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Volume I

INTEGRATED STRIKE AVIONICS STUDY

Volume I

Avionics Systems Integration
Boeing Military Airplane Company
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This document reports the results of the integrated strike avionics study (ISAS). Advanced fire control concepts emphasing the modular integration of current and emerging sensors and reduced crew workload were formulated and evaluated. A preferred system concept embodying the best features of the systems evaluated consisted of a Ku-SAR multimode radar, FLIR and Silicon TV EO sensors and a 3D Target Classifier. The mechanization was automatic with crewman participation. Post-autocuer/autoclassifier integration of sensors, manual-automatic mechanization of the concepts, and improved terminal weapon guidance were recommended.

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FOREWORD

This study was performed by the Boeing Military Airplane Company, Advanced Airplane Branch, Seattle, Washington. VERAC Inc. of San Diego, California contributed as a subcontractor to Boeing. The study was conducted under U.S. Air Force Contract No. F33615-79-C-1932, during the period 6 August 1979 through 22 September 1980, and was submitted in August 1980. Technical direction and administration were provided by Mr. Joe Boaz and Lt. Jimmy Offen (AFWAL/AART-3).

The study results are presented in two volumes, the second (AFWAL-TR-80-1145, Volume II) of which is classified. Prior to publication, this report was identified within Boeing as D180-26023-1.

The study was managed by Mr. Harry R. Fox. Principal contributors included Messrs R. L. Kinnaman, M. R. Wallace, G. L. Helser, F. M. Kim, L. Witonsky, A. D. Connot and W. A. Davis. Dr. Jeff Nash and Dr. Donald Vanderstoep participated in the study for VERAC Inc.

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GLOSSARY

AAA	antiaircraft artillery
AGL	above ground level
ALLD	airborne laser locator/designator
ALSPM	Avionic Laboratories Sensor Performance Model
ASMD	Aerosol Scattering Measurement Device
BI	battlefield interdiction
CAS	close air support
CATIES	common aperture technique for imaging electro-optical sensors
CCD/CID	charge-coupled device/charge injection device
CER	cost estimating relationship
CRT	cathode ray tube
DBS	Doppler beam sharpening
DCSD	display for correlated sensor data
DI	deep interdiction
ECCM	electronic counter - countermeasures
ECLS	emitter classifier location system
ECM	electronic countermeasures
EO	electro-optical
ERIM	Environmental Research Institute of Michigan
ERIM CYTO	a computer concept
ESM	electronic support measures
EW	electronic warfare
FAC	forward air controller
FEBA	forward edge of battle area
FLIR	forward-looking infrared radar

GMTI	ground moving target indicator
GPS	global positioning system
HC	hydrocarbon
INS	inertial navigation system
IRAR	Infrared Airborne Radar (program)
ISA	integrated strike avionics
ISAS	Integrated Strike Avionics Study
JTIDS	joint tactical information distribution system
LANTIRN	Low-Altitude Navigation Targeting Infrared for Night (program)
LCC	life-cycle costs
LLLTV	low-light-level television
LOWTRAN IV	Low Resolution Atmospheric Transmittance (model)
LWR	long-wave foliage-penetration radar
MLCCM	modular life-cycle-cost model
MTF	modulation transfer function
NAVSTAR	U.S. global positioning system
NVL	Night Vision Laboratories
PAVETACK	(a program code name)
P_K	probability of kill
PLSS	precision locator strike system
P_S	probability of survival
RBGM	real-beam ground map

SAM	surface-to-air missile
SAR	synthetic-aperture radar
SiTV	silicon-based television
SNR	signal-to-noise ratio
TA	terrain avoidance
TADS/PNVS	target acquisition/designation system and pilot night vision system
TDI	time-delay integration
TERCOM	terrain comparison
TF	terrain following
TLE	target location error
TMD	tactical munitions dispenser
VHSIC	very-high-speed integrated circuit
3D-TC	three-dimensional target classification

1.0 INTRODUCTION AND SUMMARY

This document provides the unclassified portions of the final report of the Integrated Strike Avionics Study (ISAS) performed under USAF contract F33615-C-79-1932. Together with Volume II of the series (AFWAL-TR-80-1145, Volume II), it reports research and analyses performed in the formulation and evaluation of three integrated avionic concepts. Subjects covered are radar, sensor susceptibility to countermeasures, weapon delivery timelines, concept survival, and kill capability against targets.

Details of the rationale leading to a preferred concept—an automatic system using crewman boost and Ku-band radar-EO sensor array—are presented in this volume.

1.1 INTRODUCTION

The ISAS program is designed to develop new fire control concepts that exploit the enhanced target detection capabilities provided by the modular integration of a variety of new and emerging target sensors and signal processing techniques.

The overall objective is to improve tactical weapon delivery effectiveness through improvement of the target acquisition and crew workload factors. The applicable time period is post-1987.

The study consisted of seven major tasks:

a. In task I, a number of prospective advanced fire control concepts were to be formulated and three candidates were to be selected for evaluation. Although there were no firm constraints limiting the conceptual fire control sensor arrays or mechanizations, the study scope emphasized new or emerging technology.

b. Task II consisted of analyses to define system characteristics and performance for each concept. Specific missions and weather conditions were defined as a part of the study requirements.

c. Candidate concepts were to be evaluated in task III with respect to (1) survivability and target kill (providing a figure of effectiveness), resistance to countermeasures, reduction of crew workload, weapon selection, ease of installation (retrofit) in existing aircraft, and life-cycle cost. A plan defining an evaluation methodology was required at the study midpoint. Acceptance of the plan by AFWAL signified completion of task III.

d. Task IV and V consisted of analyses and research to generate concept figures of effectiveness and life-cycle costs.

e. The ranking of candidate concepts, followed by a trade-off to implement the best conceptual characteristics in a new and final concept was to be accomplished in task VI.

f. In task VII, technology deficiencies discovered during the Boeing study to synthesize a number of sensor-processor arrays combined in three distinctive mechanizations—manual, automatic, and manual-automatic. A different sensor array was used with each mechanization, resulting in two dimensions for concept formulation and evaluation. A heavy array of sensors (three different frequency radars, TV, forward-looking infrared (FLIR), and a laser scanner) was allocated to concept I; concepts II and III used the same electro-optical (EO) sensors with Ku-band and millimetre-band radars, respectively. The sensor selection approximated what might be done on a new aircraft, a retrofit aircraft, and a minimum change addition to an existing aircraft. The final selection of sensors used in the arrays was preceded by a technology survey and update.

1.2 SUMMARY

The nine sections of this report address the study tasks accomplished in formulating and evaluating the ISAS concepts.

Section 2.0 is a part of the task II analysis. It reviews the attack mission profile and the assumptions used in the analysis.

Section 3.0 summarizes the results of a review and update of applicable sensor technology. Current and emerging sensor technology developments are considered as they apply to a sensor functional requirements summary.

The selection candidates as described in Section 4.0 were:

a. A manual/automatic system using multimode long-wave, Ku-band and millimetre radar, and a Silicon television, a FLIR and a 3D target classifier. Both the TV and the FLIR were assumed to have their own autocuer-classifiers. The system mechanization used crewman participation to ensure target recognition.

b. A fully automatic system, using a multimode Ku-band radar and the same EO complement as the first concept. The automatic system required only crewman consent to fire.

c. A manual system using multimode millimeter radar, FLIR, and Silicon TV. The manual system was essentially a limited-autonomous system and a little more versatile than a cooperative-only system. Sensor integration relied on the crewman.

The major analyses (task II) performed in the study to quantify component performance and to evaluate the candidate concepts are presented in Section 5.0. Contained in this section are performance analysis and discussions of: EO sensors, integrated sensors, crew workload, installation of the concepts in F-4, F-15, F-16, and A-10 airplanes, weapon selection, and graceful degradation. The section references radar and an ECM susceptability analyses reported in Volume 2 (AFWAL-TR-80-1145), the classified supplement to this report.

Section 6.0 also references Volume 2. The section contains classified data used in generating concept-survival and target-kill-related data as required by ISAS task IV.

Life cycle cost data (ISAS task V) are discussed and provided in Section 7.0. Concepts I and II respectively had the highest life cycle costs.

The study results and conclusions are presented in Section 8.0. A detailed ranking of the candidate concepts finds that concept I, the manual-aided system has the best performance, while concept II has a very slight survival superiority. Concept III is distinguished only by its lowest cost. The tradeoff results in a preferred system that deletes concept I's mm and long wave radars, and add the full automatic capability of concept II to concept I as backup. The resultant system should be superior to concept I under normal conditions. When the crew is overloaded, system performance should not degrade below the concept I capability level.

Section 9.0 presents a brief summary of the technological deficiencies exist because the ISAS task has not previously been attempted as addressed in this study.

The appendix in this report contains this ISAS task III ranking and tradeoff plan completed midway in the study.

The results of this study indicate:

a. The integration of sensors on the processed level (i.e., after autocueing and autoclassification) decreases crew workload and shortens weapon delivery time lines.

b. A fire control concept combining crew participation and automatic target acquisition and weapon handover is more effective than a fully automatic system.

c. Continued development of lock-on-after-launch weapons is needed to ensure full realization of integrated sensor capabilities. The target-acquisition benefits of integrated sensors can be limited by the seeker limitations of lock-on-before-launch guided weapons. For example, the probability that one or more sensors can detect or recognize the target is now constrained in usefulness because at least one of the sensors used to detect or to classify targets must be in the lock-on-before-launch weapon guidance seeker spectral region or it cannot be certain that the weapon guidance will function. Weapon seekers that lock on after launch (in the weapons terminal phase) may remove this limitation if the results of target classification can be used in a logic exercise to match the target type to the weapon terminal seeker capabilities.

2.0 SYSTEM REQUIREMENTS AND STUDY ASSUMPTIONS

The ISAS concepts have been formulated to defeat a specific set of mission, target, and scenario conditions. These conditions have powerfully influenced the nature of the concepts, the sensors selected, and their resultant performance in the concept evaluation.

2.1 SCENARIO

Threat Baseline, USAF Attrition Data Handbook, ADTC-TR-79-38, is the official ISAS scenario and threat document. It defines, among others, the central NATO scenario used in this study. Target distributions, hostile defensive weapon types, and their beddowns were extracted from this scenario as were countermeasure data used in evaluating candidate concept susceptibility to countermeasures. Details of this information are described in appropriate sections of AFWAL-TR-80-1145, Volume II, the classified supplement to this report.

2.2 MISSION AND OPERATIONAL CONSIDERATIONS

Additional numerical data and parameters not directly defined in the scenario were required to fully develop all of the conditions under which the ISAS Candidate concepts were to be evaluated. These data and parameters are summarized in Table 2.2-1 and discussed below.

2.2.1 Strike Speed and Altitude

The required attack speeds for the ISAS missions are 350 kn (close support) and 553 kn (battlefield interdiction and deep interdiction mission).

The conceptual fire control systems are required to make bomb and missile attacks from 200-ft altitude and 3,000-ft altitude. These speeds and altitudes were selected by Boeing with the approval of the USAF project officer.

The 350-kn speed was selected as representative of A-10 maximum attack speed, while mach 0.85 (553 kn) is representative of the F-14, F-15, and F-16 aircraft with weapon loads at low altitude.

Table 2.2-1. *Strike Mission Requirements*

AREA	LOCATION FROM FEBA	TARGET LOCATION ERROR	WEATHER - DAY/NIGHT
CLOSE AIR SUPPORT	(0 - 2.7 N.MI.) 0 - 5 KM	± 0.5 KM	TARGET OBSCURED BY CLOUD FOG OR SMOKE (IMPENETRABLE BY E/O SYSTEMS)
(ZONE 1)	INSIDE ENEMY LINES		CLOUD BASE 200 FT AGL NO PRECIPITATION (IMPENETRABLE BY E/O LASER SYSTEMS)
			CLOUD CEILING 2,000 FT AGL NO PRECIPITATION (IMPENETRABLE BY E/O LASER SYSTEMS)
BATTLEFIELD	(2.7-10.8 N.MI.) 5 - 20 KM	± 2.5 KM	SAME AS CLOSE AIR SUPPORT INTERDICTION
(ZONE 2)	INSIDE ENEMY LINES		
DEEP INTERDICTION	(10.8 - 54. N.MI.) 20 - 100 KM	ASSEMBLY AREAS ± 0.5 KM	SAME AS CLOSE AIR SUPPORT
(ZONE 3)	INSIDE ENEMY LINES	MOVING - DEGRADES TO ± 10. KM ON LINES OF COMMUNICATION	

TARGET ARRAYS AND DEFENSE SYSTEMS - THOSE INDIGENOUS TO AN ATTACKING ARMY OF 5 DIVISIONS - SCENARIO PER ADTC-TR-79-36 (JUNE 1970) (REFERENCE 1)

ATTACK - MEDIUM OR LOW ALTITUDE

SOURCE SOW, PARAGRAPH 4.2.2, 4.3 AND QUESTIONS/ANSWERS

The 200-ft altitude attack represents an attack mode that promotes high survival by exploiting terrain shadowing and clutter. It is preceded by a popup to 3,000-ft altitude for target acquisition.

The 3,000-ft-altitude attack is a medium-altitude condition designed to maximize the probability of having a line of sight to the target. The attacker penetrates at low altitude (200- to 500-ft altitude), pops up to 3,000 ft to attack, and immediately pops down to exit the area.

Sea level and ground level were assumed coincident and a standard atmosphere prevailed.

2.2.2 Weather

The candidate concepts are required to operate in four kinds of weather: clear, smoke and fog rising 50 ft. above ground level, clouds at 200-ft ceiling with the cloud base irregular and frequently extending below the 200-ft mark, and a cloud ceiling of 2,000 ft. In both the 200-ft ceiling and the 2,000-ft ceiling cases, the cloud tops extend well above 3,000-ft altitude.

The clouds are, by definition, opaque to EO sensors. They are assumed to be heavy cumulus clouds with a density of 1.4 gm/m^3.

2.2.3 Targets

On all missions the targets are tanks, stationary or moving, as defined by the mission.

For EO evaluations, tank dimensions are 3.6m by 9.9m by 2.3m high (11.8 by 32.5 by 7.5 ft). The tanks are painted with standard military paint over steel and are located on a short, brownish-green stubble background.

For radar, the targets are assumed a complex, slowly fluctuating target (Swerling case I) of 30 m^2 with a homogeneous background.

Moving targets travel at 45 deg from the strike airplane flightpath at approximately 25 ft/s (range and deflection components of 18.23 ft/s, respectively).

2.2.4 Target Location Errors

Target location errors (TLE) given in Table 2.2-1 are assumed to be target position errors made by reconnaissance aircraft or army units. Any target motion prior to initiation of search is assumed to be contained in the TLE and the resulting sensor search area is a combination of the TLE and ISAS navigation system errors. Army units continuously survey positions behind the forward edge of the battle area (FEBA) and, with a little coordination, sufficient navigational fix-points should be available. The last navigation fix-point is assumed 10 km behind the FEBA and the ISAS INS accuracy is equal or better than 1 nmi/h for all concepts. Average distances from the FEBA are used in target location computations.

The resulting dimensions below are minimum 1 sigma search volumes for all sensors and concepts:

Mission	TLE	Nav	Search area (km)
Close air support (CAS)	0.5	0.0732	±0.5
Battlefield interdiction (BI)	2.5	0.1295	±2.5
Deep interdiction (DI) (fixed)	0.5	0.4032	±0.6
Deep interdiction (DI) (road)	10.0	0.4032	±10.0

2.2.5 Mission-Target Combinations

The basic missions are given in Table 2.2-1. Targets are described in Section 2.2.3. A mission-target motion combination rationale for the four cases used in analysis is given in the following paragraphs.

Close Air Support—Fixed Target. Because of the small TLE (0.5 km) and short distance from the FEBA (0 to 5 km), CAS targets are assumed stationary and deployed in positions for fighting.

Close air support missions are evaluated as autonomous in this report even though close proximity to friendly forces requires direct positive visual target ID.

Battlefield Interdiction—Moving Target. The BI region is typically used to resupply ground forces fighting in the CAS region. If enemy vehicles in the BI region are not moving, supply lines are stopped and hostile combat resources are soon depleted. Secondly, the larger TLE (±2.5 km) infers "stale target" position data resulting from target motion. Although the targets do not necessarily move continuously, the assumption is that all BI targets are moving when encountered.

Deep Interdiction—Fixed Target. When the TLE is ±0.5 km (like CAS) a minimum TLE without motion aging is inferred and no target motion within the given staging or assembly area is assumed.

Deep Interdiction, Road—Moving Target. The associated TLE for this case is ±10-km; target position aging because of motion is inferred. The line of communication used in the ISAS analysis is a road. For this case TLE width is assumed to be ±0.5 km and length (along the road) is ±10 km.

2.2.6 Terrain Masking

Masking data for eight terrain types were provided in the scenario document. These terrains were compared and the average is close to that provided for the gently rolling hills terrain used in this analysis.

2.2.7 Flightpaths—Popup and Level

Typical phases of the mission profile are shown in Figure 2.2-1. For CAS (350 kn), the base is located about 150 mi behind the FEBA and loiter is included so that total flight time to weapon release is 0.6 hr. The base for BI and DI (553 kn) is approximately 200 mi behind the FEBA and flight time for BI is 0.4 hr and for DI is 0.5 hr.

The fire control mission is restricted to two mission segments, shown in Figure 2.2-2. The popup point for both profiles is initiated at minimum range to reduce exposure.

Search time (point A to B on the figure) is the time for the aircraft to traverse the 2 sigma length of the search area of uncertainty in Section 2.2.4. This corresponds to a worst case when the sensor(s) are in a spotlight or ground stabilized image mode. Human reaction and search times are excluded.

Mission	Search length (km)	Search time (sec)	
		553 kn (0.285 km/s)	350 kn (0.180 km/s)
CAS	2.02	7	11
BI	10.02	35	56
DI (fixed)	2.57	7 to 9	11 to 14
DI (road)	40.032	140	222

The release point (C) in Figure 2.2-2 is that for the specific weapon; the ground range from B to C is computed using a 4g maneuver. Ground range from B to C is computed from the minimum time for the crew to perform necessary operations to deliver the weapon at point C.

The scenario for popup/popdown in Figure 2.2-2 is as follows: pop up to 3,000 ft, search for, detect, and fire on the target. Immediately after detection, pickle and descend under line of sight to 200 ft, and navigate blind until line of sight to target is again available. Using navigation system-computed-target coordinates, reacquire, recognize, and perform a second fix (for improved accuracy) on the target. Fly without target tracking update for the short remaining distance to the release point and deliver weapon.

The scenario for the popup level delivery is the same except that the airplane does not pop down until weapon release, line of sight to the target from point B to C is continually available, and the weapon is delivered from 3,000-ft altitude.

2.2.8 Weapons

Concept effectiveness in terms of target kill using bombs and missiles is required. The weapons selected must be effective against the targets selected and mission conditions defined here.

MK-82 Snakeye. Although gravity bombs are relatively ineffective against tanks, their continued operational use is expected. To allow delivery at 200 ft, a high-drag bomb is required. Snakeye can also be delivered at altitudes up to 5,000 ft, and the weapon is compatible with the mission requirements.

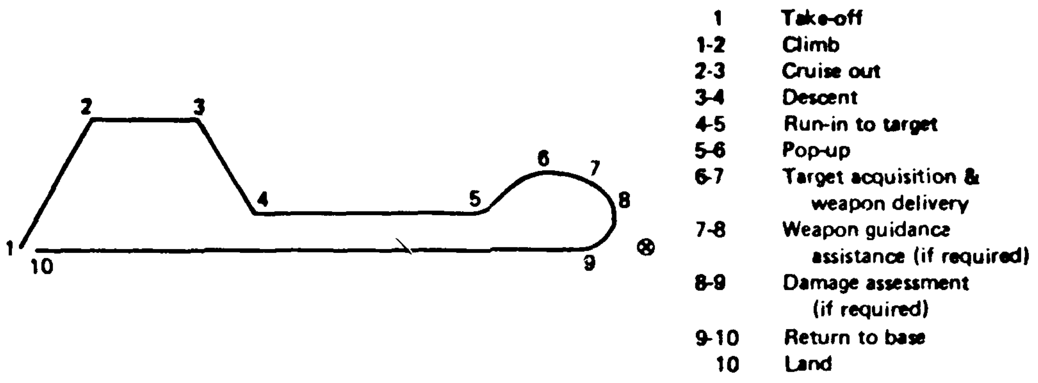


Figure 2.2-1. Interdiction Mission Phases

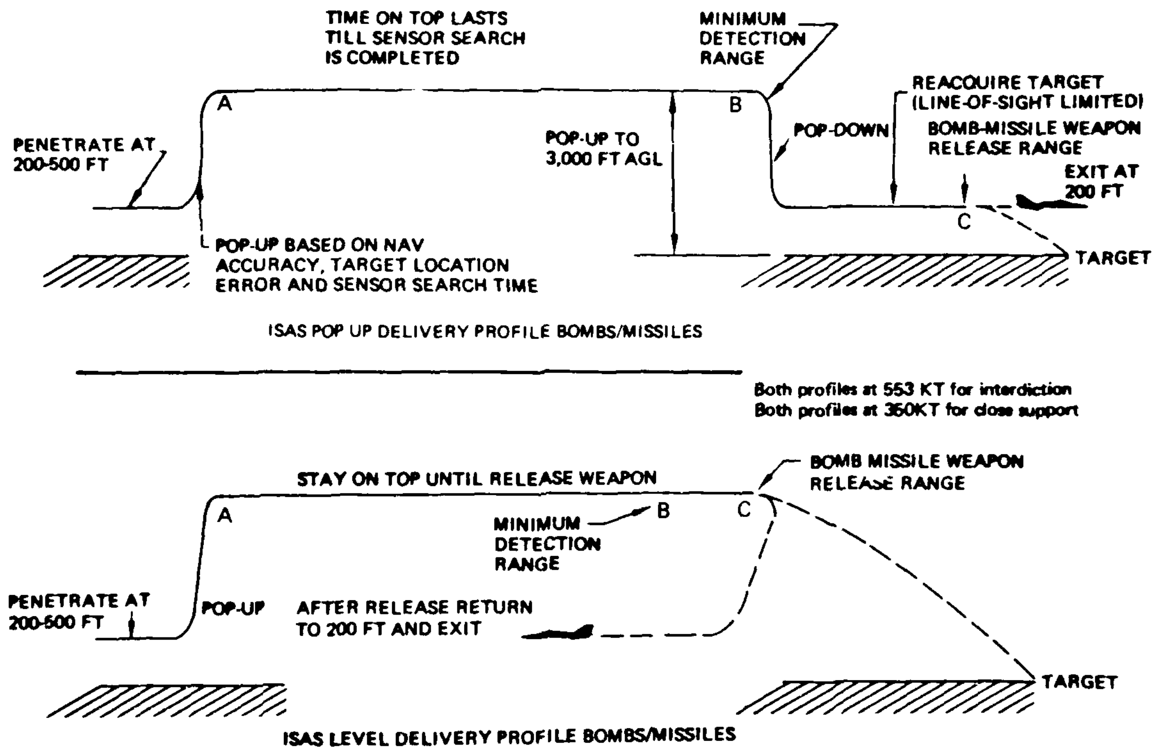


Figure 2.2-2. ISAS Weapon Delivery Profiles

Infrared Maverick. The infrared Maverick is a developmental missile specifically designed for attacks of hard targets. Available Maverick data indicate that the weapon is compatible with requirements in this section.

The infrared Maverick is a modification of the currently operational TV version and limited use of data from the operational version was made in this study. In this report, Maverick sensor gimbals are unlocked and slewed to target coordinates with the ISAS FLIR when the target is recognized, after which the Maverick sensor is locked on and tracks the target while the aircraft continues in level flight. Maverick gimbal limits are large enough to allow level deliveries at the minimum ranges used in analysis.

3.0 CANDIDATE SENSORS

A clear knowledge and understanding of current and emerging strike sensors is necessary as a prelude to concept formulation. Sensor selection criteria are: (1) that the sensor satisfies strike functional requirements, and (2) that it can function simultaneously with other sensors in an integrated system. There is no preconceived limit to the total number of sensors that may be available in concept formulation. It was planned that the concept evaluation and the accompanying analysis would guide quantification. Candidate sensors were: long-wave radar, Ku- and X-band multimode SAR, millimetre wavelength (MMW) radar, FLIR, TV, and laser EO sensor.

3.1 SENSOR REQUIREMENTS

Section 2.0 of this report established the strike mission requirements against which the ISAS concepts would be evaluated. In the next logical step a functional mission analysis was used to identify general sensor requirements. The target search, track, and recognition phases of that analysis are presented in Table 3.1-1. Key factors identified were: (1) the variety of atmospheric conditions, dictating a multispectral approach; (2) the need to accomplish target detection and recognition based on information gathered from brief observation of the target (popup condition). This in turn, dictates compatibility with scene freezing techniques and/or automatic target-cueing classification techniques; (3) the need for a high probability of target detection and classification, emphasizing the desirability of simultaneous preparation of different sensors, correlation between applicable detection and recognition signal processors, and also the desirability of a second stage (postautomatic) in the target recognition process; and (4) the need for autonomous terminal guidance of the weapon (i.e., guided weapons have self-contained sensors, and the final aircraft target acquisition sensor must be compatible with the weapon guidance to ensure successful target lock-on handover).

3.2 TECHNOLOGY REVIEW

An existing data base at Boeing, developed during the ATS study (Air-to-Surface Technology Evaluation and Integration Study, USAF Contract F33615-76-C-3150) was enlarged and updated for use in selecting ISAS sensor candidates. In addition, data inputs have been obtained from AFWAL and MICOM. Boeing directly queried industry

Table 3.1-1. ISAS Functional Mission Analysis

MISSION FUNCTION	MISSION FUNCTIONAL REQUIREMENTS	STRIKE AVIONICS SYSTEM REQUIREMENTS	MECHANIZATION - CANDIDATE AVIONICS
Search & Detect Targets	o Accomplish quickly to minimize exposure	o Freeze Data	Mass data storage for processing later
		o Automatic Detection	Correlation or signal processing or change detection-software
	o Search in Clear Weather	o Long range, high resolution sensor, useable in normal haze conditions	TV FLIR X, K-Band Multimode SAR Laser Sensor (limited range) MM radar (limited range)
	o Search in Adverse Weather	o Sensor in spectral range to "see thru" water vapor, rain particles, & overcome scattering due to particles.	X-K-Band Multimode SAR
	o Search in Smoke, Fog, Clouds	o Sensor in spectral range to "see thru" smoke particles, aerosols, water vapor & overcome scattering due to particles.	X, K-Band Multimode SAR MM Radar

Table 3.1-1. *ISAS Functional Mission Analysis (Continued)*

MISSION FUNCTION	MISSION FUNCTIONAL REQUIREMENTS	STRIKE AVIONICS SYSTEM REQUIREMENTS	MECHANIZATION - CANDIDATE AVIONICS
	o Search Through Tall Grass, Bushes, Trees, Camouflage	o Sensor in spectral range to "see thru" foliage.	Long Wave Radar
	o Jam Resistant	o Process signal to degrade jammer o Operate in spectral region(s) hard to jam	o Overcome Jamming Through signal Processing o Frequency Diverse Radar o Spread Spectrum Radar
	o High Probability of Success	o Use all applicable sensor(s) o Correlate between sensors	o Manual or Automatic Sensor Selection for Display o Sensor Registration Software
		o Sensor Weighting	o Software to apply results of sensor selection
		o Voting of Sensors	o Software to incorporate all sensor data
Track Detected Targets	Prepare for Recognition and Weapon Delivery	o "Dead Reckoned" Tracking Based on Measured Movement	o GMTI radar, angular rate data from sensor, or position change derivatives based on change detection
		o Real Time Track	o Continuous tracking by a sensor

Table 3.1-1. *ISAS Functional Mission Analysis (Continued)*

MISSION FUNCTION	MISSION FUNCTIONAL REQUIREMENTS	STRIKE AVIONICS SYSTEM REQUIREMENTS	MECHANIZATION - CANDIDATE AVIONICS
Pop-Down (1)	o Maintain C3, TF/TA Interface, Avoid Threats o Fly Course to Close on Detected Targets	o Interface with Sensors Data and Flight Control System	Software and Fault Safe Interfaces
Recognize Targets	o Accomplish quickly to minimize exposure	o Automatic Target Recognition	o Image Processing target autocover/ classifiers o Video image scene o Radar Scene o Target Signature Correlation
		o Use Frozen (Stored) Data if required	o Quick Access to Special MHSS Storage
	o High Probability of Success	o Same as for Search & Detect o Crewman Review of Classified Targets	o Same as for Search & Detect o High Resolution Display o Enhanced Video to Crw Display
		o "Marking" of Displayed Targets o Interface with Stores Management System	o Display Generator Software o Share Sensor Selection Data with Stores MGMT System.

(1) MISSION DEPENDENT

Table 3.1-1. *ISAS Functional Mission Analysis (Concluded)*

MISSION FUNCTION	MISSION FUNCTIONAL REQUIREMENTS	STRIKE AVIONICS SYSTEM REQUIREMENTS	MECHANIZATION - CANDIDATE AVIONICS
Deliver Weapons	o Select Weapon	o Interface Between Fire Control & Stores Management System.	o Logic - Software
		o Notify Pilot of Sensor Guidance Mismatch as Required	o Logic - Software o Display - Software
Deliver Weapons	Select Weapons	o Select Store Station & Store	o Logic - Software
	Prepare Weapons	o Select Fuze, Arm, Initiate Warm-Up	o Logic - Software
		o Lockon Weapons	o Match/Correlate target templates from Sensor & Weapon - Software
		o Correlate & Display Lockon(s) to Crew	o Display Generator, Sensor & Weapon Registration - Software
	Validate Target	o Crew "OK to Fire"	

sources, which included eight radar suppliers and over 28 companies in the EO and target autocueing/classification fields. Seven major sensor development programs were noted:

a. Next-Generation FLIR Sensors: Improved FLIR and FLIR display technology developments

b. Laser and EO/MMW Sensors: CO_2 laser development to promote long-range laser capability and integrated EO and millimetre wavelength target sensors

c. Advanced EO Sensors: Development of combined EO sensors using a common aperture and advanced application of nonscanning (staring) sensors

d. Automatic Target Classification, EO Systems: Development of a forward-looking active target classifier and image autoprocessors for automatic target detection and classification

e. LF Multimode Radar: Development of a foliage-penetration radar

f. Air-to Ground Strike Radar Technology: Development of next-generation, high-resolution tactical radar

g. Radar Target Classification: Development of technology to automatically detect and classify fixed and moving radar targets

Short summaries of the activities and planning in these programs are provided in Tables 3-2-1 A through I.

3.3 CANDIDATE ISAS SENSORS

Six sensors were selected for use in ISAS concept formulation:

a. FLIR: A generic second-generation FLIR (characteristics to be determined in the phase II analysis)

Table 3.2-1A. Technology Category Analysis

Technology Area/Item: Next Generation FLIR Sensors

1. Required Technology Features

   This technology category addresses the development of sensors and components for airborne FLIR incorporating onboard target detection, identification, location and designation (or strike) of critically time sensitive targets. The system must be effective both day and night and in adverse weather. Increased reliance on automatic target acquisition, classification, and tracking must be incorporated to allow deployment of one-man strike aircraft.

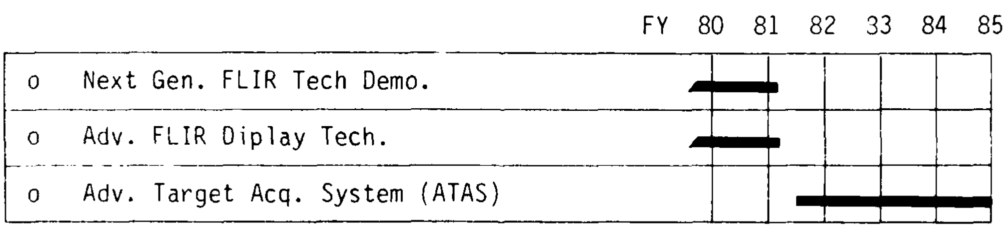
2. Current Technology Development Programs and/or Expected Results

   - Next Generation FLIR Technology Demo: Final design, fabrication, laboratory, and tower evaluation of an aperture limited FLIR with the large scale monolithic focal plane array.

   - Advanced Flir Display: Development of a display capability to handle enhanced EO (including FLIR) sensor video and symbology for the next generation FLIR and autoprocessor.

   - Advanced Target Acquisition System: To develop and flight demonstrate the advanced weapons delivery and recce pod incorporating the second generation FLIR, automatic targeting, hands-off control, autofocus, tracking, high frequency line-of-sight stabilization and EO CCM.

3. Current Technology Development Schedules



4. Applicability of Current Programs to ISAS

   Improved sensor detection capabilities are essential to the success of future tactical strike concepts like ISAS.

5. Category* Recommendation

   ATAS Category I
   Next Generation FLIR and Advanced FLIR Display Tech II

   *Category I: Development Program will not meet 1987 IOC
   Category II: Development Program satisfies 1987 IOC

Table 3.2-1B. Technology Category Analysis (Continued)

Technology Area/Items: Laser and EO/MMW Sensors

1. Required Technology Features: To study the factors limiting the deployment of tactical lasers and millimetre wave systems nd to develop target acquisition, classification, tracking and target designation systems incorporating promising devices or concepts.

2. <u>Current Technology Development Programs and/or Expected Results</u>

   - CO_2 Laser Tactical Sensor Studies: Conceptual design of CO_2 laser sensor for multifunctional applications including ranging, tracking, designation, MTI,, imaging for classification, and navigation aids, especially obstacle avoidance.

   - CO_2 Laser Sensor Technology Development: Design, demonstrate, and evaluate breadboard multifunctional CO_2 laser tactical sensor under both laboratory and low-performance aircraft flight conditions.

   - CO_2 Laser Multifunction Sensor Demonstration: Design demonstrate and evaluate a brassboard multifunctional CO_2 laser tactical sensor for a high performance aircraft under various weather conditions.

   - EO/MMW Targeting Studies: Investigate concepts to integrate E-O/MMW sensors. Use signature and atmospheric transmission measurements to evaluate potential improvements in standoff range and targeting accuracy.

   - EO/MMW Performance Measurements: Experimental comparison/synthesis of MMW sensor capability with E-O sensor to establish baseline performance envelopes under various weather conditions.

   - CO_2 Laser Radar Design Study: Covert terrain following/terrain avoidance/obstacle avoidance (TF/TA/OA) desired for the AF Combat Search and Research Helicopter (CSAR-HX). Covert capability and TF/TA/OA capability of the CO_2 laser will be explored in a design study.

3. <u>Current Technology Development Schedules</u>

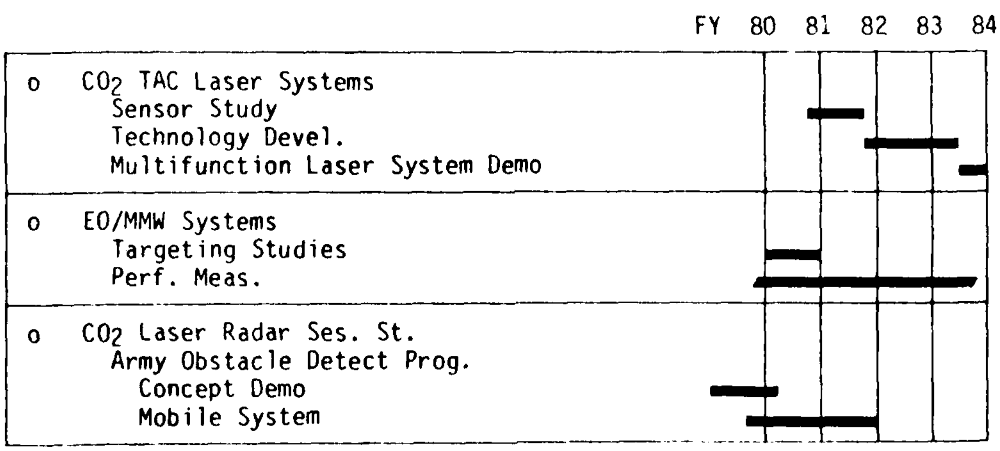


Table 3.2-1B. Technology Category Analysis (Continued)

4. Applicability of Current Programs to ISAS Programs Required

   This technology world contribute to the forward and side looking active classifier technology development - a desirable capability for ISAS concepts.

5. Category* Recommendation

   Laser Systems II
   EOMM I

*Category I: Development program progress will not meet 1987 IOC
Category II: Development Program Satisfies 1987 IOC

Table 3.2-1C. Technology Category Analysis (Continued)

Technology Area/Item: Advanced EO Sensors

1. Required Technology Features

To develop, demonstrate, and test the various necessary elements for the next generation Advanced Electro Optical Sensors. These elements will eventually lead to the Advanced Target Acquisition System (ATAS) having the objective to acquire, classify, track, and designate tactical targets for weapon delivery.

2. Current Technology Development Programs and/or Expected Results

- Strategic Sensor Technology Validation: This program will design, fabricate, and test nuclear survivable, critical FLIR components. Performance and survivability requirements will be appropriate for application to the manned penetrating bomber.

- Common Aperture Technical Integration Efforts: CATIES demonstrates feasibility of a common aperture electro-optical sensor using an active TV and a FLIR. In-house evaluation will determine the utility of TV and FLIR vs. TV alone vs. FLIR alone.

- EO System CCM Technology Demonstration: Program for fabrication and test of a multi-spectral imaging system incorporating EO CCM technologies as well as nuclear survivable technologies developed under SATIS.

- Electronic Scan Imaging Sensor Study: This is a competitive program to perform concept formulation and sensor trade-off studies to define a non-optical scanning (staring) focal plane FLIR. Such a FLIR would permit even lower cost, higher reliability, and smaller FLIR's than presently planned second generation system.

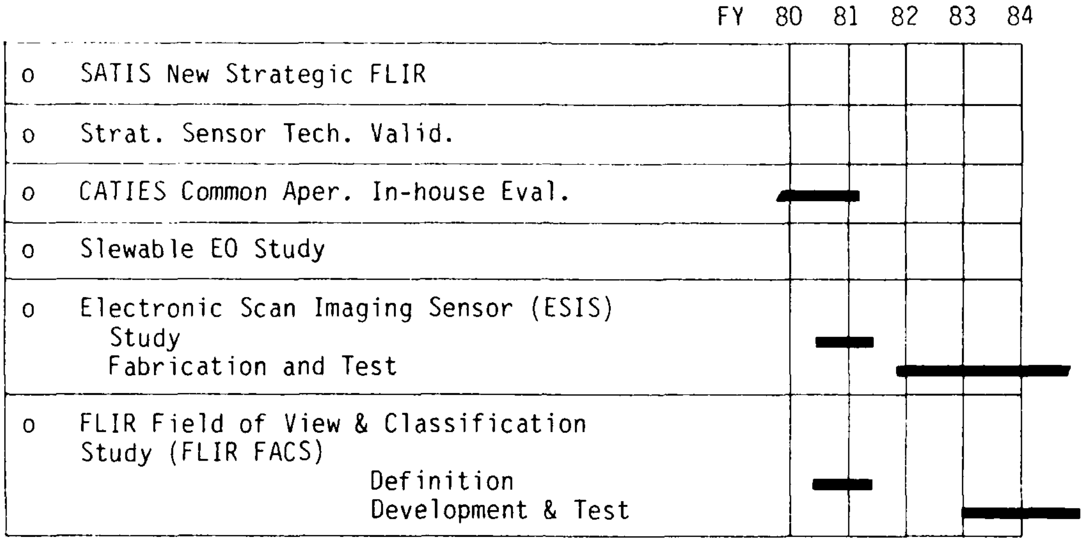
- Electronic Scan Imaging Sensor Development: This program will fabricate and test a staring FLIR as an alternate, higher risk technology to the second generation FLIR technology. Successful development will ensure maximum competition when the second generation FLIR transitions to ASD and will provide high confidence in our ability to fabricate a FLIR of the size and performance required by an F-16 for air-to-ground fire control in a high threat environment.

- CCD Scan Converter Module: Program to develop a CCD Scan Converter Module for the Tri-Service Common Modular FLIR. Module will replace an LED array visible optics, a TV camera, and associated electronics.

- FLIR Field of View & Classification Study (FLIR FACS): Program to develop a single FLIR/autoprocessor capable of simultaneously executing a wide field of view search and a narrow field of view classification. Eliminates the need for dual-dedicated sensors field of view switching or programmed coverage of an area.

Table 3.2-1C. Technology Category Analysis (Continued)

3. Current Technology Development Schedules



4. Aplicability of Current Programs to ISAS

The above programs could provide significant benefit to ISAS sensors, and sensor configurations:

5. Category Recommendation

ESIS, FLIR FACS	I
CATIES	II

Category I: Development Progress will not meet 1987 IOC
Category II: Development Program satisfies 1987 IOC.

Table 3.2-1D. Technology Category Analisis (Continued)

Technology Area/Item: Automatic Target Classification - EO Systems

1. Required Technology Features

This effort will develop the interrelated concepts leading to an automated and automatic target classification system using data from the next generation FLIR, CO^2 laser scanners, LLLTV, and the shape classification system (3 DTC).

2. Current Technology Development Programs and/or Expected Results

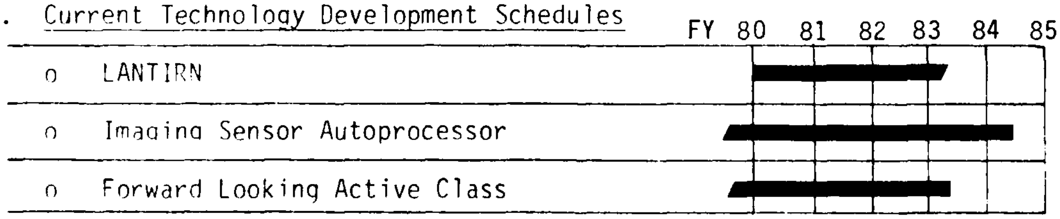
- o Automatic Image Screening: Automatic Image Screening is advanced development to achieve higher data rates and more accurate identification of targets.

- o Lantirn: Provide a pod-mounted system that will combine a FLIR and an image processor to produce a target autocuer/classifier for use on current tactical airplanes.

- o Imaging Sensor Autoprocessor: The Imaging Sensor Autoprocessor will combine target screening, image enhancement, and autocontrol functions into a flyable breadboard autoprocessor. The autoprocessor will be tested in a series of lab and flight tests to establish performance capabilities. Primary emphasis will be placed on versatility and adaptability of the breadboard to changes in signal processing algorithms/functions by software modifications. Secondary emphasis will be placed on miniaturization and packaging, but feasible technology (e.g., CCD memories) which can achieve final packaging on a subsequent effort must be identified.

- o Forward-looking Active Classification Technology: Demonstrate feasibility of real time automatic target location and classification using 3-DTC and forward looking, low depression angle 3-D sensor techniques.

3. Current Technology Development Schedules



4. Applicability of Current Program Required

The need for quick, accurate target acquisition in to ISAS strike profiles requires this basic technology.

5. Category* Recommendation

Imaging Sensor Auto Processor I
Forward Looking Active Classifier II

Table 3.2-1D. Technology Category Analysis (Continued)

* Category I: Development Program progress will not meet post 1987 IOC
Category II: Development Program satisifies IOC requirements

Table 3.2-1E. Technology Category Analysis (Continued)

Technology Area/Item: LF Multimode Radar

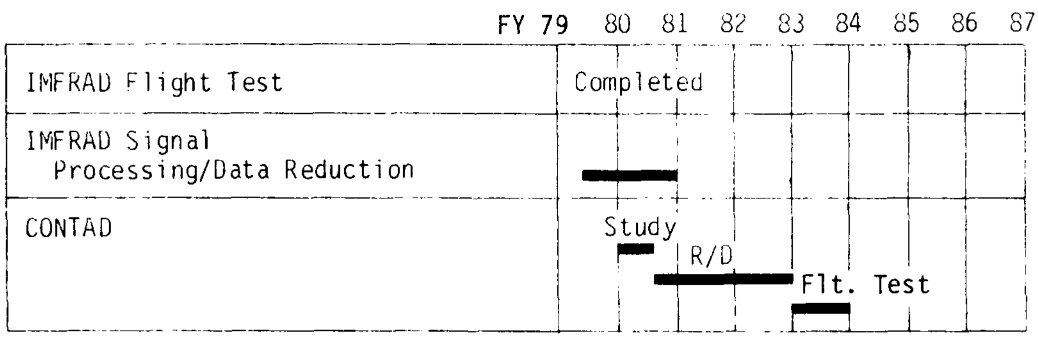
1. Required ATS Technology Features

   A **LF Multimode radar** is required for acquisition of ground targets in foliage. The radar should have the capability for strip and searchlight mapping, MTI and signature analysis for target identification, maneuver and turbulence compensation, flexible parameter control (power, prf, pw), and good ECCM capabilities.

2. Current Technology Development Programs and Expected Results

   - The WPAFB IMFRAD flight test program has been completed. Signal processing and data reduction of the test data is currently in progress.
   - Concealed Target Detection (CONTAD) program will be initiated in FY 80 to demonstrate long wavelength radar cueing of concealed targets at low flight altitudes.

3. Current Technology Development Schedules



4. Applicability of Current Programs to ISAS

   IMFRAD and the forthcoming CONTAD programs validate the basic target detection and classification techniques.

5. Category* Recommendation

   II

* Category I: Development Program progress not adequate
Category II: Development Program satisfies IOC requirement

Table 3.2-1F. Technology Category Analysis

Technology Area/Item: Air-to-Ground Strike Radar

1. Required Technology Features

   Low probability of intercept radar system for tactical aircraft capable of acquiring moving and stationary ground targets in real-time and providing fire-control data for the destruction of the targets.

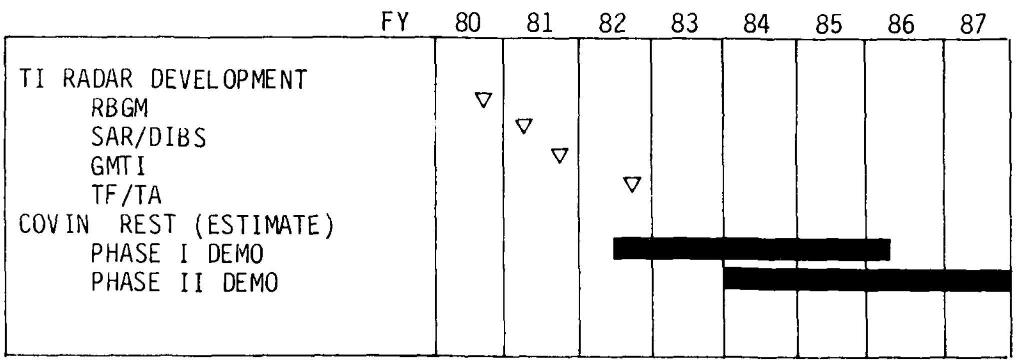
2. Current Technology Development Programs and Expected Results

   a) TIMPR. Texas Instrument Multipurpose Radar - IR&D program, Texas Instruments Co. - typical of new generation of SAR capable radar technology. Estimated progress demonstrations.

   b) COVIN REST Phase I. The goal is to demonstrate a monostatic radar using current technology to detect and classify tactical targets.

   c) COVIN REST Phase II. Demonstrate a low probability of intercept radar using a bi static radar system.

3. Estimated Technology Development Schedules



4. Applicability of Current Programs to ISAS

   The results of the study are vital to ISAS. The acquisition of ground targets, involving target identification and classification with radars require significant development.

5. Category* Recommendation

   II

* Category I: Development program progress will not meet 1987 IOC.
Category II: Development program satisifies 1987 IOC.

Table 3.2-1G. Technology Category Analysis (Concluded)

Technology Area/Item: MM Wave Radar

1. Required Technology Features

A very high resolution radar is required to back-up the EO sensors under the conditions of poor optical visibility due to cloud, fog and smoke. The radar must be able to view ground targets (fixed and moving) directly ahead of the tactical aircraft and provide real-time data. These requirements dictate the use of real beam mapping at very high frequencies.

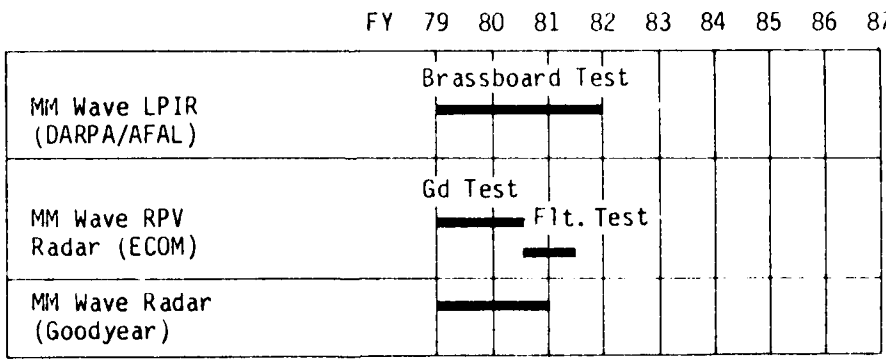
2. Current Technology Development Program and Expected Results

- o MM Wave LPIR (Low Probability of Intercept Radar: A fully coherent MM wave (94 GHz) radar is being developed by HAC to achieve stealthy operation. The radar features include real beam mapping, SAR mapping and coherent (pulse doppler) GMTI. Tests are planned in order to evaluate its performance.

- o MM Wave RPV Radar: Norden has developed and tested a MM wave (95 GHz) radar for ECOM. Final ground tests are currently being performed and a 7H test is planned for 1980. Norden's goal is to incorporate the radar on the Aquila RPV. The non-coherent radar features RBGM and clutter locked GMTI.

- o Goodyear MM Wave Radar: Goodyear has developed a 95 GHz radar largely out of company IR&D funds. The radar is non-coherent and features high resolution ground mapping. Tests have been conducted. Further tests are planned with company funds.

3. Current Technology Development Schedules



4. Applicability of Current Programs to ISAS

The current programs are important to ISAS. The information relative to performance between the coherent and the non-coherent radars, particularly in the area of moving target defection will require the continuing development of the above programs, especially the DARPA/AFAL program.

5. Category Recommendation

II

Table 3.2-1H. Technology Category Analysis (Continued)

Technology Area/Item:

1. Required Technology Feature

To develop, demonstrate & test the technology required to detect and classify tactical targets from their radar signature. The technique must be effective against both moving and fixed targets, and accomplished in real time to allow weapon delivery against the classified targets.

2. Current Technology Programs and/or Expected Results

- o Polyfrequency Data Exploitation: Analysis of data gathered against fixed targets to determine the phenomonology of classifying fixed tactical targets.

- o Target Screener Program: A technical effort to determine fixed tactical target detection techniques, using an X-Band SAR radar. Dual polarization and multiple frequencies are being utilized as tools for rejecting false targets.

- o Radar Target Discriminator: A study to investigate the use of radar return amplitude, phase and polarization to perform automatic radar classification of fixed tactical targets.

These programs appear to be essentially in the base research phase necessary to formulate the required technology.

- o Fixed Target Classifier Design Study: This program would initiate development of a radar target classifier for future demonstration and test.

- o Moving Target Classification Data Base: Basic research moving targets.

- o Target Motion Signature Data Base: Development of moving target classification based on above.

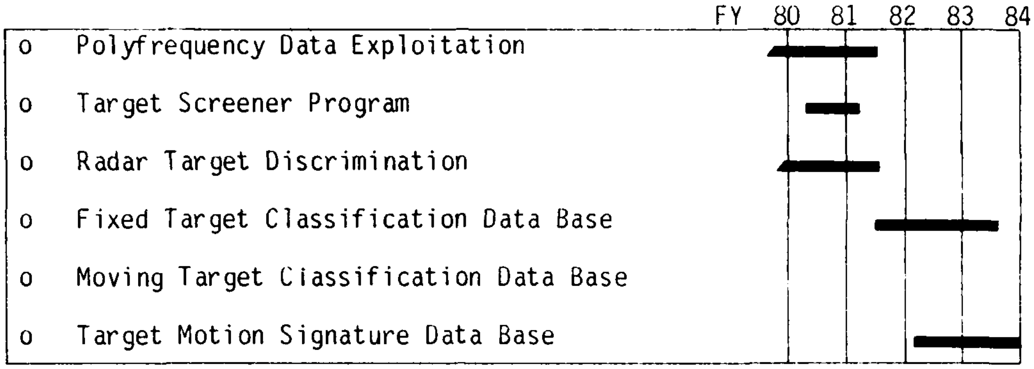
- o Target Classification Data Base: Radar experiments to obtain a moving targets doppler signature. Parameters to be investigated include target type, target motion, target orientation, grazing angle and radar frequency.

- o Target Motion Signature Data Base: When awarded, this study will conduct experiments relating target motion signatures in the inverse SAR processing mode. The data base may then be used as a basis for developing radar moving target classification algorithms.

TSC is under contract to investigate the utilization of radar information consisting of amplitude, phase and polarization to perform automatic radar target classification of fixed targets.

Table 3.2-1H. Technology Category Analysis (Continued)

3. Technology Development Schedule



4. Applicability of Current Programs to ISAS

The development of adverse-weather/all-weather target classification is essential to the success at future strike concepts like ISAS.

5. Category* Recommendation

Radar Target Classifiers I

* Category I: Development Program progress will not meet 1987 IOC

Category II: Development Program progress satisfies 1987 IOC.

b. TV: A silicon TV sensor to supplement FLIR operation under conditions that might lead to thermal washouts or high losses in certain mist environments

c. 3D classifier: An active, forward-looking classifier to provide nonimaging classification of targets

d. VHF Multimode Radar: A foliage-penetration radar (The potential of this development is high despite considerable technical risks. In the analysis of concepts, radar data furnished by CDC Corporation relative to a derivative of their IMFRAD radar research was used.)

e. Multimode Ku-band Radar: The Texas Instruments Multipurpose Radar (TIMPR) is typical of a new generation of synthetic aperture radars now becoming available. TIMPR was selected as the baseline for tactical radar studies.

f. Air-to-Ground MM-Wavelength Strike Radar: No development program dedicated specifically to developing a millimetre wavelength radar for tactical application (other than the AFWAL EO/MMW program) was found. (A hypothetical millimetre wavelength radar based on Norden Company data was used as a baseline for analysis.)

4.0 ISAS CONCEPTS

During task I, the ISAS study candidate fire-control concepts were formulated and refined to produce three integrated fire-control systems for analysis evaluation and trade-off. The research data reported in Section 2.0 (System Requirements) and 3.0 (Candidate Sensors) formed the basis for concept formulation. This section reviews three final concepts selected for analysis and evaluation and describes the significant elements of each concept. The fire-control concept descriptions are accompanied by a general discussion of related core avionics (concept-pertinent avionics discussions are included with the concepts to which they apply).

4.1 OVERALL REVIEW OF CONCEPTS

Three basic ISAS candidates were formulated at the end of task I. These varied in sensor arrays and in system mechanization. The sensor arrays in each concept are listed below:

a. Concept I
   1. Long-wave foliage penetration radar
   2. Millimetre wavelength radar
   3. Ku-band radar
   4. FLIR
   5. Silicon TV
   6. Laser-3D classifier

b. Concept II
   1. Ku-band radar
   2. FLIR
   3. Silicon TV
   4. Laser-3D classifier

c. Concept III
   1. Millimetre wavelength radar
   2. FLIR
   3. Silicon TV
   4. Laser range finder

The variation in sensor arrays spans the concept ranges shown in Table 4.1-1. The table, reading from left to right, gives the various levels of autonomy corresponding to an austere equipment selection (limited autonomous) and a full sensor complement (maximum autonomous). Operationally, a limited autonomous system depends heavily on supporting systems (i.e., PLSS, PAVEMOVER, etc.); a maximum autonomous aircraft could use "stale" target data, using its "super sensor" array to find targets.

The vertical axis of Table 4.1-1 shows another dimension in concept equipment selection—airframe application. Three degrees of equipment consideration are shown. The concept sensors can be all-up high technology that require extensive installation consideration (i.e., special radomes, infrared domes, additional antenna installations, large power demand, extensive software and hardware, etc.). It can be readily seen that the all-up high technology approach implies a new aircraft. Other choices shown are a concept that could be created by adding some new technology and by minor changes to existing sensors, or a nominal update to an existing lightweight aircraft.

Table 4.1-1. Range of Concepts

	Semi autonomous	Autonomous	Maximum autonomous
All-up high technology	–		I
Growth	–	II	
Light-weight	III		–

Squares approximately corresponding to the ISAS sensor arrays are indicated by concept number. It should be noted that in this study Ku- and X-band radars were considered equivalent, thus including fighters equipped with coherent X- or Ku-band radars as possible future ISAS fire-control recipients.

Table 4.1-2 shows that selected concepts differ in mechanization as well as in sensor array. The three concepts range from fully automatic system integration (concept II), through a man-machine combination (concept I), and a concept where all essential integration is done by the crewman (concept III).

4.1.1 Concept I

Concept I is a fully autonomous system that uses brute force and high technology to solve the ISAS detection-identification problem. The concept is said to use brute force in view of the large number of sensor types used. Each different frequency used by the radar, FLIR, or TV systems may provide special intelligence or perform better in specific weather and operational environments.

The sensors in concept I are integrated on the physical-mechanical level, the processed information level, and the display level. Physical integration is in the form of aperture and/or gimbal sharing among several sensors. Processor-level integration is accomplished by video scene registration to ensure registration of singular target and scene imagery from multiple sensors. Display integration results when autocuer-classifier votes are scored and then fused with prime sensor video for crew surveillance.

A unique feature of concept I is full aircrew participation to eliminate false targets and maximize detection and acquisition ranges. Expected advantages are: (1) there is less reliance on automatic target classifiers whose performance may be limited by the state of the art or sensor resolution, (2) processor complexity and weight may be reduced, and (3) the processor false target threshold may be set at a lower level to allow target detection and classification at longer ranges and/or under worse visibility conditions than either aircrew or processors could do alone.

Table 4.1-2. ISAS Concept Summary

	ISAS Concepts		
	I	II	III
Technology application	• Maximum autonomous • High technology • All new	• Autonomous • Selected high payoff items • Appropriate for retrofit	• Semi autonomous • Appropriate for small low cost aircraft
Sensors	• 3 radars plus EO	• K_M radar plus EO	• MM radar plus EO
Crew workload	• Crew shares with automatic functions	• All automatic	• Crew is key • Heavy emphasis on off-board processing
Sensor integration	• Common apertures/gimbals • Auto selection of prime sensor • Auto cue/classify with scoring • Auto sensor-scene registration • Prime sensor video displayed with scored auto cue/classify graphics overlay • Auto weapon guidance match • Autonomous search of prebriefed targets	• Common apertures • All sensors equal stress • Auto cue/classify with scoring • Auto sensor-scene registration • "Compressed" video displayed with scored auto cue/classify graphics overlay • Auto weapon guidance match • Autonomous search of prebriefed targets	• Common apertures/gimbals • Crew sensor select • Manual cue/classify with coop system aid • True video with pre des "box" from coop inputs • Manual weapon guidance match • Aided search with updated target information
Navigation	• Moderate quality nav	• Moderate quality nav	• High quality nav

4.1.1.1 Concept I–Concept of Operation

In concept I the aircrew and the automatic processes function as a team. Automatic detection and recognition thresholds may be set lower because the aircrew functions to "screen" automatic response. The aircrew is continuously informed on functions such as navigation and weapon selection, even though manual action may not be needed. In the discussion that follows, the concept is addressed as it applies to the ISAS missions of this study.

a. Cataloged target characteristics are provided via a mission tape to the system. Last known locations or landmarks for preplanned targets are included.

b. Target search is initiated automatically for preplanned, prelocated targets when the assigned target(s) or nearby landmarks are in sensor range. The onboard inertial navigation system (INS) in cooperation with processor-controlled sensors provides "the location basis" for this process. In the search mode, the processors automatically control all sensors without crew participation. During and after automatic search the display is automatically adjusted for optimal presentation. Hands-off display operation is provided.

c. Search for targets of opportunity can be initiated by the crew.

d. A popup can be planned or initiated on command so that a line of sight to the prebriefed target location is possible. The area searched includes allowances for navigation and targeting error. The sensor processors continuously search for the specified target. If target-like objects are found, added automatic sensor commands for more frames with maximum resolution enhancement are initiated and detection of a target triggers a video frame storing or freeze process. A navigation fix is made on the detected point. Relative aircraft position is computed accurately from the freeze point. Automatic and manual target data processing is conducted at low altitude. A second popup to release certain weapons and/or improve accuracy by reaquisition may be used. If no automatic detections are made in popup, the last target area scene frames are stored and reviewed during and after popdown.

e. Final processing provides target identification. Automatic processes are imperfect, and both real and false targets will be located. The crew can override incorrect target classification. The result of this interaction is a very high probability of correct target classification (estimated as 0.98 probability that a target that achieves sensor-related justification criteria (vis, Johnson or Ratches) is correctly classified).

f. If the automatic system is unsuccessful or the crew is not satisfied, manual targeting using any or all aids is available.

4.1.1.2 Functional Elements

As with other fire-control systems, the ISAS conceptual fire-control system is a form of state of system integration rather than a specific black box. The elements constituting the concept I system are radar, EO system, emitter classifier location system (ECLS), selection system, environmental sensor, digital image processors, controls and displays, and core avionics. The system block diagram is provided in Figure 4.1-1.

Radar. Radar provides moving-target indication and long-range, all-weather search and target acquisition. Radar functions include navigation, fire control, high-resolution SAR mapping, real-beam ground map (RBGM), Doppler beam sharpening (DBS), terrain following, limited air-to-air search and detection target for self-defense, and passive target homing (direction finding of radiation targets).

Forward sector coverage is provided. Sector coverage can be varied to provide large area coverage using a high-resolution, small-area coverage and to provide aircraft-stabilized and ground-stabilized imagery for both search and tracking operations. A searchlight mode is also included for automatic tracking.

A long-wave radar is provided for foliage penetration. A side-mounted antenna array must be used on practical tactical aircraft, and operation with squint angles smaller than about 10 deg is not practical.

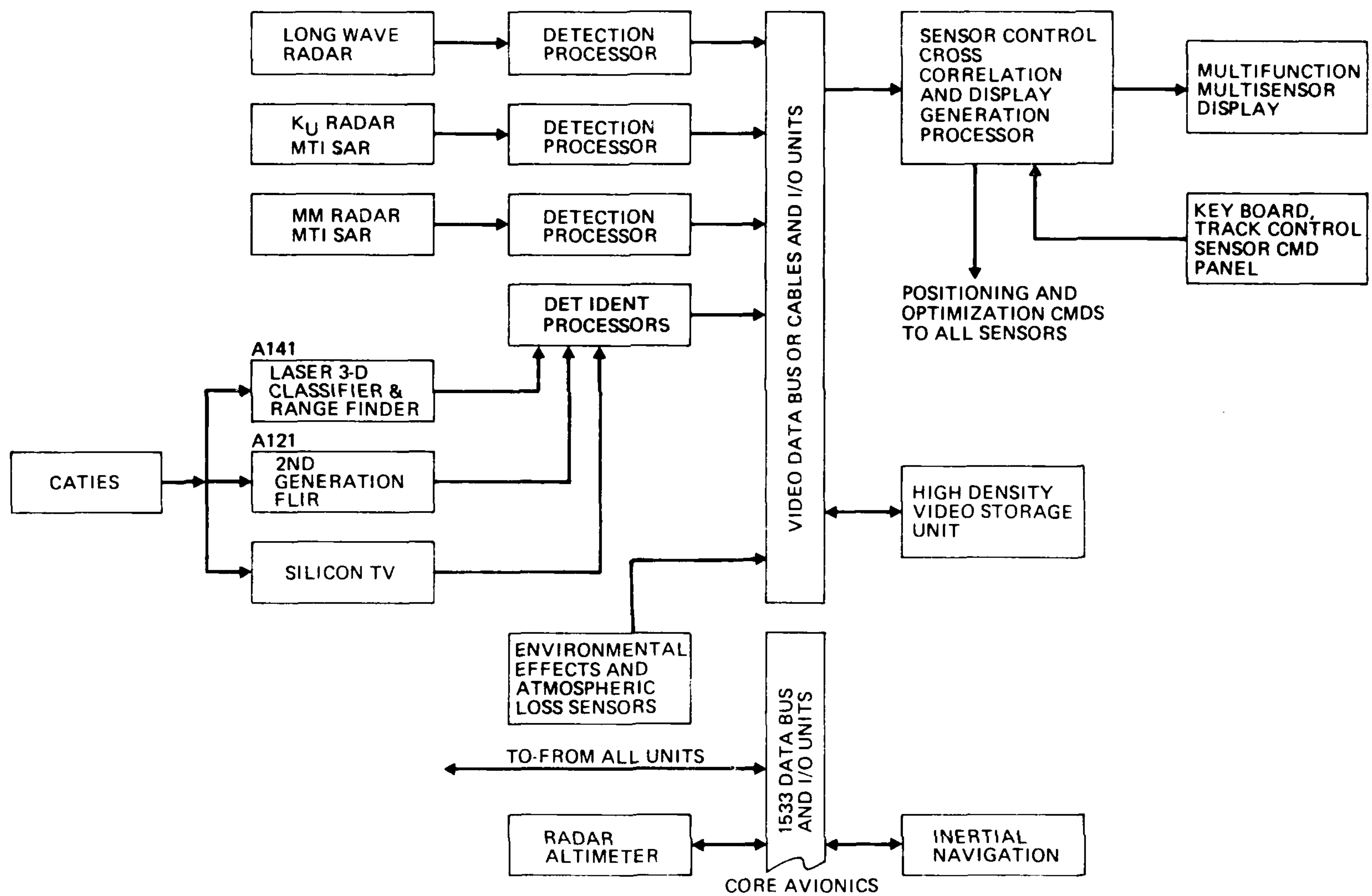


Figure 4.1-1. Concept I - Avionics

The Ku-band radar is the primary all-weather, long-range attack sensor. Although X-band radars provide longer range and much better performance in rain, Ku-band radars provide better real-beam resolution and allow use of a smaller antenna. The Ku-band radar antenna is mounted on the aircraft nose to allow completion of attack using the real beam.

The millimetre wavelength radar is also used during attack, and the antenna is nose mounted with the Ku-band antenna. Use of a common aperture or a common gimbal system for the two radars would provide the same advantages, as discussed in the following paragraphs, as the CATIES system. The extent to which radar apertures or gimbals can be combined or shared requires further study.

Radar operation in the millimetre band of 30 to 100 GHz is attainable because of recent and current advances in solid-state, high-frequency devices. Potential advantages are high antenna gain, high real-beam resolution, and potentially improved adverse weather operation, compared to EO sensors. Long-range operation, like that with lower frequency radar, is not attainable because of propagation considerations.

ISAS requirements include the ability to operate in adverse weather (clouds, fog, or smoke) where EO systems are inoperative. Although the Ku-band and LW radars provide all-weather operation, resolution is poor compared to EO systems. The millimetre wavelength radar provides improved resolution, but study analysis shows that range performance is inadequate in heavy cumulus clouds. Because of the characteristically poor resolution of radar, many of the digital image processing techniques that are used with EO systems cannot be used when adverse weather makes radar the only useful sensor.

EO System. CATIES is a common-aperture EO system in development. Use of a single gimbal, common optical system, and a single window provide advantages of smaller size, inherent boresight of all sensors, simultaneously registered TV FLIR imagery, and low cost and weight. All of these features are important for concept I. Inherent boresight and simultaneously registered imagery may be the feature that makes multisensor digital image processing feasible. In ISAS, sensor systems included with CATIES are as follows.

A second-generation FLIR (defined in Sec. 5.2.4) with an improved focal plane sensor provides a sensitivity improvement of four to five times over that for a single-column FLIR detector array. Performance analysis in this report is restricted to the self (natural) emission band of 8 to 13 , which is a more difficult task than hot infrared (3 to 5). However, operational systems are expected to include the 3 to 5 band. A primary reason for including FLIR is that one of the selected ISAS weapons is the infrared Maverick, and FLIR is used for missile seeker target acquisition. A TV system is included. It operates in the silicon band of 0.45 to 1.1 . For atmospheric conditions used in this report, TV and FLIR performances are nearly identical. Justification for inclusion of both sensors has been the subject of lengthy analysis. Current evidence is that both have advantages, and by operating in a different band the TV provides added target intelligence; herefore, both sensors are included.

A laser "3D classifier" (laser radar) is included (Forward Looking Active Classifier, USAF developmental goal A 125). This system is scheduled for a feasibility demonstration in 1981 and a flight test in 1984. In the 3D classifier system, the laser provides extremely accurate range resolution, on the order of a few inches. The system is commonly known as the "3D target (bump) classifier" and easily detects objects on roads or smooth terrain. Classification is accomplished with successive cuts or slices "through the object" to obtain a series of cross-sectional areas, which are then compared with known object cross section that have unique features such as special gun barrel profiles. The system uses a cooled detector element to pick up the CO_2 ranging energy. The CATIES installation promotes common cryogenics (DEWAR) for the FLIR and 3D detectors.

For ranging, or target classification, the laser beam is steered, or slewed, to the coordinates of the target that has been located by another sensor. In the classifier mode, the laser makes a line-scan pattern across the object of interest. (It is assumed that a minimum of six scan lines across the target are required for classification, and at least four line samples for ranging.)

By 1985 it is expected that the CO_2 laser frequencies will also be in common use for target ranging and designation.

Sensor Selection System. The sensor selection system provides real-time data for use in sensor weighting (sensor voting and scoring algorithm), and for use in determining the prime sensor. Systems for this application are not currently available but appear within the state of the art. Hardware candidates for the system were discussed with industry. Prime candidates are the Perkin-Elmer Aerosol Scattering Measurement Device (ASMO) or a laser turret. The ASMD is currently in brassboard form but not adapted for ISAS use. Software logic and sensor image quality algorithms are also needed and appear readily attainable.

Detection and Detection/Identification Processors. These dedicated processors are similar to LANTIRN and numerous other Government- and industry- sponsored research efforts. Specific characteristics are not critical in analysis and added details are therefore not provided. It is assumed that the selected system will result from a vendor competition.

Display Processor. The display processor coordinates information from the sensors and stored information, then presents this composite information onto an optimum display for the operator. Therefore, its functions are coordination and display. The functional units within the display processor are shown in Figure 4.1-2.

The processors coordination functions include—

a. Conceptually overlaying the target autoscreener results and identifications from the various sensors and, by using a weighted voting scheme, determining the most certain target locations and identifications

b. Using a scheme that determines the "quality" of the image from each sensor so that the best sensor image may be displayed as the background for the detected targets

c. Supervising all sensors, displays, and controls

d. Using stored terrain profiles, popup, and freeze mode to extend the search for obscured targets; Using display-aural warning of classified radiating threats or threats with predefined locations

e. Processing to remove spatial and temporal warp to allow overlay of displayed images (These corrections are primarily to remove those errors not compensated for by colocation of sensors, optical paths, and boresight.)

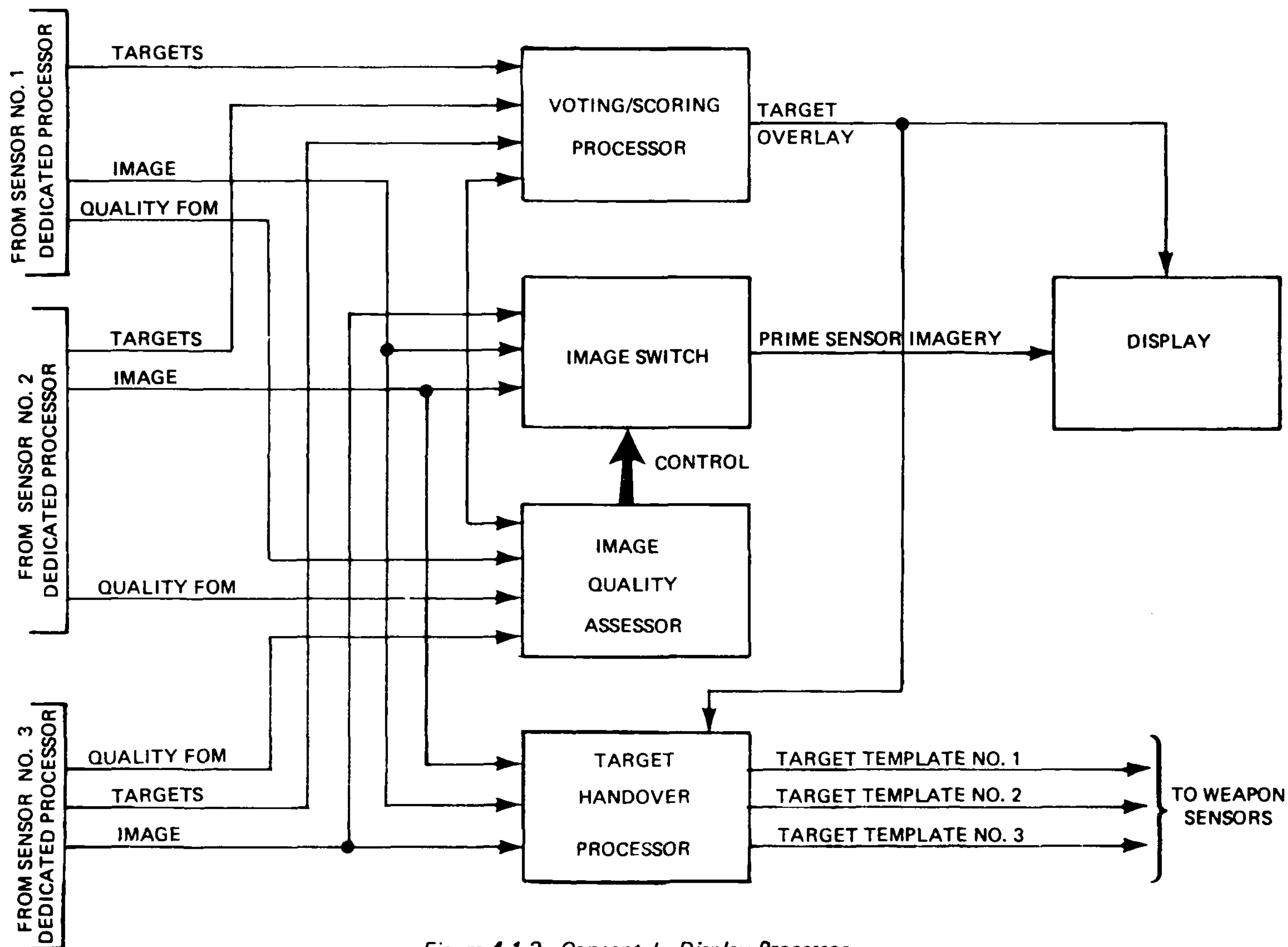


Figure 4.1-2. Concept I - Display Processor

f. Using autoregistration to remove small boresight errors for all sensors

The processor's display functions include—

a. Display of the prime sensor image as the primary background on the multicolor display (The prime sensor is the one that has the highest quality image at the given instant.)

b. Automatic gain and brightness for display

c. Display of detected and predefined targets by use of graphic overlays that indicate the identification and certainty of the target

"Tagging" of targets in the normal display presentation is the final classification performed by the automatic targeting processor. The crew must accept or reject each tagged target in turn. The display is always adjusted automatically for optimal presentation, and no added manual operations are required.

High-Density Video Storage Unit. This unit provides digital storage for selected video frames for freeze mode and processor operations.

Controls and Displays. A separately funded USAF program for display for correlated sensor data (DCSD) is about to be awarded. The program is required to be compatible with ISAS. Primary ISAS controls and displays may include a multifunction multiple-image color display, a standard keyboard, and a tracking control for cursor laying. Special control panels for high use operation may be included.

Full degraded mode manual operation is provided. This feature allows use of alternative techniques that may be more compatible with skills of selected crewmembers and to allow for failure. Commands to confine search to limited areas for faster response may also be initiated.

Core Avionics. Core avionics functions are provided by all aircraft. Selected systems that impact ISAS concept I performance are shown in Figure 4.1-1.

Because of USAF drives to limit proliferation of inertial navigation systems (INS) with specialized characteristics, two basic systems are currently emphasized. these are SPN-GEANS (Honeywell), a precision state-of-art system, and the medium accuracy USAF standard INS (LN-39) by Litton. Other systems are available, and extensive trades involving cost and accuracy are typically required before final selections are made for a specific aircraft. The USAF standard INS was selected for concepts I and II. Approximate accuracy, for purposes of ISAS analysis, is 1-nmi/h and 2.5-ft/s velocity for each axis.

A radar altimeter is used in ISAS analysis to provide a full 3D coarse fix capability in EO and radar ground map modes. Analysis indicates performance is acceptable as long as terrain is fairly flat. For performance evaluations, AN/APN 194 accuracy of 3 ft. or 4% of actual range is used.

4.1.1.3 Sensor Integration

In concept I, forms of sensor integration explored are (1) physical and mechanical, (2) multisensor registration, (3) sensor selection, (4) voting of registered processed services, and (5) display format integration. They are briefly outlined in figure 4.1-3. wherein a functional entity is shown representing the major areas of integration and how they interface.

a. Physical and Mechanical Integration: This form of integration is the oldest of those discussed here. Operational forms can be found in the F-4 TISEO system where an EO system is slaved to a tracking radar so that a high-powered telescope with a small field of view can easily acquire a small target at long range. In the ACM mode, F-4's also can slave a weapon (Sidewinder) seeker to the radar tracking line for infrared acquisition of a tracked target.

   The CATIES use of common optical paths and a common aperture are examples of the physical and mechanical integration technique exploited for ISAS. The use of common aperture and common gimbals (millimetre wavelength radar and Ku-band radar and/or search and terrain-following radar) minimizes correlation and screener registration problems.

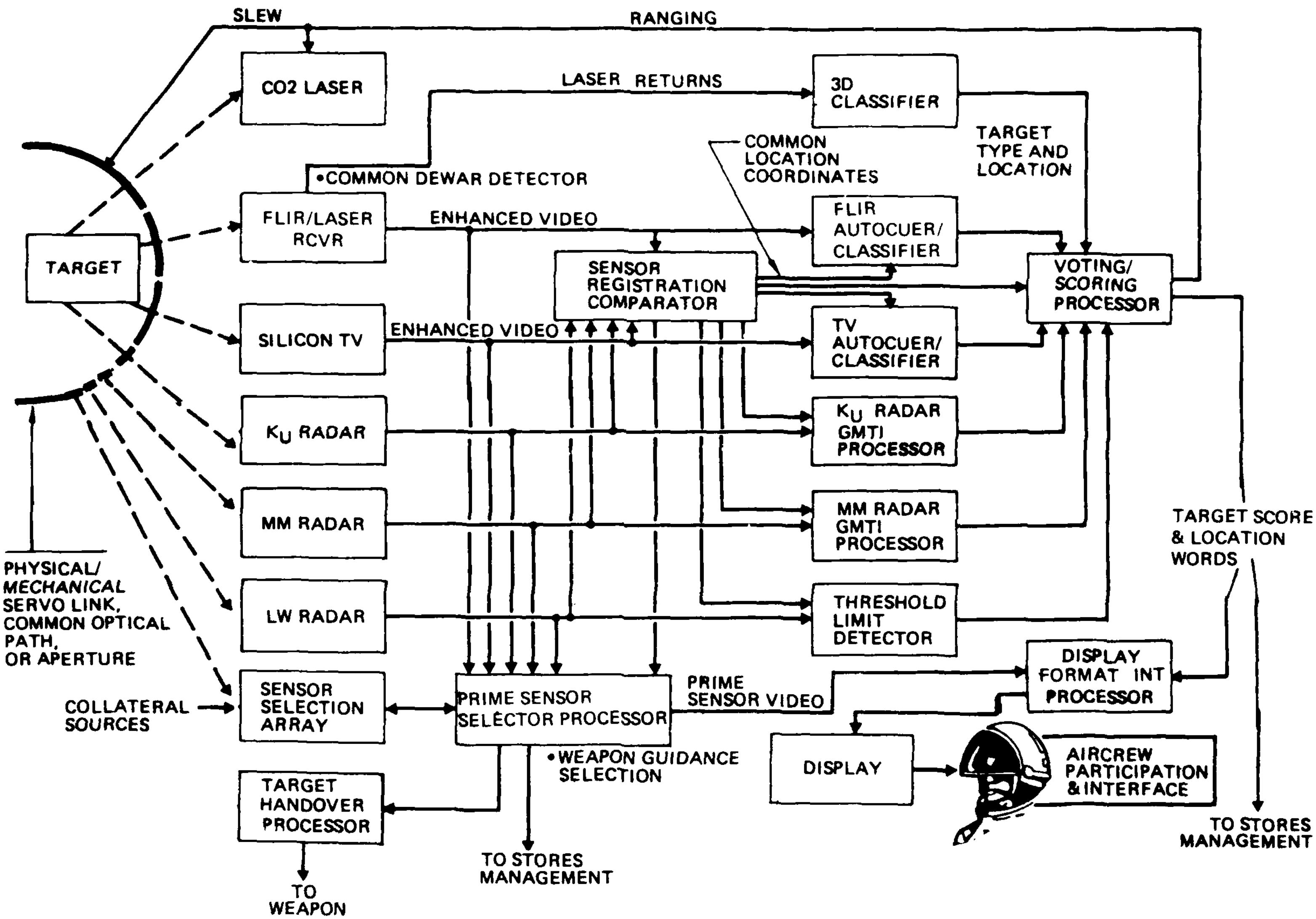


Figure 4.1-3. Concept I - Sensor Integration

b. Sensor Selection: The sensor selection array samples signals received by each sensor at a series of commonly registered points in the common search field of view. Collateral active sensors (lasers in the 1 to 12 µm region) to measure atmospheric propagation losses or an aerosol scattering measurement device (ASMD) may be included.

The sensor with the best returns from the target search area is identified as the "prime sensor" of the moment, and video from that sensor will provide the primary or "base" video for the crewman display. This logic is then correlated with stores management data to promote selection of a compatible homing weapon.

The onboard weapons mix may include only one spectral variety of sensor. If this sensor is spectrally unsuited for use at the moment (because of excessive propagation losses) the pilot will be notified. He has the option of deliberately selecting the less optimal sensor (so that he is compatible with the weapon), switching to unguided munitions, or aborting the pass.

c. Voting of Registered Processed Scenes: Each sensor is individually linked to its own full-time automatic target cueing and classification processor. Single-sensor voting uses segmentation and feature extraction with thresholds to establish amplitude limits. Correlation is accomplished by comparing extracted features with stored target characteristics. If "votes" are inadequate or more features are required for classification, the operation is repeated by automatically slewing the sensor to center the "target" and by changing to a magnified image to provide maximum use of available resolution.

The sensor registration comparator ensures that the target's location is registered for all sensors to permit use of added sensors such as the 3D classifier, FLIR, or radar to the target for ranging, improved resolution, or to search for added cues such as hot or moving targets.

Registration also ensures that multiple sensor detections and classifications for a single target complex are at the same coordinates and the same physical display location. The voting scoring processor combines votes from all single-sensor autocuers and generates target scoring coefficients for subsequent automatic operations to stores management and for display. The voting scoring processor also provides target video signal conditioning for display.

d. Display Format Integration: The output from the voting scoring processor is an enhanced color composite for each target successfully automatically detected or classified. Adjacent alphanumerics may be provided for detection classification, target, and voter scoring coefficients. This colored target box is overlayed on the prime sensor video display at the location corresponding to proper target coordinates.

To provide sufficient detail for aircrew verification of identification, the target box must cover 20 to 30 lines on the display (from Johnson, Ratches), and the display must cover less than 0.5 km. To allow the display of several targets at different locations, scale factors for prime sensor background scene video and target video are adjusted independently. A common scale factor is provided for general orientation with varying scale factors (zoom) provided to examine detail of selected targets.

4.1.2 Concept II

Concept II, is also a fully autonomous system with automatic digital image processing. The primary goal for concept II differs from concept I, which allowed a higher crew workload. The major emphasis for concept II is full automation to minimize crew workload. Ultimately in the limiting unrealistic case, concept II could become part of an unmanned self-contained attack vehicle.

In concept II complete reliance is placed on processor capability to provide automatic target detection and identification. Current programs such as LANTIRN are expected to provide much of the technology base needed for EO systems. ISAS requires all-weather operation (fog, clouds, and smoke). Manual rather than an automatic digital image processing for radar is necessary because the automatic mode is limited by attainable resolution. A manual mode to permit operation in adverse weather (when EO systems cannot function) is provided.

The unique feature for concept II is maximum reduction of aircrew workload. Human decision is required to commit weapons; however, workload reduction is achieved in functions relating to automatic target detection and identification. Maximum emphasis is on clear-weather, high-resolution EO sensor processing.

Sensors are integrated in the physical-mechanical, processing, and display domains. Physical integration has been exercised in the common aperture, common optical path of the CATIES technique used in the EO sensor concept. Automatic target cueing and classification is used with each sensor and the results are voted and scored automatically. Target scores are presented on the display. Simplified video, as used in the registration processing of the various sensor scenes, is provided as a background on which graphic target displays are shown. The system selects a high-score target for operator approval.

4.1.2.1 Concept II–Concept of Operation

Concept II is an autonomous, fully automatic system. Full reliance is placed on the automatic processes of the system. There is no partnership between man and machine. The aircrew acts to approve, or disapprove automatic processes, not to augment them; thus details of navigation, weapon selection, etc., are available upon specific "request," but normally the aircrew is involved only in principal or final decisions. In the discussion that follows, the concept is addressed as it applies to the ISAS missions.

a. Cataloged target characteristics are provided via mass storage to the system. Last known locations and landmarks for preplanned targets are included.

b. Target search is initiated automatically for preplanned prelocated targets when the assigned target(s) or nearby landmarks are in sensor range. The onboard navigation system capabilities provide the location for target search and tracking. Manual participation is not required.

c. Target search for targets of opportunity is a secondary mode that can be initiated.

d. If mission plans are to attack an obscured target, a programmed popup maneuver will be executed; the processor will store selected frames of digital video in freeze mode, and the aircraft will resume terrain following. Aircraft position is accurately computed from the freeze point. Automatic high-speed target data processing is conducted during and following freeze. Added popups, to improve accuracy by reacquisition, may be used.

e. The processors initiate search for specified target-shaped objects. If target-like objects are found, added automatic sensor commands for more frames with maximum resolution enhancement is initiated. Information from environmental sensors (weather and atmosphere) is used to select the best weapon-sensor combination. For targets that are identified, a complete final analysis and weapon selection will be presented to the crew.

f. In the search mode, the processors automatically control all sensors with no aircrew participation. The video data are processed and digested; simplified data are presented to the crew.

g. Final processor programming provides target identification. The automatic processors are adjusted to minimize false targets. Normal aircrew operation is to view a synthetic display readout of the processor target assessment and either accept or reject targets. (The probability of correct target recognition by the automatic system is estimated as 0.9.)

h. If the automatic system is unsuccessful or the crew is not satisfied, a manual mode for backup is provided. Real video displays are provided and sensor control is manual.

4.1.2.2 Concept II–Functional Elements

Concept II uses much of the same hardware as the previously described concept I, but system mechanization reflects the system design theme of maximum possible automation. The system block diagram is presented in Figure 4.1-4.

Radar. The Ku-band radar antenna is forward mounted, and aperture size is limited in attack aircraft to about 30 in. The resulting real-beam resolution is about 2 deg or one line of resolution on a tank at 1,000-ft slant range.

Use of the Ku-band radar in SAR mode provides a resolution improvement over real-beam resolution of roughly 60 times for squint angles greater than about 10 deg. The SAR mode is used to deliver weapons that can be maneuvered to offset targets.

EO System (CATIES). No changes to the CATIES system were made, and the system as defined in Section 4.1.1.2 also applies to concept II.

Sensor Selection System. The sensor selection system provides real-time data for use in sensor weighting (sensor voting and scoring algorithm), and for use in determining the prime sensor. Systems for this application are not currently available but appear within the state of the art. Hardware candidates for the system were discussed with industry. Prime candidates are the Perkin-Elmer Aerosol Scattering Measurement Device (ASMD) or a laser turret. The ASMD is currently in brassboard form but not adapted for ISAS use. Software logic and sensor image quality algorithms are also needed and appear readily attainable.

Digital Image Processors. Digital image processors will essentially be the same as in concept I. Differences are that processor functions related to full manual participation have been deleted in concept II. Objectives are very similar to those established in the LANTIRN program, and a derivative of LANTIRN may be used to limit developmental effort for concept II.

Controls and Displays. Primary concept II controls and displays include a multi-function multiple-image color display and a sensor command panel.

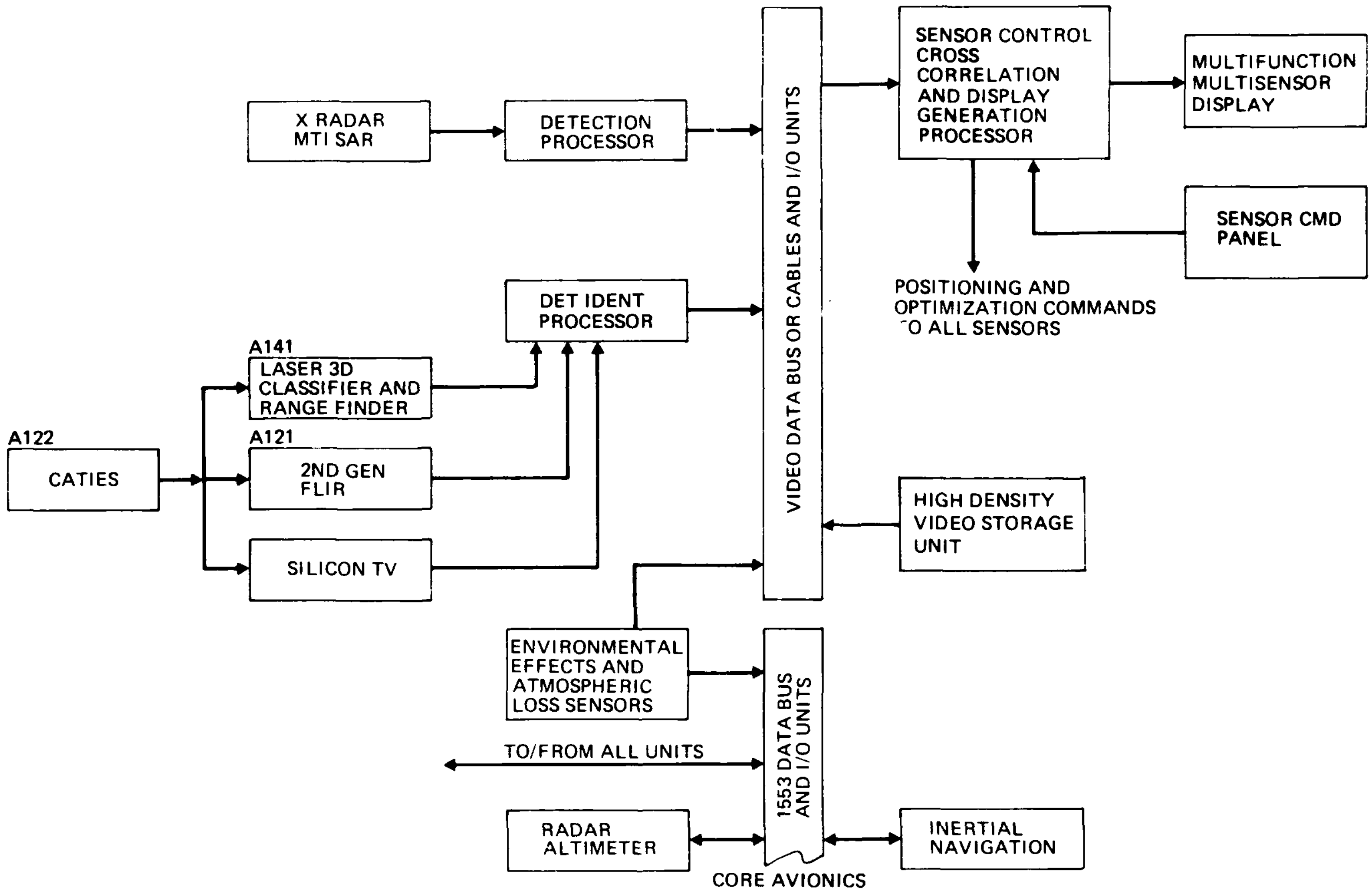


Figure 4.1-4. Concept II - Avionics

The EO sensors associated with CATIES are completely integrated, and image detection and identification processing is automatic. The display provides a target location symbol with a legend giving target number (which is also the attack sequence) and a target-type code. The only manual operation, using the command panel, is to reject the unwanted target. The system then automatically selects a new target or targets. Homing missiles can be automatically locked on and released upon target acceptance.

There is evidence that developmental processors perform about as well as a human when the person is not tired or distracted and high-quality EO display is not needed. The EO display does not provide "true" video, and the only display requirements are crude scene data (major topographical features for orientation only) and target graphics.

In adverse weather, EO sensors are ineffective and the display is automatically or manually switched to the radar mode. Although some radar image processing may be feasible, particularly for very large targets, the display concept assumes that no significant near-term improvements exist. Consequently, radar control and display operation is manual. The display is real video and operation is conventional, with a tracking control and predesignation cursors. Special control display equipment for this degraded radar mode is not shown in Figure 4.1-4. Under these adverse weather conditions, the radar ground moving-target indicator (GMTI) capability enhances the system probability of detecting moving tactical targets.

Video Storage Unit. The video storage unit provides the same functions as in concept I.

Core Avionics. Concept II makes use of the same radar altimeter and inertial navigation system used in concept I.

4.1.2.3 Sensor Integration

In concept II the forms of sensor integration used are: (1) physical-mechanical, (2) voting of registered processed scenes, (3) display format integration, and (4) sensor selection. They are outlined briefly in Figure 4.1-5. Functional entities representing the major areas of integration and how they interface are shown in the figure.

a. Physical-Mechanical: The EO sensor handover is the same as that of concept I. The same CATIES technique is also used.

b. Voting of Registered Processed Scenes: In concept II there is no prime sensor. All sensors of a type are always in use at the same time. Scene registration voting and scoring by processing are the same as in concept I, except that target type, count, and voter output are shown in the crewman display in graphic symbology at the proper coordinates.

c. Display Format Integration: The fully automated aspect of concept II does not provide a real video scene display to the crew. Instead, a simplified scene format as derived in the registration (Matchall-type format) process is provided as a background for target graphic symbology.

   The simplified scene, although devoid of detail, is intended to provide scene context to aid the operator in his decision process of committing weapons. The simplified scene format has the appearance of a cartoon; i.e., it shows only object outlines and scene boundaries without the gray-level variation of a photograph or normal cathode ray tube (CRT) screen image. The key processes in the transformation of a gray-level image into one of these binary images are the various edge detection techniques. They detect changes in gray level or texture that define object and scene boundaries. These techniques have existed for many years and therefore may be considered mature technology. In the context of the pattern recognition terminology introduced in Section 4.1.1.2, the edges are features that can be used to classify the scene for navigational update and/or object recognition.

d. Sensor Selection: The sensor selection device furnishes the necessary tie-in between weapon guidance and target sensors so that a weapon with the proper

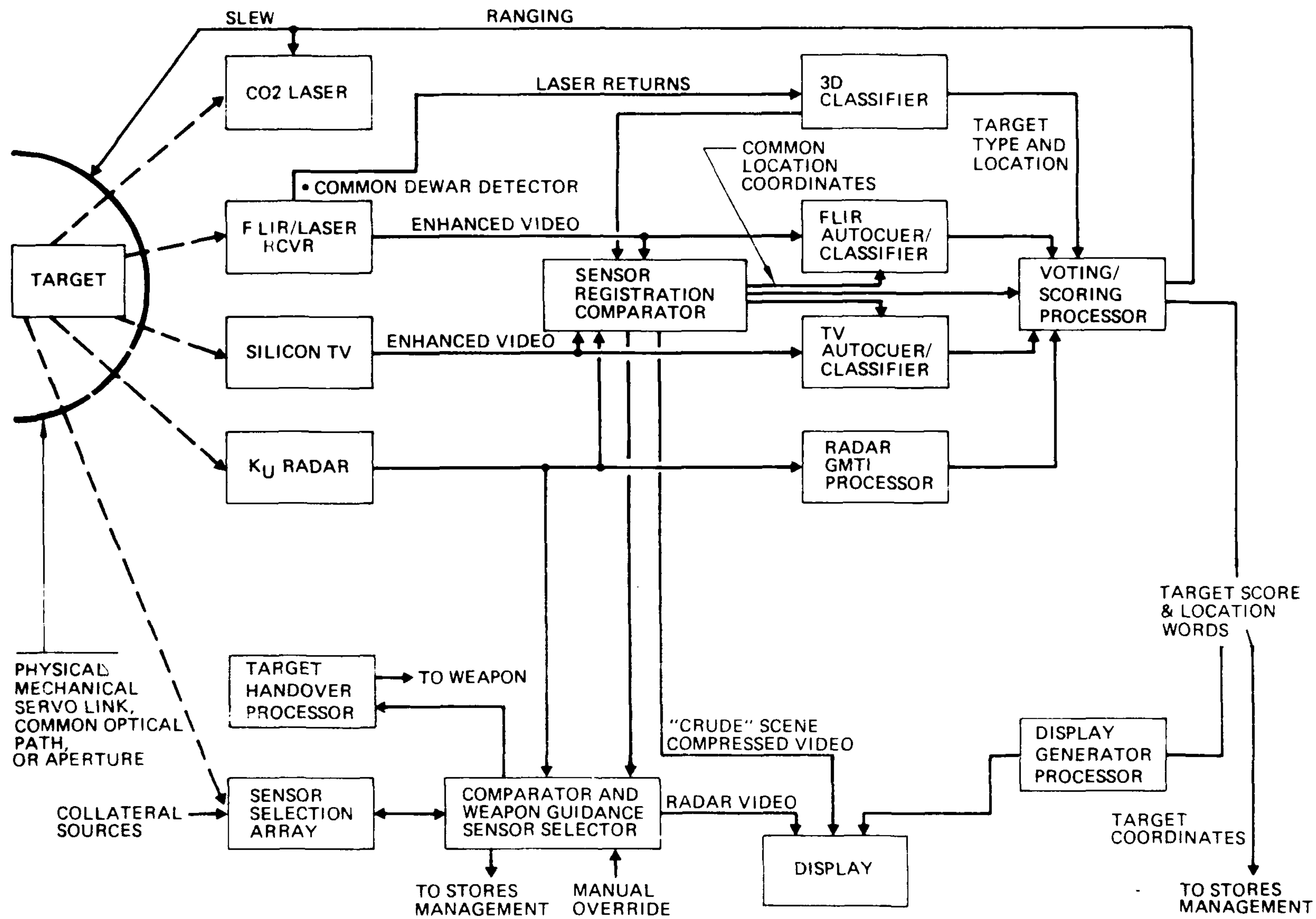


Figure 4.1-5. Concept II - Sensor Integration

guidance sensor is selected, or, if such is not available, the pilot is notified so that he may abort or use unguided weapons.

e. Target Handover Processor: Weapon guidance seekers are automatically locked-on to the target using a target template and the handover processor.

4.1.3 Concept III

Concept III is a short-range autonomous system that is also uniquely adaptable to cooperative strike activity. It represents a minimum-cost ISAS capability.

A basic objective of concept III is to recognize cooperative concepts and to provide a generalized flexible system that can be used to work with a variety of cooperative concepts. This is provided by including a digital data link that, in addition to local sensors, provides targeting and fire control data to the ISAS displays and processors. Concept III includes a data link on the ISAS aircraft, but excludes the remote aircraft or complexes that generate and transmit targeting information to the ISAS concept III data link.

It is assumed, therefore, that automatic or manual processing is included on reconnaissance aircraft or with ground or air complexes, and that data received via the data link is already processed. The system has limited onboard processing capability and does not include full onboard automatic target cueing and classification capability.

Sensor integration in concept III consists of physical-mechanical integration of radar and sensors (handover and common apertures) and cooperative linking. In cooperative linking the initial targeting system preprocesses the data and compresses it as required. The processed, compressed sensor data are then data linked to the strike aircraft for correlation and registration with onboard sensor data.

Laser designator/spot seekers and laser guided munitions have changed close support beyond all recognition in the last 10 years. Incorporation of a laser spot seeker system in concept III essentially solves the targeting problem with "instant" identification when the forward aircontroller (FAC) uses a laser designator with coded pulses to mark the target. Added advantages are that the ISAS aircraft can also use laser missiles or guided bombs that home on the designated target code. This allows weapon launch from standoff out of range of enemy fire or launch and leave. The associated ISAS crew workload is minimal.

The resulting concept, is expected to be the simplest and lightest of the three concepts, and probably could be adapted to many more existing aircraft than the other two concepts.

4.1.3.1 Concept III Concept of Operation

In concept III, sensor integration and system integration must rely extensively on the crewman. To assist the crew, the concept hardware and mechanization exploit supporting systems (e.g., reconnaissance, command and control). For example, in normal operation global position system (GPS) Navstar or JTIDS navigation updating relieves the crew of the need to make navigation fixes; the system can use target scene structure to make "fixes" that translate the concept III system from area navigation coordinates to local target coordinates.

a. Target assignments and ISAS weapons loading are made before ISAS takeoff. It may not be necessary to load precise target coordinates into ISAS mission tapes at this time, and ISAS may take off and loiter waiting for command link target coordinate updates.

b. In the cooperative mode, the ISAS aircraft must remain within line of sight of the data link relay (satellite, balloon, aircraft, or ground station) during scheduled periods when target reassignments or coordinate updates are expected. If the command data link relay is beyond line of sight, lost, or jammed, ISAS will proceed on best available data.

c. A predesignation cursor showing best system estimate of target position is provided on the display, and manual search using local sensors is confined to the area within the predesignation box.

d. In close-support, FAC laser target-designated missions, dependence on the command data link is minimal. The ISAS aircraft uses the laser spot seeker system to rapidly search large areas for assigned laser codes. High accuracy and positive target identification is provided and attack is initiated when within weapon range.

e. When the target area is obscured, popup can be initiated manually to acquire the target with local sensors. A freeze mode, as in concepts I and II, is available; automatic operation is restricted to navigation computations to find the current position in respect to freeze point.

f. Target detection and identification are manual for cases where target reacquisition is necessary. Also provided are precision navigation with automatic checkpoint update to reduce search volume, and display of stored reconnaissance maps to provide landmark and target orientation and registration.

g. The remaining operations to deliver weapons use core avionics. Sensor-weapon matching is performed manually.

4.1.3.2 Concept III Functional Elements

Concept III uses some of the sensors used in concept I. The system goal is a short-range, lightweight, low-cost fire control that would be readily adaptable to small aircraft modification. A block diagram of the concept is shown in Figure 4.1-6.

Radar. General concept II radar characteristics were defined in Section 4.2.1.2. The millimetre wavelength radar is used because of its small size and light weight.

Range capability of the millimetre wavelength radar is expected to be limited. For concept III, the assumption, in the cooperative mode, is that long-range targeting would be accomplished by reconnaissance aircraft. This allows the ISAS aircraft to fly at lower safer altitudes during penetration than the other two concepts allow, and long-range targeting with local ISAS sensors is not necessary.

EO System (CATIES). In concept III, CATIES does not link with digital image processing. The system is (otherwise) as defined in Section 4.1.1.2. As with concept II, detailed task II definition and evaluation may provide variations, such as changes in frequency spectrum, that are unique for one or more concepts.

Controls and Display. The basic system used with local sensor target acquisition and identification is conventional. Automatic sensor selection is not provided, and the sensor display is selected manually. The aircrew performs target search and identification. The track control is used to position the cursor on the "target."

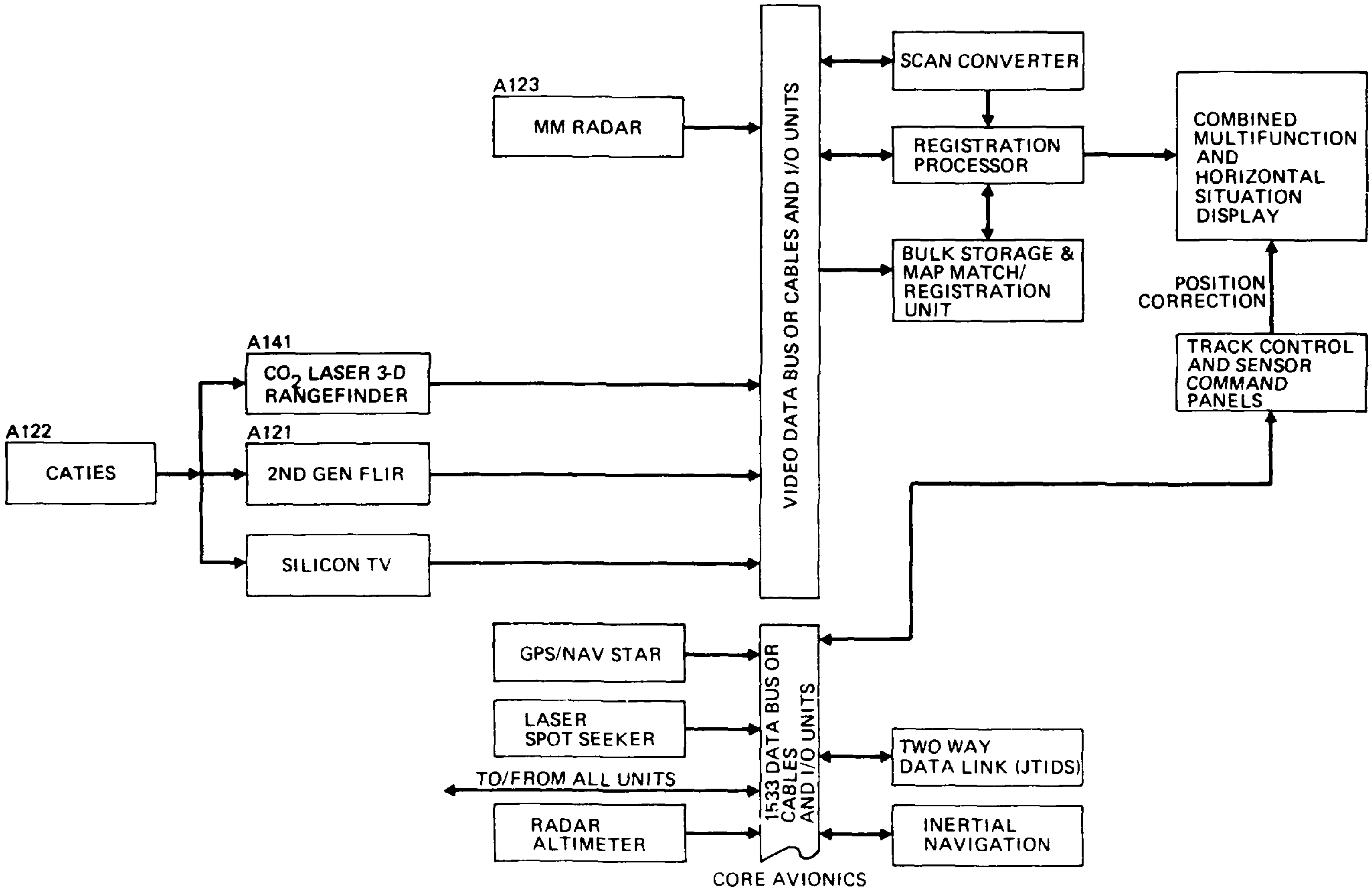


Figure 4.1-6. Concept III - Avionics

A command and control display for aircraft vectoring to the weapon release point for assigned targets is provided. For a two-man aircraft, a second or a special command display is provided to the pilot. For a one-man aircraft, the display may be added modes on the multifunction display.

Digital Bulk Storage and Registration Processor. Digital bulk storage is provided for TERCOM or pattern recognition maps and for ISAS sensor generated video frames for freeze mode. The registration processor compares ISAS aircraft position as obtained with local sensors with the reference map to find current aircraft position. Operation is automatic.

Scan Converter. The scan converter allows presentation of either radar or EO video data on a single multifunction display. The scan converter may also include features to allow alternate multifunction display presentation for the Laser spot seeker, and other core avionics sensors. Hardware is available and developments are restricted to improvements and extension of capability.

Core Avionics. The following core avionics elements identified in Figure 4.1-6 are significant to concept III.

Laser Spot Seeker. Laser spot seekers are passive and provide angular measurements to a laser-marked target. If the target is marked with a known coded pulse, automatic target identification is provided. The system can be combined with an active rangefinder to also provide range to target. Systems typically also require a gimbal system and theoretically could be included with CATIES to reduce registration and boresight errors and weight.

Inertial Navigation System. Because of the requirement for high accuracy for handover, a precision state-of-the-art INS is included in concept III. The system selected is the Honeywell SPN-GEANS. For purposes of analysis, accuracy is 0.1 nmi/h and 0.5 ft/s velocity for each axis.

Radar Altimeter. The radar altimeter is the same in all three concepts.

Data Link. The assumption is made that developmental data links, such as JTIDS, are available for communication with weapons and attack aircraft. JTIDS is a party line multiple user distributed time division multiple access system using spread spectrum. It is designed for tactical command control, communication, navigatioin, and identification. Extensive antijam features are provided. Added developmental work for ISAS is unnecessary and hardware is expected to be available.

GPS/NAVSTAR. GPS/NAVSTAR is a cooperative system and is included for growth. Performance characteristics do not impact concept III performance analysis in this report.

4.1.3.3 Sensor Integration

In concept III sensor integration consists of (1) physical-mechanical integration and (2) cooperative linking. They are shown in Figure 4.1-7 and are described below.

a. Physical-Mechanical: Handover between sensors and common aperture/optical path provisions are the same as concepts I and II.

b. Cooperative Linking: In cooperative linking of sensors, the reconnaissance target acquisition sensor performs target detection and acquisition. Target data are then processed, at the remote site, to define target type and specific location in local coordinates. This location may be in a TERCOM coordinate system or correlation coordinates (as in scene registration) or both. Both techniques are known and used today. The primary problem is that of translating from a cultural or topographical reference as viewed by the target acquisition system with a long-range sensor to an airborne ISAS sensor at another aspect angle.

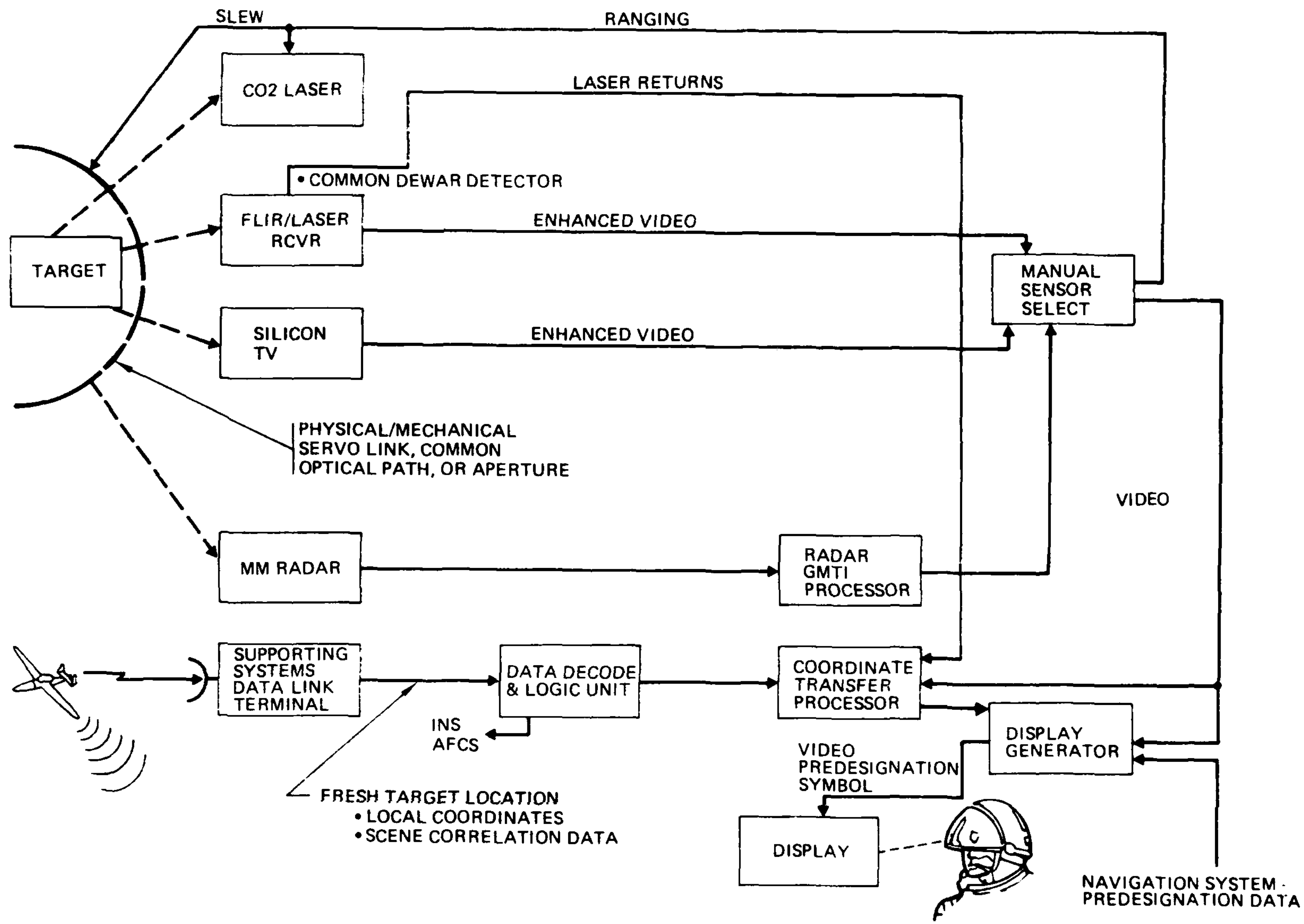


Figure 4.1-7. Concept III - Sensor Integration

4.2 ISAS CONTROL PROGRAMS AND ALGORITHMS

Table 4.2-1 summarizes the major computer control programs and functional algorithms required for the ISAS concepts. The control programs establish and implement orderly sequences of instructions, functions, modes, application of algorithms, etc. The algorithms are discrete mathematical solutions to specific control, data correlation, or mechanical problems - just as the expression $(x^2 + y^2)^{1/2} = h$ is the algorithm for determining the hypotenuse of a right triangle with sides x & y. The data in the table were extracted from the concept descriptions furnished in this section and organized by mission function. A number of subfunctions are shown with each major function. Each of the three concepts is separately addressed.

It is evident that the entire array of programs and algorithms needed is not unique to ISAS and will require adaptation rather than develoment. Other functional algorithm elements are already being partially or fully developed by other AFWAL and ASD programs. A brief review is presented below.

Initialization. This function consists of the insertion into the overall system of initial position, route planning, and mission planning data from an external source. Current tactical aircraft are capable of limited (if any) automatic initialization. The loading of bulk data for initialization is, however, already a part of the B-1 navigation system and several next-generation navigation and integrated EW systems.

The initialization requirements of all three ISAS concepts are essentially the same.

Sensor Management. This function includes preprogrammed search, sensor output control, data freeze, and handover among sensors. Automatic positioning of search scans, in accordance with preset logic driven by the navigation system, is already a part of some operational aircraft (FB-111 and B-1). The complete scope of sensor control visualized for ISAS is not yet available.

Concepts I and II have essentially the same sensor management requirement except that concept I management must provide for manual participation during normal operation. Concept III has greater reliance on management of its sensors and requires fewer management tasks.

Table 4.2-1. ISAS Algorithms & Control Programs

CONCEPT I	CONCEPT II	CONCEPT III
INITIALIZATION o Prebriefed Target Locations o Fix Points, Way Points	INITIALIZATION o Prebriefed Target Locations o Fix Points, Way Points	INITIALIZATION o Prebriefed Target Locations o Fix Points, Way Points
SENSOR MANAGEMENT o Sensor Control o Preplanned Search o Search Targets of Opportunity o Sensor Data Freeze o Handover Among Sensors o Manual Participation	SENSOR MANAGEMENT o Sensor Control o Preplanned Search o Search Targets of Opportunity o Sensor Data Freeze o Handover Among Sensors o Manual Control in Degraded Modes	SENSOR MANAGEMENT o Preplanned Search o Sensor Data Freeze o Manual Control
*SENSOR INTEGRATION o Sensor Selection o Scene/Target Registration o Voting & Scoring	SENSOR INTEGRATION o Sensor Selection o Scene/Target Registration o Voting & Scoring	SENSOR INTEGRATION o Scene Registration
———	———	COOPERATIVE LINKING o Registration of Data-Linked Local Coordinate Reference Points
TARGET DETECTION/CLASSIFICATION o Autocueing o Autoclassification o Crewman Review of Classification	TARGET DETECTION/CLASSIFICATION o Autocueing o Autoclassification	TARGET DETECTION/CLASSIFICATION o Crewman Detects & Classifies

*NOTE Automatic Target Detection & Classification Systems
Are Used By ISAS But Are Not Considered Peculiar to ISAS

Table 4.2-1. ISAS Algorithms & Control Programs (Concluded)

CONCEPT I	CONCEPT II	CONCEPT III
DISPLAY FORMAT INTEGRATION o Hands-Off, Enhanced Video o Prime Sensor Scene o Target Type/Sensor Score o Scaling o Zoom o Remove Spatial Temporal Warp	DISPLAY FORMAT INTEGRATION o Hands-Off, Enhanced Video o Synthetic Display o Target Type/Sensor Score o Manual Control In Degraded Modes	DISPLAY FORMAT INTEGRATION o Hands-Off o Predesignation Symbol o Limited Overlay of Multiple Sensors
WEAPON SELECTION/WEAPON HANDOVER o Targeting Sensor/Weapon Guidance Match o Stores Logic	WEAPON SELECTION/WEAPON HANDOVER o Targeting Sensor/Weapon Guidance Match o Stores Logic	WEAPON SELECTION/WEAPON HANDOVER o Laser Spot Seeker o Stores Logic
WEAPON DELIVERY o Weapon Release/Trajectory Computations o Target Position Fix At Freeze Instant	WEAPON DELIVERY o Weapon Release Trajectory Computations	WEAPON DELIVERY o Weapon Release/Trajectory Computations
OTHER o Damage Assessment o Navigation o Self Check o Etc	OTHER o Damage Assessment o Navigation o Self Check o Etc	OTHER o Damage Assessment o Navigation o Self Check o Etc

Sensor Integration. Several unique integration functions are required. First, real-time automatic selection of the best of several sensors has never been provided on a system. Industry has indicated that devices to make pertinent measurements are, or can be, made available without risk. The measurement device outputs will require an algorithm to translate them to an actual sensor selection and a sensor "value" weighting. Second, scene and target registration is necessary to correlate simultaneous target data from more than one sensor. This function ensures that the system can differentiate between four targets—only one of which is equal to each of four sensors and the same target seen four times, once by each sensor. Third, voting and scoring of sensor returns provide a measure of confidence that targets have been detected and/or currently classified. The measure of confidence is conveyed to the crewman via displayed information. These three items appear sufficient complex to be considered as individual algorithms.

A limited display registration capability has been claimed by Hughes Aircraft Co. This capability is consistent with displaying selected sensors (such as FLIR and TV) simultaneously.

Concepts I and II require identical algorithms for all three functions. Concept III will require scene registration capability to provide limited multisensor display capability.

Target Detection and Classification. Programs to develop image processing autocuers and autoclassifiers are well under way. The ASD LANTIRN program, AFWAL Image Sensing Autoprocessor and Augmented Target Screener Subsystem and Autothreshold/Autoscreener, Westinghouse Auto Q, and similar equipment developed at Northrup are examples. It is intended that ISAS will apply this technology.

Display Format Integration. An assembly of algorithm elements to process outputs from the sensor management, sensor integration, target detection classification, weapon selection and weapon handover, and weapon delivery functional algorithms is required. At least one program (Display for Correlated Sensor Data, RFP F33615-80-R-3603) is identified as intended to develop an ISAS-compatible display. ISAS has unique display requirements and will require an ISAS-compatible display during concept development and proof.

The display format for concept I uses enhanced real video and requires graphic annotation that will not degrade the video quality. Concept II requires cartoon-like displays. Concept III is far simpler except for the requirement to overlay imagery.

Weapon Selection and Weapon Handover. This functional algorithm ensures that the target recognition sensor is compatible with the weapon guidance sensor. Interface with the host airplane stores management system is used to promote the assignment of a suitable store and store-station. An element of the algorithm makes a target template from the recognition sensor and controls transfer of luck on one-half the weapon guidance unit by comparing sensor and guidance unit templates.

The automatic weapon assignment and weapon handover functional requirements are the same for concepts I and II. Concept III is mechanized to use manual and hardware logic for weapon selection, weapon handover, and Laser Spot Seeker use.

Weapon Release. Fix-taking algorithms and digital weapon trajectory algorithms are in common use on current tactical aircraft. Real-time launch envelope algorithms for air-to-ground weapons are not yet available. Current development programs in the real-time trajectory area are emphasizing air-to-air application. It is intended that ISAS will apply existing trajectory and launch envelope techniques and that advances in these areas be exploited as available.

Other. Damage assessment and other functional algorithms do not appear integral to the basic ISAS concept and have not been addressed.

5.0 ANALYSIS

This section presents the individual analyses performed to quantify ISAS conceptual system parameters. Analyses reported here are: Radar, EO Sensors, Integrated Sensors, Crew workload, Resistance to Countermeasures, Concept Installation, Weapon Selection and Graceful Degradation. These analyses were accomplished as a part of ISAS Task IV.

5.1 RADAR

The analysis of ISAS candidate radars will be found in AFWAL-TR-80-1145, Volume II Integrated Strike Avionics Study - Final Report, Classified Supplement.

5.2 ELECTRO-OPTICAL SYSTEM PERFORMANCE

Based on the technology contact survey made for this contract plus information already in house on sensor research trends, a next-generation electro-optical (EO) target-acquisition system has been hypothesized. It is important to stress that this is a generic system that combines features and characteristics found within the technology and industry as a whole. Care has been taken not to feature a specific system or supplier product line. It is fully recognized that composite systems often require a merging of capabilities or products from different manufacturers plus combinations of results from different research centers. No judgment is made on whether corporation A and corporation B would work on the same team for a common product goal. The recent formation of EO-industry teams for the TADS/PNVS and the LANTIRN competitions, however, indicate that development of highly complex EO systems that incorporate the product lines of several corporations is possible.

5.2.1 Atmospheric and Meteorological Phenomena

Much published analysis has attempted to resolve the FLIR-versus-TV issue. At a time when the cost of these weapon targeting systems was very high, economic considerations often dictated an either-or but not-both choice. Extensive work done by F. A. Rosell and R. L. Sendall under USAF contract attempted to quantify the problem and resolve the FLIR-versus-TV issue. Figure 5.2-1 is reproduced from their final report and represents the real world. The space of all conditions involving an atmosphere

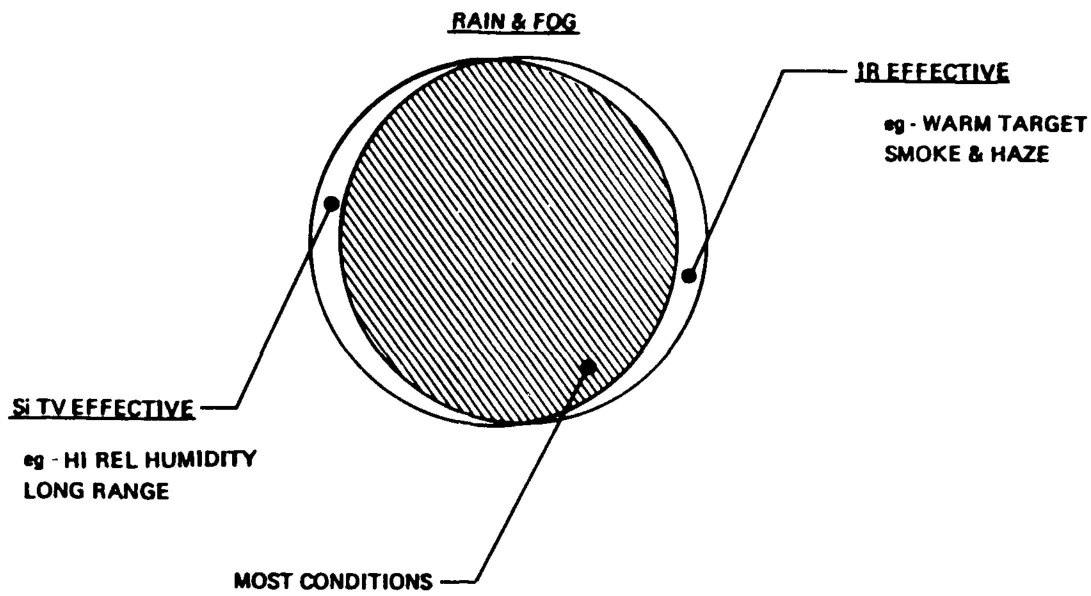


Figure 5.2-1. Space of All Conditions

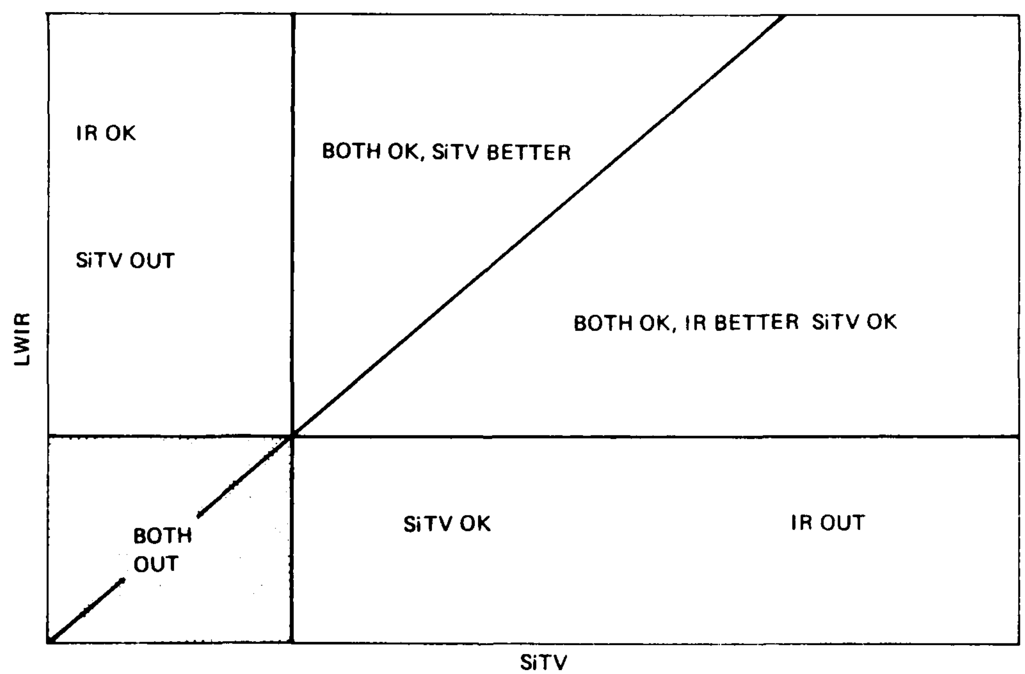


Figure 5.2-2. Task: Detect Tank All Weather

containing water phenomena (i.e., rain, fog, dissolved molecular water, plus aerosols of smoke in haze) is shown symbolically as a Venn diagram. Clearly, there are conditions that favor the use of either the infrared or the visual-to-transvisual TV.

Figure 5.2-2, also by Rosell and Sendall, illustrates the form of data presentation originally sought by the referenced study. In the final analysis, the variability of the atmosphere, including weather, allowed an unlimited number of these figures to be created, each for one specific set of conditions. Being aware of these previous results, we have chosen to follow the Lincoln Laboratories recommended concept and bound the practical problem with two, reasonable atmospheric-condition assumptions. Therefore, to provide justification for these assumptions, a brief discussion of the general atmosphere-weather effects on EO systems is given.

Atmospheric Effects. Figure 5.2-3 illustrates the primary atmospheric components confronting the EO target-acquisition system. The impact of these components on E-O systems is as follows:

• Clouds - Can be opague Attenuation to 100dB/km	• Precipitation - < 3 dB/km
• Fixed gases < .5 dB/km	• Turbulence - Not significant problem at resolutions under study
• Variable gases - < 4 dB/km	• Obscurants & camouflage smokes - Can be opaque
• Aerosols (Including Fog) - Can be opaque	• Thermal gradiants - Induce mirage effects

Figure 5.2-3. Atmospheric Components & Effects

a. Clouds: (An airborne accumulation of water droplets of varying sizes following the classical size distribution statistics). Depending on particulate density, clouds can range from diffuse to totally opaque for all optical wavelengths.

b. Fixed gases: (The known and measured molecular gases that constitute the normal atmosphere). The attenuation phenomenon is known and measured and accounts for up to 0.5-dB/km EO system energy loss (image signal loss).

c. Variable gases: (Primarily water vapor in its dissolved gaseous state). The attenuation of optical transmission is known and predictable from meteorological data. Attenuation approaches 4 dB/km.

d. Aerosols: These include precipitable water fogs (i.e., clouds) and can be unpredictable and opaque.

e. Precipitation: Can account for up to 15-dB/km attenuation during intense tropical rainstorms. However, typical rainfall statistics indicate that rainfall accounts for up to 3-dB/km signal attenuation for the candidate EO systems.

f. Turbulence: In general, turbulence becomes a problem only with extremely high-resolution systems, such as those used for astronomical observations and high-resolution photo reconnaissance.

g. Obscurants: These include dust, dirt, and camouflage smokes, and can be opaque.

h. Thermal gradients: These produce primarily a mirage effect. This is a unique phenomenon that can affect low-altitude EO systems but is not be quantifed in this study.

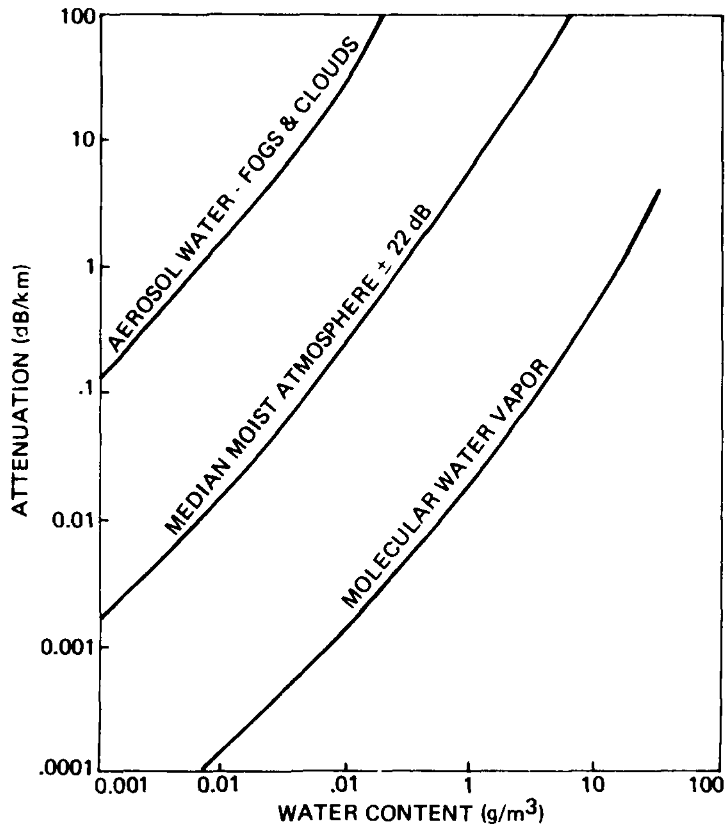


Figure 5.2-4. Range of Attenuation Effects Due to the Phases of Atmospheric Water

Water in the atmosphere introduces many various effects, as illustrated in figure 5.2-4. Data available from classical meteorological data (i.e., pressure, temperature, and humidity) equate to an absolute water content expressed in grams H_2O per cubic meter (gm/m^3). However, water can cause optical signal attenuation ranging over 4+ orders of magnitude for any specific meteorological condition.

A particular atmosphere can be quite transparent, especially to silicon-based TV (SiTv) sensors. The same moisture content, when in the mature fog phase, may be opaque to all optical wavelengths. Thus, the primary assumption about the atmosphere must be uncertainty. Water alone introduces ±22-dB uncertainty in atmospheric absorption.

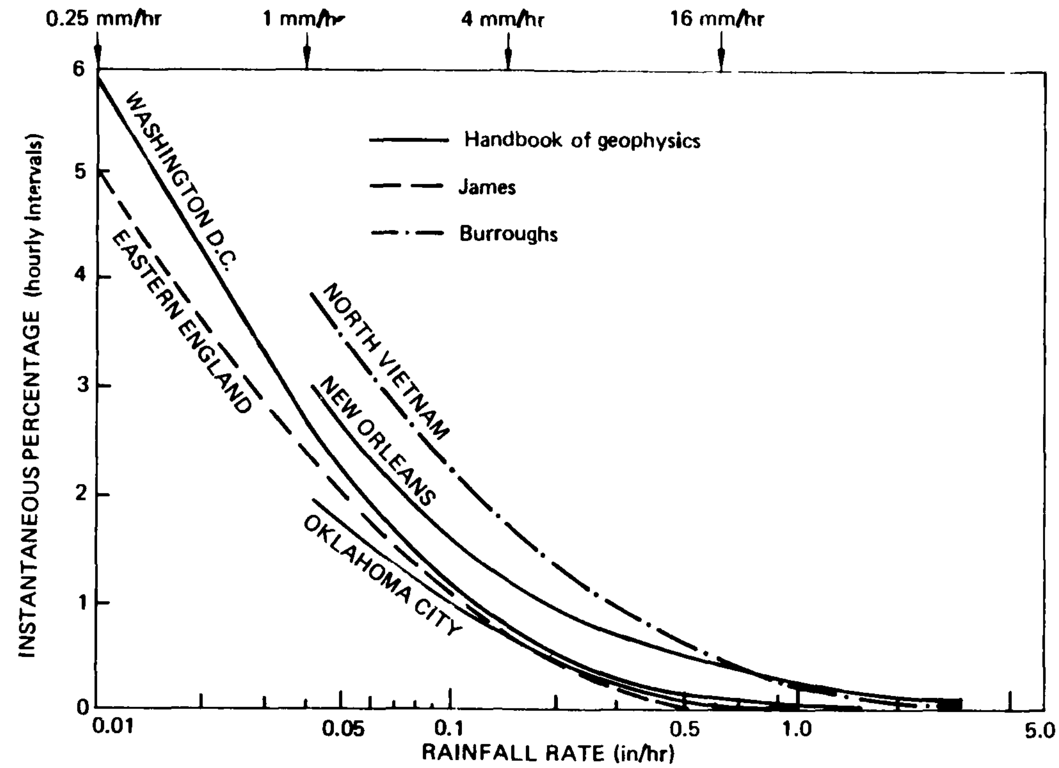


Figure 5.2-5. Percentage of Time Rainfall Exceeds a Given Rate

Rainfall. Statistics of rainfall rate are shown in figure 5.2-5, which illustrates that rates of 1- or 2-in/h do occur, but at very infrequent intervals. The 4-mm/h rate is often taken as a specification rate for military systems. As seen from Figure 5.2-5, 98% to 99% of the time conditions are not that severe; i.e., the 4-mm/h rate is approximately the 1 percentile level. Figure 5.2-6 illustrates the range of EO signal attenuation measured at two reference wavelengths. The silicon-based sensor band (SiTV), which covers the 0.4- to 1.1-µmwavelength band is represented by the 0.63-data. The FLIR band and the CO_2 laser region are represented by attenuation measurements for the CO_2 laser at 10.6 µm wavelength. Rainfall rate statistics of Figure 5.2-5 show that 99% of the time the rain attenuation is less than 4 dB/km.

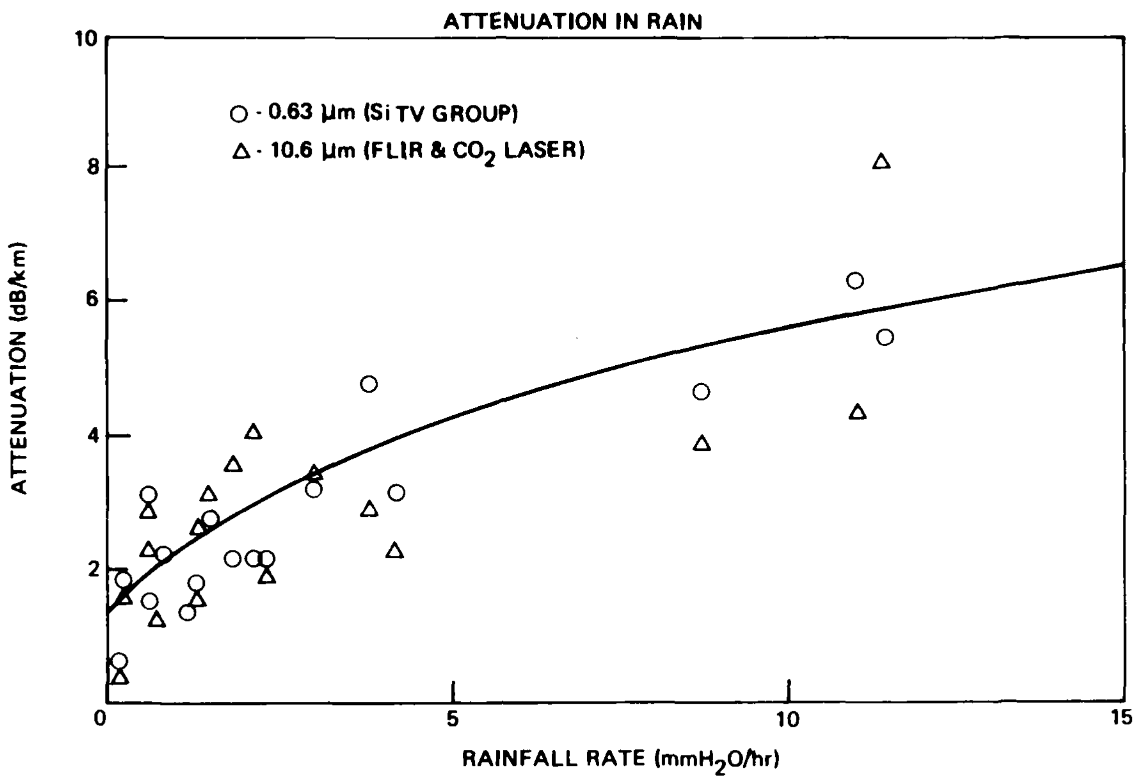


Figure 5.2-6. Bounds on Rainfall Attenuation Effects for EO Systems

Precipitation also occurs as snow. Figure 5.2-7 illustrates snowfall rate statistics for an unspecified but representative European location. A rule of thumb states that fresh, dry snow accumulates at 10 times the equivalent for rain. Thus, a 1-cm/h rain yields a 10-cm/h snow accumulation (approximately). Data on EO signal attenuation for snowfall rates are available only in the 10.6-µm CO_2 laser and FLIR band and are illustrated in Figure 5.2-8. However, these data state that approximately 1% of the time conditions are bad, with 24-dB/km attenuation.

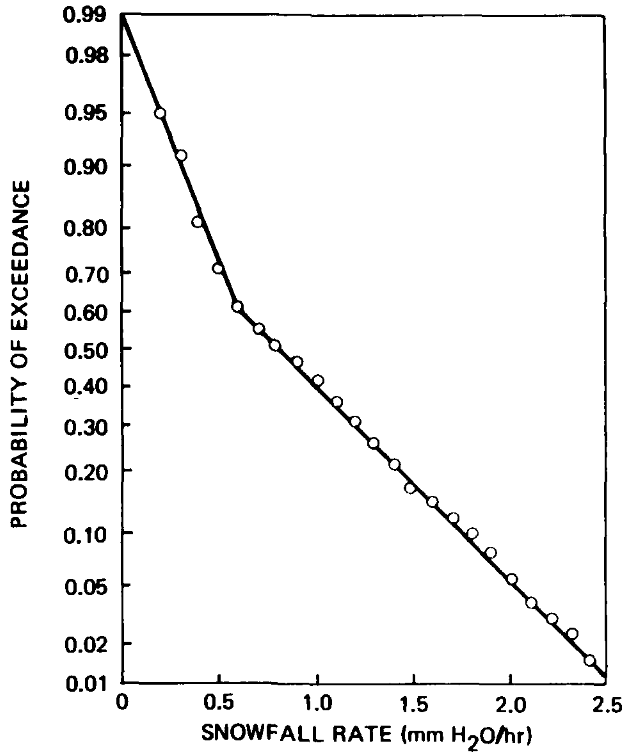


Figure 5.2-7. Distribution of Snowfall Intensity

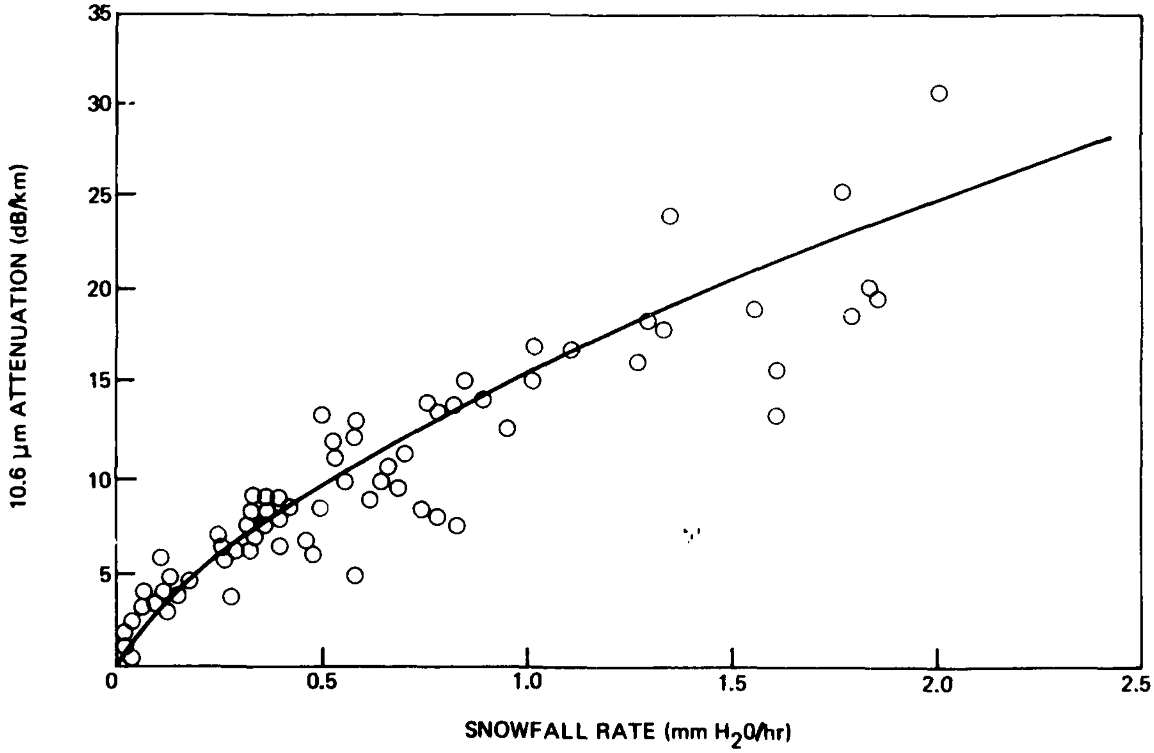


Figure 5.2-8. Attenuation of the FLIR & CO_2 Laser Band by Snowfall

Camouflage Smokes. The attenuation caused by camouflage smokes in the EO bands of interest to this target-acquisition study is shown in Figure 5.2-9. This figure illustrates that FLIR systems operating in either or both wavelength bands of 3- to 5- μm and 8- to 13-μm suffer far less attenuation than systems operating in the visual and the SiTV bands. One specific test using hydrocarban smoke to obscure a Soviet tank measured 17-dB signal attenuation in the SiTV band, and 1.1-dB signal attenuation for the CO_2 (10.6) laser.

Data taken for two specific wavelengths are shown in Figure 5.2-10. A comparison of the relative performance of the Nd:YAG laser target designator (1.06 μm in the SiTV band) and the CO_2 laser/FLIR band systems shows that signal attenuation in the FLIR band is 100 times less in fog and 5 times less in phosphorus smoke.

Other Atmospheric Effects. The mass movement of armored, tracked vehicles or an armored vehicle military engagement creates a highly complex atmospheric situation. The U.S. Army has staged several exercises to generate typical combat atmospheres and has invited experimenters to instrument, observe, and make measurements at the range. Data from these exercises, entitled "smoke week" and "dirt week," are beginning to be available as examples discussed earlier indicate. Figure 5.2-11 is an additional example of the diversity of data being gathered. Artillery projectiles (155 mm) were detonated at approximately 8-sec intervals. Atmospheric obscuration due to the ejected soil was measured using 1.06- and 9.75-μm laser transmissometry. The atmosphere, predictably became optically dense with dirt and dust.

Particulate settling is probably dependent on size: dust remains airborne for a long time after large particles have fallen or settled. This latter illustration may appear trivial and self-evident. However, it is cited to illustrate that thorough experimentation is addressing all aspects of the atmospheric image-degradation problem.

One generalization is becoming more evident from all these experiments. The atmospheric transmission under conditions of interest to ISAS-class target-acquisition systems pulsates quite dynamically with time. Target objects appear, fade, and reappear for all sensors. This image pulsation can be on different time sequences for different wavelength-band sensors. Therefore, the multiple-sensor concept as currently expressed in the forthcoming LANTIRN program and the Army attack helicopter target acquisition/designation system and pilot night vision system (TADS/PNVS)

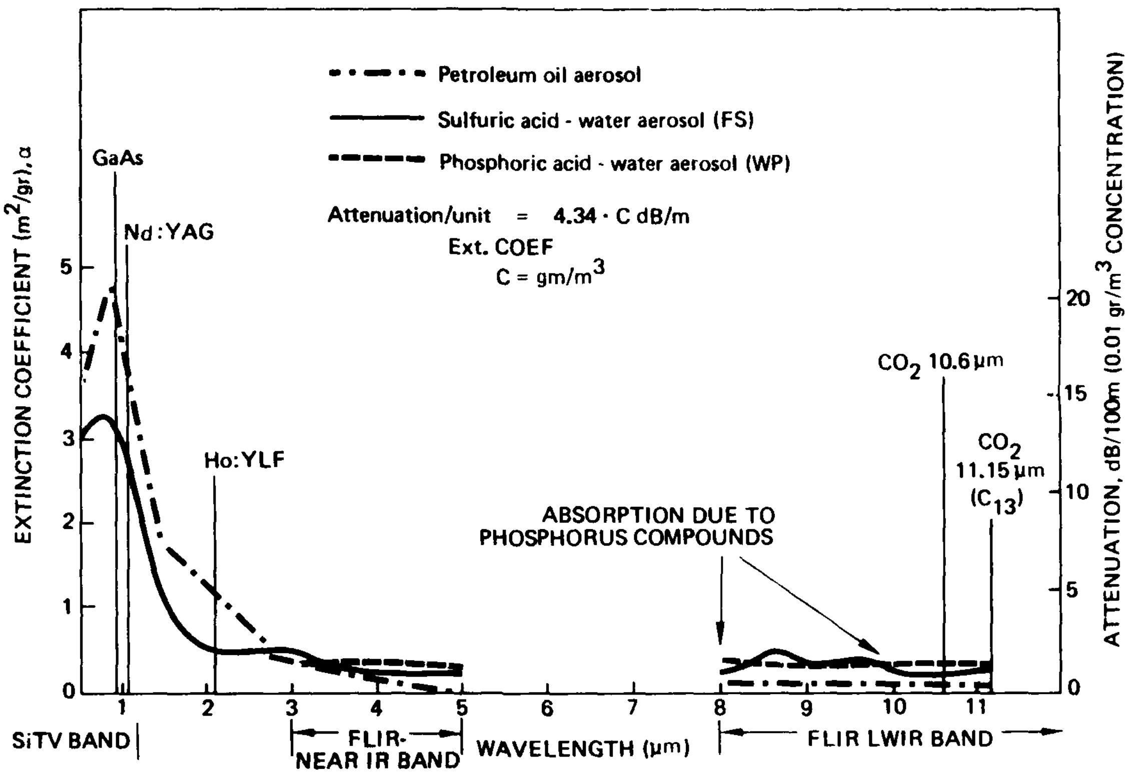


Figure 5.2-9. Extinction Coefficients of Military Aerosols

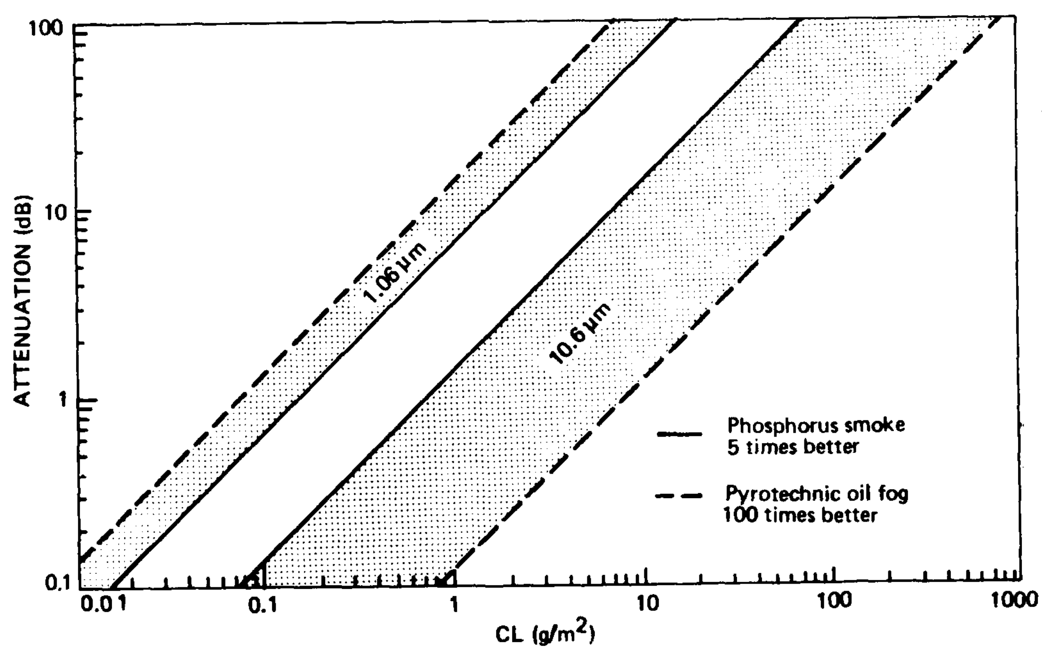


Figure 5.2-10. Attenuation by Military Aerosols

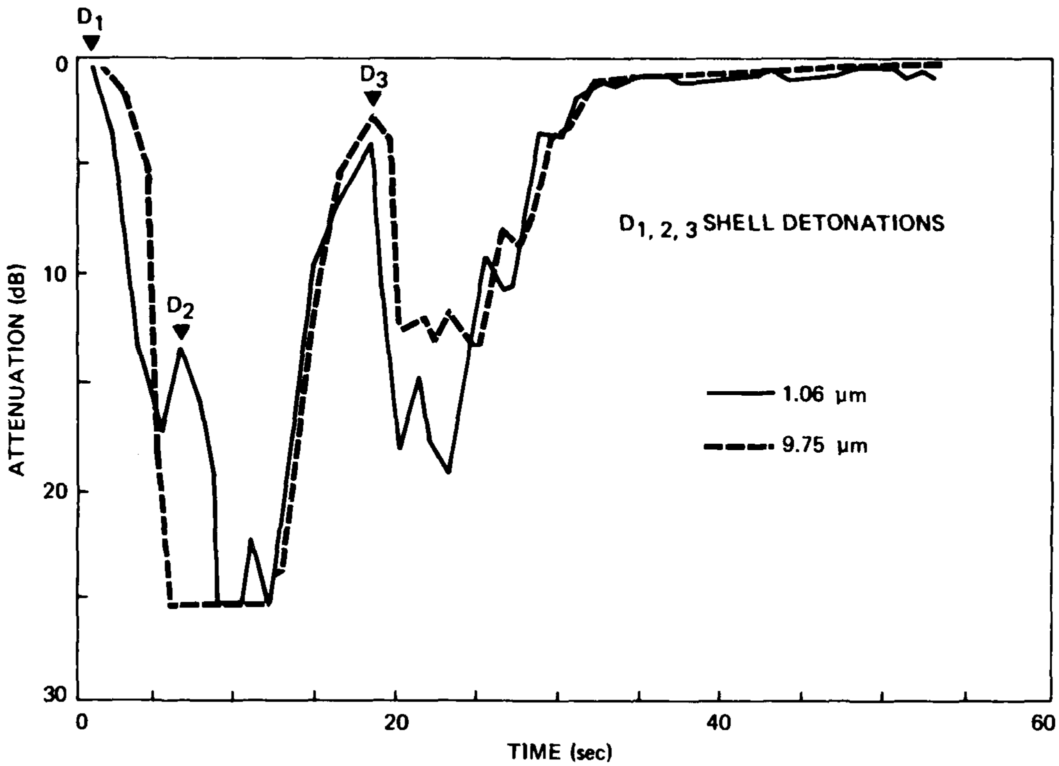


Figure 5.2-11. Optical Transmittance Through Dust Cloud Produced by Three 155-mm Projectile Explosions

will give synergistic combinations to enhance target acquisition probabilities over that which can be achieved with a single sensor. Therefore, the preferred ISAS target acquisition will combine sensors from the various wavelength windows to maximize any synergistic system benefits due to the varied nature of the atmosphere.

5.2.2 ISAS EO System Design Point

Section 5.2-1, Atmospheric and Meteorological Phenomena, described individual effects contributing to the degradations of EO imaging target-acquisition systems.

Typically, these data present decibels per kilometre as a signal attenuation as a function of phenomena (rainfall rate, time after shell burst, etc.). This attenuation causes degradations due to loss of image signal, increased noise, decreased contrast, etc. Thus, the overall effect is a decreased signal-to-noise ratio (SNR) causing loss of utility of the imaging system. The most universal solution to counteract signal loss is to increase optical aperture regardless of wavelength band. Sensor gain or sensitivity is also increased wherever possible. However, most systems use the sensor at its full design sensitivity.

Arbitrary increase of aperture is not practical in operational systems due to practical contraints that include, typically—

a. Aerodynamic drag due to frontal area

b. Installed weight

c. System cost

d. Available volume for optics assembly

Lincoln Laboratories was recently commissioned to generate target-acquisition systems design guidelines to pace industry on the LANTIRN and other next-generation EO-based target-acquisition systems. Much of the phenomenology previously summarized was assembled by D. H. Kleiman, et al., at Lincoln Laboratories for this purpose. Several significant studies have addressed the central European EO atmosphere. Figure 5.2-12 illustrates a cumulative probability for LWIR FLIR (8- to 12-band) attenuation for data taken at Meppen, Germany, during a specific winter. There is a significant knee in the curve as shown for the 90th percentile at 3-dB/km or less attenuation.

This curve illustrates a typical and significant EO system design effect. Increasing system performance (i.e., increasing aperture area) gives a high leverage to performance improvement up to the 85% to 90% cumulative-probability point. The design of aperture size to furnish adequate focal-plane photon energy (minimum required SNR) under an atmospheric attenuation condition of 3 dB/km is a productive improvement. Beyond the 90% percentile point, an optical aperture gain of +4.2 dB is required to

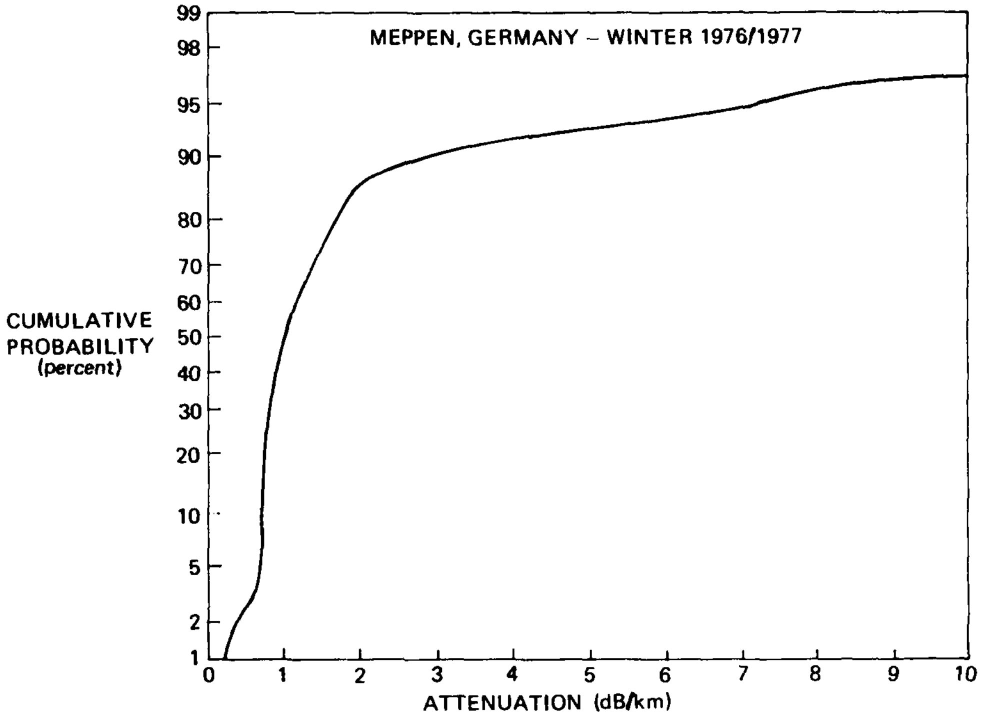


Figure 5.2-12. Project Opaque 8-12 μm Attenuation Data

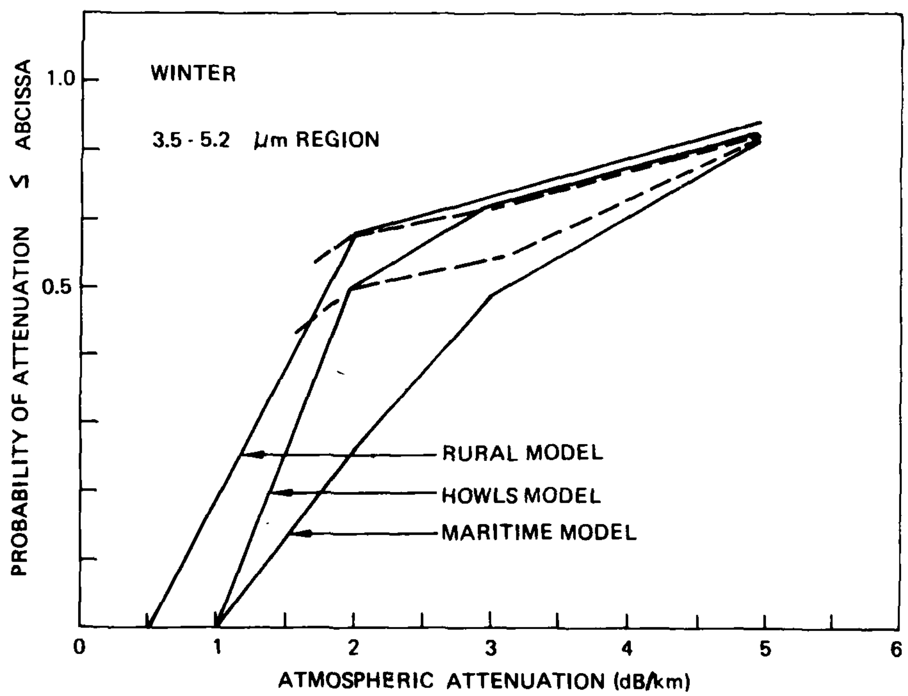


Figure 5.2-13. Atmospheric Attenuation Statistics for Moscow, USSR

yield the next 5% cumulative-probability benefit. This requires an aperture area increase of 263% or an aperture diameter increase of 162%. Typically, EO system weight and cost of optical fabrication increases approximately as the cube of aperture size (an empirical rule of thumb from production records). Thus the 4.2-dB performance increase is purchased with a 425% cost (and often weight) increase. Therefore, the strong knee in the data shown in figure 5.2-12 is a very realistic design point arrived at by plotting atmospheric degradation aggregate effects at a specific observation site. Figure 5.2-13 plots similar data for the various heuristic haze and aerosol models fitting Moscow, U.S.S.R., winter meteorological observations. It is readily seen that the rural model and the maritime model represent good bounding conditions for Moscow data. Again, attenuation of 2 to 3 dB/km is a data knee, and again the knee at approximately 3 dB/km is quite evident.

Winter weather data for Berlin, Germany, in Figure 5.2-14, also illustrate the same knee of the curve at 2 to 3 dB. Based on this analysis, Lincoln Laboratories formally

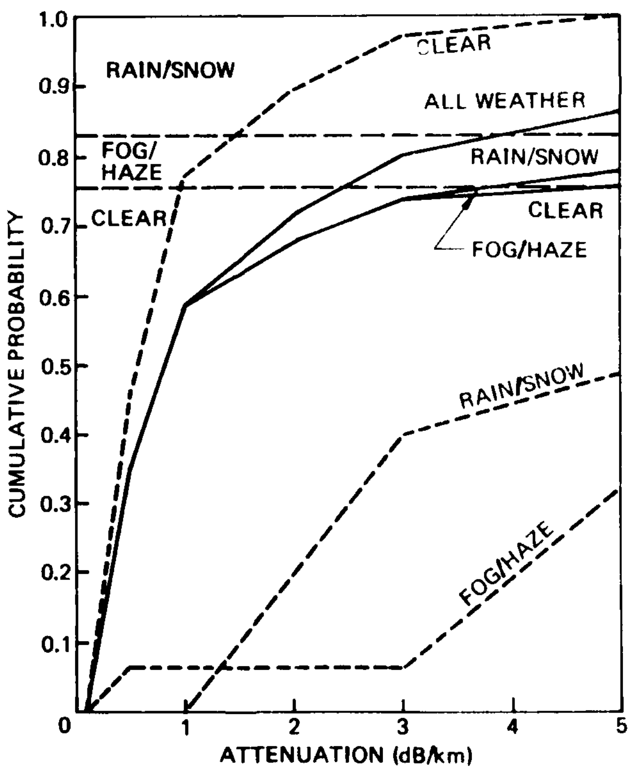


Figure 5.2-14. Composite of Various Atmospheric Effects for Berlin DDR Winter

recommends sizing EO system apertures to yield the design sensor SNR under an atmospheric attenuation condition of 3 dB/km.

Analytical atmospheric models (specifically LOWTRAN IV) should also use both the rural and the maritime haze options to place probable system bounds on the variable range. These recommendations were followed for the ISAS EO system performance analysis.

5.2.3 Sensor Evaluation Methodology

Performance for 1985 TAD potential sensor systems was calculated using a combination of the following models:

a. Avionic Laboratories Sensor Performance Model (ALSPM) resident in ASD computer, WPAFB, Dayton, Ohio

b. L^3TV Performance Model, Poppelbaum, et al., General Electric Aerospace Electronics Systems, Utica, New York

c. Boeing Military Airplane Company, developed Tank Acquisition Model, based on Naval Weapons Center TM 2760 updated with LOWTRAN IV

The general atmospheric condition chosen is summer, midday, midlatitude, using both the rural and the maritime haze models to bound performance. This is a very realistic and also taxing atmosphere for EO system evaluation. Atmospheric conditions could be chosen to optimize the performance of a specific sensor. For example, FLIR will perform very well with the following conditions: midlatitude, winter, night, with rural haze. However, this enhances the case for FLIR at the expense of SiTV sensors.

The target chosen is the typical main battle tank with standard military paint on steel. Tank dimensions are 3.6m by 9.9m by 2.3m high (11.8 by 32.5 by 7.5 ft high). This target tank is placed on a short, brownish-green grass stubble background. No system cueing advantage by the presence of a prepared road is allowed.

The probability of detection and probability of recognition and classification calculations were made, assuming—

a. Flat Earth

b. Cloud-free line of sight

These assumptions allow sensor system performance in an ideal environment to be computed. Further steps in the evaluation combined these probabilities with the probabilities of cloud-free line of sight at the designated altitude, and terrain model line-of-sight probabilities. These computation steps are necessary to prevent introduction of clear line-of-sight probabilities several times in the evaluation chain. Consultation with ALSPM model authorities* at WPAFB confirmed the appropriate control modes required to eliminate existing terrain models, and to make other ISAS-problem unique program manipulations.

Subsequent analyses in this report show that terrain line-of-sight statistics for the ISAS terrain model dominate sensor performance for the 200-ft-altitude case and are essentially in balance with atmospheric effects at the 3,000-ft altitude (above ground level).

There were extensive consultation with and technology evaluation visits to the overall EO laboratory and manufacturing community. Based on these many and diverse inputs, the potential performance parameters for TAD 1985 systems were developed. It is important to stress that the technology capabilities generally do not represent a specific manufacturer's concept, but rather a realistically attainable composite. In specific cases we have merged diverse concepts into one system because significant advantages are recognized in each technology area. One specific example is the use of the heterodyned CO_2 laser (Lincoln Laboratories) as the ranging sensor for the Perkin-Elmer Corporation/ERIM three-dimensional target-classification (3D-TC) concept. Although these two organizations are not pursuing a joint program, such a system is possible with feasible synergistic advantages derived from the various laboratories' concepts. Therefore, for purposes of the ISAS analysis, we assume a CO_2 ranging laser with its atmospheric-penetration advantages (as discussed in Sec. 5.2.1) combined with the 3D-TC Perkin-Elmer and Erwin shape-classification algorithm as a 1985 TAD

*Special recognition is given to Ms. Dorothy Johns and Mrs. Dianne Summers of WPAFB-AA-3 for assistance with the ALSPM model.

potential system. The ERIM CYTO computer concept is an alternative route to obtaining the 3D-TC system.

Specific characteristics of the basic elements of the ISAS target acquisition/classification system are described in subsequent sections.

5.2.4 Infrared ISAS System

The infrared sensor is a generic derivative of the common module and the technology-demonstration FLIR concepts. The focal-plane sensor is an improved trialkaloid, two-dimensional array, probably of the Hg-Cd-Te class. Time-delay integration (TDI) is assumed with between 16 and 25 repetitive sample steps. TDI effectively increases sensitivity by decreasing noise. The gain in sensitivity is proportional to the square root of N, where N is the number of repetitive TDI sampling steps. Figure 5.2-15 shows the number of additional TDI steps required to increase the sensitivity by a factor of two. The point of counterproductive return is described as follows:

a. Adding three stages of TDI to a single detector doubles sensitivity.

b. The next doubling requires another 12 rows (total of 16).

c. The next doubling requires adding 48 new TDI sample rows (total of 64 rows).

The consensus among the manufacturers of the two-dimensional FLIR focal-plane detector arrays is that 16 to 25 rows (total) dedicated to TDI implementation are the maximum practical. This gives a four to five times sensitivity improvement over the single-column FLIR detector array currently implemented in the common-module-based FLIR's. Note: larger two-dimensional arrays (referred to as staring arrays) are in development, but are not considered pertinent to ISAS needs nor available within the prescribed TAD.

Based on these industry data, a FLIR having the following parameters was specified within the ALSPM model:

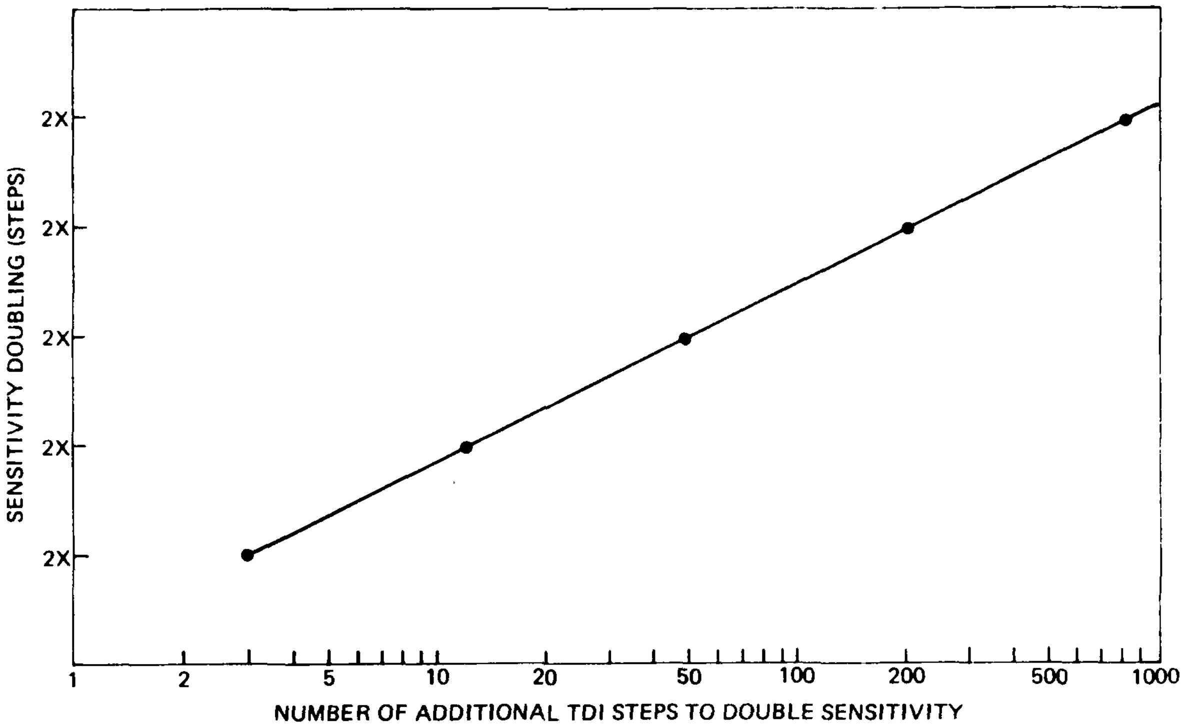


Figure 5.2-15. Time Delay Integration Gains

a. Resolution (instantaneous field of view) = 0.05 to 0.1 mrad

b. Thermal sensitivity: NE delta T = 0.1°C

c. Optical aperture: A study variable ranging between 4 in (10.16 cm) and 8 in (20.32 cm) in diameter

d. All scan parameters and dynamics as in classical 30-frame per second systems

All display parameters and man-display interaction effects are normalized, eliminated, or made transparent by using a 1.0 transfer function as appropriate for each step in the evaluation model. The atmospheric variables chosen are specified as discussed in Section 5.2.1. The Night Vision Laboratories (NVL) evaluation made for thermal sensitivity is specified with a system modulation-transfer function (MTF) that is compatible with the spatial resolution cited earlier. The resultant tank target detection and target classification/identification range parameters are shown in Figures 5.2-16 and 5.2-17, respectively.

The aperture variables cited were examined to determine the reasonable match between sensor operation range and aperture size. Atmospheric degradations combined with terrain line-of-sight limitations support the aperture choice of a 6-in diameter for ISAS. The larger (8-in) concept is an overkill for the system.

A final caveat on FLIR performance evaluation is suggested. Earlier discussion of atmospheric phenomena illustrates the great degree of variability of the atmosphere, especially as it influences infrared transmission. Data on relative concept performance should be recognized as being relative and containing a wide variance band. These data are not absolutes.

5.2.5 Silicon-Based Television Systems (SiTV)

Performance of contemporary television systems is highly constrained by the man-display requirements. ISAS systems augmented by automatic target classification/recognition elements allow consideration of video concepts currently outside the usual TV domain. Specifically, an SiTV system optimized for a frame-grabber to route a specific scene frame for analysis appears as a most likely concept. Optional display in a usual video (TV) mode must be considered because SiTV or intensified SiTV image data are processed and displayed synergistically with FLIR and/or any other sensor data.

The SiTV sensor may be implemented with a ruggedized vidicon tube or with a two-dimensional, silicon-based, charge-coupled device or charge-injection device (CCD/CID) fabricated by methods similar to those used for infrared focal-plane arrays.

Regardless of the type of physical structure, the SiTV performance obeys the basic laws of photon physics, whereby—

a. High-photon-flux-level performance (daylight) is limited by bandwidth and other factors.

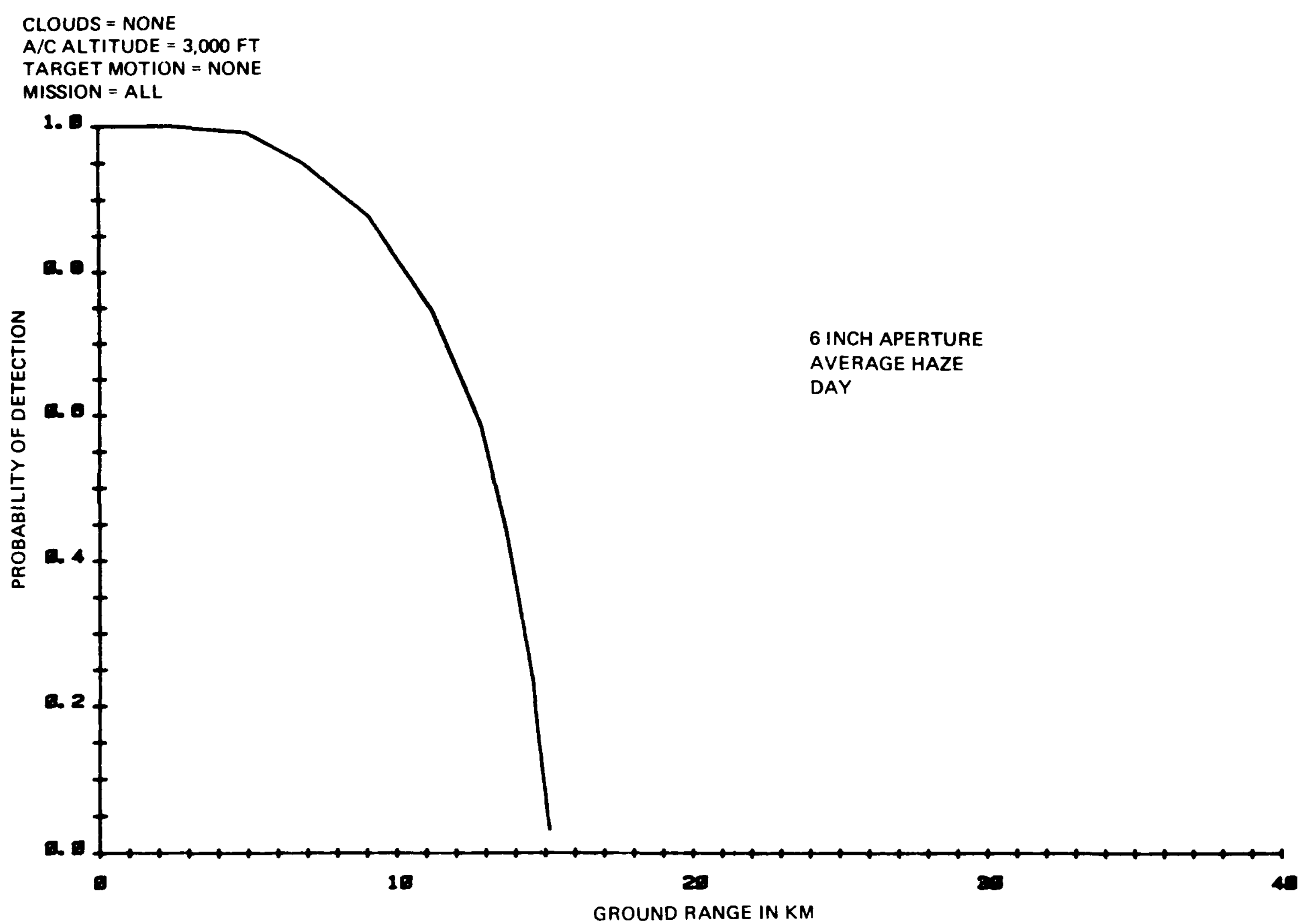


Figure 5.2-16. FLIR Performance - Detection

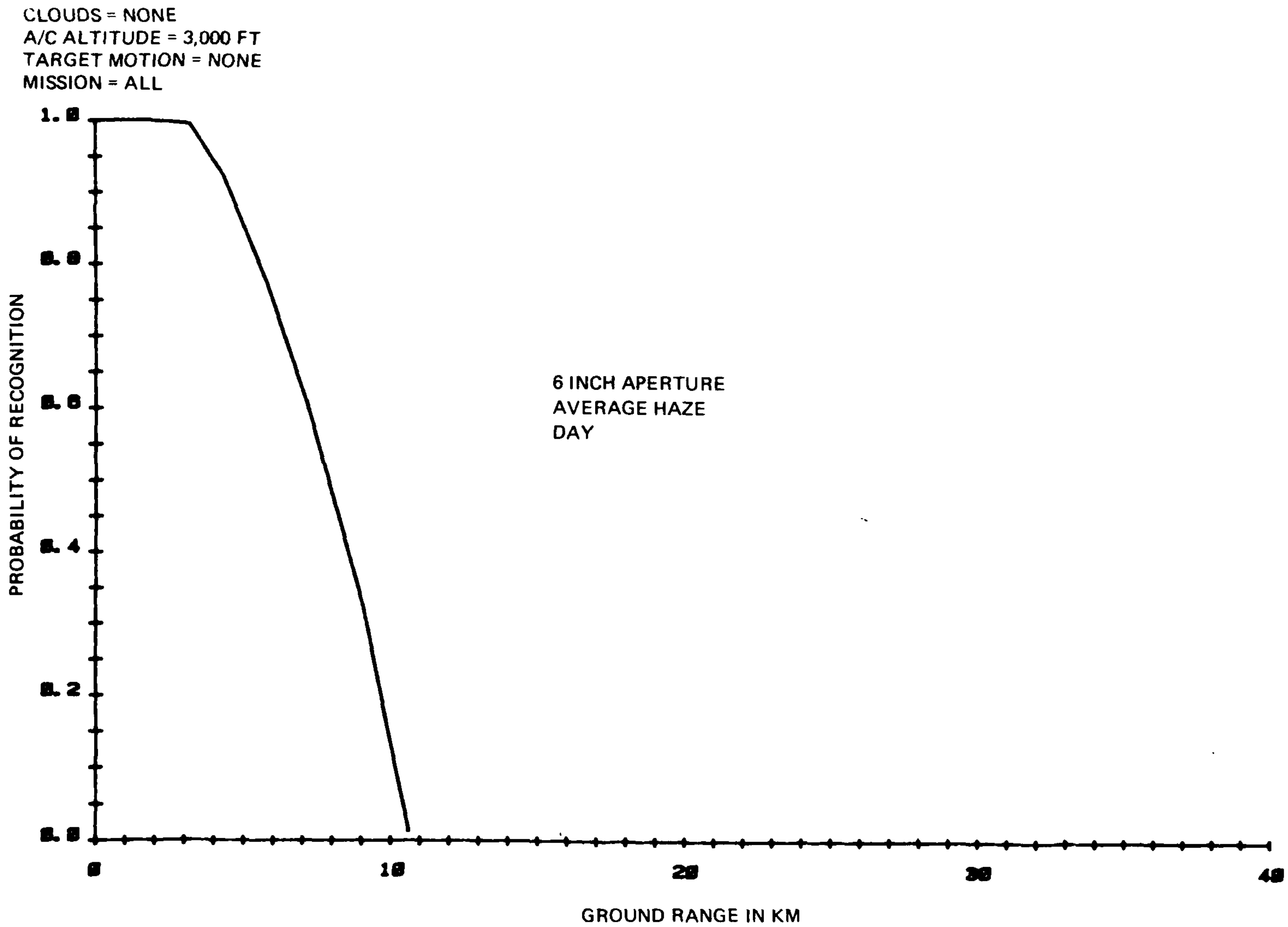


Figure 5.2-17. FLIR Performance - Recognition

b. Extreme by low-photon-flux-level performance (starlight) is limited by photon statistics and intrinsic detector noise.

c. Midrange performance (dusk, predawn, partial moonlight situations) is limited by both low- and high-photon-flux-level phenomena.

The concept of using TDI to enhance system sensitivity was initially demonstrated with SiTV focal-plane sensor arrays. Up to 100 stages of TDI (a gain of 10), with photon-limited performance, have been demonstrated. Figure 5.2-18 illustrates the response of SiTV-class systems. The performance trade is obvious: operation at low-photon-flux-levels, low-light-level TV (LLLTV) is accomplished only at the expense of resolution. Use of pre-focal-plane photon amplifiers (image intensifiers) makes isolated electronics problems easier only. Both the signal and the noise are amplified. This is not all bad, however. For some applications, such as detection and classification of ships at sea, the loss of spatial resolution at extremely low photon-flux levels (overcast starlight) still allows ship outline discrimination, a useful classification feature. Similarly, joint use of intensified video (LLLTV or LLLSiTV) with FLIR has demonstrated low-level-flight utility of both sensors. Thermal washout occurring in the few minutes after an intense rain squall can cause temporary FLIR degradation until thin water surface films drain off of objects and/or warm to the temperature of the material below. During this momentary phenomenon the intensified SiTV or classical LLLTV presents the necessary terrain imagery required for flight orientation and prevents loss of terrain content. The lower spatial resolution of the SiTV is offset by the benefits of flight control safety.

For the purposes of ISAS system analysis, an SiTV sensor is assumed to have the following characteristics:

a. Performance limitations equal to the theoretical limits documented for silicon devices

b. System bandwidth limits midway between those for TV systems of 525 and 875 lines

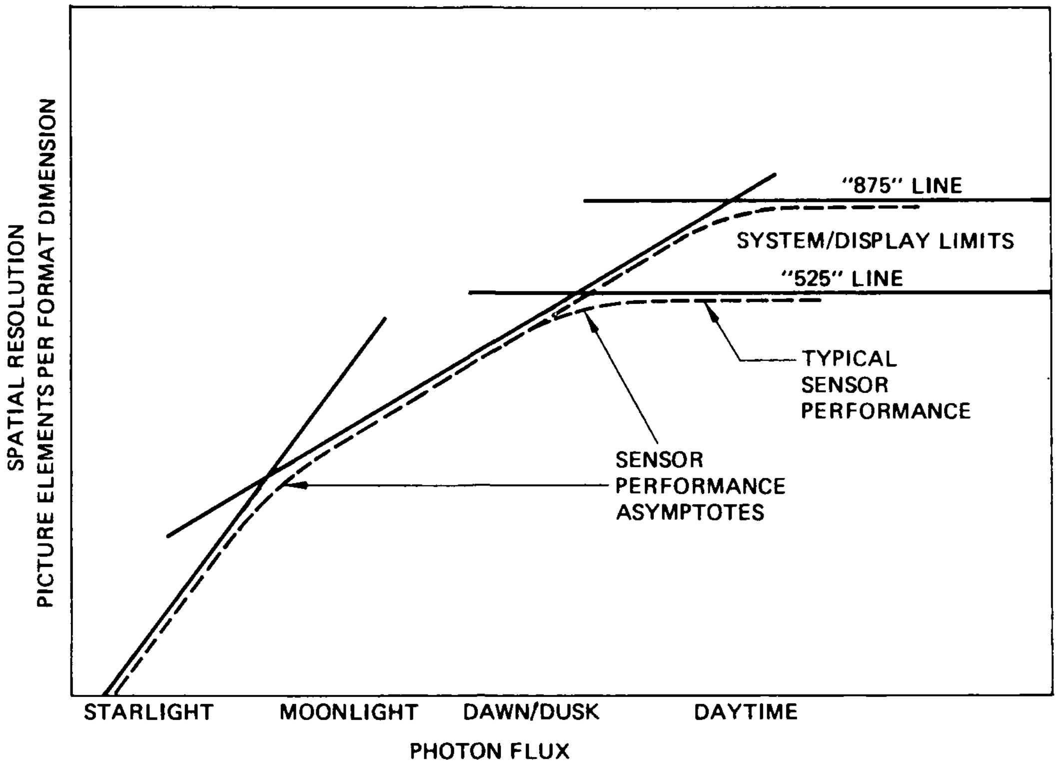


Figure 5.2-18. Physics of Response for SiTV Sensors

As with the FLIR system, aperture diameters are varied from 4 to 8 in. Terrain line-of-sight statistics, as with FLIR, become such a dominant factor that use of large apertures for better atmospheric penetration is not warranted. Because a common-aperture system concept is proposed (all EO sensors share the common, stabilized primary aperture), the 6-in diameter, as paced by the FLIR system, is preserved. Analysis of SiTV shows nonconflicting results with this aperture choice.

The TV system subsection of the ALSPM model used for FLIR analysis did not allow full freedom to incorporate the SiTV refinements discussed. However, because the performance assumed for SiTV matches the theoretical performance model for extended actinic, EO imaging systems, a computer evaluation developed by General Electric Aerospace Electronic Systems, Utica, New York, was implemented. The results of these evaluations are shown in Figures 5.2-19 and 5.2-20.

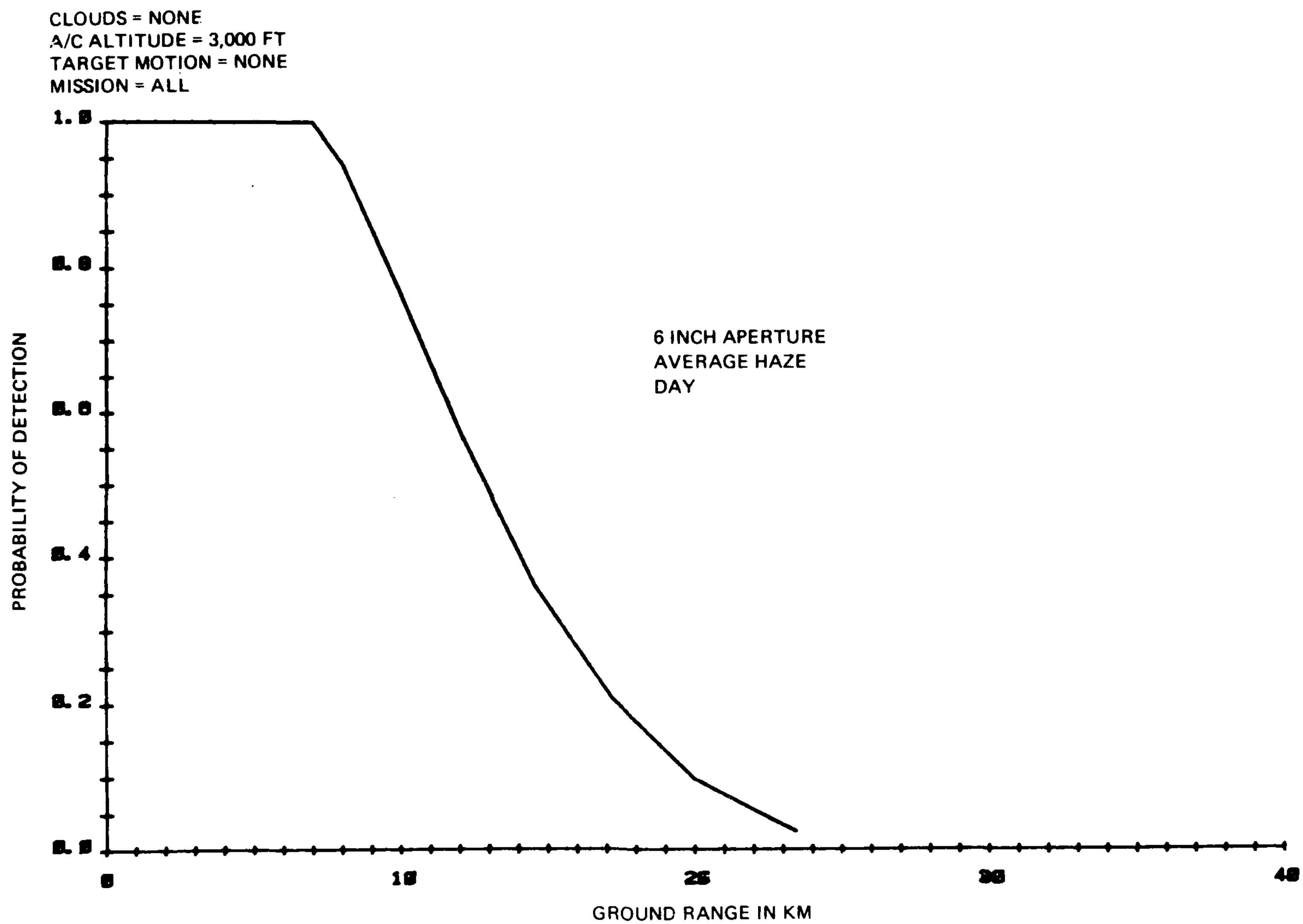


Figure 5.2-19. Silicon TV Performance - Detection

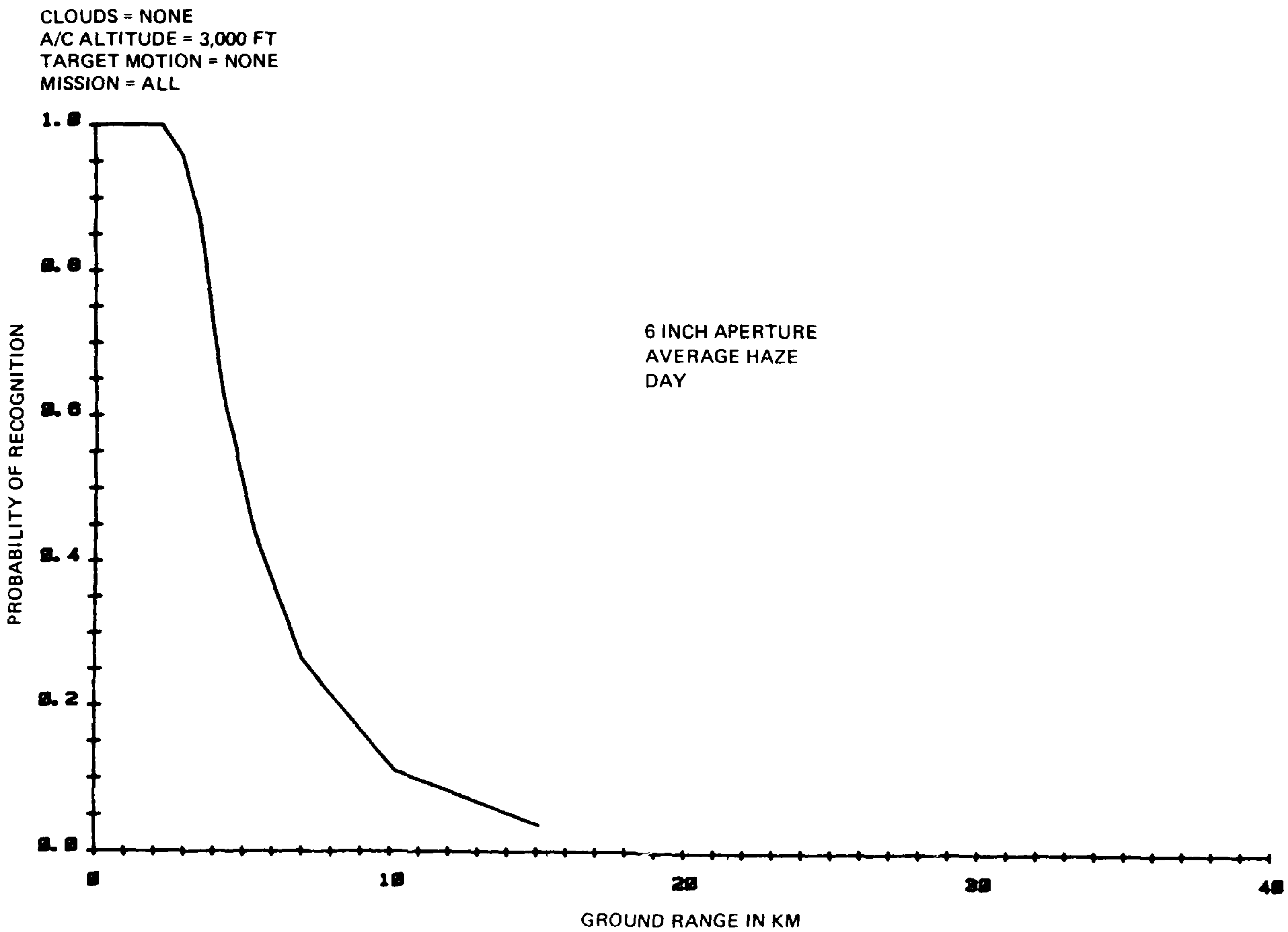


Figure 5.2-20. Silicon TV Performance - Recognition

5.2.6 Three-Dimensional Target Classification

The potential of classifying military vehicles on the basis of three-dimensional shape alone has been demonstrated with a USAF/AFWAL (RWI) flying prototype system. This system (3D-TC) precisely measures the shape of the external surface or shell of the vehicle. The goal of this concept is to classify a vehicle on the basis of shape measurements and a comparison of these measurements with a catalog of prestored shape templates of different targets. In the simplest form, a 3D-TC could be initialized for one specific target class. Increasing the supporting microprocessor capability increases capability and sophistication in multiple-target classification or threat recognition.

For purposes of this contract, we have merged results of research and analysis from the following sources:

a. Perkin-Elmer Corporation: Three-dimensional target classification scanner using GaAs pulsed laser

b. ERIM: Three-dimensional target-classification data-processing algorithm (CYTO computer algorithm)

c. Lincoln Laboratories: CO_2 laser concepts being demonstrated within the Infrared Airborne Radar (IRAR) program

d. ERIM: Pulsed CO_2 laser scanner program

e. Proprietary dedicated data processing VHSIC concepts in development for 3D-TC type applications

f. USAF, Perkin-Elmer, General Dynamics shallow depression angle 3D-TC concept flight testing

g. Inclusion of the IRAR CO_2 laser concept may provide an optional target-classification mode currently under investigation at Lincoln Laboratories. This mode uses synthetic-aperture-radar (SAR) data-processing concepts to detect vehicle signatures from processed Doppler signal return. The primary 3D-TC mode is the shape-only classification. The Doppler signature mode may be a future candidate for ISAS system upgrading.

Target Sampling. The statistics of probability of recognition and classification as a function or target sampling granularity are still being investigated. Preliminary data furnished by USAF suggests four profiling samples along the target minimum dimension. Later discussions indicate that the imaging system Johnson criterion of 8.4 scan samples per minimum object dimension may also apply to the 3D-TC. Thus, for the ISAS analysis, 4, 6, and 8.4 scan samples are considered. The standard main battle tank model used for all analysis is 3.6m by 9.9m by 2.3m high. The 2.3m (7.5-ft) height is therefore sampled 4, 6, or 8.4 times with a CO_2 laser beam no broader than 0.29m at the vehicle location. Lincoln Laboratories reports an operating pulsed CO_2 laser with the following parameters:

a. Aperture size: 133 cm^2 (13-cm diameter)

b. Beam divergence: 83 rad

c. Power required at 3-dB/km attenuation: 1W on 3-km test range

Lincoln Laboratores also forecasts—

a. Qualified airborne CO_2 lasers with 10W to 20W by ISAS TAD

b. The probability of recognition/classification will conform to the Johnson-Ratches definition:

$$P_{R/C} = 1 - \exp^{-(N/NO)^2}$$

where NO is the factor (4, 6, or 8.4 used) and N is the CO_2 laser spot beamwidth at the target location.

The predicted performance of the 3D-TC system incorporating the CO_2 laser is shown in figure 5.2-21. There are three levels of performance (8.4, 6, and 4 lines across the target). The six-line case was used in the system performance summary.

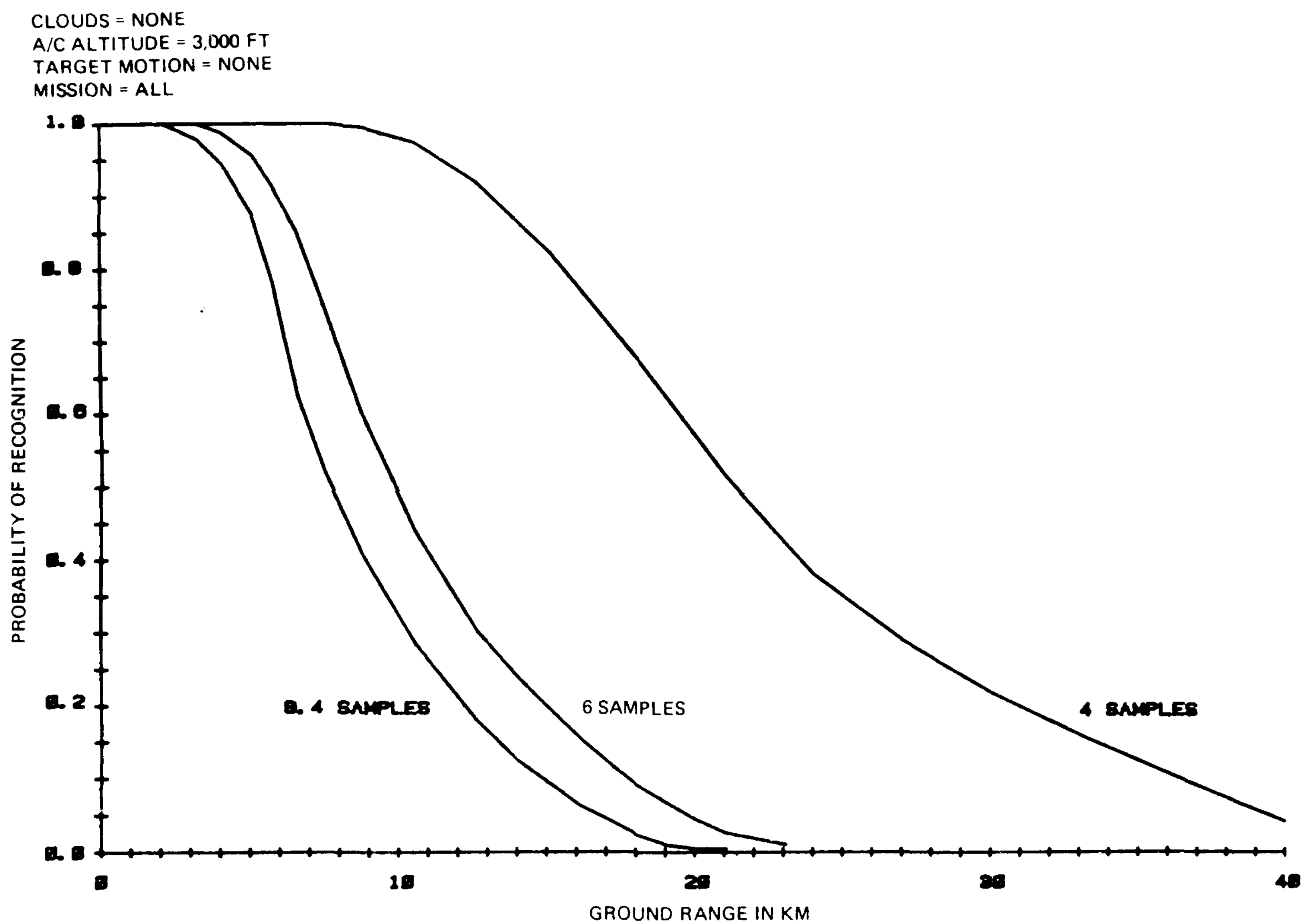


Figure 5.2-21. CO_2 Laser 3-D Classifier Performance

5.2.7 Summary of EO

The results of ranking and comparing system performance for various candidate EO concepts is strongly dependent on the time of day and momentary atmospheric conditions in the target environment. The choice of midday, midlatitude, rural, and maritime haze atmosphere allows an unbiased, multisensor competition. Specific conditions can immediately skew the results to favor or exclude a particular system. An ISAS-class of target-acquisition and target-classification sensors will be subjected to a wide variety of atmospheric, seasonal, weather, and terrain conditions. Therefore, maximum synergism between the various EO sensor concepts is mandatory.

The cost-of-acquisition and producibility trends in the EO industry today are such that exclusionary decisions between concepts based on cost and technology availability are becoming less dominant than several years ago. Based on this favorable situation, we see a firm trend (LANTIRN, TADS/PNVS, PAVETACK) to mix diverse EO sensors and wavelengths and operate in the multispectral domain to the benefit of the ISAS-class of system.

5.3 INTEGRATED SENSORS—DETECTION AND RECOGNITION

The individual sensor performance characteristics plotted in Figures 5.3-1 through 5.3-6 were derived during the performance analysis of the ISAS sensors (ISAS task II). The sensor combinations featured in these figures are those that are assigned to concept I (Figs. 5.3-1 and 5.3-2), concept II (Figs. 5.3-3 and 5.3-4), and concept III (Figs. 5.3-5 and 5.3-6).

Concept I has one each of every target-acquisition sensor deemed feasible for a tactical fire-control system: two EO detection sensors (TV and FLIR) and three radars (K_u-band synthetic aperture; long-wave foliage-penetration radar (LWR); and non-coherent millimetre-wavelength radar (MM). Because of similarity, only Figures 5.3-1 and 5.3-2 are fully discussed here. In addition to individual sensor performance data, the sensor performances have been combined to show combined-sensor performance limits. Sensors performance characteristics are plotted for weather conditions in which they are usable.

Curve 1 in Figure 5.3-1 illustrates the best overall target-detection performance: the probability that at least one sensor will detect the target ($P_1 = 1 - (1 - P_A)(1 - P_B) \ldots (1 - P_N) \ldots$) where P_A, P_B, etc., are detection probabilities of individual sensors. As the various sensors reach their range limits, the probability P_1 decreases and becomes equal to the detection probability of the sole remaining sensor.

In Figure 5.3-1, curve 2 illustrates the probability that all sensors will detect the target ($P_2 = P_A \times P_B \times P_C \ldots \times P_N$). The probability P_2 is limited by the detection probability of the the poorest sensor and emphasizes the necessity of using weighting factors in sensor voting to avoid deleterious effects of equal votes but significantly unequal performance.

In Figure 5.3-2, sensor target-recognition data are plotted in a manner similar to Figure 5.3-1. An obvious technical deficiency is the lack of all-weather target-classification and target-recognition capability. All work, surveyed in this study, leading to automatic recognition of radar targets is in the basic-research category.

Figures 5.3-3 and 5.3-4 summarize individual sensor detection and recognition capabilities of the ISAS concept II sensors. The combined-sensor detection capability

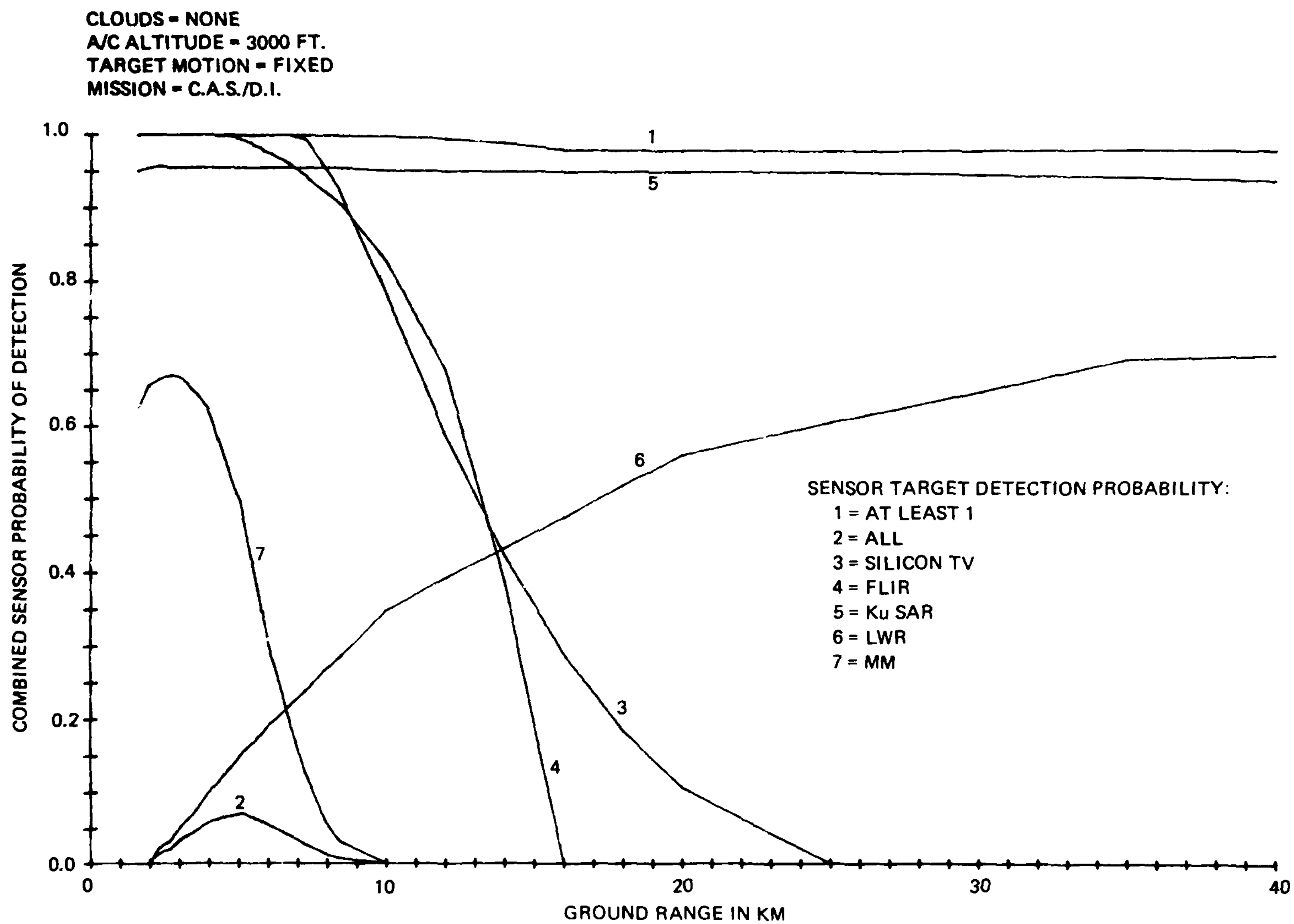


Figure 5.3-1. Concept I - Combined Sensor Detection

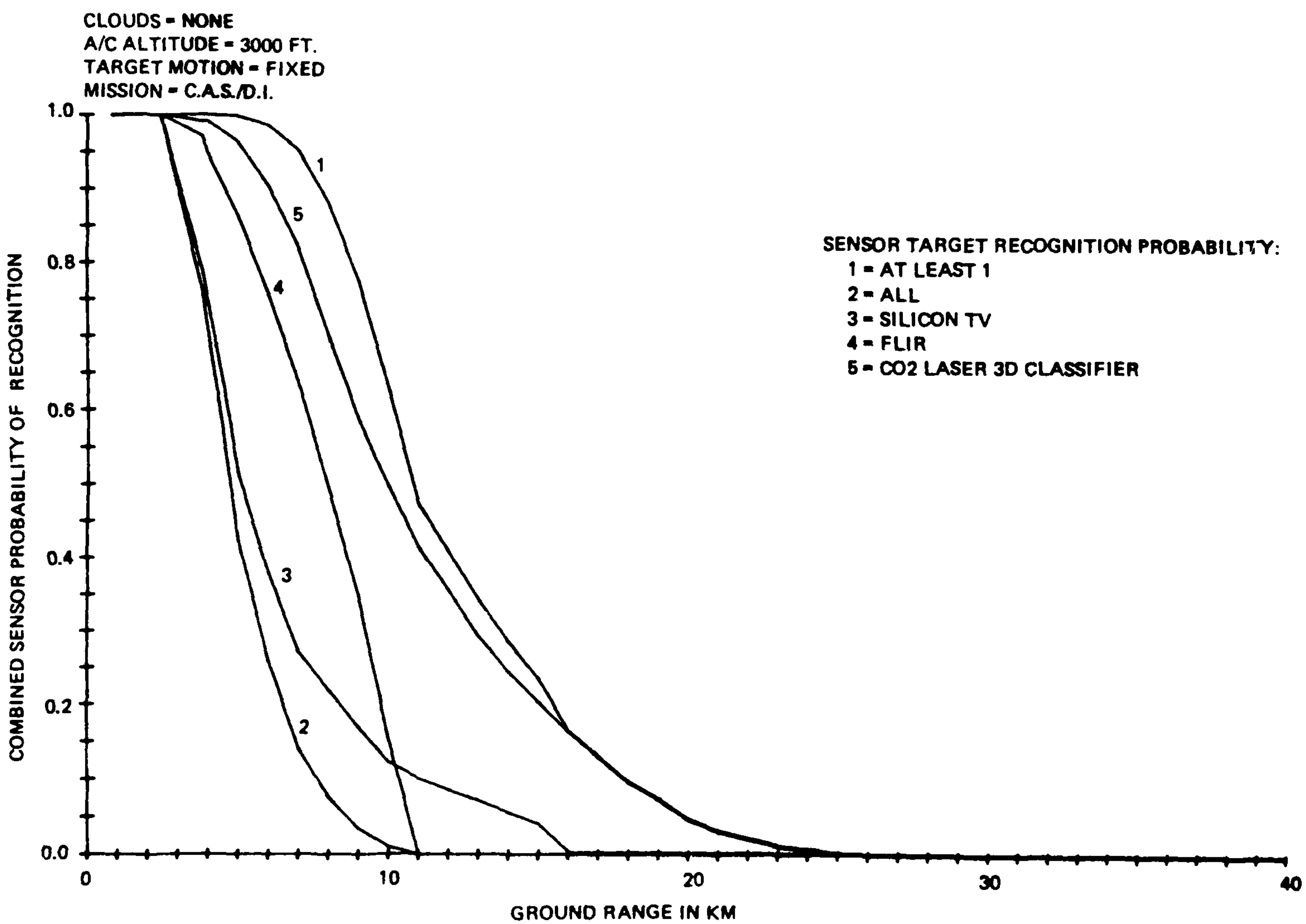


Figure 5.3-2. Concept I - Combined Sensor Recognition

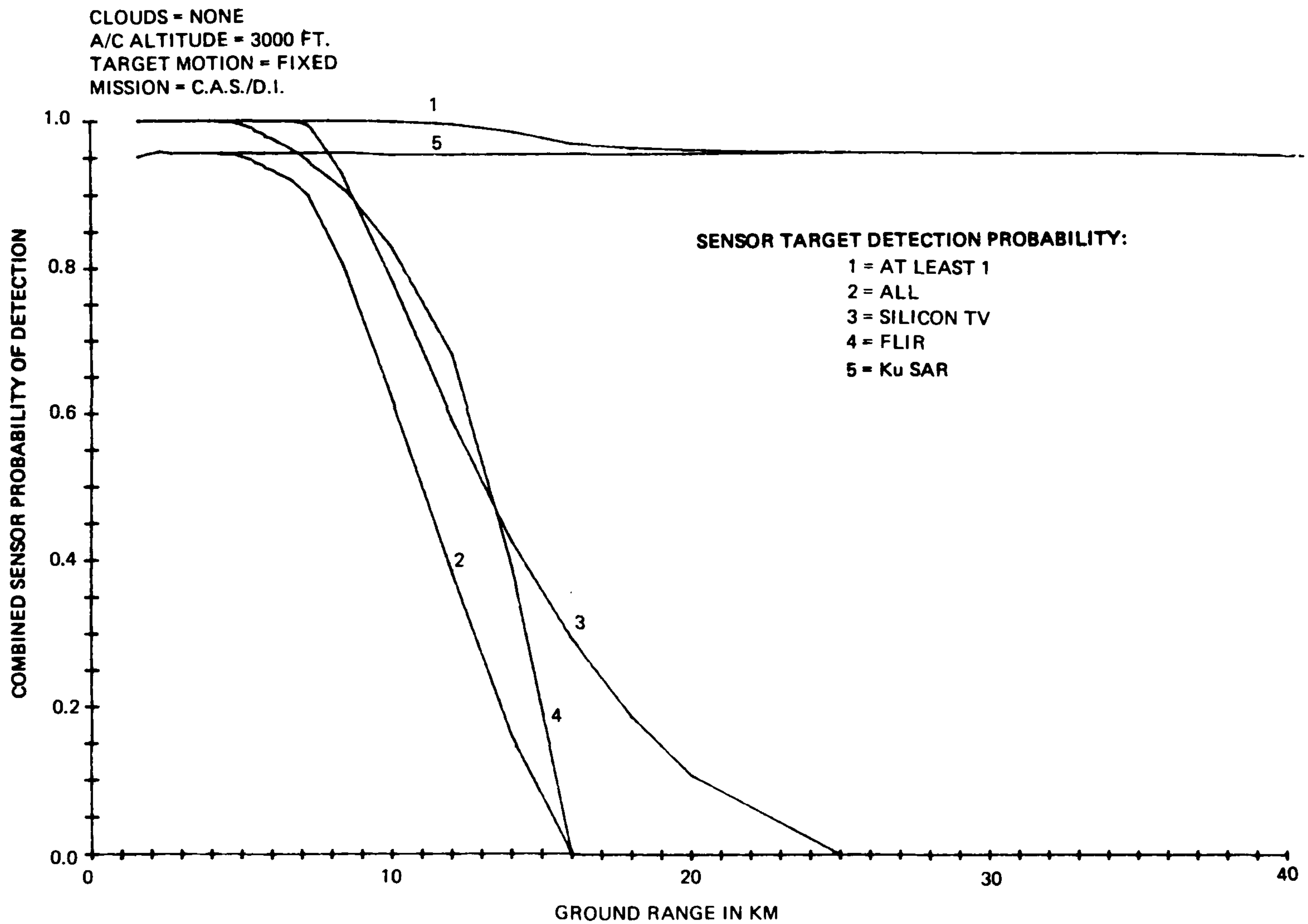


Figure 5.3-3. Concept II - Combined Sensor Detection

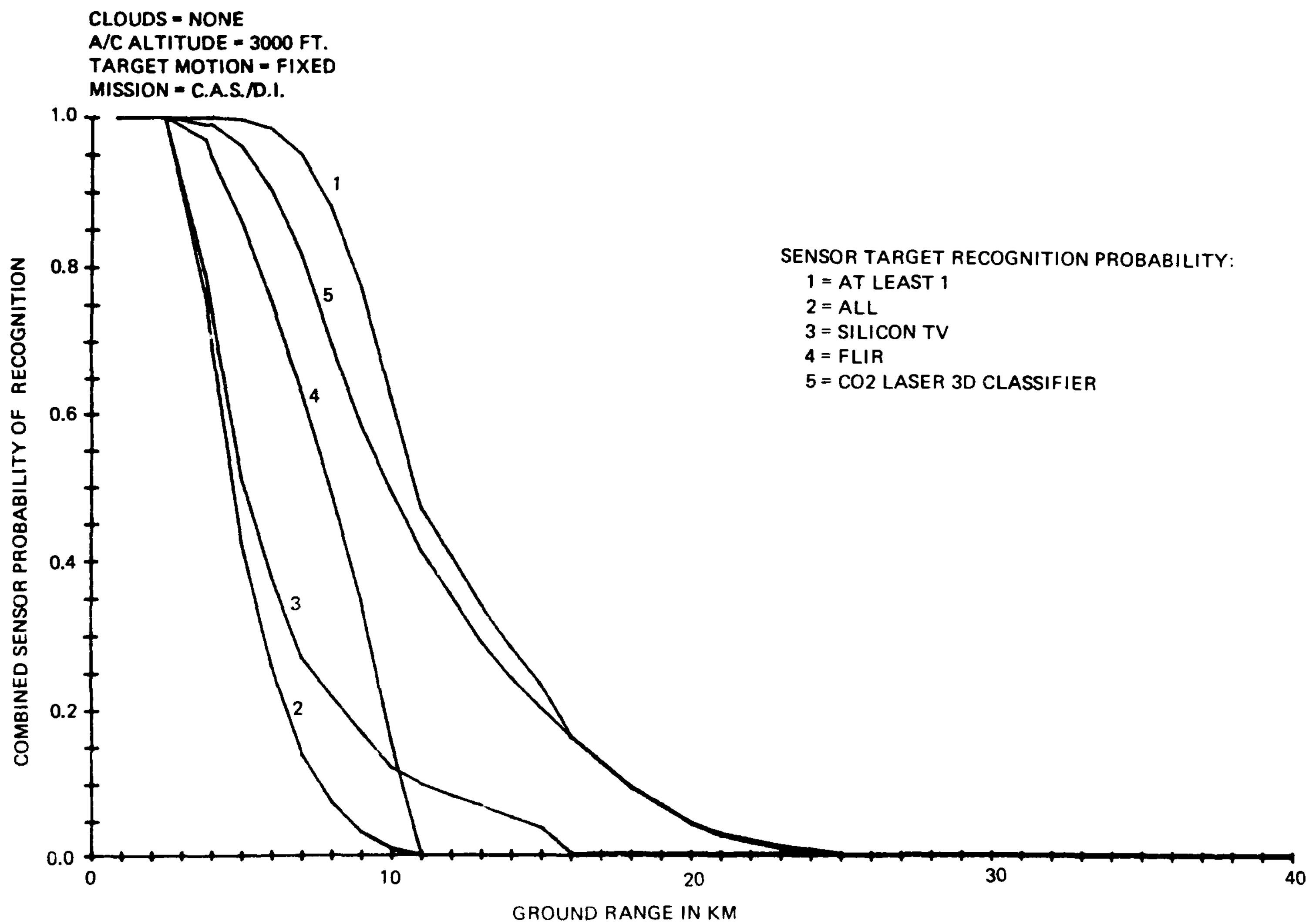


Figure 5.3-4. Concept II - Combined Sensor Recognition

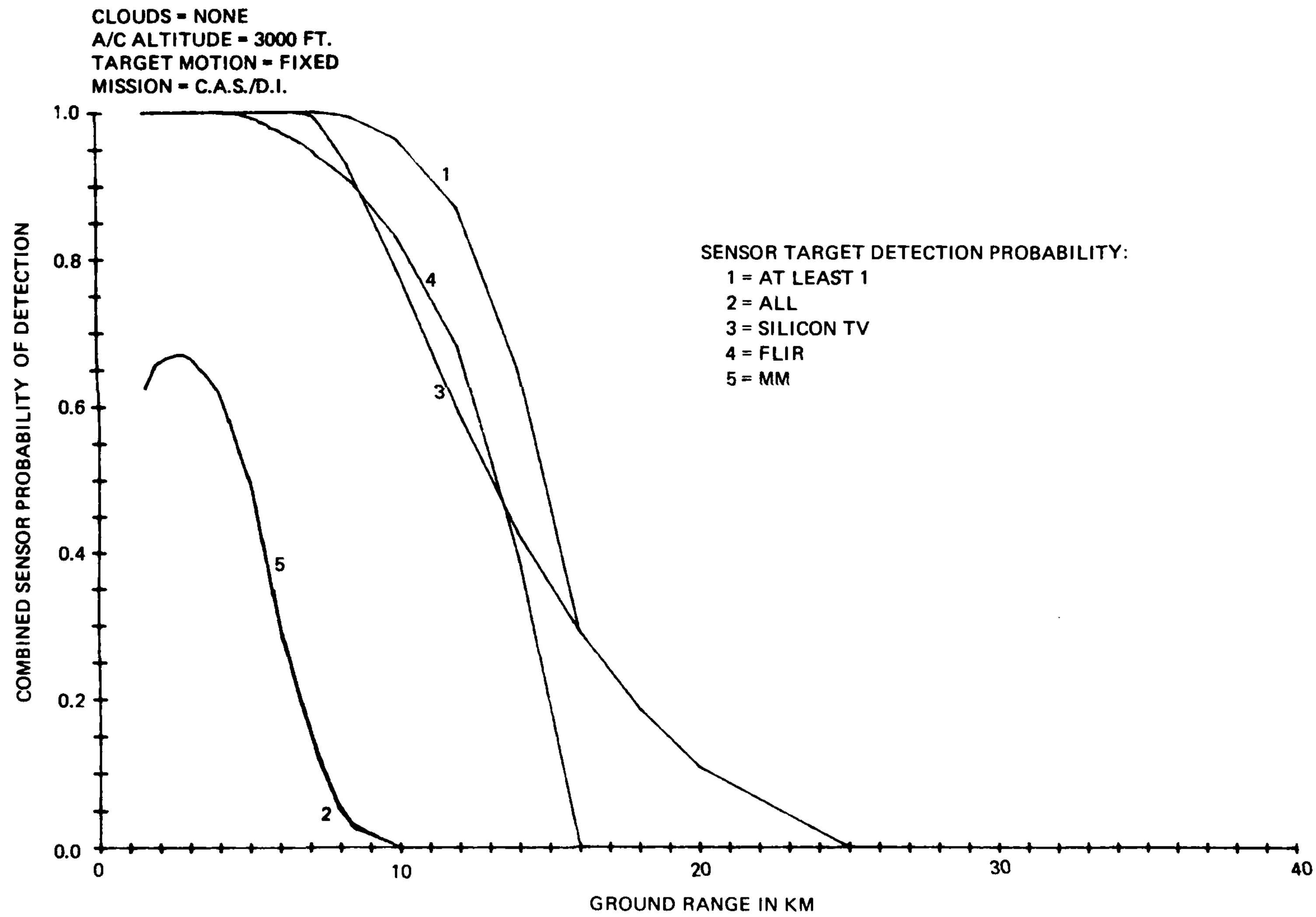


Figure 5.3-5. Concept III - Combined Sensor Detection

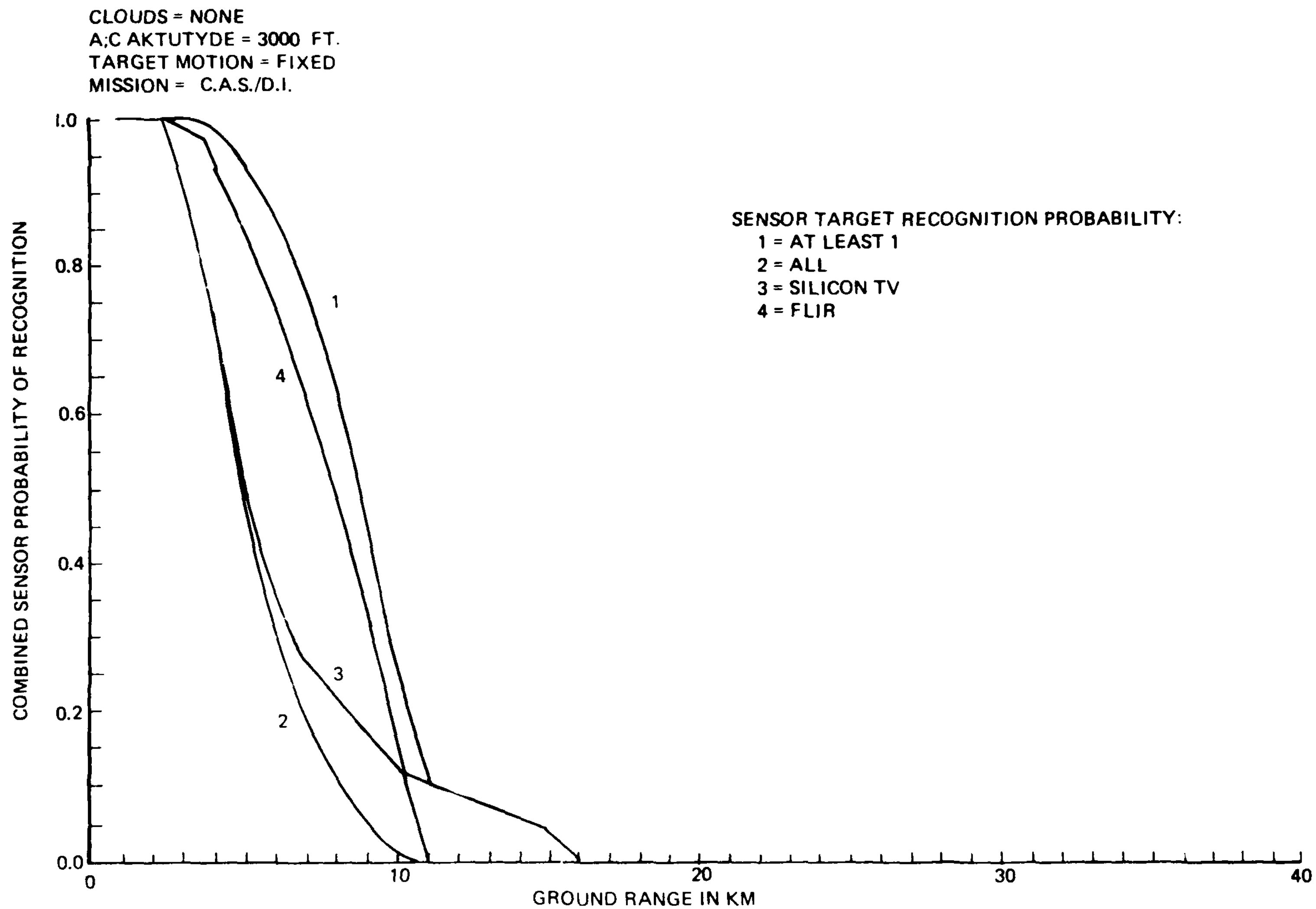


Figure 5.3-6. Concept III - Combined Sensor Recognition

closely resembles that of concept I. Little, if any, detection capability is lost by not using the long-wave radar and/or the millimetre-wavelength radar. Target recognition capabilities of the two systems are identical.

Concept III, as shown in Figure 5.3-5, has less fixed-target-detection capability than either concepts I or II because of the limited range of the millimetre-wavelength radar. Target-recognition capability of concept III is the same as concept I and II capabilities.

Conclusions. Conclusions reached during the evaluation of ISAS concepts are summarized below. These conclusions are based on the system performance data furnished by sensor suppliers and apply to the conditions of the Boeing analysis.

a. Best target-detection sensor is the Ku-band radar in ground moving target indicator (GMTI) mode. However, this sensor could only recognize that targets were moving. Its recognition capability is, therefore, limited by the percentage of all moving targets that are tanks.

b. The TV sensor has better daytime target-detection range capabilities than FLIR for the weather conditions of this study, however, the FLIR has better target-recognition range capabilities than the TV especially at night.

c. The 3D classifier has the best overall target-recognition capability in clear weather.

d. Best Ku-band radar target-detection modes are GMTI and SAR.

e. The millimetre-wavelength radar and long-wave radar (as defined in this study) target-detection capabilities are not adequate for ISAS. These sensors should be reinvestigated when better performance can be defined.

5.4 CREW WORKLOAD ANALYSIS

This section describes the analysis performed to evaluate the selected ISAS fire control concepts from a crew workload standpoint. The results of the evaluation shown in concept II, the fully automatic system has the lightest crew workload, followed by concept I and then concept III.

5.4.1 Scenario

A typical battlefield or deep interdiction mission profile is shown in Figure 5.4-1 with its mission phases. The strike aircraft takeoff from an airbase behind the forward edge of battle area (FEBA), climbs to altitude, loiters or cruises out, and descends to the penetration altitude for a run-in to target at very low altitude (TF/TA). Prior to arrival at the target, a popup is initiated for target acquisition at a predetermined location. The strike aircraft either remains at the popup altitude for weapon delivery or returns to low altitude for weapon delivery and damage assessment (if required). Upon completion, the strike aircraft returns to base at low altitude.

Figure 5.4-2 shows a typical variation, in this case a popup at standoff and minimum time exposure ranges. The target acquisition range (hence the popup distance from target) will depend on the sensors available for acquisition (avionics suite configuration or concept) and mission conditions (weather, altitude, speed, line-of-sight probability, weapon delivery parameters, etc.). These factors will influence the standoff range and, therefore, the survivability of the strike aircraft as a function of popup exposure time and weapon launch range from target defenses.

An analysis of the battlefield, deep interdiction, and close air support missions shows that except for the differences in time for the various mission phases the missions are essentially the same from a crew workload standpoint. The critical mission phases for crew workload are the last portion of target run-in, popup, target acquisition, and weapon delivery. Therefore, in the analysis of crew workload and critical mission phases, the battlefield and deep interdiction missions are considered the same. The close air support mission was not evaluated in the analysis. This decision was based on the ground rule that all avionic concepts would be evaluated autonomously. The close air support mission requires positive identification, which in this case would be visual identification. Without the cooperative forward air control (FAC), laser designator,

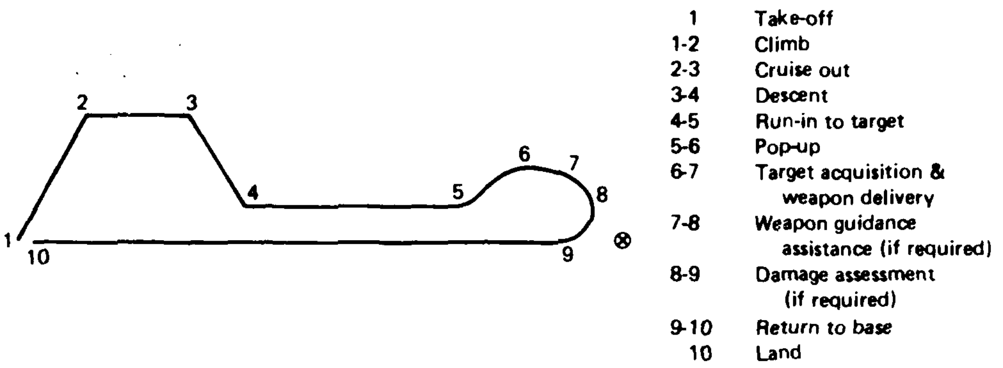


Figure 5.4-1. Interdiction Mission Phases

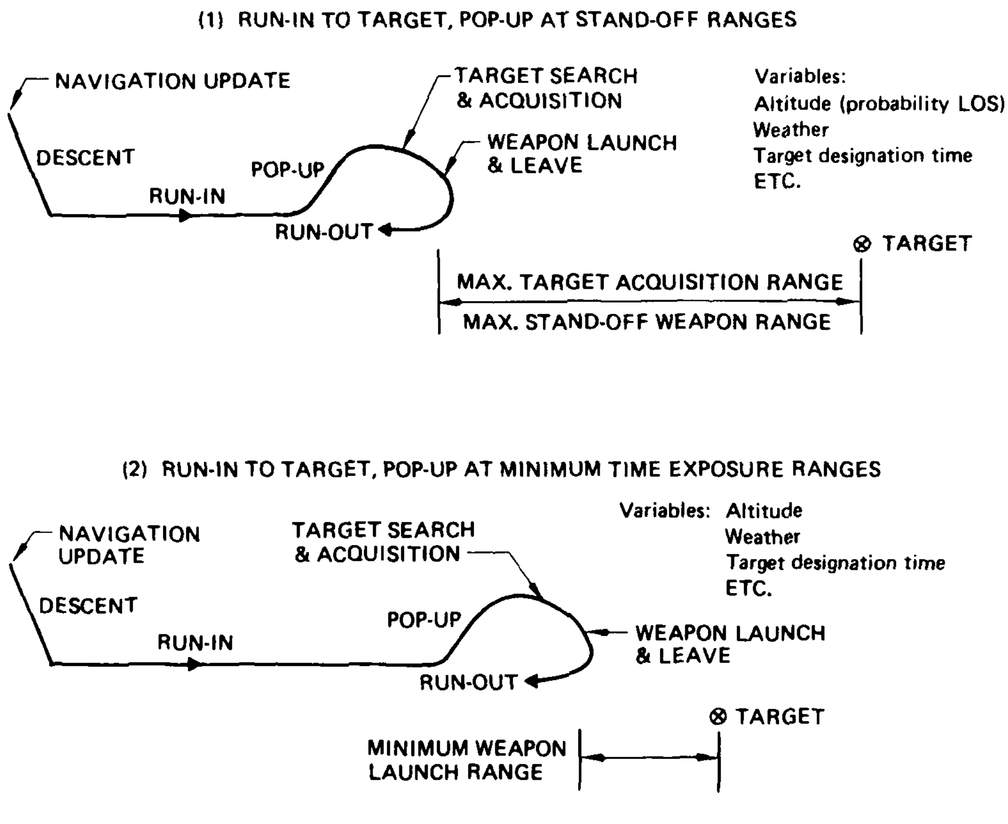


Figure 5.4-2. Typical Interdiction Run-In to Target

etc., close air support is considered the same as battlefield or deep interdiction. Analysis then was based on the critical mission phases stated above and a popup-popdown or 3,000-ft-level flight mission scenario.

5.4.2 Crew Workload Evaluation

Evaluation of the crew workload for each avionic concept was subjective, using the scenarios and variables discussed above; detailed crew functional task allocations; and weapon, aircraft, and crew interface definitions. These data, in combination with mission timelines, were used as a basis to subjectively estimate crew workload by mission phase for each avionic concept, its scenario, and variables. Results of these estimations were the construction of subjective crew task percentage matrices (a measure of workload) for each avionic concept and dependent variables. These matrix values for critical mission phases were then weighed for a value to be applied for ranking of the avionic concepts.

5.4.2.1 Evaluation Approach

Evaluation of the crew workload required some restrictions (to keep the study within limits) and some assumptions. For the purposes of this evaluation, workload is defined as the extent to which an operator is occupied by a task relative to the time available for accomplishing the task. In determining the subjective workload estimates, no degraded-mode operations were considered. Also, no stress factors were taken into account to degrade performance, and a standard crew skill level was assumed regardless of configurations. The survivability of one concept or case over another was not taken into account when estimating crew workload.

The evaluation approach to estimating workload was to consider the crew workload in two parts. The basic part was the crew workload associated with flying the aircraft, maintaining communications, navigating, and self-defense; in other words, all tasks that did not relate directly to management of the sensor suites, weapon delivery, or the target acquisition. Evaluation of this workload considered all mission phases from takeoff to landing. The same phases were used for all concepts, but varied with mission speed and attack altitude. The workload of the target acquisition functions, however, is directly influenced by the various avionic concepts, and therefore was evaluated by avionic concept. The workload associated with weapon delivery varies with weapon type and was influenced by the different avionic concepts when integrated with the fire control system. Strike aircraft, speed, and altitude influenced the basic crew workload only. The time to accomplish target acquisition and weapon delivery is not a factor of aircraft speed, but of operator skill, performance, and/or system characteristics such as processing time or time to display.

5.4.2.2 Subjective Task Estimates

Table 5.4-1, adapted from Reference 1 (Crew Workload Tactical Strike—Crew Workload Study, Boeing Document D180-26048-1) provides an estimate of the non-fire-control crew task loading. Based on the mission sequences shown in Figures 5.4-1 and 5.4-2, the figures show the percentage of crewman attention required to control the aircraft, monitor aircraft systems, and carry on normal communication, navigation, self-defense, and related mission activities. Mission phases 4 through 8 are emphasized because these data will be used in estimating total crewman task loading by summing them with fire control task percentages.

To understand the workload associated with the weapon types, three different elements were investigated: weapon interface, controls and displays, and automation. Tables 5.4-2 through 5.4-4, show the interface between weapon, aircraft, and crew for each avionic concept. It can be seen that armament functions are essentially independent of fire control concepts. Target acquisition functions, however, are heavily affected by the avionic concepts.

Table 5.4-5, also from Reference 2, lists each basic function (conventional mode) to deliver the MK-82S, the controls and displays required, and the event location by mission phase. Figure 4-3 in the classified supplement to this report similarly describes Maverick missile information and is included as a part of confidential section 4.0 of this report.

To evaluate effects of the three fire control concepts on the target acquisition crew tasks in combination with the weapon delivery task, the information given in Figures 5.4-3 through 5.4-5 and Table 5.4-5 were adapted from Reference 2. Crew functional tasks were identified with levels of automation and integration as defined by each avionic concept. The symbols are defined below.

Table 5.4-1. Estimated Basic Crew Task Percentages

Mission Phase	Description	Pop-Up From 200' to 3000' 553Kt	Pop-Up From 200' to 3000' 350Kt	Level 3000 Ft 553Kt	Level 3000 Ft 200Kt
1	Take Off	78	78	78	78
1-2	Climb	53	53	53	53
2-3	Cruise Out	46	46	46	46
3-4	Descent	45	45	45	45
4-5	Run-In to Target	65	59	65	59
5-6	Pop-Up/Down	80	80	60	52
6-7	Target Acquisition	50	42	40	35
7-8	Weapon Delivery	75	55	60	53
8-9	Damage Assessment	55	55	50	55
9-10	Withdraw Exit	65	65	65	65
10	Land	78	78	78	78

Table 5.4-2. Weapon/Aircraft/Crew Interface Concept I

WEAPON	BASIC CREW FUNCTION	AIRCRAFT EQUIPMENT	CREW/WEAPON INTERFACE
MK82S	o Select Weapon o Arm Weapon(s)/Select Parameters as Required o Monitor Automatic Target Search and Initiate New Target Types as required o Monitor Display For False vs Real Targets and Vote as Required o Initiate/Monitor Weapon Delivery	o Automatic Fire Control System (CCIP) o Automatic Target Acquisition System (Radar, Caties, and Processors) o Integrated Flight Control Fire and Weapon Control Systems	o Equipment Controls o Target/Fire Control Displays o Status Displays
AGM-65D (IR Maverick)	o Monitor Weapon System Check-out (Missile Ready) and Arm o Automatic Target Search Initiated by Crew Command of Target Type o Monitor Target Search and Initiate Pop-up if Required o Monitor Display for Target ID for False vs Real Targets o Verify Seeker Lockon and Tracking, Initiate Launch o Monitor Launch Sequence (Automatic Fire and Flight Control)	o Automatic Fire Control System o Automatic Target Acquisition System (Caties & Processors) o Integrated Flight Control Weapons System o Launch & Stores Control	o Equipment Controls o Stores Management System o Target/Fire Control Displays o Status Display

Table 5.4-3. *Weapon/Aircraft/Crew Interface Concept II*

WEAPON	BASIC CREW FUNCTION	AIRCRAFT EQUIPMENT	CREW/WEAPON INTERFACE
MK82S	o Arm Weapons/Select Parameters as Required o Automatic Target Search Initiated by Crew Command of Target Type o Monitor Target Search and Initiate Pop-up if Required o Monitor Display for Target ID for False vs Real Targets o Initiate Manual Targeting if Required o Monitor Weapon Delivery (Initiated by Crew)	o Automatic Fire Control System (CCIP) o Automatic Target Acquisition System (Radars, Caties, and Processors) o Integrated Flight Control Fire and Weapon Control Systems o Launch and Stores Controls	o Equipment Controls o Target/Fire Control Displays o Status Displays
AGM-65D (IR Maverick)	o Monitor Weapon System Check-out (Missile Ready and Arm) o Automatic Target Search Monitoring o Monitor Display for False vs Real Targets o Verify/Seeker Lockon and Tracking o Initiate/Monitor Launch Sequence (Automatic Fire and Flight Control) o Monitor Launch Sequence (Automatic Fire and Flight Control)	o Automatic Fire Control System o Automatic Target Acquisition System (Caties & Processors) o Integrated Flight Control Weapons System o Launch & Stores Control	o Equipment Controls o Stores Management System o Target/Fire Control Displays o Status Displays

Table 5.4-4. Weapon/Aircraft/Crew Interface Concept III

WEAPON	BASIC CREW FUNCTION	AIRCRAFT EQUIPMENT	CREW/WEAPON INTERFACE
MK82S	o Arm Weapons/Set Parameters o Visual Search/Acquisition Aided by A/C Sensors and Cooperative Systems o Aircraft Control for Launch	o Fire Control (CCIP) o Laser Designator/Ranger/Spot Seeker o HUD o Launch Control o Comm Links	o Equipment Controls o Fire Control Display (on HUD) o Status Displays
AGM-65D (IR Maverick)	o Check-out Weapon Systems & Arm o Visual or Sensor Search/Acquisition (Can be Cooperative Aided) o Aircraft Control for Lockon o Seeker Lockon o A/C Control for Launch	o Fire Control Launch Controls o Caties-Sensors Including Laser Designator/Ranger/Spot Seeker o FLIR Sensor Display o Comm Links	o Equipment Controls o Fire Control Display o FLIR Video Display o Status Displays

Table 5.4-5. Control and Display Requirements for Delivery of Bombs (Conventional Mode)

ACTION OR EVENT	CONTROLS	DISPLAYS	INFORMATION FLOW		ADVISORY OR CONTROL	CONTINUOUS OR DISCRETE	MISSION PHASE
			FROM	TO			
1. Active optical sight or HUD	OFF/ON selection	Optical sight or HUD	Operator	Cockpit	Control	Discrete	2-3
2. Adjust optical sight or HUD display brightness	INCREASE/DECREASE adjustment		Operator	Cockpit	Control	Continuous	2-3
3. Adjust depression angle (backup mode)	RAISE/LOWER adjustment		Operator	Cockpit	Control	Continuous	4-5
4. Supply electrical power to bomb armament station(s)	OFF/ON selection		Operator	Aircraft	Control	Discrete	4-5
5. Select fuzing for arming bombs	NOSE/TAIL/BOTH selection		Operator	Aircraft	Control	Discrete	4-5
6. Selected retarded or free fall mode of weapon fin deployment (if appropriate)	RETARDED/FREE-FALL selection		Operator	Aircraft	Control	Discrete	4-5
7. Select quantity weapons to be released on a single release signal	1/2/3.../N selection (N = quantity of weapons carried)		Operator	Aircraft	Control	Discrete	4-5

Table 5.4-5. Control and Display Requirements for Delivery of Bombs (Conventional Mode) Concluded

ACTION OR EVENT	CONTROLS	DISPLAYS	INFORMATION FLOW		ADVISORY OR CONTROL	CONTINUOUS OR DISCRETE	MISSION PHASE
			FROM	TO			
8. Select time interval (milliseconds) for desired spacing of selected bombs	10/20/30.../N selection (N = maximum selectable release interval, usually about 1,000 ms)		Operator	Aircraft	Control	Discrete	4-5
9. Turn on Master Arm Switch (energize aircraft armament release circuits)	OFF/ON selection		Operator	Aircraft	Control	Discrete	4-5
10. Track target using optical sight or HUD, or use FIREFLY HUD display	Aircraft flight Controls		Operator	Aircraft	Control	Continuous	7-8
11. Release bomb(s)	HOLD/RELEASE selection		Operator	Aircraft	Control	Discrete	7-8

For laser-guided bombs, laser designation of target from ground or airborne laser designator device must continue until weapon impact.

a. Circle: Indicates tasks that cannot be automated, and therefore would have to remain an operator task.

b. Triangle: Indicates tasks that are accomplished or monitored by the machine (automation) but must be displayed (information) to the operator. Many of these tasks need only be displayed to the operator when the system are in an out-of-tolerance condition.

c. Square: Indicates a machine (automated) function with a human override requirement. Again, information displayed is required for human operator judgment.

d. Hexagon: Indicates a machine function without operator monitoring or override.

e. Shaded Symbol: Indicates tasks that can be shared by both members of a two-man crew.

Using the above analysis from Figures 5.4-3 through 5.4-5, subjective task percentages for the two weapons and for either the automated (concepts I and II) or manual (concept III) fire control systems were developed in Table 5.4-6. While some of the functions (as defined by Figures 5.4-3 through 5.4-5) related to the AGM-65D are performed at takeoff or climb mission phases, they were not included in Table 5.4-6. This omission was made because the above mission phases were not of interest in the crew workload analysis as representing the high workload mission phases listed in Table 5.4-6.

Evaluating the crew functional task analysis from Figures 5.4-3 through 5.4-5, subjective task percentage values for the four high-workload mission phases were developed for each avionic concept in target acquisition and weapon delivery functions. These values were combined with those of Table 5.4-6 to develop Table 5.4-7, the target acquisition and weapon delivery task percentages. In Table 5.4-7, the weapon delivery functions and the target acquisition functions were influenced by concept and altitude. For the comparison of the three concepts, only moving targets were used. All-weather detection must be performed by radar sensors, and automatic target detection is currently limited to moving targe s on these systems. Although some new EO-type systems detect either moving or fi ed targets automatically, they

Function	Crew task	Taxi & takeoff	Climb	Loiter/ cruise out	Target run-in	Target Acquisition	Weapon Delivery	Withdraw	Descend	Land
Monitor sensors	Adjust sensor output parameters to fulfill needs & mission requirements					◨	◨			
	Select location of display					◑	◑			
	Determine level of processing					◨	◨			
	Determine mixing requirements					◨	◨			
Monitor Stores System	Observe status						◑			
	Select options						○			
	Manage by exception stores parameters						○			
	Select Master Arm						○			
	Consider jettison criteria	○								
Target Acquisition	Determine best sensors & maximum range to acquire target					◨				
	Adjust contract levels; initiate search					◑				
	Adjust sensor(s) to best operational mode					◨				
	Scrutinize cued target area for significant cues					◑				
	Approve most probable target(s) or					△				
	Activate small area search					◨				
	Designate probable target & monitor track					△				

Mission phase columns: Taxi & takeoff through Land.

Figure 5.4-3. Concept I Crew Functional Task Allocation (Target Acquisition/Weapon Delivery Functions)

Function	Crew task	Mission phase: Taxi & takeoff	Climb	Loiter/ cruise out	Target run-in	Target Acquisition	Weapon Delivery	Withdraw	Descend	Land
Target Acquisition (continued)	Verify target from data available					◑				
	Initiate lock-on & Weapon Delivery					◑				
Final target preparation	Obtain target data, stores data, sensor interaction					△				
	Select weapon options					◑	◑			
	Meet initial Weapon Delivery criteria					○	○			
	Select in-sequence steps to bring weapon on line						○			
Weapon(s) go/no-go	*Make value judgement; commit weapon*						◑			
Weapon Delivery	Monitor launch release						○			
	Switch to NFOV & monitor tracking						△			
	Monitor sensor, A/C dynamics & weapon to keep envelopes in concert						○			
	Make mid-course correction (if required)						◑			
BDA	Monitor BDA collection						◑			
Egress-evade enemy	Monitor enemy activity						◑	◑		
	Coordinate evasive tactics						◑	◑		

Figure 5.4-3. Concept I Crew Functional Task Allocation (Target Acquisition/Weapon Delivery Functions)(Concluded)

Function	Crew task	Mission phase: Taxi & takeoff	Climb	Loiter/ cruise out	Target run-in	Target Acquisition	Weapon Delivery	Withdraw	Descend	Land
Monitor sensors	Adjust sensor output parameters to fulfill needs & mission requirements					⬢				
	Select location of display					◑				
	Determine level of processing					⬢				
	Determine mixing requirements					⬢				
Monitor Stores System	**Observe status**						◑			
	Select options						○			
	Manage by exception stores parameters						○			
	Select Master Arm						○			
	Consider jettison criteria	○								
Target Acquisition	**Determine best sensors & maximum range to acquire target**					⬢				
	Adjust contract levels; initiate search					◨				
	Adjust sensor(s) to best operational mode					⬢				
	Scrutinize cued target area for significant cues					◨				
	Approve most probable target(s) or					◨				
	Activate small area search					◨				
	Designate probable target & monitor track					◨				

Figure 5.4-4. Concept II Crew Functional Task Allocation (Target Acquisition/Weapon Delivery Functions)

Function	Crew task	Mission phase								
		Taxi & takeoff	Climb	Loiter/ cruise out	Target run-in	Target Acquisition	Weapon Delivery	Withdraw	Descend	Land
Target Acquisition (continued)	Verify target from data available					◨				
	Initiate lock-on & Weapon Delivery					◭				
Final target preparation	Obtain target data, stores data, sensor interaction					◨				
	Select weapon options					○	○			
	Meet initial Weapon Delivery criteria					○	○			
	Select in-sequence steps to bring weapon on line						○			
Weapon(s) go/no-go	Make value judgement; commit weapon						◑			
Weapon Delivery	Monitor launch release						◑			
	Switch to NFOV & monitor tracking						◭			
	Monitor sensor, A/C dynamics & weapon to keep envelopes in concert						○			
	Make mid-course correction (if required)						◑			
BDA	Monitor BDA collection						◑			
Egress-evade enemy	Monitor enemy activity						◑	◑		
	Coordinate evasive tactics						◑	◑		

Figure 5.4-4. Concept II Crew Functional Task Allocation (Target Acquisition/Weapon Delivery Functions)(Concluded)

Function	Crew task	Mission phase								
		Taxi & takeoff	Climb	Loiter/ cruise out	Target run-in	Target Acquisition	Weapon Delivery	Withdraw	Descend	Land
Monitor sensors	Adjust sensor output parameters to fulfill needs & mission requirements					◑				
	Select location of display					◑				
	Determine level of processing					◑				
	Determine mixing requirements					◑				
Monitor Stores System	**Observe status**						◑			
	Select options						○			
	Manage by exception stores parameters						○			
	Select Master Arm						○			
	Consider jettison criteria	○								
Target Acquisition	**Determine best sensors & maximum range to acquire target**					◑				
	Adjust contract levels; initiate search					◑				
	Adjust sensor(s) to best operational mode					◑				
	Scrutinize cued target area for significant cues					◑				
	Approve most probable target(s) or					◑				
	Activate small area search					◑				
	Designate probable target & monitor track					◑				

Figure 5.4-5. Concept III Crew Functional Task Allocation (Target Acquisition/Weapon Delivery Functions)

Function	Crew task	Mission phase								
		Taxi & takeoff	Climb	Loiter/ cruise out	Target run-in	Target Acquisition	Weapon Delivery	Withdraw	Descend	Land
Target Acq[illegible]on (continued	Verify target from data available					◑				
	Initiate lock-on & Weapon Delivery					◑	◑			
Final target preparation	Obtain target data, stores data, sensor interaction					◑				
	Select weapon options						○			
	Meet initial Weapon Delivery criteria						○			
	Select in-sequence steps to bring weapon on line						○			
Weapon(s) go/no-go	Make value judgement; commit weapon						◑			
Weapon Delivery	Monitor launch release						◑			
	Switch to NFOV & monitor tracking						◑			
	Monitor sensor, A/C dynamics & weapon to keep envelopes in concert						○			
	Make mid-course correction (if required)						◑			
BDA	Monitor BDA collection						◑			
Egress-evade enemy	Monitor enemy activity						◑	◑		
	Coordinate evasive tactics						◑	◑		

Figure 5.4-5. Concept III Crew Functional Task Allocation (Target Acquisition/Weapon Delivery Functions)(Concluded)

Table 5.4-6. Weapon Delivery Task Percentages

Mission phase	Description	Weapons: Concept I & II: MK 82S	Concept I & II: IR Maverick AGM-65D	Concept III: MK 82S	Concept III: IR Maverick AGM-65D
4-5	Run-in to target	6	2	6	5
6-7	Target acquisition	–	1	–	3
7-8	Weapon delivery	3	2	4	10

Table 5.4-7. Target Acquisition and Weapon Delivery Task Percentages (Moving Target)

Key: MK82S (upper value) / AGM - 65D (lower value)

Mission phase	Description	Key	3000 FT Pop-up: Concept I: Target acquisition	Concept I: Weapon delivery	Concept II: Target acquisiton	Concept II: Weapon delivery	Concept III: Target acquisiton	Concept III: Weapon delivery	3000 FT Level flight: Concept I: Target acquisiton	Concept I: Weapon delivery	Concept II: Target acquisiton	Concept II: Weapon delivery	Concept III: Target acquisition	Concept III: Weapon delivery
4-5	Run-in to Target	MK82S		6		6		6		6		6		6
		AGM-65D		2		2		5		2		2		5
5-6	Pop-up	MK82S	5	–	5	–	5	–	5	–	5	–	5	–
		AGM-65D		–		–		–		–		–		–
6-7	Target acquisition	MK82S	33	–	22	–	45	–	30	–	20	–	35	–
		AGM-65D		1		1		3		1		1		3
7-8	Weapon delivery	MK82S		3		3		4		3		3		4
		AGM-65D		2		2		10		2		2		10

are not all-weather. Furthermore, the time for radar system fixed-target acquisition in a manual mode will be the same for all three concepts. Therefore, the moving-target case appears to show the greatest effect due to the various avionic concepts, and is used to evaluate the workload. The values of the target acquisition, and weapon delivery tasks are then added to the basic subjective task percentages (which were influenced by altitude and speed), to give the total task percentages for comparison of each concept.

Figure 5.4-6 shows graphically an example of a task percentage peak of the total subjective task percentages for all three concepts, at 553 kn for the Maverick at two altitude conditions. As stated before, the task percentage is a measure of workload, and in this case concept II has the lowest workload during the indicated mission phase. The routine maximum line is at 80 level, to indicate the usual routine maximum of crew workload. It can be seen that concepts I and III exceed this level for the period of time the target acquisition takes place on the mission timeline. Exceeding this level does not mean an excessive workload preventing accomplishment of a task. It means simply that the workload is high for a period of time. Other factors, such as stress or fatigue, may prevent or degrade performance during this time, but were not evaluated in this workload analysis.

Tables 5.4-8 and 5.4-9 summarize the task percentages for the concepts, speeds, weapons, and altitudes. Only the mission phases of run-in to target, popup, target acquisition, and weapon delivery are considered, because these phases are the basis of concept comparison. Examination of these tables reveals that the only significant variation between concepts and weapons for the same speeds is the target acquisition values for each avionic concept. This one mission phase value was then selected to establish the rating normalization factors used in the ranking system. The crew workload rankings derived show that concept II (fully automatic mechanization) ranks first, concept I is a close second, and concept III is third and last.

5.4.3 Conclusions

a. Concept II has the lowest crew workload during the critical mission phases of target acquisition and weapon delivery for moving targets. Concept I's workload is very nearly at the limit of a one-man crew performance, remembering that the analysis did not consider degraded performance by mission stress. Workload for a

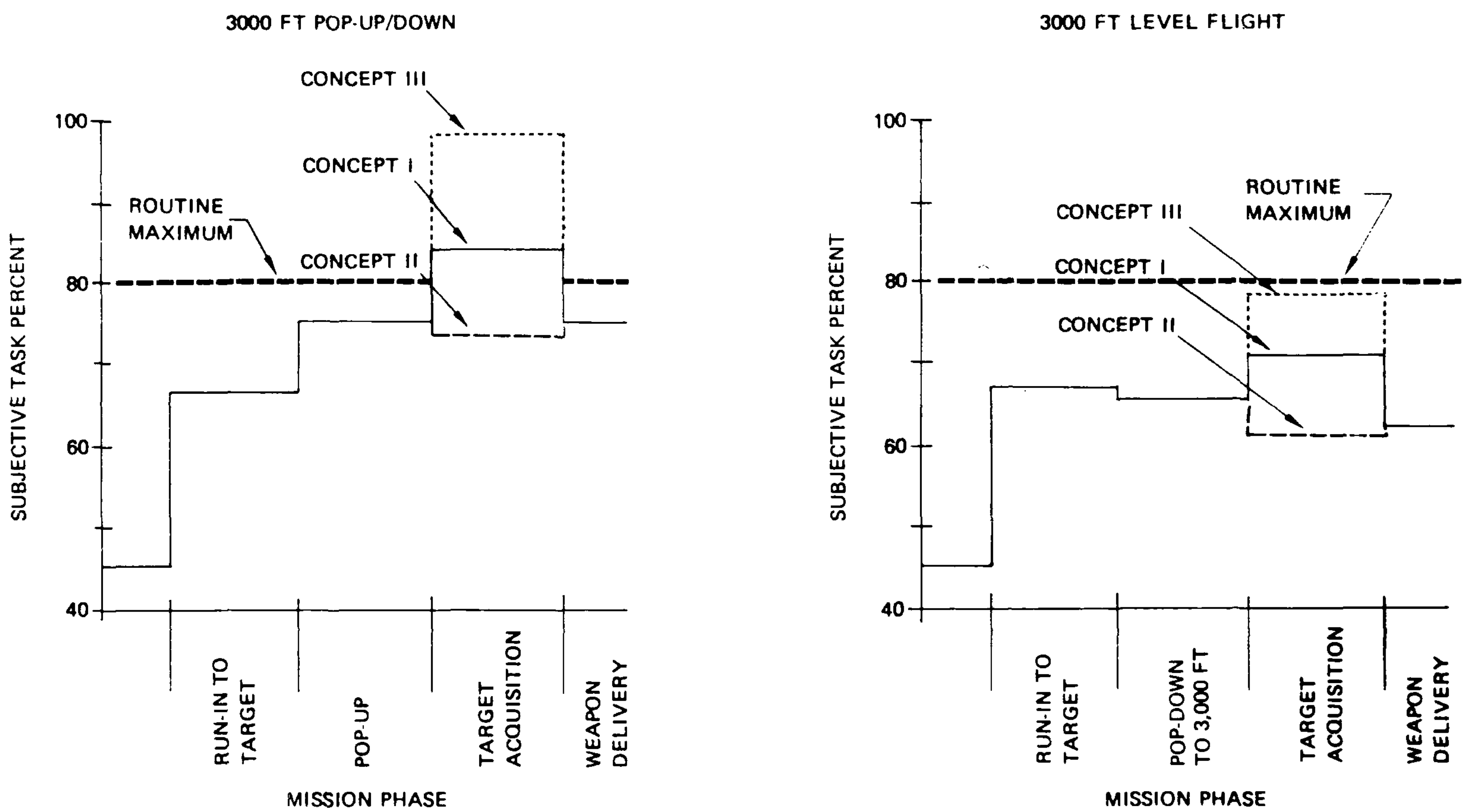


Figure 5.4-6. Estimated Task Percentages for Critical Mission Phases (Speed = 553 Knots, Maverick AGM-65D)

Table 5.4-8. Critical Mission Phases Estimated Task Percentage Ranking Factors (Pop-Up to 3,000 Ft, Moving Target)

CONCEPT	SPEED (KNOTS)	MISSION PHASE	WEAPON MK82S	WEAPON AGM -65D	TGT. ACQ AVERAGE TASK PERCENTAGE	RANKING
I	553	RUN-IN TO TARGET	71	67	83.5	2
		POP-UP	75	75		
		TARGET ACQUISITION	83	84		
		WEAPON DELIVERY	68	67		
II	553	RUN-IN TO TARGET	71	67	72.5	1
		POP-UP	75	75		
		TARGET ACQUISITION	72	73		
		WEAPON DELIVERY	68	67		
III	553	RUN-IN TO TARGET	71	70	96.5	3
		POP-UP	75	75		
		TARGET ACQUISITION	95	98		
		WEAPON DELIVERY	69	75		
I	350	RUN-IN TO TARGET	65	61	75.5	2
		POP-UP	75	75		
		TARGET ACQUISITION	75	76		
		WEAPON DELIVERY	58	57		
II	350	RUN-IN TARGET	65	61	64.5	1
		POP-UP	75	75		
		TARGET ACQUISITION	64	65		
		WEAPON DELIVERY	58	57		
III	350	RUN-IN TO TARGET	65	64	88.5	3
		POP-UP	75	75		
		TARGET ACQUISITION	87	90		
		WEAPON DELIVERY	59	69		

NORMALIZED METHOD: 80% TASK PERCENTAGE = 1.00
83.5% = .835; FACTOR = 1.00 - (.835-.80) = 1.00-.035 = .965
(higher than normal)

Table 5.4-9. Critical Mission Phases Estimated Task Percentage Ranking Factors (3,000 Ft Level Flight, Moving Target)

CONCEPT	SPEED (KNOTS)	MISSION PHASE	WEAPON MK82S	WEAPON AGM -65D	TGT. ACQ AVERAGE TASK PERCENTAGE	RANKING
I	553	RUN-IN TO TARGET POP-UP	71 65	67 65	70.5	2
		TARGET ACQUISITION WEAPON DELIVERY	70 63	71 62		
II	553	RUN-IN TO TARGET POP-UP	71 65	67 65	60.5	1
		TARGET ACQUISITION WEAPON DELIVERY	60 63	61 62		
III	553	RUN-IN TO TARGET POP-UP	71 65	70 65	76.5	3
		TARGET ACQUISITION WEAPON DELIVERY	75 64	78 70		
I	350	RUN-IN TO TARGET POP-UP	65 57	61 57	65.5	2
		TARGET ACQUISITION WEAPON DELIVERY	65 56	66 55		
II	350	RUN-IN TO TARGET POP-UP	65 57	61 57	55.5	1
		TARGET ACQUISITION WEAPON DELIVERY	55 56	56 55		
III	350	RUN-IN TO TARGET POP-UP	65 57	64 57	71.5	3
		TARGET ACQUISITION WEAPON DELIVERY	70 57	73 63		

one-man crew is very high for concept III and may be impossible to perform under conditions of high speed and stress. The crew workload for fixed radar targets is the same for all three concepts and higher than the moving-target cases.

b. The results of the timeline studies are in sec. 4.0 in the classified supplement to this report. Shorter useful detection ranges (and higher detection probabilities) are possible with a two-man crew. The one-man crew cannot perform target acquisition tasks while descending to 200 ft above ground level from popup altitude. A second man, however, can start accomplishing target acquisition while descending from altitude, reducing the total timeline by about 9 sec. for 553-kn speed and 11 sec. for 350kn. This capability would be especially important in multiple targets. The two-man crew also provides a greater margin of survivability.

c. The results of the timeline studies also indicate a lower attack speed (350 versus 553 kn) is desirable from the standpoint of exploiting low detection ranges and reducing crew workload. However, the lower speed must be traded with survivability considerations.

5.5 CONCEPT INSTALLATION

5.5.1 Aircraft and Avionics Integration

This subtask investimated the integration of ISAS equipment into four existing aircraft and a new-technology aircraft design created for operational use in the 1990's. The basic approach used in current aircraft included the following guidelines: (1) Use available space where possible—considering sensor field of view, equipment cooling, and accessibility; (2) Retain aircraft balance within the approved center-of-gravity range; and (3) Investigate design studies through the full-capability ISAS (concept I) first, then remove components for concept II and III installations. This approach was used for the F-15, F-16, A-10, and F-4. For the new-technology aircraft, the full-capability avionics suite was designed in from the start. Table 5.5-1 summarizes ISAS avionics equipment data. The first order investigation showed that only the F-16 had any appreciable performance degradation (Concept I) among the existing aircraft and for this reason, takeoff gross weight was used as a basis for comparing concepts. Concept III ranked first followed by II and I in that order.

5.5.2 A-10 and ISAS

The Fairchild A-10 available growth space restrictions required that all sensor installations be mounted ahead of the main landing gear in pod extensions, thus creating new aerodynamic shapes and new structural supports. These wing locations, Figure 5.5-1, provide good field of view for all sensors. The long wave and K_u-band radars with the missile site location system were installed in the right-hand pod extension. The left-hand pod housed the millimetre-wave length radar and the common aperture systems. JTIDS and GPS/NAVSTAR equipment was installed in the right-hand pod in Concept III. Installation weights for added structure, equipment, and wiring are included in the totals for each pod and concept. Avionics were installed in the body armor bathtub behind the pilot. The most favored nose location was considered not suitable because of gun environment and proximity to in-flight refueling receptacle. Locating sensors and electronics away from the A-10 nose section will avoid the life-shortening problems of high acoustic and dynamic loads, gun gas contamination and debris on sensor heads, fuel spillage, and potential impact damage from refueling booms. The penalty for this installation is a forward shift in

Table 5.5-1. Uninstalled ISAS Avionics Equipment Data Summary (Does Not Include Displays)

ITEM	EQUIPMENT	CONCEPT I		CONCEPT II		CONCEPT III	
		VOLUME (CU-FT)	WEIGHT (LBS)	VOLUME (CU-FT)	WEIGHT (LBS)	VOLUME (CU-FT)	WEIGHT (LBS)
A	LONG WAVE RADAR	5.25	320				
B	Ku BAND RADAR	7.03	325	7.03	325		
C	MM RADAR	3.85	200			3.85	200
D	COMMON APERTURE OPTICAL SYSTEM	10.05	583	10.05	583	7.19	470
E	JTIDS					0.84	60
F	GPS/NAV STAR					0.88	72
G	MISSILE SITE LOCATION	1.96	80	1.96	80	1.96	80
	TOTAL	28.14	1508	19.04	988	14.72	882

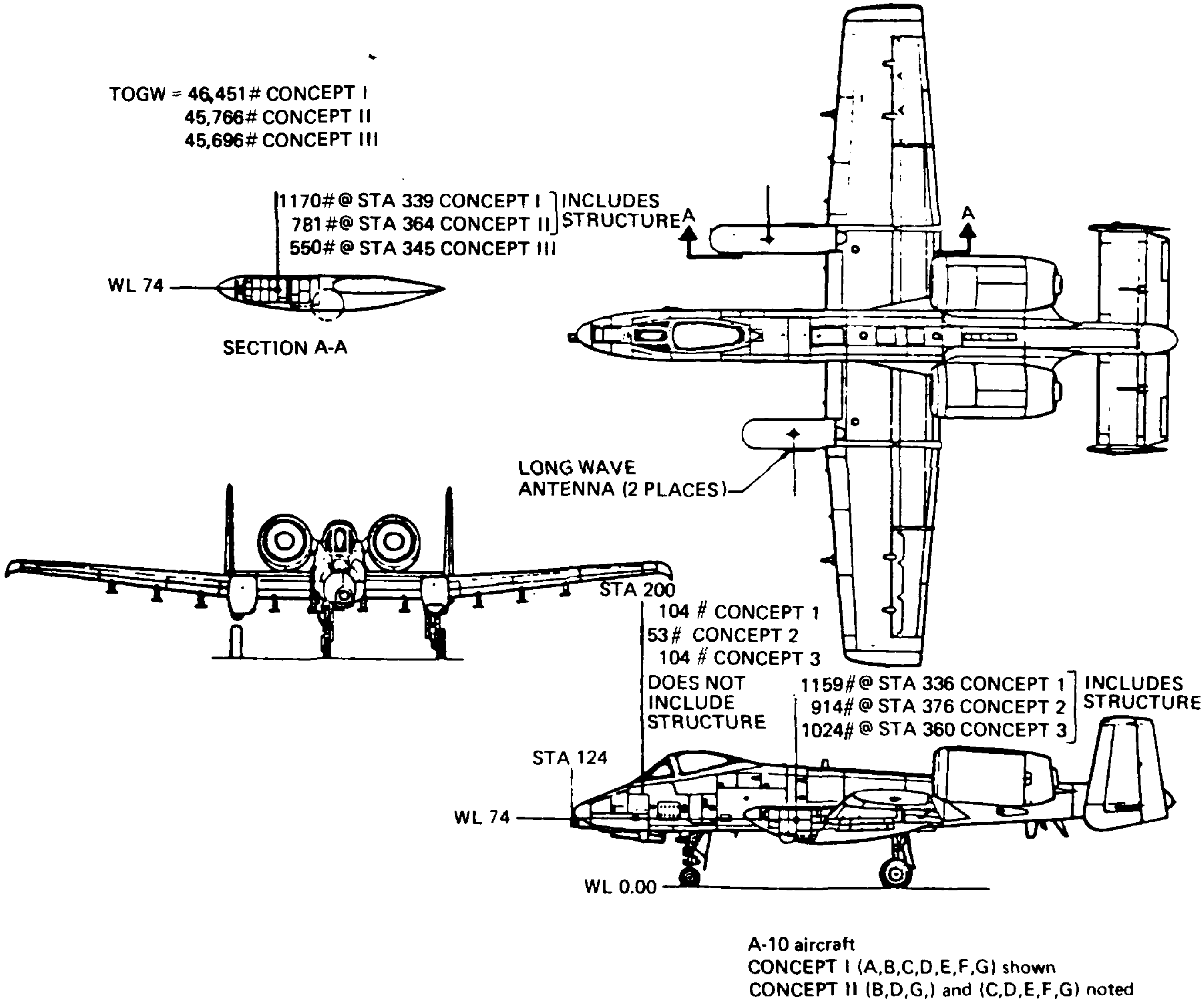


Figure 5.5-1. A-10 ISAS Equipment Installation

the center of gravity and some new flight testing to certify flight safety of the modified aerodynamics.

5.5.3 F-15A and ISAS

The large size of the F-15 would appear to make an easy installation of the all-up ISAS avionics suite. The F-15A has large growth volume behind the pilot's seat within the pressurized cockpit (Fig. 5.5-2). In later models (F-15C/D) this volume is employed for instructor pilot, avionics, or fuel. The nose radome section is available and well suited for installation of the all-up Concept I sensor set. The F-15 avoids gun and refuel hazards to ISAS (see A-10) by locating them in each wing root. Balance within the current center-of-gravity range is retained in the F-15 by exchanging APG-63 radar equipment for ISAS nose-mounted equipment. The F-15 installation is significant because of the apparent ease of modification. The F-15A still has reserve volume for growth because of its relatively recent IOC.

5.5.4 F-16 and ISAS

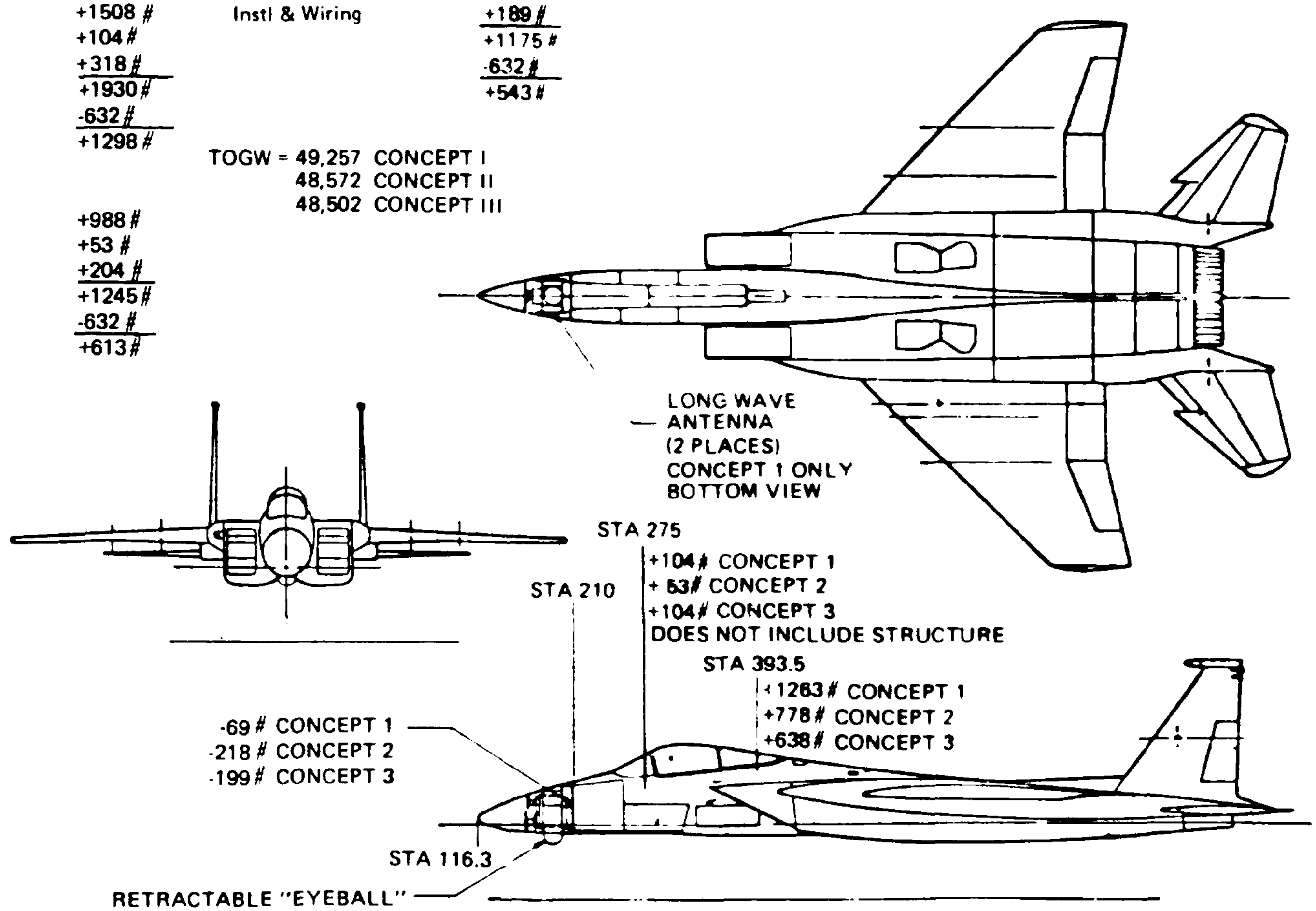
General Dynamics' F-16A (Fig. 5.5-3) represents the most difficult modification requiring more compromise to ISAS than other aircraft studied here. The principal problem is size. The result is large new bumps added to the body aerodynamic contours in an effort to retain all store stations for weapons or fuel. Equipment boxes are generally added to the body spine in an enlarged fairing fore and aft of the refueling receptacle. This fairing is essentially identical to the fairing to be employed for instrumentation on the AFTI/F-16 by AFWAL's Flight Dynamics Laboratory. The spine houses only approximately 50% of equipment boxes. Compromise is also indicated in the nose and lower aft body location of primary radar and EO sensors. For the all-up ISAS (Concept I) the entire nose must be modified, thereby requiring new certification flights to verify safe operation. Potential influence of the nose shape could induce turbulence into the engine inlet at high speeds and low altitudes. At high g maneuvers the modified nose could induce cross flows that cause stall departure and spins, thereby limiting the maximum angle of attack. F-16A is presently limited to 23-deg body angle. Millimetre-wave length field of view is severely limited by the lower body location. Any other location will take away a weapon store station. The installation shown does preserve F-16/ISAS balance within F-16A limits.

INSTALLATION ON F-15

Deleted equipment	
radar	-632 #
Concept 1	
Equipment	+1508 #
Displays	+104 #
Instl & wiring	+318 #
	+1930 #
	-632 #
	+1298 #
Concept 2	
Equipment	+988 #
Displays	+53 #
Instl & wiring	+204 #
	+1245 #
	-632 #
	+613 #

Concept 3	
Equipment	+882 #
Displays	+104 #
Instl & Wiring	+189 #
	+1175 #
	-632 #
	+543 #

TOGW = 49,257 CONCEPT I
48,572 CONCEPT II
48,502 CONCEPT III



F-15 aircraft
Concept 1 (A,B,C,D,E,F,G) shown Aircraft

Figure 5.5-2. F-15A ISAS Equipment Installation

INSTALLATION ON F-16

Deleted equipment			
radar	-299 #		
Concept 1		Concept 3	
Equipment	+1508 #	Equipment	+882 #
Displays	+104 #	Displays	+104 #
Instl & wiring	+318 #	Instl & wiring	+189 #
	+1930 #		+1175 #
	-299 #		-299 #
	+1631 #		+876 #
Concept 2			
Equipment	+988 #		
Displays	+53 #		
Instl & wiring	+204 #		
	+1245 #		
	-299 #		
	+946 #		

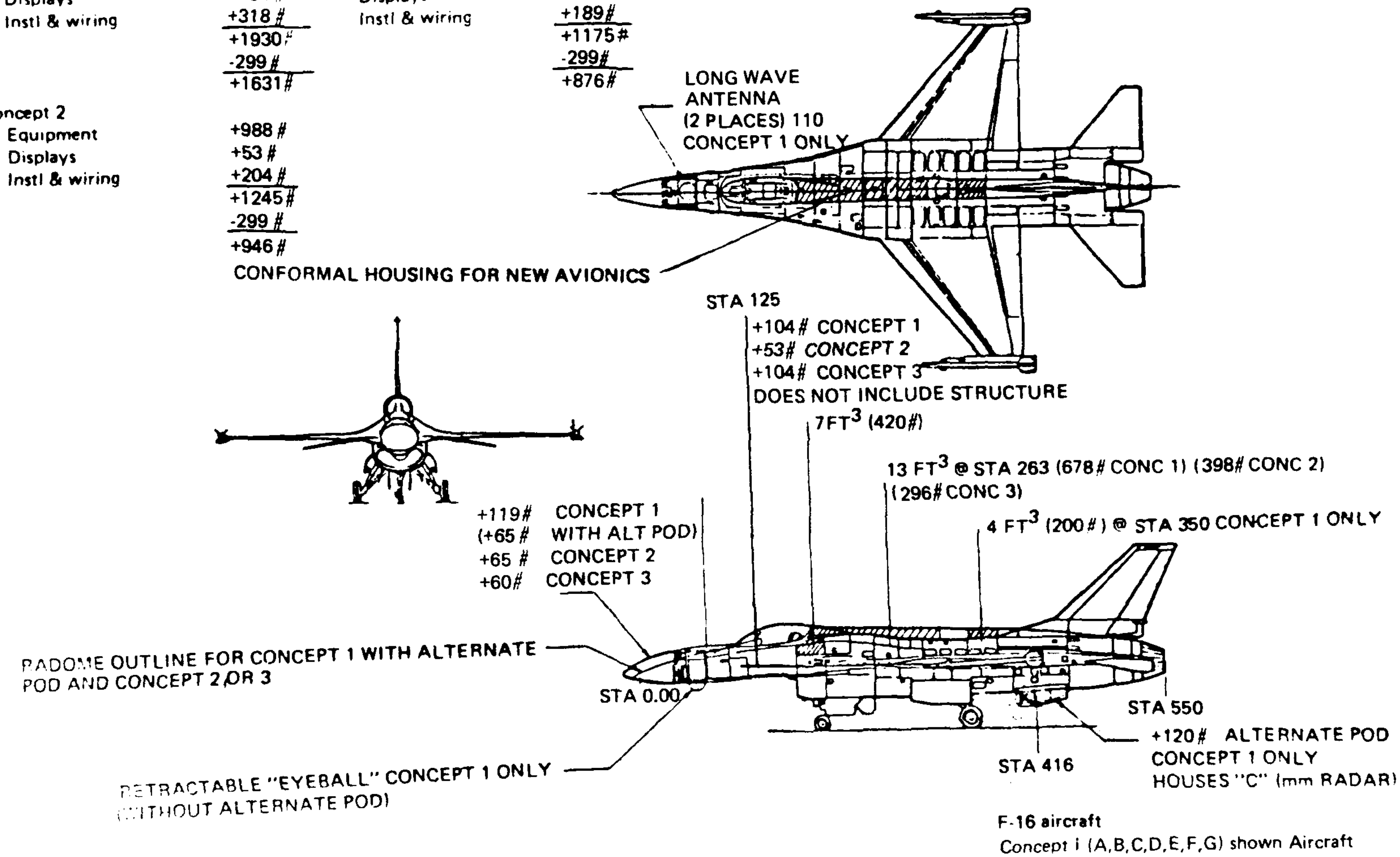


Figure 5.5-3. F-16 ISAS Equipment Installation

5.5.5 F-4 and ISAS

McDonnell Douglas' F-4 (Fig. 5.5-4) presents a still different integration problem. While the F-4 is the same size as the F-15, its military equipment has increased so that all usable space is full. The nose section was selected for conversion to ISAS. Here the radar and M-61 gun installation are removed and replaced by ISAS sensors and equipment. Control boxes are located in the rear seat.

The exchange of weight volume and power makes sense for the F-4. Removal of the gun does not seriously compromise the strike role since a 30-mm gun pod (GE POD-30) could be carried on the body centerline station and would produce a more effective antiarmor weapon than the M-61 gun.

5.5.6 ISAS Modification Effects on Existing Airplane Performance

Changes in the mission performance capabilities of the four existing airplanes were briefly examined. The bulk of the avionic concept equipment was installed within existing aircraft contours or under smooth fairings making the impact on drag minimal in comparison with the high drag of the payload (6 - Mavericks and 6 - MK82 bombs). Because all configurations retained their original internal fuel quantities, the operating radius varied by only a maximum spread of 5% from their original values.

Probably the most notable change in performance for any of the airplanes will be a degradation in the supersonic capability of the F-16. This is due to the adverse effect of the concept one radome modification and conformal "dorsal" avionics housing. The degradation was not quantified since the ISAS evaluation did not encompass supersonic speeds. Location of the retractable "eyeball" directly in front of the F-16 inlet is of some concern. Engine performance will be degraded particularly in use with the "eyeball" extended downward.

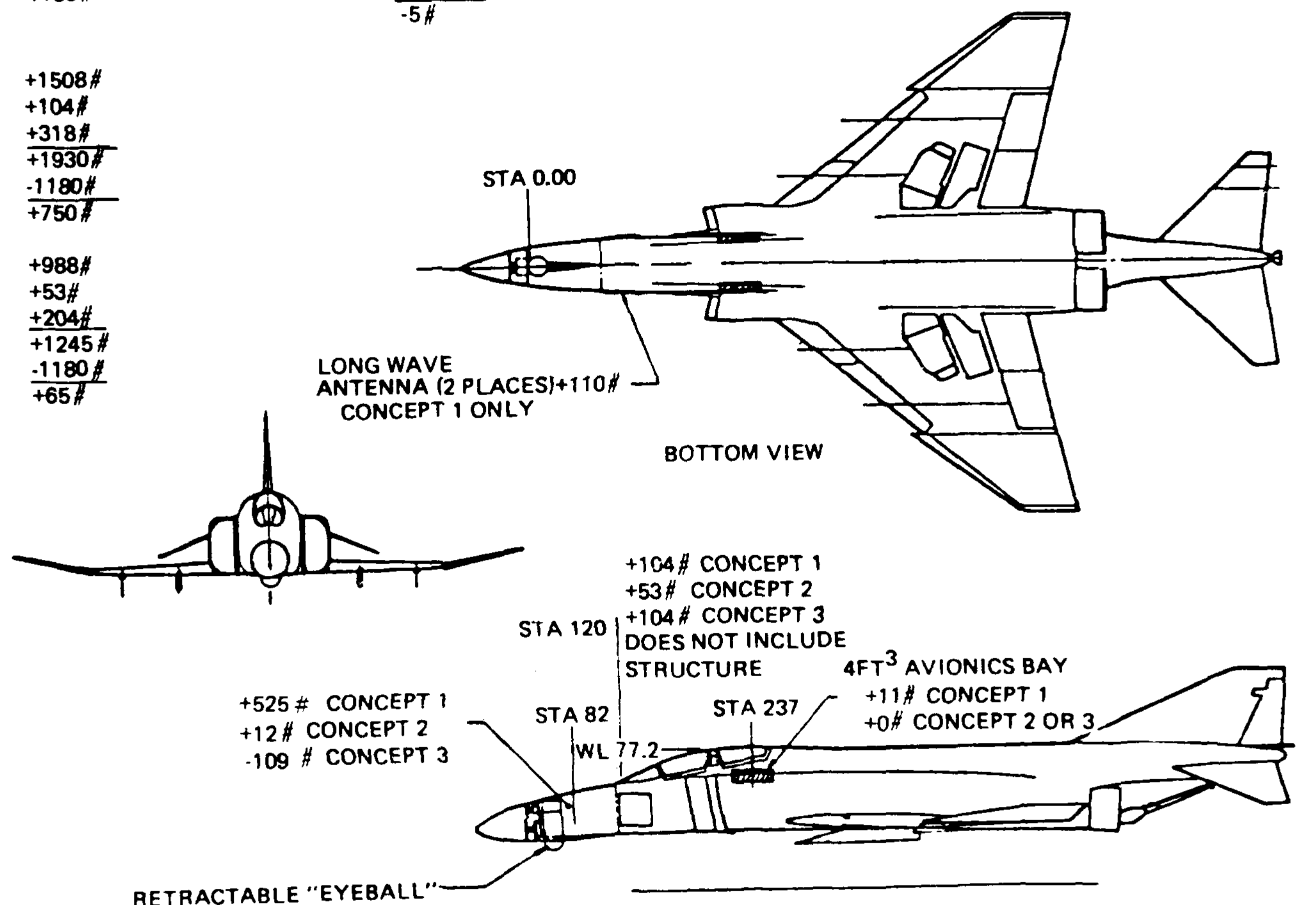
5.5.7 ISAS Modification Weight Summary

Table 5.5-2 provides the ISAS avionic modification weight summary for the four existing aircraft. The present operating weight of each aircraft is increased by the aircraft structural changes required to accommodate the ISAS equipment and the net

INSTALLATION ON F-4E

Deleted equipment	
M61A1 gun	-1035#
AN/AJB-7	-65#
NEW INS SET (f-16)	-38#
AN/ASQ-91A	-42#
	-1180#
Concept 1	
Equipment	+1508#
Displays	+104#
Instl & wiring	+318#
	+1930#
	-1180#
	+750#
Concept 2	
Equipment	+988#
Displays	+53#
Instl & wiring	+204#
	+1245#
	-1180#
	+65#
Concept 3	
Equipment	+882#
Displays	+104#
Instl & wiring	+189#
	+1175#
	-1180#
	-5#

TOGW = 54,400# CONCEPT I
53,715# CONCEPT II
53,645# III



F-4 Aircraft
Concept 1 (A,B,C,D,E,F,G) shown

Figure 5.5-4. F-4E ISAS Equipment Installation

Table 5.5-2. *ISAS Weight Summary (lbs)*

Aircraft	Present OW	Structure changes	Avionics changes	Modified OW	Payload [a]	Internal Fuel	TOGW
F-4 E	35,532	+30	I +750	I 36,312	6,030	12,058	I 54,400
			II +65	II 35,627			II 53,715
			III -5	III 35,557			III 53,645
A-10	27,288	+503	I +1,930	I 29,721	6,030	10,700	I 46,451
			II +1,245	II 29,036			II 45,766
			III +1,175	III 28,966			III 45,696
F-15	30,469	+25	I +1,298	I 31,792	6,030	11,435	I 49,257
			II +613	II 31,107			II 48,572
			III +543	III 31,037			III 48,502
F-16	17,750	+772	I +1,631	I 20,153	6,030	6,603[b]	I 32,786
			II +946	II 19,468			II 32,101
			III +876	III 19,398			III 32,031

a. Payload six MK-82 + six Maverick (AGM-65D)

b. Centerline store station available for external fuel tank of 300-gal capacity. Weight added is pylon (164 lb), tank (340 lb), and fuel (1,950 lb) = 2,454 lb.

weight change in avionic equipment, installation, and wiring. The modified operating weight is then increased by a standard payload and the internal fuel load to determine the takeoff gross weight.

5.5.8 Concept Ranking

The first order investigation showed that only the F-16 had any appreciable performance degradation (Concept I) among the existing aircraft. Takeoff Gross Weight (TOGW) was therefore used to rank the ISAS modifications to the existing aircraft. Table 5.5-3 illustrates the relative score and ranking for each concept on the four existing aircraft. These values are then averaged for the relative score for each concept.

Table 5.5-3. *ISAS Modification Ranking*

Concept	Aircraft				Avionics weight change (lb)	Takeoff gross weight (lb)	Relative score	Rank
	F-4E	A-10	F-15	F-16				
I	X				+780	54,400	1.01407	3
II	X				+95	53,715	1.00130	2
III	X				+25	53,645	1.	1
I		X			+2,433	46,451	1.01652	3
II		X			+1,748	45,766	1.00153	2
III		X			+1,678	45,696	1.	1
I			X		+1,323	49,257	1.01557	3
II			X		+638	48,572	1.00144	2
III			X		+568	48,502	1.	1
I				X	+2,403	32,786	1.02357	3
II				X	+1,718	32,101	1.00218	2
III				X	+1,648	32,031	1.	1

Average relative score

Concept 1 = 1.01743
Concept 2 = 1.0016
Concept 3 = 1.0

5.6 ECM SUSCEPTABILITY

A brief analysis and discussion of the susceptability of ISAS concepts to hostile countermeasures will be found in AFWAL-TR-80-1145, Volume II Integrated Strike Avionics Study -Final Report, Classified Supplement.

5.7 WEAPON SELECTION

This section evaluates the capabilities of each concept to deliver unguided weapons and homing lock-on-before-launch missiles. Concept I is most capable, with concept II a close second, and concept III a far third.

Target Kill (Popup and Level Deliveries and Ranking). Tables 5.7-1 and 5.7-2 list the relative target (tank) kill capability of each ISAS fire-control concept when using bombs and missiles. The basic data from which the tables were derived are provided and discussed in Section 5.0 of Volume II. The data were normalized about the best kill probability for a particular mission-weather condition.

Popup Delivery. In Table 5.7-1, all data are for a popup attack. The popup, used to overcome target masking, terminates in a 200-ft-altitude delivery. Close air support and the other missions are listed across the chart from left to right. Under each mission the relative effectiveness of each concept, over three weather conditions, is shown. The 200-ft weather condition is visualized as a cloud-cover case, in which the combined effects of an irregular (in altitude) cloud base and terrain-elevation variations result in a high percentage of terrain obscuration. This results in cases where guided weapons cannot be launched because of lack of a line-of-sight to the target at launch or during weapon flight. Cases when the guided missile could not be launched are identified by resultant blanks in the table.

The target-kill factors are summed from left to right for each concept. The average is determined by dividing by the total number of opportunities (each mission-weather condition is regarded as an opportunity, regardless of cloud constraints). The averages are not weighted by the frequency of weather occurrence, since they are intended to reflect fire-control concept capability and not actual mission value. P_K evaluations discussed in Section 5.0 (vol. II) consider the frequency of occurrence of the various cloud covers.

Level Delivery. The data of Table 5.7-2 were derived and compiled in the same manner as the preceding table. The data represent a case where the aircraft penetrates to the target area at low altitude and then climbs to 3,000 ft to acquire and deliver weapons against the target.

Table 5.7-1. Pop-Up Delivery P_k Comparison

	CONCEPT	WEATHER	CLOSE AIR SUPPORT	BATTLEFIELD INTERDICTION	DEEP INTERDICTION FIXED TARGETS	DEEP INTERDICTION MOVING TARGETS	TOTALS	AVERAGE
MK82S	CONCEPT 1	CLEAR	1	1	.86	1	3.86	.996
		200	1	1	1	1	4	
		2000	1	1	1	1	4	
	CONCEPT 2	CLEAR	.93	.94	1	.94	3.81	.918
		200	1	.89	.75	.89	3.53	
		2000	.91	.93	.9	.93	3.67	
	CONCEPT 3	CLEAR	.94	.47	.9	.47	2.78	.232
		200	0	0	0	0	0	
		2000	0	0	0	0	0	
MAVERICK	CONCEPT 1	CLEAR	1	1	1	1	4	.667
		200	0	0	0	0	0	
		2000	1	1	1	1	4	
	CONCEPT 2		.92	.94	.94	.94	3.74	.623
		200	0	0	0	0	0	
		2000	.92	.94	.92	.95	3.73	
	CONCEPT 3		.45	.62	.55	.55	2.17	.181
		200	0	0	0	0	0	
		2000	0	0	0	0	0	

Table 5.7-2. Level Delivery P_k Comparison

	CONCEPT	WEATHER	CLOSE AIR SUPPORT	BATTLEFIELD INTERDICTION	DEEP INTERDICTION		TOTALS	AVERAGE
					FIXED	MOVING		
MK82S	CONCEPT 1	CLEAR	1	1	1	1	4	1
		200	1	1	1	1	4	
		2000	1	1	1	1	4	
	CONCEPT 2	CLEAR	.92	.93	.94	.93	3.72	.98
		200	1	1	1	1	4	
		2000	1	1	1	1	4	
	CONCEPT 3	CLEAR	.83	.42	.86	.42	2.53	.211
		200	0	0	0	0	0	
		2000	0	0	0	0	0	
MAVERICK	CONCEPT 1	CLEAR	1	1	1	1	4	.333
		200	0	0	0	0	0	
		2000	0	0	0	0	0	
	CONCEPT 2		.92	.96	.96	.96	3.8	.317
		200	0	0	0	0	0	
		2000	0	0	0	0	0	
	CONCEPT 3		.87	.85	.9	.85	3.47	.317
		200	0	0	0	0	0	
		2000	0	0	0	0	0	

In the table, the blanks representing no-weapon-delivery occur for both cloud covers because delivery is from 3,000-ft altitude.

Ranking. Table 5.7-3 repeats the average P_K factors for both weapon-delivery modes and shows an average factor for each concept and each weapon. Although concepts I and II are close in capability, concept I obviously has the highest kill factor. Concept III has less than half the capability of the other concepts to deliver either bombs or missiles.

Table 5.7-3. *Ranking of Fire Control Concepts - Weapon Selection*

	CONCEPT #	AVERAGE POP-UP	AVERAGE LEVEL	GRAND AVERAGE	RANK
BOMBS (MK82S)	1	.996	1.0	.998	1
	2	.918	.98	.949	2
	3	.232	.211	.443	3
MISSILES (I^2R MAVERICK)	1	.667	.333	.500	1
	2	.623	.317	.470	2
	3	.181	.289	.235	3

5.8 GRACEFUL DEGRADATION

A significant measure of system value is the ability of the system to accept a gradual decline in effectiveness, rather than a catastrophic reversion to a useless state. The integrated sensors of the three ISAS candidates were reviewed in this respect. The results show that concept I is best able to withstand sensor failure; concepts II and III were next, in that order.

5.8.1 Effect of Sensor Failure

The ISAS system mechanizations described in Section 4.2 of this report provide each sensor with a dedicated autoprocessor for the cueing and classification function. This analysis assumes that sensor failure and processor failure are equivalent. It is further assumed that sequential worst-case failures occur (i.e., the "best" or longest range sensor fails) each time there is a failure.

Table 5.8-1 shows the decline in integrated-sensor capability, in terms of detection by one or more sensors as individual sensors fail. There is a column for the sensors of each concept; the column is partitioned to show the number of sensor failures for that concept as the sensors in the column fail.

The data show that concept I still has a 31% probability of detecting a target at 8 km after three successive failures of the longest range sensors, whereas concepts II and III are completely "down."

Concepts II and III appear to perform equally after one failure, but when the second failure has occurred, concept II emerges strongly ahead (0.924 to 0.054) because of the inherent superiority of its sensor combination. Concepts II and III catastrophically fail when their third sensor fails. Because the same combination of sensors with recognition capability are used in each concept, there is no difference in the ability of the three concepts to recognize a target at 5 km during successive sensor failures (Table 5.8-2).

Table 5.8-1. Worst Case Failure Modes - Detection

DETECTION RANGE 8 Km

SENSOR ARRAY BEST REMAINING SENSOR ALWAYS FAILS	PROBABILITY TARGET IS DETECTED BY ONE OR MORE SENSORS # FAILED	CONCEPT I	# FAILED	CONCEPT II	# FAILED	CONCEPT III
All Sensors Operating	0	1.0	0	.99985	0	.997
Kμ -Radar Failed	1	.998	1	.997	0	.997
Kμ -Radar + Tv Failed	2	.948	1	.924	1	.93
Kμ -Radar + Tv + FLIR Failed	3	.313	3	0	2	.054
Kμ -Radar + Tv + FLIR + LWR Failed	4	.054	3	0	0	.054
All Above + MM Radar Fail	5	0	3	0	3	0

Table 5.8-2. Worst Case Failure Modes - Recognition

RECOGNITION RANGE 5Km

SENSOR ARRAY BEST REMAINING SENSOR ALWAYS FAILS	PROBABILITY TARGET CAN BE RECOGNIZED AT ONE OR MORE SENSORS* # FAILED	CONCEPT I**	# FAILED	CONCEPT II**	# FAILED	CONCEPT III**
All Sensors Operating	0	.998	0	.998	0	.998
3D Classifier Failed	1	.956	1	.956	1	.956
3D Classifier & FLIR Failed	2	.708	2	.708	2	.708
All Above & Tv Failed	3	0	3	0	3	0

NOTE:
* Recognition only. It is assumed detection has already occurred.
** For use in system effectiveness evlauations, above recognition probabilities.

5.8.2 Ranking

A combined ranking of a concept's ability to degrade in a graceful manner over a period of sequential failures of the best (longest range sensor) is: concept I, concept II, and concept III.

6.0 FIGURE OF EFFECTIVENESS

Analyses and discussions of survival and target kill (ISAS Task IV) will be found in AFWAL-TR-80-1145, Integrated Strike Avionics Study - Final Report, Classified Supplement.

7.0 LIFE CYCLE COST (LCC) STUDY (TASK V)

Life-Cycle Cost: RDT&E, Acquisition, and Operating and Support. Life-cycle cost (LCC) for the integrated strike avionics study (ISAS) concepts include development, production, and operating and support costs. LCC study results are summarized in Table 7.1-1. These costs were derived as a part of ISAS Task V.

7.1 METHOD OF ANALYSIS

The physical characteristics of the ISAS concepts were used initially in the "Modular Life Cycle Cost Model" (MLCCM), Technical Report AFFDL-TR-7840, April 1978. The MLCCM is a computerized method of predicting and conducting aircraft LCC trade studies, at the subsystem level, during the conceptual- and preliminary-design stages of a new aircraft development program. The method is designed to accept, as input parameters, the output design parameters of a sizing model and/or design and performance data available during the conceptual- and preliminary-design program phases.

The MLCCM method consists of cost estimating relationships (CER) developed for each of the cost categries of the system life cycle and for the following aircraft sybsystems:

a. Structure
b. Crew system
c. Landing gear
d. Light controls
e. Cargo handling (cargo only)
f. Engines
g. Engine installation
h. ECS
i. Electrical
j. Hydraulic and pneumatic
k. Fuel system
l. Avionics
m. Armament (fighter and attack only)
n. APU (cargo, transport, tanker only)

Table 7.1-1. Integrated Strike Avionics System ISA Life Cycle Cost Summary

	INTEGRATED STRIKE AVIONICS SYSTEM ISA LIFE CYCLE COST SUMMARY		1980 $ $ MILLIONS
Concept	I	II	III
RDT&E	$ 249	$ 181	$ 157
Acquisition			
Avionics	$2,203	$1,615	$1,407
Spares	441	323	281
Support Equip.	172	99	84
Training	11	8	7
Data	20	13	11
Total Acquisition	$2,847	$2,058	$1,790
O&S	$4,979	$3,828	$3,363
TOTAL LIFE CYCLE COSTS	$8,075	$6,067	$5,310

Costs for these 14 subsystems are available for production and operating and support (O&S) phases. RDT&E costs developed in the MLCCM are visible at the engine, avionics, and airframe level only. Input parameters to the CER's are obtained either from available aircraft sizing models or from preliminary- and conceptual-design data. These data are entered into the computer in either an interactive or batch mode. The output costs can be selected for one or all of the life cycle phases, and for one or all of the aircraft subsystems, as shown in Table 7.1-1.

The MLCCM differs from the RCA Price L Model, initially recommended for this study in that it requires considerably fewer minutely detailed inputs and, therefore, involves a LCC level of effort more consistent with the intent of this study.

The results were then reviewed with in-house experts. This resulted in some adjustments to the cost levels. The final values reported herein provide correct rankings, but should not be considered as absolute values.

7.2 RESULTS

Three sets of advanced 1987 ISAS sensors were estimated. The LCC includes the cost of sensors in each of the three systems with fuel excluded. The LCC's for the following sensors have been estimated, as indicated, for each of the three concepts.

	Concepts		
	I	II	III
LF radar	X		
Ku-Band radar	X	X	
Millimetre wavelength radar		X	
Common-aperture laser sensor	X	X	X
Common-aperture active-passive TV	X	X	X
Common-aperture FLIR	X	X	X
Scanning laser	X	X	
Common-aperature laser range finder			X
Laser spot seeker			X
JTIDS			X
GPS/Navstar			X

ISAS LCC ground rules for the estimate are as follows:

a. 1980 dollars
b. 10 prototypes
c. Production aircraft: 500
d. Operational aircraft: 456 UE
d. Annual flying hours: 300/UE/yr
f. Years of operation: 15
g. Includes profit and G&A

RDT&E. The development-cost element in the LCC includes contractor efforts required to develop such a system in each concept. Boeing has performed a substantial and extensive evaluation of avionics in the Air-to-Surface study, B-1 OAS, B-52 OAS, and Innovative Strategic Aircraft Design studies. This Boeing experience and supplier support has assisted us in estimating the development cost.

Acquisition Costs. Production costs are based on vendor estimates and the extensive avionics background of The Boeing Company. The other investment portion of avionics acquisition cost is based upon percentages of hardware cost extracted from the MLCCM.

Operating and Support Costs. Operating and support costs were estimated using the MLCCM, and adjusted to reflect the impact of production-cost estimates finally agreed upon by Boeing Materiel, Engineering, and Finance organizations.

8.0 RANKING AND TRADE-OFF ANALYSIS

An analysis was performed to accomplish a final ranking and trade-off of the candidate ISAS concepts. In the initial ranking, that concept I had the best relative ranking score; concepts II and III were next, in that order. The trade-off resulted in a decrease of concept I radar sensors to the radar sensor used by concept II (Ku-band multimode radar). The ranking and trade-off were based on the plan (ISAS task III) discussed in appendix A of this report. The ranking and trade-off accomplished ISAS task IV.

8.1 RANKING PARAMETERS

The evaluation parameters used in ranking the ISAS candidates are survival- and target-kill probabilities, crew workload, ECM susceptibility, weapon-selection factors, life-cycle cost, and aircraft installation factors. Target-kill probability (P_K) includes the effects of fire-control concept sensor performance on target acquisition, classification, and lock-on. Target-kill probability (P_K) and survival probability (P_S) are combined into a figure of effectiveness ($P_K P_S$) that represents the probability that (the target is destroyed and the airplane survives to leave the target area.

8.2 RANKING

Table 8.2-1 summarizes the results of the figure-of-effectiveness study reported in volume II, AFWAL-TR-80-1145, the classified supplement to this report. The normalized data in the table are unclassified.

Weighting factors for weather and missions have been included previously. Remaining factors in the table are those that cannot be removed by reasonable weighting processes. As is shown, concept I ranks first in each of the four cases. The poor performance of concept III can be traced to the lack of an adequate radar for adverse-weather operation.

The columns for relative score in Table 8.2-1 show that concept I is better than concept II by an average of about 6% and better than concept III by an average of about 85%. Use of a modifier to account for aircrew performance in screening the

Table 8.2-1. $P_K P_S$ Relative Score and Rank

Concept	MK82S	Maverick	No Defense Suppression	70% Defense Suppression	Pop Up 200 Ft Delivery		Level 3,000 Ft Delivery	
					Relative Score	Rank	Relative Score	Rank
I	X		X		1.	1	1.	1
II	X		X		1.0865	2	1.0714	2
III	X		X		1.8073	3	1.4619	3
I	X			X	1	1	1.	1
II	X			X	1.0826	2	1.0736	2
III	X			X	1.8019	3	1.4292	3
I		X	X		1	1	1.	1
II		X	X		1.0691	2	1.0305	2
III		X	X		3.0931	3	1.1528	3
I		X		X	1.	1	1.	1
II		X		X	1.0664	2	1.0329	2
III		X		X	3.1129	3	1.1476	3

Average Relative Score

Concept 1 = 1.0
Concept 2 = 1.0641
Concept 3 = 1.8758

automatic cueing and classification system accounts for the small performance difference between concepts I and II. Without constructive aircrew participation in concept I operation, the fully automatic concept II is the most effective concept.

The final ranking matrix is shown in Table 8.2-2. The table includes the rank based on figure of effectiveness ($P_K P_S$), from Table 8.2-1, and ranks based on the other required evaluation parameters. To obtain a final rank that is based on an overall consideration of evaluation parameters, the individual ranks should be weighted according to the relative importance or significance of the evaluation parameters. Since subjective factors generally are involved in weight-assignment processes, several weight-assignment schemes are tested to determine the sensitivity of the final rank to the assignment of weights:

a. If equal weights are assigned to the evaluation parameters, the summations of rank numbers from left to right yield 12, 13, and 14 for concepts I, II, and III, respectively. Thus, concept I has the highest rank and is followed by concepts II and III, in that order.

b. If, arbitrarily, the parameter ($P_K P_S$) is given unity weight and the other parameters are given zero weight to emphasize kill capability and survivability, the final rank is concept I (highest), concept II, and concept III.

c. If the concepts are ranked according to the number of evaluation parameters for which each concept has the highest individual rank, then the final rank is concept I (highest), concept III, and concept II.

On the basis of the above tests and other relevant factors, the final rank of the concepts is I (highest), II (middle), and III (lowest).

8.3 TRADE-OFF ANALYSIS

The purpose of the trade-off analysis is to enhance the highest ranking concept with selected features from the other contenders. Three areas where concept I does not rank first are crew workload, concept installation, and life-cycle cost.

Table 8.2-2. Final Ranking Matrix

Data Source	ISAD Concept	Graceful Degradation	ECM Susceptability	Life Cycle Cost	Installation	Weapon Selection	Crew Work Load	$P_K P_5$ (P_{K_A})	Final Rank
	I	1	1	1	3	3	1	2	1
	II	2	2	2	2	2	1	2	2
	III	3	3	1	1	3	3	3	3
Paragraph		5.8	5.6	7.0	5.5	5.7	5.4	5.5 *	
Table or Figure		--	5.--1	7.1-1	--	5.7-3	--	5.5-1	

* Volume 2, AFWAL-TR-80-1145.

Crew Workload. The target-kill-capability advantage that concept I holds over concept II can be traced to the crewman-participation factor in the concept I mechanization. Crewman participation, however, results in a higher crew workload for the concept I crew. From Table 8.3-1, it can be seen that crew participation in fire control means a workload penalty of about 17% for concept I relative to concept II. The additional workload probably would not penalize a two-man crew but may significantly penalize a one-man crew, an important retrofit consideration. In the case of a new aircraft, a second crewman and his equipment may add about 550 lb to aircraft weight. This weight penalty and the penalty of additional fuel consumption may make concept I undesirable.

A desirable trade-off is to mechanize concept I so that it has a fully automatic target-cueing/classification backup capability. Thus, when the one-man crew becomes overloaded with work and cannot devote adequate attention to fire control, concept I performance is degraded only to the level of performance that is achievable with concept II.

Concept Installation and Life-Cycle Cost. The concept-installation weight data of section 5.5 are summarized in Table 8.3-2.

As shown in Table 8.3-2, the fire-control equipment of concept III has the least impact on aircraft takeoff gross weight. Relative to aircraft gross weights for concept III, the gross-weight penalties associated with concepts II and I are approximately 0.3% and 2%, respectively. The 0.3% penalty (concept II) is justifiable on the basis of a substantially higher figure-of-effectiveness for concept II relative to that of concept III. A further increase in the relative-gross-weight penalty (from 0.3% to 2%) does not appear to be compatible with the relatively small increase in figure-of-effectiveness as concept II is replaced by concept I.

The objectionable weight penalty associated with concept I may be removed without significantly affecting performance capability by deleting the long-wave and millimetre-wave radars from the concept I sensor suite. When these two sensors are deleted, weight and life-cycle costs are decreased and the last major disadvantage of concept I is removed.

Table 8.3-1. Crew Work Load Relative Score and Rank

Concept	350 Knots	553 Knots	Pop Up 200 Ft. Delivery			Level 3,000 Ft Delivery		
			Average Task Percentage	Relative Score	Rank	Average Task Percentage	Relative Score	Rank
I		X	83.5	1.1517	2	70.5	1.1653	2
II		X	72.5	1.	1	60.5	1.	1
III		X	96.5	1.3310	3	76.5	1.2645	3
I	X		75.5	1.1705	2	65.5	1.1802	2
II	X		64.5	1.	1	55.5	1.	1
III	X		88.5	1.3721	3	71.5	1.2883	3

Average Relative Score

Concept 1 = 1.1669

Concept 2 = 1.0

Concept 3 = 1.314

Table 8.3-2. *Concept Installation Relative Score and Rank*

Concept	Aircraft				Avionics weight change (lb)	Takeoff gross weight (lb)	Relative score	Rank
	F-4E	A-10	F-15	F-16				
I	X				+780	54,400	1.01407	3
II	X				+95	53,715	1.00130	2
III	X				+25	53,645	1.	1
I		X			+2,433	46,451	1.01652	3
II		X			+1,748	45,766	1.00153	2
III		X			+1,678	45,696	1.	1
I			X		+1,323	49,257	1.01557	3
II			X		+638	48,572	1.00144	2
III			X		+568	48,502	1.	1
I				X	+2,403	32,786	1.02357	3
II				X	+1,718	32,101	1.00218	2
III				X	+1,648	32,031	1.	1

Average relative score

Concept 1 = 1.01743
Concept 2 = 1.0016
Concept 3 = 1.0

8.4 RECOMMENDED CONCEPT

Features of the preferred concept are—

a. Ku-band radar, and a full complement of EO equipment (Sec. 5.2)

b. Screening of target-cueing/classification data by the crew when permitted by workload

c. Fully automatic target-cueing/classification backup capability

The preferred concept was derived from concept I by—

a. Deleting the long-wave and millimetre-wave radars, which contributed little to concept I effectiveness (thus, concept I weight and life-cycle cost are also reduced.)

b. Adding to concept I the fully automatic target-cueing/classification capability that is a feature of concept II.

The performance capability of the preferred concept should approach that of concept I when the crew participates in the target-cueing/classification process. When combat stress decreases crew attention to the target-cueing/classification process, performance capability degrades to the concept II level of performance.

9.0 TECHNOLOGICAL DEFICIENCIES

This section discusses the technological deficiencies (part of ISAS task VII) that must be overcome to make the ISAS preferred concept available for a post-1987 aircraft. Some additional technological items are discussed in recognition that the performance of the preferred combination of sensors is weather sensitive.

9.1 DEFICIENCIES

Technological deficiencies identified during ISAS studies are listed in Table 9.1-1. The list reflects the needs for the preferred concept as well as for other capabilities that might be incorporated in the preferred concept if the development could be made timely for ISAS, or if the ISAS environmental and/or operating conditions should change. For example, item 7 lists millimetre-wavelength radar range as being deficient even though the millimetre-wavelength radar is not part of the preferred concept. However, if radar range can be increased significantly or if the cloud conditions are less severe, then the millimetre-wavelength radar could be a part of the preferred concept's sensor suite.

Item 1 notes the lack of a radar automatic fixed-target detection system, which is a serious deficiency because of the importance of the function. The problem is made very complex by the presence of nonhomogeneous terrain and man-made clutter. A timely satisfactory solution of the problem for ISAS is doubtful although there is always some hope.

Item 2, a tactical radar with foliage penetration capability, does not appear to be available in time for a 1987 IOC. It is evident from a P_K matrix for all ISAS mission that the effectiveness of all ISAS systems decreases for cloudy or foggy weather conditions, as well as for conditions where the target is concealed by foliage. Item 2 (foliage penetration) and items 3 and 4 (automatic recognition of moving and fixed radar targets) are significant technological deficiencies. No breakthrough is anticipated in time to meet the 1987 ISAS IOC date. As noted in Table 9.1-1, most of the work is still in the basic-research phase.

The active three-dimensional classifier is, being developed and is expected to be available as is the television-image-processor autocuer-autoclassifier.

The baseline millimetre-wavelength radar evaluated in the ISAS program is inadequate because the sensor can not penetrate cloudy weather. Developments to improve receiver noise or to improve gain through signal processing are potential problem solutions, but no known current program is directed to extending millimetre-wave length radar range.

The mission survival data of Table 5-0, Volume II, emphasizes the desirability of longer weapon standoff ranges. According to the sensor performance characteristics of Section 5.2, it is obvious that the longer standoff launch range must be accompanied by improved weapon sensor lock-on capabilities such as lock-on after launch.

Remaining items 9, 10 and 11 deal with the need to develop algorithms for the ISAS sensor-integration task. These items are further discussed in the system 10 development plan.

9.2 The Development Program

The development program consists of the ISAS phase II program and the supporting sensor-autoprocessor programs shown in Figure 9.1-1. Technological deficiencies relating to the preferred concept are expected to be solved by the above programs. The AFWAL and other agencies scheduled have been extended, as necessary, to provide the production hardware and software in a timely manner.

Table 9.1-1. Technological Deficiencies

TECHNOLOGY DEFICIENCY	CAUSE OF DEFICIENCY	PROBLEM SOLUTION	SOLUTION ON SCHEDULE? CURRENT DEVELOPMENTS
1. Automatic Fixed Target Target Detection System using radars not available. NOTE: manual fixed-target detection is generally based on scene context since RCS amplitude context is usually not manually possible.	o Non-homogeneous terrain creates RCS threshold problems (high false alarm rates). o Target RCS varies with aspect angle and is subject to scintillation.	o Minimize cell size. o Enhance target (polarization diversity, etc.) o Develop threshold algorithm to negate some non-homogeneous aspects of terrain. (Reject tree line, etc.). This requires thorough clutter analysis (including measurements) using ISAS parameters (frequency, all size grazing angle, terrains of interest). o Use target recognition techniques. However, this requires extremely high SAR resolution and is not considered a viable concept for their time frame. o Correlate with terrain landmarks such as roads, using high resolution maps and/or prestored terrain map.	o Not for ISAS o ERIM's ARTRA (automatic radar target recognition automation) Also, Goodyear's work on poly-frequency radar.
2. Foliage penetrating radar that can detect tactical targets is not available.	o High false alarm rates due to tree trunks & terrain irregularities. o Poor resolution - high resolution ground map not available for terrain context information.	o Develop algorithm for rejecting false targets. o Determine and implement optimum all size. o Determine optimum long wave frequency of operation.	o Two programs (CONTAD study, development) to be let out in fall of 1980. o Feasibility has not yet been proven. Solution may not be on schedule.

Table 9.1-1. Technological Deficiencies (Continued)

TECHNOLOGY DEFICIENCY	CAUSE OF DEFICIENCY	PROBLEM SOLUTION	SOLUTION ON SCHEDULE? CURRENT DEVELOPMENTS
3. Automatic moving target recognition using radars is not available.	Technology not yet available.	o Continue development of ways to utilize target's doppler signature.	Not on schedule. Contractors are developing moving target classification data base.
		o ***Develop inverse SAR imagery.*** Follow up with auto detection algorithm development.	***Not on schedule.*** Contractors are developing target motion signature data base.
4. Automatic fixed target recognition with radars is not available.	The technology is not yet available.	1. Use very high resolution radar along with target signature algorithms being developed. Technique includes analysis of distribution of RCS scattering centers - parametric in target aspect angle. (ERIM's, ARTRA, Goodyear's polyfrequency radar study)	No, ISAS radars are not projected to have this capability.

Table 9.1-1. Technological Deficiencies (Continued)

TECHNOLOGY DEFICIENCY	CAUSE OF DEFICIENCY	PROBLEM SOLUTION	SOLUTION ON SCHEDULE? CURRENT DEVELOPMENTS
5. 3-D classifier not available.	Technology not yet available.	Continue development program (A 141) shown at right.	Solution on schedule. Target cueing and classification sensor program (A 141).
6. Automatic TV target cueing/classification system *not* available.	Technology not yet available.	Follow up A 124, A 125 programs (right column) with *prototype/production* development.	o Forward-looking active classification technology (silicon band TV plus LADIR A 125). o EO MMW target study (A 124)
7. MM wave radar range is inadequate - especially in heavy clouds/rain.	High mm wave attenuation in heavy clouds to rain. Receiver noise factor is high.	o Use high Tx peak power (not much improvement expected). o Develop lower noise receivers. o Develop coherent radar (coherent GMTI, DBS). This does not help RBGM, however.	No known current developments to improve mm radar range.

Table 9.1-1. Technological Deficiencies (Continued)

TECHNOLOGY DEFICIENCY	CAUSE OF DEFICIENCY	PROBLEM SOLUTION	SOLUTION ON SCHEDULE? CURRENT DEVELOPMENTS
8. Current guided tactical munitions lack standoff range for launch airplane survival against defended non RF-radiating targets. Current remotely guided weapons are unpowered-providing launch range proportional to launch altitude or are too expensive for tactical targets.	o Current tactical guided weapons require lockon before launch. Attack A/C must close to missile lockon range before launch. From low altitude this results in very close approach to target due to L.O.S. restrictions at low altitude. o When good L.O.S. is available, current tactical target guided weapons seekers can lockon at ranges greater than target recognition capability. This requires launch airplane to close to less than maximum missile launch range to fire.	Tactical weapon guidance that can: lockon after launch or does not require lockon.	WASP-minimissile being developed as a part of WAAM program. Yes - Production scheduled to begin 1987.

Table 9.1-1. Technological Deficiencies (Concluded)

TECHNOLOGY DEFICIENCY	CAUSE OF DEFICIENCY	PROBLEM SOLUTION	SOLUTION ON SCHEDULE? CURRENT DEVELOPMENTS
9. Sensor registration algorithm is not available.	Physical displacement of antennas (radars) and optical line-of-sight (TV, IR). Variation in antenna scan requirements for different modes (RBGM, GMTI, DBS, SAR). No previous work done.	o Use common apertures where it makes sense. o Develop algorithms for sensor registration.	o Part of ISAS Phase II task.
10. An integrated and detailed sensor integration system for effective target acquisition, classification and weapon delivery is not available.	Program has not been established.	Simulate the system concept and develop supporting algorithms, voting logic, etc.	Task to be performed in ISAS Phase II.
11. No proven sensor selection hardware is available. No sensor selection algorithms are available.	No previous requirement	o Perkin Elmer has candidate hardware requiring further design development. Other hardware possible. o Software solution possible. Develop algorithm.	Tasks to be performed in ISAS Phase II.

REFERENCE

1. Crew Workload Tactical Strike - Crew Workload Study, D180-26048-1, The Boeing Company, to be released.

APPENDIX

The ISAS statement of work requires that the contractor prepare, for USAF approval, a plan showing how the ISAS concepts will be ranked impartially without bias. The plan is to be presented before evaluations are started and must be included in the final report.

The sections in this appendix are the plan that was submitted to Lt. Jimmy Offen, ISAS project engineer, and Messrs. Don Sovine and Clint Coombs, AFWAL/AART-3, on approximately 18 January 1980.

Boeing submitted two plans. The alternate (Section H) was approved with the following changes:

1. Targets killed per dollar were deleted (C)

2. Probability of kill was added

3. Probability of survival was added

4. Graceful degradation was added

During study accomplishment, better visibility was provided when study requirements were defined in detail and when the behavior and availability of numerical data became known. Added changes are as follows:

1. The forms were streamlined and revised to provide better traceability.

2. Probability of kill and probability of survival were combined to provide figure of effectiveness.

3. Gross weight comparisons were used in lieu of aircraft performance. (E)

THE RANKING OF INTEGRATED STRIKE AVIONICS STUDY (ISAS) CONCEPTS

INTRODUCTION

The ISAS statement of work required that the contractor prepare, for USAF approval, a plan showing how the ISAS concepts would be ranked impartially and without bias. This report describes the ranking plan prepared by the Boeing Military Airplane Company.

Figure A-1 shows the final ranking form that will result when using the plan. There will be a final ranking form for each of the two altitudes considered in the study per weapon considered. Since Boeing plans to consider four weapons (MK-82R, TMD, IR Maverick, and WASP) this will mean two sets of four final ranking forms. Only one target is used in this plan.

The horizontal field in Figure A-1 permits each significant strike avionics system parameter to be listed. Under each parameter, such as Detection Range, the final ranking for each of the three ISAS concepts is entered. Final ranking is accomplished by summary ranks horizontally across the form. The concept with the lowest number is overall best, next lowest is second, etc.

Figure A-1 form is a derivative of the form shown in Figure 2.2.3-2 on page 66 of the Boeing ISAS proposal, D180-25264-1. A discussion of differences between the form shown here and Figure 2.2.3-2 will be found in Appendix A of this report.

Appendix A also provides a list of definitions covering terminology used in this report.

This report discusses how rankings are derived for the parameters shown in Figure A-1. The discussion is divided as follows:

A. Target Detection, Identification, and Acquisition
B. Weapon Selection
C. Targets Killed Per Dollar

FIGURE A-1 FINAL RANKING FORM

ALTITUDE = ________ WEAPON = ________

	PARAMETERS										
	DETECTION RANGE	IDENTIFICATION RANGE	ACQUISITION RANGE	TARGETS KILLED PER DOLLAR	ECM SUSCEPTABILITY	WEAPON SELECTION	EFFECT ON A/C PERFORMANCE	DELTA LIFE CYCLE COSTS	CREW WORKLOAD	RANK	FEATURES AND SELECTION RATIONALLE
ISAS CANDIDATE 1											
ISAS CANDIDATE 2											
ISAS CANDIDATE 3											

D. ECM Susceptibility

E. Effect on Aircraft Performance

F. Life Cycle Costs

G. Crew Workload

H. Alternate Plan

A. TARGET DETECTION, IDENTIFICATION AND ACQUISITION

Target acquisition, identification and lock-on are interpreted in Appendix A. Repeated for convenience, the phases of target acquisition are:

Detection	An object which could be the target is sensed.
Identification	The object is distinguished and recognized as the prebriefed target.
Lock-on	The object, having been detected and identified, is designated by a crosshair or cursor establishing its spatial coordinates for rate tracking, lock-on, or weapon aiming. The target has then been acquired.

Although the term target acquisition includes detection identification and designation, all three terms are carried to the final ranking form because of the emphasis on sensors. In this report the plan to handle target detection will be discussed as an example. Target identification and acquisition would be handled similarly.

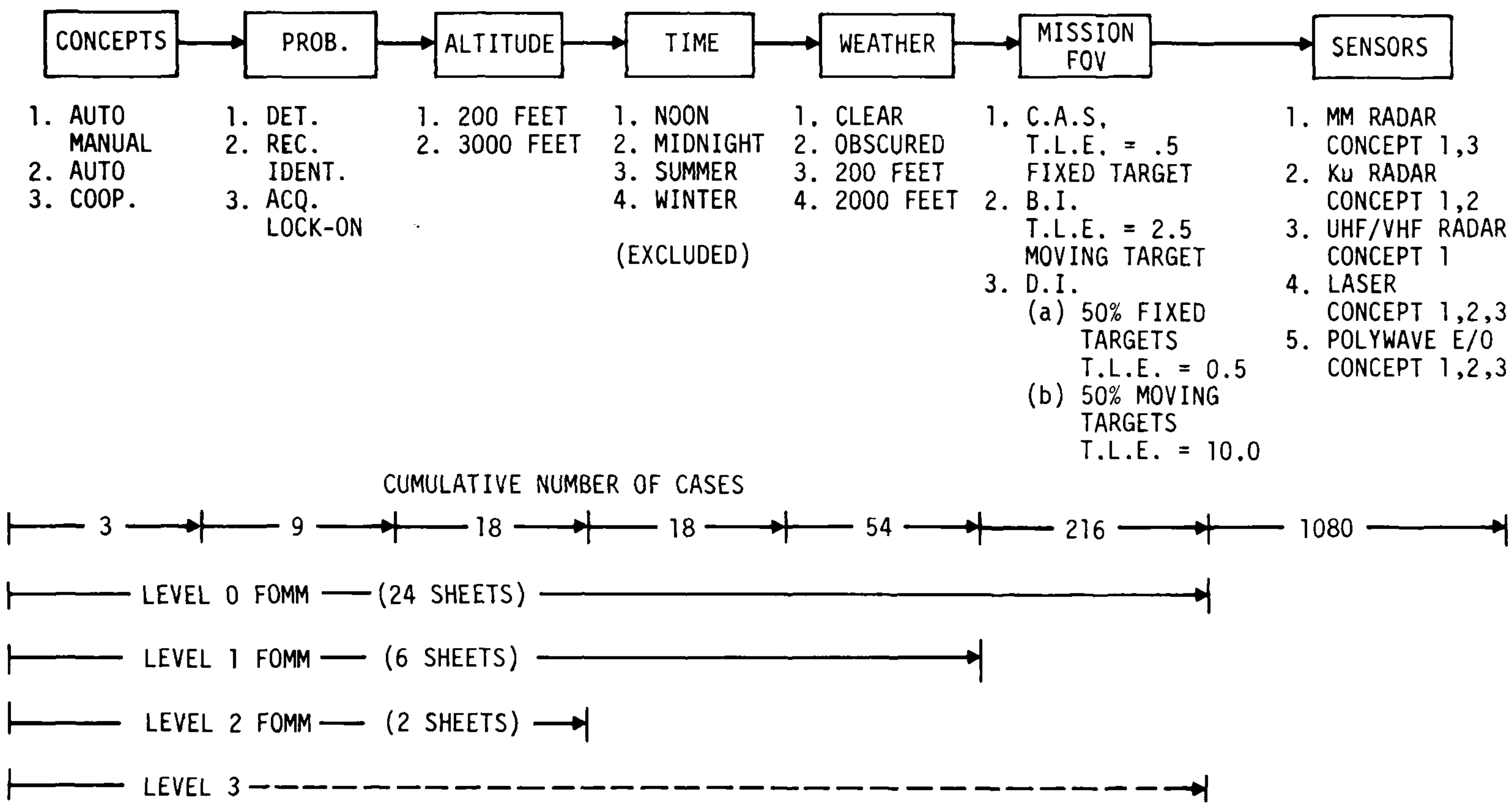
Variables

The many variables that influence target detection are pictured in Figure A-2. Even though study assumptions have aborted some cases (see below) and study conditions cancel others, a direct approach could result in one having to review over a thousand data points in order to rank the concepts. The purpose of this part of the plan is to combine the variables, by stages, into a more readily comprehensible form.

Starting from the right-hand side of Figure A-2 and moving to the left, the various levels of combination are:

FIGURE A-2 TARGET DETECTION VARIABLES

AIRCRAFT SPEED = 500 KNOTS
NON RADIATING TARGET SENSORS
TARGET = TANK
PARAMETERS NOT SHOWN ARE COMMON TO ALL CASES



FOMM = FIGURE OF MERIT MATRIX

Level Zero

In this level the sensors are combined into packages corresponding to the concept sensor configurations. Some sensors such as the laser (3-D Detector) are classifiers only, not used for detection, and they are not included in detection range considerations. Combination of sensors into concept packages reduces the total number of variables from 1080 to 216. The data are entered on figure-of-merit matrices (FOMM) like those of Figure A-3.

Level One

A weighting of missions is then accomplished to permit consolidating concept performance over all missions. The distribution of targets versus range is used as a basis for this consolidation. Level One FOMM's reduce the data to 54 variables.

Level Two

By consolidating the weather data in accordance with a weighting that corresponds to their annual-average-frequency-of-occurrence the weather variables can be reduced by a factor of three. Because of the cloud height and flight altitude relationships some weather conditions drop out because they are not applicable. For example, the clouds at 200 ft and 2,000 ft do not keep the airplane flying at 200 ft from seeing the ground.

Time of day and season have not been included as variables. Year-round averages have been used to accommodate all seasons and the sensor systems used are assumed equally capable by day or night (e.g., FLIR, active TV, radar, etc.).

Assumptions

In handling the variables of Figure A-2, the following assumptions apply:

a. Missions are defined as follows:

Close Air Support - All tank targets are assumed stationary and fighting (Target Location error of ± 0.5 KM)

VARIABLES

WEATHER CLEAR

A/C ALTITUDE 3,000 FT

TARGET MOTION NONE

MISSION DEEP INTERDICTION

REFERENCE

TERRAIN TYPE = FAIRLY FLAT FARMLAND DISTANT TREES (FIG. 84)

SPEED = 500 KTAS

TARGET = TANK

SENSORS		REFERENCE		DETECTION		RECOGNITION ID		ACQUISITION LOCK -ON	
		CONCEPT	LOS RANGE	RANGE MAX PD= .75	MAX. RANGE PD	RANGE PA = .9	MAX. RANGE PR	RANGE PR= .9	MAX. RANGE PR
MM RADAR	(1)	1, 3	< 12 KM						
Ku RADAR	(2)	1, 2		40	.75				
UHF/VHF RADAR	(3)	1							
LASER	(4)	1, 2, 3							
POLYWAVE E/O	(5)	1, 2, 3		39	.72				
		1							
		2		40	.93				
		3							
RANKING RANGE EACH CONCEPT	CONCEPT 1	X	X	X		X		X	
	CONCEPT 2	X	X	X	40	X		X	
	CONCEPT 3	X	X	X		X		X	

FIGURE A-3

SENSOR SYSTEM PERFORMANCE

Battlefield Interdiction - All targets are moving toward the FEBA (Target Location error of ±2.5 KM)

Deep Interdiction - 50% of the targets are stationary (Target Location error of ±0.5 KM) and 50% of the targets are moving along a line of communication toward the FEBA (Target Location error of ±10 KM)

b. The average speed of moving targets is 10 KT

Deletion and Replacement - All levels

During the preparation of the level zero through level two matrices it may be possible to accomplish a number of simplifying "common sense" deletions and replacements of data.

The most obvious example of potential simplification of detection range data is a case where the minimum allowable weapon release range is equal to or greater than the maximum target detection range. The case is useless and can be dropped from further consideration.

Similarly where detection range exceeds the required probability-of-line-of-sight (PLOS) range, the range at that PLOS should replace the original sensor range.

Sensor System Performance Matrix - Level Zero

The matrix table shown in Figure A-3 provides for initial data entry for the ranking study. In accordance with the sensor list in the first column, data are taken from the sensor performance curves generated in the ISAS Task II analysis and entered in the appropriate columns to the right. The detection performance of the sensors is then combined on a system level as peculiar to the concepts being ranked. There would be 24 Sensor Performance Matrices per weapon (16-2000 ft flight altitude cases and 8-200 ft flight altitude cases).

The weather, altitude, target and mission identifying data are shown in the upper left hand (L.H.) corner of Figure A-3. Reference terrain is shown at the upper right hand (R.H.) corner to qualify the line-of-sight limit that will be available for reference.

Within the matrix each sensor is listed in vertical order at the left. A reference column indicates in which concept(s) the sensor is used and provides the 0.5 probable line-of-sight for the indicated (above at right and left) altitude and terrain.

The Target Detection column provides for entry of sensor detection ranges from the data bank derived in the ISAS Task II analysis. The number entered is the detection range of the sensor with the maximum detection range at which all sensors have a significant detection probability (P_D). In the R.H. column of detection range the probabilities of detection of all sensors at that range are entered and the P_D's are summed statistically to define a concept level P_D at which the detection ranges of each concept will be determined. Several adjustments in range may be necessary to ensure a P_D that accommodates all concepts.

On the concept level composite curves of P_D versus Range for all the sensors used in the concepts must be prepared for all conditions (weather, mission, etc.). The applicable curve furnishes the composite P_D for a concept and is entered opposite that concept at the bottom of Figure A-3.

Example: Concept II, which combines a Ku band radar and common aperture EO sensors is used in this example. Formulation of data for the matrix table proceeds as follows:

1. From curves of sensor P_D vs range (generated from vendor data) make entries in accordance with the following:

   a. Examine all sensor performance data for Concept II and pick out maximum detection range at which all sensors have a P_D

      K_u Radar Detection range is 40 KM at P_D = .75.
      Enter on line 2 of Figure A-3 form.
      Common Aperture EO Detection Range is 39 KM. Enter on line 5 of Figure A-3 form (see handwritten entry).

      40 KM K_u Radar is highest detection range at P_D = 0.75 (P_{D2})

   b. Returning to curves of P_D vs range for the sensors common aperture, EO P_D at 40 KM is 0.72 (P_{D5})

c. The combined (system) probability of detecting a tank target is 1- (1-P_{D2}) (1-P_{D5}), P_D = 0.93

In assembling the data this common P_D must be used for all concepts. Where this is not possible, case handling will be required. The range at the common P_D on each concept consolidated sensor curve is entered in Figure A-3 as that concept's detection range.

Sensor System Mission Performance Ranking Matrix - Level One

The matrix form shown in Figure A-4 performs the next stage of data combination in the ranking plan. It consolidates the effect of missions by removing them as a variable. The system performances derived through Figure A-3 are tabulated for the missions at the left in Figure A-4. They are then subjected to a weighting which reflects the projected number of targets in each ISAS mission. There will be eight level one matrices per weapon (four per altitude).

Example—The Figure A-4 matrix is formulated as follows:

1. Weighting for the missions is extracted from the target distribution data shown in Figure A-5. (The target distribution data shown is an unclassified version of data provided in the ISAS Threat/Scenario document ADTC-TR-79-38. The unclassified version will be used in this example. Threat/scenario document data would be used in the ranking study.) At the ranges specified for close support (C.A.S.), battlefield interdiction (B.I.) and deep interdiction (D.I.), target distributions are

C.S.	8%
B.I.	30%
D.I. Moving Targets	31%
D.I. Fixed Targets	31%

VARIABLES

WEATHER CLEAR

A/C ALTITUDE 3,000 FT

REFERENCE

SPEED = 500 KTAS

TARGET = TANK

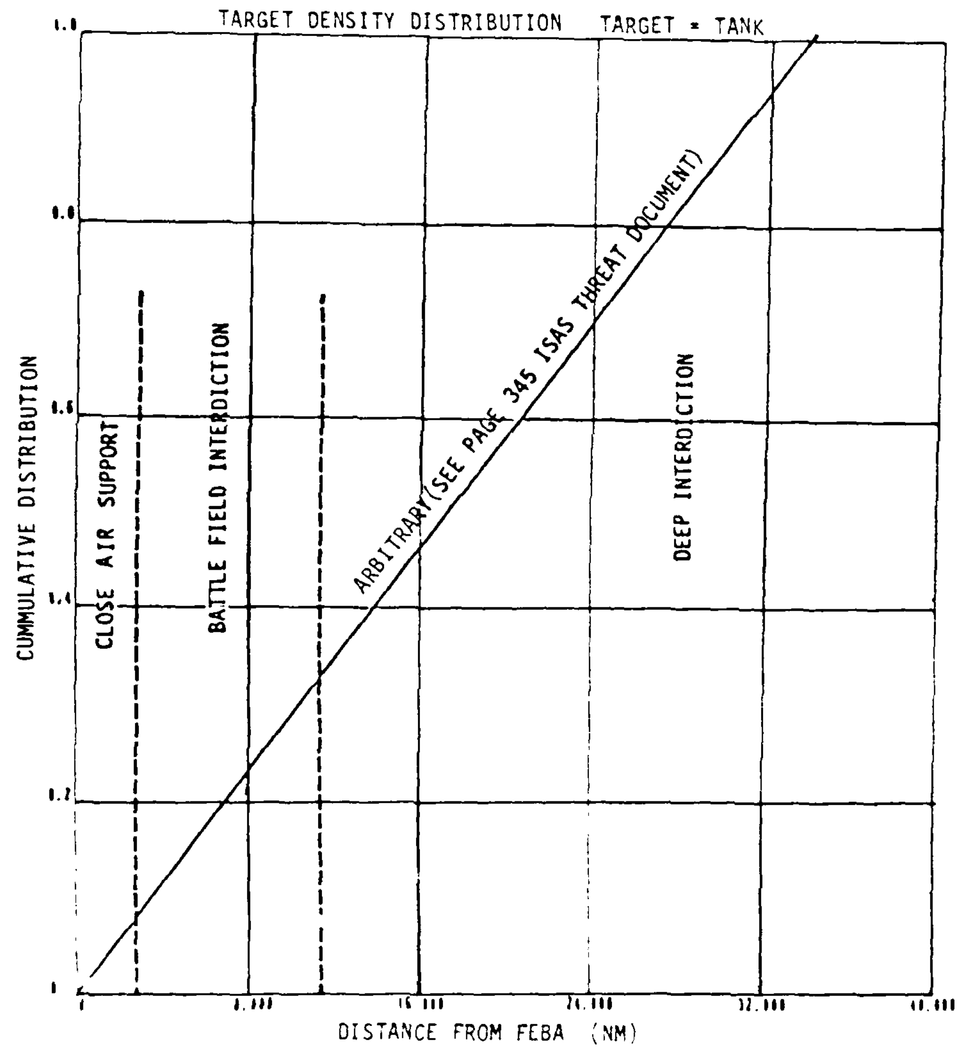
PARAMETER / MISSION — CONCEPT	DETECTION RANGE			RECOGNITION RANGE			ACQUISITION RANGE		
	1	2	3	1	2	3	1	2	3
CLOSE AIR SUPPORT FIXED TARGETS		9							
BATTLE FIELD INTERDICTION MOVING TARGETS		11							
DEEP INTERDICTION FIXED TARGETS		40							
DEEP INTERDICTION MOVING TARGETS		9							
RANKING RANGE USING WEIGHTED AVERAGE		19.21							

FIGURE A-4

SENSOR SYSTEM MISSION PERFORMANCE

FIGURE A - 5

TARGET DISTRIBUTION



2. A sample calculation using these weightings is shown below. The detection range numbers were extracted from the appropriate level zero matrices and are listed on the level one form.

Mission	%/100		Weighted
C.A.S. Fixed Targets	.08 x 9	=	0.72
B.I. Moving Targets	0.3 x 11	=	3.30
D.I. Fixed Targets	0.31 x 40	=	12.40
D.I. Moving Targets	0.31 x 9	=	2.79

Concept II Weighted Detection Range 19.21 KM

3. The Concept II Weighted Detection Range is then ready to enter in the appropriate location (bottom row under Concept II Detection Range) in the Sensor Performance Ranking Matrix.

Sensor System Performance in Weather - Level Two

In level two a further combination of mission variables is used to reduce the number of data matrices from eight to two per weapon. This is accomplished by weighting the weather conditions required for the study. Figure A-6 shows the matrix to be used in the combining process. For each weather condition (left-hand column) the applicable detection range is entered in the "Detection Range" column to the right. The weighting factor for weather must then be applied.

Weather Weighting Factor

The ISAS Threat/Scenario document provides data determining the year-round probability of a cloud-free line of sight for a range of altitudes from ground level to 8,000 ft altitude. This data is plotted in Figure A-7. Based on these annual averages, a cloud-free line of sight would occur about 50% of the time from 3,000 ft flight altitude (10-30^{O} lookdown) and 70% of the time from 200 feet. The plan reported here assumes that clear weather prevails for the same percentage of time as the cloud-free lines-of-sight.

VARIABLES
ALTITUDE 3,000 FT

REFERENCE
SPEED = 500 KTAS
TARGET = TANK

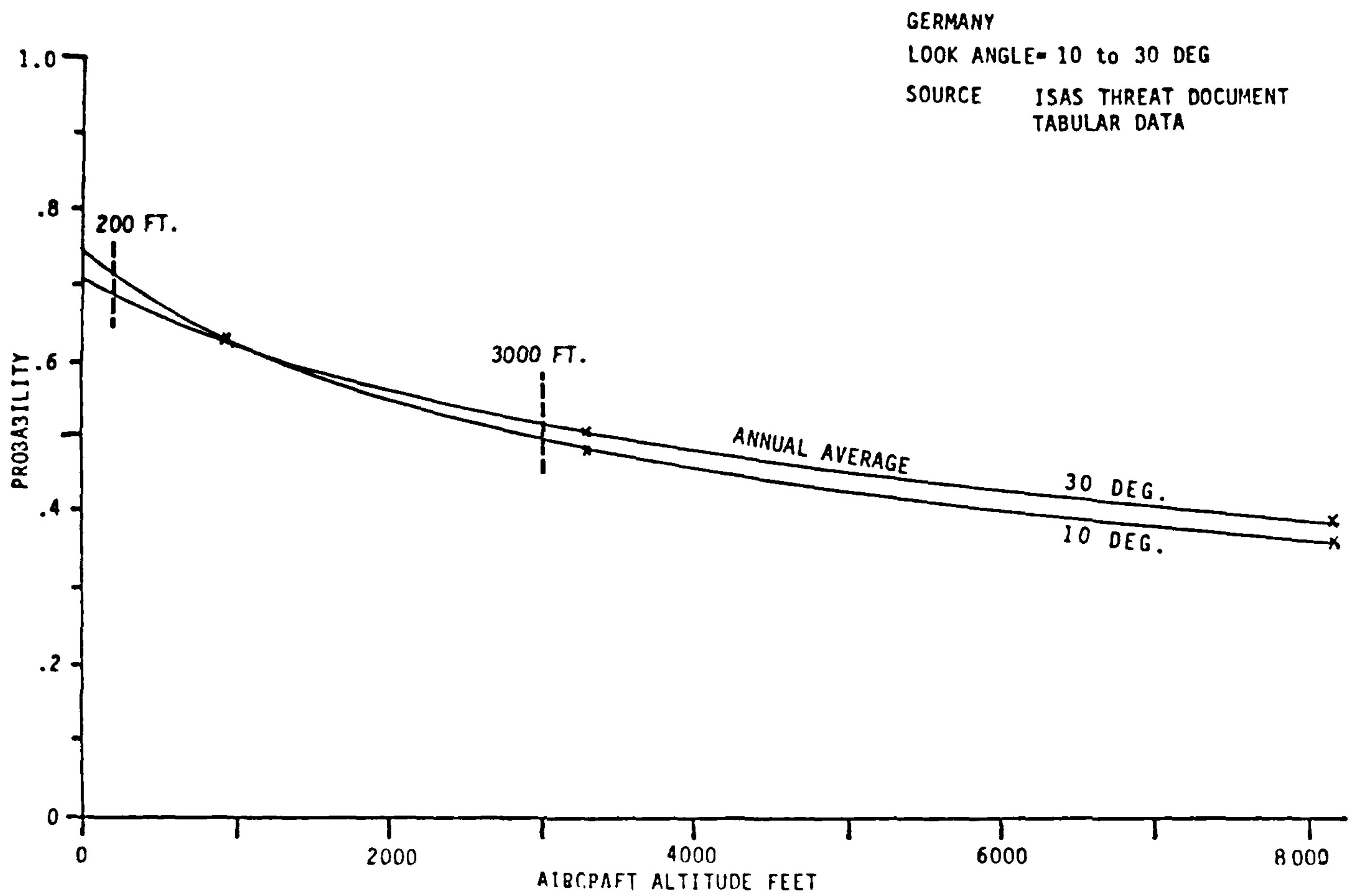
PARAMETER / MISSION — CONCEPT	DETECTION RANGE			RECOGNITION RANGE			ACQUISITION RANGE		
	1	2	3	1	2	3	1	2	3
CLEAR L.O.S.		19.21							
OBSCURED TARGET L.O.S. GROUND FOG		9.							
200 FT. CLOUDS		5.							
2000 FT. CLOUDS		8.							
RANKING RANGE USING WEIGHTED AVERAGE		12.79							

FIGURE A-6
SENSOR SYSTEM PERFORMANCE IN WEATHER

UNCLASSIFIED

FIGURE A-7

PROBABILITY OF CLOUD FREE LINE OF SIGHT



UNCLASSIFIED

As an example, clear weather is assumed 50% of the time at 3,000 ft flight altitude. The remainder of the time the weather is either:

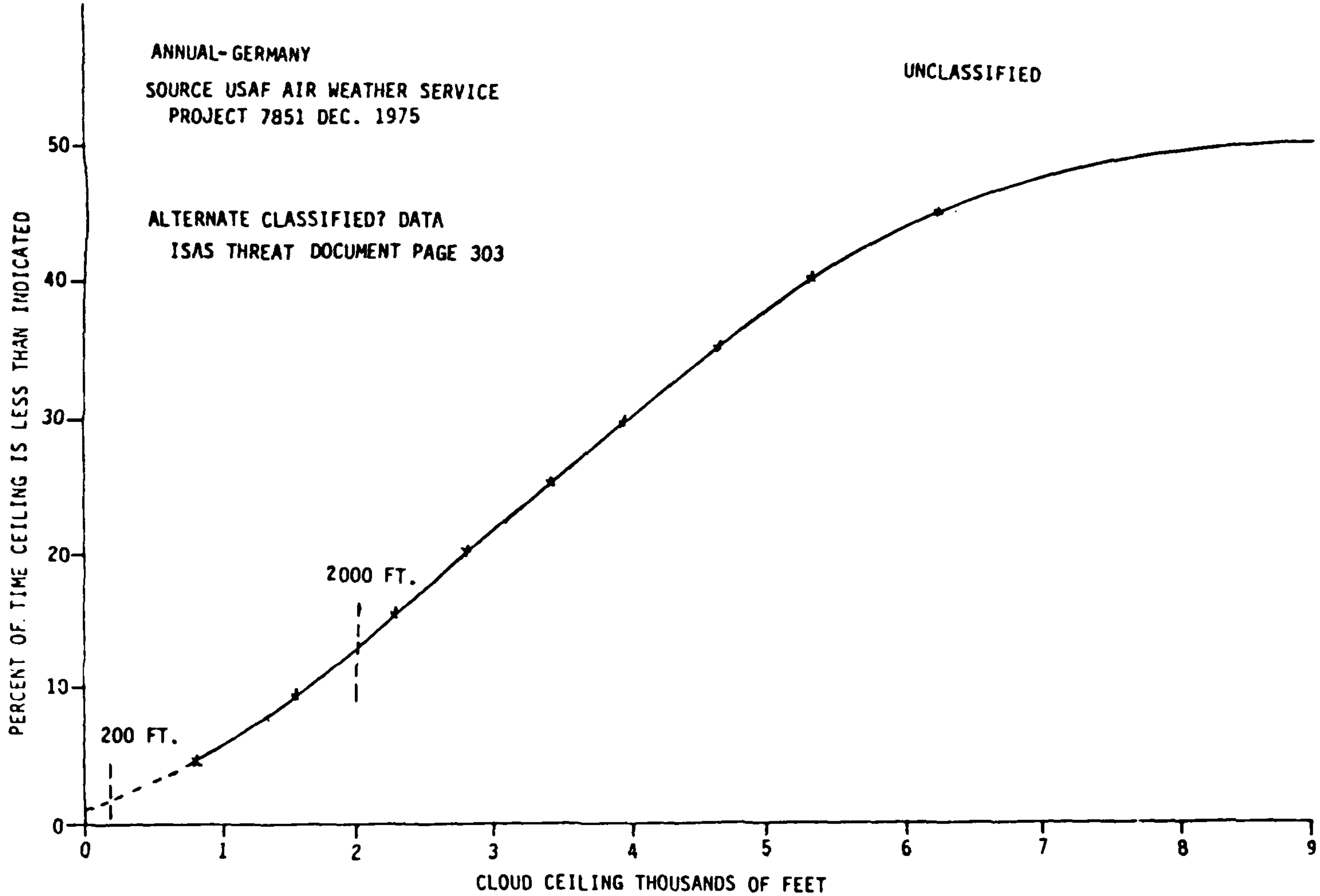
a. 2,000 ft cloud ceiling
b. 200 ft cloud ceiling
c. target is totally obscured by clouds

The ISAS Threat/Scenario document (page 303) also provides data showing the probability of cloud cover on an annual basis over Germany. Figure A-8 is a plot of data similar to that contained in the ISAS Threat/Scenario document. It will be used in this report to avoid classified data problems. In this example of weighting, cloud cover at 2,000 ft and above is expected 37% of the time. Similarly cloud cover starting at 200 ft is expected 46% of the time. The ceiling is 50 ft or less 1% of the time. These percentages provide a ratio which permits distribution (or weighting) of the remaining weather when there is less than a 50% chance of a cloud-free line of sight. The weightings for the various weather conditions as scaled to their respective parts of 50% are:

	Clear	=	50%
Weighting -	2,000 ft ceiling	=	0.22
Weighting -	200 ft ceiling	=	0.274
Weighting -	50 ft or less	=	0.006
	Sum		100%

The range data tabulated in Figure A-6 are modified by the appropriate weighting and totaled to provide a new all-weather range factor.

FIGURE A-8
PROBIBILITY OF CLOUD COVER



UNCLASSIFIED

Example—

The detection data entered in Figure A-6 are:

	Input Ranges		Weighting
Clear	19.21 KM x .5	=	9.61
Obscured (ground fog to 50 ft)	9 KM x .006	=	.05
200 ft ceiling	5 KM x .274	=	1.37
2000 ft ceiling	8 KM x .22	=	1.76
			12.79 KM

Concept II Weighted "all-weather" Detection Range

Ranking

The weighted data output of Figure A-6 is used to derive concept ranking for detection capability. The weighted ranges are normalized to the highest range number and then a rank 1, 2, or 3 is assigned to each concept range. First rank is to the highest number, second to the next highest, etc.

Example—

	Weighted Detection Range	Scaling	Absolute Rank
Concept I	11	.74	3
Concept II	13	1.0	1
Concept III	12	.80	2

Scoring

The final rankings on Figure A-1 are summed horizontally across the field of the Final Ranking Form. All factors are assumed equally important and no weighting is used. Final rank is determined by score with the lowest score being overall number one, next lower number two, etc.

B. WEAPON SELECTION

The ability of each concept to successfully deliver weapons over the scope of weather and mission variables will be scored one weapon at a time, for each altitude. When the Figure A-1 final ranking forms are compared with each other the concept's weapon selection ranks can be consolidated to determine the most versatile concept for weapon delivery.

Weapon Selection Ranking Matrix

Figure B-1 illustrates the data form that will be used for weapon selection ranking. This matrix has the concepts arrayed on the vertical axis and the ISAS missions on the horizontal.

"Points" to be entered are obtained by processing the Figure A-3 Sensor Performance Matrix-Level Zero sheets, by weapon, to establish the total number of weather conditions on each mission where the concept's sensors provide sufficient target acquisition range to allow a successful weapon release. Notes have been entered in Figure B-1 at Concept II to illustrate that in a 3,000 ft altitude release condition three of the four weather conditions (200 and 2000 ft clouds and target obscured by fog) prohibit locked-on launch of an Imaging IR Maverick making it possible to grant only a maximum of one "point" per mission for an Imaging IR Maverick at that release condition. The only permissible release is clear weather - for a maximum of one release.

The concept scores are obtained by summing points across the matrix for each concept. The concept with the highest score ranks #1, next highest #2, etc.

The versatility of the concepts can be ranked over all weapons by summing their rankings for each of the four weapons at a common release altitude.

ALTITUDE 3,000 FT

WEAPON IMAGING IR MAVERICK

NUMBER - WEATHER CONDITIONS WHERE USEFUL RELEASE IS POSSIBLE

CONCEPT #	CAS	BI	D.I. FIXED TGTS	D.I. MOVING TGTS	SCORE	RANK
CONCEPT #1						
CONCEPT #2	1 MAX	1 MAX	1 MAX	1 MAX	4 MAX	
CONCEPT #3						

FIGURE B-1 WEAPON SELECTION RANKING MATRIX

C. COST PER TARGET KILLED

The measure of system effectiveness chosen to rank variations of concept candidates is the target killed per dollars spent (KM)

$$KM = 1/(CAR \cdot AL = CPW \cdot NW) \tag{1}$$

where:

CAR	=	production cost of the "n+1" aircraft where n is based upon a 20 billion buy.
AL	=	aircraft lost per target killed
CPW	=	cost per weapon
NW	=	number of weapons expended per target killed

In order to derive the number of aircraft lost and weapons expended per target killed it is necessary to determine the number of sorties or attacks required to kill a target (N_{STK}). A target kill is defined as 70% of its elements killed. The optimum method of achieving this is to ensure that the probability of killing a single target element (P_{KE}) is .7.

Therefore, N_{STK} can be determined by the following process:

$$P_{K/A} = P_{STA} \cdot P_{SWL} \cdot P_{TA} \cdot P_{TI} \cdot P_{WF} \cdot P_{WK} \tag{2}$$

where:

$P_{K/A}$	=	probability of killing a target per attack
P_{STA}	=	probability that an attacker survives to the target area
P_{SWL}	=	probability that an attacker survives to weapon launch

P_{TA} = probability of target acquisition

P_{TI} = probability of target identification

P_{WF} = probability of weapon system function

P_{WK} = probability of weapon killing the target given launch

$$P_{KE} = .7 = 1-(1-X)(1-P_{K/A})^{N_{STK}} - X(1-P_{K/A})^{N_{STK}+1} \qquad (3)$$

where:

N_{STK} = the highest integer in N_{STK}

x = the proba ty that N_{STK} +1 attacks are required

An estimate of N_{STK} can be made by solving:

$$A = Ln\ (1-.7)/(1-P_{K/A}) \qquad (4)$$

then setting N_{STK} = A and using (3) to solve for "x" yields:

$$X = (1-(\ (1-.7)/((1-P_{KA})^{N_{STK}}\ )))/(P_{K/A}) \qquad (5)$$

so then

$$N_{STK} = N_{STK} + 1 \qquad (6)$$

and

$$N_W = N_{STK} \cdot N_{WA} \qquad (7)$$

where:

N_{WA} = the number of weapons expended per attack

The number of aircraft lost is determined by:

$$AL = N_{STK} (1-P_{MS}) \qquad (8)$$

where:

P_{MS} = the probability that an attacker survives through exit

The probabilities of attacker survival are scenario dependent in that it defines capability of each defense type, the number of each type. The capability of a defense type is defined by the probability of an attacked survival per exposure $P_{S/E}$ and the probability of exposure P_E, i.e., the expected offset capability against the attacker R_O divided by one-half of the attack corridor width. The number of encounters is dependent upon the depth of the target behind the FEBA.

CLOSE AIR SUPPORT	BATTLE FIELD INTERDICTION	DEEP INTERDICTION

FEBA	5 KM	20 KM	100 KM

The three legs of an attackers' flight profile are:

TO = penetration to target area

AT = penetration after active target detection system turn on to weapon launch

EXIT = through exit

The probability of attacked survival on any leg (P_{SLEG}) is determined by:

$$P_{SLEG} = \prod_{i=1}^{N} (1-(1-P_{S/E}\, P_E\, P_A))^{N_{LEG}} \qquad (9)$$

where:

i = defense type index

N = number of types in game

N_{LEG} = number of potential encounters on this leg

P_A = probability that the defense is available

then

$$P_{STA} = P_{STO} \cdot P_{SAT} \tag{10}$$

and

$$P_{SM} = P_{STA} \cdot P_{SEXIT} \tag{11}$$

Once the variations of the concept candidates have been ranked then a rating factor for each concept can be determined by:

$$CR_j = \sum_{k=1}^{N} KM_k(12) \tag{12}$$

where:

j = concept index

k = variation index

The concepts will then be ordered from the highest CR_j to the lowest and given the integer rank of 1, 2, ..., to the maximum number of concepts to be considered.

D. ECM SUSCEPTIBILITY

Introduction

Electronic warfare (EW) is becoming an important factor in modern warfare. EW is accomplished through the use of Electronic Support Measures (ESM), and active Electronic Countermeasures (ECM). ESM is passive detection of electromagnetic radiation from emitting targets such as ISAS radars. Active electronic countermeasures is the transmission of electromagnetic energy which prevents or reduces an enemy's effective use of the electromagnetic spectrum. This makes the use of electronic counter-countermeasures (ECCM) a necessity in order to reduce system susceptibility to ECM.

The Soviet Union considers jamming resources as weapon systems to be used in concert with other attacks on enemy systems. Their objectives are to disrupt communication, command and control, and especially control of weapons. Their basic ECM approach is "brute-force," i.e., use maximum effective radiated power (ERP) in lieu of sophistication, even though they have deception jammers.

The ISAS Threat/Scenario document provides a listing of airborne as well as ground jammers that could affect ISAS operation especially at high altitudes. In this threat evaluation only ground jammers will be considered. The typical jammers against radar and communication systems are the narrowband and wideband noise jammers, and the deception jammers operating at the corresponding U.S. communication frequencies.

Concept Ranking

This ECM susceptibility evaluation is limited to qualitative estimates which should be satisfactory for the concept comparisons and ranking. Each ISAS sensor is evaluated against all types of countermeasure techniques and the corresponding sensor susceptability is estimated such as "very high" etc. This is based on the ISAS sensor capability versus each ECM threat without the considerations for mission targets, raid size, operating range and the number of jammers/threats in the target area.

A summary matrix of the ISAS sensors and system susceptibilities to various countermeasures is shown in Table D-1. Representative data are used here for security reasons.

In the case of the radar sensors a high power sidelobe jammer (stand-off jammer) which could saturate a radar receiver front-end, even though radar antenna sidelobes are 35 to 45 db down, will be considered. The possibility of jamming an E-O sensor will be considered. The effect of IR active countermeasure against IR sensors will also be evaluated. The vulnerability of laser spot seeker signal system to deception/spoofing will also be examined.

ECM susceptibility scoring of the individual sensors is represented in the last column of Table D-1. The "Total Score" is based on the following:

Degree of Susceptibility	Weighting Points
Very High	5
High	4
Medium	3
Low	2
Very Low	1
None/NA/Negl.	0

The concept scoring is the summation of the individual "Total Score" of sensors included in each concept. However, some weighting may be required; for example with three radars in Concept I, where each radar might be highly susceptible, the probability that all three radar sensors will be jammed completely and simultaneously is quite low. It should be three times harder to jam 3 systems than a single radar in another concept; hence the effective "average" radar susceptability for Concept I will be given by:

$$(N_1+N_2+N_3)/(3 \times 3) = N_{Avg}$$

The above weighting approach is not applicable to multiple sensors that could be inoperable simultaneously by a single jammer. In Concept III no account will be taken for the ECM susceptibility of the long range radar in the cooperative aircraft.

The concept ranking and total scores of the three concepts are illustrated in the following table:

TABLE D-1 SYSTEM SUSCEPTABILITY TO COUNTERMEASURES*

CONCEPT	AFFECTED SENSOR/ SYSTEM	TYPE OF COUNTERMEASURE: SIDE-LOBE RF JAMMER	E/O JAMMER	SMOKE GENERATOR	CHAFF	FLARES	TOTAL SCORE
I	VHF RADAR	HIGH	NA	NONE	LOW	NONE	N_1
I,II	Ku-BAND RADAR	HIGH	NA	NONE	LOW	NONE	N_2
I, III	MM RADAR	LOW	NA	NEGLIGIBLE	LOW	NONE	N_3
I,II,III	COMMON APERTURE LASER SCANNER	LOW	LOW	HIGH	NA	VERY LOW	N_4
I,II,III	COMMON APERTURE ACTIVE/PASSIVE TV	HIGH	HIGH	HIGH	NA	LOW	N_5
I,II,III	COMMON APERTURE FLIR	HIGH	HIGH	HIGH	NA	LOW	N_6
I,II,III	COMMON APERTURE LASER RANGE FINDER	LOW	VERY LOW	MEDIUM	NA	VERY LOW	N_7
III	LASER SPOT SEEKER	LOW	LOW	VERY HIGH	NA	VERY LOW	N_8
III	JTIDS	HIGH	NA	NONE	NONE	NA	N_9
III	GPS/NAV STAR	LOW	NA	NONE	NONE	NA	N_{10}

CONCEPT I SCORE = $\frac{N_1+N_2+N_3}{9}+N_4+N_5+N_6+N_7=S_1$

CONCEPT II SCORE = $N_2+N_4+N_5+N_6+N_7=S_2$

CONCEPT III SCORE = $N_3+N_4+N_5+N_6+N_7+N_8+N_9+N_{10}=S_3$

* ALL EVALUATIONS IN THIS TABLE ARE FOR ILLUSTRATIVE PURPOSES ONLY.

Table D-2. ISAS CANDIDATE CONCEPT RANKING FOR ECM SUSCEPTIBILITY

Concept	Total	Rank
I	S_1	1 (Lowest S_i)
II	S_2	2 (Medium S_i)
III	S_3	3 (Highest S_i)

E. EFFECT ON AIRCRAFT PERFORMANCE

Task II Analysis will include a first order analysis to determine if there are excessive installation costs or adverse effects on performance on weapon carrying capability. These considerations are made with respect to F-4, F-15, F-16, and A-10 aircraft.

The results of the above study will be reviewed and categorized. Two categories will be established for each concept on each airplane. They will be: (1) can be installed without significant cost or performance penalty, (2) cannot be internally installed without significant redesign due to excessive cost and performance penalties. For each low penalty installation in one of the four airplanes each concept will score a "point." The concept ranking will be based on point summation. Highest score will rank first. The scores will be reviewed and any case handling adjustment in score will be justified and documented.

F. LIFE CYCLE COSTS (LCC)

In accordance with task V of the ISAS statement of work, Boeing has begun developing life cycle costs for the ISAS concepts. These costs when complete will be normalized using the lowest LCC as standard. The ranking of concept LCC's will be assigned in order from lowest LCC (1) to highest (3).

G. CREW WORKLOAD EVALUATION

Scenario Development

Foremost in the task to evaluate the crew workload for each of the Integrated Strike Avionics concepts is the development of scenarios for the significant variables. These variables are initially; mission type, attack altitude, weather, weapon delivery parameters, sensor suites, and integration/automation levels for the candidate concepts. It is thought, that during the course of the analysis, the number of variables may be reduced by identifying those which are the same or which have little effect in case-to-case comparisons. In the development of the scenarios, each mission phase is being identified and analyzed to determine similar mission phases for each of the three mission types and to determine the number of variations needed to be considered. Again, duplication or slight differences will be used to reduce the analysis effort and point out the critical areas for comparison. For instance, a cursory examination of the crew workload in the Battlefield Interdiction and Deep Interdiction missions would seem to indicate that many mission phases and variables lie identical, and that both missions might be considered as one mission with only timeline differences with a reduced number of variables. The final number of scenarios selected will be called the screening scenarios that can be applied to all strike avionics concepts.

An example of various mission phases for the Deep Interdiction Mission is illustrated in Figure G-1. A typical variation, in this case a pop-up at standoff and minimum time exposure ranges, is illustrated in Figure G-2. The target acquisition range will depend on the sensors available for acquisition (avionics suite configuration) and mission conditions (weather, mission altitude, line-of-sight probability, weapon delivery parameters, etc). These factors will influence the stand-off range and hence the survivability of the strike aircraft as a function of pop-up exposure time and launch range from target defenses.

Crew Workload Evaluation

The approach to the evaluation of the crew workload for each avionic concept will be based on a subjective evaluation using the scenarios and variables discussed above, crew detailed functional task allocations, and weapon/aircraft/crew interface matrices. These analyses in combination with mission timelines will be used as a basis to

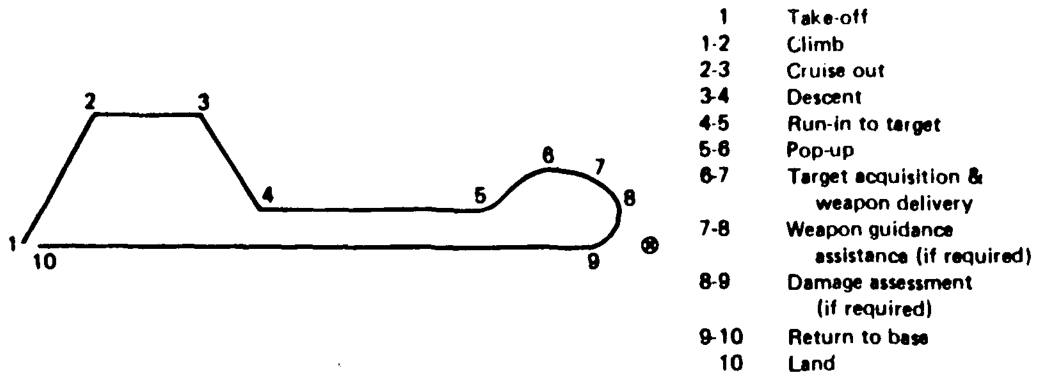


FIGURE G-1 INTERDICTION MISSION PHASES

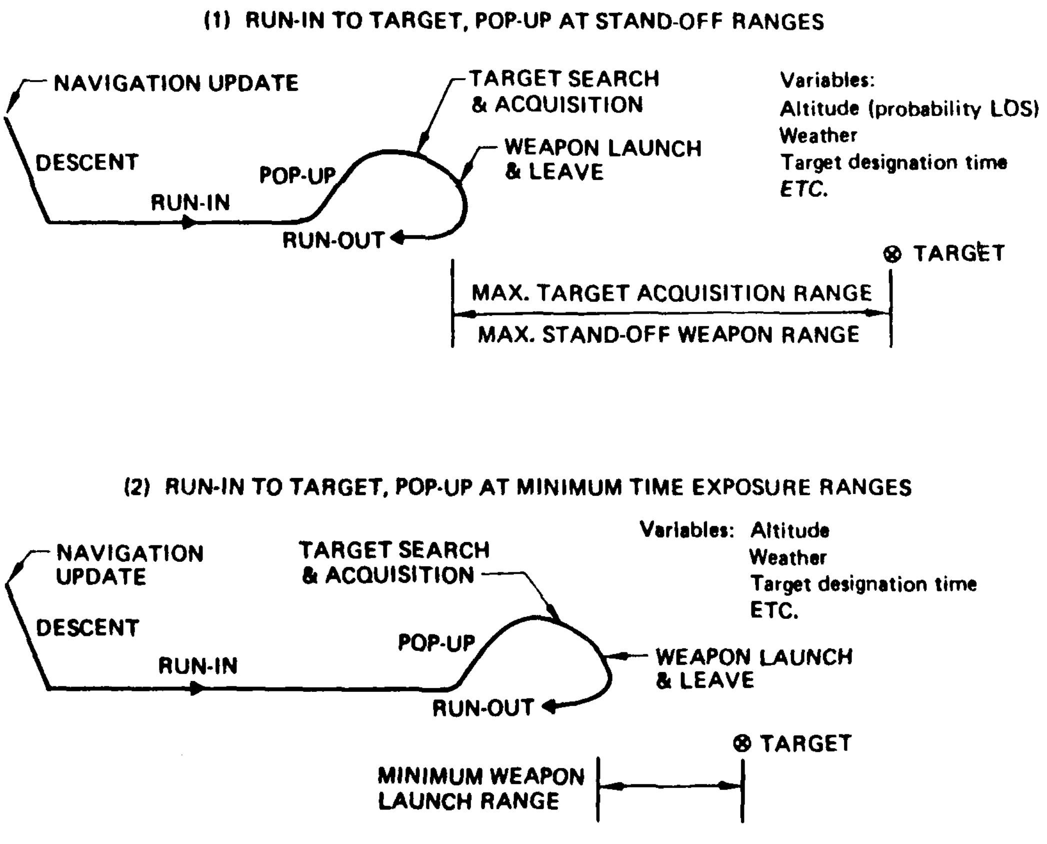


FIGURE G-2 TYPICAL INTERDICTION RUN-IN TO TARGET subjectively estimate the crew workload by mission phase for each avionic concept, its associate scenarios and variables. As the evaluation progresses, results will indicate whether a one-or two-man crew is necessary to accomplish the mission based on each scenario and variables applied to the individual concepts. The final result of this effort will be the construction of subjective crew task loading matrices (a measure of workload) for each screened scenario that is applied to an individual strike avionic concept. These crew subjective task loading matrix values for critical mission phases will then be weighted for a value to be applied for the particular strike avionics concept. The study flow process is illustrated in Figure G-3.

The key analysis elements of the study are the crew functional task allocations, weapon/aircraft/crew interface, and subjective crew task loading matrices which are used to provide the crew workload weighted value. A brief description of each follows:

Crew Functional Task Allocation - Table G-1 illustrates the crew functional task allocation analysis for each strike avionics concept. The chart lists the major functional task and corresponding crew tasks associated with the major functional task. The right side of the table divides the mission into its corresponding phases. A series of symbols is used to describe in which of the three categories the man task is placed based on the integration/automation level of the specific strike avionics concept for each listed crew task. The three task categories are:

1. The circle indicates tasks that cannot be automated and therefore must remain an operator task.

2. The triangle indicates those tasks that are man-machine function, i.e., tasks that are accomplished or monitored by the machine (automation) but must be displayed (information) to the operator. Many of these tasks need only be displayed to the operator when systems are out-of-tolerance conditions.

3. The square indicates a machine (automated) function with a man override requirement. Again, information displayed is required for human operator judgment.

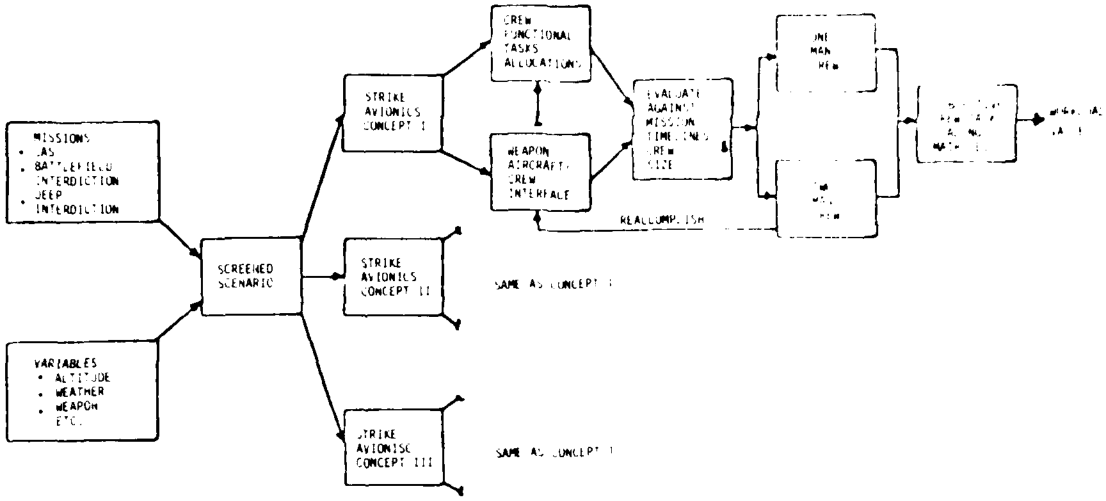


FIGURE G-3 CREW WORKLOAD EVALUATION STUDY FLOW

TABLE G-1 CREW FUNCTIONAL TASK ALLOCATION

CONCEPT ____

FUNCTION	CREW TASK	MISSION PHASE: TAXI & TAKEOFF	CLIMB	LOITER INGRESS	PENETRATION	TARGET ACQUISITION	WEAPON DELIVERY	EGRESS	DESCENT	LAND
MONITOR AIRCRAFT SYSTEMS	• MONITOR LIMITS OF AIRCRAFT SYSTEMS	○	△	△	△	△	△	△	△	○
	• EXECUTE PROPER PROCEDURES FOR ABNORMALITIES; BACKUP AUTO SYSTEMS	◑	◑	◑	◑	◑	◑	◑	◑	◑
MONITOR FLIGHT SYSTEMS	• CONTROL, MONITOR AND BACKUP	○	○	○	○	○	○	○	○	○
	• ACT IN SERIES TO AUTO SYSTEMS	○	○	○	○	○	○	○	○	○
	• MANAGE BY EXCEPTION DELEGATED FUNCTION	○	○	○	○	○	○	○	○	○
NAVIGATION	• OBSERVE SPEED CONTROL (A/S, G/S, IMC, AOA)	○	△	△	△	△	△	△	△	○
	• MONITOR AND CONTROL HEADING	○	△	△	△	△	△	△	△	○
	• SELECT NAVIGATION MODE	◑	◑	△	△	△	△	△	◑	○
	• SELECT WAYPOINTS AND DESTINATIONS		◧	◧	◧	□	□	◧	◧	
	• MONITOR AND UPDATE PRESENT POSITION		◑	◑	◑	◑	◑	◑	◑	
	• MONITOR BEARING, DISTANCE, AND TIME TO WAYPOINT		△	△	△	△	△	△	△	
	• OBSERVE GMT, ELAPSED, AND SENSOR TURN ON TIMES		◭	◭	◭	◭	◭	◭	◭	
	• MONITOR DELTA TIME ON TRACK		△	△	△	△	△	△	△	
	• MONITOR ALTITUDE, ALTITUDE RATE, FLIGHT PROGRAM ALTITUDE	○	△	△	△	△	△	△	△	○
	• SYSTEM STATUS MONITOR	△	△	△	△	△	△	△	△	△
	• SELECT EQUIPMENT	□	□	□	□	□	□	□	□	□

ETC.

The shaded symbols indicate those tasks that can be shared by both crew members in a two-man crew aircraft.

In identifying the categories of the tasks, no degrated mode of failure analysis is considered. This approach is reasonable since the final output of the evaluation is the relative comparison of the crew workload for each of the strike avionics concepts. Each relative comparison will be responsive to the distinctive features of the particular concept being evaluated. This study is not sensitive to all the variables (weather, display or sensor field of view, etc.) that complicate the sensor target acquisition ranking considerations.

This analysis provides a measure of crew task automation of each avionics concept which is used in estimating the subjective crew task loading.

Weapon/Aircraft/Crew Interface

The effect of various weapon systems on the crew workload is identified by Table G-2. The basic crew function is listed along with the aircraft equipment necessary and the crew/weapon interfaces. This provides a measure of the complexity of the target acquisition/weapon delivery problem of each strike avionics concept using the four selected weapons.

Crew Subjective Task Percentage Matrices - Utilizing the analysis data from the Functional Task Allocation and Weapon/Aircraft/Crew Interface, a crew subjective task percentage matrix is constructed for each mission, scenario, and concept. A sample format is shown in Figure G-4. Again, these estimates will not consider degraded mode analysis, variations in standard crew skill, and stress factors. A subjective crew task percentage is estimated for each box relating mission phases with major functional tasks. Values from 1 to 100 are assigned for each crew member task at each mission phase as a judgment of workload. A value of 100 percent represents the highest possible workload percentage value for a crew member function task during a mission phase. The summation of all numerical values for a mission phase is the task loading value of that crew member during that mission phase.

The crew task loading output will be one ranking per altitude per weapon for each concept. Each case crew task loading will be normalized to reflect a value of 1.0 for a

TABLE G-2 PRELIMINARY WEAPON/AIRCRAFT/CREW INTERFACE CONCEPT __

WEAPON	BASIC CREW FUNCTION	AIRCRAFT EQUIPMENT	CREW/WEAPON INTERFACES
MK 82 R	VISUAL SEARCH/ACQUISITION AIRCRAFT CONTROL FOR LAUNCH	FIRE CONTROL LAUNCH CONTROL, SENSOR DISPLAY, FLIR VIDEO DISPLAY	EQUIPMENT CONTROLS FIRE CONTROL DISPLAY(ON HUD) STATUS DISPLAYS
TACTICAL MUNITIONS DISPENSER (TMD)	SAME AS MK 82 R	SAME AS MK 82 R EXCEPT CCIP IS HUB POINT	SAME AS MK 82 R
AGM-65D (IR MAVERICK)	VISUAL OR SENSOR SEARCH/ ACQUISITION, AIRCRAFT CONTROL FOR LOCK-ON, SEEKER LOCK-ON	FIRE CONTROL LAUNCH CONTROL, SENSOR DISPLAY, FLIR VIDEO DISPLAY	EQUIPMENT CONTROLS, FIRE CONTROL DISPLAY, FLIR VIDEO DISPLAY, STATUS DISPLAYS
WASP	SENSOR SEARCH/ACQUISITION, TRANSFER TARGET LOCATION, AIRCRAFT CONTROL FOR LAUNCH	FIRE CONTROL LAUNCH CONTROL SENSOR-NAVIGATION DISPLAY	EQUIPMENT CONTROLS, FIRE CONTROL DISPLAY, STATUS DISPLAYS

1 - MAN CREW
MISSION ________
CONCEPT ________

		FUNCTIONAL TASKS								
MISSION* PHASE	DESCRIPTION	CONTROL AIRCRAFT	MONITOR A/C SYSTEMS	NAVIGATION	COMM	TARGET ACQUISITION	WEAPON DELIVERY	SELF DEFENSE	ECM, EW	MISSION ACTIVITIES
1	TAKE-OFF	40	10	15	5					
1-2	CLIMB	30	10	10	5					
2-3	CRUISE OUT	25	7	10	2					15
3-4	DESCENT	25	12	15					5	5
4-5	RUN-IN TARGET	35	15	15				5	5	
5-6	POP-UP	35	10			40				
6-7	TARGET ACQUISITION, WEAPON DELIVERY	25	5			35	30			
7-8	WEAPON GUIDANCE	35	15	5			35			
8-9	DAMAGE ASSESSMENT	25	10					10	5	20
9-10	RETURN TO BASE	25	10	15						5
10	LAND	35	10	15	5					

* MISSION PHASES CORRESPOND TO INTERDICTION MISSION PHASES SHOWN IN FIGURE G-1

FIGURE G-4 CREW SUBJECTIVE TASK PERCENTAGES - MISSION_, CONCEPT_, task loading of 80 (80% considered routine workload). Ranking of the concept is determined from the normalized summation of the numerical values generated in the study. The first ranking will be the lowest workload, the second, the next lowest, etc. The best concept from a crew workload standpoint is the concept which has the least numerical value for crew task loading. In the cases of a two-man crew, the added loading from common duties or coordination tasks will be adjusted. Coordination task loading will not be added and common duties added only once.

H. ALTERNATE PLAN

The list of parameters across the Final Ranking Matrix of Figure A-1 includes a significant number of items that are not independent of each other. Target Acquisition Range, for example, is a function of Target Lock-on Range which is a function of Identification Range - a function of Detection Range. Weapon selection is in turn a function of these ranges. Cost per Target Killed is based on the result of all of these.

The contractor suggests an alternate plan which would remove the target acquisition elements and the weapon selection element from the list of ranking parameters. The data to investigate the deleted elements will still be obtainable within the data generated in arriving at cost per target killed, but redundancy would be removed from the final ranking.

Raw data input to the systems analysis model will be provided from the detailed sensor performance data from which the inputs to Figure A-3, Sensor Performance Matrix - Level Zero, would have been derived.

Figure H-1 illustrates the revised Final Ranking Form.

FIGURE H-1 FINAL RANKING FORM (ALTERNATE)

	PARAMETERS							
	TARGETS KILLED PER DOLLAR	ECM SUSCEPTABILITY	WEAPON SELECTION	EFFECT ON A/C PERFORMANCE	DELTA LIFE CYCLE COSTS	CREW WORKLOAD	RANK	FEATURES AND SELECTION RATIONALLE
ISAS CANDIDATE 1								
ISAS CANDIDATE 2								
ISAS CANDIDATE 3								

APPENDIX A

DIFFERENCES AND DEFINITIONS

As integrated strike avionics studies have progressed, it has occasionally been necessary to "pin down" a term by establishing a definition for it so that it will receive consistent handling. The study is also providing a degree of insight that encourages reformulation of some of the categories and formats that date back to the Boeing ISAS proposal. A discussion of definitions and changes pertinent to this report follows:

Definitions

For the purposes of this study, the following definitions apply to Target Acquisition, Identification, and Lock-on:

Target Acquisition - is the process whereby the aircrew/sensor searches and detects various objects, inspects these objects, and then decides that one of them is actually the prebriefed target for lock-on and weapon delivery (Reference 1 and 2). The target-acquisition task is completed with lock-on, at which point the weapon-delivery task commences.

Detection -	An object is distinguishable from its background or surroundings (potential target).
Classification -	An object is recognized as natural, man-made, fixed or mobile (possible target).
Identification -	An object is recognized as the prebriefed target, i.e., SAM site, tank, truck.
Target Lock-on -	The target position is designated in three-dimensional space and can be tracked as it changes position relative to the weapon delivery system.

References

1. The Boeing Company, Low-Altitude, High-Speed, Visual Acquisition of Tactical and Strategic Ground Targets, Part V, Seattle, WA., D6-2385-5, November 1965.

2. Joint Chiefs of Staff, Joint Task Force - III, Low Altitude Test 4.1 Visual Target Acquisition, Sandia Base, New Mexico, December 1966.

Differences

Figure I-1 is a copy of Figure 2.2.3-2 "Typical Ranking Matrix" from Boeing ISAS proposal D180-25264-1. A number of the parameters listed across the matrix have been deleted and others changed, in the plan reported here. These are briefly discussed below.

Probability of Attack - In this report this parameter has been expanded into three subparameters of target acquisition - Detection, Identification, and Lock-on. These subparameters are defined in this Appendix.

Target Error - CAS, BI, DI - These errors influence the sensor capabilities that establish ranges and probabilities of detection, identification, and lock-on. They are redundant and have been deleted because their importance does not merit ranking.

Exposure Time, Probability of Survival, Targets Destroyed per Mission - These parameters are included in Cost per Target Killed. They can be traced in data sheets related to cost per target killed.

CONDITIONS
F-4 AIRCRAFT
GRAVITY WEAPON
MEDIUM ALTITUDE
CLOUDS 2000 FT AGL
TARGET #1

TOTAL CASES
4 AIRCRAFT
2 WEAPONS
2 ALTITUDES
3 WEATHERS
MAX = 48 CASES/TARGET

	PARAMETERS													
	PROB. ATTACK (DET. ACQ. I.D.)	TARGETING ERROR CLOSE SUPPORT	TARGETING ERROR B.F. INTERDICTION	TARGETING ERROR DEEP INTERDICTION	TARGETS DESTROYED PER MISSION	EXPOSURE TIME	PROB. SURVIVAL	ECM SUSCEPTABILITY	WEAPON SELECTION	EFFECT ON A/C PERFORMANCE	DELTA LIFE CYCLE COSTS	CREW WORKLOAD	RANK	FEATURES AND SELECTION RATIONALLE
ISA CANDIDATE 1														
ISA CANDIDATE 2														
ISA CANDIDATE 3														

FIGURE I-1 "2.2.3-2" TYPICAL RANKING MATRIX

☆U.S.Government Printing Office: 1980 - 757-002/259