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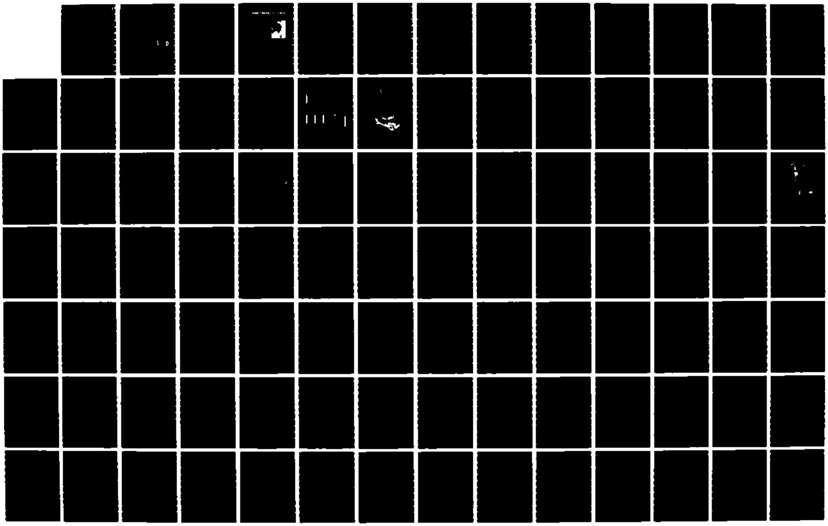

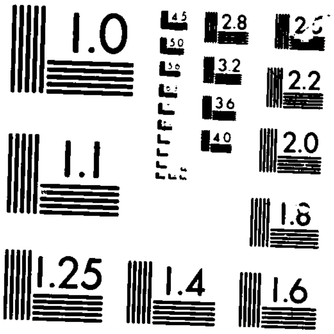

MICROCOP CHART

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Unclassified Proceedings

1982 SYMPOSIUM ON FIRE CONTROL

Fire Control As A Force Multiplier

US Navy Surface Weapons Center

White Oak, Maryland

March 23-24, 1982

Biography

United States Air Force

Secretary of the Air Force, Office of Public Affairs, Washington, D.C. 20330

BRIGADIER GENERAL DELBERT H. JACOBS

Brigadier General Delbert H. Jacobs is deputy for General Purpose Forces, Directorate of Operational Requirements, Headquarters U.S. Air Force, Washington, D.C.

General Jacobs was born in Seattle. He studied engineering at the University of Washington in Seattle and was a distinguished graduate from the U.S. Military Academy at West Point, N.Y., in 1955. He later attended the California Institute of Technology in Pasadena, receiving a master of science degree in aeronautics in 1960 and completing course work for a doctorate in 1961. The general is a 1975 distinguished graduate of the National War College, Fort Lesley J. McNair, Washington, D.C.

He entered the U.S. Air Force in 1955 and completed pilot training in T-33s at Laredo Air Force Base, Texas. In 1956 he became a flight commander and North Atlantic Treaty Organization instructor pilot at Furstenfeldbruck Air Base, Germany.

His successive assignments include being an assistant professor of astronautics and ski coach at the U.S. Air Force Academy, Colo.; chief test pilot for F-101s at Tyndall Air Force Base, Fla.; F-4 fighter weapons school test pilot at Nellis Air Force Base, Nev.; commander of the 390th Tactical Fighter Squadron at Da Nang Air Base, Republic of Vietnam; and deputy chief, New Initiatives Office, and later chief, Fighter Armament Requirements Division, Office of the Deputy Chief of Staff Research and Development, Headquarters U.S. Air Force. He served as the F-16 deputy system program director and the F-15 system program director at the Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio. Prior to assuming his current position in July 1981 he was the deputy chief of staff for plans and programs at Air Force Systems Command headquarters, Andrews Air Force Base, Md.

General Jacobs won the General Vandenberg Trophy in 1968 for outstanding contribution to aerospace science in the United States; the Air Force Association Citation of Honor the same year for test pilot achievement; the Eisenhower Award from the president of the United States in 1955 for the highest achievement at West Point in military leadership; and in 1955 won the special award given the cadet in his West Point graduating class having the highest achievement in athletics over four years.

He has flown 168 combat missions in F-4s, and has more than 3,400 flying hours in F-101s, F-102s, F-106s, F-15s and other fighter-type aircraft.

(Current as of October 1981)

OVER

His military decorations and awards include the Legion of Merit with one oak leaf cluster, Distinguished Flying Cross with two oak leaf clusters, Bronze Star Medal, Air Medal with nine oak leaf clusters and Air Force Commendation Medal with one oak leaf cluster.

He was promoted to brigadier general July 1, 1979, with date of rank June 9, 1979.

General Jacobs and his wife, the former Shirley Griffin of Vancouver, Wash., have four children: Lynn, Greg, Cheryl and Jeff. Jeff is a cadet in the class of 1985 at the U.S. Air Force Academy.

BIOGRAPHY OF REAR ADMIRAL ROGER DAVID JOHNSON, USN

Rear Admiral Johnson was born 23 March 1932 near Montpelier, North Dakota. He attended school in Willmar, Minnesota prior to enlisting in the U.S. Navy where he served as an Electronics Technician.

Graduating "with distinction" from the U.S. Naval Academy in June 1955, Rear Admiral Johnson entered flight training directly and was designated a Naval Aviator in October 1956. Reporting to VFP-63, he served as a team pilot and detachment maintenance officer flying F9F-8 Cougar and F8U Crusader reconnaissance aircraft.

From February 1959 to June 1960, he served in the Power Plants Division of Fleet Air Service Squadron NINE during the developmental demonstration of the Jet Engine Complete Repair Concept.

Attending the U.S. Naval Postgraduate School, Monterey, California Rear Admiral Johnson was a student in the Weapons System Curricular, performing specialized studies in Plasma Physics and Controlled Thermonuclear Reactions. He earned an M.S. in Physics in June 1963.

Postgraduate school was followed by three years on the Staff, Commander Fleet Air Western Pacific in various assignments including Attack Class Desk and Airframes Officer. Reporting to the Power Plants Division of the newly formed Naval Air Systems Command in August 1966, Rear Admiral Johnson was a member of the TF-34/S-3 development team and the early VFX/F-14 study and specifications effort.

Assigned to Commander Naval Air Force Pacific Fleet in April 1969 as the F-4 Fighter Class Desk, Rear Admiral Johnson coordinated fleet participation in the development of the F-4B to F-4N Service Life Extension Program. In August 1971, he reported as Executive Officer of Naval Air Rework Facility North Island.

Selected for Senior Service School, he attended National Defense University, the Industrial College of the Armed Forces, and was a distinguished graduate of the Class of "76." He then reported to the Naval Air Systems Command as the F-14/PHOENIX Deputy Project Manager, and then in September 1977 as the F-14/PHOENIX Project Manager. On 1 August 1980, he assumed his current assignment as Assistant Commander for Systems and Engineering of the Naval Air Systems Command.

Rear Admiral Johnson holds the Navy Commendation Medal and the Navy Unit Citation. He is married to the former Jean Ann Bernard of Omaha, Nebraska. They have three children, Kimberly, Karen and Scott, and currently reside in Vienna, Virginia.

PRIVACY ACT STATEMENT: Authorty 5 USC.301 Departmental Regulation.

PURPOSE: To provide the Command Public Affairs Office with specific information concerning employees receiving awards.

ROUTINE USE: Commander would use in regards to Awards Ceremonies.

DISCLOSURE IS ENTIRELY VOLUNTARY.

R. D. JOHNSON, RADM, USN

RESUME OF SERVICE CAREER As of 8 August 1979

of

ALLEN HERBERT LIGHT, JR., Major General

DATE AND PLACE OF BIRTH: 5 April 1929, Lebanon, Pennsylvania

YEARS OF ACTIVE COMMISSIONED SERVICE: Over 25

PRESENT ASSIGNMENT: Commanding General, United States Army Armament Research and Development Command, Picatinny Arsenal, New Jersey, since July 1979

MILITARY SCHOOLS ATTENDED
The Chemical School, Basic and Advanced Courses
The Infantry School, Advanced Course
United States Army Command and General Staff College
Industrial College of The Armed Forces

EDUCATIONAL DEGREES
Lebanon Valley College - BS Degree - Chemistry
George Washington University - MS Degree - Management

MAJOR PERMANENT DUTY ASSIGNMENTS (Last 10 years)	From	To
Commanding Officer, 548th Supply and Service Battalion, 100th Chemical Group, Fort McClellan, Alabama	Mar 67	Aug 67
Staff Officer, Capabilities Branch, Plans Division, J-4, Organization, Joint Chiefs of Staff, Washington, D. C.	Sep 67	Jul 69
Student, Industrial College of the Armed Forces, Fort Lesley J. McNair, Washington, D. C.	Aug 69	Jun 70
Chief, Systems and Requirements Division, Chemical and Nuclear Operations Directorate, Office, Assistant Chief of Staff for Force Development, United States Army, Washington, D. C.	Jun 70	Jun 72
Chief, Chemical Branch, Officer Personnel Directorate, Office of Personnel Operations, United States Army, Washington, D. C.	Jun 72	Apr 73
Commanding Officer, Seneca Army Depot, Romulus, New York	Apr 73	Jan 75
Commanding Officer, 60th Ordnance Group, United States Army, Europe	Jan 75	Jun 76
Chief, Munitions and Missiles Division, Office of the Deputy Chief of Staff for Logistics, United States Army, Europe	Aug 76	Jun 77
Commanding General, 3d Support Command (Corps), United States Army, Europe	Jun 77	Jul 79

ALLEN HERBERT LIGHT, JR., Major General

PROMOTIONS	DATES OF APPOINTMENT Temporary	Permanent	Other (USAR)
2LT			8 Nov 52
1LT	23 Sep 57	23 Sep 57	7 Nov 55
CPT	26 Mar 59	8 Nov 59	
MAJ	28 May 63	8 Nov 66	
LTC	21 Feb 67	8 Nov 73	
COL	16 Mar 73	4 Dec 76	
BG	1 Jul 77	1 Jun 79	
MG	1 Aug 79		

US DECORATIONS/BADGES

Legion of Merit
Bronze Star Medal
Meritorious Service Medal
Army Commendation Medal (with 2 Oak Leaf Clusters)
Joint Chiefs of Staff Identification Badge
General Staff Identification Badge

SOURCE OF COMMISSION: OCS

Regular September 1981

REAR ADMIRAL WAYNE E. MEYER
AEGIS SHIPBUILDING PROJECT MANAGER
NAVAL SEA SYSTEMS COMMAND, WASHINGTON, D.C.

Rear Admiral Wayne E. Meyer, a native Missourian, is the Project Manager for AEGIS Shipbuilding, the Navy's major project to build surface warships to carry the AEGIS Integrated Combat System. To this post, he brings broad fleet and command experience with extensive experience in shipboard missile systems. He is also an award-winning naval engineer.

His academic degrees include a Bachelor of Science in Electrical Engineering from the University of Kansas (1946), a B. S. in Electronics Engineering from the Massachusetts Institute of Technology (1947), and a Master of Science in Astronautics and Aeronautics from MIT (1961). His Master's studies included two years at the U. S. Naval Postgraduate School. He also graduated from the tri-service Officer's Guided Missile School at Fort Bliss, Texas (1951), and the Naval Line School at Monterey, California (1954).

His Navy career began on 12 May 1943 when he enlisted as an apprentice seaman. He was commissioned an Engign in the U. S. Naval Reserve in 1946 and was transferred to the regular Navy in 1948.

RADM Meyer's first sea duty, which included participation in the first ex-German V-2 missile launching from a surface ship, USS MIDWAY, was as Electronics Officer and Combat Information Center Officer/Fighter Director of the radar picket destroyer GOODRICH (DDR-831). His tour in this ship also included duty in the Mediterranean during the 1947 Palestine Crisis and the 1948 Greek Civil War. RADM Meyer then became Electronics and Catapult Officer in the gun cruiser SPRINGFIELD (CL-66). While he was aboard SPRINGFIELD she departed Shanghai, the last warship to leave Mainland China before it fell to the Communists in 1949. His third consecutive sea assignment as Communications and Operations Officer of the destroyer tender SIERRA (AD-18) returned him twice to the Mediterranean.

Ashore from August 1951 through May 1955, RADM Meyer attended the Guided Missile School and the Naval Line School. During the interval between his own studies, he served as an instructor at the newly commissioned Special Weapons School in Norfolk, Virginia.

RADM Meyer then returned to sea duty as Executive Officer, Navigator, and Senior Air Controller in the radar picket STRICKLAND (DER-333). During his tour, STRICKLAND made the first complete twenty-seven day patrol on station ONE of the Atlantic Distant Early Warning Line. His next assignment, which began in December 1956, was Assistant Operations and Plans Officer and Special Weapons Officer on the staff of the Commander, Destroyer Force Atlantic.

After two years at the Navy Postgraduate School and a year at MIT, he became one of the early Naval Officers to earn a Master's degree in Astronautics and Aeronautics upon graduating from MIT in 1961.

Returning to sea once again, he served from 1961 to 1963 as Fire Control and Weapons Officer of the guided missile cruiser GALVESTON (CLG-3). He was in charge of installation and testing of the TALOS missile aboard GALVESTON; and he participated in the first TALOS direct hit on a surface target. Also during this tour, he supervised development of the first Daily System Operability Test for surface missile systems. This test became the model throughout the surface missile system fleet.

Following his tour aboard GALVESTON, RADM Meyer was assigned to the Surface Missile Systems Project of the Naval Material Command as Fire Control and Anti-Air Warfare Modernization Manager of the TERRIER Guided Missile Ships. His work with the TERRIER Modernization Program proved to be innovative in the field of combat systems integration. He transferred to the Ordnance Engineering Corps in 1965.

In February 1967, he became Director of Engineering at the Naval Ship Weapons Systems Engineering Station at Port Hueneme, California. In this capacity, he was responsible for the engineering and technical support of more than 80 ships of the surface missile fleet. During the three years of his tour, NSWSES' engineering responsibilities doubled.

Upon his selection to manage the full-scale development of the AEGIS Weapon System, he came to the Naval Ordnance Systems Command in Washington, D. C. Based on his work on AEGIS, he was selected for major command as Project Manager. Soon after that in July 1972, he was appointed Project Manager for Surface Missile Systems. In addition to AEGIS, these systems include TERRIER, TALOS, TARTAR, Standard Missile, Basic and Advanced Point Defense, and Anti-Ship Missile Defense.

With the establishment of the Naval Sea Systems Command (formed by merging the Navy's Ordnance and Ships Systems Commands) in July 1974, RADM Meyer was assigned collateral duty as the first Director of Surface Warfare Systems. These additional duties enlarged the scope of his responsibilities to include Harpoon, Patrol Frigate weapon systems, Surface Gun Systems, Command and Control Systems, and other surface warfare projects.

RADM Meyer was selected for flag rank in January 1975. After several reorganizations, he was assigned as Project Manager for AEGIS Shipbuilding. This assignment, which represents a major post-merger decision by the Commander, Naval Sea Systems Command, vests engineering, design and construction responsibility for both the AEGIS ships and combat systems in a single Project Manager.

RADM Meyer has served on, and headed, numerous technical panels and boards in the Department of Defense and industry. He has authored many articles on tactical missilery and surface ship combat system design and development. An outspoken proponent of seapower, he is in great demand as a speaker by a wide variety of government and civilian groups.

He is a designated Naval Ordnance Engineer, holding certificate 99. He is a member of several professional societies including the American Society of Naval Engineers, the American Institute of Aeronautics and Astronautics, and the American Defense Preparedness Association.

RADM Meyer's awards include the Navy's Meritorious Service Medal, which he received in recognition of his directorship of NSWSES and specific contributions to the Anti-Ship Missile Defense Program (1968), and the American Society of Naval Engineers Gold Medal for distinguished service in development of the AEGIS Weapon System (1976). He is recognized as a Distinguished Engineering Service graduate of Kansas University (1981). In addition to these awards, he wears several campaign medals, among which are China Service, American Campaign, World War II Victory, Navy Occupation Service, both Asia and Europe, National Defense Service with Bronze Star, Naval Unit Commendation, Vietnam Service, and Republic of Vietnam Campaign Medals with clasps.

RADM Meyer is married to the former Margaret Garvey of Dorchester, Massachusetts. They live in Falls Church, Virginia, and have three children, all grown. His parents live in Brunswick, Missouri, and Biloxi, Mississippi.

COVERT MULTISENSOR CUEING AND FIRE CONTROL

MR. COZY KLINE, TEXAS INSTRUMENTS INCORPORATED

I. THE CHALLENGE

The threat to NATO Air Defense from Warsaw Pact Air Forces is formidable. Soviet designed aircraft reflect major advances over previous Warsaw Pact equipment. The M16-27 Flogger D, SU-17/20 Fitter C, SU-19/24 Fencer and helicopters such as the M1-8 HIP C/E and M1-24 A/D/E have the capability to inflict devastating damage to NATO ground units already outnumbered by the enemy.

Warsaw Pact forces through combat experience obtained in the Arab-Israeli conflicts of 1967 and 1973, Vietnam, Angola, Ethiopia-Somalia and Afghanistan, have developed weapons and tactics that enhance their forces combat capabilities. This experience has yielded great improvements in the quality and training of Soviet Air Forces. Major advances have been made in Air-to-Surface Munitions (Precision Guided Weapons, Cruise Missiles, Anti-radiation Missiles, Anti-Tank Guided Weapons) and tactics to deliver these weapons (Helicopter NOE, Air Assualt, All Weather, Terrian Following/Avoidance).

The "battle space" will be characterized by sudden attacks against multiple targets by large numbers of surface and airborne vehicles using diverse types of munitions. Since friendly ground force operations will require intensive use of fixed and rotary wing close air support, the airspace is expected to contain many friends and foes. Additionally, the dynamic nature of measure/counter-measure and sophisticate electronic warfare dictate an URGENCY for rapid reaction and response prior to possible sensor degradation and/or complete loss of target data.

II. MULTISENSORS; A FORCE MULTIPLIER

Texas Instruments; with support from the Advanced Sensor Directorate, U.S. Army Missile Laboratory, has successfully demonstrated multisensor concepts. In particular, the co-location of several sensors on a common gimble have a synergism which enables each sensor to operate within its optimum capabilities. TI has combined; Radar, FLIR, acoustics, and precision radar direction finding receivers for a covert cueing and fire control system. This common gimble/sensor fusion provides:

(1) Precise location and identification of enemy emitters.

(2) Acoustic detection, localization, and classification of nap-of-the-earth helicopter threats.

(3) Target handoff from either acoustic or RF/DF to narrow field-of-view FLIR.

(4) Passive target handoff for covert radar operation.

(5) Multisensor non-cooperative target identification.

III. SENSOR SYNERGISM

Multisensors on a common gimble allows almost instantaneous handoff from one sensor to another. The existing systems in the Army are distributed, thus requiring a command and control system to distribute the target information to the actual firing unit. Additional advantages such as acoustic helicopter detection and bearing to within a few degrees with immediate handoff to the narrow field-of-view FLIR minimizes target search timelines. The narrow FOV FLIR mode has a factor of two to three times resolution over a wide FOV mode. Thus the FLIR capability is maximized with this multisensor capability.

Today, the majority of the Army, Airforce, and Navy all weather capabilities are radar directed. These radar directed fire control systems are extremely vulnerable to both passive radar direction finding and anti-radiation missiles. The multisensor system allows the radar D/F subsystem to locate all "emitting" attackers within one-half degree spatial resolution with immediate handoff to the radar. The D/F handoff is within the radar's beam width which allows the radar to operate with a few milli-seconds transmit burst for ranging the target. This radar burst mode is non alerting to enemy receivers allowing the MS unit to remain covert.

The beyond visual range identification of targets is and remains a significant factor in the fire control equation. The MS system allows non-cooperative ID of approaching enemy targets. Emitting targets are ID'd by frequency, pulse width, pulse repetition interval, and scan rates; acoustic targets are ID'd by rotor and tail blade configurations; the radar covert burst modes utilize jet engine modulation identification; and the FLIR applies target shape and size to the ID equation. This multiple verification significantly increases the probability that the target is truly the enemy.

In the final analysis the sum of the multisensor parts are significantly more powerful than their distributed capabilities.

IV. MULTISENSOR TESTS

Texas Instruments, with very important cooperation of: the Advanced Sensors Directorate, U.S. Army Missile Laboratory, U.S. Army McGregor Test Range, and the Chaparrall Program Office; tested a multisensor unit during September of 1981.

The MS unit was a combined D/F receiver with a narrow field-of-view FLIR. Acoustics sensors were arrayed at the test sight for recording helicopter targets. The D/F and FLIR were real-time systems with software for RF D/F closed loop targeting of the emitting target.

The sensor setup is shown in Figure I. With target flight paths Alpha and Charlie sidelobe emitter tracking was required. TI successfully acquired and tracked both A-7 runs flying at 250 feet above ground level at 500 knots and UH-1 runs flying at 100 feet above ground level at 80 knots.

The acoustic subsystem was operated in a record mode with post test acoustic signal processing. The data was synchronously digitized and processed through the signal processing stream as shown in Figure 2. The test sight had two to three diesel units operating continously during the data gathering which made the background noise uncommonly cluttered. Figure 3 shows the acoustics helicopter track from processed data with range provided by range instrumentation.

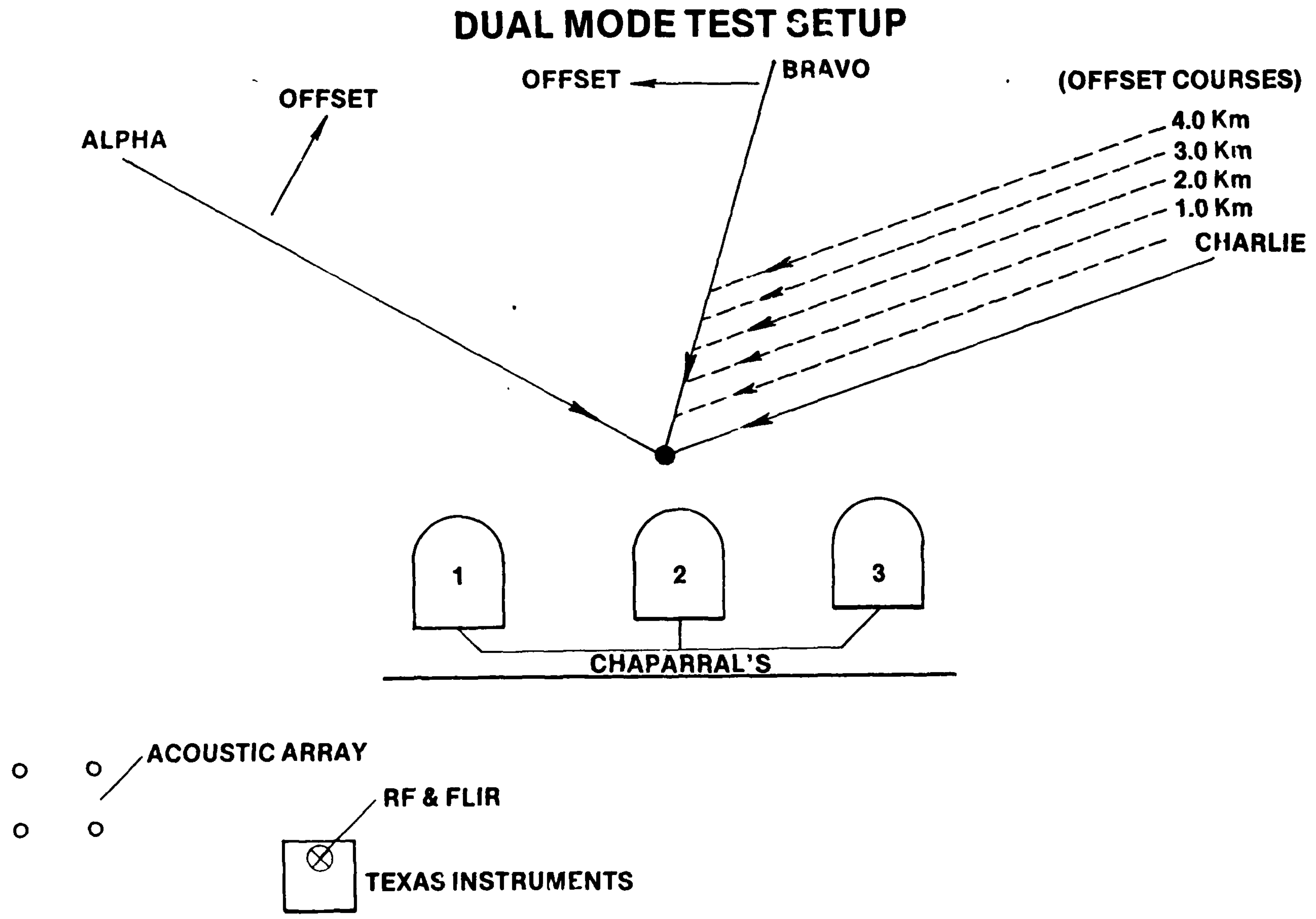
V. MULTISENSOR SYSTEMS

The application of multisensor systems could take a variety of forms. The Multisensor system diagram in Figure 4 shows the signal flow for a generic four sensor system, that combines: Radar, FLIR, Acoustics, and RF/DF.

A universal multisensor configuration which is highly mobile, light weight, and dual purpose is shown in Figure 5. In this unit we have a fifty foot telescoping mast with the multiple sensors on a gimbled platform.

This system has high value on the battlefield since it can serve in both an air defense role and a surface-to-surface role. For example, the acoustics subsystem can detect and direction find: Helicopters, slow speed RPV's and tanks. The RF/DF can detect and direction find emitters on airborne targets and ground based targets such as the ZU-23. With a laser designator on this unit, target detection and lasing for laser guided weapon is an additional capability.

In summary the sum of the parts are significantly more powerful than distributed individually optimized sensors.



DUAL MODE TEST SETUP

FIGURE 1.

* ACOUSTIC SUBSYSTEM DEMO HARDWARE *

```
          B&K       B&K
          4165      2619T          B&K
MIC #1    O------>|=====|          2804
                  |     |        |=========|      |=========|
MIC #2    O------>|PRE- |        |BATTERY  |      |  FIXED  |
                  |AMPS |------->|PACK/MIC |----->|GAIN AMPS|---------------
MIC #3    O------>|(4CH)|        |P.S.(4CH)|      |  (4CH)  |              |
                  |     |        |=========|      |=========|              |
MIC #4    O------>|=====|                                                  |
                        long coaxial cables                                |
----------------------------------------------------------------------------|
|                        |==============|
|    |=========|      -->|RMS VOLT METER|   |=========|
|    |VARIABLE |      |  |==============|   | ANTI-   |
|    |GAIN AMPS|      |                     | ALIASING|   |===|   |===|
---->|WITH PRE-|--------------------------->| FILTERS |-->|S/H|-->|A/D|----
     |EMPHASIS |      |  |==============|   |  (4CH)  |   |===|   |===|   |
     |  (4CH)  |      |  |MULTI-CHANNEL |   | 48DB/oct|                   |
     |=========|      -->|TAPE RECORDER |   |=========|                   |
                         |==============|                                 |
                                                                          |
---------------------------------------------------------------------------|
|
|    |======|     |====================|      |===========|
|    |MEMORY|     |     TM990/1481     |      | CONTROL&  |
---->|BUFFER|---->|  HIGH-PERFORMANCE  |----->| DISPLAY   |
     | (4CH)|     |        CPU         |      | PANEL     |
     |======|     |====================|      |===========|
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FIGURE 2.

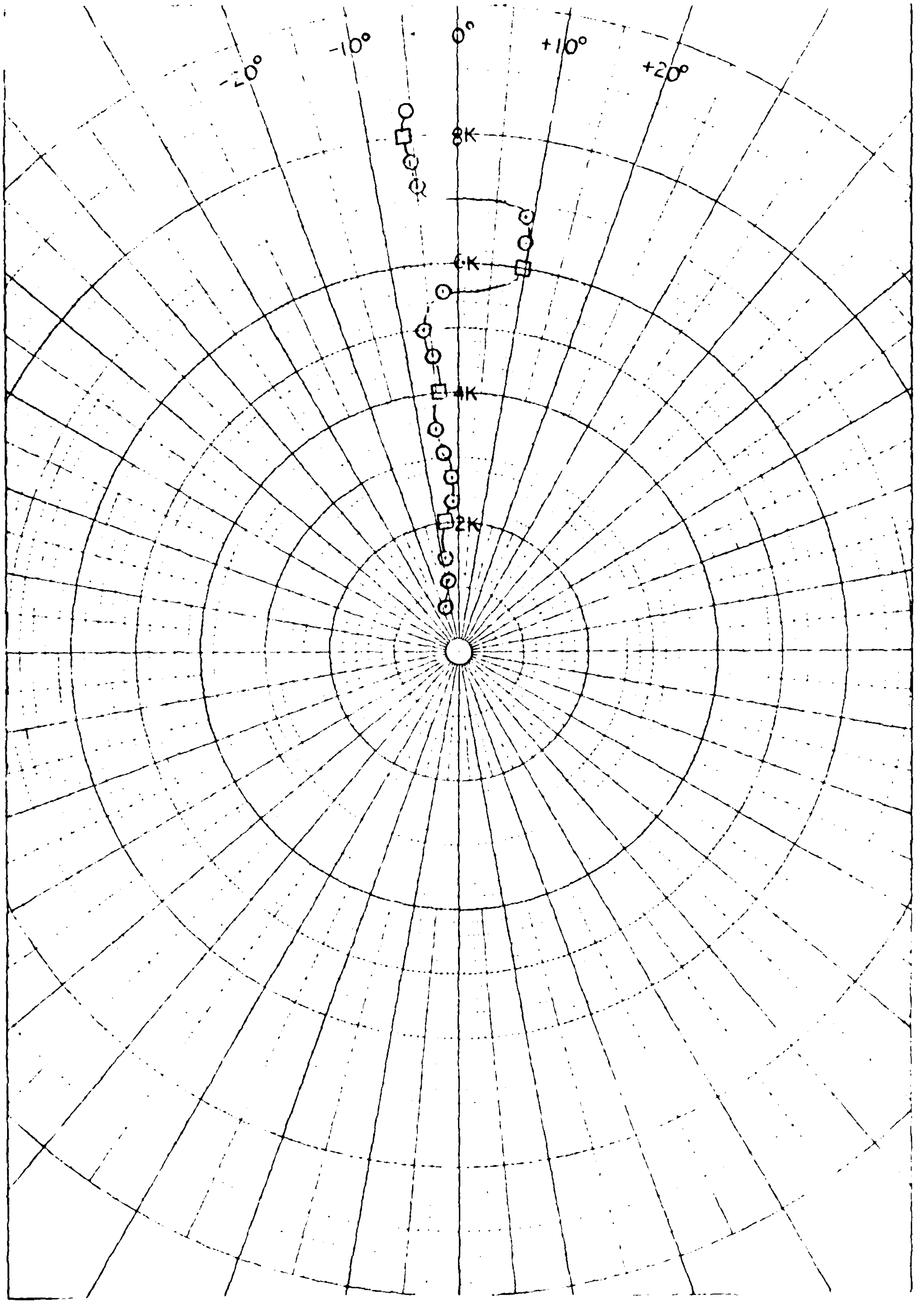


FIGURE 3.

MULTI-SENSOR BLOCK DIAGRAM

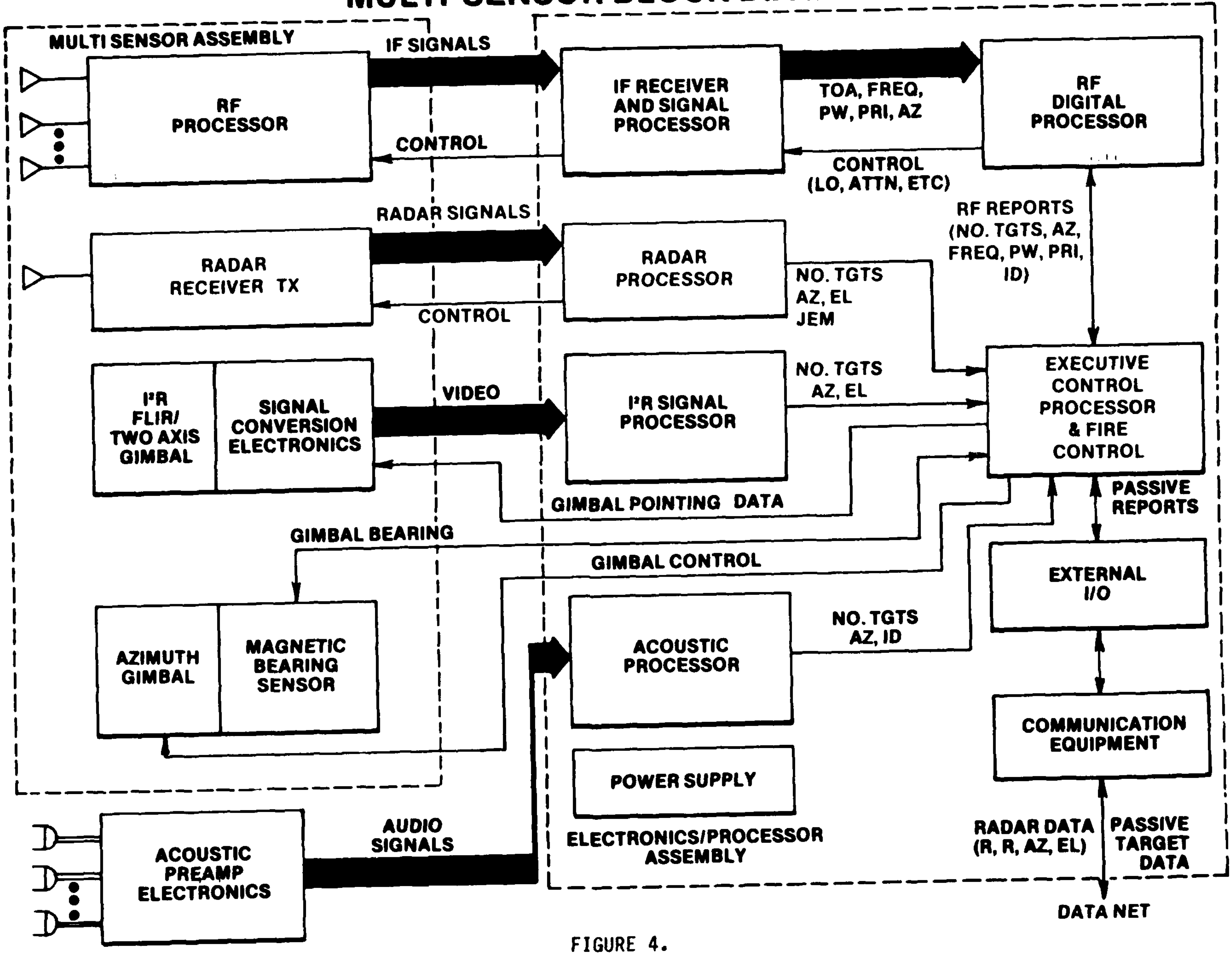


FIGURE 4.

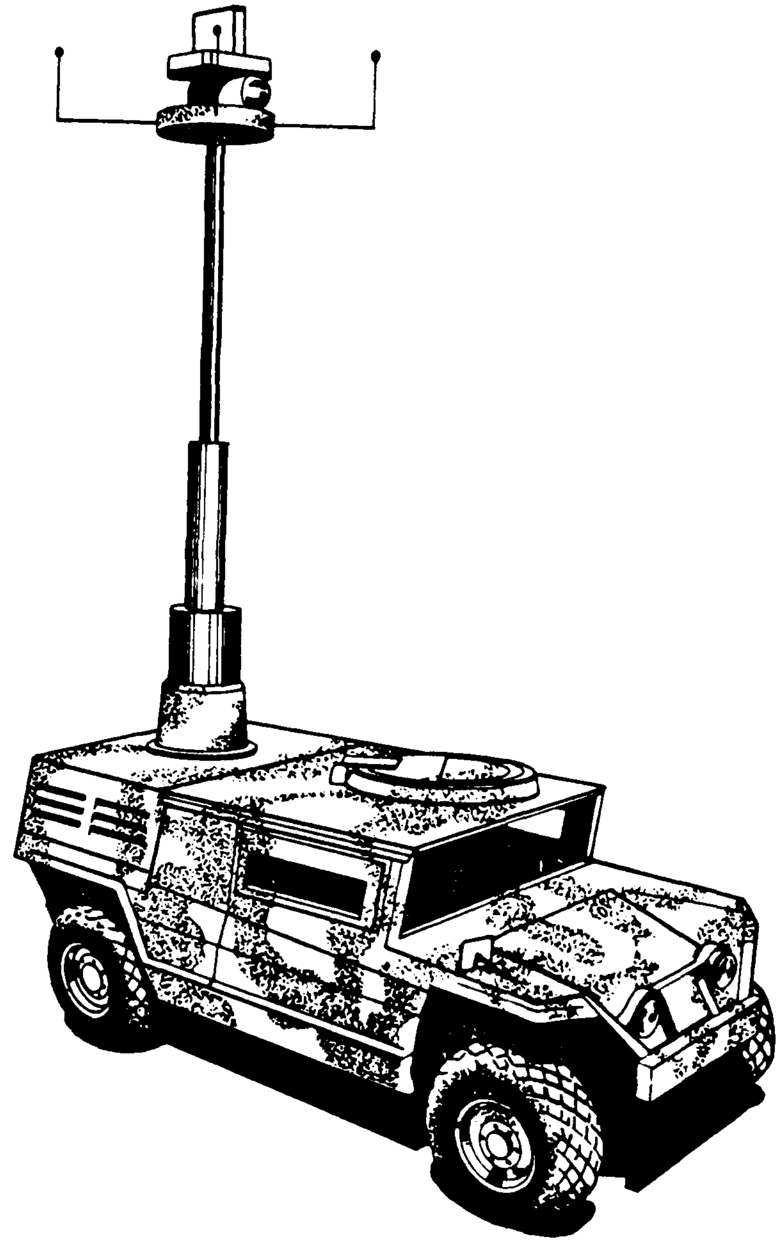


FIGURE 5.

A DISTRIBUTED COMMAND/FIRE CONTROL SYSTEM
FOR
LIGHTWEIGHT AIR DEFENSE WEAPONS

William C. Cleveland
Ford Aerospace & Communications Corporation

INTRODUCTION

The objective of an ongoing company sponsored program at Ford Aerospace and Communications Corporation (Aeronutronic Division) is the conduct of preliminary design studies on Lightweight Air Defense Systems (LADS). These systems are intended for deployment in the mid-1980's by Army Light Infantry and Air Mobile Divisions, the Marine Corps, and Rapid Deployment Joint Task Forces. The systems must be largely self-contained in terms of target sensors, Command and Control Communications, and weapons. Operation in a variety of theaters and environments is a prime requirement, including deployment in battle areas where Fire Control operation in the face of anti-radiation missiles and electronic countermeasures is a necessity. A major problem addressed during these studies is the integration of elements of a Distributed Command and Control (DC^2) system with the fire control functions required for lightweight air defense weapons.

SYSTEM REQUIREMENTS

The system requirements and constraints for the Lightweight Air Defense System are summarized in Figure 1. The air threats are helicopters and fixed wing aircraft. A self-defense capability against lightly armored ground vehicles is also desirable. In order to meet the varied requirements for threats and helicopter air lift weight limits, a family of weapons is desirable. In our studies, lightweight mobile gun and missile fire units have been considered. It has also been assumed that man-portable surface to air missile squads will be deployed during most missions.

In order to coordinate and control the weapons, and provide target data for weapon acquisition and fire control, a distributed command and control system is required which can operate at the battery and platoon level.

SYSTEM DESCRIPTION

The weapons deployment and C^2 concept is illustrated in Figure 2. A mobile Fire Control Center (FCC) is provided, which contains target detection sensors and communications equipment. The FCC is deployed with four to eight weapon Fire Units. Communications links are provided to adjacent Fire Control Centers and to Battalion and Division Tactical Operations Centers. Communications are indicated to the Reliable Sting type of Division Air Defense Control Center. A manually operated prototype of this mobile TOC has been developed and tested as a part of the High Technology Test Bed by the Army Ninth Infantry Division at Ft. Lewis, Washington.

The principal functions of the FCC are listed in Figure 3. Target detection is accomplished by a sensor collection which includes a Search and Track radar, a FLIR, passive RF and acoustic detectors. Computation functions are provided by an on board computer. A crew of three is provided to allow operation on the move and around the clock. The crew consists of a Driver, Sensor Operator and Fire Control Commander.

The FCC provides target data with varying degrees of angular accuracy, depending upon the sensors employed and the weapons utilizing the data. Figure 4 lists the primary data modes organized by target angular data accuracy and use. Other data such as target range, velocity, type, etc. are also available, depending upon the sensors in use. The radar is utilized to provide data to the Fire Units during all weather and fire control data modes.

The data modes indicate the flexibility of the Fire Control Center in providing alerting and cueing data, acquisition and pointing data for fire unit gunners and fire unit sensors, and precision fire control data for gun and missile seeker pointing. The FCC and Fire Units are equipped with a strap-down inertial system which provides land navigation data for unit position determination. This information is used to convert the target coordinate information into a universal grid system for transmission to fire units. The fire units then convert the target position data into the fire unit coordinate system for sensor pointing and fire control.

To communicate commands and data between Fire Control Centers, higher level TOCs and the Fire Units, voice and digital data links are required. The system design is being developed so that interfaces and data rates are compatible with the present Army VRC-12 family of radios. Provisions are also being made for interfacing with new communications systems equipment, such as SINCGARS-V and PACKET radios, when they are fielded.

CONCLUSIONS

The conceptual and preliminary design studies accomplished on LAD systems indicates that a distributed, netted, collection of highly mobile sensors can be integrated into current and future SHORAD C^2 networks and can provide fire control data to near term lightweight air defense weapons.

A test bed system is being defined which can be implemented with currently available hardware. A series of field experiments is being planned to demonstrate concept feasibility and generate data for system simulation and evaluation.

● LIGHTWEIGHT	- MINIMUM WEIGHT/LENGTH FOR MAXIMUM AIR TRANSPORTABILITY/ LIFTABILITY (7,000; 14,000; 28,000 POUND CLASSES)
● MOBILE	- MUST BE TRANSPORTED BY HIGHLY MOBILE VEHICLES (HMMWV, LAV)
● MULTIPLE SENSORS	- REQUIRED FOR TACTICAL FLEXIBILITY
● SHORAD C^2 INTERFACE	- BATTALION AND DIVISION LEVELS
● SHORT EMPLACEMENT/MARCH ORDER TIMES	- 2 MINUTES
● COUNTERMEASURES AND ARM RESISTANT	
● EARLY IOC	- 1985/87 - HARDWARE FROM CURRENT PROGRAMS/ DEVELOPMENTS
● P^3I GROWTH COMPATIBILITY	- SENSORS - COMMUNICATIONS

FIGURE 1. LADS SYSTEM REQUIREMENTS AND CONSTRAINTS

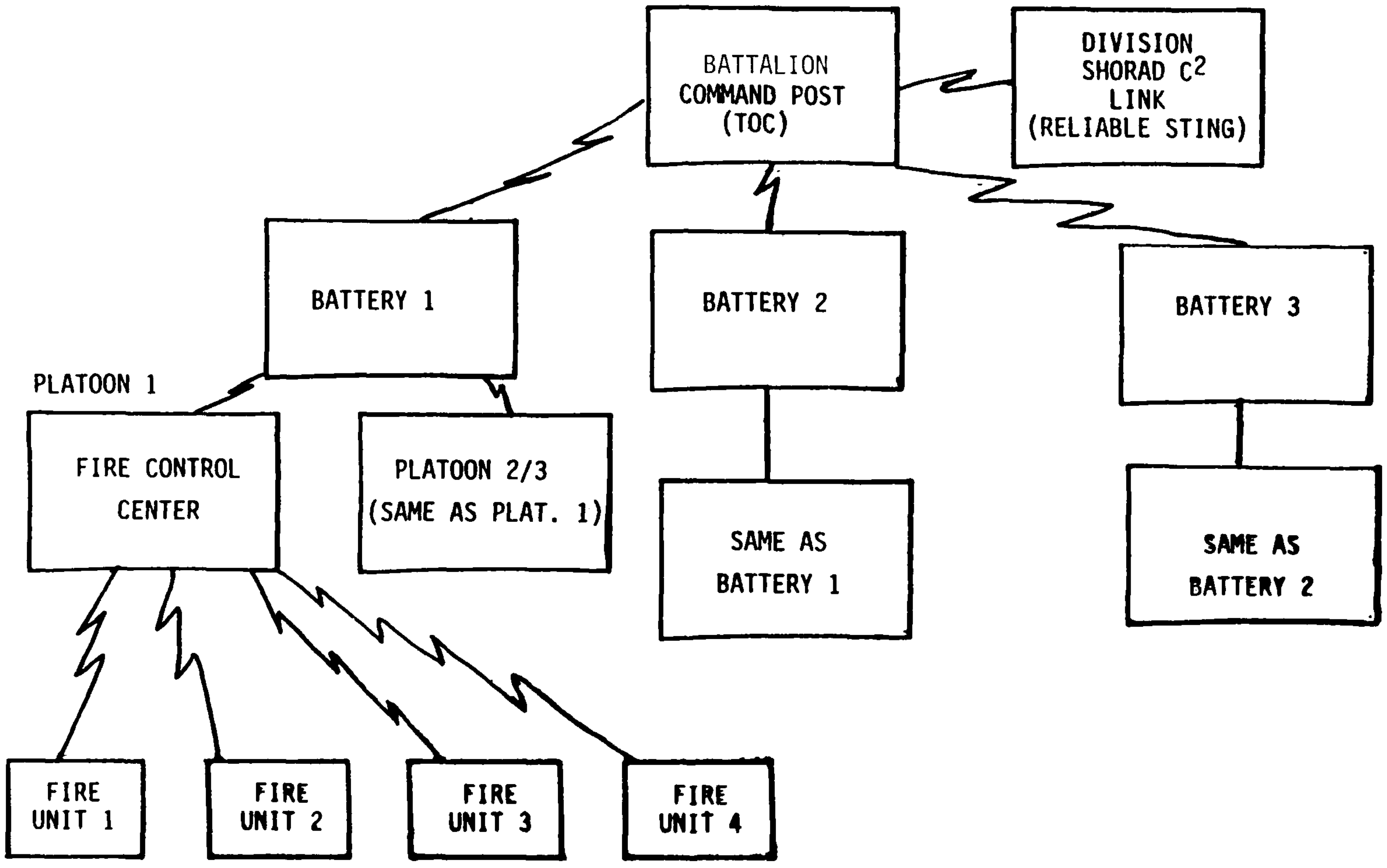


FIGURE 2. BASELINE BATTALION C^2 SYSTEM

TARGET SEARCH AND DETECTION OF AIR AND GROUND TARGETS

DEVELOP TARGET TRACK FILES

PERFORM IFF/TARGET CORRELATIONS (AIR TARGETS)

PERFORM TARGET CLASSIFICATION (A/C, HELIOS, GROUND TARGET)

FORMAT DATA/MESSAGES FOR DISPLAYS AND DATA LINK TRANSMISSION

DISPLAY SEARCH/TRACK DATA TO SENSOR OPERATOR

PROVIDE COMMUNICATIONS AND DISPLAYS TO FIRE CONTROL COMMANDER

FIGURE 3. FIRE CONTROL CENTER FUNCTIONS

- ALERTING/CUEING (TO 5^0)
  - STINGER
  - CHAPARRAL
  - DIVAD
  - TOW
- ACQUISITION/POINTING (TO 1^0 - 2^0)
  - NIGHT CHAPARRAL FLIR
  - LADS OPTICAL SIGHT
  - PASSIVE RF ANTENNA
  - LASER RANGE FINDER
- FIRE CONTROL (TO SEVERAL MILS)
  - LADS GUN
  - CHAPARRAL MISSILE SEEKER

FIGURE 4. FIRE CONTROL CENTER DATA MODES

Survivable SHORADS Weapons Control

> NO MODERN ARMY CAN EXPECT TO WIN IN BATTLE UNLESS ITS MANEUVER FORCES OPERATE UNDER A COHESIVE, EXTENSIVE, AND MOBILE UMBRELLA OF MODERN AIR DEFENSE.
>
> Field Manual No. 44-3

C. L. Christianson
RCA MSR

SURVIVABILITY IN CONTEXT

The Warsaw Pact threat to the Army Short Range Air Defense Systems will include mass raids of rotary and fixed wing aircraft flying under the cover of jamming and penetrating at low altitudes.

The Army's response to date has been focused primarily on manually operated weapons with visual target acquisition, identification, and fire control.

Technology has provided weapons improvement, as in Stinger vice Redeye, and the tactical performance potential now exceeds the operator's capabilities in good visual weather while the enemy has been developing equipment and tactics to provide operation under reduced visibility conditions and at night to enhance their own survivability.

We must now develop a new generation of active sensors and weapons control systems to counter the enemy but the very nature of the emissions of these radar and communications systems will create a new set of vulnerabilities for the enemy to exploit.

Over the past two years, RCA has been designing a survivable weapons control system to enhance the performance of the SHORAD Guns and Missiles. We understand that survivability means physical damage avoidance through mobility and hardening, but more importantly, it means surviving the enemy efforts to destroy the system's utility through electronic warfare and the fear of electronic targeting.

For example, a system that provides the STINGER gunner with targeting information using 2-way radio will probably not prove survivable. The radio emission provides the gunner's position to the enemy through radio D.F. and T.O.A. measurement and makes the gunner vulnerable to artillery attack.

Active radar controlled weapons may not prove tactically survivable because the enemy can sense the emission and fly around the weapon and attack the asset to the rear.

This paper will discuss the radar and system trade studies that lead to a unique multistatic radar and a survivable architecture.

SHORAD WEAPONS CONTROL OBJECTIVES

The first step was to establish the desirable SHORAD improvements. In Figure 1 you will note that survivability is considered as important as control and fire power in the definition of our new SHORAD C^2 and weapons control system.

- IMPROVED CONTROL
  - PROVIDE CONTROL POINT FOR DATA MERGING AND FOR AIR SPACE MANAGEMENT
  - BETTER IDENTIFICATION, POSITIVE DESIGNATION OF HOSTILES
  - PRECISION 3D TARGETING DIRECTLY TO GUNNER

- IMPROVED FIREPOWER WITH EXISTING WEAPONS
  - REDUCED REACTION TIME, ACCURATE RANGING FOR MORE EFFECTIVE FIRING
  - FULL PERFORMANCE WITH REDUCED VISIBILITY AND AT NIGHT
  - SIMPLIFIED CREW TRAINING -- SAVINGS IN MANPOWER

- IMPROVED SURVIVABILITY
  - ECM RESISTANT SENSOR, ECM RESISTANT COMMUNICATION
  - ARM RESISTANCE, TOA TARGETING RESISTANCE
  - HIGH MOBILITY, SELF NETTING
  - "QUIET" WEAPONS
  - TACTICAL REDUNDANCY

Figure 1. SHORADS Weapon Control

Various sensors including passive IR, passive ESM, and sanctuary radars were considered for SHORAD weapons control, but only precision short range active radar provided the data quality needed for pointing Stinger, Chaparral, and other IR weapons.

The choice of radar frequency was addressed first with the constraint that the short range radar must be lightweight, and an 8' x 4' antenna size was as large as practical. The radar frequency was established and the results of this study are shown in Figure 2.

You will note that it is impossible to provide a practical tactical radar that can resist main lobe barrage jamming. The acceptable compromise is to design a system that provides nearly full performance in the presence of the strongest sidelobe jamming and acceptable loss of coverage in main beam jamming by keeping the beams very narrow. 'K'-band provides this solution.

PARAMETER / CHARACTERISTIC	L-BAND 1.1 - 1.2	S-BAND 3.1 - 3.5	C-BAND 5.2 - 5.7	X-BAND 9.2 - 9.8	Ku-BAND 16 - 18
● AVAILABLE BANDWIDTH (MHz)	100	400	500	600	2,000
● 100 kW ERP JAMMER SPECTRAL DENSITY (W / MHz)	1,000	250	200	166	50
● 0 dBi SIDELOBE RECEIVE APERTURE (m^2)	6.6×10^{-3}	8×10^{-4}	2.4×10^{-4}	8×10^{-5}	2.5×10^{-5}
● JAMMING-TO-NOISE SOJ AT 50 km	5,280	160	40	10.8	1
● AZIMUTH BEAMWIDTH (deg)	8.13	2.83	1.72	0.98	0.55
● MAINLOBE SHADOWING SECTOR OF SOJ (deg)	16.26	5.66	3.44	1.96	1.10
● % ANGLE COVERAGE REMAINING 6 JAMMERS IN 90° SECTOR	0	62	77	87	93
● % RESULTING RANGE WITH SIDELOBE SOJ	12	28	40	54	84
● TACTICAL UTILITY	NOT USEFUL	LIMITED UTILITY	SEVERE PERFORMANCE LOSS		FULL PERFORMANCE

Figure 2. Survivable Radar Frequency

The next step was to investigate system architecture and the two candidates that survived initial screening were:

1. A high performance monostatic radar with data links and a "quiet" radar on every weapon for local lock on.

2. A bistatic system with a central radar and passive receivers on the weapons for local lock on.

Other candidates were rejected because they could not provide 3D data to the gunner for night operation.

The results of the architecture study summarized in Figure 3 show that the bistatic architecture is far less vulnerable to enemy counters than either the TWS radar or the quiet radar because:

1. The bistatic weapons are silent and nearly immuned to jamming because they use the higher power of the central radar

2. The quiet radar is safe from TOA targeting but is vulnerable to D. F. detection and to barrage jamming.

3. The TWS system could be designed to incorporate some of the bistatic system ECCM features, but the system would be still vulnerable because of the data links that must operate continuously to provide data to the quiet radar at the weapon.

Once the survivable system concept was identified, a bistatic baseline was developed and analyzed in more detail.

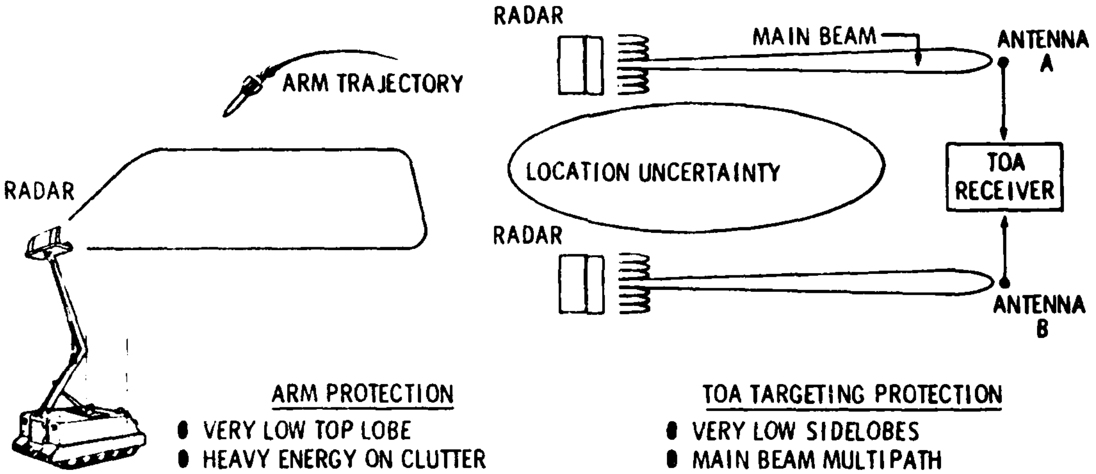
PARAMETER / CHARACTERISTIC	MONOSTATIC		BISTATIC	
	TWS	QUIET	RADAR	PASSIVE RECEIVE
● FREQUENCY	X-BAND	K-BAND	Ku-BAND	Ku-BAND
● LOCATION	PLATOON	WEAPONS MOUNTED	PLATOON	WEAPONS MOUNTED
● SIZE (ft)	8	2	8	2
● ANTENNA GAIN (dB)	36.0	30.0	40.0	30.0
● POWER (WATTS)	5,000	10	10,000	NONE
● RANGE (km)	40.0	10.0	40.0	20.0
	VULNERABILITY			
● ENEMY DF RANGE (MAINLOBE) (km)	$\gg 100$	$\simeq 25$	$\gg 100$	0
● ENEMY TOA RANGE (SIDELOBE) (km)	$\simeq 30$	$\simeq 1$	$\simeq 30$	0
● BARRAGE JAMMING RANGE SL (km)	22	$\simeq 8$	34	16
● BARRAGE JAMMING MAINLOBE RANGE (km)	2.8	1.5	3.4	4

Figure 3. Survivable Radar Architecture

Design of the Bistatic Radar

The central radar is a 'K'-band, multifunction phased array that provides surveillance, monopulse target track, target signature, digital radar communication to the weapon, and hostile target illumination for use by the bistatic receivers. The radar vehicle contains ESM and IFF sensors as well as digital data links to the rear and to adjacent radar systems to provide data merging, netting and control. Special emphasis was placed on survivability in an electronic warfare environment.

Figure 4 summarizes the special design features that enhance survivability.



ARM PROTECTION
- VERY LOW TOP LOBE
- HEAVY ENERGY ON CLUTTER
- MULTIPLE "BLINKING" SYSTEMS
- HIGHLY MOBILE PLATFORM
- SECTOR COVERAGE

TOA TARGETING PROTECTION
- VERY LOW SIDELOBES
- MAIN BEAM MULTIPATH
- MULTIPLE "BLINKING" SYSTEMS
- HIGH RADAR MOBILITY
- SECTOR COVERAGE

EW DESIGN FEATURES
- BROAD BANDWIDTH -- 2 GHz FREQUENCY OCCUPANCY
- FREQUENCY DIVERSITY
- IRREGULAR ARRAY SCANNING
- RFI IMMUNITY PERMITS DIVERSITY OPERATIONS
- HIGH MOBILITY -- SELF NETTING

Figure 4. EW Survivability

System Building Blocks

The design studies produced a small number of interchangeable building blocks as shown in Figure 5.

The weapons pieces are designed for simplicity of operation, and since there are no high-powered components or moving parts, the power consumption is very low and the reliability is very high.

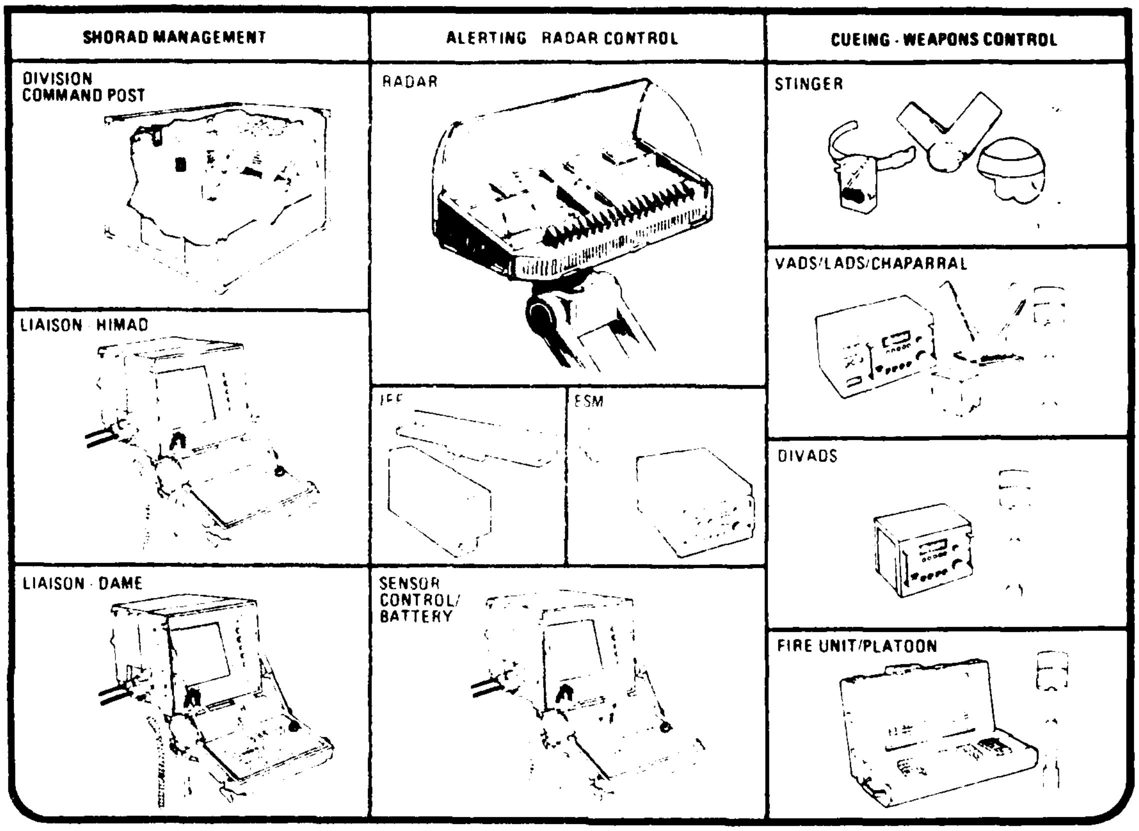


Figure 5. SHORADS Building Blocks

By designing the user equipment with low cost VHSIC components, the production costs of the weapons equipments will be low enough to make self-testing and throw-away assemblies attractive, thereby reducing logistic support costs.

The central radars and control centers will require maintenance, but the numbers of equipments is small and the overall costs reasonable. The liaison equipments are designed to utilize the JTIDS nets and computers that will be available at division level, and to provide tactical redundancy with similar equipments used for other tactical functions.

Bistatic Operation

The bistatic system operation is pictorially represented in Figure 6. Note that a single radar services many weapons types by providing the transmitter for all of the users. The system is self netting because both the central radar and weapons utilize the same target reflection.

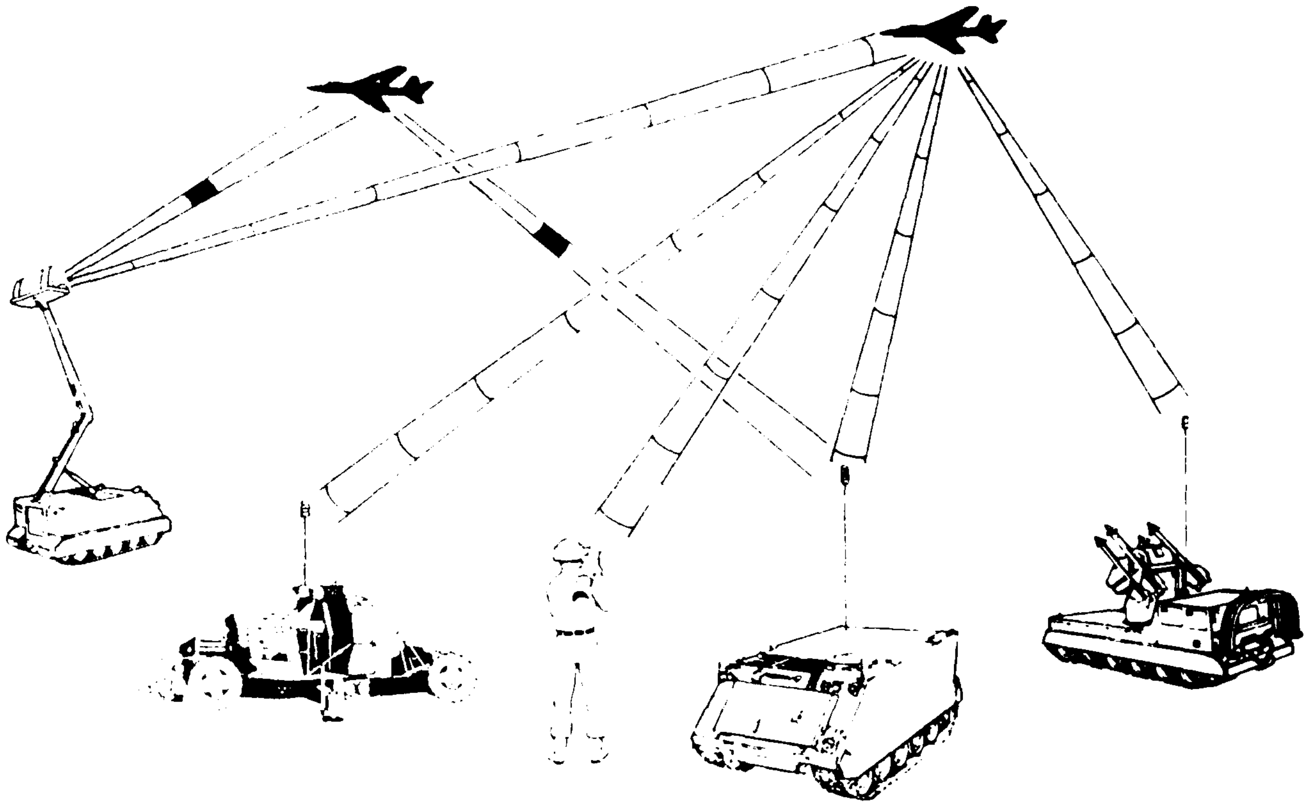


Figure 6. Bistatic Operation

The unique advantage of this concept is that a 2D radar track provides precision 3D target designation to the weapons. The illuminated target is initially located by the weapon using a scanning "search" antenna and this signal is used to cue the weapon to the target. The weapon has an Az/El passive monopulse receiver attached to the weapon mount to provide precision Az and El tracking information. The passive receiver provides fire control accuracy tracking at the gun using the 10 points per second data rate and a high precision passive tracker.

SUMMARY

Figure 7 examines survivability from the enemy's point of view. We believe that the objectives of design for survivability have been met. Our military worth studies show that the enhancement is achievable and at the same time the opportunities for enemy exploitation have been significantly reduced.

ENEMY OBJECTIVES	COUNTER
ESM	
LOCATE WEAPONS	PASSIVE RECEIVE ONLY
LOCATE SENSORS	TOA/DF RESISTANCE
INTERPRET OPERATING MODE	HOSTILE ILLUMINATION ONLY
BYPASS RADAR	RADAR IN SANCTUARY
UNDERFLY RADAR	VERY BROAD AND LOW COVERAGE, NETTED
ECM	
DISRUPT SYSTEM OPERATION	ECCM DESIGN
INJECT FALSE MESSAGES	TOA TEST, C^2 CONFIRMATION
BARRAGE JAMMING	WIDE BANDWIDTH, HIGH POWER
DEFEAT MISSILE	SECURE DESIGNATION, IR TERMINAL
SIDELOBE JAMMING	VERY NARROW AZIMUTH BEAMWIDTH, VERY LOW SIDELOBES
TACTICS	
AVOID WEAPONS	LOCATION DENIAL
ATTACK WEAPONS/RADAR	QUIET WEAPONS, BLINKING RADARS
ARM/TBM KILL	LOW TOPLOBE, HIGH MOBILITY
EXPLOIT HOSTILE RADIATION	LIMITED UTILITY
FOCUS-SATURATE	DEFENSE IN DEPTH
KILL RADAR FIRST	MOBILITY, REDUNDANCY, NETTING

Figure 7. The Survival Scoreboard

The enemy must overfly a deep field of very effective weapons to attack the C^2 radars. Enhanced kills with passive weapons provide network survivability.

VIDEO TECHNIQUES FOR THE TANK FIRE CONTROL SYSTEM

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Most of the modern Tank Fire Control Systems are based on a sight that contains a FLIR and/or a T.V. system. As a first result, an electric signal (mostly T.V. compatible) of the picture as seen by the sight, is available, and will be available in the future systems.

This paper will describe a basic approach of a concept for a Tank Fire Control System, based on the assumption of having a video signal of the picture as seen by the tank gunner. This signal contains all the scene information, as well as the location of the laying reticle. The concept approach will try to be realistic by basing itself on existing and proved techniques and technologies on one hand, and on operational needs and constraints on the other hand. It also takes into account that a realistic concept to be implemented in a main battle tank must be relatively cheap based on quantities needed, survaivability and the cost of existing fire control systems.

Description of the basic system

Without touching the generality of the approach, we shall refer to a basic fire control system like that of the M60A1, based on the M32 sight, but containing a laser rangefinder integrated with the daysight. The initial (reference) position of the reticle is such that the line of sight defined by the reticle, and the pointing direction of the laser rangefinder are both aligned with the gun by an initial boresight procedure.

For the analysis described below, we shall refer, for example, to a thermal sight integrated into the basic gunner periscope. This thermal sight will contain an electronically generated reticle, superimposed on the picture video signal, displayed on a T.V. display. The reticle shall be able to be positioned in an initial boresight position with the daysight, the rangefinder and the gun, and it shall be driven by signals of an electronic balistic computer in azimuth only. The elevation ballistic correction is applied directly through the head mirror of the periscope.

Scenerio operational analysis

The first task of the operator is to detect the target which is assumed to be located in the field of view. The next step after detection is to recognize it. From the operational point of view it is allowable that after completion of detection, the reticle shall be brought on the target in order to accomplish recognition. After recognition is accomplished, there is a need to measure range to target by means of the laser range finder.

A basic requirement is that the laying reticle should also be the reticle for pointing the laser, even when the reticle is not in the boresight position (because of previous ballistic correction for wind or cant angle, for example, from the computer).

The measured range, and all the other manual and automatic inputs, are fed into the ballistic computer which generates a new ballistic solution. The ballistic solution will move the reticle of the night sight to a new location. The condition for firing the round will be that the reticle will lay on the target.

Description

Let us now try to look at the problems associated with the above mentioned condition. Before going into details, I want to mention again that we are referring to the sight only. There will be three situations considered:

- Stationary fire on stationary target
- Stationary fire on moving target
- Fire-on-move on moving target

Stationary fire on stationary target

Under this situation, the basic problems of the operator to be attacked are:

- To improve the detection and recognition probability.
- To allow the use of one reticle, without the need to come back to boresight position in order to fire laser.
- To reduce time needed to fire.

Even if the firing will be done in the stationary position, the observation for detection might be done on the move. In order to improve the picture quality while moving, a technique should be applied where residual signals from the gun gyros should be applied to the sync pulses and/or to the opto-mechanical scanning mechanism, and thus move the picture in order to correct for a stabilized line of sight. Those residual signals coming from the gun gyros, are a result of the fact that the gun (and therefore the sight which is mechanically connected to the gun) is not fully stabilized because of its high inertia. By applying this technique, the whole picture should be stabilized, or at least, significantly improved in the presence of bandwidth limitations.

When the tank comes to a stationary position, and the need is to recognize the target and prepare for firing, we can allow, from the operational point of view, that the reticle will be brought on the desired target. In this case, it is enough to apply a technique that will improve the picture quality only in the center vicinity only. The most powerful technique will be integration in a window (the area has to be limited because of technical and technological constraints), centered around the reticle and moved with the reticle location. This technique will be applied according to the signal picture quality (if bad). Other applicable real-time techniques will be histogram equalization, edge enhancement, etc., which can be easily applied from the current technological point of view. Therefore, when the target is recognized, the reticle lays on, or in very close proximity to it.

The next step will be now to operate the laser rangefinder. For generality we shall not assume that the reticle is in the initial boresight position, but positioned in the previous ballistic solution. We also assume that we do not have a second reticle that will remain in the boresight position or the need to bring the laying reticle to its boresight position as condition for measuring range with the laser rangefinder.

In order to give an adequate answer to these operational requirements, the following technique should be applied, and the assumption is that a closed loop servo is controlling the turret position in azimuth:

- The operator should lay the reticle on the target and initiate the LRF control.
- At this instant the laser should not be fired, but the reticle should be automatically brought to the B.S. position in azimuth only and closed loop servo will move the turret in a counter rotation made such that the reticle will point again on the target.
- When this azimuth servo loop shall converge to a given accuracy (≅ 03 - 04 mr good enought compared to the laser beam divergence), the LRF is fired automatically.
- The range to the target is now known, applied automatically to the computer, and a new ballistic solution is generated.
- This new ballistic solution will drive the reticle and the head mirror of the periscope to a new position, and simultaneously drive the gun in a counter rotation and a counter elevation direction.
- The result will be that the operation will end the procedure with the reticle on the same target (or its very close vicinity), when the new ballistic solution is applied.

For the stationary fire on a stationary target, the system is now ready for firing.

Stationary and fire-on-move on moving targets

In order to describe the other two situations for fire on a moving target and/or to fire-on-move, we shall assume that a video tracker is connected to the servo loop (in azimuth and elevation), and that the tracker will automatically track the target at which the reticle is pointing, at the moment that the range measuring command is initiated (if the LRF is in a battle range mode or in a manual range mode, only the video tracker will be operated by this command). It is also assumed that the tracker will track the target, in such a way that the residual signals between the location of the target (as it was when the command for track was initiated) and the reticle location should be always known. There is no need to display the tracking window, because the system will close the loop and correct such that the lead angle between the gun and the target (when the reticle is kept on automatically) will be the actual ballistic solution. Thus, the tracker shall operate as a target location sensor, and the servo loop in azimuth and elevation shall dynamically maintain the line of sight and the gun in the relative ballistic position.

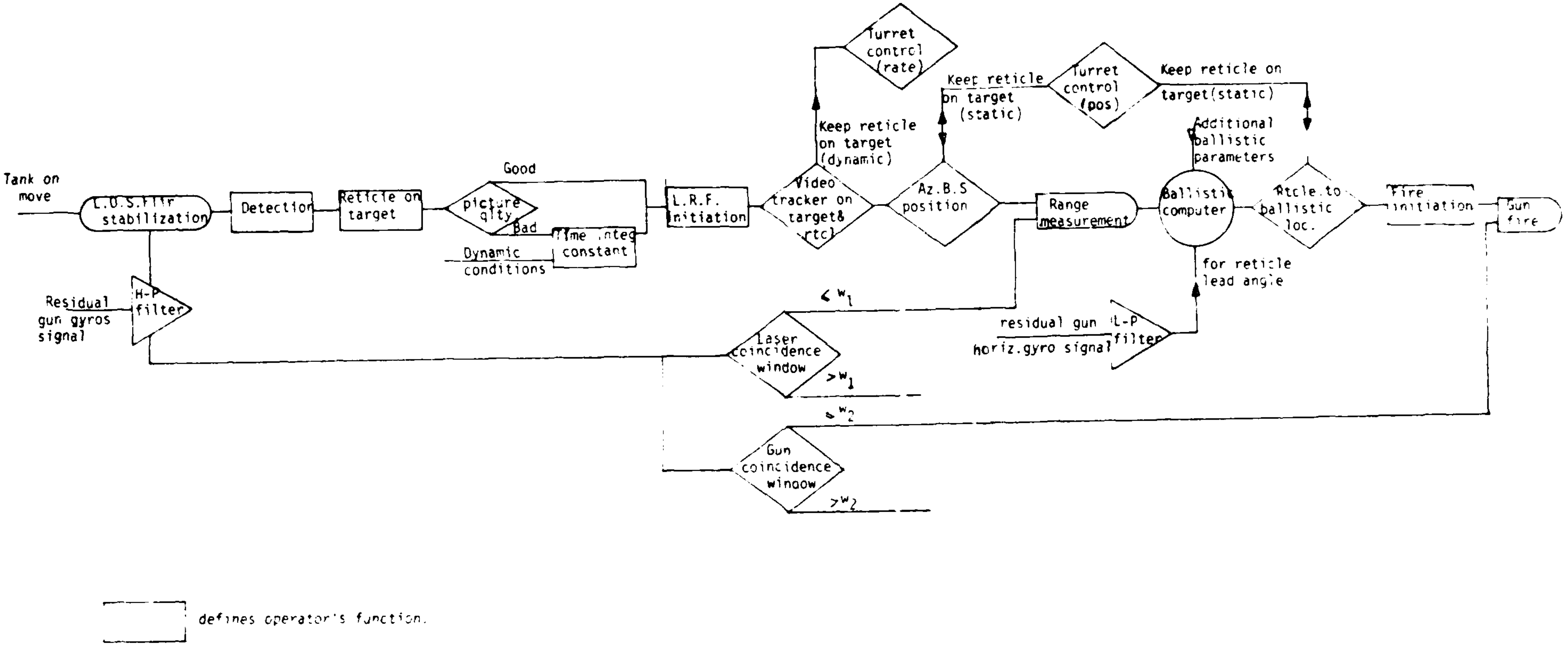
In principle, the way that the operator shall operate the system in the two other modes will be very similar, but the way that the system operates shall be quite different because of the additional and different situations.

By operating the azimuth loop when tracking moving targets, a signal has to be applied which will represent the momentary turret angular velocity. In the case of stationary fire on moving target, this angular velocity will be the signal applied for the lead angle due to the angular movement of the target.

The situation is quite different in the fire-on-move mode, because then what has to be taken into account for correcting the fire is the angular velocities due to the movement of the target and due to the angular velocity as a result of the linear velocity of the hull. One has to be careful to discriminate between those velocities significant for correcting for moving targets and the angular velocity of the tank due to maneuvers (for example, as rotation on place).

One has also to remember the complexity that the line of sight stabilization will cause, due to the fact that the LOS is corrected by residual signals from the gun gyros. The result will be that a coincidence window condition should be implemented into the circuit prior to firing the laser and the gun. The difference between them probably will be the size of those windows, due to the laser beam divergence in respect to the allowed gun position uncertainty allowed when the round is initiated.

The following diagram describes the system from the operational and from the fire control loop points of view.



FUNCTIONAL AND OPERATIONAL DIAGRAM.

Conclusion

A fire control system taking advantage of a video signal available from the main sight by incorporating available techniques like image enhancement and video tracking and integrating them with the main servo and fire control loop of the tank, was described.

Potential advantages will be improving the system from the operational point of view, and as a result of those operational needs.

Another advantage is that based on the video recording, a relatively easy quasi simulation of such a system can be analyzed and evaluated in field conditons.

Summary

SEA ARCHER 2 PERFORMANCE

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The Sea Archer 2 Electro-optic Fire Control System (FCS) was developed to provide a solution to the increasingly complex fire control problem resulting from jamming, emission control (EMCON), and clutter environments. Utilization of a multiple sensor suite FCS, operating in the visual, infra-red, and radar electromagnetic frequency spectra, provides passive and active target data. Utilization of Television and Infra-red (3.4 to 4.2 micron and/or 7.75 to 11.75 micron) sensors provide passive threat detection and target angular tracking performance for assorted missions, including those requiring EMCON and/or covert operations. Active target detection and angular tracking is accomplished utilizing a millimeter wave (MMW) tracking radar (35 gigahertz or 95 gigahertz). Completion of the fire control solution is accomplished utilizing range data obtained from either a Laser Rangefinder (1.06 micron) or the millimeter wave radar. For fire control solutions, required in emission control operating environments, the Sea Archer 2 system incorporates a straight line target psuedo range prediction algorithm. The system provides for operator manual range translation of the algorithm predicated path.

Modular construction of the Sea Archer 2 system permits flexibility both in the selection of sensor suites for optimization against primary threats, and in the installation configurations. (The system, although primarily designed for small boat applications, can be employed as a large ship combat inner defense system or in a mobile ground defense system). Multiple processors provide simultaneous data extraction from the television or infra-red image (two dimensional target to boresight angular space position displacement), radar conical scan data (range position and boresight space two dimensional angular displacement), and laser target reflections (range position). Versatility in processing of assorted television and infra-red sensor images is accomplished through the utilization of a compatable video format.

The Sea Archer 2 system has been designed for one man operation utilizing functionally sequential controls which optimize mission parameters and select appropriate target tracking algorithms. Independency between sensor viewing data and sensor tracking data permits operator data evaluation from the sensor suite without perturbation of target tracking.

Naval Surface Weapon Center (NSWC) operational tests were conducted at Fort Monroe, Virginia, during March 1981, to evaluate the Sea Archer 2 system's electro-optic sensor suite capability in performing Surface Mission Warfare. The Sea Archer 2 configuration shown in figure 1, consisting of a Television camera (with 10:1 zoom), a 3.4 to 4.2 micron Infra-red detector, and a 1.06 micron Laser Rangefinder sensor suite complement, was utilized to evaluate automatic image tracking of high speed MK 3 Patrol Boats, operating in complex backgrounds, with and without laser ranging. Each of three implemented angular error video image processing algorithms (centroid, correlation, and edge) were independently evaluated to determine optimum performance for targets with land/sea backgrounds being modulated by sun glint reflections, wave white caps, and target bow wave. The NSWC demonstration was extended to passive angular tracking of surface/air targets of opportunity, including known map documented objects for navigational assistance and NGS reference point solution. In addition, immersed personnel detection exercises were conducted to determine day/night recovery capability for flier down and/or covert operations team (SEAL). NSWC land based test site operations included on site training of personnel and determination of system availability. Sea Archer 2 system performance results from the Ft. Monroe evaluation are summarized as follows:

(a) System reaction time (Designation through Track): 6 seconds.

(b) Dynamic target angular tracking jitter: 0.14 milliradians rms.

(c) Static target angular tracking jitter: 0.097 milliradians rms.

(d) Small boat average detection range: 10 kilometers.

(e) Optimum image processing algorithms for automatic target tracking in complex backgrounds: Correlation with positional upgrade.

(f) Personnel detection for day/night recovery operations: 0.6 nautical miles.

(g) Operator average training period: 4 hours.

(h) System availability: 99.8 percent.

Data extraction from the Sea Archer 2 system was accomplished utilizing the test equipment configuration shown in figure 2. Video tape recordings of the operator's display documented target dynamics and background complexity. Specific recorded frame(s) provide target to background signal ratios and profiles. The combination of the Kennedy Magnetic Type Drive, Uniscope 100, and Univac 800 Terminal Printer were employed to extract and printout specific performance parameters. Of primary interest during the Sea Archer 2 testing was the target to boresight displacements and their system contributions.

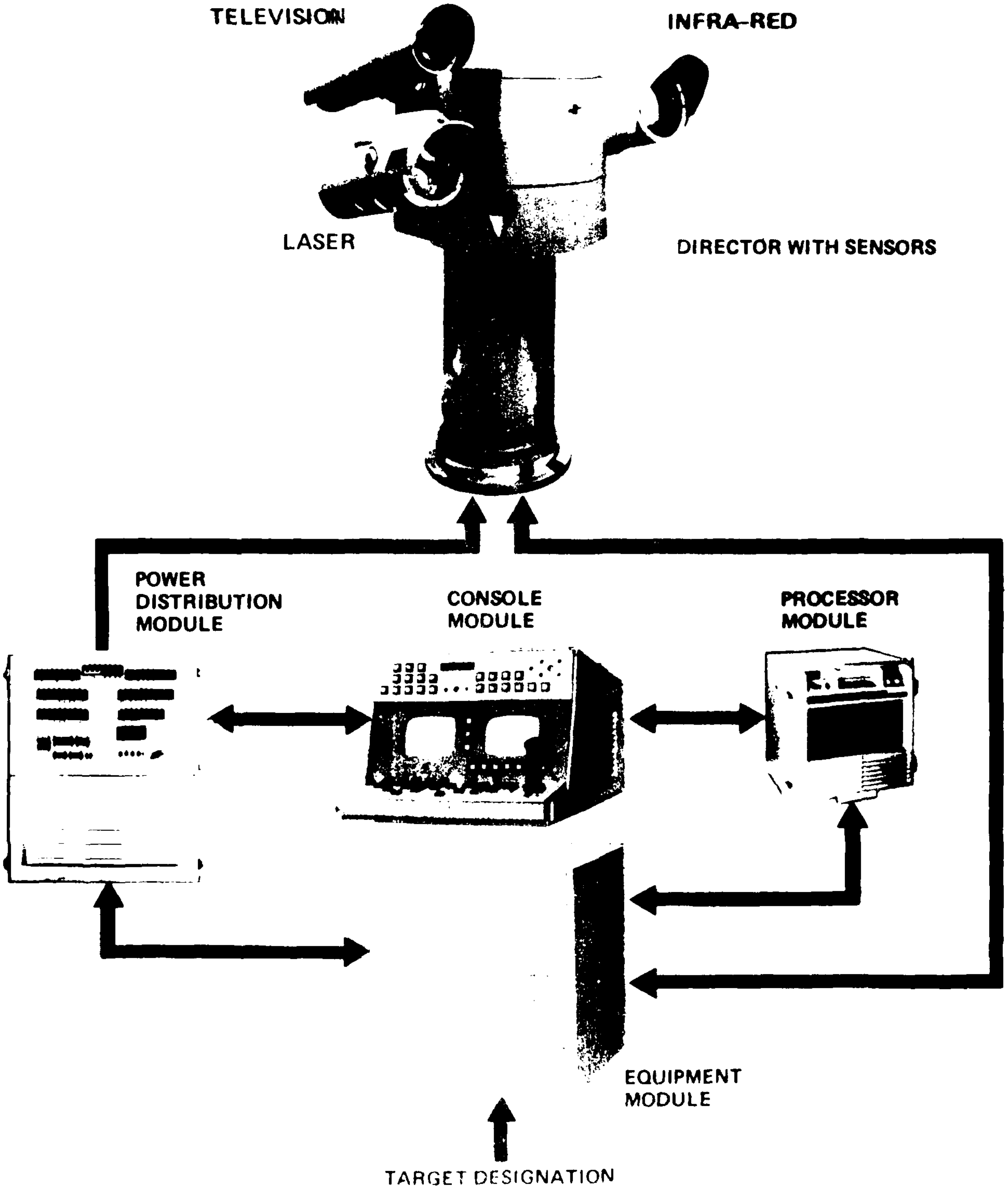

Figure 1. Sea Archer 2 Electro-optic Fire Control System

To permit evaluation of the system tracking performance a pen recorder was utilized to document the servo error drive commands to the Sea Archer 2 elevation over train director for evaluation of system jitter and target dynamic lag.

To determine Sea Archer 2 performance against high speed maneuvering aircraft the system was demonstrated at the Le Bourget, France, Air Show, during June 1981. (The sensor suite consisted of the Television camera, a 3.4 to 4.2 micron Infra-red detector, and a 7.75 to 11.75 micron Infra-red detector). Utilizing both television and infra-red video image processing, automatic tracking was conducted for crossing targets (at near field minimum ranges of 100 meters) which were demonstrating their combat maneuvering capabilities. Observations of the performing aircraft tactical maneuvers have resulted in the incorporation of algorithms which permit rapid tracking adaptation to large dynamics occurring relative to the system processing, such as:

(a) Director acceleration sensitive adaptive tracking bandwidth filters.

(b) Independent vertical and horizontal image processing gate automatic dimensional adjustment.

(c) Instantaneous field of view (IFOV) adjustment to maintain target to processing background area ratio.

(d) Boresight independent image processing gate rapid positional transistion.

(e) Background averaging level control for infra-red sensor image processing.

Sea Archer 2 performance demonstrations at Fort Monroe, Virginia and Le Bourget, France have provided the necessary information to empirically determine the alterations required to optimize the electro-optic automatic tracking features of the system. The end result is the minimizing of operator envolvement in accomplishing assorted tactical missions through maximizing the automatic features of the Sea Archer 2 Fire Control System.

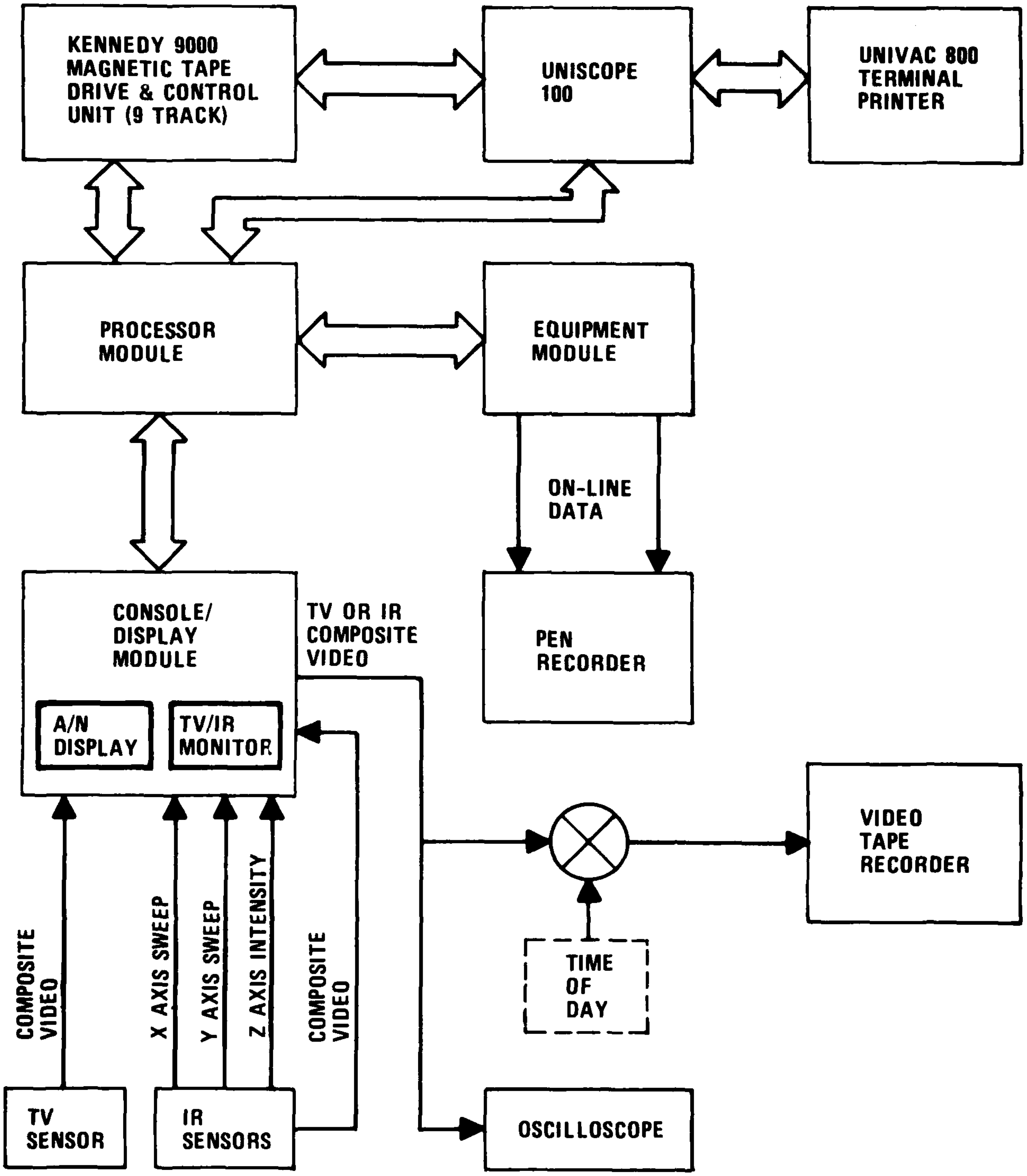

Figure 2. SA-2 FCS Test Equipment Complement

Abstract: Target Classification Utilizing Collateral Tracking Data

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Introduction

The purpose of this paper is to present an image-based target classification technique for dynamic targets which yields improved speed, accuracy and noise sensitivity. The time-varying nature of the image sequence of a target in motion is exploited together with radar track data to determine target aspect, which is incorporated into a high speed hierarchical pattern recognition system.

Consider a typical static-image based target classification system, as in Figure 1. A first step is to segment that portion of the image/signal originating from the target, rejecting background noise and clutter. This paper addresses situations where segmentation can be successfully accomplished using techniques such as those discussed by D. Milgram in [2].

Once the subset of the image which represents the target has been identified, i.e., the target silhouette, one then proceeds to extract shape descriptors with which to develop a classification hypothesis.

The problems associated with such snapshot classifiers are multiple, and are further compounded by the dependence of imagery on the 3 parameter space of target aspect. The design of shape descriptors and decision criteria are complicated by both the necessity of discriminating between different targets and compensating for the differences between a single target at different aspects. The number of comparisons, and therefore response time, necessary to make a decision increases not only with the number of possible targets, but with the number of stored aspects of each target.

This paper will demonstrate how target aspect and dynamics can be utilized to perform feature reduction, simplification of decision criteria, and obtain increased speed and accuracy in target classification.

A factor providing demonstration of feasibility for this approach has been the design of algorithms which determine aircraft attitude from optical imagery and radar tracking data, for the purpose of maneuver prediction in a ballistics weapon control system [7]. The underlying idea for these algorithms is that target motion is highly correlated to spatial orientation. Work is in progress to apply the ideas presented here to aircraft classification from optical imagery and collateral radar track data.

Aspect as a Descriptor

Target tracking information plus some collateral knowledge about the type of target being tracked can yield approximate spatial orientation of the target. For example, an aircraft points approximately in its direction of motion, modulo angle of attack and crab angle. It has been shown in a different context, [7], that this data plus an image can be used to derive the full spatial orientation of the A/C in many situations.

From the previous discussion on the nature of descriptors for 3-D objects, knowing target orientation would reduce degrees of freedom to only 1: scale. Assume then the use of scale invariant features such as normalized Fourier Transforms [8] and [9]. The design of decision criteria can now take into account the target orientation. Rather than discriminating amongst class regions with 4 or 2 degrees of freedom, one faces the simpler problem of discriminating amongst discrete sperical clusters where variability is only due to noise. It is likely and even advantageous that different decision criteria might be necessary for different target orientations.

Decomposition of the Classification Algorithm

Knowledge of target orientation has the effect of splitting a complex decision-theoretic problem into a set of simpler ones, indexed by orientation, as illustrated in Figure 4.

Each subproblem consists of designing a decision criteria between regions defined by single points. This organization of the problem allows one to take advantage of the fact that two different targets may look very similar from some perspectives and very different from others.

One technique for design of an individual aspect-based decision rule is as follows: Apriori choose some set of descriptors, such as Fourier boundary coefficients. Apply feature reduction algorithms such as in [4]. Then, for each aspect, use either correlation matching or find an appropriate set of linear discriminant functions.

Improvements in Real-Time and Storage Considerations

Apriori estmates of target aspect allow indexing into the library of feature vectors during pattern matching. Rather than matching at all aspects of each target, matching only needs to be done at a single aspect for each target. If the number of target aspects stored is, for example 100, search time can then be reduced by that same factor. Even taking aspect uncertainty into consideration, rather than performing comparisons with a reference set of intrinsic dimension 3, (or 2 in the case of rotation invariant descriptors, one can match with a set of intrinsic dimension zero (a spherical cluster). These properties are diagrammed in Figure 5.

In this situation, the advantages of rotation invariant features are modified. In standard use, rotation invariant features are valuable because they both reduce the number of reference features stored, and therefore the number of comparisons to be made. If aspect is utilized as in index into the reference library, then essentially 1 comparison per target is necessary. Thus, in an aspect-based classifier, the usefulness of rotation invariant features is to yield a reduction of memory requirements, and not a reduction in search time. This provides an opportunity for a systems design tradeoff analysis as follows.

Consider the use of different non-invariant features keyed to aspect.

This organization of the problem allows one to take advantage of the fact that 2 different targets may look very similar at some aspects, requiring complex, fine discrimination features, while at other aspects look very different, allowing use of simple, easy to compute features.

This will lead to increased speed of computing the feature of the unknown target, since simpler lower dimensional descriptors can be used. Also, comparisons between descriptors is faster for lower dimensional feature vectors. There is also the opportunity to optimize correct classification, sensitivity to noise, and reduce false alarm rate by tailoring features to each aspect. For example, there may be some aspects at which 2 targets are indistinguishable, and others at which they are easily distinguished. By splitting the classification problem into a set of simpler ones based on aspect, the decision rules can be optimized locally rather than globally.

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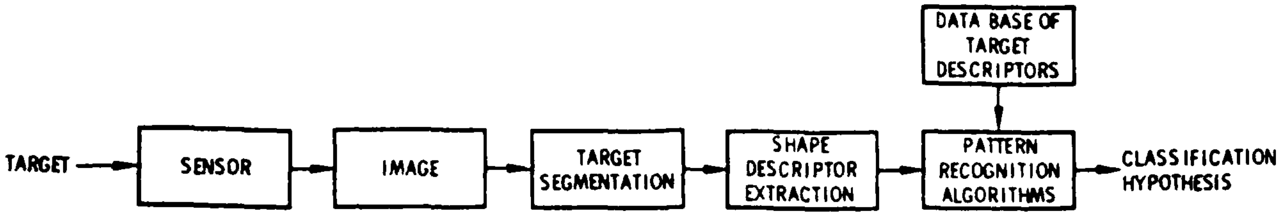

Figure 1. An Image Based Target Classification System

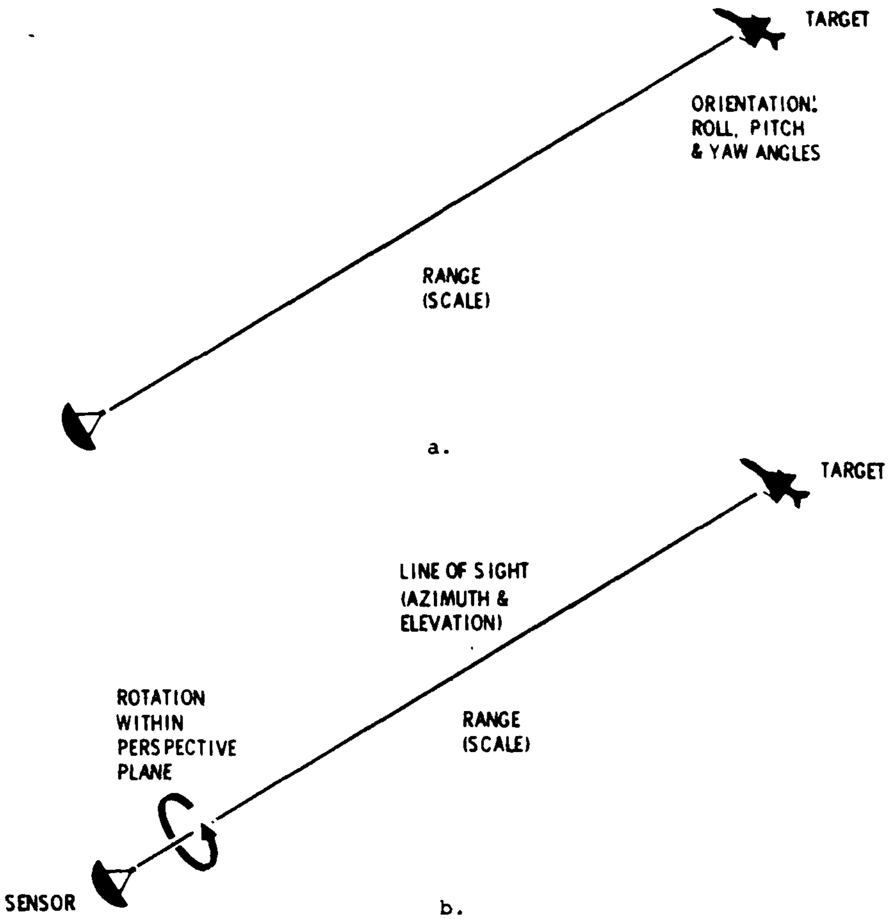

Figure 3. Equivalent Views of the 4 Degrees of Freedom in Imaging a 3-D Target

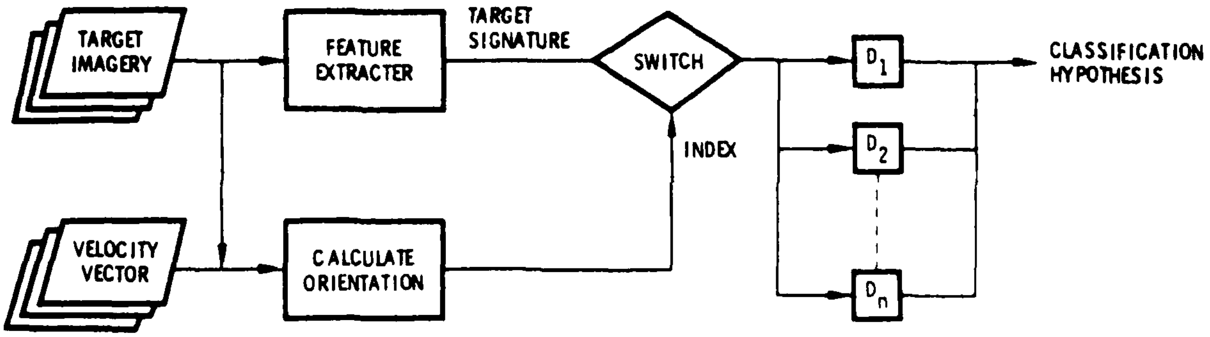

Figure 5. Classification Algorithm Decomposition Based on Perspective

"Advanced Point Defense System (APODS): Midcourse Guidance Analysis" †

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APODS is a conceptual shipboard missile system for multiple simultaneous engagement of far-term, low radar cross section targets in an all weather and far-term ECM and clutter environment. Although APODS has a very interesting "family" history, with SIRCS as an ancestor and with more-or-less close relatives like ACIM, AIAAM, AMRAAM etc., this paper will not deal with programatic issues such as these but will instead only briefly treat the model and results. APODS also provides a common point of departure for some other programs sponsored by the Close-In and Midrange Guidance and Control Block. These programs are the AJAMS seeker - already included in the APODS model - and the Mirror Track Radar which is expected to be added in the forthcoming year.

To date, four midcourse guidance modes have been studied with this APODS model. They are:

1. Fire and Forget and Active RF Terminal Guidance
2. Command Inertial Midcourse with Active RF Terminal Guidance.
3. Command Midcourse with Active RF Terminal Guidance
4. Sampled Data Semi-Active (SDSA) Guidance All the Way

The first three modes all provide autonomous terminal guidance while mode 4 requires a time-shared illuminator until intercept. Fire and Forget is, of course, attractive since it relieves the burden of providing fire control system support of the engagement after missile launch. The basic questions for this mode relate to the availability of the required seeker technology and the capability to deal with target maneuvers after launch. The only difference between Command Inertial and Command Midcourse is the requirement in the Command Mode for tracking own missile. For Sampled-Data Semi-Active, no updates are available to the missiles - as in Fire and Forget - but it is questionable whether technology is ready to provide a phased array illuminator within the desirable cost and other constraints.

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† Work sponsored by Naval Sea Systems Command, Code 62R

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The model is of the error covariance and probability type as opposed to the more widely used Monte Carlo technique. The Monte Carlo method takes the system model, which can be linear or non-linear, and drives it with computer generated noise representing the error sources. This process must be repeated many times and the results averaged in order to obtain a reasonably accurate estimate of ensemble statistics representing system performance. The error covariance/probabilistic technique uses the same system model but has been augmented with system error covariance propagation equations and probability calculations to obtain in just one run the system performance. Thus, as long as the system model is not terribly complex - requiring extraordinary effort to generate the error covariance equations - the error covariance/probabilistic technique is much more efficient than Monte Carlo. If the system model is linear, then the error covariance technique will work easily only if the errors can be linearized with reasonable accuracy. This is a common situation and describes the conditions encounted in this study. If the system is highly nonlinear and has errors that cannot be linearized, then a more complicated analysis utilizing so-called "describing functions" can be employed.

The primary output of this study is the instantaneous value of probability of seeker acquisition P_{ACQ}. It, in turn, is the product of the probability of two events that must occur if acquisition is to occur. These events, assumed to be independent, are that the target must be in the seeker field-of-view (FOV) - that is, the seeker must be pointed at the target - and the target to missile range must be sufficiently close such that seeker detection of the target can occur. So we write

$$P_{ACQ} = P_{FOV} \cdot P_{DET}$$

The models of these effects will be discussed shortly. Probability of acquisition, per se, does not, however, tell the whole story because an acquisition that occurs under conditiions that do not allow successful navigation to the target is not a particularly useful acquisition. Ideally, this problem can be solved by utilizing a terminal guidance model that would yield the conditional probability of a "successful engagement" - whatever one might want to define for this term - given acquisition. $P_{ENG/ACQ}$ would them properly weight P_{ACQ} to give us the probability of successful engagement.

$$P_{ENG} = P_{ACQ} \cdot P_{ENG/ACQ}$$

Unfortunately, the scope of this work did not include a terminal guidance model - included in plans for the coming year - so that another tact was undertaken to at least exclude those conditions which we have reason to expect will not lead to a successful navigation to the target. Instead of calculating $P_{ENG/ACQ}$, we have chosen to calculate an "effectiveness" function E and a probability of an "effective acquisition" P_{EFFACQ} where

$$P_{EFFACQ} = P_{ACQ} \cdot E$$

and we define the effectiveness function to be the product of two other effectiveness functions

$$E = E_{TG} \cdot E_{ACC}$$

The first factor, E_{TG}, is the time-to-go effectiveness and, as shown in Figure 1, tends to vanish as time-to-go becomes significantly less than some required time for terminal guidance, usually expressed as $N^*\tau$ where τ is the total missile system time constant and N is a number which is a function of the type of terminal navigation law employed, the range of general conditions under which terminal guidance commences and the target maneuvers encountered during terminal guidance. The other factor, E_{ACC}, is shown in Figure 2 and is the acceleration saturation effectiveness function. Whenever the acceleration, G_{PN}, required to navigate to the target, calculated by (say) an assumed proportional navigation guidance law, is greater than the acceleration, G_{MAX}, available from the airframe, then the E_{ACC} function vanishes. This effectiveness function technique, while far from perfect, yields a more realistic measure of acquisition than not using it.

The calculation of P_{FOV} Probability that the target is in the field of view, is depicted in Figure 3. The true target location is offset from the seeker center line by a deterministic bias error. This bias error is the result of target prediction error due to target maneuver and the seeker looking where it was last told the target would be. Centered on the true target position is an error ellipse whose size and orientation are computed by the error covariance equations which uses all the random error sources in the system and propagates them to the correct time and in seeker coordinates. Time and space do not allow the presentation here of the error covariance technique and the reader is referenced to an NSWC Technical Report by the author which should be in publication at the time of the ADPA symposium.

The probability of detection P_{DET} is calculated from the signal-to-noise and detection equations for the various seekers under consideration. All results are for Swerling 1 fluctuating targets and false alarm rates and detection signal-to-noise ratios are the same for all seekers. The expression for P_{DET} is

$$P_{DET} = \exp[-\gamma/(1 + S)]$$

where γ is related to the detection threshold and where S is the average signal-to nose ratio and can be expressed as

$$S = (Ro/R^*)^4 \exp(-\alpha \ell_{RAD})$$

R^* is the effective radiation path and ℓ_{RAD} the attenuation path length where the value of both depends on whether the seeker is active or semi-active. The factor α is the atmospheric attenuation coefficient. The zero-dB range R_0 is

$$R_o^4 = \frac{\overline{P}_T \; d_T \; G_T \; G_R \; \epsilon^2 \; \lambda^2 \; L \; \sigma}{(4 \pi)^3 \; (k \; T_o \; F_n + N_J) \; B \; dG}$$

where the jamming noise term is

$$N_J = \frac{ERPD \; \lambda^2 \; G_{JM}}{(4 \pi)^2 \; R^2_{JM}}$$

The definition of all these terms can be found in Table 1.

If the beamwidth of the seeker is so small that the seeker must be scanned in order to locate the target, one is faced with the choice of FOV value that will deliver acceptable acquisition performance. This choice is constrained in that the minimum value is the beamwidth and the maximum value is limited by the available scanning rate and amount of time available to complete the scan. The choice of FOV involves a tradeoff because, if FOV is increased to increase P_{FOV}, the P_{DET} is reduced due to lower signal-to-noise. In fact, if S_0 is the signal-to-noise at some nominal FOV f_0, then for any other value of FOV f, one finds

$$S = So \; (fo/f)^2$$

Figure 4 is an example that shows the improvement one can obtain (on the right) by optimally choosing FOV as target-to-missile range varies compared to an optimal fixed FOV on the left. Studies of optimal FOV were conducted over the entire spectrum of targets and engagement ranges and it was determined that a fit of FOV versus target-to-missile range yields essentially optimal performance with a technique that can actually be implemented.

As stated previously, the primary output of the model is the instantaneous value of effective acquisition probability. This value is available for an array of target-to-missile ranges for each intercept range, for an array of intercept ranges for each target and, finally, for a select set of targets from our scenario. This represents an enormous amount of data that cannot be readily assimilated from the computer run. One method to condense this data for a particular engagement is to calculate cumulative probability of an effective acquisition. This calculation is complicated, however, by the fact that the serial correlation of the errors influences the integration of probability required to calculate the cumulative. This effect is demonstrated in Figure 5 where a single sampled time sequence of probability yields two entirely different cumulative probability histories depending on whether the errors driving the original probability history are uncorrelated (correlation coefficient $\rho = 0$) or totally correlated ($\rho = 1$) like a dynamic bias. Examination of the correlation characterization of the missile system errors (Table 2) tells us that these systems basically operate in the highly correlated regime where ρ is near unity. That being the case, one finds that the cumulative probability is found to be the maximum value of the original probability sequence. Therefore, we will repeatedly refer in the results discussion to the "maximum effectiveness" conditions - that is, the conditions that occur at that time instant or that target-to-missile range when the effective acquisition probability peaks. A summary number which represents the overall "goodness" of any particular system configuration or parametric set is then the average of this maximum effective acquisition probability over all intercept ranges and all targets.

Due to the unclassified nature of this summary, there are many tables, charts and vu-graphs, etc. in the classified presentation that are not included here. For completeness, the following is a list of these classified vu-graphs.

- X-Band Seeker - A parametric table of seeker characteristics including jamming conditions used in the study and detection probabilies as a function of target-to-missile range.
- AJAMS Seeker - A similar characterization of this seeker including behavior as a function of scanned FOV.
- Missile System Parameter Set - A table listing the chosen nominal values of parameters that characterize the fire control system, the missile kinematics and the guidance system.
- Targets - Pictures of some of the targets studied.
- Results - An example of the results for a particular case tracing the performance to see how any particular result can be explained. A summary table of all the comparative results.
- Conclusions

Table 1
Definition of Radar Equation Parameters

Symbol	Definition
$\overline{P}_T$	Average transmitted power (watts)
d_T	Duty cycle of transmitter
G_T	Transmitter gain
G_R	Receiver gain
ϵ	Ecclipsing factor
λ	Wavelength (meters)
σ	Target cross section (meters^2)
L	Loss (non-atmospheric)
k	Boltzmann's Constant = 1.37×10^{-23}
T_0	Effective temperature = 300°K
F_N	Noise figure
N_J	Noise due to jamming (watts/Hertz)
B	Bandwidth (Hertz)
d_G	Receiver gating factor
ERPD	Effective radiated power density (Watts/Hertz)
G_{JM}	Gain of jammer relative to missile seeker
R_{JM}	Range of jammer relative to missile (meters)
α	Attenuation coefficient (meters^{-1})

Table 2.
Characterization or Errors

BY SOURCE	TYPE	CORRELATION
Target Prediction Maneuver	Deterministic	Highly Correlated (Dynamic Bias)
Ship Radar	Random	At Update Rate - Uncorrelated At Seeker Rate - Highly Correlated
Guidance System		
Alignment	Random	Pure Bias (Angular)
Gyros	Random	Dynamic Bias
Seeker Pointing	Random	Uncorrelated
Ouantization	Random	At Update Rate - Uncorrelated At Seeker Rate - Highly Correlated

FIGURE 1. TIME-TO-GO EFFECTIVENESS FUNCTION

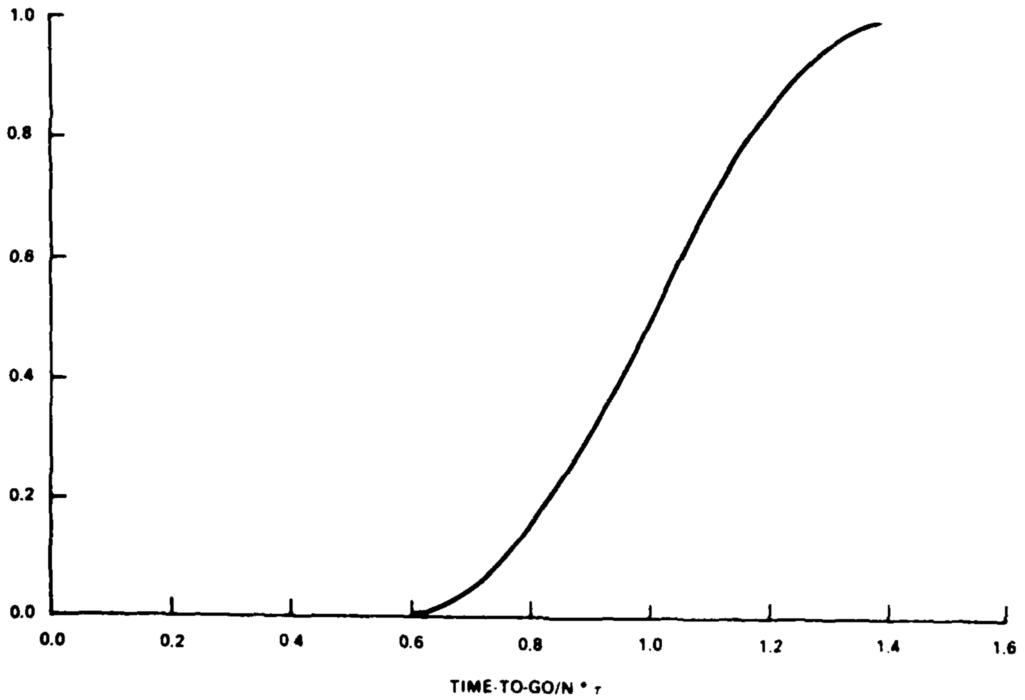


FIGURE 2. ACCELERATION SATURATION EFFECTIVENESS FUNCTION

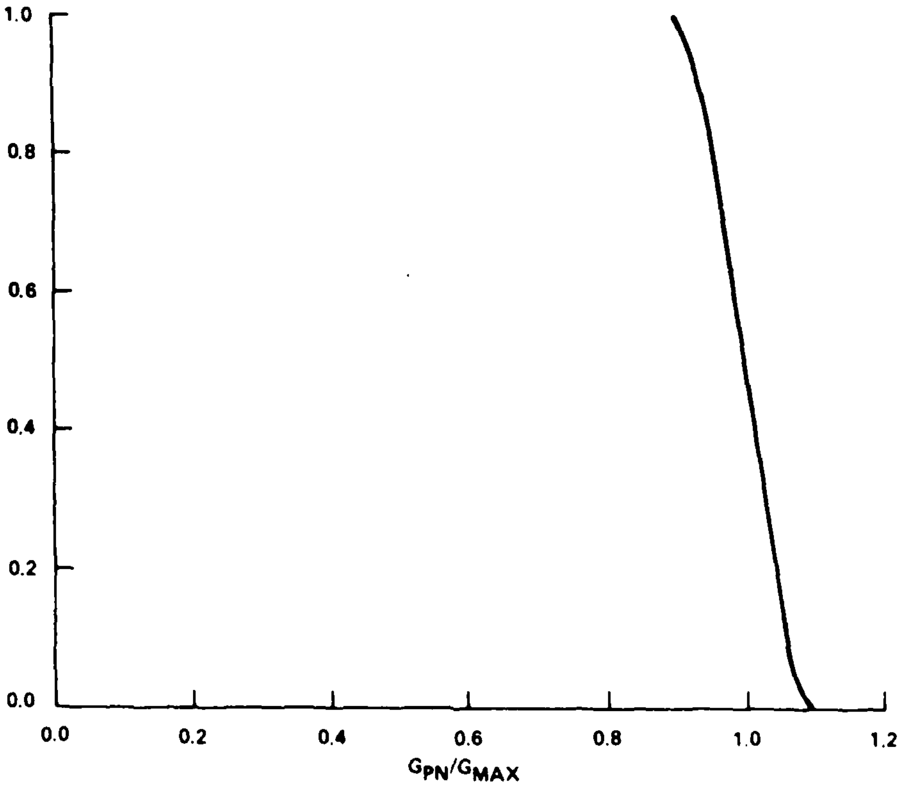


FIGURE 3. PROBABILITY THAT TARGET IS IN FIELD OF VIEW

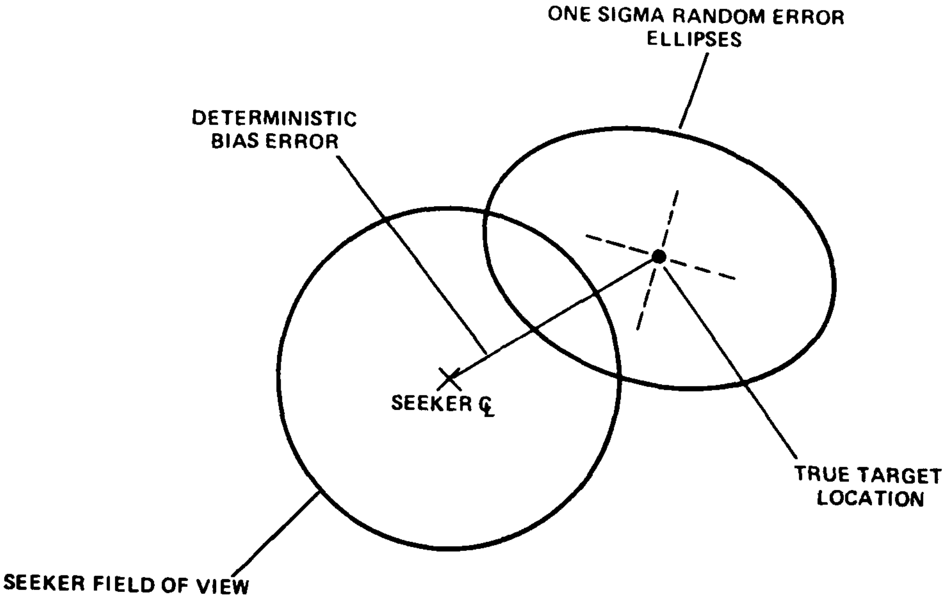


FIGURE 4. EXAMPLE OF SEEKER FOV OPTIMIZATION

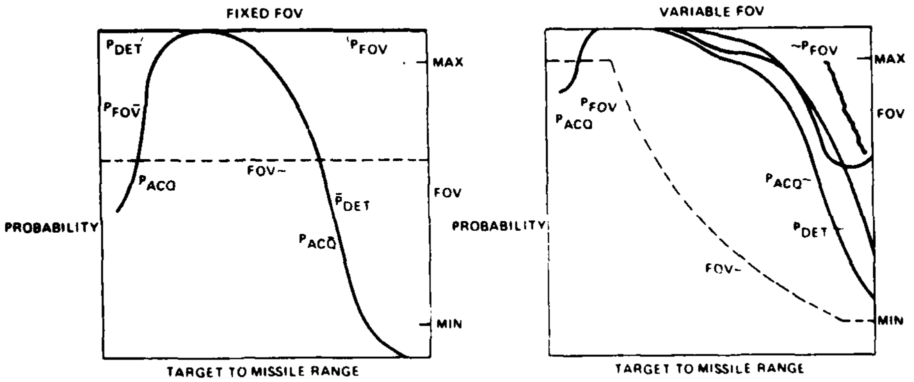
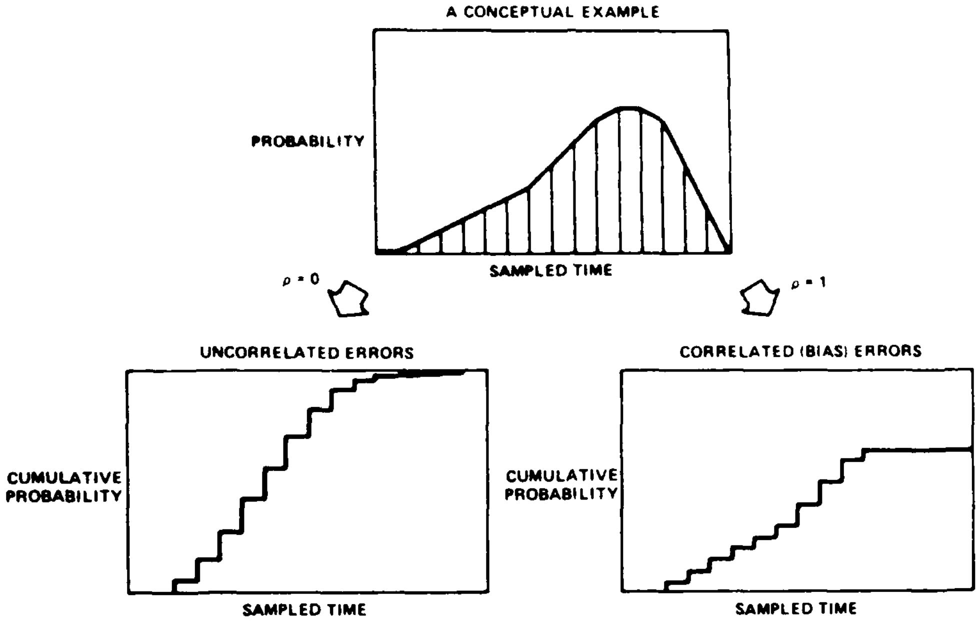


FIGURE 5. CUMULATIVE PROBABILITY: A CONCEPTUAL EXAMPLE



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JOINT NRL/NSWC MIRROR ANTENNA AAW RADAR SYSTEM DEVELOPMENT

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INTRODUCTION

Mirror antenna technology has potential application in fire control and surveillance radar systems. The Naval Surface Weapons Center (NSWC) is investigating applications for self defense while the Naval Research Laboratory (NRL) is looking at area defense.

BASIC MIRROR ANTENNA TECHNOLOGY

There are a variety of implementations used in mirror antenna systems. Figure 1 shows the basic two-axis implementation discussed in this paper. The feed illuminates a parabolic reflector which collimates rf energy to form a pencil beam in the far field. The beam movement is accomplished by intercepting this collimated rf energy with a mirror which can be tilted to reflect the beam in a desired direction.

A requirement of the mirror antenna is to make the parabola transparent to the energy reflected from the mirror. This is accomplished by using a linearly polarized feed and a parabola composed of a grid of wires parallel to the feed polarization. The mirror is a polarization-twist reflector which rotates the polarization 90° and the parabola grid then becomes essentially transparent.

Echo signals of the same polarization as that propagated into space pass through the parabola to the mirror. The echo signal polarization is rotated 90° by the mirror and focused by the parabola into the feed.

Encl. (1) to NRL Ltr
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As can be seen from this description, the only moving rf component is the mirror. Having to move only the mirror has two major advantages. First, the requirement for rotary joints is eliminated since the feed remains fixed as the beam is moved. Second, the mirror has low inertia and can be moved rapidly, thus providing rapid beam motion.

SUMMARY

The mirror antenna can be a very flexible system, and many options exist insofar as operating philosophy is concerned. Utilizing the novel capabilities and major advantages of these antenna systems, effective operating system concepts will be defined during the ensuing demonstrations of system feasibility.

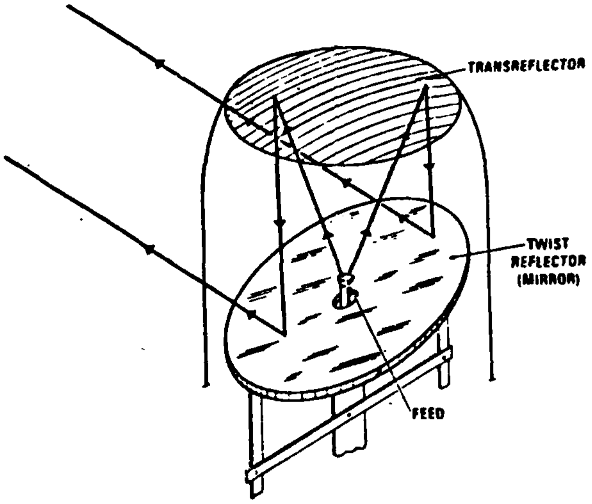

Figure 1 - Two-Axis Mirror Antenna Configuration

SELF-DEFENSE MULTI-TARGET WEAPON CONTROL RADAR

By

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Dr. Hugh K. Wolfe

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ABSTRACT

(U) Presented are selected results of an on-going exploratory development effort to build a low cost, light weight, Ka and X-band multi-target tracking radar which shows promise of providing an adequate self-defense capability for many non-Aegis ship classes when used in conjunction with a search radar and advanced high performance missiles. An error covariance pointing and tracking model was developed to define the quantitative performance of the Mirror Track Radar (MTR) in a multi-target environment and to establish mirror pointing design goals. The implementation methodology being pursued to realize the potential MTR capabilities is discussed. Emphasis was placed upon servocontrol electronics employing time-optimal principles and a beam sequencing philosophy based on concepts of information directed data acquisition. The Electronic Countermeasures (ECM) resistance of the radar to intense jamming both in the sidelobes and the mainbeam is characterized. Also, threat detection in a rain/ECM environment is analyzed.

A CONFIDENTIAL paper of this same title is available by making a request to Commander, Naval Surface Weapons Center, Dahlgren, Virginia 22448.

SUMMARY

A RAM-D CASE HISTORY

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LOCKHEED ELECTRONICS COMPANY, INC.

RAM-D (Reliability, Availability, Maintainability-Dependability) is a relatively modern day achronym. It describes the design parameters that ultimately determine whether or not an item will function when it must. The achronym was not used when the MK 86 Gun Fire Control System (GFCS) was being conceptually designed in 1963. Unlike current new development programs, some elements of RAM-D, namely Availability and Dependability were not specified as requirements in development contracts of that era. A historical review of the MK 86 program is synonomous with a study of how and why RAM-D requirements emerged, and why they are important requirements on new programs.

MK 86 GFCS PROGRAM BACKGROUND

In the mid 1960's the need to improve the tactical fire control capabilities of our surfaces ships was highlighted. Lockheed Electronics Co. (LEC) undertook a major design and development program that would ultimately provide our fleet with superior gun fire control capabilities. The latest technological advances in radar and digital circuit design were harnessed to produce the first digital computer based gun fire control system in the fleet. Forty-two MK 86 systems are now operational. More than 80 systems are scheduled to be deployed.

Designed to combat surface, shore, and air targets, the MK 86 consists of the following groups:

Surface Search Radar AN/SPQ-9A
Air Track Radar AN/SPG-60
Optical
Computer/Data
Display

By use of a general-purpose digital computer and multiple sensor capabilities, the MK 86 provides control functions on a variety of weapons ranging from 35mm to 5 and 8 inch guns, to surface- to-surface and surface-to-air missiles. Modular construction enhances versatility. Six (6) configurations of the system are now available. These configurations allow diverse application of the MK 86 in Helicopter Landing Assault Ships (LHA), SPRUANCE Class Destroyers (DD-963), Nuclear Powered Guided Missile Cruisers (CGN 36 and CGN 38 Classes), DDG and Aegis class ships, etc. A MOD 3 MK 86 system (most common system built) consists of 23 units totaling 40,000 electrical/electronic components.

The initial system design concept for the MK 86 has enabled constant upgrading of its capabilities to meet the latest mission threats. On-going improvements include the addition of the

"SEAFIRE" laser sensor/illuminator, FLIR and TV tracker to provide independent and complimentary target acquisition and gun fire control. The capabilities of firing semi-automatic laser guided projectiles and infra red seeking guided projectiles was also recently added to the MK 86.

RAM-D PROGRAM DEVELOPMENT

Original specifications for the MK 86 placed a heavy emphasis on the performance criteria that would provide capabilities lacking in the fleet at that time. The original system reliability and maintainability requirements presented in SOR 12-04 are 300 hour MTBF by group, 100 hour system MTBF and a Mean Maintenance Time (MMT) of 0.3 hours. The predicted system MTBF was 103 hours. Neither Operational Availability (Ao) or Dependability were specified.

In order to assure that the predicted MTBF was achieved, LEC and the Navy instituted a comprehensive reliability program. Data provided by NSWSES (Naval Ships Weapons Systems Engineering Station) shows a demonstrated total system MTBF of 310 hours on operational systems as of August, 1981. There is no reason for not achieving predicted reliability on operating systems.

The reliability effort on the MK 86 was initiated during the design phase of the system by making a reliability prediction using MIL-HDBK-217. Additional elements of the reliability program such as design reviews, component selection, and component derating/ stress analysis were done by LEC to assure that the system design was compatable with its reliability requirements. As the MK 86 program evolved, the need for a more intensive commitment to RAM became apparent. The reliability program expanded to include vendor surveillance, failure analysis, and corrective action.

From a reliability standpoint, the MK 86 program was a success. The demonstrated system MTBF of 310 hours had exceeded its 100 hour requirement. As more systems became operational, a new challenge developed. This challenge centered on the excessive system down time that was experienced in the fleet. An examination of the problem by both the Navy and LEC indicated that logistic delays are the primary factor affecting down time. Fault isolaton times were also lengthy. A need to address logistics problems as equal to reliability became paramount. In response to this, a joint Navy/LEC Integrated Logistics Support team was formed. The support team's focus was to identify and correct the problems which were impacting reliability, maintainability and logistics support. System performance goals were developed around the concept of Operational Availability (Ao), rather than establishing separate goals and requirements for MTBF & MTTR. This approach, using the operational availability as a composite measure of reliability, maintainability and logistics delay, was supplemented with the establishment of a closed loop RAM program for the MK 86. This program, as established under the joint efforts and cooperation of the Navy and Lockheed Electronics Company, has provided and will continue to provide the means for the monitoring of reliability and maintainability data, the identification of RAM trends, and the preparation and implementation of engineering change proposals to correct field problems. As a result, the future success of the MK 86 can be assured, as its expanded capabilities meet new challenges and threats.

OPERATIONAL AVAILABILITY (Ao)

In response to the need for specifying and measuring operational parameters as well as reliability and maintainability, a new set of requirements, centered on the concept of operational availability (Ao) by mission mode, were developed. Ao serves as a composite measure of reliability, corrective maintenance, logistics delay and administrative support. The term Ao is defined by the following expression:

$$Ao = \frac{MTBF}{MTBF + MDT}$$

Where

MTBF = Mean Time Between Failures

MDT = Mean Down Time = $(h_4 + h_5 + h_7 + h_8)$

h_4 = corrective maintenance

h_5 = logistic delay

h_7 = awaiting outside help

h_8 = administrative delay

The new requirements set forth in SOR 12-04R3 in May 11, 1981 establish an MTBF and an Ao threshold and goal for each of the four primary mission modes of the MK 86. MTBF goals by mission mode on operational systems have been surpassed. MTBF and Ao thresholds, goals and demonstrated performance are as follows:

	THRESHOLD		GOAL		DEMONSTRATED 1/1/81 to 9/30/81	
	MTBF	Ao	MTBF	Ao	MTBF	Ao
Full Surface	160	.8	200	.9	402	.80
Full Air	150	.7	180	.9	361	.74
NGF Direct	160	.8	200	.9	742	.86
NGF Indirect	160	.8	200	.9	976	.91

Logistics support needs to be improved to achieve demonstrated Ao of 0.9 minimum for all mission modes.

OPERATIONAL READINESS-DEPENDABILITY

As the MK 86 RAM program has matured so has the method for assessing performance. Emphasis is now being placed on Operational Readiness; a term which is synonomous with Dependability. And so, the final element of RAM-D is now being properly addressed.

In order to optimize the MK 86 GFCS, an Operational Readiness (OR) sensitivity anaysis has been performed by LEC and the Navy to highlight additional areas for improvement. Operational Readiness is defined as:

$$OR = A_E \times ER$$

Where

OR = Operational Readiness, expressed as a percentage probability that an equipment at any point in time will perform its intended mission without failure for the prescribed mission time.

A_E = Engagement Availability

ER = Engagement Reliability

$$A_E = \frac{MRHBF}{MRHBF + MDT}$$

Where

MRHBF = Mean Radiate Hours Between Failure

MDT = Mean Down Time

$$ER = e^{-t/MRHBF}$$

t = Mission Time

Achieving an Operational Readiness (Dependability) of 90% will require implementation of ECP's/ORDALTS now being developed plus improved logistics support. As the MK 86 program continues into the 1980's RAM-D activities will be directed toward achieving the optimum level of Operational Readiness.

RAM-D TRENDS

New technology provides the basis for future systems with very high Reliability and Operational Readiness that are easily maintained.

Technology presently availble in the form of VLSI (Very Large Scale Integration) devices such as 16 Bit microprocessors and support chips plus VHSIC (Very High Speed Integrated Circuits) and MIMIC (Microwave Monolithic Integrated Circuits) devices which will soon be available will enhance reliability. With advances in components and use of distributed networks, fault tolerance techniques, etc. the MTBF of signal processing portions of a system can be measured in years. Techniques and methodologies of achieving hardware reliability are well established.

Maintainability (MTTR) is heavily impacted by fault detection and fault isolation times. If these tasks are operator dependent, MTTR can be severely impacted. Todays technology provides the means for making fault detection and fault isolation automatically with a minimum level of operator skill and involvement. Built-in-test can be devised to be capable of fault detecting and isolating almost all of the components of a system. Operator skill level should not be the determining factor in the maintenance of equipment. The inherent design of the equipment can be such that required operator skills are minimal. A proposal for Automatic Test Equipment (ATE) for the MK 86 has been made. With improvements in component technology, use of redundancy, incorporating fault tolerance capability, etc. systems can be developed that are "maintenance free" for months.

Software Quality/Reliability/Life Cycle Costs are a new challenge. Software costs of new electronic systems will soon approximate the cost of hardware. Cost of software maintenance has been estimated at twice the cost of initial procurement.

Software Reliability concepts are in their initial stages. These concepts consist of MIL-Spec's that require a series of tasks to be performed during the course of software development which should improve the general quality of software delivered. Broadly speaking these tasks are:

- Configuration Management
- Testing-Verification & Validation
- Computer Program Design
- Software Documentation
- Reviews and Audits
- Tools, Techniques and Methodologies

- Library Controls
- Subcontractor Controls
- Corrective Action

Within each of the above categories Software Technology Innovations need to be developed and implemented which will improve Software Reliability and minimize Life Cycle Costs. Among the Software Technology Innovations needed are:

- Standard Software Packages
- Software Metrics
- Error Detection and Verification
- Software Tools
- Portability

The degree to which the above and other aids to Software Quality/Life Cycle Cost get implemented, will influence Software Reliability and Life Cycle Cost.

CONCLUSIONS

The RAM-D program currently in place on the MK 86 matured out of necessity and a strong commitment on the part of LEC and the Navy to achieve increasingly higher goals for system reliability and dependability. The case history of the MK 86 serves as testimony that the RAM-D tasks being specified in current development contracts are essential to achieving dependable performance. The view of RAM-D activities as cost drivers and contributors to procurement cost overruns is inappropriate. RAM-D is cost effective and reduces Life Cycle Costs.

PROTOTYPE E-O FIRE CONTROL SYSTEM FOR AUTOMATIC MUNITION GUIDANCE AND TARGET INTERCEPT

by

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ABSTRACT

The closed loop acquisition, track, and control of a TOW wire guided missile through utilization of a passive, lightweight, modular, E-O Imaging System has been demonstrated in successful firings at Redstone Arsenal on August 14th and 15th 1981. A critical subsystem, the Image Automatic Tracker (IAT) was uniquely configured to act simulataneously as both an acquisition system for the TOW missile and a closed loop controller for guiding the missile to an automatically tracked target. The test program demonstrated the soundness of this approach by achieving three successful hits in three attempts. The demonstrated ability to incorporate this automatic guidance technique into a multi-purpose, stabilized sensor system for light attack helicopters enhances the overall performance of such weapon systems.

The sensor configuration consisted of two TV cameras which input scene video to the two, independent point trackers, designated the Capture and Narrow FOV Trackers, respectively. After missile launch, the point trackers develop error signals proportional to the displacement of the missile from the center of the TV FOV. These error signals are used to steer the TOW missile into the center of the FOV. The Capture Tracker is responsible for acquiring the beacon; the Narrow FOV Tracker guides the TOW Missile to target impact.

BACKGROUND

A TOW (tube launched, optically tracked, wire guided) missile may travel up to 3.75 km. It is equipped with a Xenon beacon emitting in the near infrared (~.8um). The beacon is tracked and its deviations from the desired trajectory are sensed to produce steering commands which are transmitted up the wire to the missile. The automatic tracking and guidance system demonstrated in Huntsville had to meet these requirements:

(i) The missile beacon must be acquired very rapidly (less than 200 msec from its entrance to the FOV) or the missile will abort.

(ii) Tracking must continue through a degrading signal to noise ratio as the TOW travels downrange.

(iii) After initial acquisition, the tracking subsystem must be able to reacquire the beacon if a breaklock occurs. This requires the tracker to automatically change its internal tracking parameters.

SYSTEM DETAILS

The system configured to meet these requirements is shown in block diagram form in figure 1. A wide angle camera defines the field of view (FOV). The cameras are silicon diode array vidicons which offer good spectral response well into the near infrared. Signal processing is enhanced by the essentially linear light-to-signal transfer characteristic of these vidicons.

In the narrow FOV, a target is selected by manually slewing the camera, then locking on with a T.V. Area Correlator (TVAC) tracker for scene stabilization. The capture contrast tracker receives video from the wide FOV camera. The nearly identical and independent narrow FOV tracker receives video from the narrow FOV camera. These two contrast trackers are microprocessor (Z80) controlled instruments which acquire the TOW beacon and develop error signals that control the TOW to the center of the FOV.

TOW SHOT SCENARIO

Upon missile launch, the capture tracker goes into a lobing search mode which covers the entire wide FOV except for small stability boundaries at the edges. When the tracker detects the TOW beacon video, the gated portion of the video is significantly decreased to enhance discrimination of the beacon from obscurations and background clutter within the FOV.

After a short interval in which it is expected the TOW has been commanded into the center of the FOV, the narrow FOV tracker is activated and assumes responsibility for acquiring, tracking and guiding the TOW. With its smaller angle picture, the beacon signal to noise ratio is increased to make possible tracking the dimming beacon until target impact.

CONTRAST TRACKERS

The contrast trackers are basically gated video trackers which operate on the beacon "modulation" less background. A Z80 microprocessor within the tracker provides the flexibility necessary for controlling the tracker modes as well as processing the sensor video. This flexibility was the key to enabling the tracker to do double duty as both an acquisition sub-system and a tracking sub-system. Previous TOW operational modes required a human operator to manually move the camera and acquire the TOW before automatic tracking via a non-imaging scanned array was possible.

It is believed that the successful demonstration at Huntsville of the system described here is the first time a TOW has been automatically tracked and guided using a T.V. Sensor.

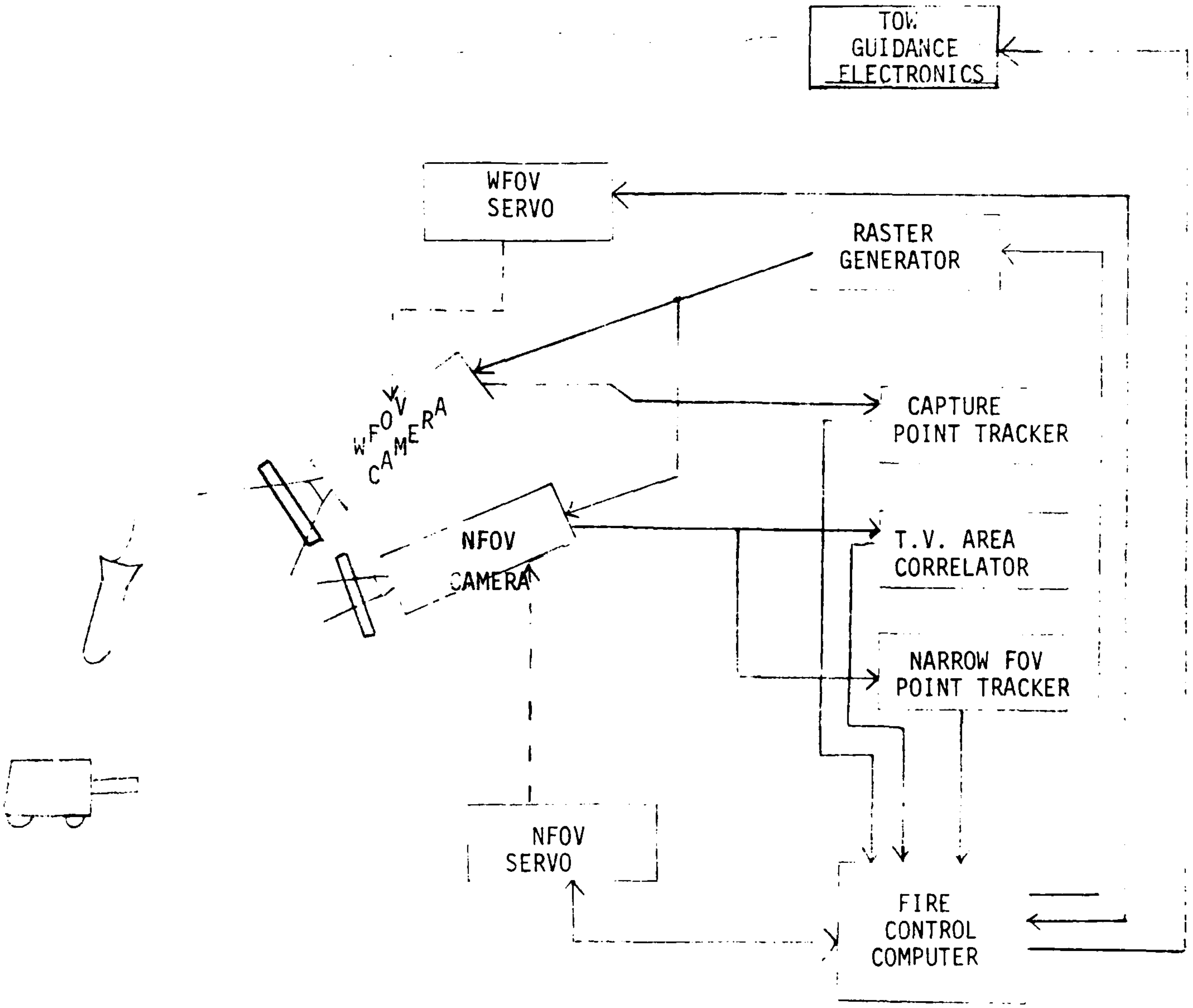

FIGURE 1 - BLOCK DIAGRAM OF FIRE CONTROL SYSTEM FOF AUTOMATIC TOW INTERCEPT AND GUIDANCE

DIRECTOR GUNSIGHT EVALUATION

Gary D Bohn, Major, USAF

Current gun fire control systems such as the lead-computing optical sight(LCOS) and the historic tracer or hotline gunsight (HLGS) will not meet future aerial gunnery requirements to combat ultra-high performance aircraft with increased structural strength and excess energy. Future aerial combat will be characterized by high aspect encounters with very brief opportunities to open fire. The Director gunsight system presents a solution to this problem.

The LCOS assumes that the attacker turn rate closely approximates the attacker-to-target line-of-sight rate. This requires a steady-state tracking solution; consequently LCOS performance suffers in high angle-off encounters where the target cannot be tracked or in front quadrant encounters where the target and attacker accelerations are significantly different. The HLGS accurately predicts the path of the bullet stream, but does not determine target position, thus requiring the pilot to predict the proper lead angle.

The Director gunsight offers the potential to meet the performance required of future gun fire control systems. The Director gunsight utilizes a tracker to determine the target position (range and angle). Kalman filters are used to estimate target velocity and acceleration and to predict future target position. The computed lead angle is based on attacker states and estimated future target position. The pilot uses the Director much as he would an LCOS except there is no requirement to track the target.

A 133-mission flight test program was conducted at the USAF Air Defense Weapons Center over a 21-month period to evaluate the effectiveness of the Director gunsight. An F-106A was modified to add a ROLM 16/64 computer, a Hughes Modular Digital Scan Convertor (MDSC), a Honeywell H-478F Inertial Sensor Assembly, a Polhemus SHMS-III Helmet-Mounted Sight(HMS), and a Bendix Adaptive Scan Optical Tracker(ASCOT). The F-106A fire control computer, the ASCOT, the MDSC, and the HMS communicated with the ROLM 16/64 via MIL STD 1553A bus. Distance Measuring Equipment(DME) was added to provide accurate ranging to a cooperative, instrumented target. Six combinations of angle and range trackers (ASCOT/RDR, ASCOT/DME, IR/RDR, IR/DME, RDR/RDR, RDR/DME) could be used as inputs to the Director system.

Two problems were identified with the original Director algorithm. The algorithm recommended using the LCOS time-of-flight(TOF) computation rather than recomputing the TOF within Director. The LCOS TOF was found to have a very high noise content, driven by noise in unfiltered range. The noisy TOF did not affect the LCOS because of its damping factor, but made the Director sight unusable. The noise on the Director reticle increased as bullet TOF increased and was on the order of ±20 mr at one-second TOF. The pilot was required to average the pipper position to employ the system. The noise on the Director reticle was dramatically reduced by computing TOF within the Director algorithm using filtered range and range rate. The resulting reticle was comparable to an LCOS reticle.

The second problem was associated with TOF limiting. The original algorithm included empirical equations to limit the maximum TOF to two seconds (Eq 1-3). The limiting TOF varied from 1.5 - 4 seconds at altitudes between 10000' - 20000' and attacker airspeeds between 400 - 1000 ft/sec. Additionally, the limit was not constant as a function of range rate and had a discontinuity at a range rate of one-half attacker velocity. A new empirical equation was developed which produced a continuous limiting TOF with range rate and which varied less than 10% in the same flight envelope (Eq 4). While this change was made to allow valid encounters in the front quadrant, it produced an unexpected result. The old TOF limiting scheme not only gave an undesireable limit at a given condition: it produced a limit which was noisy. This caused large erratic excursions of the reticle when TOF was limited and made it impossible for the pilot to predict the eventual solution. The new TOF limiting scheme also corrected this problem. Figure 1 compares the two TOF limits on a typical front quadrant encounter. The result of these two changes was a noise-free radar Director reticle across a full range of altitude, airspeed, and closure rates.

For $Va+2\dot{R}>0$ (low range rates):

$$VLSlim=0.45Vm/(1+2.3(Va+2\dot{R})/Vm) \qquad (1)$$

For $Va+2\dot{R}<0$ (high range rates):

$$VLSlim=0.45Vm \qquad (2)$$

$$Rlim=VLSlim/Kb*s*\sqrt{(Va+Vm)} \qquad (3)$$

$$VLSlim=1200-0.016H-0.78s*\dot{R} \qquad (4)$$

Where:

Vm=muzzle velocity(ft/sec)
Va=attacker velocity(ft/sec)
$\dot{R}$=range rate(ft/sec)
Kb=ballistic coefficient
s=air density ratio
H=altitude(ft)

The front quadrant (head-on) attacks additionally revealed an implementation error in coding the algorithms. This error caused a one-computer-cycle delay in computing filter states. This delay was not apparent during stern encounters with low closure rates, but created a noticeable elevation error in the Director reticle at high closure rates. This error was not corrected by the termination of the flight test program.

The results of the employment envelope evaluation for the radar Director are presented in Figures 2 through 7. They are parameterized as a function of TOF, range, angle-off, target crossing rate, range rate, and attacker load factor, and are normalized to the ordinate value of LCOS. The probability of hit (PH) was determined by grouping the passes into "bins" and then dividing the number of successful passes (those with one or more hits) by the total passes within each bin. The data are represented by linear regressions in these figures. Due to the inherent limitations in the F-106, very little data were gathered in the beam area at angles-off between 60 and 120 degrees. Data for LCOS and HLGS were extracted from the Comparative Gunsight Evaluation Program Final Report, July 1978.

While the ASCOT Director provided a better PH than did the radar Director at the same conditions, the ASCOT was not acceptable because its design limited the employment envelope. The ASCOT was a non-imaging, fixed focus, fixed f-stop device mounted on the aircraft centerline at a 13 degree depression from the waterline. It was very difficult to acquire a target and was extremely susceptible to break-lock to clutter. The 30 degree field-of-view and fixed optics limited the employment to a small portion of the stern quadrant. A means of tracker hand-off from radar to ASCOT was implemented but did not provide a graceful upgrade and was unusable. (These are limitations of the ASCOT and may not apply to other EO trackers.)

A real-time gunnery evaluation system, the Aerial Combat Evaluator (ACE), was included with this program as an additional experiment. ACE used the tracer gunsight to determine the bullet stream position, while target position was determined from range and angle track. The target was modelled as a bivariate normal distribution. The size of the target model could be adjusted by the pilot.

The position of the bullet stream at target range was compared with target position to determine pass success. The output from ACE consisted of "Opportunities" and "Hits". Opportunities were accumulated if the target coincided with the bullet stream at target range without regard to whether the pilot had fired. ACE Hits were a subset of Opportunities in which the pilot had fired and bullets were at target range.

When the F-106 radar was used as the angle tracker, the lag with target crossing rate caused poor correlation with actual pass success. This poor correlation usually resulted from the radar track point ("target") passing through the bullet stream after the bullets were no longer at target range. Such a pass would be successful as determined by computer scoring, but unsuccessful by ACE. If the crossing rate were not as great, or the burst length longer, ACE would score a successful pass, but the number of hits would be less than computer scoring. ACE did not produce good hit-for-hit correlation with other forms of scoring, but did give a qualitative indication of pass success, thus providing an acceptable means for cold fire gunnery training.

The Director gunsight system was effective, providing increased probability of hit over the LCOS and HLGS and a larger employment envelope. The radar Director demonstrated a capability in front quadrant encounters when changes to TOF computation and limiting were effected. The computed Director lead angle accurately accommodated attacker and target motion and contributed to short burst lengths. Refinements are still required in the areas of TOF computation at high closing velocities and graceful upgrade/degrade modes of operation.

The total system should be designed to capitalize on the all-aspect capability of the Director gunsight. An aircraft capable of sustained high rate of turn is essential. The tracker should have a large acquisition and track volume, and rapid, off-boresight automatic lock-on. The probability of one-shot acquisition of the desired target should be very high. A large field-of-view HUD with comparable over-the-nose visibility, and an elevated gun are required to use the Director system in the beam of the target.

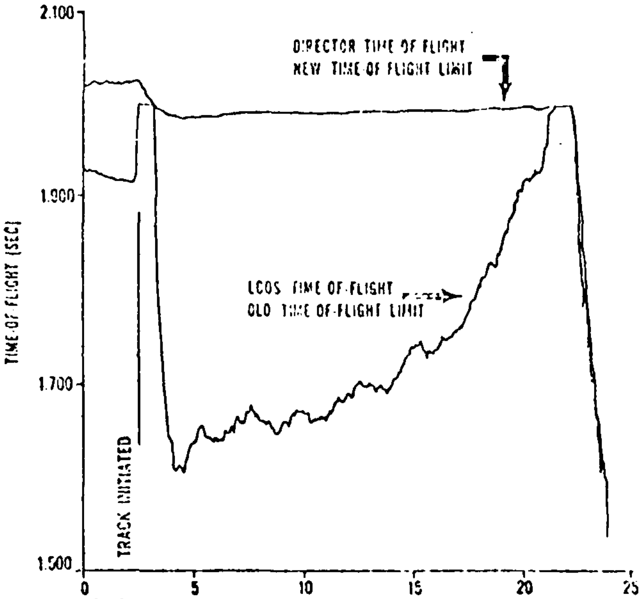

Figure 1

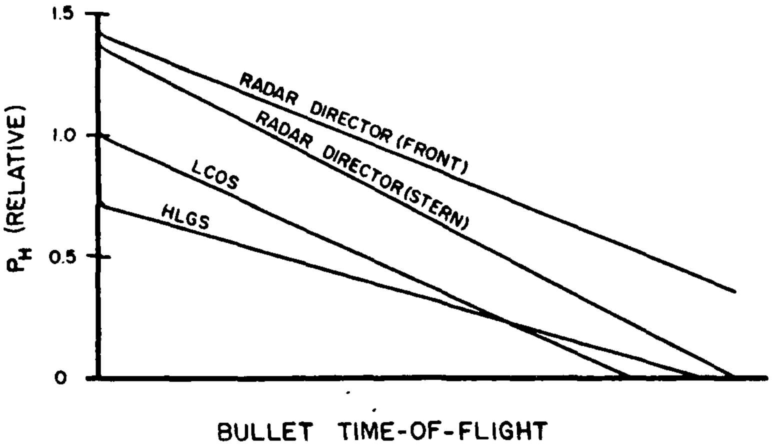

Figure 2

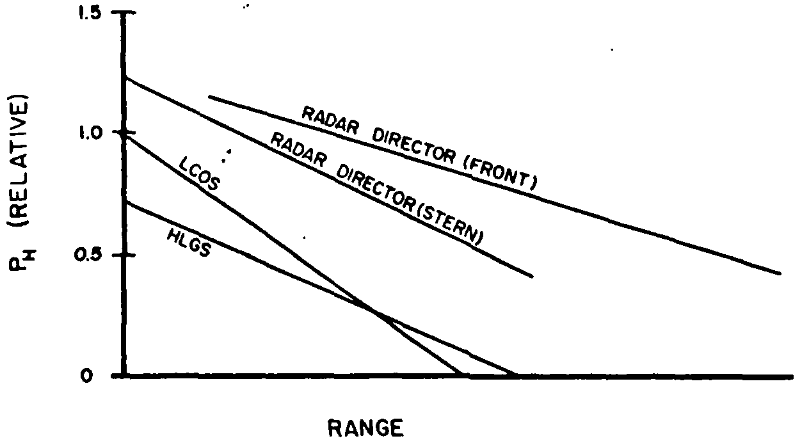

Figure 3

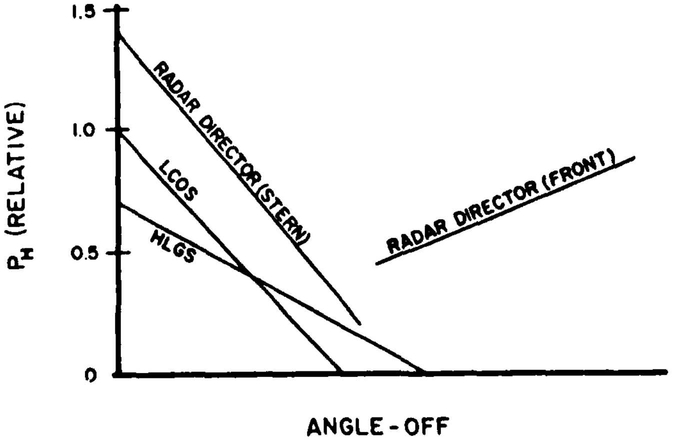

Figure 4

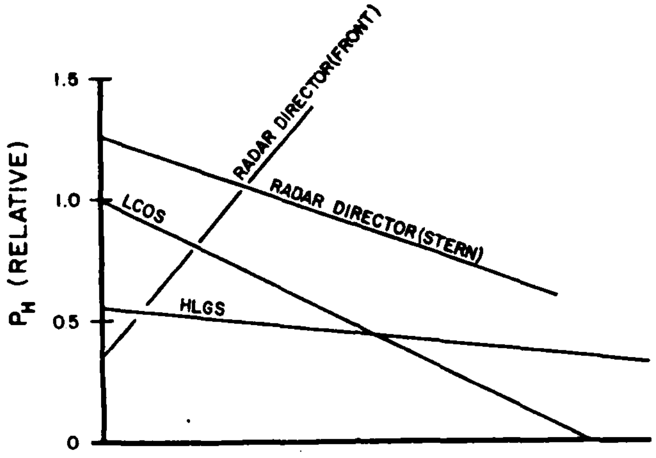

Figure 5

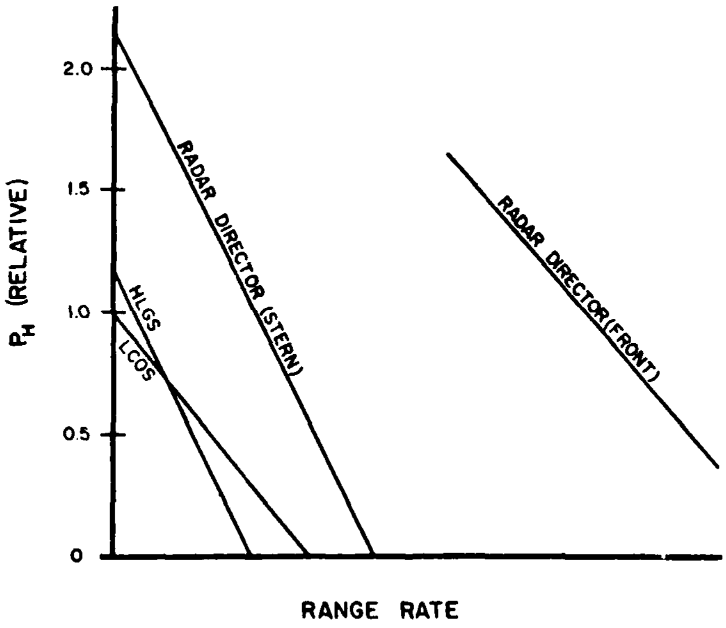

Figure 6

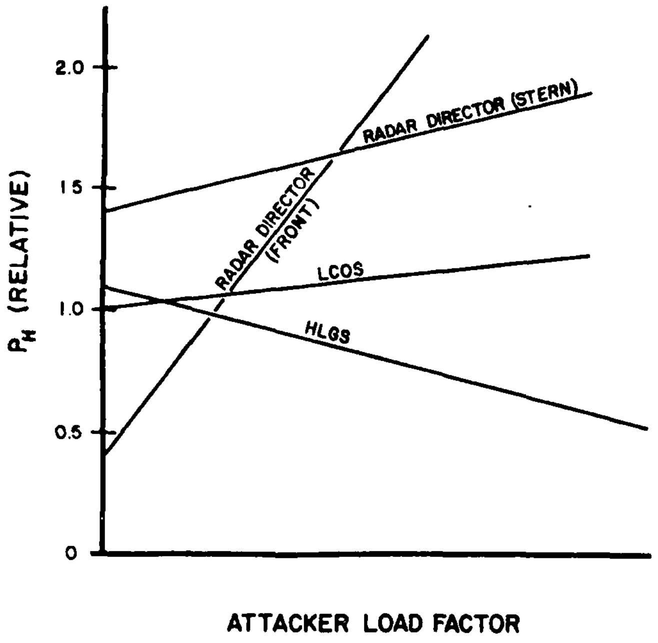
2.0
1.5
1.0
0.5
0
P_H (RELATIVE)
RADAR DIRECTOR (STERN)
RADAR DIRECTOR (FRONT)
LCOS
HLGS
ATTACKER LOAD FACTOR

Figure 7

PAPER TITLE: Defense Suppression Fire Control Design
CLASSIFICATION: Unclassified Abstract of SECRET Paper
AUTHOR: T. C. Pinkerton
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This audience is well aware of the threat situation but sometimes we have a tendency to concentrate on one particular threat. In this case there will be a concentration on the ground-to-air threats with an effort to cover all aspects of those threats.

Low level penetration has been accepted as a method of overcoming the longer range threats. Low level flight also reduces the effectiveness of short range weapons, even those with a low level capability, if exposure times can be kept short. The difficulty is the very large number of weapons involved and the consequent impossibility of dealing with them on an individual basis. The illustration of the vertical coverage tends to make the situation seem virtually impossible and the simple uniform distribution, even without the lighter weapons, gives little cause for optimism in the horizontal.

There are, however, at least two aspects wich deserve consideration. The first is the comparatively small number of threats which deny the use of medium altitudes and the second is the restriction in coverage which comes with an advance which is restricted to being close to main road systems.

It is not the business of system developers to dictate tactics but every effort should be made to give the local commander the maximum flexibility with the minimum of complication. To this end it is necessary to examine some of the potential capabilities of proposed systems. Further, it must be borne in mind that the system to be described does not pretend to "do it all". There are too many threats to risk cancellation of any development. Rather it is necessary to ensure maximum interoperability.

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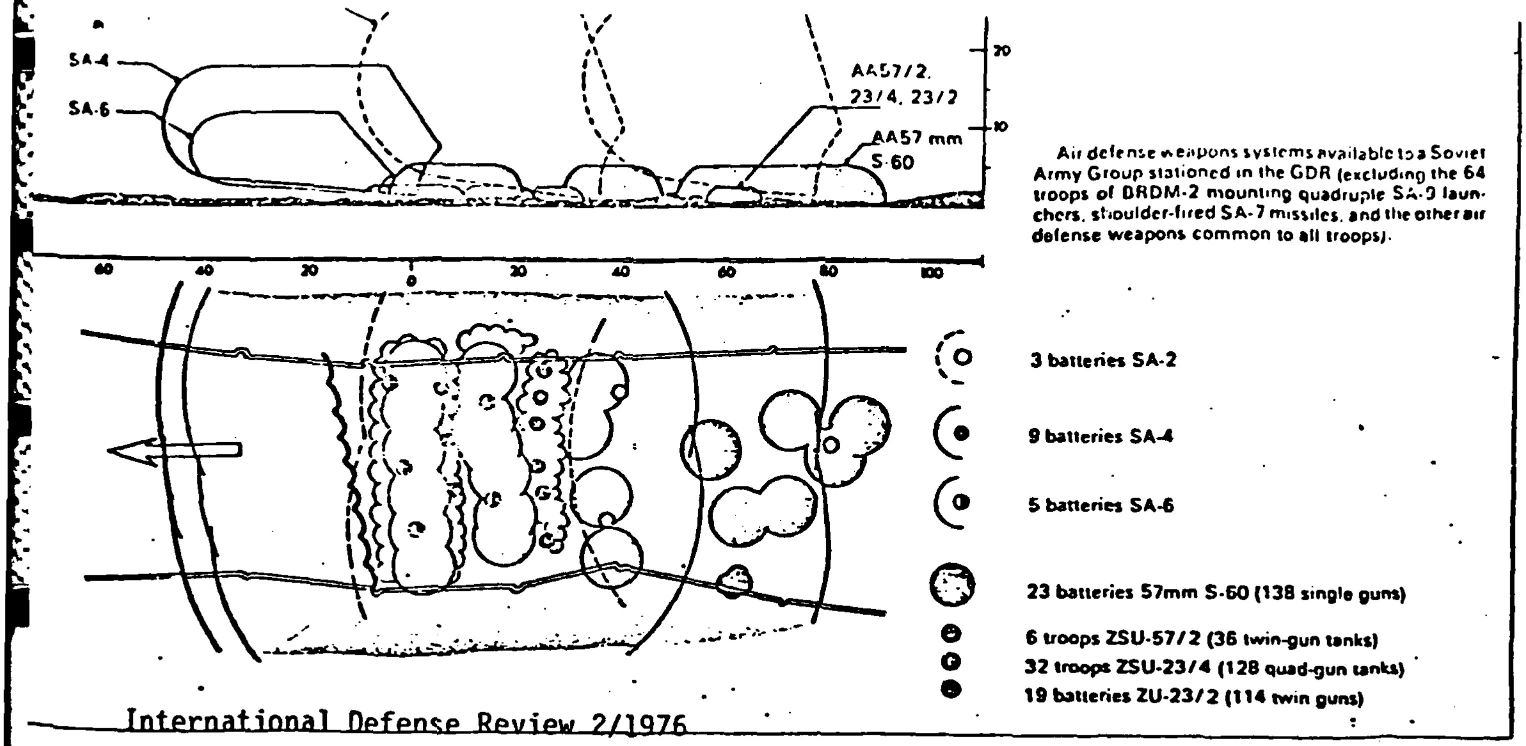
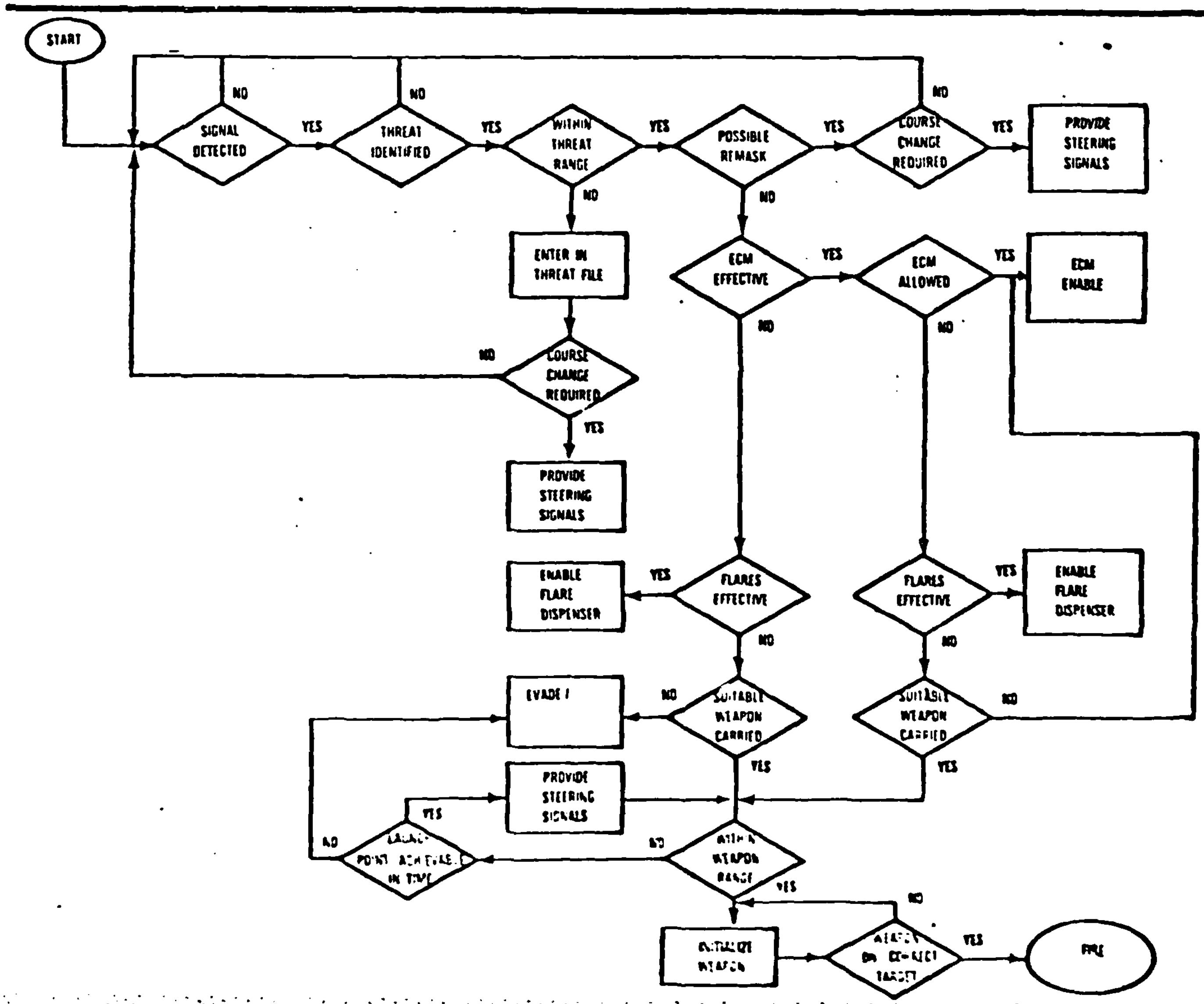


Air defense weapons systems available to a Soviet Army Group stationed in the GDR (excluding the 64 troops of BRDM-2 mounting quadruple SA-9 launchers, shoulder-fired SA-7 missiles, and the other air defense weapons common to all troops).

International Defense Review 2/1976

DEFENSE SUPPRESSION FIRE CONTROL LOGIC



As an introduction to the present fire control design effort the logic flow should be examined. This does not pretend to be the perfect nor the final logic flow but it does allow some of the critical aspects to be illustrated.

The identification of radar signals is the province of our friends in Electronic Warfare. They are doing an excellent job in keeping up with an increasingly complex threat situation and can meet the difficult time requirements of this type of fire control. Progress is being made in the EO/IR threat field but false alarms are still high and therefore identification by type difficult.

To make decisions on the seriousness of the threat or the actions to be taken it is not sufficient to identify the threat. The next desirable piece of information is the relative position of the threat. Much progress has been made in refining angular measurements to the threat but it has become apparent that careful system engineering is necessary to obtain and maintain high angular accuracy over a large look angle. Casual installation of equipment, no matter how basically good, is unlikely to give the accuracy needed. With this proviso the technology is available to give some one to two degree accuracy in azimuth.

There is still the problem of range and here the EO/IR detection has a great advantage. The range of the threat is immediately available so, with the high angular accuracy of such a tracker, the relative position of the threat is known. The same is not true for the radar threat.

This may seem to contradict the success of ELINT systems in pinpointing the location of emitters, especially in view of the improved angular accuracy already mentioned. The difference is time. Here we are trying to take action to avoid the enemy destroying our aircraft. Although times vary in different circumstances and for different threats two to three seconds is a good target for the interval between threat detection and action.

There have been several methods proposed to obtain range. Power, power rate, angle (triangulation), angle rate and unmask geometry have all been proposed. Those that have been tested have failed to produce the accuracy needed in this application. Litton AMECOM have modeled a phase rate system which shows a considerable improvement in accuracy while keeping the observation time short. A combination of techniques may be necessary to achieve the accuracy needed.

The difference between an electronic warfare threat file and a fire control threat file should be noted. For electronic warfare it is a listing of the electromagnetic characteristics of potential threats but for fire control it is the type and position of already located threats--known for many years as inertial targeting.

To depend on remask for survival requires detailed terrain information to be available. Today's data storage capability and speed of computation make this practical. Unfortunately, it will not be the simple matter of remasking from one threat but rather of finding a preferred path past many threats. This depends on keeping exposure time less than the enemy reaction time or chosing a path which minimizes enemy effectiveness when other defensive measures are included.

When there is no method of avoiding the threat, or when a specific target has been identified then an appropriate weapon must be initialized, locked-on and fired. If the weapon is one which is already catered for in the existing fire control computer then there is little to be added. If it is a special weapon then there will be a new need for information transfer according to the type of guidance involved.

So far, only on-board detection has been mentioned but it would be short-signed to fail to make use of information from other sources. Obviously the use of outdated information in a mobile situation can be confusing but, in general, the longer the range of the threat the longer it is likely to remain in one place. If such threats can be pinpointed relative to the terrain information then there is a much better chance of making a reasonable approach.

Terrain information has been mentioned for several uses. As well as the mask / remask problem and the threat location log this information can be used for navigation, improvement of the terrain following/terrain avoidance capability and display creation. With this potential improvement in low level capability it may well be asked "why bother to stress defense suppression?" First there is the density of the defenses which must be taken to include heavy and light machine guns and automatic rifles. There is also the extreme difficulty of detecting and engaging targets at low level. When the possibility of a new application of an old defensive system is added then there are very strong reasons to want to remove the threats with a capability above 12,000 ft. This will then allow vertical standoff and the employment of low cost weapons against the large number of targets in the enemy force.

This still leaves the air-to-air battle to be won.

INTEGRATED FLIGHT/FIRE CONTROL DEMONSTRATION

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The Integrated Flight/Fire Control (IFFC) program is an Air Force sponsored program to design, build, test and evaluate a system to improve aircraft weapon effectiveness through automatic control of the weapon line and flight path. Increasing attacker weapon delivery accuracy and survivability are the primary goals. An IFFC modified F-15B testbed aircraft is currently in flight test at Edwards AFB. This paper addresses overall system implementation, tracking and flight control features, predicted weapon delivery performance and flight test results to date.

SYSTEM DESCRIPTION

IFFC involves blending automatic flight control commands with pilot control of the aircraft during tracking of an airborne or ground target in the end game. The automatic commands are based on steering errors calculated by the fire control system. Figure 1 compares baseline F-15 weapon line control with the IFFC modified F-15.

There are three modes of operation: air-to-air gunnery (AAG), air-to-ground gunnery (AGG) and bombing (BMG). A director fire control system computes weapon aim solutions for both gunnery modes. Air-to-ground gunnery and bombing use maneuvering attack profiles as a means of enhancing attacker survivability while achieving wings level accuracy.

Both new and modified existing equipment have been added to the testbed F-15B to implement the IFFC system. The Coupler Interface Unit (CIU) contains all fire control software, sensor/tracker interfacing, coupler control laws, Built-in Test (BIT), In-Flight Integrity Management (IFIM) and Onboard Simulation (OBS) capability. The Central Computer (CC) has been modified to communicate with the new IFFC subsystems, and its Controls and Displays module processes modified HUD symbology. The existing F-15 analog Control Augmentation System (CAS) has been modified to accept command signals from the CIU and to provide flight control responses tailored to the weapon delivery task.

The ATLIS II sensor/tracker is an electro-optical imaging tracker that provides target line-of-sight (LOS) information to the fire control system for accurate target state estimation. It is carried externally at the left forward sparrow missile station. Initial target acquisition is accomplished by pilot control or slaving to a position commanded by the radar or INS. A laser ranging capability exists for air-to-ground operation.

IFFC cockpit controls are designed to have minimal impact on normal cockpit control positioning and pilot workload. The IFFC Control Panel powers the CIU, assigns new IFFC throttle and stick functions and displays subsystem status. Throttle controls include a couple/uncouple button to engage the coupler, onboard simulation start/stop control, weapon delivery mode select switch and sensor/tracker controls for slew, lock-on and field of view change. IFFC parameters, which are pilot selectable, are stored in the CC as Navigation Control Indicator (NCI) "destinations" and can be transferred from the CC to the CIU by selecting the appropriate NCI entry. Options in the coupler and flight control system configurations lend considerable flexibility for flight test development purposes. Also included are parameters affecting sensor/ tracker operation and selection of various OBS encounters.

The IFFC system contains extensive fault detection and safety features. BIT can detect an estimated 94% of failures and isolate 94% of those detected. Since it can interfere with normal system operation, BIT is run only on the ground. The IFFC BIT includes baseline F-15 BIT checks and self-checks of the CC, CIU and sensor/tracker. In-flight operation of the IFFC system is monitored by In-Flight Integrity Management tests. These consist of self-checks of the CIU, CC, CAS and S/T along with cross-checks between these components. Should a critical system failure be detected by IFIM, it will prevent coupling (engagement of automatic IFFC system) or cause disengagement of IFFC if already coupled. In addition to BIT and IFIM, multiple safety design features are a part of IFFC including control command limiters, engage-disengage switching logic and laser fire command interlocks. Criteria for range to target, altitude and attacker orientation and body rates must also be satisfied for coupled operation.

The Onboard Simulation capability allows closed-loop checkout of the IFFC system on the ground and in the air for air-to-air and air-to-ground weapon delivery tasks. This simulation includes various encounters and specifies initial conditions for the simulated target including relative geometry. For use on the ground, attacker F-15 dynamics and sensors are simulated in CIU software and the ATLIS II can be either simulated or used with a target board. Airborne use of OBS includes a simulated ATLIS II. OBS is especially useful for pre-flight checkout of attack encounters, pilot familiarization and training, and development of the coupled IFFC system.

TRACKING/FLIGHT CONTROL LAWS

IFFC has "outer loop" tracking and "inner loop" flight control schemes which are tailored for each weapon delivery mode. For AAG, pitch tracking control matches the attacker's pitch rate to that of the LOS to the target while simultaneously nulling the elevation tracking error. Roll tracking nulls large tracking errors by rolling the aircraft such that resulting track error is primarily in the pitch plane. Yaw tracking matches the attacker's yaw rate to that of the LOS while simultaneously nulling small (less than 100mr) traverse tracking error. All proportional gains on the tracking error commands are dual gradient. Options in the tracking control laws include rate-aiding signals using pitch and yaw rate of the LOS to the future target position and integrators on tracking error. Flight control (inner loop) laws have been modified for AAG. The pitch axis is reconfigured from blended normal acceleration and cancelled pitch rate feedback (baseline F-15) to an uncancelled pitch rate feedback system. Forward loop and integral gains are increased. The roll axis has increased forward loop gain. The yaw axis has increased forward loop gain, roll rate times gun angle feedback in place of coordination feedback (lateral acceleration and roll-rate-times-aircraft-angle-of-attack feedback) and a lead-lag network in place of a yaw rate canceller. These modifications to the flight control laws accommodate the new tracking control laws and provide more precise control of the weapon line.

Air-to-ground gunnery tracking control has a "MIN TIME" and a "MAX MANEUVER" mode, which achieve maneuvering attack in somewhat different ways. Each mode has two distinct phases, convergence and terminal steering. Convergence steering is designed to take the aircraft from any attitude (usually wings level) into a banked, accelerating turn and can be accomplished either manually or coupled in the pitch and roll axis. Tracking control laws during convergence steering are the same as for AAG in pitch and roll. "MIN TIME" convergence steering aims the attacker's velocity vector at a point which is a gravity drop above the target; "MAX MANEUVER" convergence steering introduces a large traverse error resulting in more sideslip and lateral acceleration during terminal steering. Tracking control laws during terminal steering are also the same as for AAG except that "MIN TIME" is automatic in all three axes while "MAX MANEUVER" is automatic in pitch and yaw only, allowing the pilot to manually control roll. AGG flight control laws are identical to AAG with the exception of increased integrator gain in the yaw axis.

IFFC Bombing also consists of convergence and terminal steering phases. As in AGG, convergence steering is designed to take the aircraft from any attitude into a banked accelerating turn and is accomplished manually or coupled in the pitch and roll axes. For either manual or coupled convergence steering, the pilot inputs a desired release range from which a desired load factor and bank angle are calculated. Terminal steering is the precision steering phase during the few seconds prior to bomb release and is automatic in one (roll) axis or two (pitch and roll) axes. The roll command for terminal steering is calculated based on the achieved turn rate magnitude of the aircraft. In one axis terminal steering the pilot controls pitch and can adjust release range by varying "g" level. With two axis terminal steering, pitch command is held at its end-of-convergence steering value while proportional plus integral control in roll nulls the bank angle commands. Flight control laws are baseline F-15 in pitch and yaw to accommodate automatic normal acceleration inputs to the pitch CAS and to retain coordinated flight characteristics of the standard F-15. Roll axis forward loop gain is increased for quick response.

Outer loop tracking commands for all weapon delivery modes have limited maximum authority levels. These maximum levels, shown in fig. 2, are designed to enhance system safety while maintaining adequate system performance. The authority level limiters are programmable in the CIU and hardwired by mode in the CAS.

PREDICTED RESULTS

The IFFC system was designed using all-software and hardware-in-the-loop simulations. Preliminary evaluation of IFFC configurations for all weapon delivery tasks indicates many potential payoffs. Implementation of director fire control equations for gunnery tasks drastically increases the attacker's effective encounter envelope. All aspect air-to-air engagements, including head-on passes, and non-wings level air-to-ground gunnery maintain accurate fire control solutions. Analyses have shown that coupling the flight and fire control gives air-to-air gunnery improvements of: 4:1 increase in duration of gun firing opportunity; 3:1 increase in expected hits on target; 2:1 reduction in time to first hit.

IFFC air-to-ground gunnery and bombing capabilities return the advantages of speed and maneuverability to the attacker while retaining or improving conventional wings-level accuracy. Curvilinear attack profiles greatly complicate a defender's task and promise 10:1 increases in attacker survivability. Other beneficial payoffs are a reduction in pilot workload by avoiding target fixation and enhanced situation awareness.

FLIGHT TEST RESULTS TO DATE

Flight test of IFFC began with delivery of the testbed F-15B to Edwards AFB on 19 May 1981. Preliminary ground testing included aircraft weight and balance, HUD parallax assessment, flight control system cycling, boresight of avionics, sensor/tracker and gun, live fire gun harmonization and a bomb separation velocity and timing delay test. Flight testing was divided into phases for logical progression of overall system development.

Eight flights completed a preliminary functional checkout of aircraft and IFFC components, furthered pilot familiarization and gathered data for validation of onboard gunnery scoring and radar accuracy. Onboard gunnery scoring is done by the Air Combat Evaluator (ACE) which computes predicted number of hits over a pass. Also displayed on the HUD is a Bullets-at-Target-Range (BATR) hot point symbol provided by the TRACER routine.

A night-tracer mission was flown to obtain HUD film of the BATR position during live gun fire with a high concentration (2 rounds in 7) tracer mix. Firing the gun while performing various maneuvers allowed correlation of the hot point with actual bullet position at target range over a variety of possible firing conditions. A preliminary look at the HUD film showed accurate prediction of bullets-at-target-range position.

To determine possible biases and noise levels of the IFFC test aircraft radar, the test aircraft tracked a target aircraft through a series of encounters. Onboard recorded radar range and range rate data will be compared to ground-based optical measurements. This mission also supplied data for validating the Target State Estimator. Data collected for Target State Estimator validation will also be used to verify proper lead angle prediction by the director fire control algorithms for gunnery tasks.

Live bullet scoring from a towed aerial target (for AAG) and ground target banners (for AGG) will be used to validate onboard CIU bullet scoring. Post-flight bullet trajectory analysis and scoring will also be performed with the Air-to-Air Gunnery Assessment System (ATAGAS) which is a standard analysis computer program at the Air Force Flight Test Center.

The second phase of flight test, System Integration, is to insure that all IFFC system elements interface correctly and to implement changes as problems are identified. This phase is near completion in all weapon modes. Use of onboard simulation to check out coupled tracking response and maneuvering delivery algorithms has proven very valuable. Considerable buildup in system gain and authority levels also took place during simulation flights.

Live, coupled deliveries yielded results as follows:

AAG - Low Cost Tow Target recorded 18 hits of 110 rounds fired. Target was 2.7G, 3100 feet range, 30 degrees aspect angle.

AGG - 2 straight-in passes, 77 and 118 rounds fired.

BMG - 19 BDU-33 drops, straight-in and maneuvering, with approaches of up to 3.5gs and release ranges of up to 17000 feet.

Operation of the sensor/tracker for accurate target designation and tracking has not yet been fully integrated. Problems with pilot control of the pod line-of-sight and obtaining a point track on ground targets have hindered demonstration of the full system potential. The IFFC system is, however, ready for the next task of optimizing control laws and maneuvering delivery algorithms. This task should take approximately ten additional flights in each mode. Following selection of a primary IFFC configuration for each mode, a final evaluation phase to assess weapon delivery accuracy and attacker survivability is planned.

SUMMARY

The Integrated Flight/Fire Control program is providing the Air Force the opportunity to demonstrate a dramatic technology breakthrough which can greatly improve the combat effectiveness of most present and future fighter aircraft. Flights to date have shown that the IFFC system can provide excellent weapon delivery accuracy with reduced pilot workload for air-to-air gunnery, air-to-ground gunnery and bombing. Improved attacker survivability for the interdiction of anti-aircraft artillery defended ground targets through the use of maneuvering deliveries have also been shown. Recent flight test results promise the successful fulfillment of all IFFC program goals.

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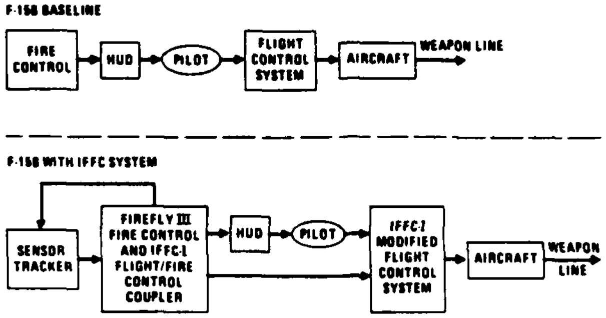


FIGURE 1
WEAPON LINE CONTROL COMPARISON

	AAG	AGG	BMG
PITCH (G's)	-1, +6	-2, +2	-1, +2
ROLL (DEG/SEC)	±60	±60	±60
YAW (DEG/SEC)	±6	±6	±6

FIGURE 2

AUTOMATIC CONTROL AUTHORITY LIMITS

ON—LINE MONITORING AND CORRECTION SYSTEM

INTRODUCTION

The complexity of today's military equipment exceeds the maintenance capabilities of the typical serviceman. To alleviate this situation, "on—line" and "off—line" built in test equipment (BITE) is provided to monitor performance and aid in troubleshooting. Tomorrow's BITE will do even more. New designs will additionally: determine how much monitored parameters are varying, compensate for minor variations to correct system performance, warn the operator if the compensation approaches maximum limits, and more precisely identify the component (or component "group") causing the problem(s).

DESIGN

A model of the desired hardware is programmed into a computer. Input commands are applied to both the hardware/software control system and its computer model. See figure 1. The actual error (E_a) is the difference between the input command (C) and the actual response (R_a). This error is compared to the equivalent error (E_i) in the computer model, which resulted from the identical input command. The difference between the two errors is then processed in the non-linear compensator (H_n) to obtain a correction signal (Hc). Hc is added to the "normal" signal generated in the computer. The combination is the corrected analog servo drive signal, which is sent to the actual plant.

If the magnitude of the errors exceed thresholds that represent normal operating limits, the monitor warns the operator that the system is being compensated. The magnitude of the error sequences in the monitor determine what characteristics are abnormal, and therefore, what component or group of components have to be changed or adjusted.

Analytical analysis is presented below starting with the non-linear compensator.

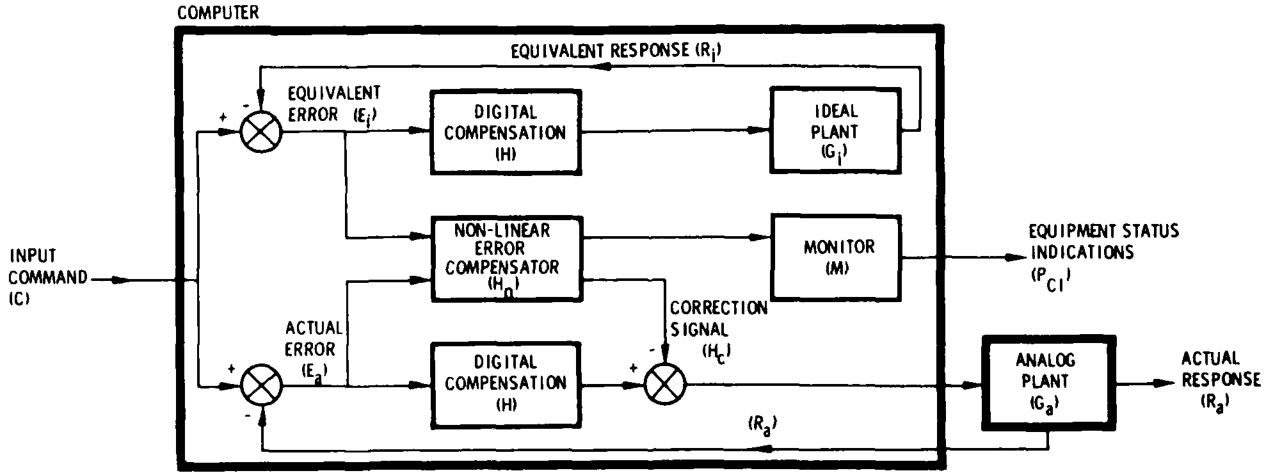


Figure 1. On-line Monitoring and Correction System, Simplified Diagram

NON—LINEAR COMPENSATOR (H_n)

The compensator is derived as follows:

$$d(HG) = G \cdot dH + H \cdot dG$$

for no change in the system transfer function $[d(HG) = 0]$:

$$dH = -H \cdot dG/G$$

but $G = G + dG$ so that:

$$dH = -H \cdot dG/(G+dG)$$

from figure 1 without error compensation:

$$E_i - E_a = [C/(1 + H \cdot G_i)] - [C/(1 + H \cdot \left\{ G_i + dG_i \right\})]$$

so that:

$$dG_i = (E_i - E_a) \cdot (1 + H \cdot G_i)/(E_a \cdot H)$$

integrating dG_i produces the change in the actual transfer function:

$$DG_a = [(E_i - E_a)/s] \cdot [1 + H \cdot G_i)/(E_a \cdot H)]$$

where s = the Laplace operator
D = the change operator (delta)

substituting into the equation for dH:

$$Hc = \frac{-H \cdot [E_i - E_a)/s] \cdot [1 + H \cdot G_i]/[E_a \cdot H]}{G_i + [(E_i - E_a)/s] \cdot [1 + H \cdot G_i]/(E_a \cdot H]}$$

This is implemented as shown in figure 2.

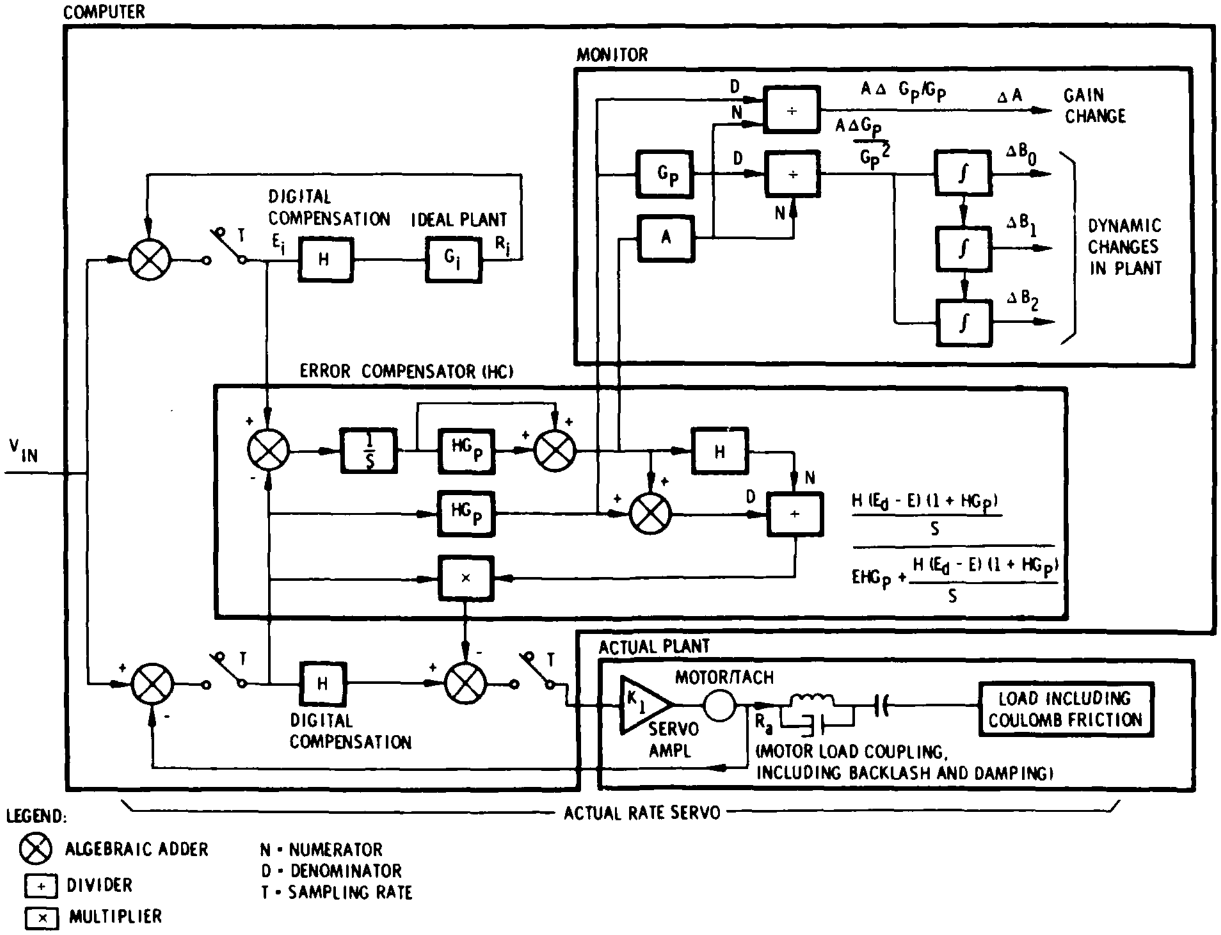


Figure 2. On-line Monitoring and Correction System, Detailed Diagram

MONITOR

The monitor is developed as follows:

Consider a linear transfer function with the order of the denominator greater than the order of the numerator. It can be written as follows:

$$G = A/F(s)$$

where: G = the transfer function
A = the gain
$F(s)$ = a polynomial in s

then differentiating:

$$dG = dA/F(s) - A \cdot dF(s)/[F(s)^2]$$

Then a change in gain is:

$$dA = A \cdot dG/G$$

or:

$$DA = A \cdot DG_a/G_i$$

Since DG_a is known from above, then DA is known.

A change in a pole or zero changes the coefficient of F(s). If one considers the nth coefficient (B_n) of F(s), then:

$$dBn = - A \cdot dG_a/[G_i^2 \cdot s^n]$$

or:

$$DBn = - A \cdot DG_a/[G_i^2 \cdot s^n]$$

Therefore, all the changes in plant parameters are known. This implementation is also shown in figure 2.

SIMULATION

A complete simulation of the non-linear self-correcting servo shown in figure 2 was performed using the ANSIM digital simulation program. The actual plant shown is a rate servo containing backlash and coulomb friction non-linearities.

The simulation was used to demonstrate each of the features of the design as follows:

1. Gain changes:

The simulation was run with the ideal plant, and the responses are plotted in figure 3. The steady state error for the ideal plant is about 0.01 volt. The gain was reduced by 10 and the simulation was rerun. The results in figure 3 show a steady state error of 0.10 volt. Then, the monitor and correction circuit was incorporated into the simulation. The results of the simulation with the correction are shown in figure 3. There is a transient time of about 1.3 seconds into the run for the correction to be performed with the steady state error at 0.01 volt.

The parameter identification portion of the simulation is plotted in figure 4. The monitor indicates a gain reduction of 10 after about 1.5 seconds into the run.

2. Pole changes:

The simulation was run with a nominal gain (A_i) of 16.2 and a nominal pole (W_i) of 14.59 radians per second. The results, shown in figure 5, indicate a gain change of 0.015 (0.09% error) and a pole location change of 0.205 radians per second (1.4% error). The simulation was rerun with a new pole location in the actual plant (G_a) of 24.73 radians per second.

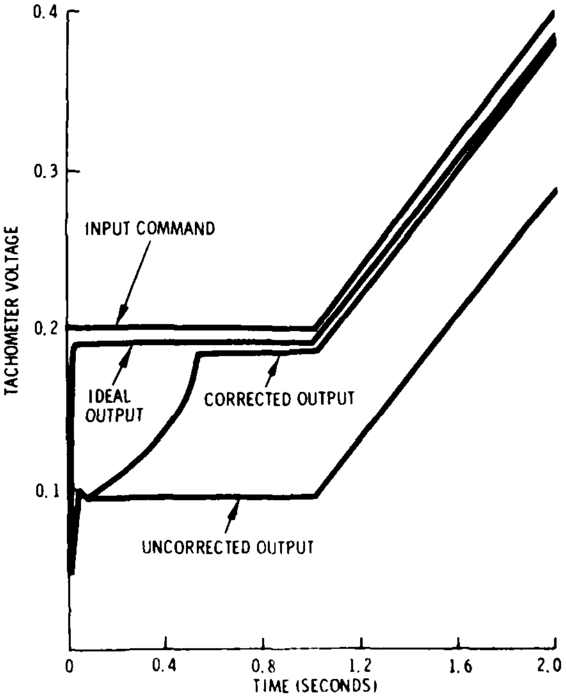


Figure 3. Operation With and Without Correction for a Gain Reduction of 10

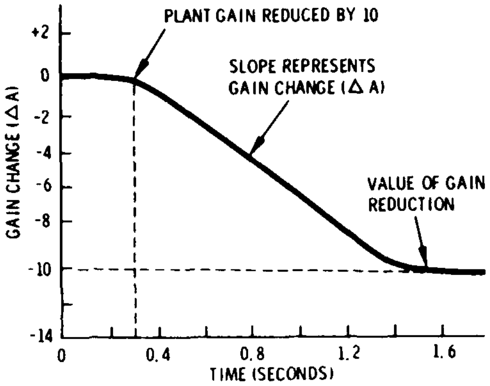
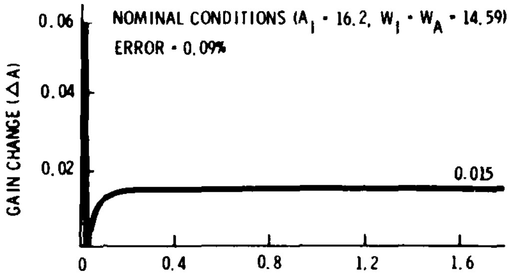
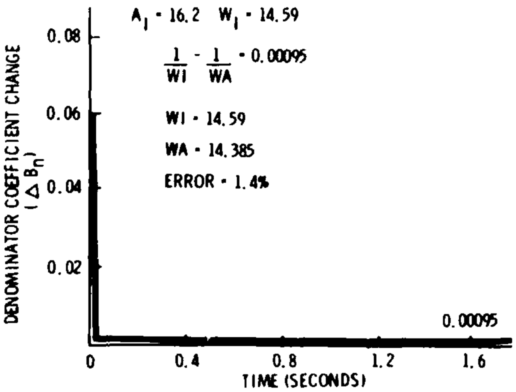


Figure 4. Parameter Identification of Gain Change (Δ A)

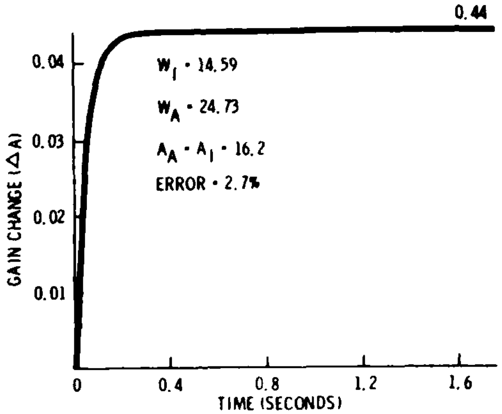


GAIN CHANGE WITH NOMINAL CONDITIONS

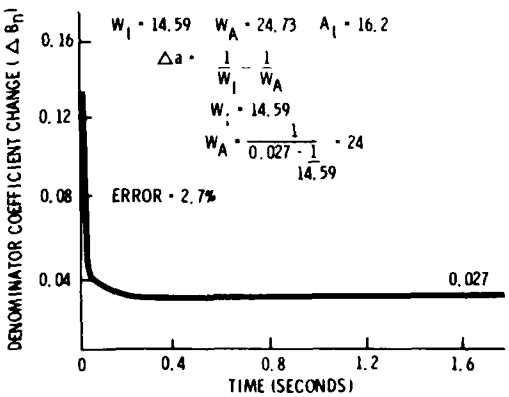


NOMINAL CONDITIONS

Figure 5. Gain Change Simulation



GAIN CHANGE FOR POLE LOCATION CHANGE



CHANGE IN POLE LOCATION

Figure 6. Pole Location Change Simulation

The results shown in figure 6 indicate a gain change of 0.44 (2.7% error) and a pole location change of 9.48 radians per second to 24.07 radians per second (2.7% error). The output tachometer voltage changes from 0.1883 to 0.1882 volts (0.05% error).

RESULTS AND CONCLUSIONS

- The On-Line Monitoring and Correction System compensates for changes in the transfer function of a closed loop system.
- For changes caused by degradation, it warns the operator that a parameter is exceeding normal operating limits so that he can take corrective action *before complete failure occurs.*
- This technique is the medium to increase system availability, and decrease operator maintenance and training requirements.

DEFINITIONS:

A = gain of the analog system
a = subscript representing the actual analog system
Bn = the coefficient of the nth order term in the denominator of analog system
C = input command to the control system
d = differential operator
D = total change (delta) operator
E = error in the control system
F = polynominal in the denominator of the transfer function
G = analog transfer function
H = digital compensation signal, or digital transfer function
i = subscript representing the ideal analog system
M = monitor transfer function
n = subscript representing either an index number, or a non linear transfer function
R = response of the actual plant
s = Laplace transform operator
W = frequency of the pole

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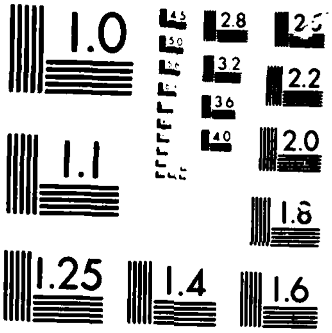

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