An Integrated Systems Approach to Helicopter System Design using Redundant Multiplexing Techniques

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ABSTRACT

This paper presents a general Integrated Multiplex System (IMS) approach based on tying together major aircraft subsystems through a redundant and survivable information handling system. The system utilizes units in each major zone of the aircraft to interface and control aircraft and mission equipment. These are tied together through a system of multiplexed digital data buses to a group of multiprocessors which replace other aircraft processors and relay logic. A system of interactive multimode cathode ray tube (CRT) displays are used to display flight instrumentation and other control functions.

Benefits of this system approach to aircraft design include: reduced weight, aquisition cost, cost of ownership, pilot workload and maintenance.

A typical system configuration and analysis results for typical military attack and aircraft are presented based on many application studies led by the Author at Harris.

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1.0 Summary

An increasing complexity of aircraft electronics has been needed to meet new missions. This has created many problems for the aircraft users, manufacturers and subsystem suppliers in the areas of integration, construction, pilot workload and field supportability. The technology and program experience exist today to solve many of these problems by making use of new developments in electronics and hydraulics to cut across functional boundaries and integrate major subsystem functions such as:

- Avionics systems
- Electrical systems
- Flight control
- Navigation
- Instrumentation
- Weapon control and visionics
- Caution, warning and diagnostics

This paper presents a general Integrated Multiplex System (IMS) approach based on tying together major aircraft subsystems through a redundant and survivable information handling system. The system utilizes units in each major zone of the aircraft to interface and control aircraft and mission equipment. These are tied together through a system of multiplexed digital data buses to a group of multiprocessors which replace other aircraft processors and relay logic. A system of interactive multimode cathode ray tube (CRT) displays are used to display flight instrumentation and other control functions.

Because aircraft logic, system management, flight control, fire control, navigation and graphics display functions are all performed in the common system multiprocessors, these pieces of separate equipment are eliminated and there is a significant net reduction in hardware and hardware acquisition cost.

Because digital data bus handling is used to transmit information between all zones of the aircraft, the Integrated Multiplex System approach results in a large savings in wire installation cost and weight. Signals and power distribution, handled by multiplex remote units in each zone, are short and direct which greatly simplifies modification or battle damage repair.

If done properly, the actual number of interfaces with the aircraft is reduced because wiring is more direct and because much equipment is replaced by the IMS itself.

The IMS acquires data from all functions of the aircraft continuously to monitor aircraft status and manage its redundant paths. As part of this function the IMS also isolates faults automatically to a line replaceable unit for easy maintenance.

The IMS will meet all redundancy and survivability needs and is lower in cost and weight than conventional approaches. It is also simpler to repair and support in the field and is extremely flexible and economical to change for future growth because of its modularity.

Crew workload is significantly reduced because the IMS will supply all the data the crew needs clearly displayed on multiple CRT's when they need it. It can also supply more detailed data on one button request. The system constantly monitors and compares data via redundant paths to perform the routine tasks of aircraft and subsystem management. Thus, the flight crew is freed from their equipment technician tasks to apply their innovation and skill to the mission outside the aircraft.

The largest single disadvantage of multiplex integration is that it must be applied broadly to as many systems as possible to gain the maximum benefits. For this reason Multiplex Integration is most advantageous to new aircraft programs or major aircraft retrofit.

One of the best applications where Multiplex Integration produces the strongest advantages is in small tactical aircraft and new helicopter programs.

Basic considerations and application results for typical military Scout and Attack helicopters are summarized in Section 6.0.

2.0   The Apparent Integration Problem

The History of Aviation has been built on the Airframer who integrates and sells the aircraft. He has been traditionally supplied with Electronics, Avionics, Flight Control systems and Engines by many individual and sophisticated specialists who each build excellent equipment.

For most of its life the Avionics industry has been outstanding in developing better and better functional black boxes: including radios, radio control, Doppler radar, air data computers, generator control boxes and so on.

We have done the same with aircraft instrumentation and flight control: Attitude/Direction Indicator instruments, better altimeters, better Horizontal Situation Indicators, power boost actuators, and stability augmentation.

Electrical distribution is still much the same with better generators, circuit breakers, wires and terminals.

Each of these sophisticated aircraft subsystems comes with its own wire, gauges, control panels, computers and software. Although all of these functions must work together to complete the mission, very little real progress has been made in their integration. These subsystems generally depend on the pilots to do the integration. The pilots are often heavily charged as equipment operators, technicians and troubleshooters or tending the aircraft rather than using their tactical preception and skill to fly a mission.

Our industry has forced the aircraft manufacturer into the ever increasing role of system integrator. He must understand and select all of these boxes and try to connect them in the best possible way with masses of

wire terminal boards and custom interface boxes. Some are very
sophisticated.

The wiring installation and checkout add weight, reduce reliability,
:.icrease maintenance, increase the production cost and often destroy
flexibility required by many users for different missions or with different
equipment.

The Users of these aircraft both commercial and military have met the
challenge of our sophisticated electronics and hydraulics with a breed of
very sophisticated highly trained pilot/technicians who are justifiably
proud. This creates a heavy burden in extensive pilot and maintenance
training and logistics cost.

For all involved this situation has led to custom integration which
is very difficult and costly to change and cannot easily take advantage of
new technology.

Many of these problems can be dramatically reduced by multiplexed
Integration.

3.0   Multiplex Programs Experience

The development of an Integrated Multiplex System architecture
by Harris was a response to common problems and solutions found in its
experience.

Some excellent programs are making use of current technologies
to integrate portions of their aircraft using multiplex data buses,
processors and multimode displays such as the F-18, F-16 and Boeings's
commitment to the 767 and 757 cockpit. However, the largest and most
fruitful program for multiplexed integration to date has been the
development of the B-1 bomber by Rockwell. Harris Corporation was proud to
be a major designer, developer and supplier of the electrical multiplex
system which would replace much of the aircraft electrical system to
integrate and control over 13,000 electrical/electronic interfaces. (See
Figure 3.0).

The B-1 aircraft was designed from its inception to utilize this
multiplex integration in major subsystems including: electrical power
management, fuel management, engine control and instrumentation, aircraft
hydraulic control (e.g., wing articulation, landing gear, spoilers), weapon
systems, avionics, and system diagnostics.

All B-1 aircraft have been flying very successfully for over 4 years
and 1100 hours.

Even with the older technology used then, the benefits to the B-1 were
very significant and typical of those which can be attained in small
aircraft using present technology.

Harris has worked closely with the engineering of most major
helicopter and aircraft companies to fully evaluate various multiplex
applications for present small aircraft and helicopters. Typical examples
will be shown at the end of this paper but in general include:
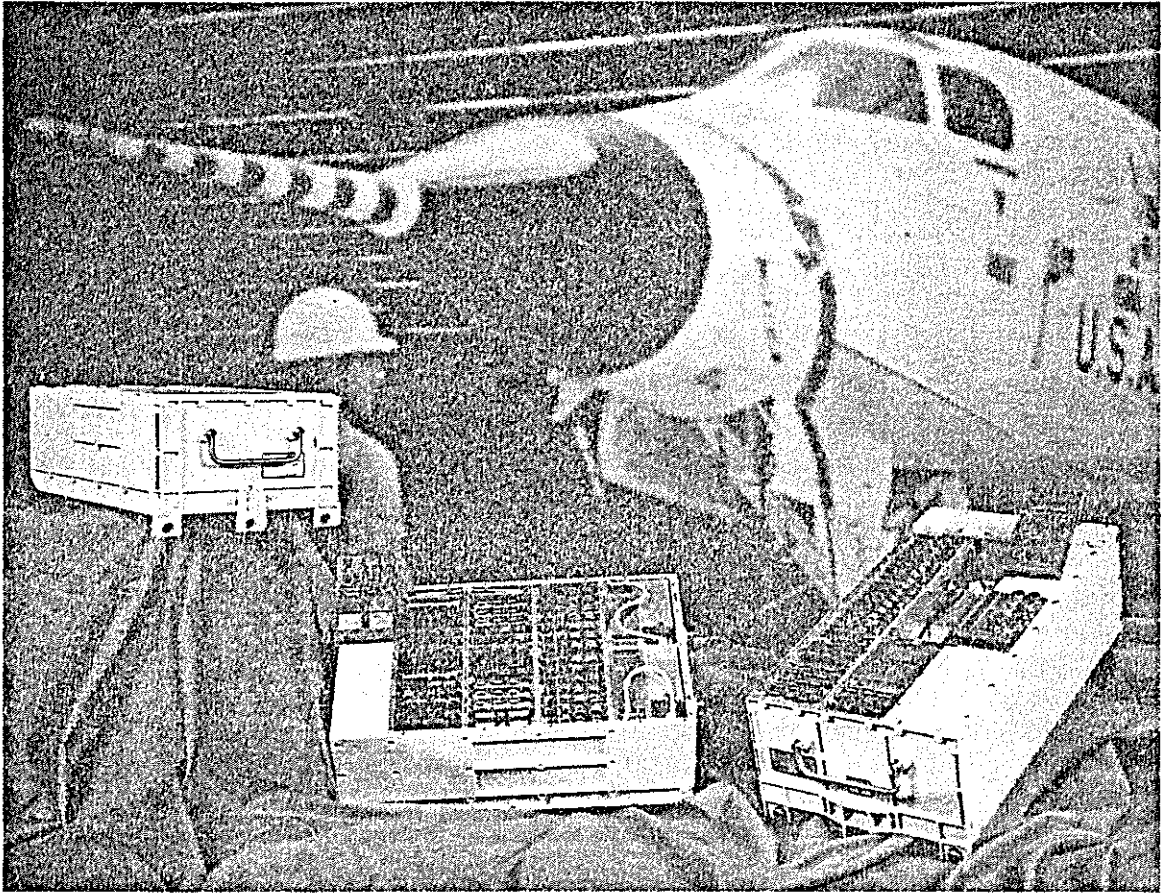
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Figure 3.0. Flight Multiplex Equipment Developed by Harris for
the B-1 Bomber

- A net saving in aircraft subsystems weight of 25 to 30 percent
- A reduction in Hardware or equipment weight of 10 to 25 percent
- An improvement of 6:1 in reliability
- A very large reduction in maintenance rates and times

4.0   Applying New Technologies

A major improvement in typical aircraft integration problems lies in integration across functional boundaries using a common system architecture which is flexible to change, redundant and survivable.

New electronics design and software resources are now available which make this task feasible for even small aircraft using proven techniques.

These new resources include:

- High speed microprocessor based multiprocessors
- High density digital memory
- High intensity Cathode Ray Tube displays
- Solid State Power Controllers
- Monolithic digital and analog interface circuits
- Advanced survivable hydraulics and
- Redundant/survivable high speed Electromagnetic Interference immune digital data buses to tie it all together.

The system architecture designed to utilize these resources is probably more important than any other factor. Although specific standards and methods must be chosen now to meet the immediate requirements, we recognize that change is the status quo. Thus, unless the system has extreme flexibility it will be useless for future growth and expansion.

A highly flexible general system architecture has been developed by Harris to accomplish the multiplex integration. The design encompasses:

- Hardware
- Software, and
- Support equipment

The system developed is modular in all areas and can be grown, shrunk or changed to match new technology; easily and efficiently; so that it is good from program to program or from application to application.

4.1   General Operational Aircraft System Architecture

Figure 4.1-1 shows the basic system elements which are briefly discussed below:

- Zone remote units are placed in each zone of the aircraft to service electrical inputs or outputs regardless of function. One such box might interface with air data sensors, a radio, electrical loads, hydraulics or a flight control actuator. The size of a zone is usually a 3 foot (1 meter) sphere and is also limited by the expected sphere of battle damage.

- All zone remote units convert the conventional analog syncro or other input/output traffic to a serial digital stream or plug in circuit cards for communication to all other zones.
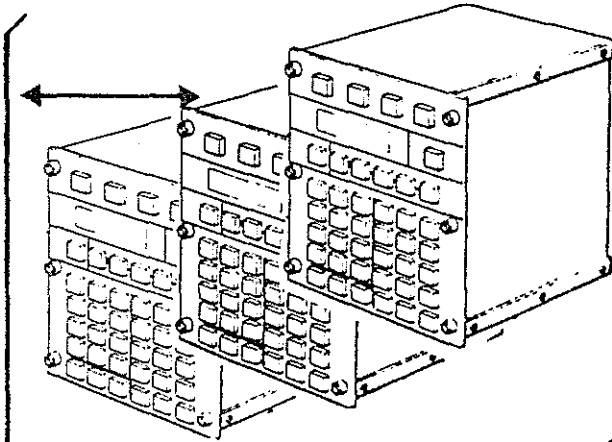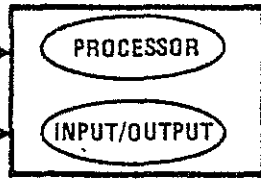
MULTI FUNCTION DISPLAYS
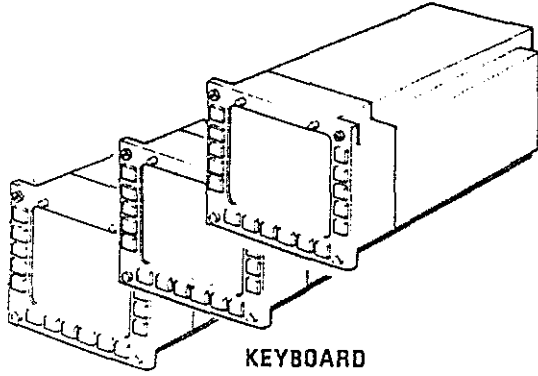
MULTIFUNCTION CRT DISPLAYS
- FLIGHT INSTRUMENTATION
- RADIO CONTROL AND TUNER
- NAVIGATION

KEYBOARD

MULTIFUNCTION KEYBOARD
- SINGLE RADIO DISPLAY
- FLIGHT DIRECTOR
- NAVIGATION ENTRY
- RADIO CONTROL ENTRY

EXPANDABLE MULTIPROCESSOR
(450 KOP INCREMENTS)

MIL STD
1553B
DATA BUS
SYSTEM
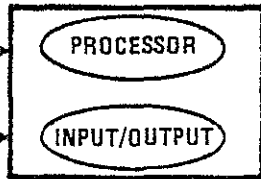
PROCESSOR
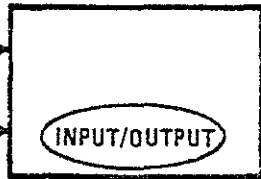
INPUT/OUTPUT

ZONE REMOTE

EXPANDABLE MEMORY
(8 K WORD INCREMENTS)

PROCESSOR

INPUT/OUTPUT

ZONE REMOTE

EXPANDABLE VARIETY
OF INPUT/OUTPUT CARDS

B: LEVEL
ANALOG
POWER CONTROL
AC, DC
SYNCRO

INPUT/OUTPUT

ZONE REMOTE

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Figure 4.1-1.   Modular Integrated Multiplex System

- A minimum of two of the zone remote units also contain system processors in the same housing and act as independent and redundant system controllers. Each processor is a multiprocessor based on one or more plug in modular Z8000 microprocessors which share the load, plus a complete set of memory including nonvolatile read write memory for navigation or radio frequency storage.

- The architecture is designed to permit any number of plug in processors in as many zone remote units as needed to provide dual, triple, or quad redundancy or to operate in a distributed federated load sharing system. Dual multiprocessors have been found sufficient for most configurations but more will be necessary for future full fly-by-wire systems.

- Individual units are not internally redundant because the most likely failure mode is battle damage which would destroy local redundancy. Interface redundancy for dual, triple or more paths to critical mission equipment can be provided by cross-strapping drive from nearby units from a safe distance. Interfaces and software have been designed to accommodate this multiple redundancy.

- Keyboard units are used for each crew member to call data from or enter data into the system. Flight plans waypoints, frequencies and other diagnostic data may also be entered or removed using a conventional audio cassette tape recorder and prepared or analyzed elsewhere.

- Multimode displays are separate from keyboards for mounting convenience. They are standard 525/875 line high brightness CRT's with function select keys. Graphics generators plug into other system units and provide a wide range of specialized flight, graphic and alphanumeric displays. Displays can be provided in a wide variety of sizes and configurations.

Harris has devoted considerable development to the interface circuitry for each circuit type. We are particularly proud of our low voltage drop high current switches and power controllers, see Figure 4.1-2. As shown, the Harris Corporation research has lead from good bipolar designs to even better MOSFET designs with a total power dissipation of under 0.86W for the 5A power controller and 0.43W for a 2A power controller.

The major units of the system, such as Master Units and Remote Units, are designed as 1/2 ATR wire wrapped card trays to hold the system cards in the MIL-E-5400 Helicopter environment and provide cooling.

All system functions are on plug-in circuit card modules of the same size (approximately 4.5 inches wide x 6 inches length use area). These can be used where appropriate in any system and are uniquely keyed to prevent improper use.

Spare card slots are provided so that additional processor CPU's, additional memory, or additional Input/Output circuit cards can be added and simply wired in. By ordering a larger or smaller housing, any reasonable grouping of card functions can be accommodated for future mounting requirements.
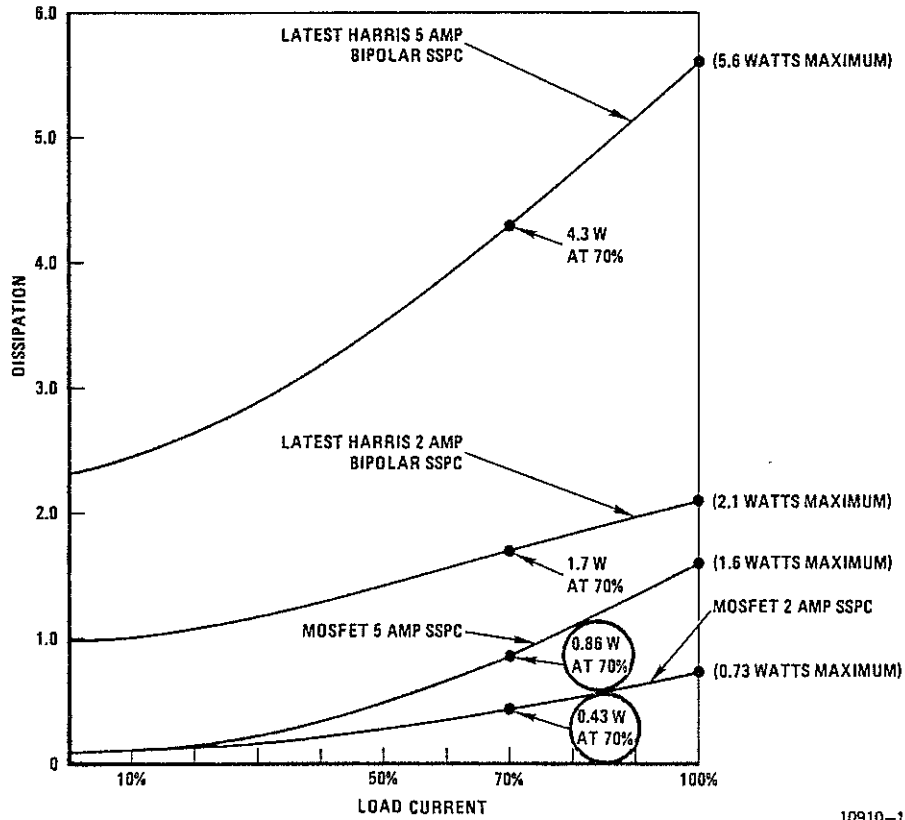
Figure 4.1-2. SSPC Power Dissipation

A typical group of equipment (with combined display/keyboard) is shown in Figure 4.1-3.

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Figure 4.1-3. Typical Multiplex System Equipment Packaging

4.2　Software Modularity Programming and Growth

Software is written in assembly language and can be converted to higher order FORTRAN or JOVIAL if needed later. Each operational software module is handled separately so that software changes can be made with minimum effect to other modules.
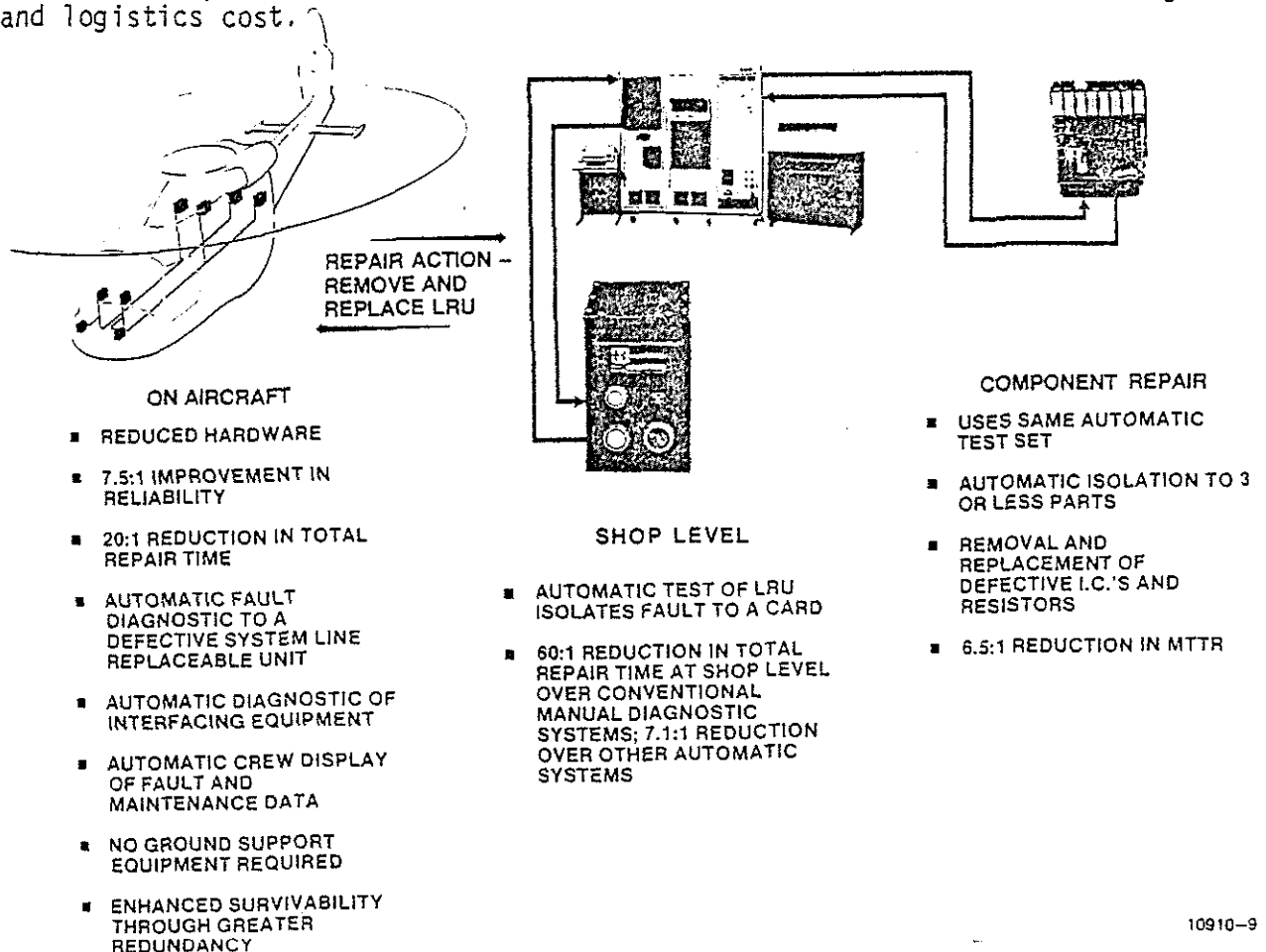
The basic architecture anticipates all requirements including flight control, fly-by-wire or fly-by-optics, weapons and visionics. Growth to at least 128K words is provided for.

Harris has designed a software preparation facility and Hot Mockup Support (validation) Station which will provide the capability to write, modify, and validate programs. In addition, the equipment is designed for growth and is upward compatible with a wide range of airborne microprocessors, ground based processors and processor peripherals.

4.3　Maintenance and Support Equipment

The IMS processors will monitor and record all in-flight faults detected as well as recording engine and drive train trend data. Caution and warning messages will alert the crew in flight. This information can also be recalled for maintenance after the aircraft has landed. This will improve aircraft checkout and turn-around times significantly.

Figure 4.3 shows the field support flow. Note the dramatic reduction in maintenance time at all levels. This is primarily due to use of an aircraft diagnostics built into the Integrated Multiplex System units and automatic shop test isolation to a failed card. This will reduce training and logistics cost.

REPAIR ACTION --
REMOVE AND
REPLACE LRU

ON AIRCRAFT

- REDUCED HARDWARE
- 7.5:1 IMPROVEMENT IN RELIABILITY
- 20:1 REDUCTION IN TOTAL REPAIR TIME
- AUTOMATIC FAULT DIAGNOSTIC TO A DEFECTIVE SYSTEM LINE REPLACEABLE UNIT
- AUTOMATIC DIAGNOSTIC OF INTERFACING EQUIPMENT
- AUTOMATIC CREW DISPLAY OF FAULT AND MAINTENANCE DATA
- NO GROUND SUPPORT EQUIPMENT REQUIRED
- ENHANCED SURVIVABILITY THROUGH GREATER REDUNDANCY

SHOP LEVEL

- AUTOMATIC TEST OF LRU ISOLATES FAULT TO A CARD
- 60:1 REDUCTION IN TOTAL REPAIR TIME AT SHOP LEVEL OVER CONVENTIONAL MANUAL DIAGNOSTIC SYSTEMS; 7.1:1 REDUCTION OVER OTHER AUTOMATIC SYSTEMS

COMPONENT REPAIR

- USES SAME AUTOMATIC TEST SET
- AUTOMATIC ISOLATION TO 3 OR LESS PARTS
- REMOVAL AND REPLACEMENT OF DEFECTIVE I.C.'S AND RESISTORS
- 6.5:1 REDUCTION IN MTTR

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7830A　　　Figure 4.3.　Integrated Multiplex Equipment Support

5.0 Typical Light Attack or Scout Application

This section summarizes a typical system application for a light attack or Scout Aircraft.

5.1 Functions Served

Figure 5.1-1 shows typical functions handled by the IMS. Functions shown with a diamond are largely taken over or replaced by the IMS.

INTEGRATED HELMET DISPLAY AND SIGHT SYSTEM			▲ AUTOMATIC DATA LINKS
PILOT NIGHT VISION/FLIR			PROVISION FOR JAMMERS
AIRCRAFT PERFORMANCE MONITOR	▲		▲ ARMAMENT MANAGEMENT
MULTIMODE PRIMARY FLIGHT DISPLAYS	▲		▲ TARGET ACQUISITION SYSTEM INTERFACE AND COMPUTATION
THREE (3) DIMENSIONAL AUTOMATIC NAVIGATION	▲	INTEGRATED MULTIPLEX SYSTEM REDUNDANT AND SURVIVABLE	▲ STABILITY AND NAVIGATION
FOUR (4) AXIS AUTOPILOT	▲		SURVIVABILITY EQUIPMENT CONTROL
BACKUP FLY-BY-WIRE	▲		▲ RADIO COMMUNICATIONS CONTROL AND DISPLAY
FUEL MANAGEMENT	▲		▲ ELECTRICAL POWER SWITCHING AND MANAGEMENT
ENGINE INSTRUMENTATION	▲		▲ CAUTION AND WARNING COLLECTION AND DISPLAY
			INTERCOMMUNICATION

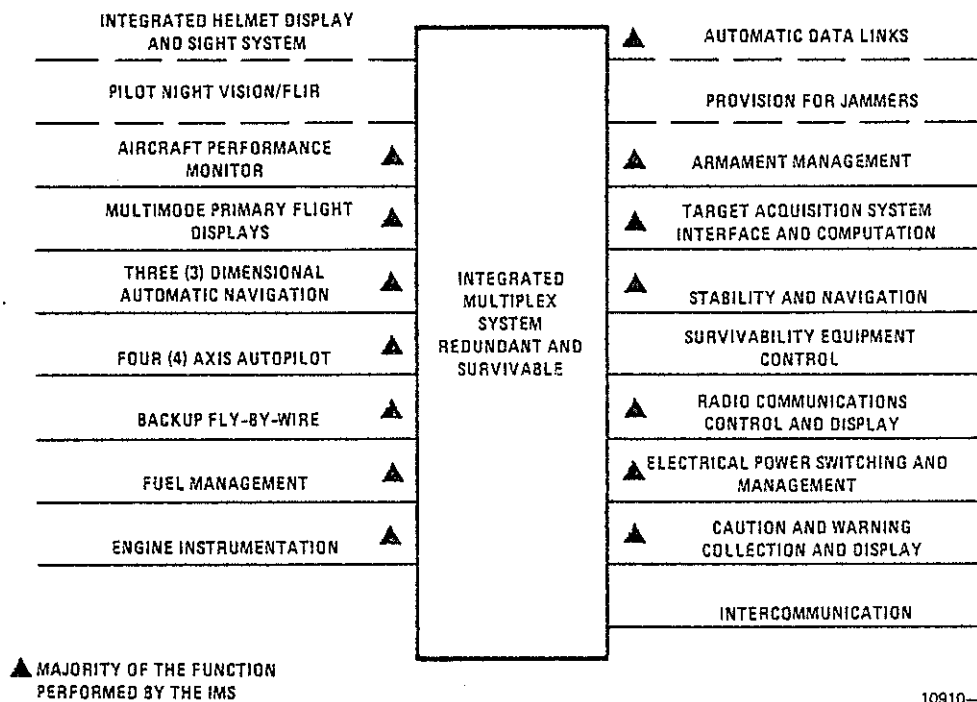▲ MAJORITY OF THE FUNCTION PERFORMED BY THE IMS
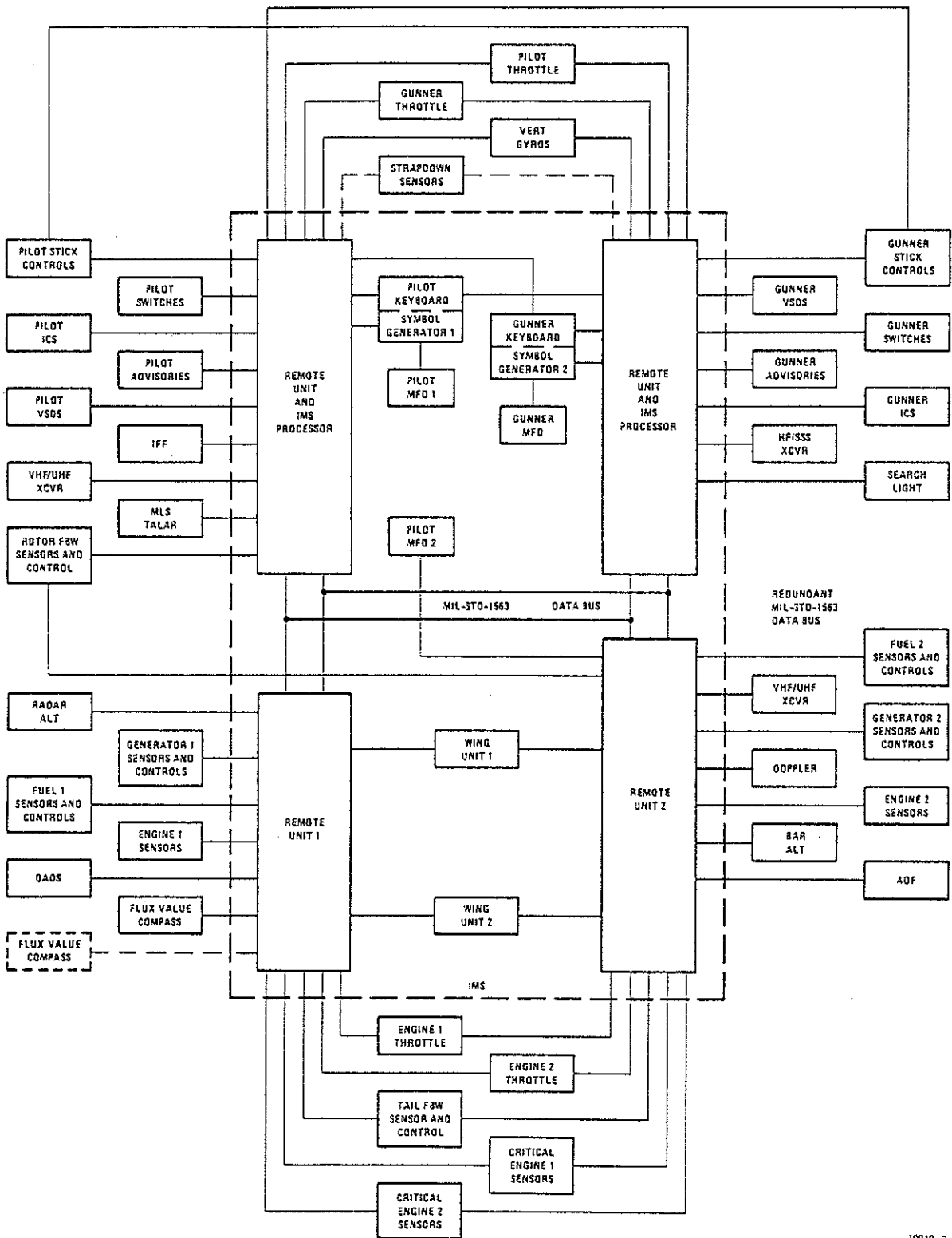
10910—4

Figure 5.1-1. Typical Functions Served

Figure 5.1-2 indicates the aircraft and mission equipment interfaces with the IMS equipment shown in dotted lines. Note that equipment served by each remote is in its battle damage zone. All mission or flight critical functions are interfaced with more than one remote.

Table 5.1 is a partial list of mission communication equipment served by the IMS. The heavy borders around selected equipment show hardware which is deleted and entirely replaced by the IMS interface, keyboard, display as processor capability.

Figure 5.1-3 shows a pictorial display of the IMS equipment and its interface.

Figure 5.1-4 shows the location of the equipment by zones in the aircraft.

Figure 5.1-5 and 5.1-6 shows the crew cockpit panels with the multimode displays used as primary flight displays. Either display will display radio status, caution and warning and other data via keyboard selection.

Figure 5.1-2. Typical IMS Interface

Table 5.1. Typical Hardware Removed Using Integrated Multiplex System		
Functions	Equipment Weight (Pounds)	Weight Change With IMS Pounds
ADF-Control (614L-11)	1.2	-1.2
CV-3555/APN-221 SDC Doppler	20.8	-20.8
MT-6018/APN-221 Doppler Mount	2.2	-2.2
RT-1291/APN-221 Doppler RTR	12.3	
C-10549/APN-221 Doppler CDU	7.8	-7.8
Radar Altim. Transceiver (HG 7105A6)	7.5	
Radar Altim. Mount	1.1	
Radar Altim. Antenna (2)	2.0	
Radar Altim. Indicator	1.5	-1.5

6.0 Application Results

The net results expected for two typical helicopter configurations are shown in Table 6.0.
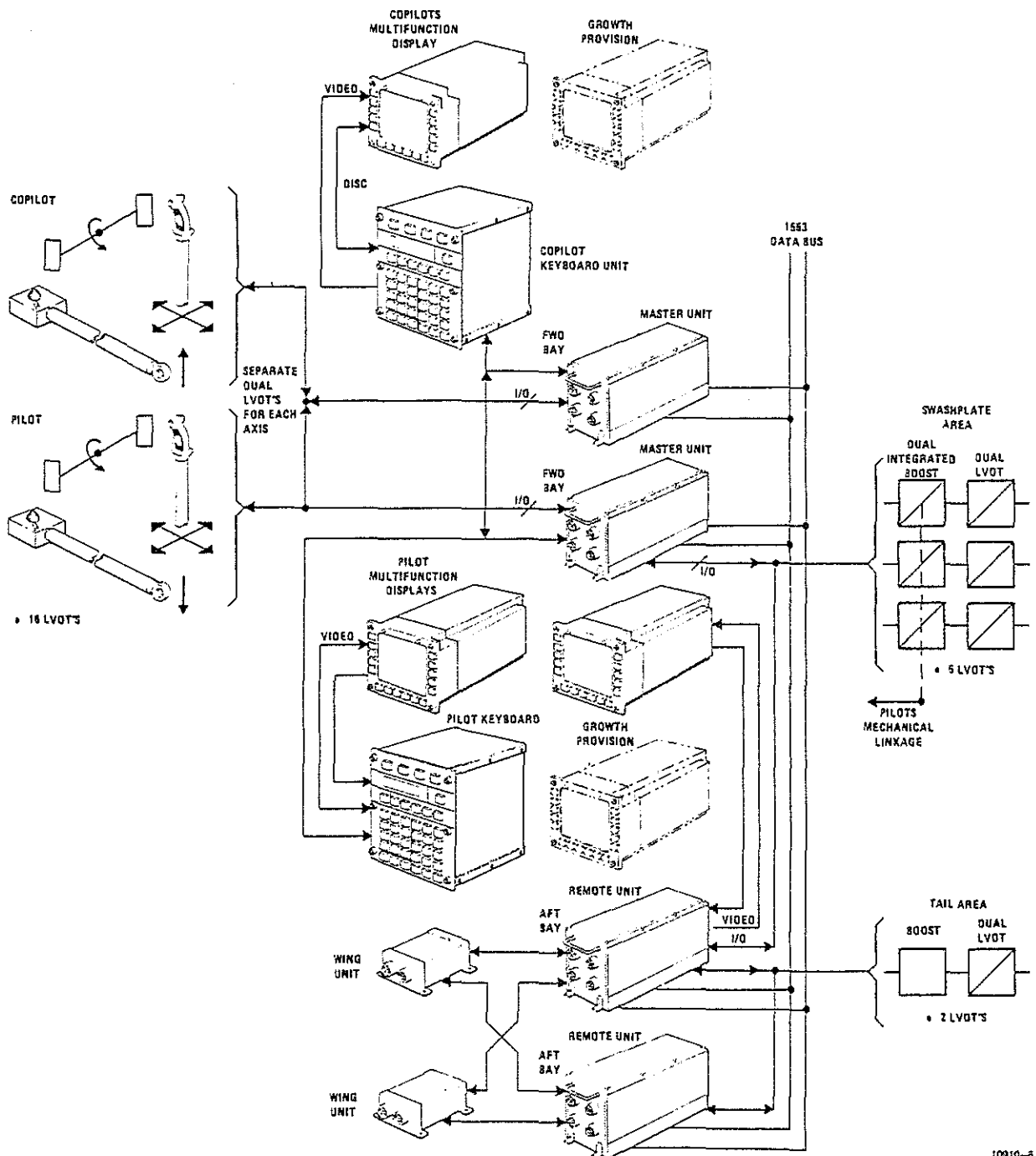
The results for a full military Attack of Scout type aircraft are so close that they have been tabulated together. The largest real differences are in specific mission equipment.

The results are also shown for a retrofit on an existing twin engine attack aircraft such as a Cobra-T. In this case, conventional flight instruments are retained which makes the IMS system weight significantly lighter. In spite of this the total weight saving is greater for the aircraft. This is because the existing Cobra-T technology and wiring is quite old.
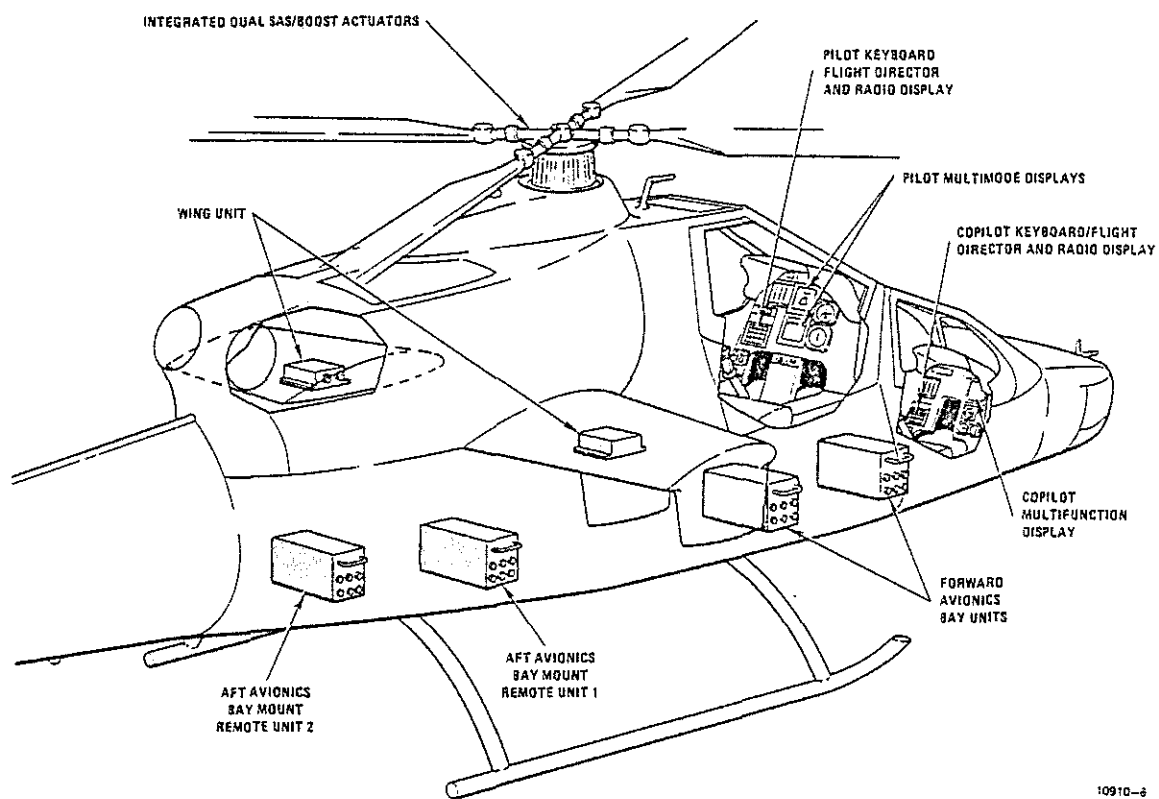
7.0 Conclusion

Harris has worked in close cooperation with several aircraft manufacturers and their engineering and is experienced in the data handling and functional requirements of an IMS. We have jointly prepared sufficient data to conclude that these results apply in general to meet aircraft, large or small, fixed wing or helicopter.

We have also been led to conclude that the system software and hardware must be customized to each application. Thus it is imperative that the IMS be of an extremely flexible and modular design not only so that it economically meets the specific aircraft needs, but so that it can economically grow and change with that aircraft.
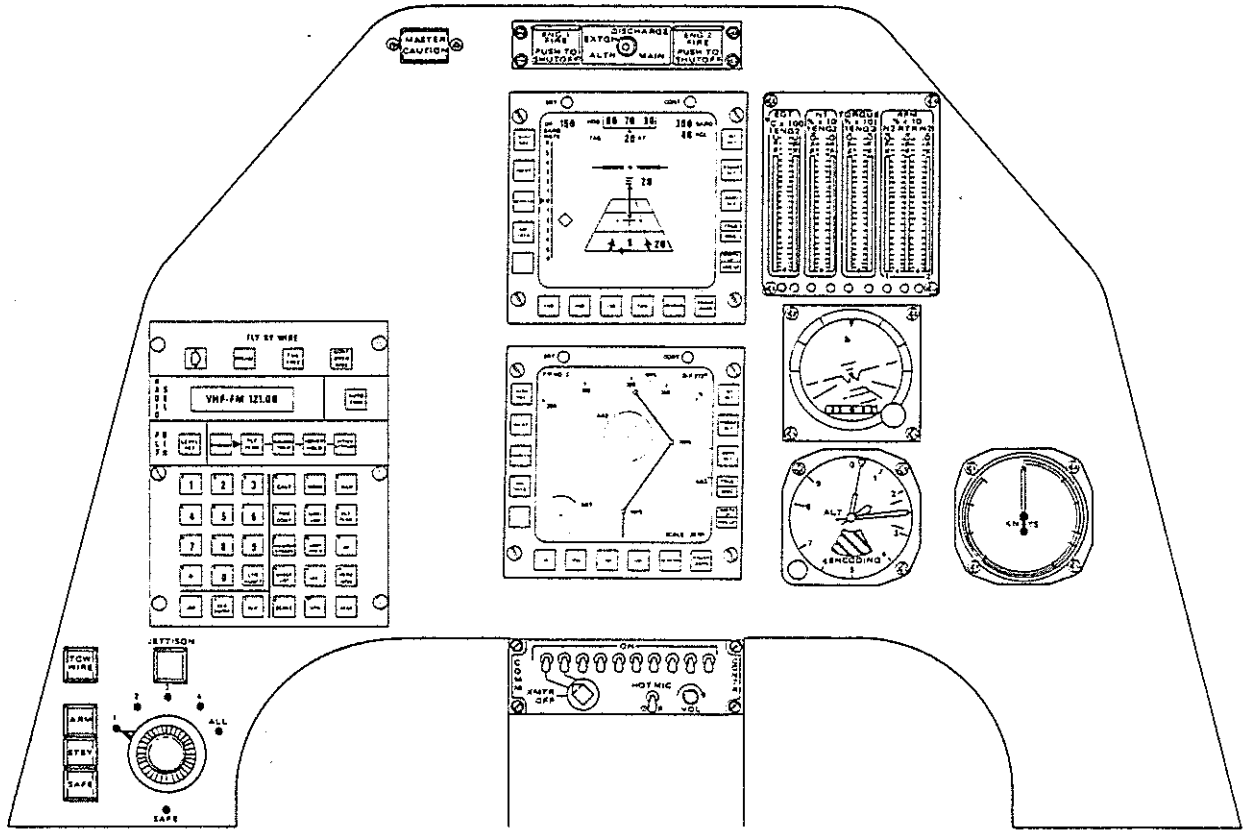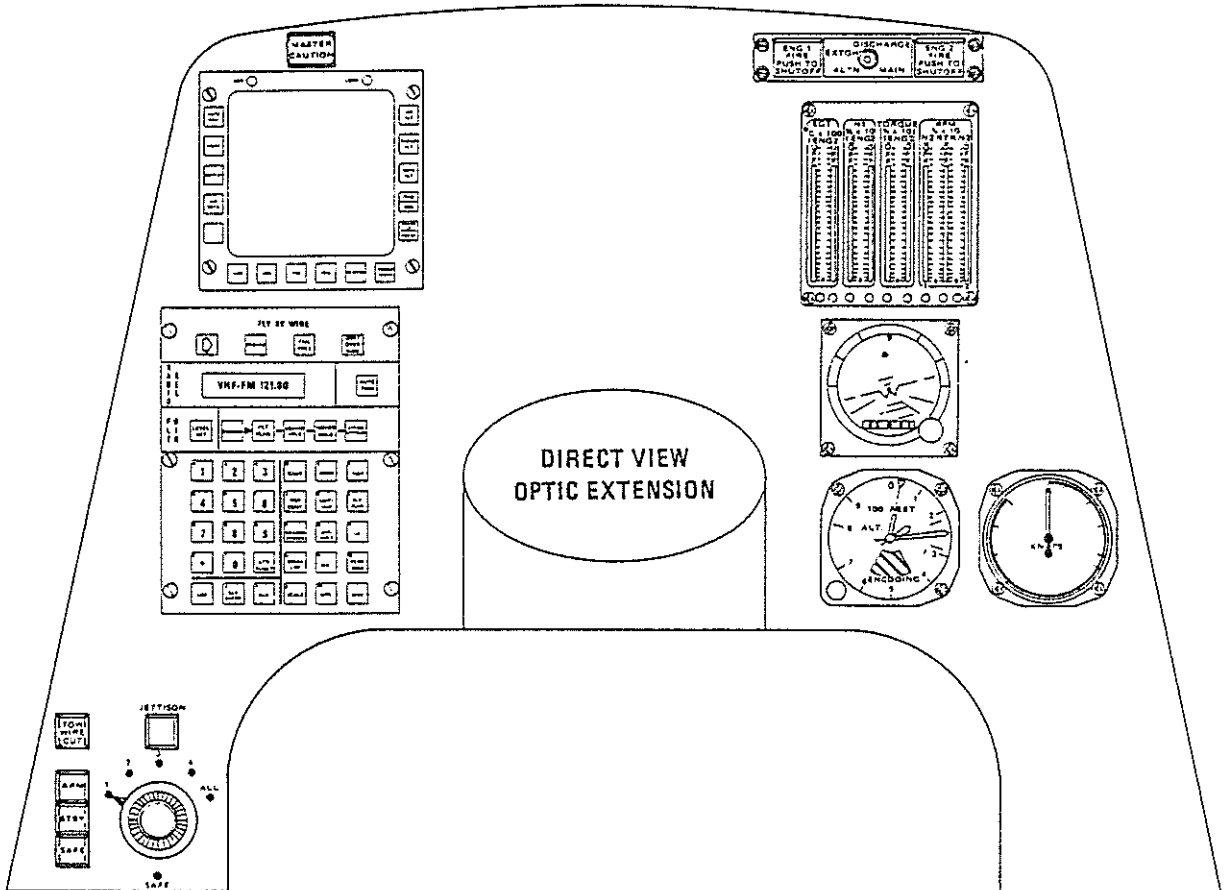
Figure 5.1-3. IMS Pictorial

INTEGRATED DUAL SAS/BOOST ACTUATORS

PILOT KEYBOARD
FLIGHT DIRECTOR
AND RADIO DISPLAY

PILOT MULTIMODE DISPLAYS

WING UNIT

COPILOT KEYBOARD/FLIGHT
DIRECTOR AND RADIO DISPLAY

COPILOT
MULTIFUNCTION
DISPLAY

FORWARD
AVIONICS
BAY UNITS

AFT AVIONICS
BAY MOUNT
REMOTE UNIT 1

AFT AVIONICS
BAY MOUNT
REMOTE UNIT 2

10910—6

Figure 5.1-4.   Typical IMS Equipment Locations and Zones

Figure 5.1-5. Integrated Pilot's Cockpit Panel

Figure 5.1-6. Typical Observer/Attack Gunner Panel

Table 6.0. IMS Application Results		
Parameter	New Attack or Scout Aircraft	Retrofit of Existing Attack (Cobra-T Baseline)
● Integrated Multiplex System Equipment Weight	133 lbs. (60.5 kg)	70 lbs. (31.8)
● Net Weight Saving to the aircraft over a conventional configuration	120 lbs. (54.5 kg)	187 lbs. (85 kg)
● Improvement in Battle Survivability	over 3:1	over 2:1
● Mission Reliability (between mission alert)	660 hours	400 hours
● Piece Part Reliability	200 hours	300 hours
● Reliability Improvement Factors	5:1	6:1
● Memory Required	62K words	48K words
● Modular Memory Utilization	48 percent	38 percent
● Processor Utilization	360 kop (40%)	260 kop (29%)
● Data Bus Utilization (MIL-STD-1553 B)	45 percent	40 percent
● Pilot workload reduction (estimate)	4:1	2:1