Technology, January 31, 1977, pp. 164-164.

[66] NAVAIRINST 5511.4B (Ch-2, 4 November 1974), pp. 25-29.

[67] NAVAIRINST 5511.4B (Ch-1, 25 May 1973), pp. 46-47.

[redacted]

[69] Hughes Aircraft Company, AIM-54A Phoenix Missile (U), November 1971, p. 18. (Confidential document)

[70] Aviation Week and Space Technology, March 15, 1976, pp. 83-84.

[71] Jane's Weapon Systems 1976, p. 171.

[72] Jane's All the World's Aircraft 1976-1977, p. 657.

[redacted]

[74] International Defense Review, 5/1975, p. 724.

[75] Jane's All the World's Aircraft 1976-1977, p. 789.

[redacted]

[77] Jane's All the World's Aircraft 1976-1977, p. 753.

[78] Aviation Week and Space Technology, November 29, 1976, p. 47.

[79] Aviation Week and Space Technology, March 12, 1973, p. 38.

[80] Aviation Week and Space Technology, June 9, 1969, p. 77.

[81] Aviation Week and Space Technology, June 9, 1969, p. 79.

[82] Aviation Week and Space Technology, June 9, 1969, pp. 76-80.

[83] Aviation Week and Space Technology, November 29, 1976, pp. 52-53.

[84] Aviation Week and Space Technology, March 12, 1973, pp. 40-41.

[85] Aviation Week and Space Technology, March 12, 1973, pp. 37-39.

[86] Aviation Week and Space Technology, November 29, 1976, p. 53.

[87] Jane's Weapon Systems 1976, p. 121.

[88] James Ferry Stevenson, Grumman F-14 "Tomcat", p. 90.

[89] Russel H. Stolfi and Peter C.C. Wang, General Methodology for Forecasting Soviet Naval Technological Threat (U), pp. 1-37. (Unclassified section of Secret document)

[90] C.F. Woodhouse III, Advanced Weapons Forecasting (Techniques and Applications), pp. 13-14.

[91] C.F. Woodhouse III, Advanced Weapons Forecasting (Techniques and Applications), p. 21.

LIST OF REFERENCES

BOOKS

1. Bridgman, Leonard, ed., Jane's All the World's Aircraft 1958-1959. London: Sampson Low Marston and Company, Ltd., 1958.

2. Columbia Research Corporation Report 118.3, The F-4 and the F-14, by G.C. Sponsler, N. Rubin, D. Gignoux and E. Dore, May 1973.

3. [redacted]

4. [redacted]

5. Naval Air Systems Command NAVAIR 01-F14AAA-1, F-14A NATOPS Flight Manual, 1 November 1975.

6. [redacted]

7. Pretty, R.T., ed., Jane's Weapon Systems 1970-1971. London: Sampson Low Marston and Company, Ltd., 1970.

8. Pretty, R.T., ed., Jane's Weapon Systems 1976. New York: Franklin Watts, Inc., 1975.

9. Skolnik, Merrill I., Introduction to Radar Systems. San Francisco: McGraw-Hill Book Company, 1962.

10. Shibayev, N.F., Antimissile Warfare. Translated by Daniel Wolkonsky. Washington, DC: Aerospace Technology Division, Library of Congress, Report 66-41, 18 April 1966.

11. Stevenson, James Perry, Grumman F-14 "Tomcat". Fallbrock, California: Aero Publishers, Inc., 1975.

12. Taylor, John W.R., ed., Jane's All the World's Aircraft 1960-1961. London: Sampson Low Marston and Company, Ltd., 1960.

13. Taylor, John W.R., ed., Jane's All the World's Aircraft 1963-1964. London: Sampson Low Marston and Company, Ltd., 1963.

14. Taylor, John W.R., ed., Jane's All the World's Aircraft 1965-1966. London: Sampson Low Marston and Company, Ltd., 1965.

15. Taylor, John W.R., ed., Jane's All the World's Aircraft 1966-1967. London: Sampson Low Marston and Company, Ltd., 1966.

16. Taylor, John W.R., ed., Jane's All the World's Aircraft 1967-1968. London: Sampson Low Marston and Company, Ltd., 1967.

17. Taylor, John W.R., ed., Jane's All the World's Aircraft 1972-1973. London: Sampson Low Marston and Company, Ltd., 1972.

18. Taylor, John W.R., ed., Jane's All the World's Aircraft 1975-1976. New York: Franklin Watts, Inc., 1975.

19. Taylor, John W.R., ed., Jane's All the World's Aircraft 1976-1977. New York: Franklin Watts, Inc., 1976.

PERIODICALS

1. "F-14 Tomcat," United States Naval Institute Proceedings, October 1976, pp. 76-77.

2. Aviation Week and Space Technology, January 1956-March 1977.

3. Flight, Aircraft, Spacecraft, Missiles, January 1959-December 1961.

4. Flight and Aircraft Engineer, January 1956-December 1958.

5. Flight International, January 1962-March 1977.

6. Interavia, January 1956-February 1977.

7. International Defence Review, No. 1/1968-No. 6/December 1976.

8. "Missile Armament of the U.S. Navy's Carrier-Based F-14A 'Tomcat' Fighter," Morskoy Sbornik, No. 8, 1973, pp. 94-95. (Draft, unedited translation by 2nd Interrogator-Translator Team, 2nd Marine Division, Fleet Marine Force, Camp Lejeune, North Carolina)

9. Vectors, Hughes Aircraft Company magazine, Vol. I-Vol. XVIII.

10. "Weapon Systems: Phoenix" by Mark Hewish, United States Naval Institute Proceedings, October 1976, p. 142.

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