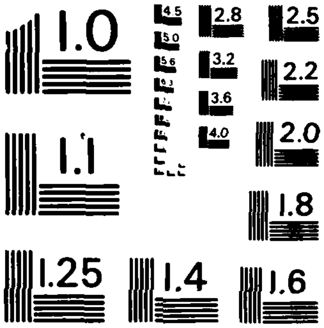
AD-A169 749 PROCEEDINGS OF THE AVIONICS SECTION AIR ARMAMENT DIVISION AMERICAN DEFENS..(U) AMERICAN DEFENSE PREPAREDNESS ASSOCIATION WASHINGTON DC 1/1

UNCLASSIFIED E M BROWNE ET AL. 03 DEC 81 F/G 1/3 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

PROCEEDINGS OF THE AVIONICS SECTION
AIR ARMAMENT DIVISION
AMERICAN DEFENSE PREPAREDNESS ASSOCIATION

AFFORDABLE AVIONIC SYSTEMS
AND
TECHNOLOGY DEVELOPMENTS
TO
MEET EVOLVING AIR WARFARE REQUIREMENTS

U.S. ARMY ELECTRONICS RESEARCH & DEVELOPMENT COMMAND
ADELPHI, MARYLAND

2-3 DECEMBER 1981

PUBLISHED BY
EMERSON ELECTRIC CO.
ST. LOUIS, MO.

IN COORDINATION WITH
AMERICAN DEFENSE PREPAREDNESS ASSOCIATION
WASHINGTON, D.C.

TABLE OF CONTENTS

TABLE OF CONTENTS

Paper #25 was withdrawn by authors. Those interested in the subject matter should contact scheduled presentor or obtain a copy of proceedings of the DoD meeting on Optical Radar Systems, 20, 21, 22 October 1981, at which meeting the same basic information was presented.

CURRENT RESEARCH, PLANS AND DEVELOPMENTS IN AVIONIC SYSTEMS AND AVIONIC TECHNOLOGY

1. "Keynote Address - View of Avionic Research and Development"
   Dr. Robert S. Cooper, Director
   Defense Advanced Research Projects Agency, Arlington, VA.

   A DARPA view of current Avionic Research and Developments. In many cases, a better understanding of what phenomena are taking place is needed.

2. "Army Programs"
   Major General Edward M. Browne, U.S.A., Program Manager
   Advanced Attack Helicopter, St. Louis, MO.

   Description of current Army Avionic programs, recognized problems and planned future programs with particular attention to the Advanced Attack Helicopter. A design for today with growth for tomorrow.

3. "Air Force Programs"
   Major General James H. Marshall, U.S.A.F.,
   Director of Development and Production
   HQ U.S.A.F., Washington, D.C.

   Description of Air Force Avionic programs and planned future programs.

4. "U.S. Navy Programs"
   Rear Admiral Leland S. Kollmorgen, U.S.N.,
   Chief of Naval Research and Development
   Deputy Chief of Naval Material
   Arlington, VA.

   Description of current Navy Avionic Programs, technical barriers and planned future programs.

RPV MISSION ELECTRONICS

JON DESMOND

U.S. ARMY NIGHT VISION & ELECTRO-OPTICS LABORATORY

The RPV offers an affordable alternate to manned aircraft for performing, reconnaissance, conventional artillery adjustment and designation for precision munitions on the Enemy's side of the FEBA. Just completing Advanced Development is the FLIR sensor which will expand the RPV's operational capability to 24 hours and in limited visibility conditions. Test results and performance predictions will be presented for this system. Full-scale development program plans and technical requirements will be presented.

Future enhancements to the RPV system include improved signal processing through the utilization of target cuers for increased bandwidth compression of 1,000 to 10,000: 1 and improved target tracking. Program plans and status along with results from earlier effort from these exploratory development programs will be presented.

SEARCHWATER - A Long Range Radar for Maritime Surveillance and Over-the-Horizon Targeting

V.M. Farmer - EMI Electronics Ltd. Hayes, Middlesex. England

There are many reasons why it is necessary to undertake surveillance and classification of shipping in both peacetime and wartime at increasingly long ranges. It is generally accepted that the most effective means of undertaking this task is by using maritime patrol aircraft equipped with a variety of sensors. However, in wartime an immediate constraint is placed on the minimum distance at which it is wise for such aircraft to approach unclassified vessels since hostile frigates, destroyers and cruisers are all equipped with surface-to-air missiles having long engagement ranges. The next generation of missiles will have even greater engagement ranges. In order to allow some observation time at a safe distance without requiring the patrol aircraft to deviate from a straight course, the classification process has to be executed at a range well in excess of the missile engagement range.

The situation, of course, becomes more demanding in a complex scenario involving a group of vessels. Here it is necessary to identify the most remote ship without entering the missile engagement zone of the closest ship. It is easy to visualize that the complexity can be extended further to include several groups of vessels in a given search area leaving little safe airspace from which to determine friendly and hostile vessels.

In peacetime, detection and classification of surface shipping at long range is desirable to avoid wasting fuel and flying time in obtaining visual confirmation of identity.

If the patrol aircraft is fitted with air-to-surface missiles, these too must have effective engagement ranges long enough not to put the aircraft at risk. However, there is no point in equipping the aircraft with such weapons unless there is a means of selecting a target confidently at the maximum useful range.

At ranges required by the above analysis, optical and infra-red sensors are not suitable either because of poor visibility or because the resolution of such systems is not good enough to allow confident recognition of vessels.

IFF systems have the inherent problem that no response indicates merely that the vessel being interrogated is not an ally (or that the shipborne transponder is unserviceable). There is nothing to indicate whether the vessel being interrogated is a civil ship, a neutral warship or a hostile ship.

Analysis of the position and characteristics of electronic emissions provides a powerful means of classification. However, rigorous emission control policies, particularly during peacetime, may restrict the usefulness of this method of identification.

The only sensor, therefore, which can reliably offer long range detection and classification is radar. Inputs from other sensors such as IFF and ESM are useful as confirmatory data.

The electronic countermeasures environment in which a surveillance radar may have to operate is becoming increasingly severe. Already the electronic jamming techniques available include broadband FM and AM noise, spot frequency and frequency jumps. Deception includes the use of chaff. In the next few years there will be an intensification of the power densities employed and much more use will be made of rapid-response intelligent electronic jamming. More representative deception measures will be employed including electronic synthesis of false targets, disguise of one ship to look like another by the addition of a number of significant reflectors, and the deployment of active and passive decoys. The radar system must operate competently in the presence of this variety of jamming techniques and it must be possible to discriminate rapidly between false and real targets.

The design of a maritime surveillance radar is also affected by the particular requirement for prolonged missions with a minimum of crew. All the functional tasks must be achieved without increasing the operator's workload.

Of the maritime surveillance radars at present in service the only one which comes close to meeting the requirements is SEARCHWATER, developed in the UK by EMI Electronics Ltd. This equipment has been in service with Nimrod MR.Mk.II aircraft of the RAF since 1979.

The long range performance of the radar in the system noise limited case is enhanced by a high power travelling-wave tube transmitter, a large aperture aerial and a low noise-factor receiver employing a parametric amplifier as the first stage. In maritime search, however, sea clutter is frequently the limiting feature. In this situation the detection capability of SEARCHWATER is improved by various signal processing techniques which assist in discriminating between a target return and sea clutter. These take advantage of space, frequency, time and amplitude effects.

The total clutter return is reduced by keeping the illuminated patch of sea small. In range the fine resolution is achieved by processing a narrow pulse using pulse compression techniques and in azimuth the aerial produces a narrow beamwidth.

Since the reflection characteristics of targets and clutter vary differently with change of transmitted frequency, SEARCHWATER employs pulse-to-pulse frequency agility and the returns occurring in the time taken for the aerial beam to pass a given point are integrated.

Clutter characteristics change over a long time interval whereas target characteristics are broadly maintained. These distinctions are exploited by employing an integrating digital scan converter to store and superimpose information from scan-to-scan.

Immediately after the detection process a threshold is introduced which is continuously adjusted by a control signal derived from the instantaneous clutter level so that in conjunction with the other processing techniques a uniform low false alarm rate is presented to the operator. All these techniques result in a North oriented, ground stabilised plan position detection display which is virtually clutter-free under all sea conditions and at all ranges so that any new radar contact is readily apparent.

Although this paper is concentrated on surface vessels the means of discriminating against clutter returns together with appropriate use of system parameter options available to the operator, results in an outstanding detection performance on submarine periscopes and snorts in high sea states.

In order to examine the characteristics of targets over a period long enough to obtain positive identification, targets are tracked automatically. The integral digital computer enables many targets to be tracked and monitored simultaneously.

High resolution displays in B-scope and A-scan formats allow classification data to be determined. Information from any of the target files is presented in alphanumeric form on the single display. After a short period of tracking the information available on a target is sufficiently detailed to permit confident classification without the need for visual confirmation. In particular the A-scan displays a detailed radar profile of the target under examination.

The means adopted for enhancing the detection performance also assist in providing the radar with effective resistance to electronic jamming. In addition, the fact that vessels can be classified implies that it is possible to recognise when deception measures are being employed.

Simple sequences of push button and roll ball operation are used for all the operating routines. The television form of display using a bright black and white tube can be viewed in normal cabin lighting levels. Operation is further simplified because the radar operator is relieved of many routine tasks which are undertaken automatically by the integral computer. In addition, a built-in test system provides automatic detection and diagnosis of faults to unit level during flight.

SEARCHWATER, in its current production form, provides all the performance described. Nevertheless, in order to be in a position to respond to the continually changing nature of operational requirements and threat analyses, there is an ongoing programme of evaluation and improvement. Incorporation of improvements is facilitated by the large scale use of software control and by the modular nature of the hardware. For these reasons SEARCHWATER can be expected to maintain its position as the leading airborne maritime surveillance radar well into the future.

LIASAR (LASER INERTIAL AIDED SYNTHETIC APERTURE RADAR)

D. E. Mertens, H. L. Jeffrie, J. A. Ziegler

Emerson Electric Company
Electronics and Space Division
St. Louis, Missouri

ABSTRACT

The LIASAR Program, sponsored by Naval Air Systems Command, will provide an integrated avionics capability for airborne weapon delivery with application to light attack/fighter aircraft. It employs a lightweight synthetic aperature radar, strapdown ring laser gyro Inertial Measuring Unit (IMU) and a common militarized general purpose computer synergistically integrated. Status and test results will be presented.

1. INTRODUCTION

Deficiences in the all weather/night operations capability of current light attack aircraft form the premise from which the LIASAR program evolved. Several of these aircraft (e.g., A-4, AV-8B, A-10, etc.) have no all weather sensors at all and others (e.g., A7-E) have sensors which represent 20 year old technology. This deficiency has been caused by the fact that conventional all weather/night operations systems are too expensive and are physically incompatible with light attack configuration.

The LIASAR system is an integrated avionics solution to this problem. The objective of the program is to perform a feasibility demonstration of an integrated radar/navigation system which has application to an all weather/night operations weapon delivery system for light attack aircraft. The light attack aircraft constraints which guide the development phase include cost, reliability/maintainability, pilot workload (single seat aircraft assumed) and physical constraints (size, weight, power).

The basic approach used in the LIASAR program is to integrate existing hardware technology to achieve the synergistic benefits accrued by their integration. Specifically, LIASAR is composed of a lightweight Synthetic Aperture Radar (SAR), a programmable digital signal processor, a MIL-specified General Purpose Computer (GPC) and a strapdown, Inertial Measuring Unit (IMU) which employs Ring Laser Gyros for basic motion sensing. Software integration of these subsystems and radar and navigation functions results in an integrated avionics system suitable for the light attack mission.

The lightweight SAR and programmable signal processor used in this application were developed with Emerson IR&D funding. The strapdown IMU was provided by Naval Air Systems Command (NAVAIR), who is sponsoring this multiyear program under Contract No. N00019-80-C-0613. The Advanced Tactical Inertial Guidance System (ATIGS X-0) was developed by Honeywell under NAVAIR sponsorship at the Naval Weapons Center. It incorporates three, GG1300 Ring Laser Gyros to perform the basic motion sensing. A triad of accelerometers is also a part of this package. While this system is in itself a proven inertial navigation system with its own navigation computer, the LIASAR interfaces directly with the ATIGS sensors to perform radar-aided navigation using its own radar/navigation software package. Synergistic benefits are derived from the fact that the ATIGS motion sensing is the fundamental mechanism which leads to the ability of the SAR to make navigation related radar measurements. Conversely, the radar measurements are utilized to update the navigation system state through a Kalman Filter to improve navigation accuracy.

The LIASAR program includes hardware and software integration of the system elements followed by test and evaluation of the system at critical milestones. The test and evaluation milestones of LIASAR were designed to minimize the risk of proceeding to the next milestone. These test phases are:

1) Hardware-in-the-Loop, Bomb Navigation Software Validation Test/Evaluation,
2) Motion Compensation Test/Evaluation,
3) Rooftop Test/Evaluation,
4) Flight Test/Evaluation.

The first two milestones (Hardware-in-the-Loop T/E and Motion Compensation T/E) were achieved in FY'81 and are reported upon herein.

2. SYSTEM DESCRIPTION

A pictorial block diagram of the LIASAR flight test hardware is shown in Figure 1. The system operates at X-band and employs a dual-axis monopulse flat plate slotted array which provides a 4.8 degree azimuth beamwidth and an 8 degree elevation beamwidth. The transmitter provides 8k watts of peak power at a 2% duty cycle using a crystal controlled X-band excitation to a Litton, Ring Loop Traveling Wave Tube Amplifier (TWTA). Prior to amplification by the TWTA, a bi-phase modulation is applied to the coherent transmit signal to allow later pulse compression to achieve a 40 foot range resolution. Low noise, GaAs FET RF amplifiers are employed in the receiver monopulse channel to minimize the system noise figure and enhance system performance. The video receiver amplifies the IF signals after coherent down conversion to 30 MHz. A frequency synthesizer is programmed by the GPC to track the clutter doppler reference frequency. Its output provides an appropriate reference for down-conversion of the IF signals to baseband for subsequent synthetic aperture processing. To retain both amplitude and phase information, both In-phase (I) and Quadrature (Q) components of the sum and difference channel signals are formed. Azimuth and elevation difference signals time share the difference channel by diode switching at the antenna. The four video channels (sum I, sum Q, difference I, difference Q) are amplified and filtered (overall bandwidth of the receiver is matched for 40 foot resolution) prior to A/D conversion in the synchronizer at a 12.5 MHz rate. The synchronizer stores the sampled data (640 range cells) in PRF buffers where it is accessible by the programmable signal processor (MSSP/DP). The processor performs all signal processing and display processing functions under the control of the GPC. These include pulse compression (128:1), motion compensation, and all doppler processing (presum filtering, FFT, etc.) required for the synthetic aperture mapping and the measurement modes. A control and display console is provided for operator control of both radar and navigation modes. Also, the display utilized serves the dual-role of radar display for high resolution mapping and navigation advisory and checkpoint editing monitor for the operator. Antenna servos and power amplifiers are housed in the power/electronics unit.

The ROLM 1664 GPC was selected as the LIASAR data processor for interim tests. All software modules were developed in a Higher Order Language to provide a transportable development software package. This integrated radar/navigation software package is built around a 16 state navigation Kalman filter which is utilized to apply radar measurements to correct the navigation system in radar-aided navigation modes.

The Inertial Measuring Unit (IMU) is housed in the ATIGS X-0, which, in itself, is a complete navigation system as mentioned earlier. Basic motion sensing is accomplished by a triad of ring laser gyros (2^{-17} radians/pulse) and a triad of Sunstrand Q-Flex accelerometers (2^{-6} fps/pulse). The LIASAR interface with ATIGS is directly to the IMU, although the ATIGS provides a parallel free inertial navigation solution which is useful in evaluating the LIASAR operating modes.

The system is implemented to perform radar aided-navigation in both overland and overwater missions. Table 1 provides a summary of the program goals. Figure 2 provides a qualitative measure of the navigation performance improvements achievable using radar-aided navigation. At the conference, actual laboratory test results are presented. The range-to-sea surface mode (unique to LIASAR) provides a 6 to 1 improvement over conventional navigation systems in overwater operation. The velocity update mode provides a 10 to 1 improvement over free inertial navigation in overland applications. Position updating using high resolution SAR maps provides 100 foot rms accuracy.

3. HARDWARE-IN-THE-LOOP, BOMB NAVIGATION SOFTWARE VALIDATION TESTS

The first major milestone in the LIASAR program was the integration of the ATIGS X-0 IMU with the LIASAR GPC with the purpose of providing a laboratory controlled validation of the navigation capabilities of the LIASAR system software. ATIGS X-0 was received from the Navy in November of 1980 at the Emerson facility. The navigation software package had previously been developed and exercized extensively using simulated navigation and radar measurement data. In addition, the ATIGS/GPC interface had been fabricated and tested prior to ATIGS arrival using a hardware simulator for the ATIGS IMU.

Integration of the ATIGS/GPC was followed by testing which duplicated ATIGS performance in the Align and Free Inertial Navigation Modes. The major difference between the ATIGS Navigation Solution and the LIASAR navigation solution was the implementation of the 16 State Kalman Filter in the LIASAR software. This was used in both the align and navigation processing (although system states are slightly re-configured for navigation) in LIASAR. In the LIASAR Free Inertial Navigation Mode, the baro is applied to the Kalman Filter as a measurement and barometric altitude is modelled as a Kalman filter state. Validation testing included duplication of ATIGS sensor pulse counts (within ± 1 count in 10 minute align), duplication of ATIGS alignment (1 mrad heading in 10 minutes), duplication of ATIGS free inertial navigation (2 nmi/hr radial position error) and duplication of the long term stability of the navigation software (stable over runs of up to 24 hours in duration).

Once these tests proved the validity of the LIASAR navigation software package, the radar-aided navigation modes were evaluated with test software utilized to simulate the "noisey" measurements of the radar system. Within the limits of the laboratory environment, radar-aided navigation performance was substantiated for the velocity update mode (position error far below 0.3 nmi/hr with 0.1 fps velocity measurement accuracy), the range-to-sea surface update mode (position error less than 0.8 nmi/2 hr with 10 mrad pointing error and 100 foot range measurement accuracy) and the position and velocity update mode (peak position errors less than 120 feet with 15 minute position update rate and 1 minute velocity update rate). These tests proved the performance of the radar-aided navigation modes with actual IMU sensor data being received, compensated and propagated to generate the navigation solution.

A fast align capability was also investigated during these tests. The Kalman Filter parameters were empirically adjusted to achieve optimum performance with the ATIGS IMU sensors. Alignment to 1 milliradian of heading in 3 minutes was achieved in the lab testing.

4. MOTION COMPENSATION TESTS

The next major milestone in the LIASAR program was the motion compensation tests. LIASAR uses a single IMU (provided by the ATIGS X-0) to perform both navigation and antenna line-of-sight motion compensation functions. This approach is implicit in the integration of avionic subsystem capabilities to achieve low cost, weight and size. Synthetic aperture radar systems must compensate for aircraft motion effects along the antenna line-of-sight to produce meaningful radar imagery. In the LIASAR system, this motion is sensed at the ATIGS location and projected (through software) to the antenna line-of-sight. Because of the physical separation between the antenna and ATIGS locations, uncompensated relative motion could occur. The Motion Compensation tests were performed to validate that this motion was within tolerance for high resolution, synthetic aperture mapping. In addition, these tests validated the capability of the LIASAR system software to properly position the antenna and motion compensate the received signals in the presence of aircraft disturbance.

For these tests, the ATIGS, LIASAR GPC, radar antenna and servo control electronics (housed in the Power/Electronics Unit) were integrated and proper operation was validated in the laboratory environment. The ATIGS and radar antenna were then installed in the flight test fixture for subsequent dynamic testing. (The LIASAR will be flight tested in a T-39D aircraft at Naval Weapons Center in late FY'82. The actual T-39D flight test fixture was utilized in these tests.)

The fixture was mounted to a LING dynamic motion table using the fixture's mounting surface which will be attached to the bulkhead of the T-39D flight test aircraft. Sinusoidal vibration inputs were applied in each of three axes (azimuth, elevation and longitudinal) with amplitudes of ± 0.25 g's and frequencies ranging from 3 to 200 Hz. This g level was picked to model the environment anticipated in the T-39D nose based upon data recorded in a previous flight test program at NWC.

Actual line-of-sight antenna motion (sensed by an accelerometer on the front face of the antenna) was compared with that predicted by the LIASAR software based upon the motion sensed by ATIGS and projected by the system to the antenna line-of-sight. Post-test data analysis was used to relate the differences noted to anticipated SAR performance. The results showed conclusively that LIASAR did satisfactorily perform motion compensation. Measured data was utilized to evaluate periodic acceleration errors, random displacement errors, antenna flat plate bending (accelerometers were placed at three locations across the flat plate and compared for this test) and antenna pointing commands. All measured errors were well below the specification values established for a 40 foot resolution mapping capability.

As a result, these tests demonstrated the ability of the LIASAR to simultaneously navigate, sense and correct antenna line-of-sight motion (for any programmable direction within the antenna gimbal limits of ± 45 degrees) with realistic dynamic motion input to the actual flight test hardware configuration. Success of this test provides a high confidence level that 40 foot resolution mapping can be achieved in the upcoming LIASAR flight test.

5. SUMMARY

The LIASAR program has successfully passed the first two program milestones as discussed above. During FY'82, the remainder of the hardware and software elements will be integrated together and tested in a rooftop environment at Emerson Electric. These tests will validate system interface, hardware and software prior to actual installation and test in the T-39D flight test aircraft at NWC. Actual system flight test will be initiated at Naval Weapons Center during late summer of 1982 as a final proof of the performance capabilities achievable with the LIASAR system.

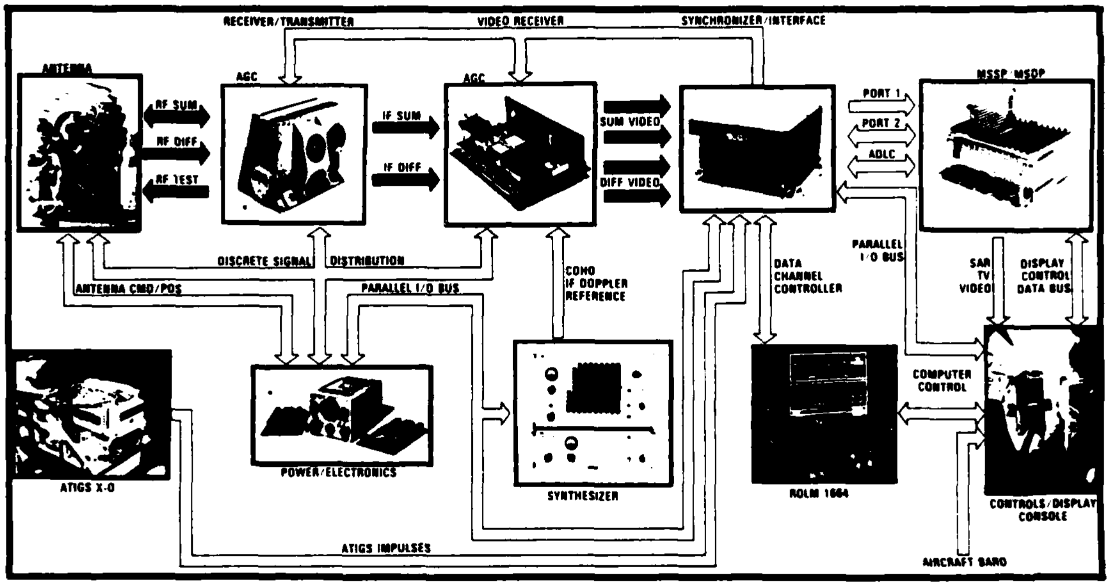


FIGURE 1. FLIGHT TEST HARDWARE BLOCK DIAGRAM

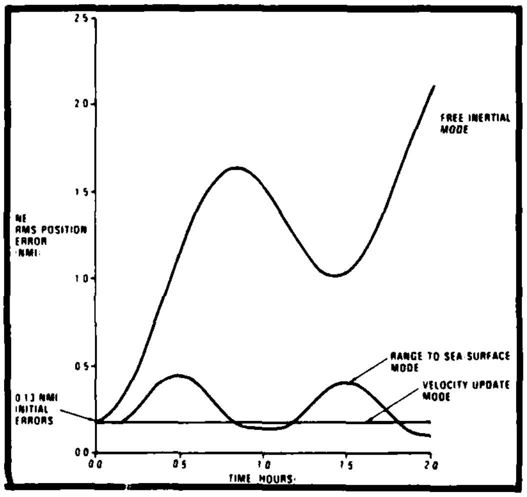


FIGURE 2. RADAR-AIDED NAVIGATION PERFORMANCE

● NAVIGATION ACCURACY	
– FREE INERTIAL (INTEGRATED BARO)	3 NMI/HR
– VELOCITY UPDATED-OVER LAND	0.3 NMI/HR
– RANGE-TO-SURFACE UPDATED-OVER WATER	0.5 NMI/HR
– POSITION FIXED (15 MINUTE INTERVALS)	100 FT RMS
● GROUND ALIGNMENT CHARACTERISTICS	4 MIN
– TIME TO ALIGN	1 MRAD AZ HEADING
– ALIGNMENT ACCURACY	0.1 MRAD LOCAL LEVEL

TABLE 1. LIASAR PROGRAM GOALS

3544-1

ARMY NEAR TERM SCOUT HELICOPTER
MISSION EQUIPMENT SYSTEM

The Bell Helicopter Textron (BHT) Model 406 (see Figure A below) provides the integrated mission equipment package necessary to effectively carry out the demanding U.S. Army Near Term Scout Helicopter (NTSH) mission. An efficient man/machine interface and superior equipment performance allow the Model 406 crew to navigate with precision; acquire, locate, and designate targets; hand off target location; and coordinate target engagement while flying nap-of-the-earth (NOE) in a high-threat environment.

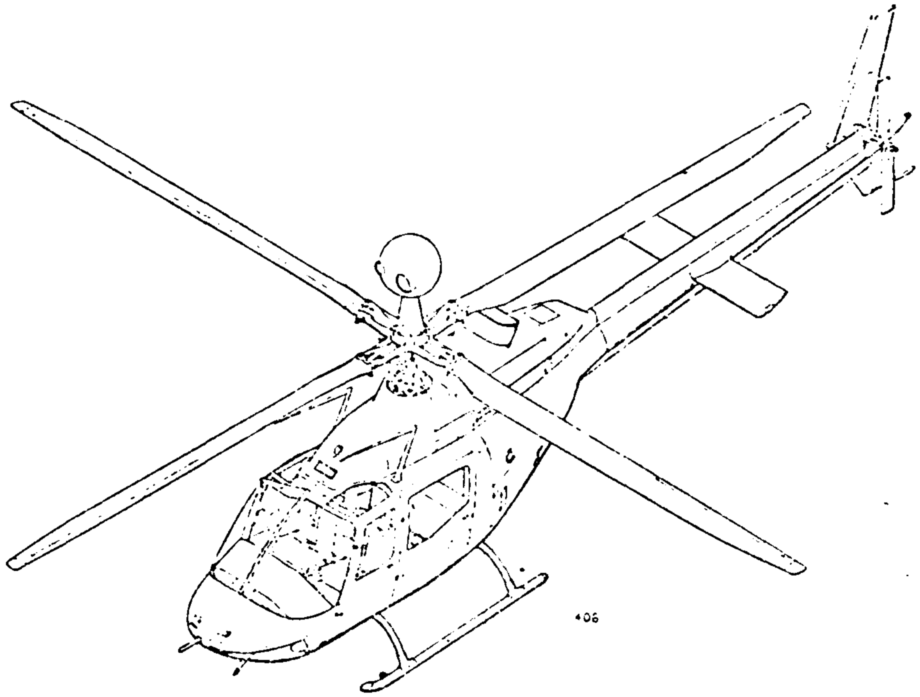


Figure A. Bell Model 406 with MDAC MMS

Bell Helicopter Textron, teamed with McDonnell Douglas/Northrop, Sperry Flight Systems, and Litton Guidance and Control Systems, provides a mission equipment package with all required capabilities, most desired capabilities, and significant growth potential.

The visionics equipment includes the McDonnell Douglas/Northrop Mast Mounted Sight (MMS) subsystem capable of acquiring, locating, and designating targets day or night or in obscured atmospheric conditions from a significant standoff range. Multifunction cockpit displays provide MMS imagery and integrated flight and mission information to enhance crew performance.

The Litton LR-80 Attitude and Heading Reference System (AHRS) and AN/ASN-137 Doppler navigation set provide accurate, autonomous navigation. The MMS, AHRS, and Doppler are fully integrated and optimized to meet the stringent target location accuracy requirements of the NTSH. The helicopter transmission and main rotor mast design is instrumented to enhance target location accuracy. Backup navigation is provided in both the AHRS and Doppler and by FM homing. The radar altimeter allows NOE operation in desert or arctic environments where visibility is reduced.

The communication equipment provides simultaneous communication with other helicopters, ground elements, close air support aircraft, and distant command and control elements. The communications equipment covers the military frequency bands from 2 MHz to 400 MHz and includes dual VHF-FM transceivers. Automatic target handoff is provided by digital data link through the communications radios. Communications security is provided for each radio to prevent the compromise of voice or data transmission.

Identification friend or foe (IFF) equipment with Mode 4 computer ensures battlefield interoperability.

The Sperry Flight Systems Control/Display Subsystem equipment provides the flexible man/machine interface functions essential to mission effectiveness.

Model 406 defensive systems include radar threat warning equipment and space, weight, and power for the Multipurpose Lightweight Missile (MLM).

The Model 406 instruments display provide backup information and engine, drive train, and electrical system parameters. The cockpit electroluminescent lighting is tailored to third generation night vision goggles.

The MMS accomplishes its targeting functions by means of a day TV subsystem (TVS), a night/poor-visibility thermal imaging system (TIS), and a laser rangefinder/designator - all mounted on a high-precision, stabilized platform.

The sight is mounted so that the sensor lines-of-sight are 32 inches above the rotor and the sight can be pointed over a ±30° elevation angle and ±190° azimuth (giving full 360° coverage with 20° overlap at the rear). The elevation and azimuth pointing capability place the minimum limitation on aircraft roll and pitch attitude and no limitation at all on direction of target engagement.

The MMS turret/aircraft interfaces are depicted in Figure B. The stabilized platform contained within the ball is supported by a conically shaped composite post that also contains the MMS heat exchanger. The post is bolted to a stationary sight-support platform which is prevented from rotating by means of a standpipe that passes through the center of the rotor mast. Wiring between the mast mounted portion of the MMS and its electronic boxes in the electronics compartment below passes through the standpipe.

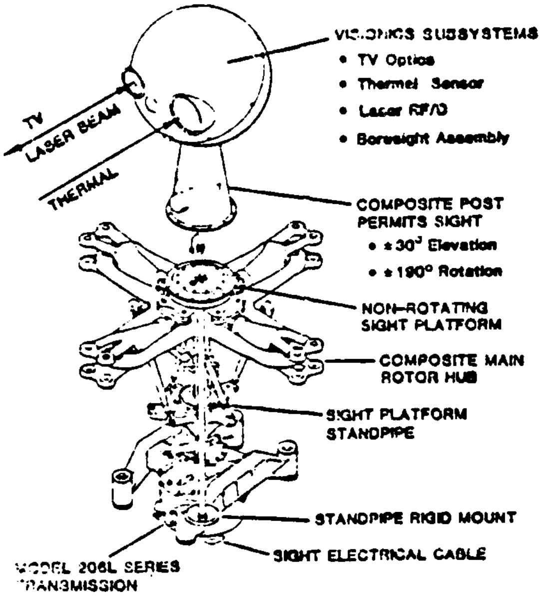


Figure B. MMS turret/standpipe interfaces.

The functional interface between the Mast Mounted Sight subsystem and the rest of the aircraft is established by a MIL-STD-1553 data bus for the exchange of data and control information and EIA RS-343 video signals.

The TIS is designed using DoD common modules and afocal optics to produce a thermal image. A digital scan converter (DSC) converts the parallel image format of the common module scanner to a standard display format, which is then presented on either the pilot's or copilot/observer's displays.

The TVS is formed by combining a qualified silicon-target vidicon TV camera, developed for TADS and modified for SEAFIRE, with a 4.0-in aperture refractive telescope. The objective aperture for the TVS is shared with the Neodymium: YAG, 1.064-μm laser rangefinder/designator (LRF/D). TV imagery is presented on either display surface.

A more detailed illustration of the mast mounted sight is presented in Figure C.

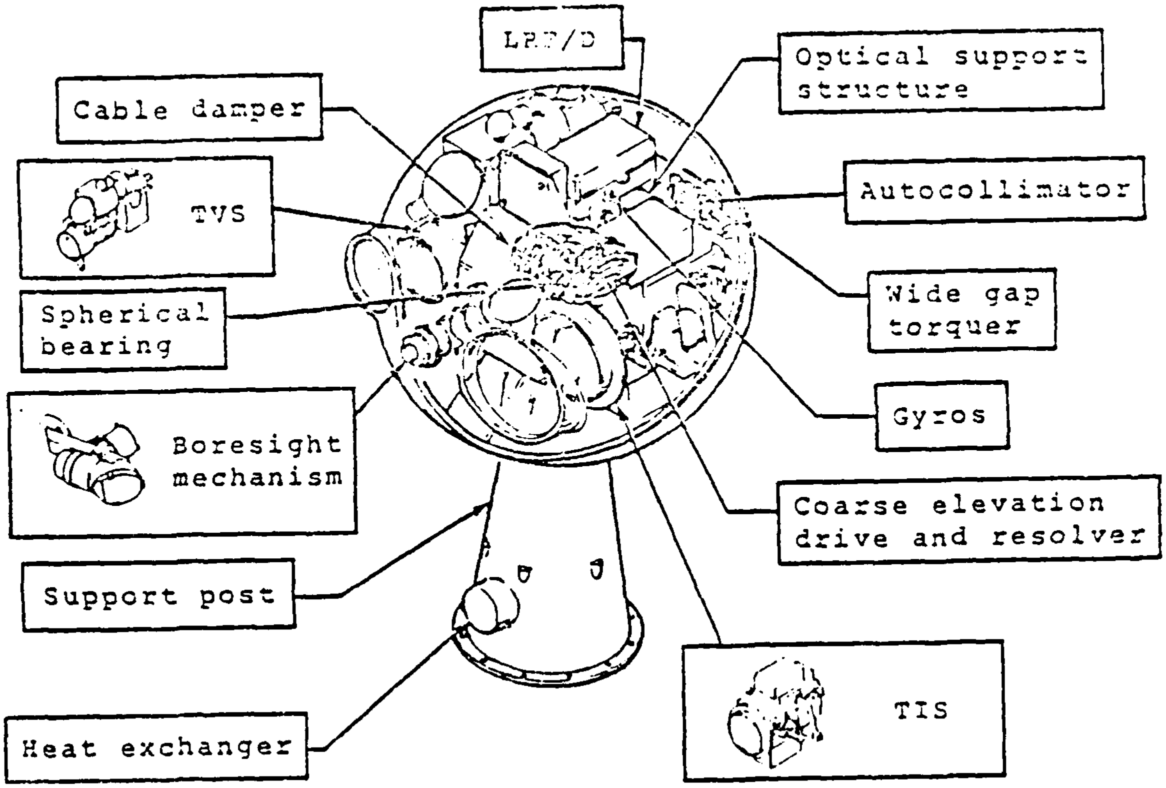


Figure C. MMS turret components.

The sensor package is complemented with an boresight assembly that enables inflight boresighting of the TIS and TVS to the LRF/D. The automatic boresight (no operator action required) is accomplished in 30 seconds to maximize designation performance.

The Mast Mounted Sight provides target line-of-sight angles, angle rates, and range data to the navigation system. Using these data the navigation system computes the UTM coordinates of the targets more accurately than required by the Army. The angle rate data also permit the system to compute the speed and direction of moving targets.

As shown in Figure D, the pilot and copilot/observer each have a large 8-in diagonal, high-quality video display. On these two displays they can simultaneously view the TVS or TIS or one crewmember can look at the TVS while the other observes the TIS. A set of pushbutton switches surrounding each multi-function display permits each crewmember to call up a variety of display data and to control many of the functions of the NTSH.

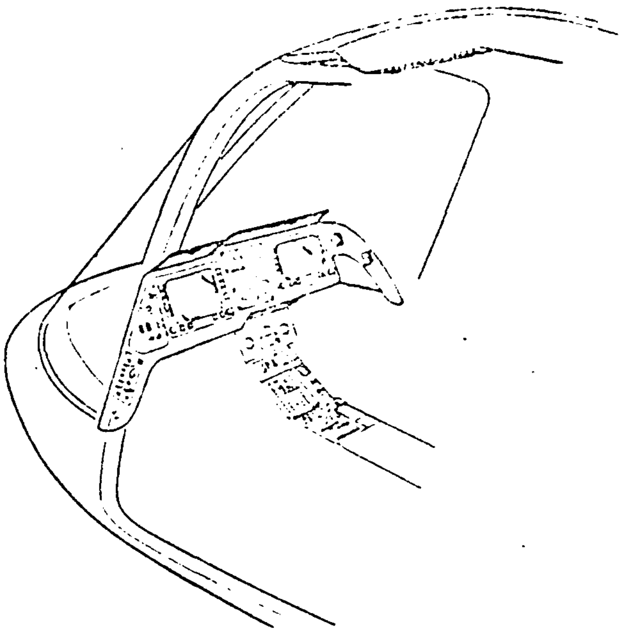


Figure D. NTSH panel layout.

The performance of the MMS would be considered excellent if it enjoyed the relatively benign vibrational environment found on the nose of a helicopter; but to achieve such performance despite the more severe vibrations encountered on the rotor is exceptional. The fact that the MMS can perform so well in this hostile vibration environment is due almost entirely to the vibration isolation provided by the Internal Bearing Sight Stabilization Unit (IBSSU). The IBSSU was developed by McDonnell-Douglas and has been flight-proven in an Army AH-1 helicopter. Isolation from linear motions of the sight support is achieved by means of a set of soft, well-damped springs, or isolators. Angular isolation of the payload about all three axes of rotation is provided by a very-low-friction spherical multiball bearing. The payload is slewed by wide-gap electromagnetic torquers that never physically touch the payload, thereby eliminating unwanted torques reaching the payload. In fact, the isolation from rotor vibrations provided by the IBSSU is so effective that the disturbance to the sensor lines-of-sight is less than 10 μrad (0.000573°). This virtually rock-steady stabilization system provides the foundation for the high performance sensors.

An automatic tracker system (ATS) provides the accuracy necessary for detection/recognition and designation at the longest ranges. It is a dual-mode tracker with one algorithm for scene tracking and a second point track algorithm for high-accuracy tracking of a target within the scene.

The NTSH navigation subsystem is based on the Litton LR-80 Attitude and Heading Reference System (AHRS) and AN/ASN-137 Doppler navigation set. Doppler velocity and helicopter inertial data are combined and statistically optimized in the AHRS. The AHRS functions as the navigation computer providing position, attitude, heading, target location, and refined velocity and acceleration to the CDS computer elements, the master controller processor units (MCPUs). The MCPUs manage data flow in the subsystem and convert the navigation data to integrated display formats available to the crew on the multifunction displays (MFDs). Navigation accuracy meets the stringent NTSH requirements and is enhanced by periodic position updating. To update, the crew sights a known checkpoint with the MMS and the AHRS corrects accumulated error and refines its knowledge of system error sources.

The Model 406 upgrades Aeroscout communications for secure NOE operation and battlefield integration. Dual VHF-FM radios operating from 30 to 88 MHz with 40 W effective radiated power increase NOE communication range. An HF-SSB radio with grounded loop antenna adds medium and short range NOE capability from 2-30 MHz. A UHF-AM radio provides communication with close air support aircraft from 225 to 400 MHz. Communication security equipment for each radio prevents compromise of mission information. Automatic target handoff provides digital data communications over any radio ensuring interoperability with current and future weapon systems. Retransmission capability allows the Model 406 to automatically relay radio messages increasing the communication range of ground units.

The mission equipment architecture provides substantial backup capability through the use of multiple processors and distributed interface electronics.

The NTSH mission equipment architecture allows growth to new technologies without extensive modification. Digital interfaces, computer control techniques, and the MIL-STD-1553B data bus provide flexible baseline avionics capable of software modification to accommodate new subsystems. The reserve capacity ensures growth capability throughout the Model 406 service life.

IMPROVED ELECTRONIC WARFARE DISPLAYS FOR ATTACK AIRCRAFT[1]

Richard J. Farrell, Weslie L. Andres and James D. Gilmour
The Boeing Company, Seattle, Washington

Radar-directed surface weapons pose a severe threat to aircraft survival during combat. The electronic warfare (EW) threat-warning system provides the crew of an aircraft with information about current radar-directed threats that can be used to enhance survival. Conflicting requirements are imposed on the display portion of the EW threat warning system. The display must provide the aircrew with enough information about the EW threat to decide what response, if any, to make, but the aircrew is often in a high workload situation that leaves little time to scan and interpret the display.

The goal of this study was to develop concepts for improving the display of EW information to the aircrew based on existing or near-term EW sensors and computational capability. The scenario for this development was a low-level interdiction mission by Navy attack aircraft over land. The primary emphasis was on land-based threats, but the future addition of airborne and sea-based threats was an important consideration.

The study was crew-oriented in that the emphasis was on what information the aircrew needs to respond effectively to the EW threat and how this information might be displayed for most effective use by the aircrew. The approach to the concept development involved four activities: (1) identification and analysis of threat characteristics and threat warning sensor capability, (2) determination of what EW information is required by aircrews, (3) development and evaluation of several candidate display concepts and (4) utilization of the results of the previous three activities to evolve two display concepts and associated information processing algorithms for future simulator evaluation.

The results of the first activity, identification of threat and sensor characteristics, are described in the classified supplement to the study report.[1] The remaining three activities are described below.

PRESENT EW DISPLAYS

The AN/ALR 45 display currently in use in A-6 and A-7 aircraft is illustrated in Figure 1. In this display, site azimuth is indicated by the orientation of a coded signal line. The line length indicates signal strength and the line pattern (solid, dashed, etc.) along with other discrete signal lights (not shown here) indicates the type of threat.

The AN/ALR 45F/67 display currently under development by the Navy is illustrated in Figure 2. In this display, site type is indicated by an alphanumeric symbol such as a "6" for an SA-6 and a "3" for an SA-3. The symbol is positioned further out on the display as the severity of the threat posed by the site increases, hence this might be called a "severity out" display. The characteristics of the RF signals received from the threat are compared with a threat signature reference file to compute severity. The radial position of the symbol indicates the azimuth of the site relative to the aircraft.

EW DISPLAY INFORMATION REQUIREMENTS

An EW display should present all the EW information essential to the aircrew in carrying out their mission but should not be cluttered with irrelevant information. To establish what information was most important we took two complementary approaches. These were (1) interviews with and evaluations by crews of Navy attack aircraft and (2) analysis of the EW aspects of interdiction type missions in terms of threat characteristics, sensor capabilities and probable mission tactics.

The following list of information categories that might appear on an EW display was evaluated during the study. Note that some of this information may not be available with currently operational sensors and data processing.)

[1] This study was sponsored by the Naval Weapons Center, China Lake, CA, under contract N60530-80-C-0230. An NWC technical report is in preparation. Contract monitors were Ron Erickson and Mike Barnes.

A. DELETED

B. Type of Site - The site is a specific type, such as an SA-6 or ZSU-23-4. An SA-6 might be encoded as a "6", or by a special symbol or pattern.

C. Azimuth of Site - The site is located in the indicated direction relative to the display user's aircraft.

D. Site Operating Mode - The site is in the specified operating mode, such as tracking, prelaunch (guidance carrier present), launch (data present on guidance carrier, illuminator on), etc.

E. Threat Severity - The severity of the threat posed by the site is as indicated. This information would be based on an algorithm representing a combination of other information such as site type, location and operating mode, and on aircraft vulnerability to that type of site at current altitude and velocity.

F. Site Range - The site is located at the indicated distance from the display user's aircraft.

G. Range Certainty - This is the certainty with which the location of the site has been established. It might be displayed as an envelope enclosing specific probability limits for the site range and azimuth relative to the display user's aircraft.

H. Missile launched - A missile launch by the site is confirmed. This might be based on data other than passive RF.

I. Missile location - The missile launched by the site is at the indicated location relative to the display user's aircraft.

J. Premission - hardcopy - This information about threats is available to the aircrew prior to the start of the mission. It is presented in a hardcopy form such as a map.

K. Premission - displayed - This is the same information described in Category J, except that it is contained in the aircraft data store and it appears in real time on the aircraft EW display.

L. Best maneuver - Based on an algorithm representing current conditions, the optimum flight maneuver is displayed.

M. Best route - Based on an algorithm representing current conditions, the optimum route or direction to fly is displayed.

N. ECM target site - This is the threat that is the current target of the aircraft Electronic Countermeasures (ECM) system.

O. ECM effectiveness - This is an indication of the success achieved by the aircraft ECM system in responding to each threat.

This list of information categories was evaluated for importance by nine A-6 aircrew members at Whidbey Island NAS, five A-7 pilots at Lemoore NAS and two A-7 pilots in VX5 at China Lake NWC.

Referring to the summary of their ratings in Table 1, aircrews were most concerned with information about threat status that would allow them to interpret and then respond to the threat. Information categories rated most important concerned a launched missile (G - MISSILE LAUNCHED, and H - MISSILE LOCATION RELATIVE TO THE AIRCRAFT) or the launch site (A - SITE TYPE, B - SITE AZIMUTH RELATIVE TO AIRCRAFT, C - SITE OPERATING MODE and E - SITE RANGE FROM AIRCRAFT).

Information categories that represented a processing of threat status information and a display of the conclusions were rated less important. These were Category D - THREAT SEVERITY (red for extreme danger in a particular area, etc.), Category L - BEST MANUEVER and Category M - BEST ROUTE. The major concern here seemed to be whether adequate sensor data and algorithms necessary for such processing would be available.

Premission data were not rated a desirable addition to the EW display (Category K). This low rating reflects two factors. In an era of increasingly mobile threats, data gathered prior to the mission are likely to be too old to be valid. Also, the primary role of the EW display is to warn of immediate threats that are currently active against the aircraft. To achieve this goal, clutter from data not of immediate use (such as most premission data) must be minimized. More remote threats are better displayed on the horizontal situation indicator (HSI) or the moving map display. Alternatively, the EW display might have several operating modes, with premission data appearing only when requested by the aircrew.

CANDIDATE EW DISPLAY CONCEPT EVALUATION

A total of about 13 candidate display concepts were developed and evaluated during the study. This process helped us to assess both the feasibility of displaying particular categories of information and the desirability of particular display features. Several different features were compared in the candidate display concepts. Some, for example, used color for coding information while others did not. A few of the concepts.utilized a "forward-looking" ("out-of-window") format to show the threats ahead and to the sides of the aircraft while others used a "plan-view" (map-like) format to show the threats on all sides of the aircraft.

One problem with a plan-view display format is that it provides less space for showing the threats that are closest to the aircraft. Unfortunately, these are often the threats of greatest interest to the aircrew. In an attempt to alleviate this problem, some of the candidate concepts incorporated nonlinear scaling, with the region closest to the aircraft (at the display center) expanded relative to the display periphery. Other plan-view concepts used a constant scaling.

The candidate display concepts were evaluated by Navy A-6 and A-7 aircrews in static presentations. This provided us with inputs from crews of both one-place and two-place aircraft. Based on their evaluation and on our own assessment of the concepts, we reached a number of conclusions about an EW display for use in an attack aircraft.

In general, the candidate display concepts rated most favorably by the aircrews were those that included the greatest number of the most important EW information categories. To put this another way, the aircrews wanted to know as much as possible about the threat situation. Displaying large amounts of information poses potential problems of clutter and reduced interpretability of the display that need further evaluation.

The presently-used EW display illustrated in Figure 1 is undesirable because it is too difficult for the user to establish the type and operating mode of each threat.

Our first impression of the display in Figure 2 was also negative. The display seemed to be inside out. The most important threats were located at the edge of the display, where they were most distant from the aircraft position at the center of the display. As a result, the display seemed to be anti-intuitive and potentially hard to interpret.

As we attempted to develop better concepts we become more favorably disposed toward this display. Within the cockpit-imposed limitation of a very small display, the placement of the most severe threats at the edge of the display provided two advantages. It yielded good indication of threat azimuth, and it provided the greatest possible area for displaying threat symbols without overlap. Through continued exposure to the display, we also become more comfortable with what initially seemed to be an "inside out" presentation.

We expected that "forward-looking" displays would have some appeal over plan-form displays because the former portray threats in a manner more akin to the way they appear in flight. The forward-looking concepts proved to be among the least preferred by the aircrews. One difficulty was that such a display shows only a portion of the ground area that can contain threats.

Another problem a forward-looking display is the difficulty of adequately encoding the threat situation. The aircrews expressed a need to know both the type and operating mode of each threat, rather than just a summary of threat severity in a particular direction. However, the large number of threat types and operating mode categories makes it difficult to present all of this information in a forward-looking format.

Finally, the aircrew members noted that even though a plan-view display was not visually similar to the flight situation, they regularly use plan-view displays (maps) for planning and navigation and hence such a display format is not difficult for them to interpret. All of these points support the superiority of plan-view over forward-looking presentation of EW threat warning data.

Nonlinear scaling of the display, with the central region expanded, appears to be desirable in a plan-view format. However, nonlinear scaling poses potential problems of interpretability that require evaluation.

EW DISPLAY CONCEPTS FOR FUTURE DEVELOPMENT

The final activity in this study was development of two EW display concepts and associated information processing algorithms for future simulator evaluation. These concepts are illustrated in Figures 3 and 4 and the categories of information that can appear on each are listed in Table 2. Note that because of the need to minimize clutter whenever any threat enters the launch mode, not all of these information categories would be present simultaneously. In addition, not all of these categories of information are necessarily available with presently operational EW sensors.

Both concepts display threat type, operating mode and azimuth relative to the aircraft. Concept A is entitled "Signal Strength" because it uses threat signal strength, normalized to nominal signal strength at the threat lethal range, to provide a rough indication of the range to the threat. Concept B is entitled "Nonlinear Map" because it displays threats at their measured range and azimuth relative to the aircraft using a map-like format and because the scaling is nonlinear. The scale is expanded toward the center, where knowledge of threat location is more important to the display user. The scale illustrated in Figure 4 happens to follow a fifth-root function from 0.1 to 100 nautical miles; these values will probably be modified somewhat during subsequent development of the concept.

TABLE 1. Mean Rated Importance of Information Categories

INFORMATION CATEGORY	AIRCREW		
	A-6	A-7 LEM.	A-7 VX5
B. Site Type	9.1	9.8	9.5
C. Site Azimuth	9.8	10.0	10.0
D. Site Op Mode	8.3	9.4	9.5
E. Threat Severity	8.2	7.6	7.5
F. Site Range	8.8	8.8	9.5
G. Range Certainty	7.3	6.2	5.5
H. Missile Launched	10.0	9.8	10.0
I. Missile Location	9.6	8.4	9.0
J. Premission-Hardcopy	7.7	2.0	6.0
K. Premission-Displayed	4.6	2.2	1.5
L. Best Maneuver	4.6	6.8	4.5
M. Best Route	7.1	4.6	5.5
N. ECM Target Site	5.7	6.6	5.5
O. ECM Effectiveness	5.2	8.2	6.0

NOTE: Very important = 10, not important =1

TABLE 2. Coding of Information in Each Display Concept.

INFORMATION DISPLAYED	METHOD OF DISPLAY	
	CONCEPT A	CONCEPT B
Missile Location	Not Displayed	Location of Triangle
Launch Confirmed	Symbol Blinks	Symbol Blinks
Guidance Data or Illuminator (Probable Launch)	Azimuth Line Strobes	Azimuth Line Strobes
Guidance Carrier Present	Larger Reverse Video Symbol	Larger Reverse Video Symbol
Site Location	Not Displayed	Symbol Location on Display
Site Signal Amplitude	Length of Line	Not Displayed-Can Contribute to Range Data
Site Tracking You	Assumed if Site is Displayed	Assumed if Site is Displayed
Azimuth of Site	Azimuth of Line and Symbol	Azimuth of line
Type of site	Symbol Code	Symbol Code
A Site is Present	Displayed	Displayed
GCI Radar Active	Symbol Code Possible	Symbol Code Possible
Flight Advisory	Arrow Possible	Arrow Possible

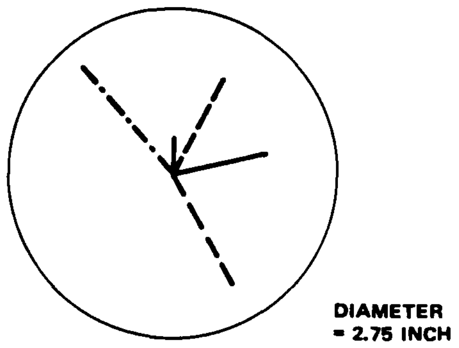


Figure 1. AN/ALR 45 Display

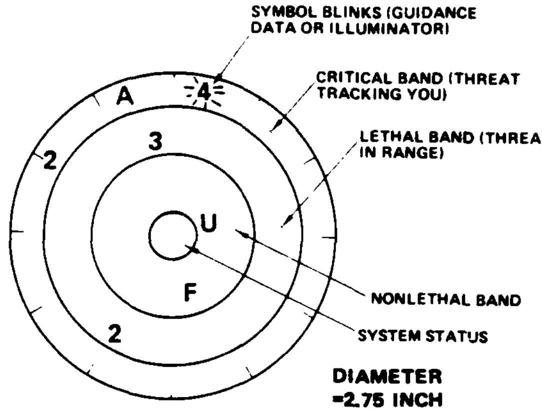
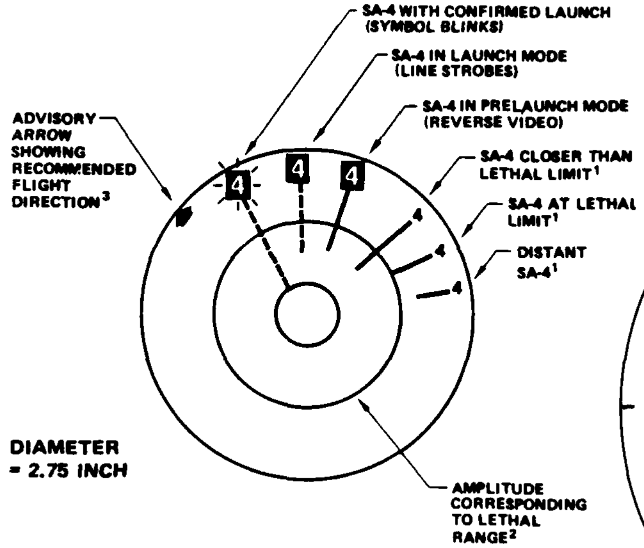


Figure 2. AN/ALR 45F/67 Display



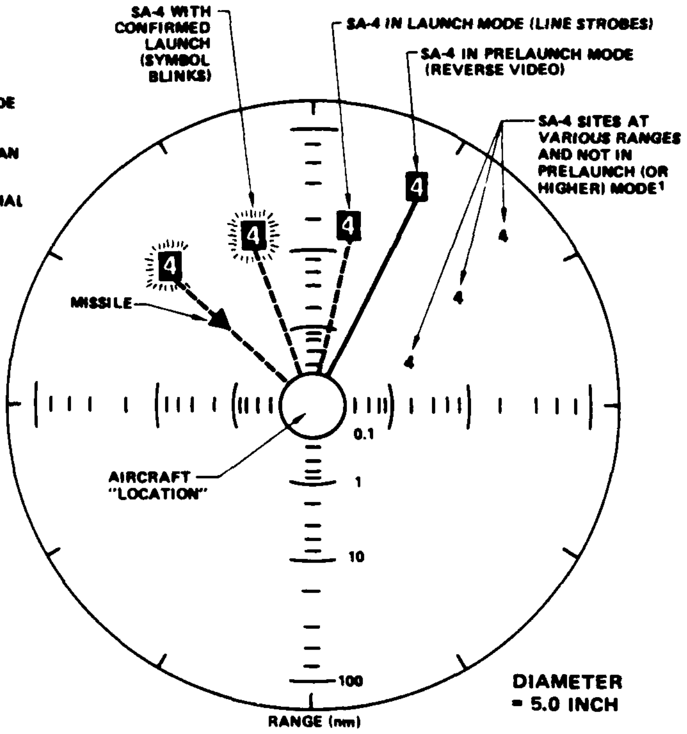
Coding:

Symbol indicates type of threat (SA-4, etc.)
Length of line indicates signal amplitude from threat
Location of symbol (and of amplitude line) indicates azimuth
Larger, reverse video symbol indicates possible launch

1 User can set up normal operating mode to display these lower priority threats, to suppress them entirely or to delete the signal line when high priority threats are present.

2 Lethal amplitude ring optional with user

3 Advisory arrow optional with user



Coding:

Symbol indicates type of threat (SA-4, etc.)
Symbols are located at probable site location
Larger reverse video symbol indicates possible launch

1 User can set up normal operating mode to display these lower priority threats or to suppress them.

Figure 3. Display Concept A, "Signal Strength", Showing Examples of all Encoding Possibilities

Figure 4. Display Concept B, "Nonlinear Map", Showing Examples of all Encoding Possibilities

INFRARED GUIDANCE DEMONSTRATION (IRGD)

Larry J. Marshall, Robert N. Cullis, R. Lloyd Riffe, W. Meriwether Furlow

Martin Marietta Aerospace
Orlando, Florida

This paper summarizes the test results obtained with a state-of-the-art infrared seeker during the Infrared Guidance Demonstration (IRGD) program sponsored by the Air Force Armament Laboratory, Eglin AFB, Florida under Contract F-08635-79-C-0236. This program is a benchmark for the capability of available real time infrared technology in the anti-armor role. A brief definition of the problem, identification of the technology employed and description of the test program are presented as a preface to the test results.

The intended application of the seeker is to a completely autonomous anti-armor weapon that, after delivery to the target area, will search for, discriminate, acquire and track ground combat vehicles in the presence of background clutter and in an adverse weather and countermeasures environment. The requirements to search large areas and penetrate under cloud cover lead to a low altitude level cruise trajectory. At the resulting shallow depression angles target thermal signatures are small compared to those seen from the top aspect. (Figure 1) A low false alarm rate is also necessary because of the large area searched. The technical problem is to recognize the small target signature embedded in background clutter, reject the clutter, and rapidly search a large area (300,000 square meters in 1 second).

The baseline target detection technology is real time image processing. (Figure 2) In the prefilter, an algorithm operates on the input scene to enhance selected target features and extract them from the clutter. The post processor accumulates the features in an area commensurate with the target size and develops a merit function indicative of the liklihood that the area contains a target.

The detection function generates an adaptive threshold and applies criteria such as spatial extent to the decision process. Processing is done simultaneously in two color bands to provide rejection of countermeasures and fires. The centroid of the active thermal features on the target is used for tracking rather than a predominant hot spot. The seeker was implemented as a flyable brassboard with integral test instrumentation. A detailed computer simulation model of the seeker was developed and validated concurrently to predict and corroborate test results.

A year long test program consisted of static tower tests and captive flight tests flown in a Sikorsky S-58 helicopter at Eglin AFB, Florida. Flight tests were also conducted at the Stockbridge facility near Griffiss AFB, N. Y., to investigate the effects of a winter climate.

Realistic conditions were maintained with both foreign and domestic armored vehicles as targets. These were viewed from all aspects under operational conditions from idling to actively exercising. A countermeasures environment was available during participation in Smoke Week III and at other times by devices placed in the target area.

The major results were characterization of the seeker maximum acquisition range capability, and the acquisition probability as functions of test variables. Thermographs showing the quantitative target signature were collected for each trial by an independent instrumentation system and made available by the Air Force for correlation with test results.

Acquisition probability against 4 target types, idling after exercise, was measured at a fixed range during tower tests. Targets were positioned on an earth embankment to provide a realistic depression angle from the 290 foot seeker altitude. Performance was measured against the four principal aspects in 300 trials. As a check on the results the seeker simulation model was exercised using signature data from the Air Force data bank. Measured and simulated results correlated well.

During captive flight tests the impact of target aspect, operational history and climatic conditions were established.

Approximately 500 trials were conducted in measuring acquisition performance of the seeker. Range at acquisition and probability of acquisition were consistent with tower test results. Target ΔT, determined from thermographs, was used to compute the range dependence on temperature for all aspects of two target types. The limits of seeker performance were found.

False target detection performance is as important as true target acquisition in assessing the tactical value of the seeker. This was measured by searching prescribed areas, each several square kilometers in extent, and computing the density per square km of false target objects detected. The objects were categorized by type. A measure of the seekers ability to reject false targets demanded knowledge of ground truth. In the case of the houses, barns and rural buildings prevalent at Stockbridge, ground truth was established by aerial photography of the search area and the rejection rate for this type objects was found. The photographic approach was not applicable to counting the terrain features and discontinuities that caused clutter detections. Although clutter rejection capability could not be quantified, the density of clutter detections measured at Stockbridge and Eglin was acceptably low.

Conclusions reached as a result of the comprehensive test program are:

- Performance of the seeker represents a significant advance in the major areas of system parameters:
  - Target acquisition capability
  - Countermeasures immunity
  - False target discrimination
- Real time image processing technology is applicable to IR seekers and is available to support future autonomous anti-armor weapons.
- The rapid advances currently being made in image processing and the progress in large scale integration of electronics offer the promise of practical IR seekers that can bring enhanced performance to a variety of tactical roles.

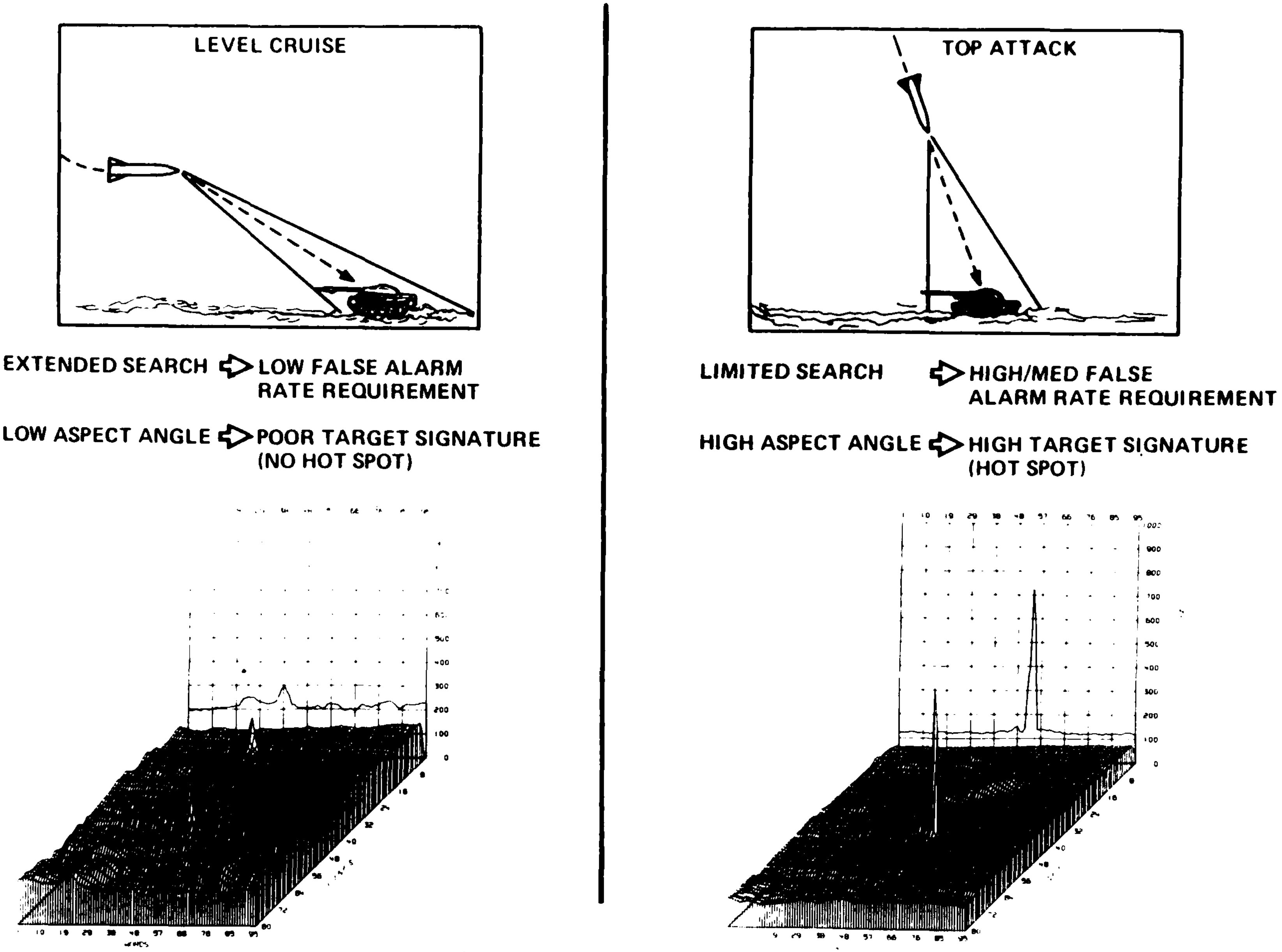


Figure 1. Scenario Comparison

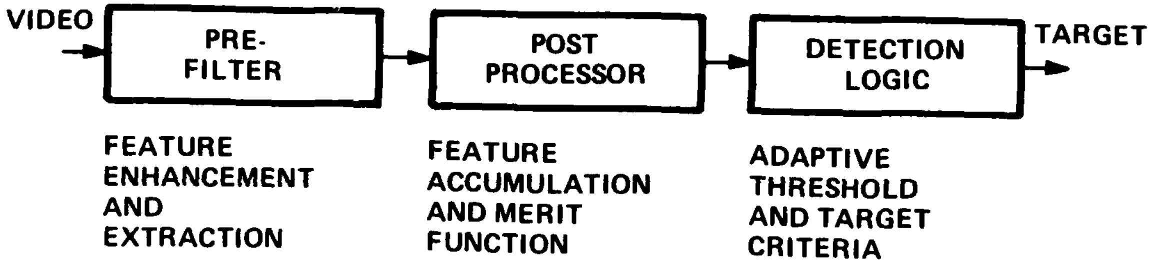


Figure 2. Image Processing Techniques

OPERATIONAL REQUIREMENTS FOR AN ARMY AIRCRAFT SELF-PROTECTION CONTINUOUS-WAVE JAMMER

Lawrence A. Eusanio
Principal Research Engineer
Arvin/Calspan Advanced Technology Center
Buffalo, New York 14225

This paper describes an analysis effort to determine the operational requirements for a continuous-wave (CW) jammer to be employed as self-protection on U.S. Army Special Electronic Mission Aircraft (SEMA). The Navy is the lead service in the development of the ALQ-162 jammer, which is based on previous developments by the Army, the Navy, and industry. One of the objectives of the analysis effort was to determine whether the Navy's specifications would fill the Army's operational requirements. The Army plans to employ this equipment on low-performance, fixed-wing aircraft and on rotary-wing aircraft that generally fly stand-off missions on the friendly side of the Forward Line of Own Troops (FLOT). The Navy plans to employ the equipment on high-performance aircraft that penetrate FLOT. The analysis addressed a number of distinct issues regarding the Army's employment of a CW jammer including its effectiveness against threats to Army aircraft, signal environment, aircraft installations, interfaces with other equipment and crew, and counter-countermeasure susceptibility. It was found that the system specified by the Navy could also meet the Army's requirements. Recommendations were made for several modifications to the system that would enhance its capabilities for the Army's applications.

This presentation outlines the scope of the study and presents a few sample results. Perhaps the most important point of this presentation is that an electronic jammer can be developed to satisfy a variety of applications and can be used by more than one service. The ALQ-162 program is a noteworthy example of interservice and industry cooperation. It would be interesting to trace the history of development involving the activities of various Navy agencies, the Army's Electronic Warfare Laboratory, and private industry.

However, Calspan was not involved in the early history of the program and can neither take credit for the cooperative activities nor report them on a first-hand basis. So the story will be picked up at the point at which the Army's Project Manager for Aircraft Survivability Equipment (PM-ASE) asks the questions: What are the requirements for a CW jammer on Special Electronic Mission Aircraft (SEMA), and how do the evolving specs for the ALQ-162 match these requirements?

One of the characteristics of the ALQ-162 design concept is built-in flexibility including many programmable features. Such flexibility makes it possible to employ the jammer in multiple applications. However, it is necessary to examine the requirements imposed by each application to ensure that the system can encompass them.

The SEMA are identified in Table 1. A previous study* analyzed the tradeoffs between survivability and mission accomplishment and established optimum flight profiles for each mission type. In general, the ability of a SEMA system to perform its mission increases with decreasing standoff range to FLOT and increasing altitude. The opposite is true for survivability. Since the Warsaw Pact presents a formidable air defense, the SEMA will fly relatively far from FLOT, but at a relatively high altitude to reduce the effects of terrain masking on mission accomplishment. Consequently, the Army needs to use a CW jammer on low-performance aircraft flying at relatively high altitude and far distances from FLOT. The Navy plans to use the ALQ-162 CW system high-performance jets flying close support and penetration missions at relatively low altitudes. Under these conditions, the greatest CW threats to the Navy's mission are surface-to-air missiles (SAMs); the greatest CW threats to the Army's mission are air-to-air missiles (AAMs).

The Navy system includes a single antenna with coverage primarily

---

*"Summary - U.S. Army Special Electronics Mission Aircraft Survivability and Mission Accomplishment Tradeoff Analysis (SEE SAFE)", Calspan Report No. AV-6063-X-3, March 1978, SECRET.

Table 1. SPECIAL ELECTRONIC MISSION AIRCRAFT (SEMA) SYSTEMS INCLUDED IN STUDY

MISSION SYSTEM	MISSION	PLATFORMS
QUICK FIX	COMMUNICATIONS INTERCEPT/DF/ECM	EH-1H, EH-1X, EH-60A
MULTEWS	RADAR ECM	EH-1U
SOTAS	COMBAT SURVEILLANCE/TARGET ACQUISITION	EH-60B
SLAR	COMBAT SURVEILLANCE/TARGET ACQUISITION	OV-1D
QUICK LOOK	RADAR INTERCEPT/DF	RV-1D
GUARDRAIL V	COMMUNICATIONS INTERCEPT/DF	RU-21H, RC-12D
IR/PHOTO	RECONNAISSANCE	OV-1D

in the lower hemisphere. Because of the flight profiles and threats, it was considered necessary for the Army to add a second antenna and a power splitter to provide more extensive coverage in the upper hemisphere at the expense of the system gain. Thus, receiver sensitivity and jammer power became more important issues in the Army application.

The Navy's system is intended to use both an external CW radar warning receiver (APR-43) and the receiver in the ALQ-162. Since the Army aircraft are very weight limited, the APR-44 CW warning receiver will be removed when the ALQ-162 is installed. Therefore, the ALQ-162 must also provide the warning function when employed on SEMA systems.

PM-ASE has sought to standardize the types of information that compose the operational requirements for the various equipments he is developing. In specifying these requirements, Calspan addressed a number of issues including those identified in Table 2. While it is not possible to cover these in any detail in this presentation, some sample results will be presented to illustrate the first four issues identified in Table 2.

The Navy's specification required the signal recognition threshold to be settable over a wide range of signal powers. It was found that it would be desirable to have an even lower threshold for the Army's application because of the signal power losses involved in a two-antenna installation. This would be particularly important for the airborne threats that have relatively low-power radar illuminators. However, if the threshold were at a very low level to detect the airborne threats, the SAM radars (which are very powerful) would cause false alarms from hundreds of kilometers away. It was, therefore, recommended that 1) the signal recognition threshold be settable or programmable over a wider spread, 2) separate thresholds be available for each frequency band (threat band), and 3) separate thresholds be available for warning and for jamming.

Several candidate installation configurations (each assuming use of the existing APR-44 antennas) were examined from two points of view for each

Table 2. ISSUES ADDRESSED IN STUDY

- SIGNAL RECOGNITION THRESHOLDS
- SYSTEM EFFECTIVENESS FOR DETECTION AND FOR JAMMING
- RECEIVER, TRANSMITTER, INSTALLATION GAIN REQUIREMENTS
- INSTALLATION/ANTENNA CONFIGURATION REQUIREMENTS
- LAUNCH ENVELOPES AGAINST SLOW-SPEED TARGETS
- MISS DISTANCE AND JAMMING POWER-TO-SIGNAL POWER RATIO (J/S) REQUIREMENTS
- PULSE DOPPLER THREAT
- SUSCEPTIBILITY TO COUNTER-COUNTERMEASURES (CCM)
- CREW INTERFACE
- MINIMUM AIRCRAFT SEPARATION

aircraft. First, if the receiver and transmitter designs were fixed, what must the required gains/losses be to defeat the threat? Second, if the installation were fixed, what must the required receiver sensitivity and jamming power be to defeat the threat? Candidate fixed-wing-aircraft installations appeared to be adequate, but improvements were recommended for the rotary-wing-aircraft installations.

The ALQ-162 program is a good example of interservice and industry cooperation leading to the development of equipment having distinct applications in more than one service. This presentation outlines an analysis of operational requirements for a self-protection, continuous-wave (CW) jammer for Army aircraft. The analysis demonstrated that the ALQ-162 CW system, whose development is being led by the Navy, could be effectively used by the Army to protect its SEMA system. Relatively minor modifications have been recommended to enhance the capabilities of the ALQ-162 jammer for particular Army applications.

DEVELOPMENT AND FLIGHT TEST OF A HELICOPTER-MOUNTED RF INTERFEROMETER

PROBLEM

The proliferation of low-altitude air defense systems within the Warsaw Pact tank and motorized rifle divisions has placed increased emphasis on searching for methods and techniques that provide a reasonable level of survivability for attack and scout helicopters.

The enemy air defense system uses radar for search, acquisition, and tracking, thus permitting it to acquire airborne targets and to direct artillery and missile fire. These radar systems use a pulse radar that employs conical-scan with compensated tracking techniques and a moving target indicator to permit target tracking in ground clutter. Wind compensation techniques operate in conjunction with the moving target indicator to reduce the radar signals from windblown chaff.

TECHNICAL SOLUTION

A solution to the problem is to detect the enemy air defense radars by using a passive RF interferometer (RFI) device integrated with a helicopter fire control system. The RFI integrated system should be capable of unambiguous acquisition of enemy radar emissions outside their lethal perimeter and provide autoranging/target position information to the pilot. Having advance target position/ranging data and using nap-of-the-earth (NOE) flying techniques, the RFI-equipped helicopter could then engage and destroy the enemy air defense unit before the enemy could detect the presence of the helicopter.

APPROACH

The overall approach to solving the air defense threat problem was to first demonstrate the technical feasibility of the RF Interferometer/Helicopter System before entering engineering development. This initial step for demonstrating feasibility in a low cost program was to make maximum use of proven hardware/system elements. Application of technology, hardware system, and experience previously gained from the Mast Mounted Sight (MMS) program and an RF Interferometer program (MICOM) and from other independent programs reduced the technical risk. A Yuma Proving Ground (YPG) flight demonstration test was conducted in conjunction with the TADS/PNVS/YAH-64 testing to further reduce the cost.

Martin Marietta, Hughes Helicopters, and Litton AMECOM were the principal members of the development and test team. Other major companies participating in the system development included Litton Industries, Teledyne Ryan, SCI, Maxon Inc., Delco Electronics, Computer Automation, and Kaiser Electronics.

Martin Marietta was responsible for the MMS/RF interferometer system design and integration on the helicopter. Studies, analyses, and technical coordination were provided to ensure that the defined integration concept successfully met the flight test objectives. An RF interferometer developed by Litton was integrated into the system and flight tested at Orlando and at YPG. Using previously obtained vibration data, tests were conducted to certify the structural adequacy of the system and to verify the hardware reaction to the vibration spectrum. Subsequent analyses showed that the system's environmental, electrical, and mechanical interface compatability, and target detection and stability would not be substantially degraded during the YPG flight tests. Litton designed and fabricated the required RF interferometer modification and provided interface mounting hardware for the MMS. Analysis of their subsystem hardware, including laboratory testing data, showed that the hardware would meet the specification requirements.

Hughes Helicopters supplied the MMS 500 MD helicopter. Analyses and subsequent testing to obtain safety of flight certification were accomplished. The helicopter was delivered to Martin Marietta (Orlando) for integration of the MMS/RF interferometer system on the 500 MD helicopter. Hughes Helicopters provided support personnel for the MMS/RFI operation and maintenance at the Orlando and Yuma sites.

SYSTEM DESIGN CONCEPT

The RF interferometer is a system of multiple antennas spaced so the arrival of the radio wave, after electronic processing, can be used to determine with accuracy the direction from which the wave emanated. The RF wave direction of arrival can be coupled to a heading and attitude reference system to determine the angle (azimuth) to the emitting target. If a helicopter flies between two points (A and B) with a navigation system that determines this distance, then the requirements for triangulation are available (i.e., two angles and one side). A computer with stored trigonometric functions can then compute the location and range of the target. A system design description of hardware and software to mechanize this concept follows. Figure 1 shows the interconnection of the required equipment functions plus instrumentation and control.

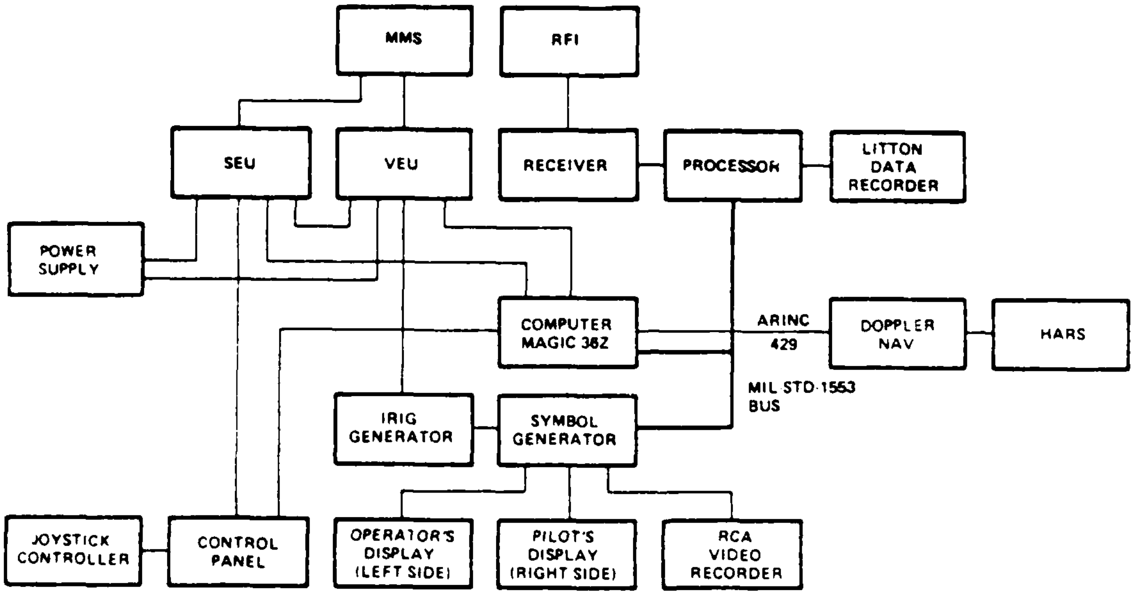


Figure 1. System Diagram

TEST OBJECTIVE

The overall objective of this program was to demonstrate through analysis and helicopter flight tests the feasibility of integrating a precision RF interferometer with the Martin Marietta MMS to detect, locate, and attack forward area enemy air defense radars. The specific test objectives were:

1. Determine RF sensor performance in multipath environments at ranges up to 15 km
2. Demonstrate in actual flight (hover) the emitter azimuth location accuracy of the MMS/RF interferometer helicopter system
3. Demonstrate automatic video cueing using the RF interferometer and target identification in the MMS NFOV
4. Conduct field tests that simulate engagements between helicopter and emitter targets to determine improvements in helicopter masking and feasibility of launching air-to-surface missiles against emitter targets.

TEST RESULTS

The tests conducted at Yuma Proving Ground covered system calibration, target detection, functional performance (single and multiple emitters), and operational performance (free play conditions).

Target detection and position tests were successfully accomplished. An undetected approach to the attack position was achieved in all the free play experiences. The RF interferometer accurately pointed to the target so that the optical narrow field of view (NFOV) of the MMS TV contained the target. The free play test results (from the simulated tactical competition between the helicopter and radars) showed that the potential for increased enemy target kill probability as well as aircraft survivability improvements can be achieved.

Runs made during Flight 131B were used to derive statistical distributions for both target location and pointing errors. Analysis of the flight test data resulted in a target location (i.e., radial distance between the actual target location and its computed location) circular error probability (CEP) of 225 meters at ranges of 8 to 10 km, and a system angular error (angular error between vectors from helicopter to actual target and helicopter to computed target location) CEP of 0.45 degree. Plots of target location error distribution and angular error distribution are shown in Figures 2 and 3.

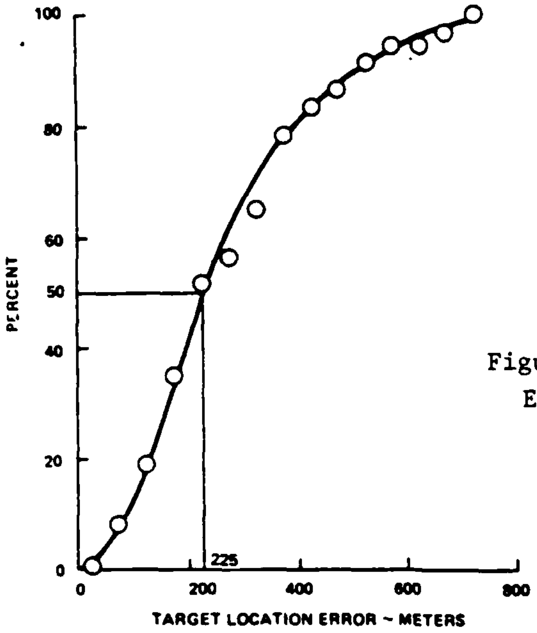


Figure 2. Target Location Error Distribution

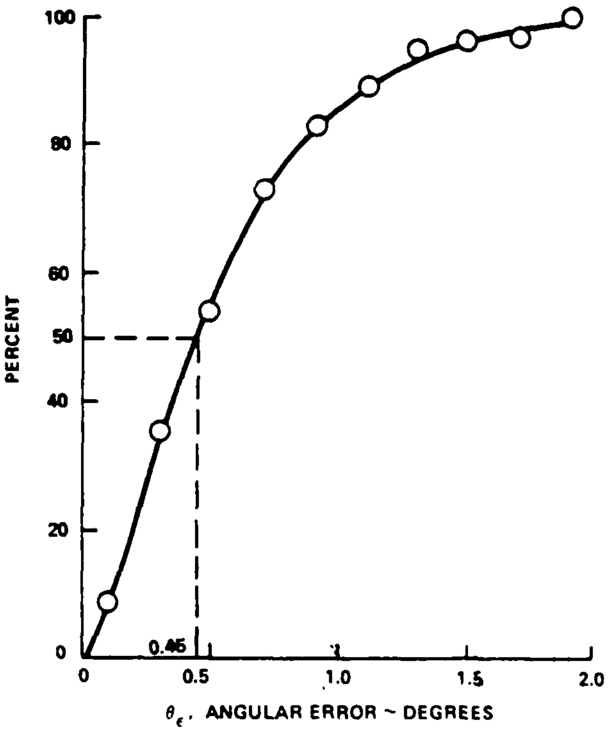


Figure 3. Angular Error Distribution

ELECTROMAGNETIC ENVIRONMENT SIMULATORS
IN THE
EVER CHANGING AIR ELECTRONIC WARFARE MISSION

(Unclassified)

By

John F. Michaels
Vice President Marketing
Republic Electronics, Inc.
575 Broad Hollow Rd.
Melville, NY 11747
(516) 249-1414

In recent years, the exotic art of electronic warfare has added another dimension to the formidable undertaking of war. Much like a chess game, there is an offensive move or measure, a countermeasure, then a counter-countermeasure...and so on to ultimate checkmate of the opponent. As in chess, the art of electronic warfare takes form in the ability to create the act and the counter act. The need for this art will grow and become more demanding as long as men seek power in an increasingly complex and hostile world. Success lies in the ability to create timely and effective electronic moves and countermoves because the ingenuity of the EW equipment manufacturer is soon outdone - or undone - by the weapons producer. In turn, the latter is thwarted by the next generation of EW hardware, which itself will be quick to mature and short lived.

It follows that in the course of developing surveillance, weapon release, countermeasure, jammer power management and other EW systems, determination of their effectiveness becomes the object of a massive effort. The cost of such evaluation under actual field conditions can be staggering... and hence, is often neglected. But the proof of the pudding need not be in the eating. It can be in the testing of system performance by true simulation of the electromagnetic environment. The creation of meaningful environments and the ability to control, repeat, alter and hold them can only be done economically by simulation.

The ability to accurately monitor and assess reaction to precisely controlled stimuli is the name of the game. Consider an EW suite that has been recently programmed to perform certain parameter sorts on newly identified and anticipated threats. Is it enough to make a memory verification of the new resident program's accuracy? Is it enough to know that the new active threat table is correctly filed in memory? How will the hardware perform in the presence of a dense signal environment when the program now dictates new commands for new parameter sorts?

Also, among other considerations, it is reasonable to expect that during the course of the mission certain ambiguities in identification will occur. Their cause may be the inability to resolve almost identical parameters associated with two different illuminators. Or perhaps inadequate sensitivity masks the ability to measure the beam scanning rate. Many other possibilities come readily to the analyst's mind.

Reduced to lowest terms, what is needed is the generation of an environment that will be indistinguishable from the real world to the the equipment under test and that will stress it sufficiently to truly verify its capability and, perhaps, its potential.

THE REES-100

A simulator has been developed by Republic designated the REES-100 that provides the density and exotic signatures of the most advanced search, track, command, control and guidance radars. The REES-100, can introduce up to 13 emitters in a 2 superhetrodyne's narrow instantaneous IF or saw filter pass band. Scenarios are generated and age out to simulate mission profiles. Along the way there are multibeams and CW illuminators, agility (PRI and RF), TWS, guidance and others. Each scenario might contain a cross section of emitters that could represent, for example, the East German corridor, the FEBA or a small enclave, such as a beseiged embassy.

Aging of signals, or termination of the presence of emitters after a prescribed interval, permits the test operator to determine the adequacy of the cycle time of the unit under test. This is an important consideration when a superhet receiver is burdened with a dense environment, long dwell times and time-consuming program housekeeping. One other plague on the system is the price that is paid for "Look-Thru." Its effect can be measured as the "Look-Thru" period or density of signals is varied.

A summary of the REES-100 salient features is tabulated below.

Physical Characteristics

Size	-Two suitcase style carrying cases	
	-Simulator	7.2" x 18" x 21"
	-Power Supply	6.5" x 14" x 18"
Weight	-Simulator	45 pounds
	-Power Supply	27 pounds
Primary Power	115 VAC; 50 to 400HZ; 125 Watts	
Battery Power	-Customer Option 1 Hour at 0°C	

Emitter Features

- Automatic Mode
  - -Sequenced Scenarios
  - -Single Scenario
    - Multiple Emitters
    - Programmable Parameters
- Manual Mode
  - -Programmable Parameters
- High Single Density
- Guidance Correlation

R.F. Characteristics

- Frequency Coverage .85 to 18 GHz
- Up to 8 High Band Emitters in Modularly Selectable Band Using Plug-In R.F. Head
- Three CW Emitters Closely Spaced
- One Emitter Anywhere in Hi-Band, May Be Time of Arrival, Simultaneous With One of the 8 Interleaved Emitters
- One Low Band Pulsed Emitter
- Frequency Accuracy:
  - Low Band - ± 1%
  - High Band - 2-18 GHz ±0.2%
    - CW Multitone ±0.1%
    - \- Plug-In ±1.0% (Option ±0.2%)
- Frequency Repeatability ±3 MHz
- Frequency Agility

Modulation Characteristics

- CW
- Pulse
  - Up to 83 Different Emitters in an 8 Second Interval
  - Pulse Density
  - Pulse Dropouts
  - Correlated Emitters
  - PRI Range - 4 μ sec to 8000 μ sec

- Stagger - Up to 16 Level
- Agility -PPM/FM/Random
- PW Range 0.1 μ sec To 10.0 μsec

- Antenna Scan
  - Conical
  - Sector
  - TWS
  - Loro

The REES-100 only becomes classified as a result of its program and application. Until the instrument is programmed by PROM, tape and/or keyboard, it remains simply a very sophisticated signal generator. As such, many applications for it come to mind. Some examples...

The REES-100 augments Bit in preflight checkout of transmission lines and antennas. Simulation of multiple threats and friendlies can serve as a training device to test operator interaction and reaction abilities. Further behind the line, it can provide production system support and supplement GSE at intermediate, second and third levels of support. Program and design verification testing becomes standardized, reliable and thorough.

THE REES-200

The other side of the spectrum is the electromagnetic environment that exists about radar systems. Republic has developed a simulator that delivers real-time microwave signals to 2 radars at "L" and "S" bands. Both radars (2D & 3D) operate independently of one another but see the same simulated environment. These signals represent multiple dynamic airborne targets with chaff events and selected coherent and noncoherent ECM emanating from predesignated targets. Accurately modeled RF signal sources produce a realistic coherent synchronous skin return which includes the effect of Doppler, noise due to aircraft and antenna motion, effects of time, frequency, spatial parameters and antenna pattern scan modulations. The environment also includes clutter plus weather effects such as rain.

In other words, the object is to create an environment real enough so that a true evaluation can be made of a radar's performance, real enough so that radar operator training means something and to do it at a fraction of normal flight trial costs. With appropriate simulation, you do not have to fly aircraft or airborne jammer platforms, or drop chaff. In addition, you are able to obtain repeatable data that is extremely difficult to achieve with actual tests.

How do you evaluate multiple Surface-to-Air Missile (SAM) radars, for example, operating in a common battlefield scenario? How do you effectively train the operation teams?

Real-world, real-time testing is a formidable undertaking to say the least. Consider the high cost and impracticality of flight testing with chaff drops and jammers and the difficulty in obtaining repeatable data under the conditions necessary for system study and evaluation. Here is a better, more cost-effective way to perform system testing.

In order to achieve the degree of coherency necessary, certain information is required from the radar. The STALO and COHO frequencies and their anticipated variations are necessary to recreate a return echo with the necessary degree of phase coherency. A radar trigger to synchronize the system, azimuth, elevation scan data, and platform are also necessary.

A video display terminal is essentially the front panel of the radar simulator. The terminal is used to enter all data, control commands and scenario decisions. The following data is displayed on the video terminal: aircraft, jammer, chaff, rain selected radar parameters, selected platform parameters, IFF, wind and clutter level.

The target model simulates both maneuverable and fixed targets in three dimensions (range, azimuth, and altitude). The maneuverable targets are capable of linear and circular motion having a rate of ascent or descent applied individually.

Microprocessors perform the calculations for proper attenuator words, compute the range delay, set the pulse width, and output the object in the proper elevation and azimuth beam. The digital attenuator, as driven by the digital interface circuits, provides the range, antenna pattern and other dynamic and static target losses.

The RF circuitry has been designed to correspond to the desired degree of simultaneity between radar and jammer returns. There are no conflicts between coherent target returns and sea clutter, chaff and rain with screening effects of the above considered as they effect target return amplitude.

A series of control elements (i.e., phase shifters, linear attenuators, RF switches, mixers and digitally-controlled attenuators) are used to control the doppler frequency offset, timing, width and amplitude of each RF signal. The linear attenuator superimposes the noise modulation generated by the noise generator in each RF processor.

The jammer channel is separately VCO-derived with identical control elements as used in the coherent return channels. Both the coherent and non-coherent outputs are combined, allowing a simultaneity of events without conflict.

CONCLUSION

Today's electronic technology allows the generation of a simulated electromagnetic environment virtually undifferentiable from real world returns. Whether needed for system evaluation, test or training the environment simulated must be as close to reality as possible. Operator survival may be dependent on it.

ANGULAR RATE BOMBING SYSTEM

(ARBS)

"Accuracy is the Name of the Game"

by

Dean W. Elliott

INTRODUCTION

Since the beginning of World War II, man has been searching for a better, more reliable, and cost effective method of delivering iron bombs accurately onto unfriendly targets. One problem which has hampered this process over the years has been the lack of an accurate inexpensive device which would measure range to the target. ARBS solved this problem by using angles and angular rates to compute these parameters. This Abstract will discuss the mechanization of this particular solution to the weapon delivery problem.

ARBS HISTORY

Initial thinking toward the modern ARBS concept began in 1963 at the Naval Weapons Center (NAVWPNCEN) where analysts devised a technique of using angles and angular rates to determine target range, thus eliminating the need for the height above target measurement. This concept was successfully tested during two flight test programs (1968 and 1971) using simple analog computing and display technology. Bombing was in the specified accuracy range. In 1972 the United States Marine Corps established a close air support VFR bombing requirement for a system with the capability of releasing ordnance on a laser or TV designated target. The NAVWPNCEN, supported by two contractors, integrated the first digital mechanization of the concept using an off the shelf IBM 4π computer and a unique Dual Mode Tracker (TV and laser). Flight tests, which were conducted in the summer of 1974 in an A4 aircraft, again showed bombing accuracy to be in the specified range.

In 1975, a contract was awarded to the Hughes Aircraft Company for the development of prototype systems using the advanced development model as a baseline. This hardware reflected the latest techniques in quality and reliability by design. Six systems were built and through an extensive test and fix program a 191-hour mean time between failure reliability was achieved and verified in subsequent TECHEVAL and OPEVAL flight test programs. Features other than accuracy that have been achieved are the first pass detection and identification (via the 7x TV magnification), the capability against moving targets, and the system accuracy in high wind conditions.

Currently the system is in production with first system delivery to A-4M squadrons expected in mid-1982. The AV-8B Harrier will be testing the system during Full Scale Development Flight Tests, also in 1982. AV-8B ARBS fleet delivery will commence in late 1983.

MECHANIZATION

There are a multitude of ways to solve the weapon delivery problem. In each technique, however, a common element, range to target, must be measured or computed. This range can be attained by "eyeballing", triangulation, radar, laser, or by using angles and angular rates, which is the method used in ARBS. The ARBS solution is based on the fact that the angle to the target changes at an increasing rate as you approach the target and at the point of bomb release, this rate has a unique value (see Figure 1).

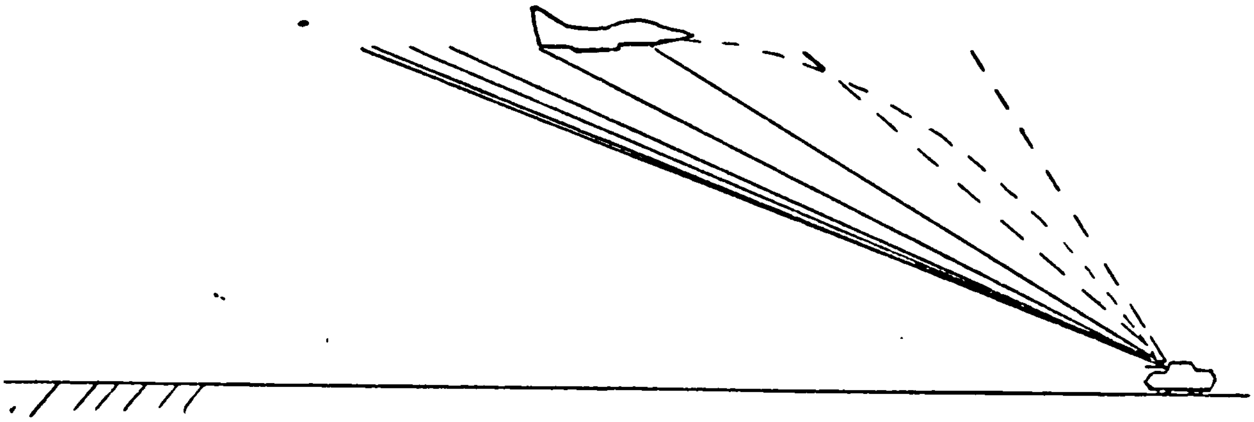


FIGURE 1.

The system receives inputs as shown in Figure 2 and, based on the current aircraft flight trajectory and the selected ballistics, computes the angular rate and ballistic range required for the weapon to impact the target. At the same time the inertially stabilized tracker measures the angle to the target and its rate of change. From this angular rate a range to target is computed. When the required range to target is equal to the computed range to target, the weapon is released either automatically or manually, dependent upon pilot selection.

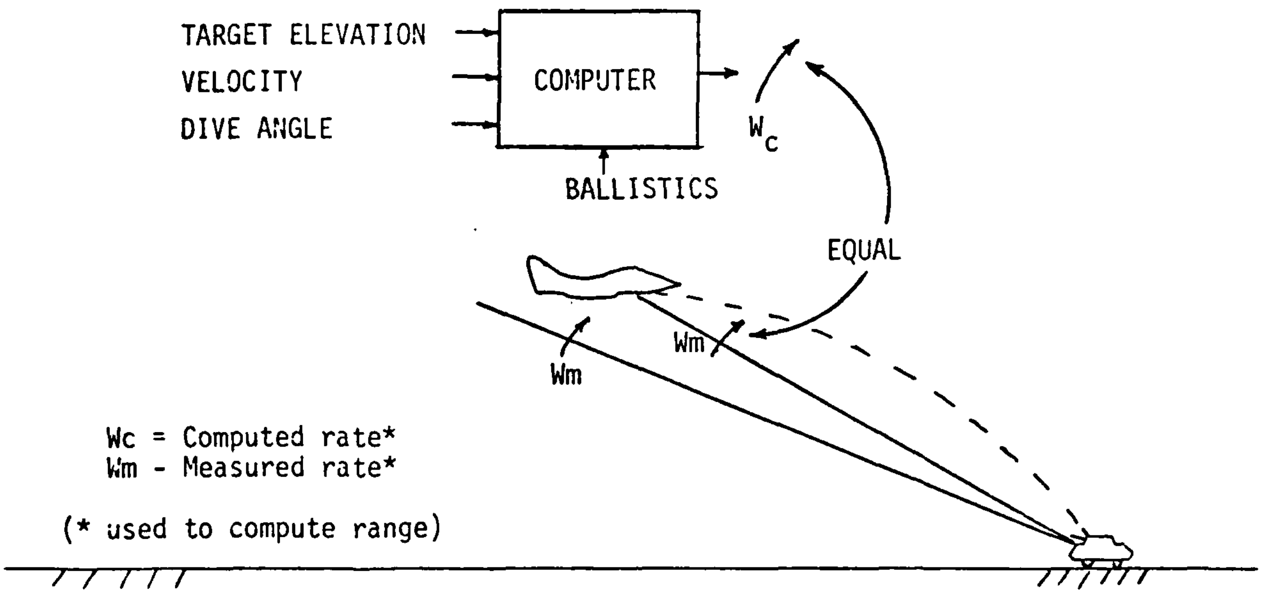


FIGURE 2.

The cockpit mechanization unique to ARBS consists of (1) a Head Up Display (HUD) which provides symbology to show tracker aimpoint and allow the pilot to shift the track point to any object within the HUD Field of View, (2) a Data Entry Panel which provides the pilot with the capability to enter data into the computer, (3) a Designate Switch on the stick grip to allow the pilot to select a target of his choosing for track, and (4) a Slew Control on the throttle which provides the capability of updating the aim point. This setup was devised to minimize pilot workload in the target area under high threat conditions.

SYSTEM FEATURES

Salient features of the system are listed in Table 1. Of these features, comments are most frequently received from pilots on (1) the ease of operation; (2) the manual bombing capability where the pilot in a "short fuze" situation can accurately bomb any target in the vicinity of the track point without actually tracking the desired target; and (3) the capability for positive target identification prior to out of window visual identification made possible with the 7x TV magnification.

TABLE 1. System Features.

- Automatic/Manual Acquisition
- Automatic Tracking
- Automatic/Manual (CCIP) Bombing
- Dual Mode Tracking: TV, Laser
- Day/Night Visual Capability
    - TV: Dawn to Dusk VFR
    - Laser: Day/Night VFR
- TV 7x Magnification
- Laser Acquisition Capability at Sufficient Ranges to Readily Accomplish First Pass Attacks
- Total Azimuth Correction for Moving Targets and Crosswinds
- Ease of Operation

OPERATION

A typical scenario, one the Marine Air Corps refers to as the primary scenario, is depicted in Figure 3. The pilot approaches the laser designated target area with the tracker scanning for laser energy (3a). When coded energy is detected, lock on and track are achieved (3b). Target identification is achieved on the cockpit display (3c) and the pilot commands a shift to TV track, after which the designator can shut down to reduce his time of vulnerability. The pilot nulls his steering, flies to release as indicated by the HUD display (3d) and holds the bomb-button through the point of automatic release, also displayed on the HUD. Without a laser designator, the sequence initiates as in 3c, with a pilot designated lock on.

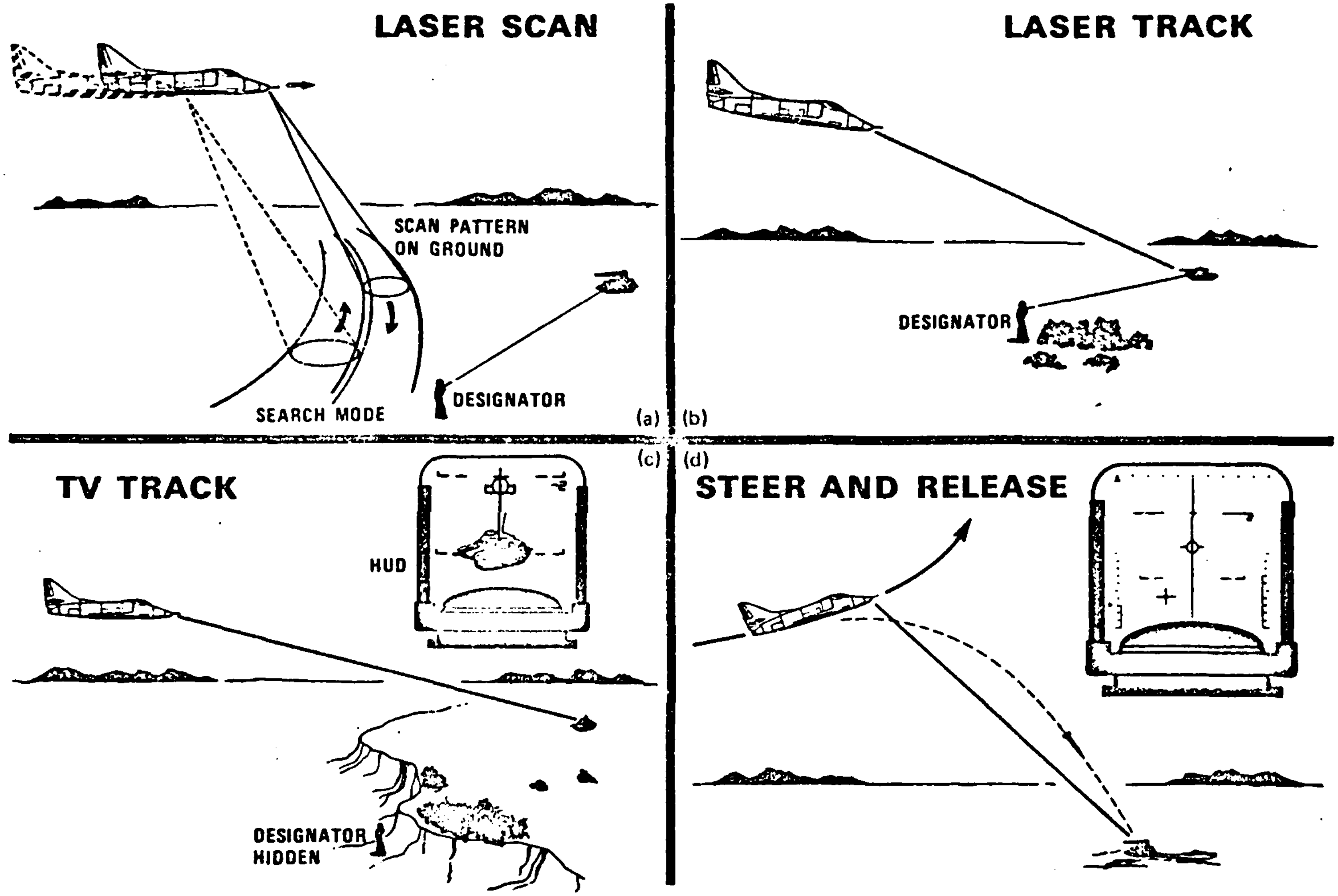


FIGURE 3 Typical Scenario

The prime alternate mode of operation which will receive wide use is the manual continuously computed impact point (CCIP) mode. This sequence differs from the automatic mode in that the pilot can lock on to anything in the target vicinity and steer the HUD displayed CCIP symbol over the target. When the target and symbol coincide, the pilot commands weapon release by depressing the bomb button. This mode will be used largely when time does not permit refining the trackpoint to the desired target. In any of these modes the pilot is free to jink and maneuver through the pass as long as the steering is nulled or the CCIP symbol is over the target when release occurs.

SUMMARY

This system has been a success story from inception, through design and test, and into the fleet and will continue to be so primarily because of the continued dedication of Government and industry scientists, engineers, and service personnel to meet the needs of the pilot and combat soldier in a close air support situation. This is evidenced not only by the accuracy of the bomb impact but by its proven reliability and maintainability in the field.

Finally, I quote from CDR C. Sapp, recent Weapons System Manager for T-38, T-34B, T-2B/C, T-39, U-11, and A-4M aircraft:

> "Another added feature is simplicity of operation. For a squadron commander concerned with bringing a new pilot from training command up to peak combat efficiency in the shortest possible time, ARBS is the answer to his problem. ARBS has done for the inexperienced and mediocre bomber pilot what the Colt .45 did for small cowboys - i.e. it has made him competetive with the best.
>
> "This system may very well be the most accurate free fall weapon delivery system in the free world."

ZAP - An Advanced Missile Launch Envelope Algorithm and Display for the F-15 Eagle

Extended Abstract

Authors: G. M. Jordan (FAAC) and T. Ross (AFWAL/AART-2)

First Ann Arbor Corporation and McDonnell Aircraft Company have developed an advanced missile launch envelope (MLE) algorithm and associated displays for the F-15 Eagle called ZAP (Zone Acquisition Process). It was developed under the Air Force Avionics Laboratory MISVAL Program which began in May 1977.

The objectives of this program were to develop and demonstrate a new MLE algorithm and display with: 1) Flexibility to adapt to changes in missile performance characteristics and to new missiles; 2) Adaptability to both short and medium range missiles; 3) Accurate solutions under all engagement conditions throughout the aircraft and missile operational envelopes; and 4) Meaningful information provided to the pilot including the effects of target maneuvers.

Since tactical decision in air combat are best left to the pilot, ZAP takes the approach of providing the necessary information to the pilot to make these decisions, i.e., options are provided to allow room for pilot judgments. Target maneuver options are bounded by providing maximum launch range for a non-maneuvering target, maximum launch range for a "worst" case target maneuver, and minimum launch range. Only one minimum range is presented since MLE sensitivity studies have shown that the effect of target maneuvers at minimum range is no more than the uncertainty in actual missile performance. Since all firing opportunities inside the MLE are not of equal quality, ZAP includes a figure of merit (FOM) which indicates the quality of the shot. FOM is particularly useful to inexperienced pilots. Steering commands are also provided which, when followed, result in minimum time to zone entry when out of zone and optimum launch heading when in zone.

ZAP includes a post launch mode where the missile is monitored after launch using the actual target track. Time-to-go to intercept and FOM are continuously updated. If post launch target tactics defeat an inflight missile, this is detected and the pilot informed of the impending failure. All of this information is updated approximately once per second.

ZAP generates this set information using a new technology very high speed high fidelity five degree of freedom flyout simulation. MLE boundaries are searched for and tracked using this flyout simulation. The flyout simulation also produces missile intercept parameters for a missile launch from current conditions when in zone. These parameters are used for computing FOM and optimum steering and also yield time-of-flight (TOF). A re-entrant version of the flyout simulation is used to simulate post launch missile flight in real time against the actual target track.

Maintaining flyout simulation fidelity while achieving very high speed execution is made possible through the use of Complex Factored Quaternions (for handling vectors and coordinate transformation) and a new approach to solving the differential equations describing missile flight. The guidance law is assumed to be perfectly solved each iteration. Missile velocity vector orientation required to solve the guidance is determined and then checked against the previous iteration velocity vector. If the change in orientation exceeds the missile trim limit, command limit, or the guidance command magnitude, it is limited to the lower value. All other guidance and control limits are checked between iterations. Time and geometry are then integrated and iterations repeated until either intercept or a catastrophic failure occurs.

ZAP interfaces with the fire control system simply. Inputs are range vector (launcher to target), ownship velocity vector, target velocity vector, and ownship altitude, all in North, East, Down coordinates. Outputs include:

RMAX - Max range boundary for non-maneuvering target
RMAX2 - Max range boundary for "worst" case target maneuver
RMIN - Min range boundary
FOM - Figure of merit
TOF - Time of flight (when inzone)
TCOMLE - Time to MLE entry (when out of zone)
Steering command
ASE - Allowable steering error
TGO - Time to go to intercept or failure (with missile inflight)
PFAIL - Predicted missile failure if applicable (with missile inflight)

ZAP has been tailored to the F-15 for demonstration purposes. The algorithm is completely contained in the central computer and uses the existing unmodified HUD and VSD. The generated data and information presented assists the pilot in gaining and recognizing superior AIM-7F and AIM-9L firing opportunities.

As the primary flight instrument, the HUD presents calibrated airspeed, heading, altitude, and a conventional pitch ladder. These may be removed by the pilot to declutter the HUD. Upon radar acquisition the range range (nm) and closing rate (knots) are displayed against a range bar on the right (figure 1). Range is indicated by a moving caret and closing rate by a numeric which moves with the caret. RMAX and RMIN launch ranges for the selected missile are displayed along the range bar as solid bars. Also displayed is no escape range (RMAX2). This is based on a worst case target maneuver beginning at launch with the maneuver type being a function of the selected missile. Accuracies are equivalent to the uncertainty in actual missile performance. Allowable steering error (ASE) is displayed as a varying radius circle about the aircraft reference. Steering command is presented as a dot. Acceptable launch error is indicated by the steering dot being within the ASE circle and optimum steering when the dot is centered.

The target's angular location is indicated by the target designator (TD) box, when the target is within the field of view of the HUD. It is limited so that it stays on the HUD when the target is outside the HUD field of view. A triangular shoot cue is displayed, beneath or above the TD box depending on location of the box, indicating all launch requirements are satisfied including seeker tone when SRM is selected. When range is between RMAX and RMAX2, the shoot cue blinks and is on steady between RMAX2 and RMIN.

The first lower left window on the HUD indicates the missile type selected and number available, and M for medium range and S for short range missiles. To the right on the same line, a ZAP feature, called off missile, is presented. Whenever the "off missile" is in zone, an M or S and the number of available missiles of that type available appears and flashes. For example, when MRM or gun is selected, this symbol indicates when a short range missile is in zone. This permits the pilot to switch weapon types if he chooses.

The first lower right hand window presents ZAP derived advisary information. These include no zone and heading error. No zone is when no MLE exists for present conditions. Heading error is when range is between RMAX and RMIN but the steering dot is outside the ASE circle. The second window presents a figure of merit. It varies from zero to six Xs reflecting the quality of a missile shot if made now. Included are the susceptability of the missile to both early and endgame evasive target maneuvers and variation of kill probability. Six Xs is the highest quality shot and one X is a poor quality shot when target tactics can easily defeat the missile. The third window displays missile TOF in seconds or TGO with missile inflight. With a missile inflight, MLE boundaries, ASE circle, steering dot, shoot cue, and off missile information continues to be displayed for the selected missile. Only TGO, FOM, and, if applicable, PFAIL, apply to the inflight missile. The pilot may change the selected missile with no effect on the inflight missile information. However, the boundary, shoot cue, and off missile inzone indication will switch to the newly selected missile.

If, after launch, target maneuvers are detected as defeating the inflight missile in the future, PFAIL is flashed on the HUD in the first lower right hand window. Time to go becomes time to go to the failure, allowing the pilot to make a decision to drop that missile, fire another, or disengage. PFAIL is also displayed flashing on the VSD in place of time of flight. Figure of merit drops immediately to zero when PFAIL is displayed. When TGO reaches zero, ZAP reverts to the prelaunch mode. For multiple launches all displayed information for the inflight missile is for the last one launched.

The VSD is the primary radar display (Figure 2). It presents target detections in a range azimuth format as solid rectangles at their range azimuth location. Radar altitude coverage in thousand of feet at the range of the acquisition gate is displayed just above the grid in search mode. A target is acquired manually by the pilot. In the track mode the top window now displays target speed in knots, target heading in degrees, target aspect in ten degree increments left or right of tail aspect, and target maneuver "gs." Target altitude is displayed in thousands and hundreds of feet in the antenna elevation caret. Target range, range rate, RMAX, RMAX2, and RMIN are indicated along the right hand side similar to the HUD. Along the bottom FOM, TOF, and true air speed are presented. ASE and steering command are also displayed.

ZAP has been extensively evaluated on the MCAIR Manned Air Combat Simulator by ten current F-15 TAC pilots. Each has endorsed it enthusiastically pointing out that it provides directly the information that is currently taught but must be remembered by the pilot and manually applied. They have indicated that little transition training would be required and that inexperienced pilots would be greatly helped. ZAP is currently being flight tested by MCAIR. The technology has been proven and is ready for application. More information may be obtained from First Ann Arbor Corporation or from the Air Force, Captain Daivd Chaffin (AFWAL/AART-2).

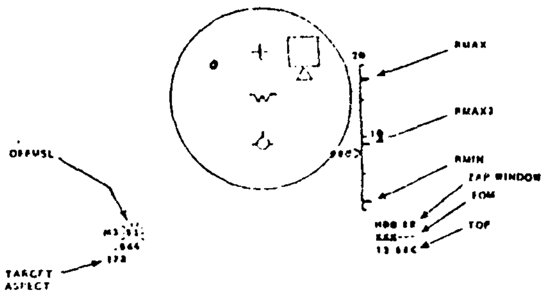


Figure 1

HUD- Scale Reject

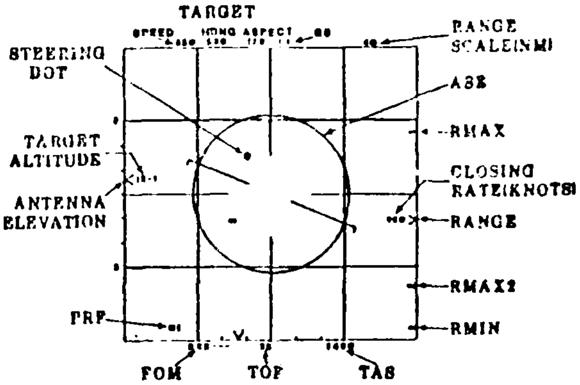


Figure 2

VSD - Track Mode

AVIONICS INTEGRATED FUZING

THOMAS RIORDAN

FAIRCHILD WESTON SYSTEM, INC.

An Avionics Integrated Fuzing (AIF) concept entailing fuzing parameter computations and transmission thereof, to the fuze at the moment of weapon release is described. Data from the Stores Management System and from various aircraft sensors are utilized. Objectives of this program are to obtain quantitative data concerning benefits and to derive an implementation concept for AIF.

VOICE COMMAND
THE NEXT THRESHOLD IN COCKPIT OPERATION

A. M. Godwin, B. B. Wyatt and Dr. J. C. Ruth
General Dynamics, Fort Worth Division
Fort Worth, Texas

INTRODUCTION

In recent years, advances in solid-state technology have made it possible to perform more and more avionic functions in an ever-decreasing volume. One of the principal beneficiaries of these advances has been the modern attack aircraft, which embodies a wide variety of offensive and defensive avionic capabilities. The achievement of these capabilities has not, however, been without penalty. Increasing system complexity also increases the burden upon the aircrew. In the case of the single-seat, high-performance fighter, this burden is approaching a critical level. Here the pilot must simultaneously fly the airplane and operate the offensive, defensive and communications equipment. For the most part, this burden falls upon his hands. Thus, situations arise where optimum control of the airplane demands that the hands be kept on the control stick and the throttle. During these crucial times, alternative means must be provided to achieve optimal control of the total weapons system.

The purpose of the General Dynamics (GD) Voice Command project is to evaluate the use of the pilot's voice as an alternative method of achieving interaction between himself and the weapons systems. The ultimate goal is to off-load tasks from the pilot's hands to his voice, thereby enabling him to exercise hands-on control of the airplane a higher percentage of the time, particularly during critical periods, while providing a means of simultaneously achieving positive control over avionic system operation. This verbal interaction between the pilot and the system is called Voice Command. It is predicated upon the use of computer-based voice recognition technology to identify and classify verbal commands and, subsequently, to initiate the appropriate system response.

On the surface, the concept of using computer voice recognition technology as an alternative combat aircraft command and control medium appears to be very promising. However some key questions remain to be answered. These questions are:

1. Is the use of voice command really a viable alternative to more traditional manual methods?

2. Can the voice recognition technology base be extended sufficiently to provide reliable operation in the stringent combat aircraft environment?

3. Assuming that the previous two questions can be favorably answered, which control functions best lend themselves to voice commanded control and which offer the highest payoffs in terms of overall weapon system performance?

The General Dynamics Voice Command program was established in 1978 to provide answers to these questions. The program was partitioned into three interconnecting phases: Phase 0, Phase I, and Phase II. Each of these phases is designed to answer one of the preceding questions utilizing the results obtained in the previous phase. The questions described above and their corresponding phase will be addressed in the following paragraphs.

The program began answering the question of concept viability in Phase 0 by using pilot opinion surveys and developing a cockpit mockup to familiarize pilots with voice recognition. Favorable results from this phase convinced GD that voice command could be a viable alternative if the voice recognition technology could be extended to overcome the environmental problems associated with the airborne environment. In the follow-on phase, Phase I, efforts are concentrating on solving the problems associated with reliable recognition in an airborne environment. As a part of this effort, General Dynamics in cooperation with the Air Force is developing an audio tape data base in an attempt to isolate each of the problems associated with the aircraft environment. We intend to use this tool as an aid in determining which voice recognizers will provide the reliability necessary for cockpit operation. The tapes are also intended to provide participating firms with a description of the environmental problems. A selected number of voice recognizers will be flown on the joint Air Force, Navy, NASA Advanced Fighter Technology Integrator (AFTI) flight test airplane. These recognizers will determine the actual effects of the cockpit environment. The final phase, Phase II, will concentrate on demonstrating the use of voice in the cockpit. During this phase, we will investigate the potential operational payoffs of the use of voice commands. Concepts for functional utilization will be developed on the General Dynamics Research and Engineering (R&E) Simulator. Using the results from human factors studies and man-in-the-loop tests in the simulator, a final set of functions will be selected and mechanized for flying on the AFTI/F-16 flight test airplane.

VOICE COMMAND, A VIABLE ALTERNATIVE?

There are really two facets to the question of the viability of voice command in the cockpit. The first is the matter of pilot acceptance. Clearly, the time and effort put into the development of the technology would be wasted if the pilots refused to accept or use the capability provided. Accordingly, one of the efforts undertaken in the first year of this project was to conduct a pilot opinion survey. This survey surprisingly revealed that most respondees not only recognized the need for assistance in avionics control but were very receptive to the concept of using voice for this purpose if the technology can provide reliable performance. A summary of the results of the survey is provided in Figure 1. Subsequent conversations with numerous pilots have reinforced these results.

Another concern of the question of the viability of voice command is whether or not it would be an improvement over the methods currently employed. If so, how much of an improvement? What are the payoffs in terms of overall pilot/weapon system performance? These questions are not easily answered. Analytical methods alone will not suffice. The resolution of these issues requires extensive test and analysis in the laboratory and in flight test.

In order to begin the process of providing answers, it was decided to utilize commercially available voice recognition equipment for the purpose of conducting tests in the General Dynamics Human Factors Laboratory (HFL). Accordingly, a VIP-100 system was purchased from Threshold Technology Inc. and integrated with the Behavioral Test Station (BTS). The BTS is a generic cockpit mockup and, for this test series, it was programmed to simulate the characteristics of a high-performance fighter. A mission scenario that included very high workload segments was used. Test subjects were all either current or recent military pilots.

The intent of this test series was to evaluate not only the effects of voice command but also the effects of two different types of feedback, visual and audio. Audio feedback was provided by use of a VOTRAX voice synthesizer. Visual feedback was provided on a CRT display. Each test subject flew missions under four test conditions; both manual and voice command with either visual or audio feedback. The test series is illustrated in Figure 2. In the actual tests, five test subjects were used. These tests were completed in December 1980. Each of the five subjects generally agreed that voice commanded control is a viable alternative in the cockpit. Negative comments were typically directed at the particular mechanization of the voice commanded functions rather than the use of voice command itself. One particular comment involved the control of a rotary option on the emulated multi-purpose display. Although rotary operations are a very natural manual operation, they are accomplished much easier by directly selecting the option. However, it was noted that under stressful situations, poor recognition performance would aggravate the situation and cause pilots to become frustrated with the system. Clearly, better system performance than that provided by the commercial recognizer is needed.

ENVIRONMENTAL EFFECTS

In order to fully answer the question of voice command as a viable option, one must first determine whether voice recognition technology can be made to provide acceptably reliable operation in the very stringent environment of the combat aircraft. It was recognized that the greatest potential drawback to the use of voice command in the cockpit is the degradation of system performance due to factors peculiar to the airborne environment such as the oxygen mask and the effect of physical and emotional stress on the human voice. Understanding this total environment and its effect upon voice recognition performance is essential. It is also a very difficult task since the total combat aircraft environment cannot be recreated in the laboratory. It is, however, possible to individually reproduce in the laboratory most of the suspected error sources. A centrifuge, for instance, can be used to subject a test subject to closely controlled acceleration levels and to determine the effects of the acceleration on his voice characteristics. Similarly, other aspects of the airborne environment such as background noise, vibration, etc. can be individually reproduced. Then each test can be considered separately, treating each environment as an independent error source. In order to determine the individual effects of these error sources, GD has developed a set of audio tapes each demonstrating the effects of one aspect of the aircraft environment on a pilot's voice. The tapes are being used by participating firms to investigate potential problems In addition to isolating the error sources, these tapes will provide a means for evaluating potential flyable recognizers before final evaluation in flight test. This will constitute an important part of the process of extending the state-of-the-art of voice recognition for operation in the airborne environment.

Data from several of these tests has been gathered. The tests for acceleration, background noise and vibration effects were performed by the Air Force Aerospace Medical Research Laboratory (AMRL) using their facilities; i.e., centrifuge, noise chamber, vibration table. A small (15 word) vocabulary was selected to be repeated in random fashion by the test subject under each test condition. This vocabulary consists of the digits zero through nine and the following words: FREQUENCY; ENTER, CCIP; THREAT; and STEP. In each case, the utterances of the test subject were recorded on audio tape. Additional tapes have been made at General Dynamics in production F-16s on the ground and in flight. Since the effects of the oxygen mask/microphone assembly are believed to be coupled to the other environmental error sources, it was decided to include an oxygen mask in all of the tests. Furthermore, it has been found that the breath noise associated with the oxygen mask is a major error contributor and warrants additional independent study.

Copies of the audio tapes are made available to qualified firms interested in investigating the usage of voice recognition in the cockpit. A criteria has been established to govern participation by other firms:

1. The firm must have the capability to produce militarized equipment for airborne use.

2. The firm must have an internally-funded voice recognition development program that is targeted at the military market.

3. The firm must state an internal commitment to the development of a flightworthy version of their voice recognition system.

Two firms have satisfied the above criteria and are currently participating in the Voice Command program. The first of these is Lear Siegler, Inc. (LSI) Instruments Division. Partial funding for the development of a flightworthy LSI voice recognition system has been obtained from the Air Force under the AFTI/F-16 contract. LSI is currently under contract to General Dynamics to provide this system. Delivery of the flightworthy LSI system is expected early in 1982. The second participating firm is ITT Defense Communications Division. Plans are currently underway to initiate the development of a flyable version of the ITT system. In addition, preliminary talks have been held with several other potential suppliers, but they have not yet committed their resources.

The final step in establishing the credibility of voice recognition technology relative to its ability to provide acceptable performance in the combat aircraft environment is flight test. The initial flight test series for voice command will occur in the Phase I flight test program of the AFTI/F-16 in 1982.

FUNCTIONAL UTILIZATION

It is difficult to confine the remaining question concerning functional utilization to one particular phase. Poor design of the voice command/aircraft system could easily bias the pilot's opinions as to the viability of voice in the cockpit. For this reason General Dynamics began voice command system design studies early in the program.

Any system design study must consider the method by which the voice command system will be interfaced with the remaining avionics. The standard method of interfacing digital avionics at present is via a MIL-STD-1553 data bus. If one accepts, as is very likely, that this is by far the most cost effective approach, then some immediate constraints are placed on the functions available for voice commanded control. Thus, only those functions which can be commanded via the bus can be controlled by voice. The potential for the use of voice command is therefore, highly configuration dependent. The more highly integrated the aircraft avionics, the greater the potential that exists for the use of voice. Clearly, this implies that the future of voice in avionics lies with the advanced systems that are beginning to emerge today and will probably not prove to be cost effective with older systems.

Several tools were used to determine the best methods of incorporating voice in the cockpit. A cockpit mockup of the proposed system was developed using small low-cost computers and a commercial voice recognizer. Using this mockup, pilots were introduced to the concept of voice command.

Once pilots have been familiarized with voice command, a series of man-in-the-loop tests were performed on the General Dynamics R&E Simulator. The R&E Simulator is a fixed-base flight simulation system that features a visual scene projected on a 24-foot dome. A cockpit mockup of any desired configuration can be operated within the dome. For this series of tests, the cockpit configuration used was that of the AFTI/F-16 flight test airplane. The voice recognition system was interfaced with the simulator via a MIL-STD-1553 multiplex data bus. This system was developed by Lear Siegler, Inc. (LSI) as a preliminary breadboard version of the flightworthy unit that is currently being manufactured under contract to General Dynamics.

For this test series, voice command was utilized to control dual multi-purpose CRT displays in the simulator cockpit. Again, the test subjects were all former pilots. The air-to-ground mission selected for analysis is depicted in Figure 3. This scenario involved a low level night attack mission with a demanding manual terrain engress steering task. Enroute to the target, several threats were encountered requiring pilot response. The mission ended with an attack and then reattack on a visually acquired target. The tests were completed at the end of May, 1981, and the collected data is being evaluated to quantify the enhancement of degradation created by the use of voice command.

Using the preliminary results of these tests and keeping in mind the purpose of Phase I, a set of functions were selected and mechanized for AFTI/F-16 flight test. During this phase, voice control of the dual multi-purpose displays (MPDs) and the four Mission Phase Control Switches will be provided (see Figure 4). The Mission Phase control switches permit the selection of the basic operational modes: air-to-surface, air-to-surface guns, air-to-air missiles, air-to-air guns, or navigation (if no switch is selected). The MPD switches permit weapon selection, delivery mode configuration, and limited data entry. By limiting voice commanded control to the above functions, a set of only thirty-six words was selected for recognition. This allowed the flight test program to concentrate on the investigation of the voice recognition technology which would not be possible with a larger vocabulary.

During the Phase II Voice Command program, General Dynamics will concentrate on determining the optimum utilization for voice command. A systematic approach will be taken in Phase II to actually determine the areas where voice command offers the greatest payoffs. The first step will be to develop a task analysis of an air-to-air mission and an air-to-ground mission. This analysis will indicate where the workload is highest and hence place the greatest demands on a pilot's time. A preliminary set of functions will be chosen for voice recognition to aid in redistributing the tasks during the high workload segments. These functions will be implemented first on the low-cost laboratory cockpit mockup and then on the R&E Simulator. Investigation into the possible uses of voice feedback will also occur during this phase. Man-in-the-loop tests will be used to determine those functions which appear to improve the cockpit performance. From this a detailed mechanization of this set of functions will be developed for incorporation into the AFTI/F-16 flight test vehicle. These functions will be flight tested in the AFTI/F-16 flight test program.

SUMMARY

The future of voice command in military aircraft is dependent upon three factors; operational viability, functional utility, and operational reliability. The General Dynamics program, which was initiated in 1978, is designed to provide an orderly, in-depth investigation into each of these areas of concern. A graphic portrayal of the program is provided in Figure 5.

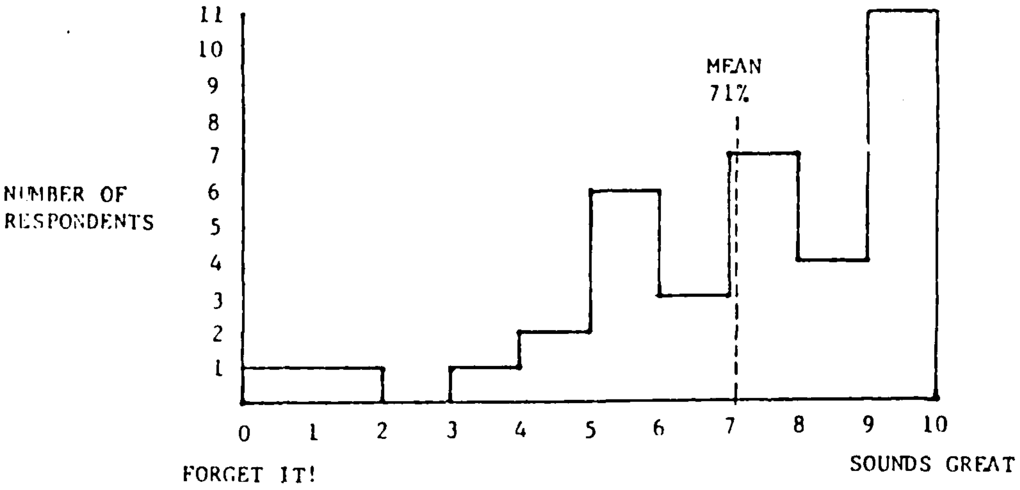
The operational viability and functional utility of voice command are being investigated and evaluated using simulation and man-in-the-loop testing as the primary tools. The goal is to determine if the use of voice command offers significant payoffs in terms of improved overall pilot/weapon system performance.

Operational reliability refers to the capability of voice recognition technology to provide an acceptably high level of performance in the intended environment; in this case the combat aircraft. An integral part of the voice command program is a systematic investigation of the effects of this environment upon the human voice and its consequent effects upon voice command system performance. The investigation is making use of environmental simulation on a centrifuge, a noise chamber and a vibration table, as well as a series of flight tests in the AFTI/F-16 fighter to determine the composite effects of the high performance aircraft environment.

It is anticipated that the voice command program at General Dynamics will result in the first voice recognition system to be designed for and tested in the military aircraft environment and that the result will constitute a significant advancement in command and control of aircraft systems.

PILOT OPINION SURVEY

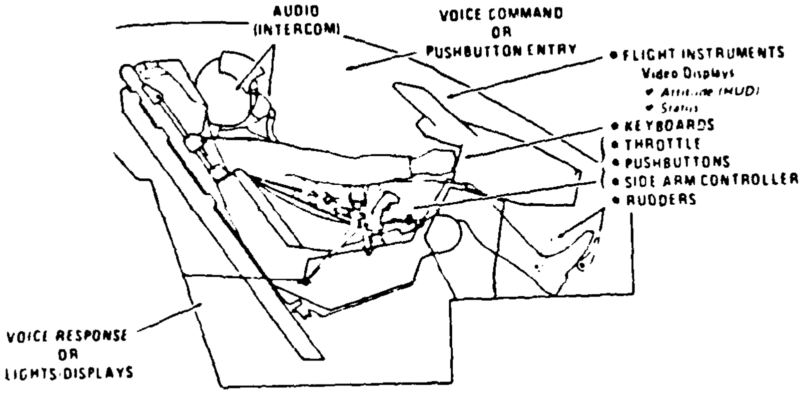
"HOW DO YOU FEEL ABOUT USING A VOICE COMMAND SYSTEM IN A HIGH PERFORMANCE MILITARY AIRCRAFT?"



- o 36 TOTAL RESPONDENTS:
  - MILITARY PILOTS, 39% CURRENT
  - 50% HAD COMBAT EXPERIENCE
  - AVERAGED 2910 FLIGHT HOURS

- o OPINIONS OF FUNCTIONS TO BE ACTUATED BY VOICE
  - BOMB/NAV AND RADAR MODE SELECT, AND M&TC FUNCTIONS WERE RECEIVED FAVORABLY
  - FLIGHT CONTROL & TRIM, EMERGENCY SYSTEMS, SMS AND FUEL SYSTEM MANAGEMENT WERE NOT RECEIVED FAVORABLY

Figure 1 Pilot's Opinion Survey



BEHAVIORAL TEST SYSTEM

PILOTS FLEW A POINT INTERCEPT MISSION UNDER HIGH STRESS CONDITIONS

USING THE VOICE COMMAND/KEYBOARD ENTRY SYSTEMS THEY INPUT RADAR RANGE, TARGET I.D., AND OTHER DATA

EACH PILOT FLEW 5 SORTIES UNDER EACH OF THE FOUR TEST CONDITIONS

Figure 2 Man-In-The-Loop Tests in the BTS

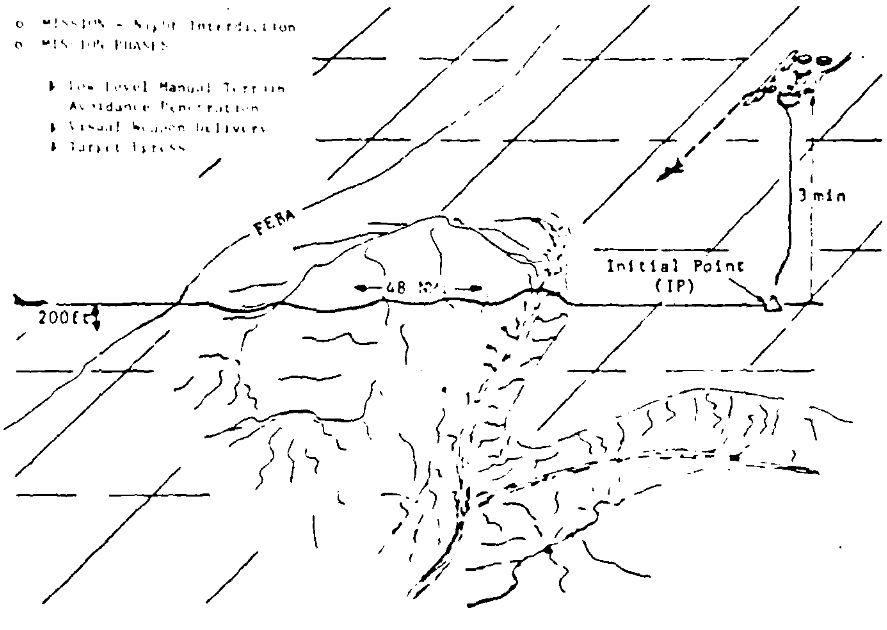


Figure 3 Air-To-Ground Mission Scenario

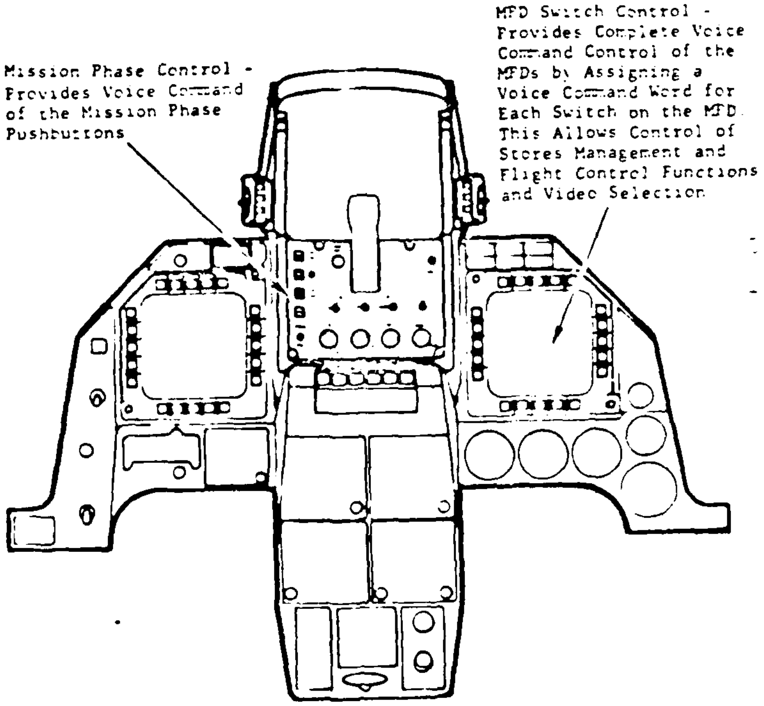


Figure 4 Initial Voice Command Mechanization on the AFTI/F-16

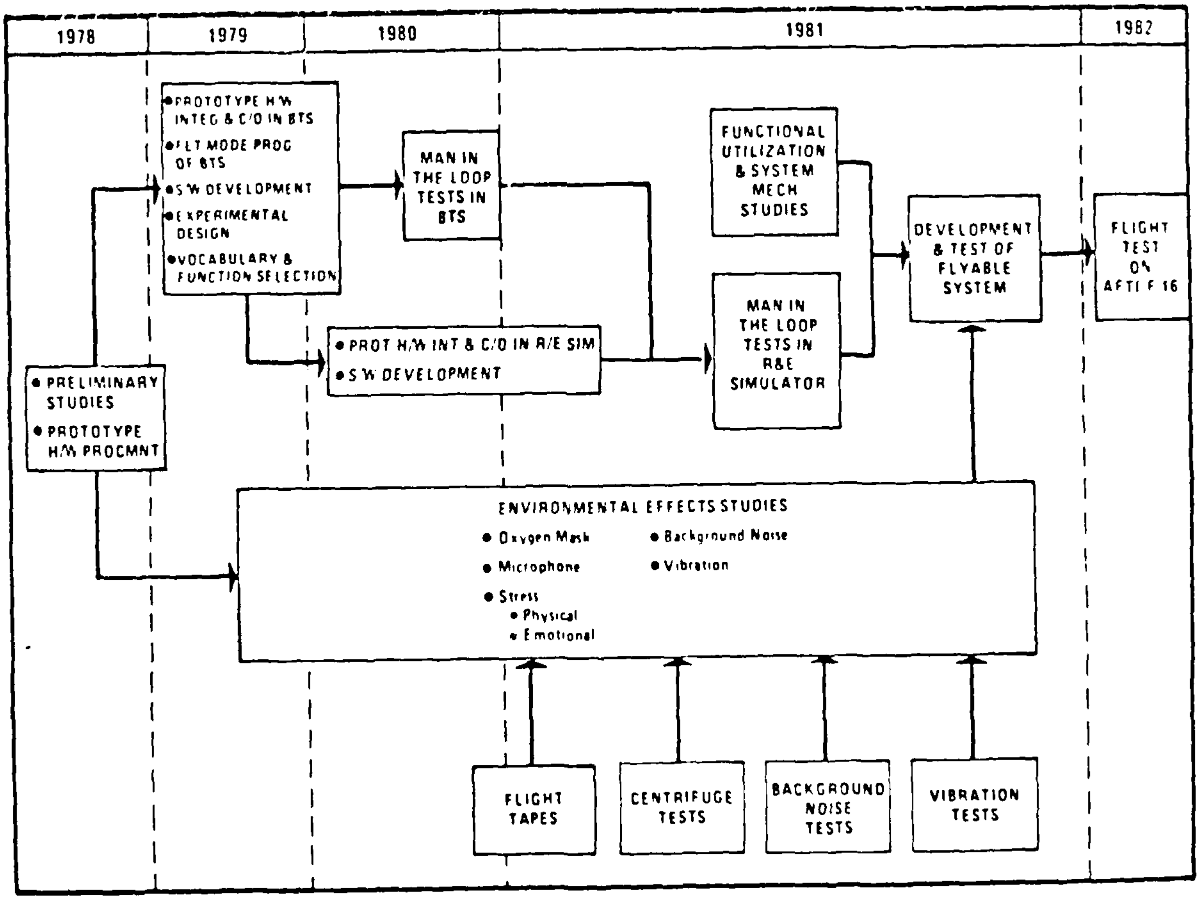


Figure 5 Voice Command Development Program

THREAT TRENDS

DR. JOHN O'HARA

National Security Agency

Fort George G. Meade, MD.

An assessment of the current and projected threat (1990) will be presented. The challenges created for avionic systems and thus technology are implicit.

U.S. ARMY AIRCRAFT SURVIVABILITY EQUIPMENT (ASE)
TECHNOLOGICAL DEVELOPMENT PROGRAM

Michael J. Garsik
U.S. Army Aviation Research and Development Command
St. Louis, MO

This paper will provide an overview of the Army's Aircraft Survivability Equipment (ASE) development program and focus on several of the key efforts and remaining unsolved survivability equipment programs. Despite its title, the principal goal of the ASE program is not to enhance the survivability of Army aircraft. That result, which is a desirable one, can be accomplished through a strengthening of the aircraft fuselage and the use of such features as armor crew seats, crashworthy fuel cells, and nitrogen inerting systems. Instead, the primary objective of the ASE program is to enhance the combat effectiveness of the Scout and Attack helicopters and the mission effectiveness of the Cargo and Utility helicopters along with the Special Electronic Mission Aircraft (SEMA). In order to understand the structure of the ASE program and how its design is intended to achieve its goal, it is important to have an appreciation for the philosophy upon which it is based.

The Army's approach to the whole aircraft self-protection problem has been really three-fold. First, examine the aircraft in its combat mission role and determine what the aircraft can do through tactics and agility to defeat the threats. For helicopter operations, terrain flying is essential to survivability. Terrain flying makes as much use of the cover and concealment afforded by the terrain that the proximity to the threat and the mission being flown will allow. Terrain flying includes (in order of ascending altitude) nap-of-the-earth (NOE) flight, contour flight, and low-level flight. For SEMA aircraft, this means operating at standoff ranges and altitudes outside of the lethal envelope of the air defense weapons when possible and from which the mission can still be performed.

Secondly, we examine the aural, optical, radar, and infrared signature of the aircraft and seek to eliminate as much of the signature as possible within the state of the art. This was the technique used to defeat the SA-7 in southeast Asia.

Warning devices and active countermeasures are considered only after all efforts have been made to reduce the signature and develop tactics. The reduction of aircraft signature also makes the application of active devices easier. The last item is vulnerability reduction. By this is meant the modifications to the basic aircraft configuration that will significantly improve its ability to withstand ballistic hits and thus reduce attrition. Such items as standby engine and transmission lube; redundant flight controls; strategically placed, armor protection, low-pressure, fire-resistant hydraulics; and composite multispar rotor blades that can withstand 23 mm high explosive hits are examples of this.

In support of the ASE development program, the Project Manager's Office has conducted an analysis to identify those equipments which will provide increased combat and mission effectiveness at acceptable levels of cost and aircraft performance penalty. The study has been divided into two sections, one considering the SEMA and the other Scout, Attack, and Utility/Cargo aircraft. This division was necessary due to the uniquely different missions and threat scenarios the aircraft are required to operate in. The SEMA portion of the analysis will be a tradeoff between mission performance and the ability of the aircraft to survive and still maintain its on-station position through the application of selected countermeasure systems and tactics. The first step in this effort is to select mission profiles based on tradeoffs between mission accomplishment and on-station survivability. From this, the best ASE countermeasure suits and maneuvers are defined along with the operational requirements for individual

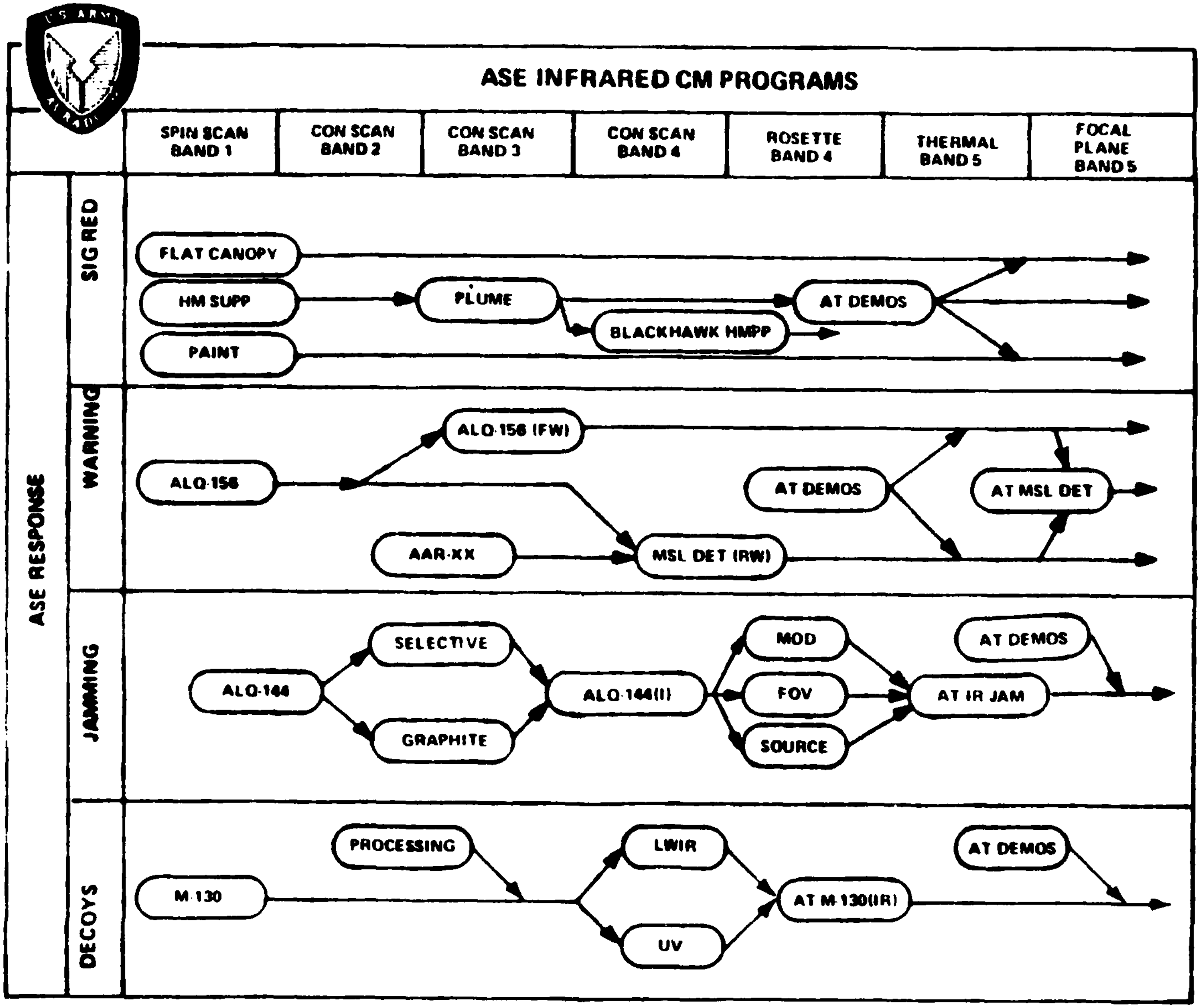
ASE. These suits are then introduced into the analysis methodology which generates relative attrition rates based on threat encounters determined from an encounter matrix built up from a SCORES scenario. The results of this analysis will provide an insight into the operational employment tactics and ASE groupings which provide the maximum level of mission effectiveness. The Scout, Attack, and Utility/Cargo portion of the analysis first addresses the identification and representation of Army aircraft missions, threat encounters, and ASE in potential conflict situations. Combinations of these elements are selected to form a matrix of cases for which high priority ASE will be determined. The analysis methodology is then exercised to determine what ASE are needed based on the relative menace of the threat systems to the mission. Additional prioritization factors are also defined and applied to establish a set of feasible and affordable ASE which provide increased combat effectiveness through reduced mission attrition. This analysis is currently being updated to assist in the expansion of the ASE program in order to incorporate responses to the latest confirmed and postulated threat weapon systems.

Results from the first ASE requirements analysis and subsequent updates have led to the creation of an aggressive program which is approaching the combat and mission enhancement problem in three principal technological areas of concern. They are optical, radar, and infrared. Within these three areas, the development programs are divided into four types of responses, signature reduction, warning, jamming, and decoys. The infrared countermeasure program is directed toward improving the performance of the infrared ASE countermeasure systems at longer infrared wavelengths and against systems employing more sophisticated scanning or imagery techniques. The radar contermeasure program is designed to provide a countermeasure capability at higher operating frequencies, more complex ECM features, and improved signal processing and identification means in a high density pulse environment. The optical program is addressing the development of systems intended to detect threat weapon systems employing passive optics or laser rangefinders, illumination, or beamrider guidance techniques. All of these programs are attacking the signature reduction problem in their respective area to reduce the detectibility of the aircraft.

Regardless of the many successful achievements of the ASE program to date and these ongoing performance improvement programs that are directed toward maintaining, in the future, the levels of combat and mission effectiveness already reached, there are still unsolved difficulties related to the use of more sophisticated and a broader scope of technology being employed by the threat systems of the 1980's and beyond.

Specific items against which the performance of current and future ASE countermeasure systems is limited are those threat systems using monopulse tracking methods, high PRF pulse doppler radars, and cooled IR seekers.

Steps are being taken, however, to form interservice and Government-Industry teams in an effort to solve these problems and to sustain the viability of Army aviation on the battlefield of the future.


ASE INFRARED CM PROGRAMS

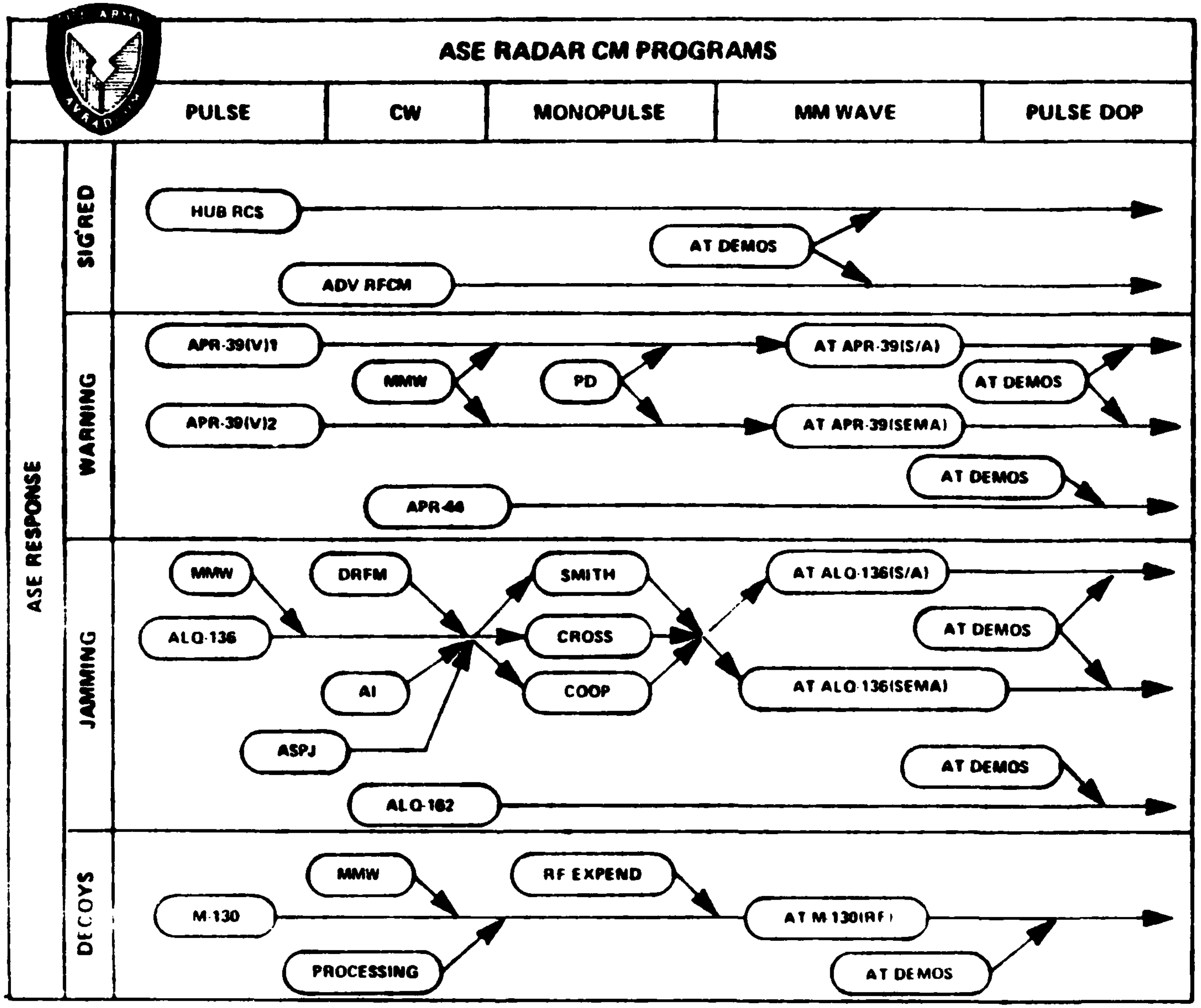
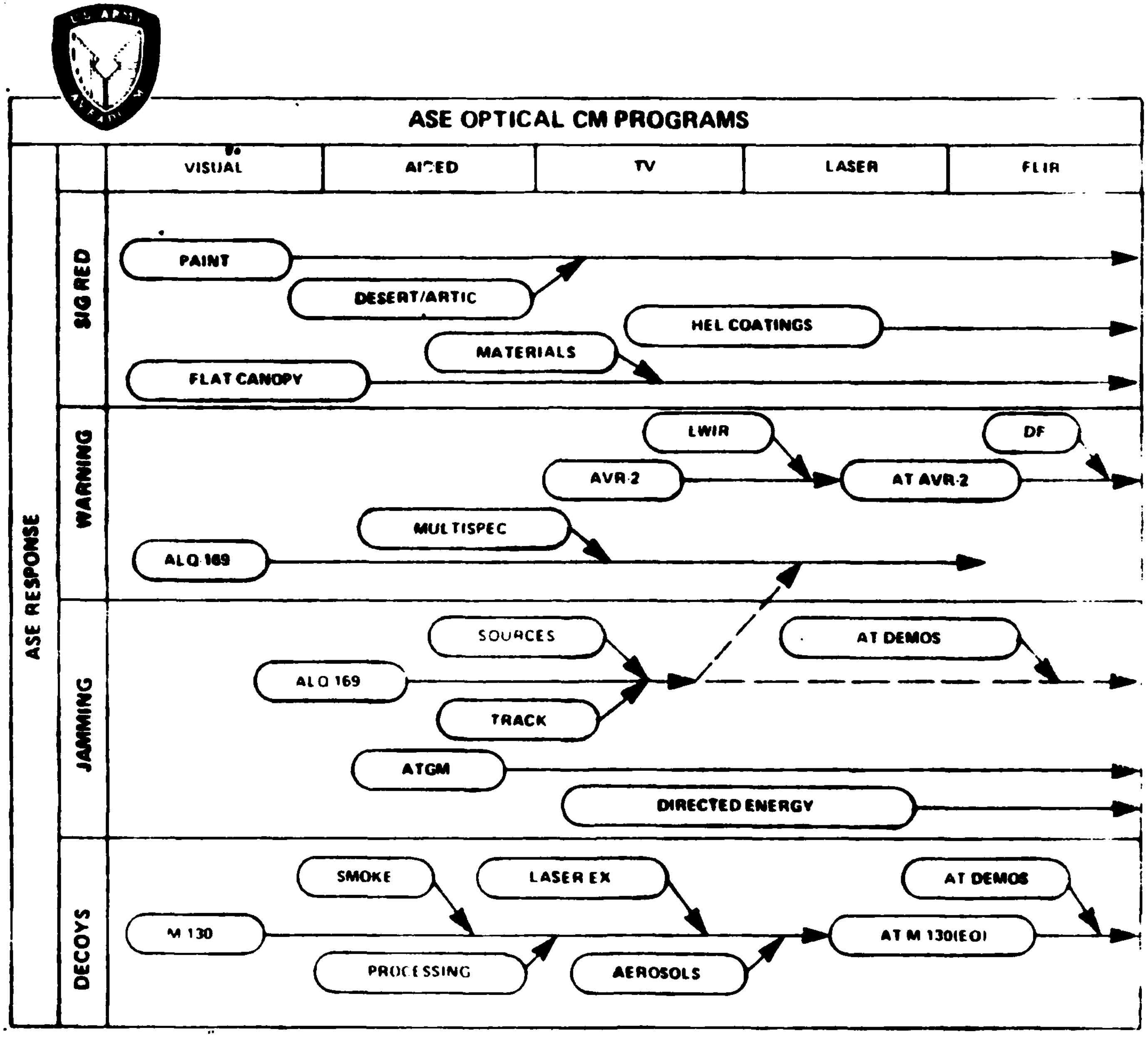

ASE RADAR CM PROGRAMS
PULSE
CW
MONOPULSE
MM WAVE
PULSE DOP
ASE RESPONSE
SIG'RED
HUB RCS
AT DEMOS
ADV RFCM
WARNING
APR-39(V)1
MMW
PD
AT APR-39(S/A)
AT DEMOS
APR-39(V)2
AT APR-39(SEMA)
AT DEMOS
APR-44
JAMMING
MMW
DRFM
SMITH
AT ALQ-136(S/A)
ALQ-136
CROSS
AT DEMOS
AI
COOP
AT ALQ-136(SEMA)
ASPJ
AT DEMOS
ALQ-162
DECOYS
MMW
RF EXPEND
M-130
AT M 130(RF)
PROCESSING
AT DEMOS

FIGURE 3

ASE OPTICAL CM PROGRAMS



LHX AVIONICS

DR. GENE R. MARNER

U.S. Army Aviation Research and Development Command

The Army has started to develop the concepts for a family of light helicopters which would respond to several significant challenges of the future. Both performance and aforability are critical issues in this concept development. Investigations are under way to establish the nature of the needs, to clarify the mission characteristics, to identify vehicle parameters, to select weapons, and to determine the integrated suite of subsytems and associated cockpit configuration. This paper reports on results to date on the last item.

Both contractural and in-house efforts have derived a baseline conceptual system for the armed scout version of LHX which will permit single crew operation at night and in adverse environments. The mission functions include armed reconnaissance, air defense suppression and defense against air attack. In order to achieve these functions, it is necessary to use an integrated avionics suite with highly coupled flight control modes and new target acquisition capabilities. A number of advanced systems may be necessary. These include a new navigation and target acquisition radar, an E-O system with automatic target detection, classification and tracking, computed image map and voice actuated controls. The reliability issues posed by such a system have been analyzed. It has been concluded that a self-healing architecture will be needed.

A competition is under way for the next phase of the project. This will determine the control and display concepts, the self-healing architecture, and the electronic technology approach to minimize cost, weight and failure rate.

The paper will discuss the project goals, the baseline conceptual system, the new systems involved, the reliability analysis, and the results to date of the contractual effort.

Modular Electronic Surveillance Measures (ESM) Systems: Designing for Expandability, Flexibility, and Cost Effectiveness

by
Dennis H. McCallam
David R. Crebs

Westinghouse Defense & Electronic Systems Center
Baltimore, Maryland

The development of advanced Electronic Surveillance Measure (ESM) systems is becoming a necessity due to the deployment of highly sophisticated radar and guidance mechanisms. A complete understanding of the ESM problem involves sophisticated processing requirements. The basic premise of ESM is to search for, identify/classify and provide effective countermeasure for hostile targets. Furthermore, as the sophistication of the threat systems increase, the complexity of the ESM systems increase. The anticipated advances in the threat arena must be effectively countered in the ESM arena. In order to provide some centralization and management of this growth, a unified approach to future development must consider these expectations. This paper presents a modular approach to the future needs of ESM design. The paper focuses upon the compatibility between the different classes of ESM systems, incorporation of this compatibility into the design and the resulting flexibility in the deployment of such a system. The central theme in this paper revolves around the modular approach not only to software/hardware development, but to the systems design as a whole.

The intent of this paper is to demonstrate that this approach will allow the passive type ESM systems to be interleaved with not only the active ESM systems but eventually with the radar systems as well.

The first section of this paper examines the major classes of ESM systems. These classes include radar warning/system identification, ELINT, passive fire-control and power management systems. The discussion focuses on the fact that these classes as listed are upward compatible. A detailed functional breakdown of the basic types of ESM processing include, as a minimum environmental search, environment ID, signal tracking, threat reaction, and countermeasures Figure 1 shows the upward nature of the processing requirements of the classes of ESM systems. Beginning with the radar warning/system identification class, the levels of complexity can be clearly seen. Discussion continues by detailing each of the ESM processing areas and presenting the upward complexity as a unified addition of well-defined modular subsystems. This transition feature of one ESM class to another shows the flexibility in the application and the expandability in the possible implementations of such a system.

	Environment Search	Environment ID	Signal Track	Threat Reaction	Counter Measure
Radar Warning/Signal ID	Yes (directed)	Yes	-	-	-
ELINT	Yes	Yes	-	-	-
Passive Fire-control	Yes	Yes	Yes	-(limited)-	
Power Managed Systems	Yes	Yes	Yes	Yes	Yes

Figure 1. ESM Class Processing Requirements

The second section of the paper addresses the software considerations that are necessary in order to provide coherent transition from one class to another. The key to providing design transportability for ESM software is examined by using the abstract/PDL approach to software design and development. This approach maintains a constant functional allocation for the software design regardless of the final target computer. This does not mean the target code is transported but rather the software requirements and the ddetailed top-down modular structures are preserved. The structure of abstract/PDL is a design tool which insures that coherent functional allocation can be maintained in the transition from on ESM class to another.

Further discussion is done using examples of existing modular software design that demonstrates the integrity of this concept. As in the previous section, the flexibility/expandability features are detailed.

The third section of the paper addresses the various hardware configurations that are necessary to support the classes. The minimum hardware to perform the warning/identification function requires a signal encoding system and a processor for signal evaluation. The signal encoding system consists of a wide-band receiver to perform the environmental search and a narrow-band receiver to make precision measurements. When time-critical signal discrimination must be performed, interleaving of the wide and narrow bands may be employed. The processing system requires a general purpose computer that can quickly and efficiently perform the required data reduction on the encoded data. This data reduction consists of signal separation and signal identification. Expansion of this baseline system can be accomplished by implementing signal processing to perform the signal separation and, if desired, some of the identification functions. This incremental addition of "black-box" units allows reasonable transition from one ESM class to another.

The final section re-examines the modular approach in light of expandability to existing systems and in providing cost-effective expandability to future systems. Consideration is given to more complex identification tasks such as platform and event scenarios along with the requirements that information feedback of display systems impose upon the ESM design.

A VHSIC PROCESSOR ARCHITECTURE FOR ADVANCED EW SYSTEMS

Raymond J. Garbos
Sanders Associates, Inc.

INTRODUCTION

Electronic Warfare systems can be defined as those which protect the friendly use of the electromagnetic spectrum while denying the use of the spectrum from the enemy.

The electromagnetic threat has been repidly increasing from a few stable frequencies in the mid 1950's to several hundred very complex signals anticipated in the 1990's. These new signals have complex modulations in RF and pulse intervals and are located throughout the entire frequency spectrum of interest.

Simultaneous with this rapid growth in threat requirement in which our systems must operate, the packaging volume for airborne applications has remained the same and in many situations must be further reduced to provide practical size, weight, and power implementations. This is the basic reason that systems need to go to VHSIC technology. However, VHSIC technology must be complimented with new architectures which maximize the use of VHSIC components to solve the future electronic warfare requirements.

PROCESSING REQUIREMENTS

Although the number of emitters and resultant signal density can very with mission due to scenario, aircraft altitude, receiver sensitivity, etc., it is clearly accepted that input pulse densities will exceed 1 to 2 million pulses per second. With each pulse having to be digitized for each of the key parameters it contains (RF, Angle of Arrival, Pulse Width, Amplitude, and Time of Arrival), the resultant pulse descriptor word could be in excess of 80 bits wide. With each pulse requiring hundreds of operations per second, the effective processing requirement exceeds hundreds of billions of bit operations per second (BOPS). This demand is several orders of magnitude more that today's standard military processors which approach 10 million BOPS. Even with VHSIC technologies applied to conventional computer architecture, the processing capability can be improved only 300 to 500 million BOPS.

To bridge this gap, two solutions have been combined to handle the EW signal processing requirements. The first is a preprocessing filter or sorter which can operate on these wide (80 bit) pulse descriptors arriving at several million pulses per second. Front end sorters made up of VHSIC components can reduce the input rate to individual VHSIC preprocessors which can then process at 300-500 million BOPS. The second solution is a multi processing architecture which is well defined, modular, and adaptive. This architecture can also provide additional system availability through fault tolerant features. The summary requirements established during Phase 0 of the VHSIC program for an advanced EW processing system are:

1. A high-speed, small, low-power, processing element is a major requirement for EW systems. The element must be expandable by paralleling elements to gain throughput.

2. A front-end data preprocessor module is required to handle the very high input data rate decisions, which require greater than several hundred billion bit-operations/second, before signals are sent to any processing element.

3. Having identical modular elements, each with the flexibility to perform all functions, makes a much better architecture than unique functional elements and also reduces logistic support.

4. The fault-tolerance and built-in test that is needed to increase system availability can be achieved with VHSIC technology.

5. Ada, because of its multi-tasking capability, is an expecially suitable high-order language for EW processing.

6. A two-bus structure becomes an important design feature as very wide pulse descriptor words are needed, and input pulse rates exceed several million pulses per second.

EW SIGNAL PROCESSING ARCHITECTURE

An architecture which meets the above requirements is shown in Figure 1.

The 80 bit wide input pulse descriptor from the EW receiver is shown in the upper left. This bus is uni-directional because of the high throughput of the data. The pulse descriptor enters the input filter and address generator. This function provides for a programmable adaptive "Between-Limits'Compare" function on any one or all of the parameters of the pulse descriptor (typically RF frequency and Angle of Arrival (AOA) are used). If a signal is within the programmed limits, an address is generated which is used to load that descriptor into the proper processing element(s) shown as GSP's (General Signal Processors). The resource management processors can adaptively select which parts of the frequency spectrum each GSP can process, thus reducing the input rate to each GSP. Once a GSP has been assigned a signal or signals, it can adaptively change/track the input filter through the 2nd bus (shown below each of the GSPs in the diagram). This second bus is a control bus and operates at a much lower data rate; it also communicates with external devices.

This structured approach offers many desirable features:

1. Each GSP module can be identical - comprised of only 6 unique VHSIC chips.

2. Fault tolerance can be achieved through majority voting schemes which periodically check each porcessor and rearrange resources as required.

3. Simple programming concepts and use of Ada.

4. The input filter is developed from two unique chips (Between-Limits-Compare and a Cross-Bar Priority Encoder), each of which has application to other VHSIC applications.

5. Each part of the system can be expandable to handle differing EW applications, thus providing a common architecture adaptable to the majority of EW systems.

INPUT FILTER AND ADDRESS GENERATION

This key feature of the design needs additional description. The left side of Figure 2 shows the use of 3 VHSIC chip types to construct an entire digital input sorter. These types are the Between-Limits-Compare (BLC), Cross-Bar Priority Encoder (CPE) and High Speed Interface (HSI). The raw 80-bit data enter a bank of Between-Limits-Compare (BLC) chips. When a BLC match occurs, the match outputs are transferred to a priority logic in a VHSIC in a VHSIC Cross-Bar Priority Encoder (CPE) chip. The results of the priority logic go into an address generator, also using a CPE chip, which generates the address of the module where the data is to be sent. The various parameters used in the compare and priority logic modules are loaded through the system bus. In this way, the input filter can be adaptively changed, based upon the instantaneous priority within the system. Each BLC chip is partitioned into a 32 word x 20-bit limit compare; therefore, five BLCs must be paralleded to properly handle the input word format. Each CPE is 64 bits in and can generate 8 bits out. Both BLC and CPE must operate in under 100 nanoseconds.

As can be seen, each BLC performs a 20 bit compare on a 32 bit work - in each 100 nanoseconds. This is 6.4 gigabit operations per second. The cross-bar switch is even more impressive as it effectively handles 100 words by 64 bits in each 100 nanoseconds, resulting in 64 gigabits operations per second. Figure 2 shows how several BLC and CPE chips are arranged to handle the input data rate. This arrangement has the capability of providing the several hundred billion BOPS throughput for EW processing discussed earlier.

It is clear that conventional computer architectures could not handle rates such as these.

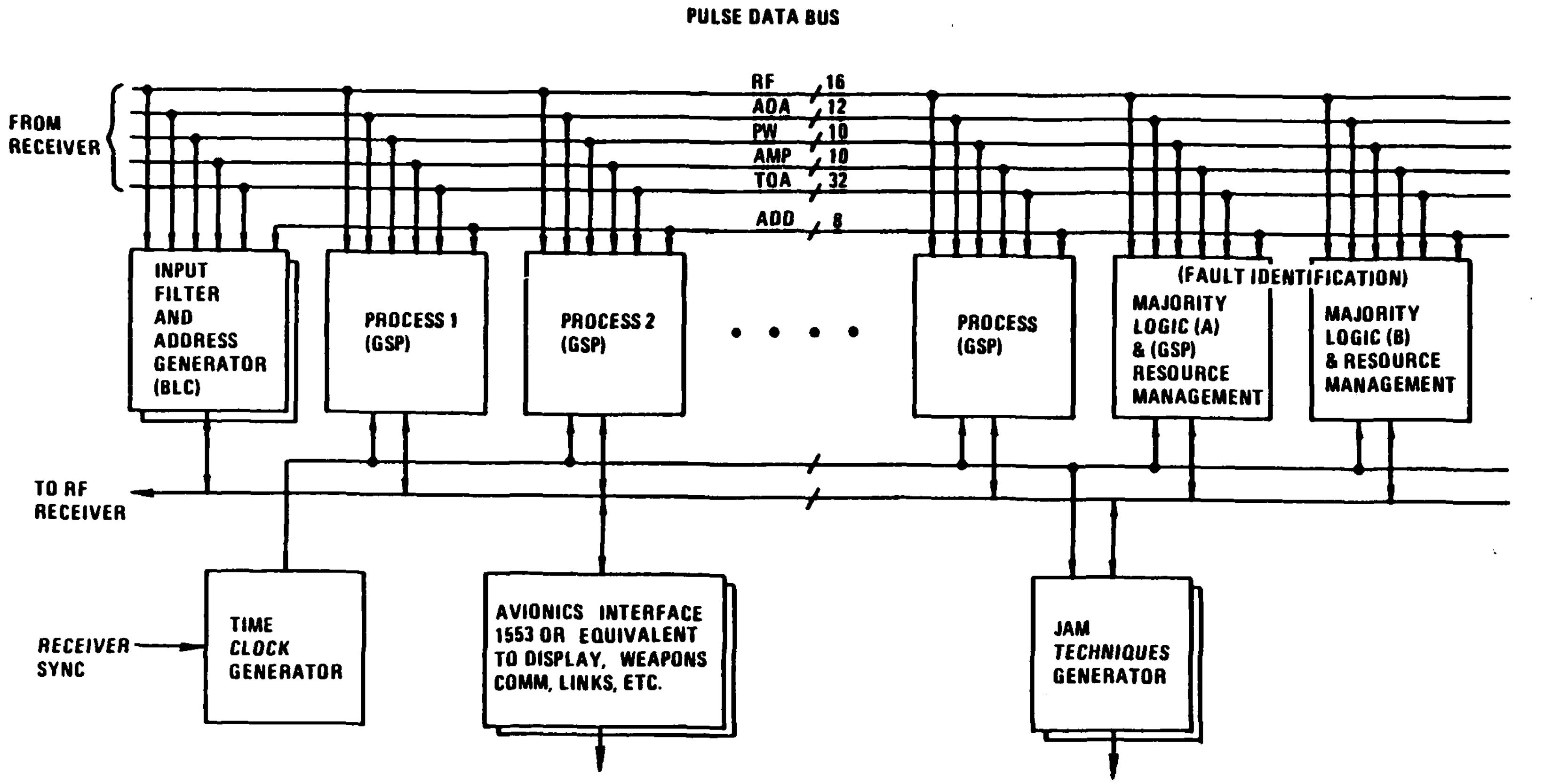
PACKAGING

The size, weight and power of EW systems are key considerations. This relates to the need to develop detailed packaging concepts. Figure 1 shows the general partitioning of a system.

The input filter and address generator can be contained on a signal circuit card and be capable of handling several hundred simultaneous signal characteristics. Each of the processing elements can be a single circuit and with self contained memory. Figure 2 indicates the key to the packaging - the multi-chip carrier. Because of the high speed, short lead lengths are a necessity and the compact structure of the milti-chip carrier becomes a necessary subelement. This co-fired package can contain over 25 VHSIC chips and with proper colling can dissipate over 25 watts, which provides a large margin versus a technology such as CMOS-SOS with a power dissipation requirement of approximately 6 watts. Since a VHSIC geometries, CMOS speeds become very suitable for the processing elements discussed earlier, and with the greatly improved power and density factors over other technologies, CMOS-SOS appears to be the best technology for EW applications.

CONCLUSIONS

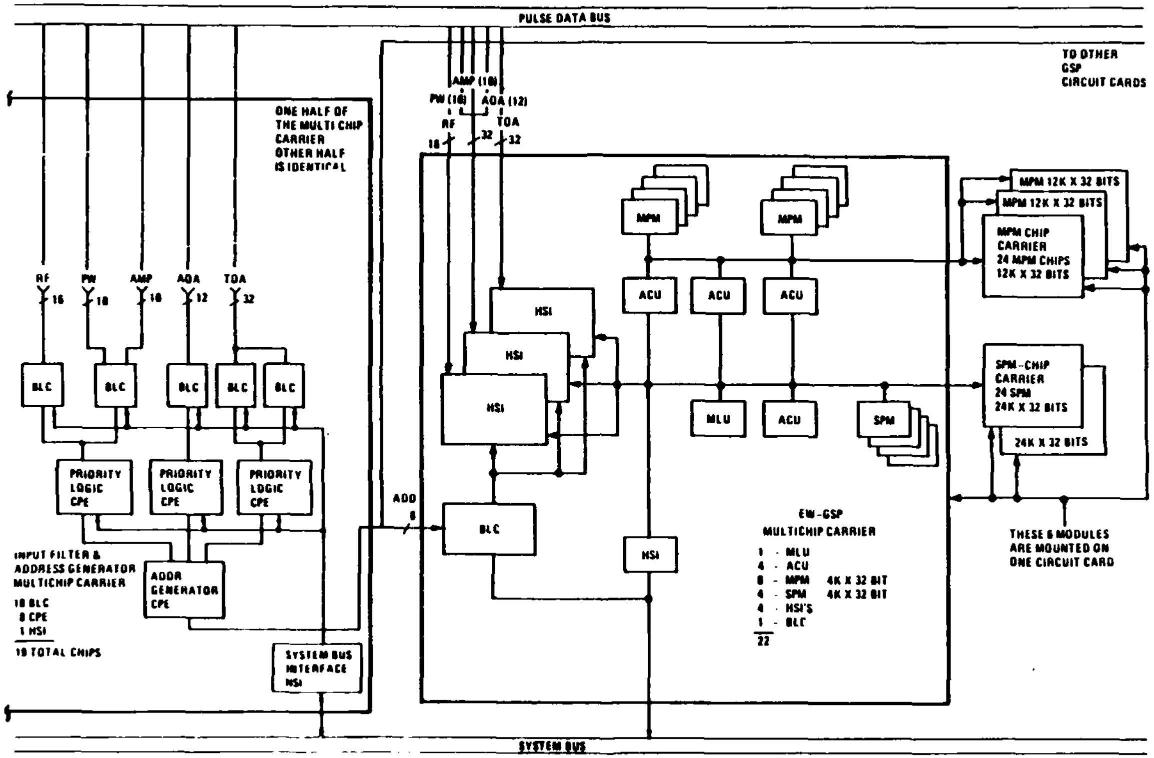
VHSIC technology will allow advanced EW systems to meet the new threat requirements. However, careful application and understanding of this technology is necessary to develop proper solutions and architectures as shown above. An architecture which employes only 2 unique circuit cards, 4 unique multi-chip carriers and only 7 qunique VHSIC chips provides a modular approach which can reduce development time and cost and simultaneously produce a tremendous improvement in life cycle cost and system effectiveness.



SANDERS

V-81-0264-005

Figure 1



NOTE 6 IDENTICAL INPUT FILTER AND ADDRESS GENERATOR CARRIERS CAN BE MOUNTED ON ONE CIRCUIT CARD

Figure 2

MONOPULSE RADAR ECM

WAYNE E. CRAIL

CINCINNATI ELECTRONICS CORPORATION

JOSEPH LASKA

NAVAL AIR DEVELOPMENT CENTER

The monopulse radar has the capability of accurately tracking airborne targets by using multiple receivers and antenna beams to produce sum and difference error signals. This design also minimizes the effect of Electronic Countermeasures. There are several techniques which have been developed to degrade the tracking accuracy of this radar. However, some of these rely on the physical size of the aircraft or require several vehicles and restricted flight paths to effectively implement the technique. The subject of this paper will address an approach which is currently under investigation to improve aircraft survivability.

Cincinnati Electronics Corporation is under contract with the Navy and Army to develope feasibility model hardware to be used to test the ECM effectiveness against simulated monopulse radars. By simulation the feasibility models can be exercised along with a variety of deployment parameters without the high cost of flight tests in the early stages of development.

In August 1980, the feasibility models developed for the Navy, underwent simulation testing at the Pacific Missile Test Center. The ECM technique was shown to be effective in countering the monopulse radar. Alternate scenarios have been planned for additional simulation testing. The scenarios and test results will be discussed in this paper.

FIRE CONTROL CONCEPTS FOR COOPERATIVE ATTACK OF MULTIPLE AIRBORNE TARGETS

by

Daniel E. Fisher, Senior Engineer
Westinghouse Electric Corporation

Eugene H. Thompson, Fellow Engineer
Westinghouse Electric Corporation

and

David E. Chaffin, Captain, USAF
Air Force Wright Aeronautical Laboratories

This paper presents an integrated fire control concept which will enhance the ability of tactical fighter aircraft to conduct counterair missions in the multiple target environment of 1985 to 1995.*

The avionics system must provide an effective capability over a wide range of scenarios. Some of the most demanding scenarios are derived from the chosen design point; a conventional mid-intensity conflict. This conflict features many unique fire control challenges including:

a. Protracted adverse weather periods

b. Variable terrain (plains to mountains)

c. Dense, mobile, ground-based ECM

d. Airborne standoff and escort jammers

e. Spectrum of surface and airborne threats

f. Extensive opposing EW, GCI and C^3 network

g. Premiere Soviet Frontal Aviation units

h. Rapid deployment of successive waves with a spectrum of objectives

i. Overlapping threat weapon system capabilities

j. Threat numerical superiority

k. Unacceptable threat lethalities in close air combat

l. Restricted engagement airspaces

m. Enemy, neutral and friendly aircraft in close proximity.

*This work was sponsored by the Avionics Laboratory, Wright-Patterson AF Base, Ohio.

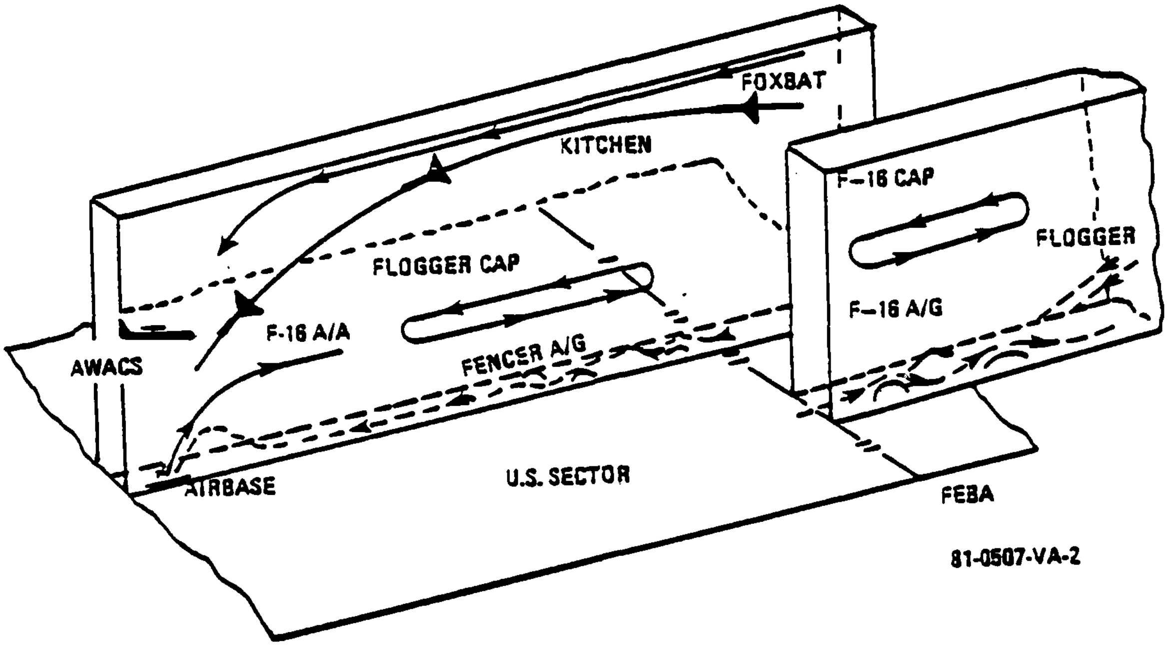


Figure 1 (U) Baseline Missions

Figure 1 illustrates four important missions postulated for the selected conflict. The first mission is blue force CAP or strip launched intercept whose objective is to repel low altitude offensive air strikes conducted by red forces against blue operating bases. The second mission is to intercept red forces attacking an airborne high value asset such as AWACS. The third mission is to intercept a red force high speed high altitude cruise missile attack. The fourth mission is to escort a blue force offensive strike against red force main operating bases.

Each blue fighter is responsible for a corridor fifty miles wide extending from the blue operating base to the FEBA. In order to successfully complete the mission, the blue fighter must perform a series of critical functions which include:

a. Search the corridor

b. Detect and track targets

c. Identify and count the target track

d. Plan the attack

e. Execute the attack

f. Assess the target kill status

The ranges and angles at which, and the time periods during which these functions must be performed have been determined by simulating engagement timelines using the aircraft and missile performance characteristics of the combatants engaged in the postulated scenarios.

Search detection, track, identification, and target count are largely sensor and sensor processing functions. Planning the attack includes prioritizing multiple target tracks and coordinating the attack with other friendly units so all red target tracks can be targeted without duplication. Executing the attack includes aircraft maneuvers to attain a launch position and missile launch and guidance. Assessing the target kill status is necessary for making reattack decisions.

Obviously, in a multiple target environment, these functions are cumulative. You must maintain search over the corridor and track on many targets while attacking the current target. Attack planning is continuously updated as new targets are detected and old targets maneuver out of the field. The attack execution begins with the maneuvering on the first target and continues until the last missile launched reaches its target.

The avionics system is required to perform these functions in all weather day/night operations and in the presence of heavy electronic jamming. It must be survivable and operate even when some components have failed or are otherwise neutralized. It must be capable of stealthy operation and have a low probability of intercept.

Figure 2 illustrates the configuration of the selected avionics suite. Multiple sensors are integrated to provide the search, track, identification, and raid count information in weather and during night operation. For stealthy operations or in the presence of jamming, passive ranging is provided. The attack planning function is performed by the pilot assisted by prioritization and cooperative attack algorithms. The attack execution is performed by the pilot assisted by the attack steering and missile launch envelope algorithms.

In the absence of pilot direction, the prioritization algorithm will automatically prioritize red target tracks in the track file. Priority is first based on target type (i.e., bomber, fighters, etc.), then on time required for the blue fighter to reach a launch position, time required for the blue missile to reach its active terminal phase, and a metric representing red target escape likelihood. Likewise, in the absence of pilot direction the cooperative attack algorithm will automatically assign targets to friendly fighters based on target type and time required to reach a launch position. Attack planning data is typically presented on a heads down multi-purpose display. Once the highest priority target is selected it is "bugged", and now attack execution data on that target is displayed heads up.

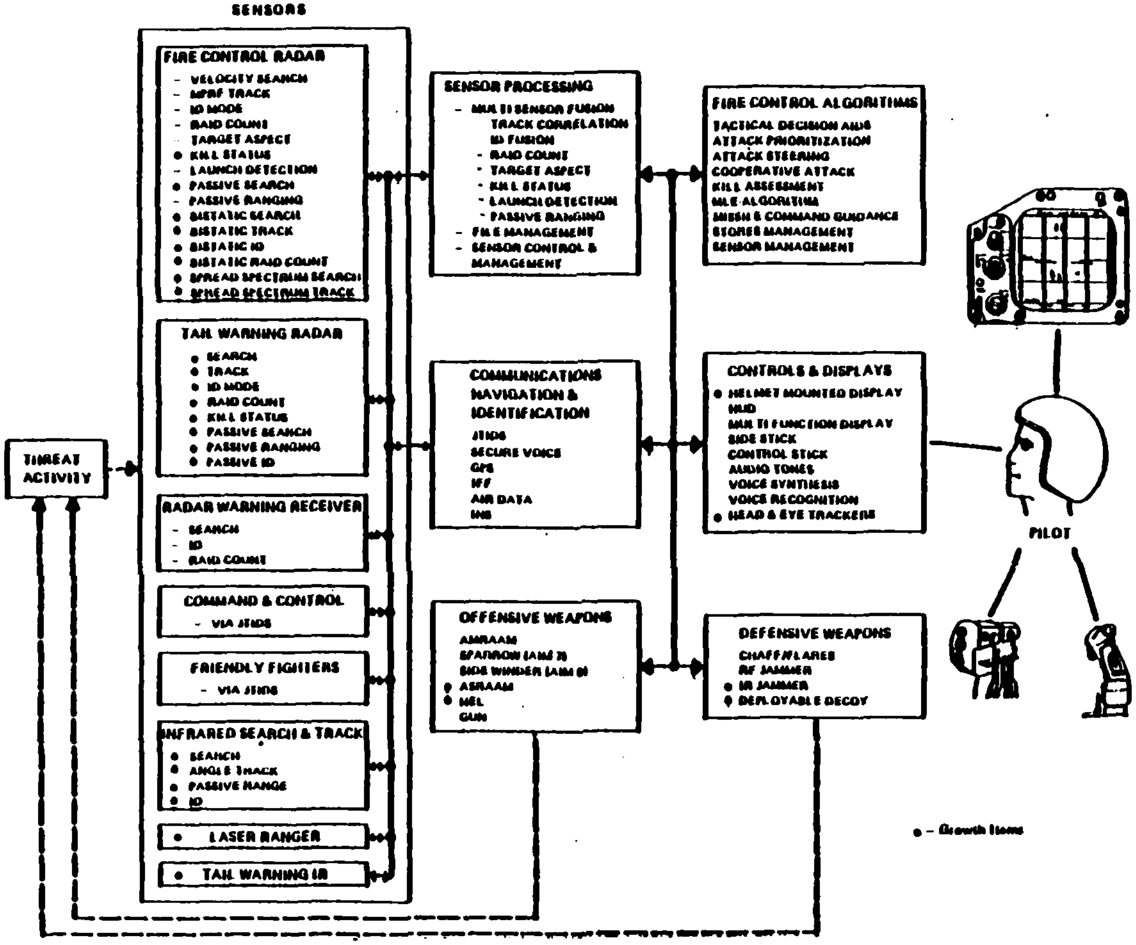


Figure 2 (U) Preferred Avionics Configurations (1985 - 1995)

Executing the attack is entirely the pilots job. Algorithms provide the pilot data only. In the multiple target environment, the pilot attacks his current highest priority target without losing track on targets yet to be attacked, or command link coverage to previously launched missiles, or track on targets already launched on but whose missiles still require command link updates. These constraints move dynamically and are displayed to the pilot for the next highest priority target as shown in Figure 3. This display contains launch range and off boresight data from the missile launch envelope algorithm.

This display format narrows the pilots attention to the next highest priority target for the time period required to reach a launch position. During this time period, the dynamics of the engagement will change, and a target of opportunity may cross in front of the blue fighter. In order to take advantage of this new target, a special alert signal is placed on the attack steering display. This cues the pilot to look at the attack planning display. If the pilot so desires, this free shot is "bugged" and attack data on the new target is displayed heads up. After the free shot is launched, the previous highest priority target is returned to the heads up display.

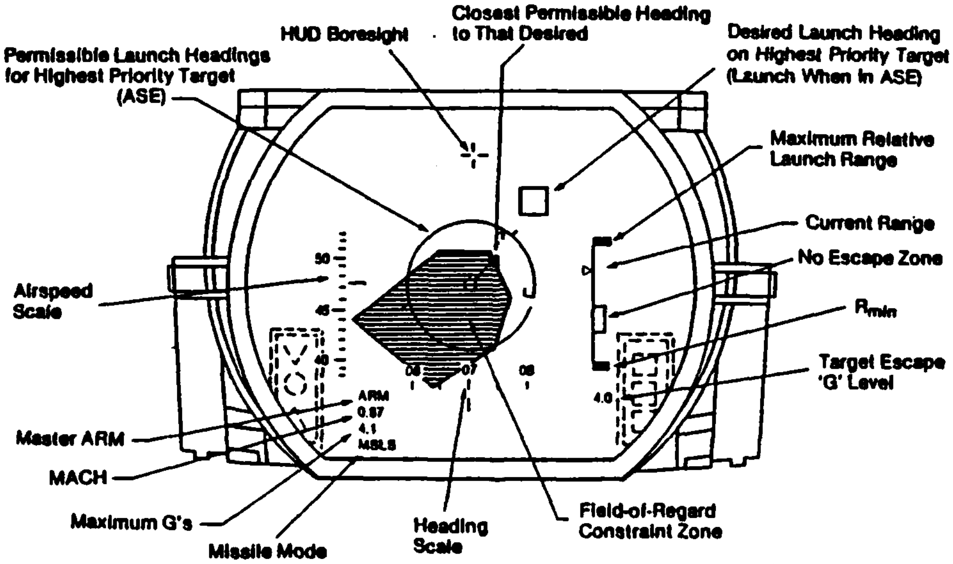


Figure 3 (U) HUD Display Format with Multiple Target Attack Zone (No Launch Situation)

Presenter's Address and Phone Number

Jon Desmond Att: DELNVSI
U.S. Army Night Vision & Electro-Optics Laboratory
Fort Belvoir, VA 22060
(703) 664-6535

V. M. Farmer
Thorn-EMI Electronics
Radar Products Group, Radar House, Dawley Rd.
Hayes, Middlesex, UB3 1 HN England
01-573-3888 X 2048

Don Mertens
Emerson Electric Sta. 4007
8100 W. Florissant
St. Louis, MO 63136
(314) 553-4007

George L. Cohill
Bell Helicopter Textron
P.O. Box 482
Fort Worth, TX 76101
(817) 280-3346

Richard Farrell
Boeing
Box 3999
Seattle, WA 98124
(206) 655-3963

R. N. Cullis
Martin-Marietta
P.O. Box 5837 M.P. 304
Orlando, FL 32855
(305) 352-2117

L. A. Eusanio
Arvin/Calspan
P.O. Box 400
Buffalo, NY 14225
(716) 632-7500

Dr. Alvin E. Cowan
Martin-Marietta
P.O. Box 5837 M.P. 295
Orlando, FL 32855
(305) 352-3284

John F. Michaels
Republic Electronics, Inc.
575 Broad Hollow Rd.
Nelville, NY 11747
(516) 249-1414

Dean W. Elliott
Naval Weapons Center
China Lake, CA 93555
(714) 939-5578

Gene Jordan
First Ann Arbor Corp.
214 East Huron St.
Ann Arbor, MI 48104
(313) 761-5836

Thomas Riordan
Fairchild Weston Systems, Inc.
300 Robbins Lane
Syosset, NY 11791
(516) 349-2200

Dr. John C. Ruth
General Dynamics, Fort Worth
P.O. Box 748 Mail Zone 2449
Fort Worth, TX 76101
(817) 732-4811 X 5391

Michael Garsik
U.S. Army Aviation Research & Development Command
4300 Goodfellow Blvd.
St. Louis, MO 63120
(314) 263-1477

Dr. Gene Marner
U.S. Army Aviation Research & Development Command
4300 Goodfellow Blvd.
St. Louis, MO 63120
(314) 263-1078

Dennis H. McCallam
Westinghouse Electric Corp.
Box 746 M.S. 432
Baltimore, MD 21203
(301) 765-4392

Raymond Garbos NCA1-6236 Dept. 2350
Sanders Associates, Inc.
95 Canal St.
Nashua, NH 03061
(603) 885-4480

Wayne Crail
Cincinnati Electronics Corp.
2630 Glendale Milford Rd.
Cincinnati, OH 45241
(513) 563-6000   X 827

D. E. Fisher
Westinghouse Electric Corp.
Box 746
Baltimore, MD 21203
(310) 765-7696

END

DTIC

8-86