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AIR FORCE/NATIONAL AIRSPACE SYSTEM INTERFACE STUDY.(U)

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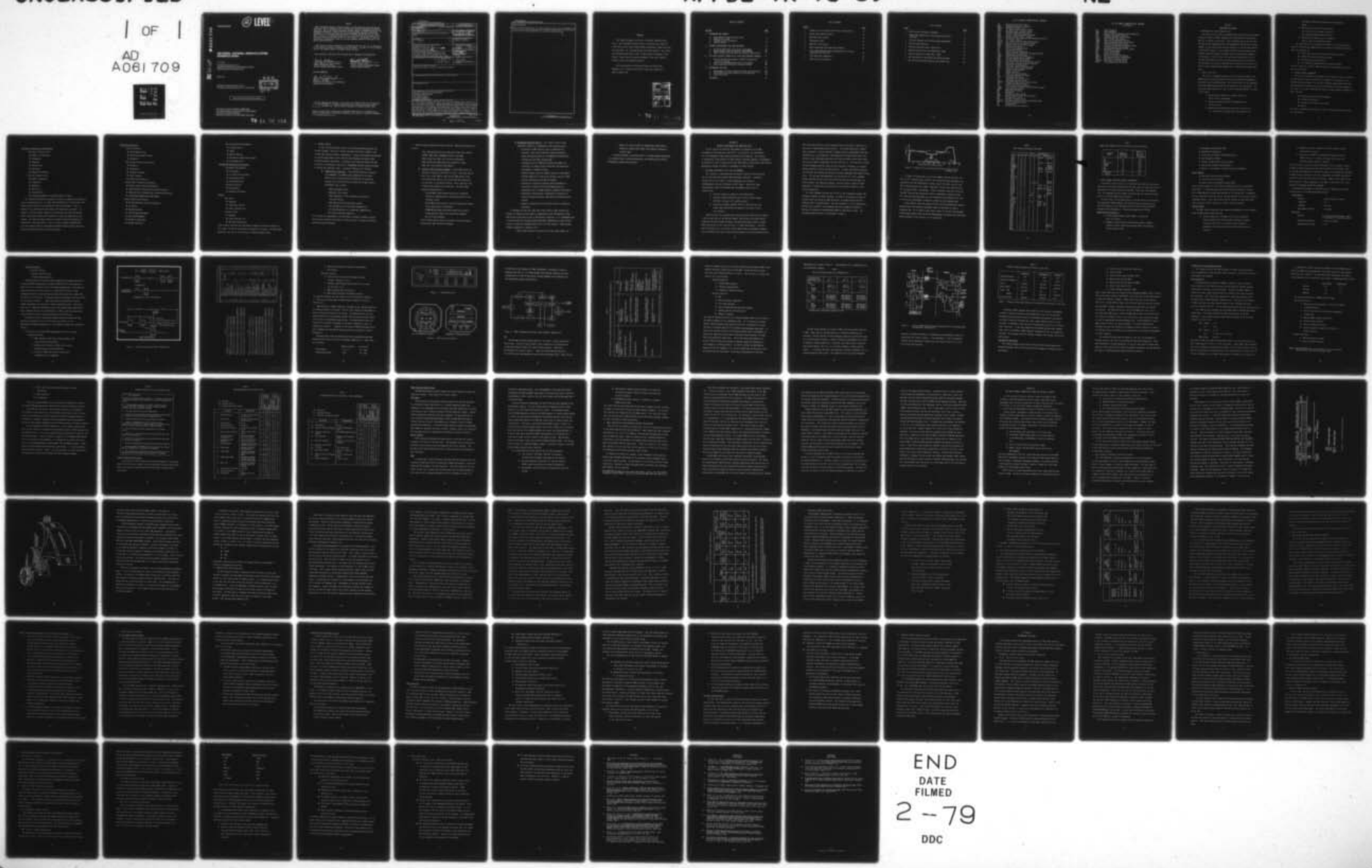

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AIR FORCE / NATIONAL AIRSPACE SYSTEM INTERFACE STUDY

E. H. BOLZ

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CHAMPLAIN TECHNOLOGY INDUSTRIES DIVISION
WEST PALM BEACH, FLORIDA 33401

JUNE 1978

TECHNICAL REPORT AFFDL-TR-78-69
Final Report for Period September 1977 – January 1978

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This technical report has been reviewed and is approved for publication.

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FOR THE COMMANDER

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report documents the results of a study to determine what actions the Air Force should be taking to remain compatible with the National Airspace System as it evolves in the future. The Federal Aviation Administration (FAA), through implementation of the Upgraded Third Generation Air Traffic Control System, will be requiring new avionics functions in aircraft which operate in the Air Traffic Control system. A large number of Air Force aircraft regularly operate in the Air Traffic Control system and so are affected by changes to its structure. The purpose of this study was to determine those FAA plans or programs which will

(see reverse)

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impact avionics requirements, to analyze the major new avionics development plans of the Air Force, and to determine the interface problems which will then exist for Air Force aircraft operation in the National Airspace System.

FOREWORD

This report documents the results of efforts conducted under Task I, "Air Force/NAS Interface Study," of Contract No. F33615-77-C-3079 with the Air Force Flight Dynamics Laboratory, Wright-Patterson Air Force Base. Mr. Jim Guckian was the Project Monitor. This effort was conducted under Project 2403, "Flight Control Technology," Task 240302, "Flight Control Systems Development," Work Unit 24030237, "Flight Control Law Design/Validation."

This investigation was performed during the period from September 1977 to January 1978 and the report was submitted to AFFDL in March 1978.

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LIST OF SYMBOLS, ABBREVIATIONS, ACRONYMS

ADF	Automatic Direction Finder
AMST	Advanced Medium STOL Transport
ARINC	Aeronautical Radio, Inc.
ARTCC	Air Route Traffic Control Center
ARTS	Automated Radar Terminal System
ASA	Aircraft Separation Assurance
ASDE	Airport Surface Detection Equipment
ASTC	Airport Surface Traffic Control
ATARS	Automatic Traffic Advisory and Resolution Service
ATC	Air Traffic Control
ATCRBS	Air Traffic Control Radar Beacon System
AWACS	Advanced Warning and Control System
BCAS	Beacon Collision Avoidance System
BPSK	Biphase Shift Keying
CAS	Collision Avoidance System
CFC	Central Flow Control
CMA	Control Message Automation
CNI	Communications, Navigation and Identification
CONUS	Conterminous United States
CPSM	Continuous Phase-Shift Modulation
DABS	Discrete Address Beacon System
DME	Distance Measuring Equipment
DTDMA	Distributed Time Division Multiple Access
EADI	Electronic Attitude Director Indicator
ECM	Electronic Countermeasures
ETABS	Electronic Tabular Display System
FAA	Federal Aviation Administration
FSS	Flight Service Station
GA	General Aviation
GPS	Global Positioning System
IAP	Instrument Approach Procedure
ICNI	Integrated CNI System
IFF	Identification Friend or Foe
ILS	Instrument Landing System
INCADS	Integrated Control and Display System
INS	Inertial Navigation System
IPC	Intermittent Positive Control
JTIDS	Joint Tactical Information Distribution System
LORAN	Long Range Navigation
M&S	Metering and Spacing
MHz	Mega-Hertz
MLS	Microwave Landing System
MSAW	Minimum Safe Altitude Warning System
MSK	Minimum Shift Keying
NAS	National Airspace System
NAVSTAR	Navigation Satellite Timing and Ranging GPS
PAR	Precision Approach Radar
PN	Pseudo-Noise
PWI	Proximity Warning Indicator

LIST OF SYMBOLS, ABBREVIATIONS, ACRONYMS
(continued)

RF	Radio Frequency
RNAV	Area Navigation
RTCA	Radio Technical Commission for Aeronautics
SID	Standard Instrument Departure
STAR	Standard Terminal Arrival Route
STOL	Short Takeoff and Landing
TACAN	Tactical Air Navigation System
TAGS	Tower Automated Ground Surveillance
TDMA	Time Division Multiple Access
TIPS	Terminal Information Processing System
TRSB	Time-Referenced Scanning Beam
UG3RD	Upgraded Third Generation ATC System
UHF	Ultra-High Frequency
VFR	Visual Flight Rules
VHF	Very High Frequency
VNAV	Vertical (3D) Area Navigation
VORTAC	VHF Omnidirectional Range/TACAN
WVAS	Wake Vortex Avoidance System
4D RNAV	Time-Control Area Navigation
4GATC	Fourth-Generation ATC System

SECTION I

BACKGROUND AND SUMMARY

1. REQUIREMENT FOR A NAS INTERFACE STUDY

The intent of this study is to determine what steps the Air Force should be taking in order to remain compatible with the National Airspace System (NAS) as it evolves in the future. This is necessary due to the fact that the FAA, through implementation of the Upgraded Third Generation ATC System (UG3RD), will be requiring new avionics functions in aircraft which operate in controlled airspace. A large number of USAF aircraft (transports and fighters) regularly operate in the NAS, and so are affected by changes to its structure. In view of this fact, and the fact that the Air Force is currently developing new avionics systems which would be utilized during NAS operations, this study to determine the actions which are necessary for the Air Force to maintain NAS compatibility in future years has been undertaken.

2. SCOPE OF THIS STUDY

This study is intended to consider the firm plans which comprise the UG3RD system, and other ATC plans which have been formulated subsequent to the definition of the UG3RD system. Also, possibilities for the subsequent ATC system (4GATC-Fourth Generation ATC System) are to be considered. The tasks which were performed as a part of this study were executed in a series of five steps:

1) Determine those FAA plans or programs which will impact avionics requirements
2) Analyze the major new avionics development plans of the Air Force
3) Determine the interface problems which will then exist; i.e., the avionics functions which are needed but not

furnished, or which are furnished in an inconsistent manner

4) Where possible within the limitations of this initial effort, propose solutions to the interface problems identified, and

5) Determine what research tasks are needed in order to solve the remaining problems.

Air Force avionics plans analyzed were limited to four major programs which are concerned with communications, navigation and identification (CNI). These four programs are:

- JTIDS (Joint Tactical Information Distribution System)
- NAVSTAR GPS (Global Positioning System)
- MLS (Microwave Landing System)
- 4-D INCADS (Integrated Control and Display System)

Avionics systems not related to NAS CNI functions, such as weapons delivery, were not considered.

3. USAF/NAS AVIONICS PARAMETERS

This section introduces the parameters which charaterize avionics functions and performance in order to establish the framework for examination of the USAF/NAS interface problem. Each of these parameters (where applicable) have been evaluated with reference to each avionics system or function examined in this study. As stated in reference 29, avionics systems typically perform four major functions:

- Information Transmission and Reception
- Information Processing
- Information Distribution and Display
- Control

The avionics parameters which pertain to each of these major functional areas are listed below.

Information Transmission and Reception

Transmitter Characteristics:

- Number of Transmitters
- Frequencies
- Bandwidth
- Average Power
- Peak Power
- Modulation Technique

Receiver Characteristics:

- Number of Receivers
- Frequencies
- Bandwidth
- Sensitivity
- Internal Noise
- Antenna Requirements (including remote RF stage)

The transmission/reception category of function is generally considered to consist of dedicated units; i.e. where time-multiplexing is not possible, dedicated transmit/receivers are required for each active channel. This is generally true, although a certain amount of integration is possible. For example, if several receive channels are required in one band, the antenna and RF stage may be shared, while separate IF strips are required for each channel. The remaining three functional categories offer the potential for integration in the total sense. That is to say, a single control/display unit (for example) might be configured to perform several avionics functions, eliminating separate C/D units for each function.

Information Processing

Avionics Function:

- Data Communications
- Surveillance/Identification
- Navigation

Anolog Signal Processing Functions:

- Modulation
- Correlation
- Frequency Tracking
- Phase Tracking
- Digital Data Detection

Analog Signal Processing Performance:

- Dynamic Phase Tracking Requirements
- Phase Detection Accuracy (Positioning Accuracy)
- Repeatibility, Predictability, Relative Nav Accuracy
- Update Rate/Augmentation Requirement

Digital Processing Functions:

- Message Generation and Data Formatting
- Encryption
- Message Decoding
- Data Storage Requirement
- Data Base Management
- Navigation Algorithms
- Guidance Functions

Digital Processing Performance:

- Instruction Set
- Speed
- Memory Capacity
- Peripherals & Mass Data Storage
- I/O Capabilities

Information Distribution and Display

Information Distribution:

- To Displays
- To Flight Control System
- To/From Data Links
- To/From Data Base

Information Display:

- Data Readout
- Guidance Instruments

Control

Data Input:

- Keyboard
- Slew Cursor Control
- Knobs, Switches, etc.

Function Control:

- Keyboard
- Knobs, Switches, etc.
- Data Base Manipulation

These avionics functions and performance parameters have been evaluated in this study in light of the avionics requirements for present and future NAS operations, and the Air Force avionics system development plans.

4. OVERALL RESULTS

In this section the major results of the three remaining sections are briefly reviewed. Section II reviews the future ATC plans in detail, and isolates the specific avionics requirements. Section III presents explanations of the four major USAF avionics efforts, and discusses the specific NAS interface problems identified. In Section IV the solutions which have been arrived at are presented, along with a recommended research program intended to resolve the remaining issues. The major findings are as follows:

- <u>UG3RD Avionics Functions</u> -- The functions which are required, or recommended, for UG3RD system compatibility for those USAF aircraft conducting regular operations in controlled airspace, but which may not be provided for in USAF avionics development plans include:
  - DABS transponder Beacon
  - DABS data link display
  - ATARS (Automatic Traffic Advisory and Resolution Service) Display
  - BCAS (Beacon Collision Avoidance System)
  - Area Navigation civil functional compatibility
  - 4-D Area Navigation civil functional compatibility
  - MLS complex approach capability

All of these are recommended to be installed on transport category aircraft, while certain exceptions are made for fighter aircraft if space availability problems cannot be resolved.

Besides simply providing the above functions, additional problems exist in that:

- The L-band spectrum must be shared with JTIDS (this affects ATCRBS, DABS, BCAS, TACAN/DME and MLS L-band DME)
- RNAV systems must meet civil accuracy requirements
- RNAV systems must demonstrate the capability to meet RNAV civil certification requirements

- Potential 4GATC Interface Problems -- While 4GATC plans are uncertain at present, one factor is clear: that some form of data link, either DABS or some form of TDMA concept (Time Division Multiple Access) will be utilized and required of all operators in controlled airspace. Also, some other form of new avionics would also be required. The major 4GATC scenarios considered are:
    - Synchro-DABS, which would be used as an integrated navigation, communications, surveillance and collision avoidance system
    - Astro-DABS, which utilizes a satellite-based surveillance system using special transponders
    - A NAVSTAR GPS-based system which would utilize data-linked position reports for surveillance purposes and collision avoidance.

  Each of these systems could be configured such that primary surveillance radar could be eliminated.

- Recommended Research Efforts -- As a result of this study additional research is recommended in the following areas:
  - Evaluation of DABS features (such as ATARS and ATC displays), their costs, benefits, need and available space, and specification of a recommended implementation strategy for each USAF aircraft type.
  - Configuration of an ATARS/ATC display which meets the constraints of cockpit space limitations and operational environment in fighter aircraft.
  - Economic benefit and cost tradeoff analysis of deployment of BCAS capability in each of the several classes of USAF aircraft operating in the NAS environment.
  - Evaluation of navigation systems under development or envisioned in order to facilitate demonstration of compliance with civil RNAV avionics standards requirements.
  - Evaluation of the possible interference interactions of JTIDS with potential Fourth Generation ATC System avionics systems.
  - Analysis of potential civil/military avionics integration techniques.

In reference to the last item, due to the critical space availability problem on fighter aircraft, which is aggravated by the introduction of new USAF avionics functions as well as NAS avionics functions, it is recommended that a research effort be directed towards functional integration of these various avionics systems into hardware which will fit in the aircraft. Space savings through integration is possible since:

- Many systems operate in essentially the same radio bands, and

- Nearly all involve extensive computational requirements, leading to schemes where fewer, more powerful processors could be used.

A research program is specified which is oriented towards developing an optimum avionics system configuration, and formulating the system development program plan necessary.

SECTION II

AVIONICS REQUIREMENTS FOR UG3RD AND 4GATC

In this section the avionics requirements for operators in the NAS environment of the future are identified. In particular, the requirements for IFR (Instrument Flight Rules) operations are of interest. This section is preparatory to the analysis of USAF avionics interface problems in Paragraph 3 of Section III, which is based also on the definition of future major USAF avionics development programs discussed in Paragraph 2 of that section.

1. AIR FORCE OPERATIONS IN THE CIVIL ENVIRONMENT

This analysis is concerned with the avionics which Air Force aircraft are to carry which would affect NAS environment operations. Therefore, systems such as fire control, stores management and electronic countermeasures are not of interest in this study. Three basic types of operations, each with different NAS environment effects, are of interest here:

1) Training (usually in remote or restricted areas)
2) Transport (affect ARTCC [Air Route Traffic Control Center] operations and many civil terminal areas)
3) Intercept, strategic weapons delivery, ferry mission, etc. (affect ARTCC operations but operate at military or joint use airports)

Specifically we are concerned with identifying which USAF aircraft operate in the various parts of the NAS environment (particularly the higher density terminals and high altitude airspace), and determining what avionics requirements must be met as the "price of entry" in those environments. From that point the objective is to evaluate current USAF avionics development programs and to determine which meet future NAS requirements either without modification, with minor modification, or only through extensive functional integration or provision of separate NAS-unique avionics. The second operational category above, transport, involves the most stringent avionics requirements since the transports are fully integrated in NAS operations and would affect many civil terminal areas (even when operating at military airfields within those areas). The aircraft types included here are the C-141 and C-5. The next most strongly affected category would be those aircraft involved in intercept or strategic weapons delivery or which are being ferried. In these cases ARTCC operations are affected, but terminal operations are usually conducted from remote military sites. The aircraft considered here are intercept (F-15, F-16), strategic weapons delivery (B-52), cruise missile carrier, and all aircraft types for ferry purposes. The remaining category, training, usually involves fighter operations in restricted areas which have little effect on ARTCC or civil terminal operations.

Air Force transport missions are similar to civil operations except that different airports are often involved. In order to illustrate the types of missions which are unique to USAF operations, an example mission profile (Reference 29) is presented here. The case presented is an F-4 interdiction mission which involves a nine hundred mile cruise segment at 20,000 ft, delivery of ordinance at approximately 8000 ft, and return to base. The altitude/distance profile is illustrated in Figure 1.

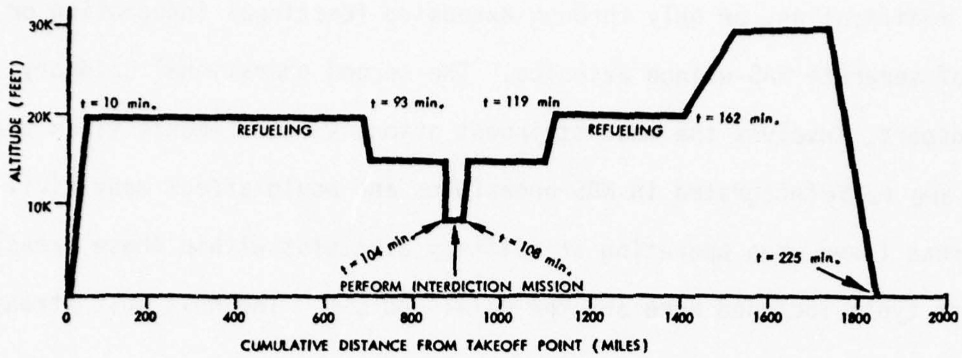


Figure 1. - Example of an F4 Interdiction Mission Flight Profile (Reference 29)

In support of operations in civil environments (US and foreign), the Mark XII IFF (Identification Friend or Foe) system has been developed to be compatible with the ATCRBS Mode 3C system, and all military aircraft have been retrofitted with this system. Many USAF aircraft carry VOR receivers for use where TACAN is unavailable. Table 1 presents a detailed listing of the USAF fleet and the navigation avionics complements of these aircraft. This table was developed under an area navigation study (Reference 10), and so the inertial and Doppler systems are identified by AN-nomenclature.

In more general terms the numbers of USAF aircraft equipped with generic communications and navigation equipment types are presented in Table 2 (Reference 29). As is shown on that table, nearly all are UHF comm-equipped, although approximately 40% are VHF and VOR-equipped, indicating the significant number equipped in anticipation of civil operations.

TABLE 1

USAF AIRCRAFT NAVIGATION EQUIPMENT

Aircraft	Tacan	VOR	DME	Loran C/D	Omega	Inertial Type	Inertial Accuracy (nm/hr.)	Doppler
A-7D	x					ASN-90	.74	APN-190
A-10	x	x						
A-37	x	x						
A-1E	x	x						
B-1	x					ASN-101	.10	APN-185
B -52B	x	x						
B-52C	x	x						APN-89
B-52D/E/F	x	x						APN-108
B-52G/H	x	x				LN-15A	.50	APN-89A
FB-111	x					AJN-16	.50	APN-185
B-57	x	x						
C-5A	x	x		x		NIS-105	.80	Nortronics
C-7A	x	x						
C-9A	x	x	x					
C-47	x							
KC-97	x	x						
VC/C-118A	x	x						
C-119	x	x						
C-123	x	x						
C-124	x	x						APN-147
C-130	x	x		some	planned			APN-147
C-131	x	x						
C-135	x	x				planned	<1.0	
C-140	x	x						NC-103
VC-137	x			x		LTN-51	1.0	
C-141						planned	<1.0	APN-147
EC-135	x							APN-81
EC-137	x							
EC-121	x	x		some				APN-153
EB-66	x	x						APN-82
F-4	x	x		planned		LN-12	3.0	
F-5E	x					LN-33	1.0	
F-15	x					LN-31		
F-100/101/ 102/106	x							
F-105	x			some		ASN-100		
F-111A/E	x					LN-14	2.0	
F-111D/F						LN-16	0.5	
F-104	x					LN-12	3.0	
RF-4C						x		
RF-101	x							
RF-5A	x							
T-29	x	x						
T-33	x	x						
T-37		x	x					
T-38	x							
T-39	x							
T-41		x						
T-43		x						
U-3		x						
U-4		x						
U-6		x						
U-10		x						
U-17		x						
H-3	x	x						APN-175
H-53		x						APN-175
H-1	x	x						
O-2	x	x						
OV-10	x	x						

TABLE 2

COMMON USAF COMMUNICATIONS AND NAVIGATION AVIONICS EQUIPMENT

Equipment Type	Number of Different Unit Types	Number of Units in Aircraft (Thousands)
HF	17	8.6
VHF	22	7.8
UHF (Voice)	15	17.0
TACAN	9	12.0
LORAN	7	3.8
DF	21	21.0
VOR	8	7.3
ILS	23	19.0
Totals of Sample	122	96.5

2. UG3RD PROGRAMS INVOLVING AVIONICS REQUIREMENTS

The purpose of this section is to review the short term and intermediate term plans of the FAA and to determine how those plans will affect the avionics requirements of aircraft operating in the NAS. These plans are reasonably firm. The subsequent section reviews the options open for possible implementation in the Fourth Generation ATC System.

The major plans for ATC modernization by the FAA consist of the Upgraded Third Generation System programs, and some additional programs which were conceived subsequent to the proposals of the Air Traffic Control Advisory Committee (ATCAC, Reference 1). The major programs are as follows:

UG3RD Programs (Reference 2)

- Discrete Address Beacon System (DABS), including the data link feature.
- Automatic Traffic Advisory and Resolution Service (ATARS); formerly Aircraft Separation Assurance (ASA) and Intermittent Positive Control (IPC)

- Microwave Landing System (MLS)
- Upgraded ATC Automation
- Flight Service Station (FSS) Modernization
- Area Navigation (RNAV)
- Airport Surface Traffic Control (ASTC)
- Wake Vortex Avoidance System (WVAS)
- Aerosat -- Development of Aerosat has been suspended.

Other Programs

- Wind shear detection and avoidance
- Profile Descent procedures
- Beacon Collision Avoidance System (BCAS)

Each of these programs will be briefly reviewed and avionics requirements identified. It should be noted that the ASA concept originally included both a DABS-based IPC concept and some form of air-derived CAS. Independent CAS has subsequently been replaced by the BCAS approach since several economic advantages result. Also, the scope of the IPC concept has been diminished from a positive control concept to a traffic advisory approach.

DABS and ATARS

The DABS concept integrates three separate enhancements to the secondary radar (ATCRBS) surveillance function:

1) Discrete addressing, intended to solve the synchronous garble problem and to allow accurate tracking of closely spaced aircraft (This is necessary to the successful automation of ATC functions, and for the traffic advisory function).

2) Monopulse Azimuth, intended to greatly increase azimuth determination accuracy.

3) Data Link, intended for automated ATC messages and the ATARS function; it follows relatively easily once the discrete address concept is adopted.

As an alternative, monopulse azimuth measurement could be added to ATCRBS, increasing azimuth accuracy and reducing the amount of interrogator noise in the radar environment (by reducing the number of interrogations required). The DABS system is designed to be fully compatible with ATCRBS transponders in order to facilitate the transition process. However, the intent of the UG3RD program is indeed transition, since DABS is required for full implementation of Upgraded Automation and ATARS.

The expected performance of the DABS system is summarized as follows (from Reference 3, the DABS System Description):

Surveillance

Capacity	> 2000 aircraft per sensor
σ(Azimuth)	$\sim 0.1°$
σ(Range)	$\sim$ 100 feet
Data Update Interval	$\sim$ 4 seconds

Data link

Capacity	All identified ATC messages require a few percent of available capacity
Delivery Reliability	> 0.99 in 4 seconds
Undetected Error Rate	$< 10^{-7}$

System Reliability

Multiple Coverage

Automatic Monitoring and
Network Reconfiguration

The DABS system will maintain ATCRBS compatibility through provision of simulated ATCRBS interrogations (so-called "DABS All-Call Interrogations"). These will elicit standard replies from ATCRBS equipment but, since they are specially coded with an extra pulse, as illustrated in Figure 2, DABS transponders which have not yet been acquired and tracked will respond with the special all-call reply. The standard DABS interrogation (with data block) is also shown in Figure 2. DABS interrogations automatically lockout ATCRBS transponders by providing a sidelobe suppression pulse. The uplink data rate is 4 Mbps and differential phase shift keying (DPSK) modulation is used. Downlink replies are transmitted at a 1 Mbps data rate using pulse position modulation (ppm), which was selected to minimize cost.

The detailed uplink and downlink message format structures have been tentatively defined, and will be finalized upon adoption of the DABS National Standard (Reference 4). The tentative formats are presented in Figure 3.

The functions of airborne DABS transponders will be as follows:

Required Functions:

1) DABS responder capability to unique address with present altitude transmitted
2) Reception and decoding of ATARS (IPC) traffic avoidance data and ATC instructions
3) Display of ATARS data and ATC instructions (rudimentary set of commands)

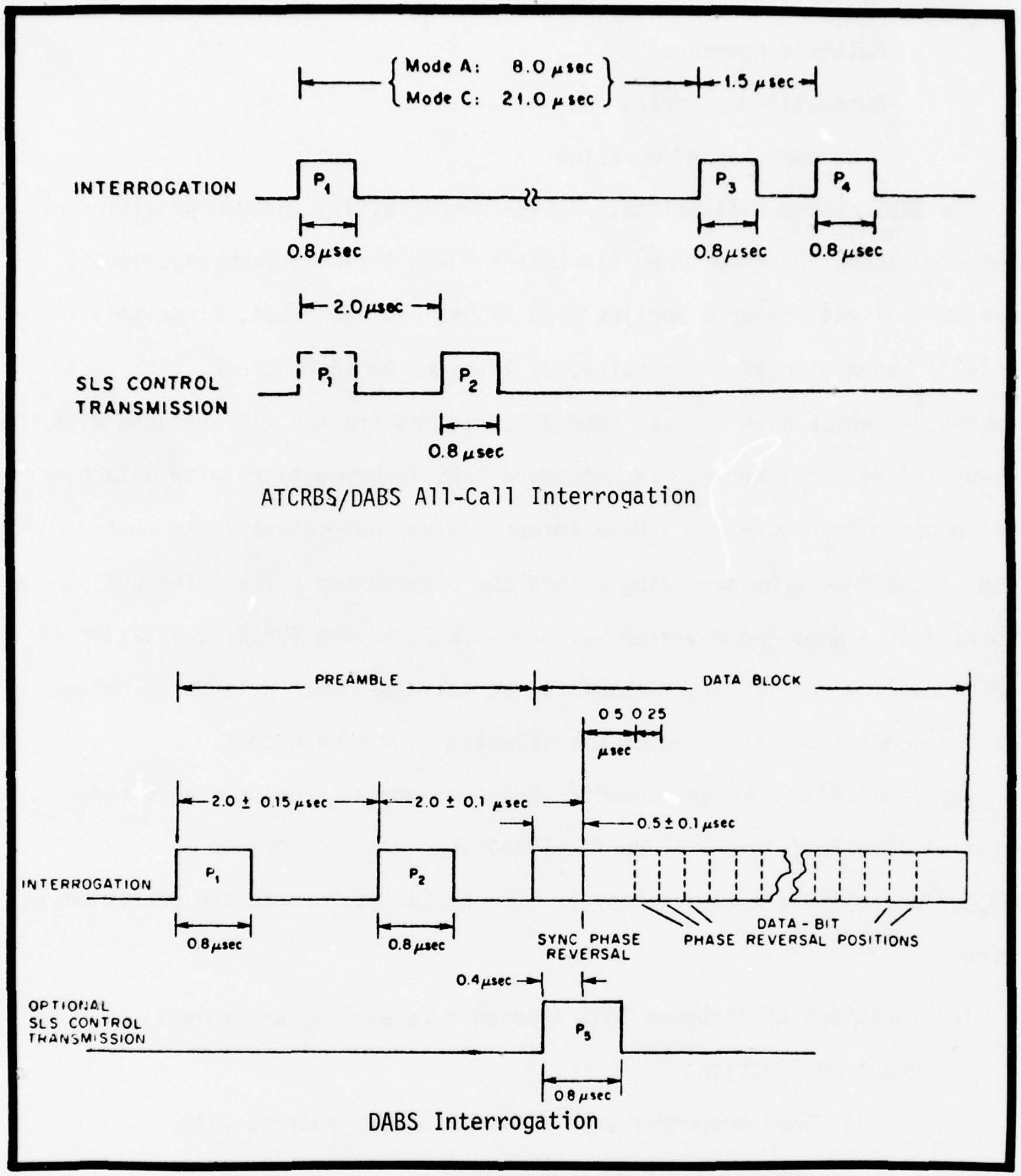
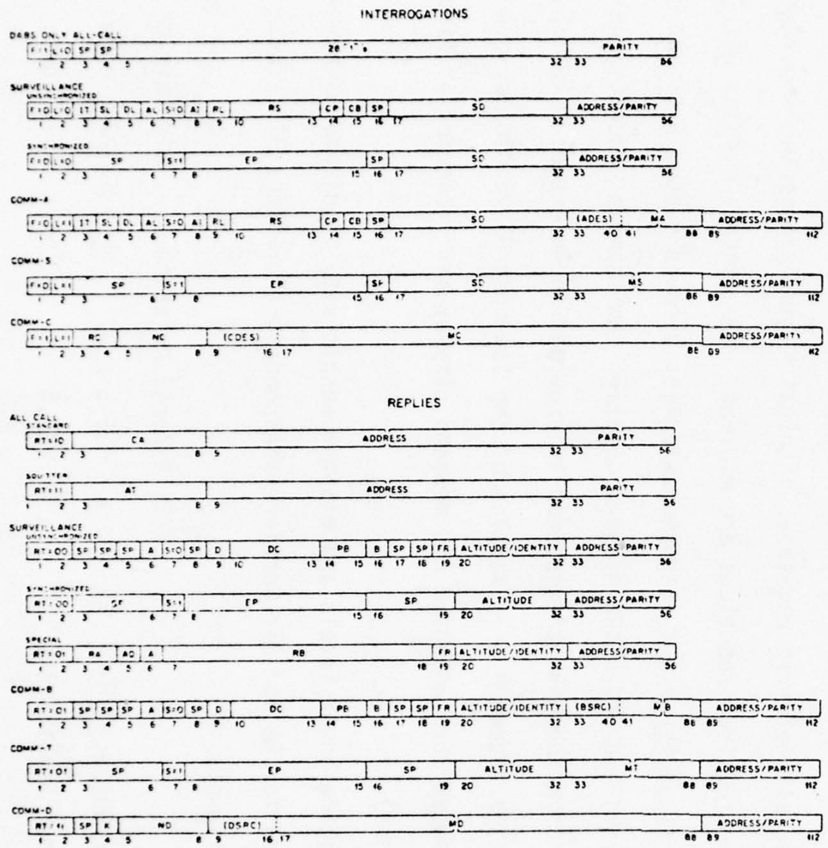


Figure 2. - Uplink Interrogation Formats (Reference 4)



Abbrev.	Name	Bit Number Interrog.	Bit Number Reply	Class
A	Alert	-	6	I
ADES	Message Type/Destination	33-40	-	X
-	Address	-	9-32	I
-	Address/Parity	33-56,89-112		I
-	Address/Parity		33-56,89-112	I
AI	Altitude/Identity Flag	8	-	I
AL	ATCRBS Lockout	6	-	I
-	Altitude/Identity Field	-	20-32	I
AQ	Acquisition Flag	-	5	I
AT	Truncated Altitude	-	3-8	I
B	Comm-B Message Waiting	-	16	X
BSRC	Message Type/Source	-	33-40	X
CA	Capability	-	3-8	X
CB	Clear Comm-B	15	-	X
CDES	Message Type/Destination	9-16	-	IE
CP	Clear PB	14	-	X
D	Comm-D Message Waiting	-	9	IE
DC	Length of Reply ELM	-	10-13	IE
DL	DABS Lockout	5	-	I
DSRC	Message Type/Source	-	9-16	IE
EP	Synchronous Time	8-15	-	IS
EP	Synchronous Time	-	8-15	IS
F	Format Type	1	-	I
FR	Flight Rules Indicator	-	19	X
IT	Interrogator Type	3	-	I
K	ELM Control Indicator	-	4	IE
L	Data-Block Length	2	-	I
MA	Interrogation Data	33-88	-	X
MB	Reply Data	-	33-88	X
MC	Interrogation ELM Segment	9-88	-	IE
MD	Reply ELM Segment	-	9-88	IE
MS	Synchr Interrogation Data	33-88	-	IS
MX	Maximum Airspeed	-	11-13	I
MT	Synchronized Reply Data	-	33-88	IS
NC	Interrog ELM Segment No	5-8	-	IE
ND	Reply ELM Segment No	-	5-8	IE
-	Parity	33-56	-	I
-	Parity	-	33-56	I
PB	Pilot Acknowledgement	-	14-15	X
RA&RB	Special Surveillance Data	-	3-4,7-18	X
RC	Reply Type for Comm-C	3-4	-	IE
RL	Reply Length	9	-	I
RS	Reply Selector	10-13	-	I
RT	Reply Type	-	1-2	I
S	Synchronization Indicator	7	-	I
S	Synchronization Indicator	-	7	I
SD	Surveillance Data	17-32	-	X
SL	Squitter Lockout	4	-	I
SP	Spare	3,4,16	3-5,8,17-18	X
SR	Segment Request	9-24	-	IE
TA	Transponder Technical Acknowledgement	-	9-24	IE

Figure 3. - DABS Data Block Formats (Reference 4)

4) Display of Altitude Echo (ALEC) for performance verification

Optional Functions:

1) Display of more involved ATC commands and data (runways, frequencies, etc.)
2) Extended Length Message (ELM) capability for private use (airlines, etc.)
3) RNAV navigation data distribution
4) BCAS-related functions (see BCAS discussion)

The required functions and some optional ones are described in Reference 3. These may be revised when the DABS national standard is finalized (Reference 4).

DABS operates at ATCRBS frequencies (1030 MHz uplink, 1090 MHz downlink). An encoding altimeter is required. Digital signal processing requirements to perform the required functions are minimal. The control/display unit must have provisions for pilot response switches, baro-corrected altitude display (ALEC uplink) and ATC/ATARS message display. An example generic panel configuration for the DABS transponder is provided in Reference 3, which is reproduced as Figure 4. Examples of the low-cost ATARS/ATC message display and a somewhat more advanced ATC message display are presented in Figure 5 (Reference 3).

Operating power levels and minimum sensitivity requirements have been established for GA and Air Carrier Transponders (Reference 3). These values are as follows:

	General Aviation	Air Carrier
Power Output	25.5 ± 3	27 ± 3dBw
Minimum Sensitivity	-72.5	-74 dBm

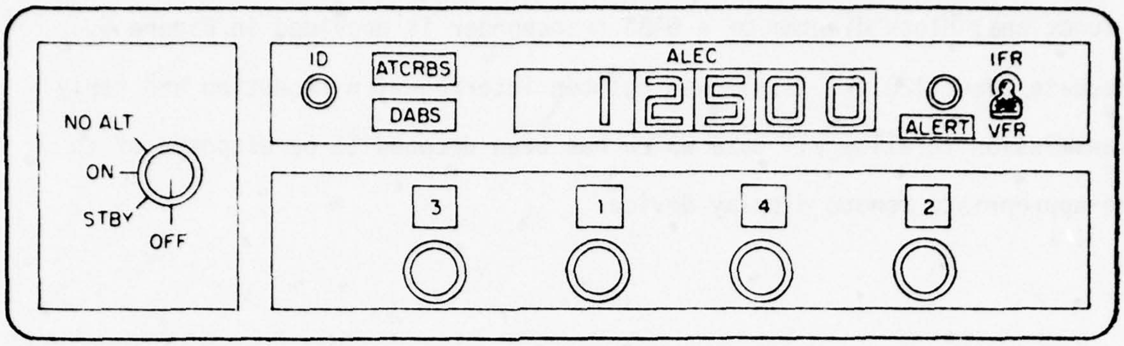
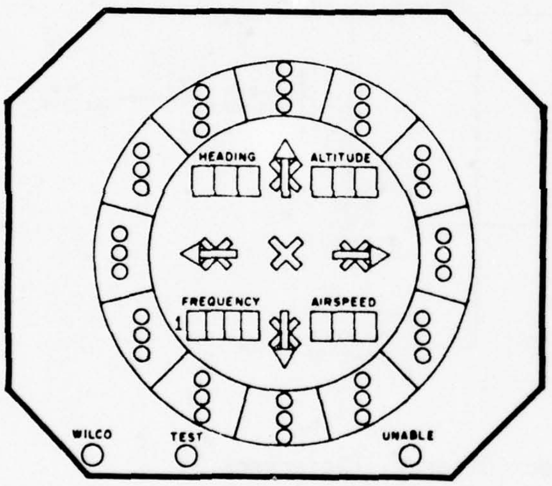
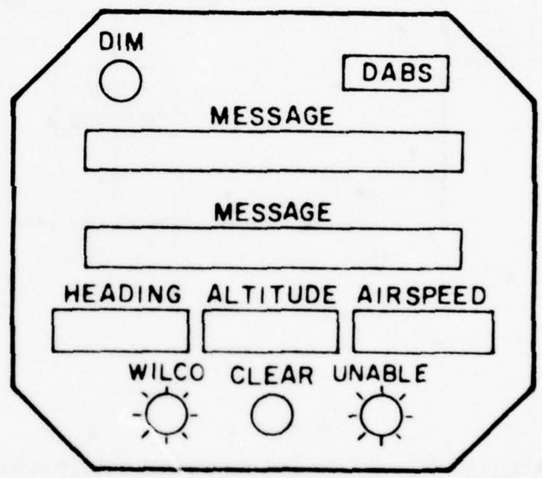


Figure 4. - Transponder Panel



Low-cost ATARS/ATC Display



Advanced ATC Message Display

Figure 5. - DABS Data Link Displays

A functional block diagram of a DABS transponder is provided in Figure 6. Adequate time (128 μs) is allowed between interrogation reception and reply transmission to allow all data which has been decoded to be disposed of to the appropriate remote display device.

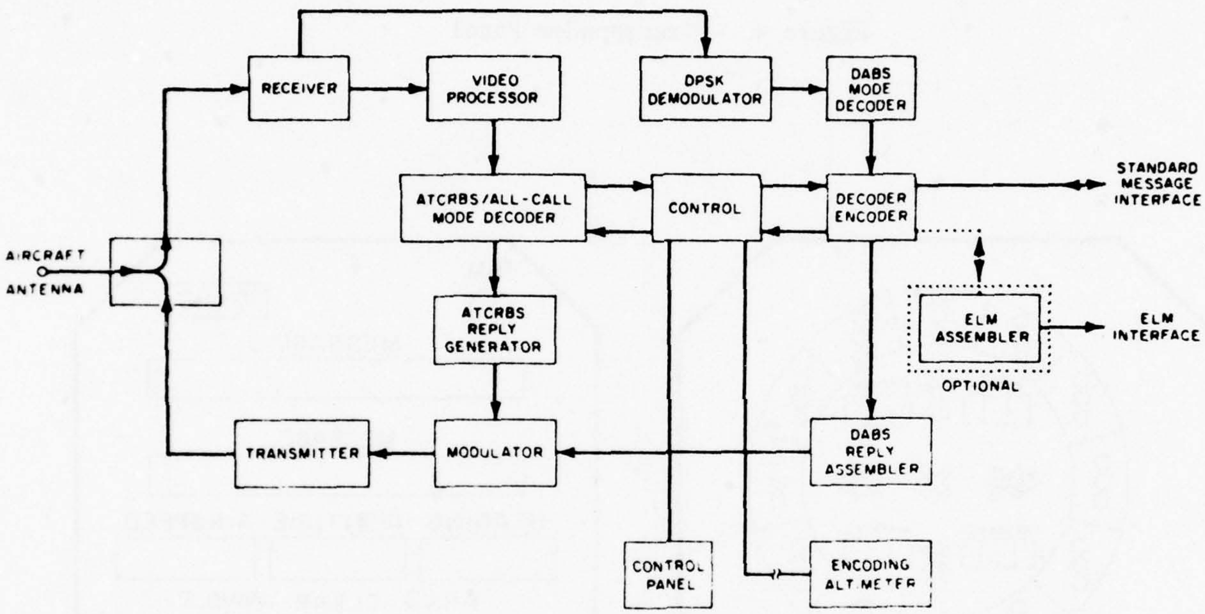


Figure 6. -DABS Transponder Functional Block Diagram (Reference 3)

MLS

The Microwave Landing System program is, of course, a joint program with the military. As such it has evolved in such a manner as to satisfy most of of the requirements of both civil users and the services. These basic requirements are listed in Table 3, which also notes the deficiencies of ILS in meeting the requirements, and the solutions provided by MLS. While certain

TABLE 3

PRECISION APPROACH AND LANDING SYSTEM REQUIREMENTS THROUGH AND BEYOND 2000 (REFERENCE 5)

REQUIREMENT	ILS	MLS
Expanded Service (1250 or more Systems)	Channel Limited (20-40 Channels)	200 Channels
Operational Flexibility	Fixed Path Narrow Guidance System	Complex Paths Broad Sector
Civil/Military Compatability	Unsuited for Tactical/Shipboard Use	Meets All Civil/ Military Requirements
High Reliability	Adverse Weather Effects Course Aberrations Due to Multipath	Relative Insensitivity To Weather High Multipath Rejection Cleaner Beams
Environmental Immunity	Site Sensitive Sometimes Fails To Meet Required Performance	Relative Freedom from Site Effects Highly Reliable
Low Cost	Low Potential for Annual Cost Reduction	High Potential Reduction in Annual Maintenance and Flight Inspection Costs
	Sometimes Costly Siting Solutions	Minimum Site Preparation

technical problems are yet to be finally decided (scanning beam (TRSB) versus Doppler technique; C-band versus L-band DME), the MLS function has been relatively well defined (References 5 and 6). The functions of airborne MLS avionics will be as follows:

Required Functions:

1) Azimuth beam decoding
2) Elevation beam decoding
3) Straight-in approach guidance

Optional Functions:

1) DME
2) Radio altimeter integration
3) Flare beam decoding
4) Back course/missed approach beam decoding
5) Complex approach path navigation
6) Automatic landings

The range of complexity and cost of airborne equipment which will be found in the NAS environment will be exceedingly wide. It is uncertain at present whether complex approach path capability will be a requirement at certain terminals to increase capacity or to provide noise-abatement approaches. In general the optional functions listed above provide direct improvements to operational capability and so may be acquired by those operators for whom they are economically worth while. Initial Air Force requirements will be satsified by simply the straight-in approach capability (Reference 7) with Category II landing minimums. In order to achieve the performance required of MLS for Category I, II, and III operations, the accuracy of the MLS sensors must be quite good. The accuracy requirements of the three measurements are stated in Table 4, from Reference 30, as appropriate for each operations category.

TABLE 4

RTCA MLS SPECIFICATIONS (1σ) (REFERENCE 30)

Configuration Operational Use	D Cat. I	F Cat. II	K Cat. III
DME			
Bias	91.4 m (300 ft.)	30.5 m (100 ft.)	6.1 m (20 ft.)
Random	*	*	*
Total	91.4 m	30.5 m	6.1 m
AZ			
Bias	.125 degrees	.090 degrees	.036 degrees
Random	.065 degrees	.033 degrees	.024 degrees
Total	.141 degrees	.096 degrees	.042 degrees
EL			
Bias	.050 degrees	.050 degrees	.050 degrees
Random	.058 degrees	.038 degrees	.035 degrees
Total	.077 degrees	.061 degrees	.061 degrees

* Random error negligible compared to bias

The MLS system operates at C-band (∿5 MHz) with the possible exception of DME. Other than for the DME function, no airborne transmitters are required. Control functions include frequency selection and gradient choice (in variable-gradient systems). Digital processing requirements are minimal. If automatic landing capability is required, the flight control system becomes quite complex, just as it is in present automatic landing systems. Figure 7 illustrates the basic configuration, including redundancy, for an advanced capability MLS system. The capabilities of the ground equipment

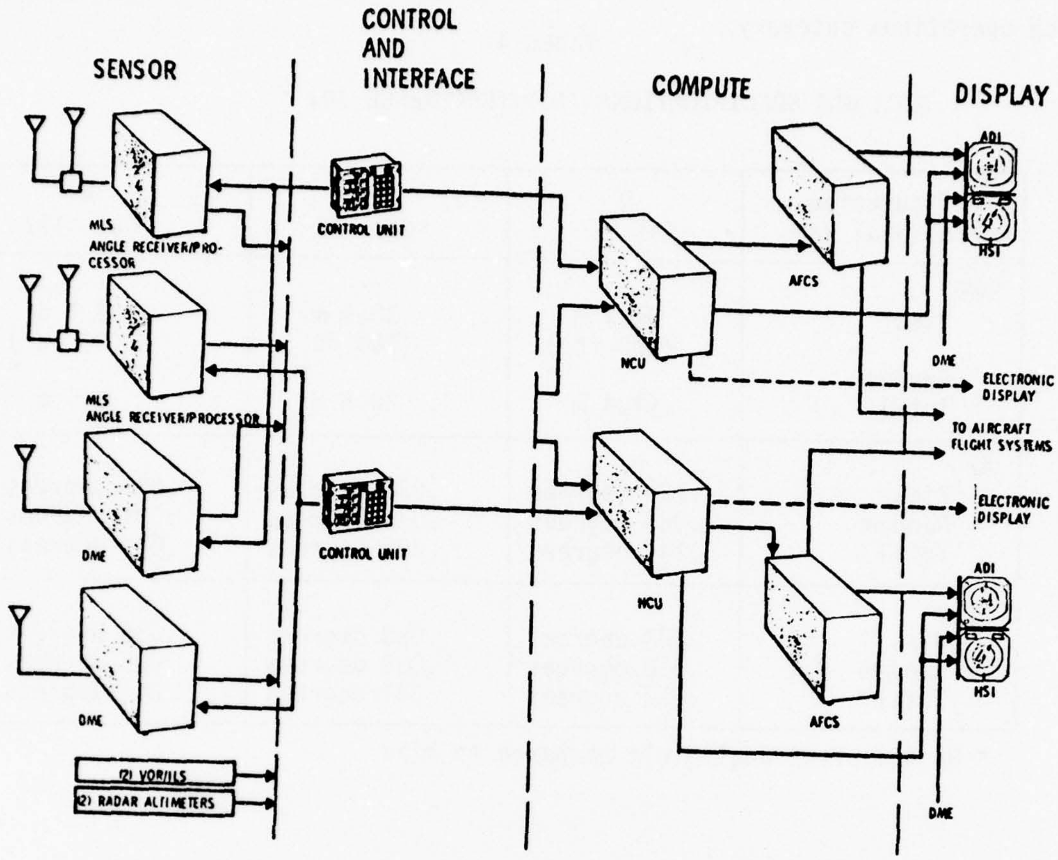


Figure 7. - Typical Advanced MLS System Configuration for Curved Approaches and Autoland (Reference 5)

necessary to support elementary, intermediate and advanced MLS system configurations are listed in Table 5 from Reference 5. The corresponding airborne system operational capabilities are listed in Table 9 for civil and military applications.

TABLE 5

GROUND SYSTEM OPERATIONAL CAPABILITIES (SEE NOTE)

	Elementary	Intermediate	Advanced
Azimuth Guidance	±10°	±20°	±40°
Elevation Guidance	2-7°	2-10°	1½-20°
Flare	Optional	Optional	Optional
Back Azimuth	Optional	Optional	Optional
Range: DME	Optional	Yes	Yes
Marker	Yes	Optional	Optional
Auxiliary Data	Optional	Optional	Yes

NOTE: Unique military requirements will necessitate variations in the above.

Providing complex approach path capability will require a considerable increase in digital processing system complexity since, not only do Area Navigation-type calculations have to be performed and maneuver anticipation or guidance functions provided, but route storage capability must also be provided. Furthermore, route data must be supplied by the pilot, or selected from a data base. It has been suggested that complex approach path computations could be performed in RNAV computers (Reference 6) for civil operations. Obviously, this approach could be extended to RNAV or GPS systems for military applications.

Upgraded ATC Automation

This broad category covers several distinct ARTS or NAS automation enhancement programs, most of which do not involve changes to airborne avionics requirements:

1) Conflict Alert and Conflict Prediction

2) Conflict Probe

3) Control Sector Design (ETABS, TIPS)

4) Metering and Spacing (M&S)

5) Minimum Safe Altitude Warning (MSAW)

6) Central Flow Control (CFC)

7) Control Message Automation (CMA)

Some of these functions are presently being implemented (MSAW, Conflict Alert). They do not affect avionics requirements since they only involve modifications to ground ATC computer software. Others which also have no such avionics effect will include Conflict Probe, Control Sector Design (Electronic Tabular Display-ETABS, Terminal Information Processing System-TIPS), and Central Flow Control. The CMA function will utilize the DABS Data Link, as was discussed under DABS, above. While the M&S function does not directly imply any changes to airborne avionics, the utilization of 4D (time control) RNAV in order to upgrade M&S system performance will. The performance of the 4D RNAV system will have to be quite accurate. It has been demonstrated (Reference 6) that such systems will probably be able to deliver a 5 second (1σ) delivery error on approach, which would result in worthwhile improvements to arrival capacity.

The airborne 4D system must be capable of not only a high degree of delivery accuracy, but also of performing the required 4D maneuvers. These were determined to include (Reference 6) arrival time control through speed control on fixed routes and on direct-to-waypoint clearances, but may preclude the usage of airborne-generated path-stretching functions.

Flight Service Station Modernization

This program involves the centralization of Flight Service operations and the automation of many presently manual functions. No effects on avionics requirements are expected.

Area Navigation

The Area Navigation feature of UG3RD is planned in order to achieve several benefits to the ATC system and aircraft operators through improved navigational techniques and ATC procedures. The basic 2D RNAV capability allows more direct routes and more efficient terminal area route structures and procedures. Very significant reductions in controller workload result through the use of RNAV procedures (Reference 8). The usage of the 3D RNAV, or VNAV, technique can allow further savings in fuel consumption through control of vertical profiles. The 4D RNAV capability has been discussed previously.

Civil RNAV accuracy standards were developed based on VOR/DME performance capabilities. The current standard for RNAV certification, AC 90-45A (Reference 25), provides accuracy tables which are based on the following component accuracies (2σ):

VOR - Ground	1.9°
Air	3.0°
DME - Ground	0.1 nmi
Air	0.5 nmi or 3% of range
RNAV System	0.5 nmi

The current route width specification which results is ±4 nmi (enroute) with a 3.25° splay beyond 51 miles, or ±2 nmi (terminal). Future RNAV plans (Reference 10) call for reduction of enroute route widths to ±4 nmi with no splay. Earlier RNAV work (Reference 31) postulated that route widths need to be reduced to 2.5/1.5 nmi, although such a stringent requirement will probably not be necessary.

AC 90-45A also states accuracy requirements for non-VOR/DME systems, which are probably more appropriate to the USAF system case (INS, Doppler, LORAN, GPS, etc. systems). The required overall performance, including flight technical error, required of such systems is summarized below (2σ, nmi):

	Cross Track	Along Track
Enroute	2.5	1.5
Terminal	1.5	1.1
Approach	0.6	0.3

The required functions of an RNAV system include:

Required Functions:*

1) Route data input (waypoints in lat/lon or VORTAC-related Rho/Theta)
2) Cross Track Deviation and Distance-to-Waypoint calculations.
3) Approach Mode (higher sensitivity)
4) Parallel Offset function
5) Direct-to-Waypoint function
6) Accuracy required to meet FAA AC 90-45A, or future revisions.

Optional Functions:

1) Multiple waypoint storage
2) Route structure data base

*Note: RNAV capability may only be required in certain airspace (high altitude) and certain terminal areas.

3) Multi-sensor operation (higher accuracy, greater reliability)
4) VNAV capability
5) 4D capability

The various types of RNAV systems are discussed in References 9 and 10. The required Minimum Operational Characteristics have not yet been finalized.

Basic RNAV systems utilize analog signal processing or intermediate scale digital signal processing. More complex systems can get quite involved. A pilot control/display unit with frequency selection and waypoint knobs, or a keyboard, is required. Waypoint and track parameters must be displayable, and the nav data output integrated with the flight director, HSI and/or autopilot.

The most advanced civil RNAV system for which an industry specification exists is the "Mark 2 Air Transport Area Navigation System", ARINC characteristic 582 (Reference 32). It is a radio-updated INS-based system with an integral route structure data base. Since it serves as a model for all INS-based RNAV systems to be used in the civil environment, it is appropriate to excerpt the system functions and required outputs specifications from the ARINC document. Table 6 states the required RNAV system functions, while Table 7 lists the detailed outputs and their formats. Table 6 and the functions list above should both be considered in defining the functions for USAF navigation systems.

TABLE 6

REQUIRED FUNCTIONS FOR THE ARINC MARK 2 RNAV

1.2.1 Basic Functions The digital computer program should, as a minimum, perform the following processes using a spherical or other accepted earth model. a. Compute present position from best available sensors such as, VOR, DME, ISS(INS), Air Data, Compass System, Doppler and other navigation systems. b. Perform lateral track guide computations. c. Compute a wind corrected lateral steering signal suitable for the AFCS and flight director command display. d. Compute deviation from a desired vertical profile. e. Compute a compensated vertical steering signal (relative to the profile d. above) which is suitable for the AFCS and flight director vertical command displays. f. Perform range and bearing computations to selected points. g. Perform all support functions associated with the R-NAV control and display unit. h. Perform all support functions associated with the R-NAV flight data storage unit. i. Perform comprehensive checking and verification functions. j. Perform automatic VOR/DME facility selection and tuning, when the VOR/DME Auto Tune option is included. k. Perform control and display functions associated with an Automatic Chart System when such an option is included.

Airport Surface Traffic Control

Current plans for ASTC modernization include development of an improved ground surveillance radar (ASDE-3) and an ATCRBS beacon tracking system (TAGS). There is no currently planned program that would affect airborne avionics requirements.

TABLE 7

REQUIRED OUTPUTS FOR ARINC MARK 2 RNAV

R = Required

CO = Customer Option

X = Possible Use (Application)

FUNCTION	COORDINATES	REQUIREMENT STATUS	SIGNAL FORMAT: ANALOG	SIGNAL FORMAT: BCD	SIGNAL FORMAT: BINARY	SIGNAL FORMAT: UNSPECIFIED	APPLICATION: INSTRUMENTS	APPLICATION: AFCS	APPLICATION: OTHER SYSTEMS
1. Distance-to-go	N. Miles to Destination or Way Point	R		R			X		
2. Time-to-go	Minutes to Destination or Way Point	R		R			X		
3. Ground Speed	Knots	R		R	R		X		X
4. Present Position	LAT/LONG	R		R	R		X		X
5. Cross Track Distance	N. Miles from Desired Track	R		R			X		
6. Cross Track Deviation	"DOTS" from Desired Track	R	R				X	X	
7. Vertical Profile Displacement	Feet from Desired Vertical Profile	R		R			X		
8. Vertical Profile Deviation	"DOTS" from Desired Vertical Profile	R	R				X	X	
9. Desired Track	Degrees from Selected reference direction	R	R	R			X		
10. Track Angle	Degrees from True (or Mag) North	R	R	R	R		X		X
11. Drift Angle	Difference between Heading and Track Angle	R	R	R			X		
12. Track Angle Error	Difference between Desired Track and Present Track Angle	R	R	R			X		
13. TKE + DA	Difference between Desired Track and Heading	R	R				X		
14. Desired Vertical Speed	Feet/Min	R		R			X		
15. Desired Altitude	Feet	R		R			X		
16. Wind Angle	Degrees from True North	R		R	R		X		X

TABLE 7

REQUIRED OUTPUTS FOR ARINC MARK 2 RNAV (CONTINUED)

R = Required
CO = Customer Option
X = Possible Use (Application)

FUNCTION	COORDINATES	REQUIREMENT STATUS	SIGNAL FORMAT				APPLI-CATION		
			ANALOG	BCD	BINARY	UNSPECIFIED	INSTRUMENTS	AFCS	OTHER SYSTEMS
17. Wind Speed	Knots	R		R	R		X		X
18. Lateral Steering Signal	0.393 Volts/Degree Roll	R	R					X	
19. Vertical Steering Signal	No ARINC Specification	CO	R					X	
20. Omni Bearing	Degrees from Magnetic North	CO	R				X		
21. Relative Bearing	Degrees from Aircraft Heading	CO	R				X		
22. Computer Cross Talk		R				R			X
23. TO-FROM	"TO" Way Point	R	R				X		
24. Leg Change Alert	"Time" to Next Way Point	R	R				X		
25. Vertical Profile Change Alert	"Time" to Next Way Point	R	R				X		
26. Failure Warnings	"YES" or "NO"	R	R				X	X	X

Wake Vortex Avoidance System

The WVAS development program includes both vortex detection systems and prediction systems. There would be no avionics impact.

Wind Shear

The occurrence of wind shear related accidents over the past few years has stimulated intensified efforts to: 1) better understand conditions conducive to the development of low altitude wind shear conditions, for avoidance purposes, and 2) develop airborne wind shear detection schemes. Several airborne detection techniques have been suggested. The most promising involve accurate ground speed measurement, either through DME techniques or inertial sensors, and real time comparison to airspeed in order to detect changing wind conditions. If good wind shear detection systems are developed, many commercial operators may elect to equip. However, there is no indication that equipage would be a requirement for operators at specific airports.

Profile Descent

Profile descent procedures have been used on a trial basis at several terminals in an effort to conserve fuel. The procedure involves essentially eliminating low altitude cruise and promoting idle thrust descents. The procedures have been designed such that no special avionics are required for their execution.

BCAS

In recent years several proposals have been offered concerning collision avoidance systems which utilize conventional ATCRBS transponders, rather than dedicated CAS equipment, for their operation. The major motivation for this effort is that such a system could provide protection for BCAS-equipped aircraft against any transponder-equipped aircraft (presumably virtually all aircraft at some future date). The disadvantage is that most GA aircraft (presumably not BCAS-equipped) would have no CAS protection against similarly non-equipped aircraft, unless a very low cost system could be developed which would proliferate.

Extensive research, development and test effort has been expended on the BCAS concept recently. The only concept which has emerged as being really practical is a dual mode (active/passive) system. In environments where several ATCRBS antennas are active, the BCAS operates in a passive mode whereby it listens to both ground interrogations and airborne replies, and sorts out range, approximate bearing, altitude and closing rate of nearby aircraft the system tracks. (Altitude is extracted from the Mode C data; if nearly all aircraft do not eventually Mode C-equip, the utility of BCAS will be limited). Where only one (or none) ATCRBS antennas are active, the system operates in an active mode where simulated ATCRBS interrogations are transmitted at a slow rate in order to elicit replies from nearby aircraft. Bearing data cannot be obtained if there are no active ATCRBS antennas nearby. The concept easily evolves to a DABS environment; however, significant changes to the DABS ground system structure may be required.

An airborne BCAS unit would require the following components:

1) Two receivers (1030 MHz, 1090 MHz) continuously providing data (decoded interrogations and replies)
2) One dual-frequency transmitter for sending standard ATCRBS replies and BCAS active mode interrogations
3) Two antennas (top and bottom) and appropriate switching systems

4) Substantially complex digital processor for acquiring and tracking targets, detecting threats and generating avoidance commands

5) BCAS PWI/CAS cockpit display, in addition to standard ATCRBS control head

The cockpit display would show relative bearings of nearby aircraft at nearby altitudes, and would also display avoidance maneuver comamnds. This display could possibly be integrated with the ATARS system. This could save space; also, the possibility of ATARS and BCAS giving conflicting avoidance commands has been the subject of much controversy.

3. 4GATC POSSIBILITIES AND POTENTIAL AVIONICS IMPLICATIONS

There are not at present any formal plans or policies regarding the direction of the Fourth Generation ATC System (4GATC).* Many avenues have been suggested (References 11, 12, 13, 14, 15); however, none have been decided upon to serve the post-1990 time frame. There are several options regarding navigation, surveillance, collision avoidance, and communications which may come to pass, each having unique avionics implications. These are reviewed in this section. Some concepts go to the very heart of the question as to the role of any form of ground-based surveillance (secondary radar) system.

An objective of nearly all concepts is the elimination of the need for primary radar through substitution of an accurate, reliable secondary radar or position reporting system. The motivation is to eliminate the costly radar installation. Naturally, airborne equipage would be mandatory and redundancy would probably also be required.

*The 4GATC has periodically been given other names, such as, the "Air Traffic Management System (ATMS)", but will be called the 4GATC here for simplicity.

One serious contender for the 4GATC is the Synchro-DABS concept (Reference 12). The basic concept is that a DABS-compatible modification to the DABS system could be made whereby Synchro-DABS-equipped aircraft would be automatically time-synchronized to the ground net. All DABS aircraft would be caused (unknowingly and without equipment modification) to periodically transmit time-synchronized replies from which Synchro-DABS aircraft could perform accurate one-way range measurements. The results would be accurate knowledge of range, range rate and altitude of nearby DABS-equipped aircraft, forming the basis of an air-derived CAS. The advantages of Synchro-DABS are that it is evolutionary, it is integrated with the ground ATARS function and automated ATC messages, and that it could easily be transformed into a low cost, highly accurate navigation system as well. This would be done by simply providing low-cost Synchro-DABS transmitters at surveyed ground points (ATCRBS sites, VORTAC sites) which would transmit time-synchronized messages containing site latitude/longitude (lat/lon). All Synchro-DABS aircraft could thereby obtain one-way range data from multiple known ground sites and solve a relatively easy triangulation problem. Thus navigation, surveillance, CAS and communications could be integrated into one relatively simple system with low cost avionics. Multiple ground system redundancy would be provided, and airborne redundancy would be providable at much lower cost than several competing schemes.

Synchro-DABS could evolve into a modified surveillance system whereby many (or all) rotating surveillance antennas could be eliminated. This would be accomplished by omnidirectional antennas transmitting time-ordered role call DABS interrogations eliciting replies which would be heard at several ground sites, from which triangulation would be used for position determination. Alternatively, Synchro-DABS aircraft could transmit air-derived position, heading and speed data on the downlink message, which would then be cross-correlated against the ground-derived range measurements (this also allows ground monitoring of airborne navigation equipment). Alternative means of airborne synchronization and one-way ranging for navigation purposes have been suggested, such as one proposal to modify the TACAN DME signal for such purposes (Reference 16).

Another modification to the DABS concept has been proposed (Reference 15) which would eliminate most ground DABS sites. This concept, called ASTRO-DABS, would require establishment of a net of surveillance satellites which would locate aircraft by transmitting interrogations and then performing triangulation with the replies. This concept has several technical problems, not only with the satellite system, but with the ground system and with airborne avionics. Redundancy is provided through satellite count and through provision of two ground control stations. The problem of disseminating this centrally collected surveillance data to all CONUS users is quite involved. Avionics would be expensive since far lower received interrogater power levels are involved, and since the CAS problem is not directly addressed by this concept. Also, standard DABS capability would also be required for many terminal areas, further increasing avionics costs.

A further technique for the 4GATC system is to utilize the Navstar GPS system, or a civil navigation satellite system, as the basis of the entire ATC system (Reference 13). The basic concept is to utilize an accurate source of navigation data such as GPS, and utilize an air/ground data link to supply this position data to the ATC system for surveillance purposes. The data link could also be used for collision avoidance purposes, by having all aircraft listen in for these position reports. Presuming that all aircraft would be time synchronized through GPS, the ground and air receptions of data link messages could be used for measuring one-way range for crosscheck purposes. The data link would also serve the ATARS and ATC message functions. Some form of time-synchronized data link technique, such as Time-Division Multiple-Access (TDMA), would probably be used. This is functionally similar to the military JTIDS technique, except that the jam resistance, secure code, frequency hopping, and spread spectrum modulation techniques are not needed. Instead, straightforward modulation and coding techniques may be used, considerably reducing airborne equipment costs. A problem with the GPS/Data link approach is that is is not evolutionary; dual systems would have to be supported for quite some time. Another problem lies in the cost of the airborne GPS equipment. Even the so-called low cost equipment would probably be quite expensive in comparison to the Synchro-DABS or modified TACAN DME approaches. Also, the update rate is very slow (every two minutes) as compared to the Synchro-DABS or modified TACAN approach (probably one update per second or faster). Some form of dead reckoning, probably involving the integration of sensed heading and airspeed data (unavailable in electronic form on a large number of aircraft), would probably be required. Provided that sufficient redundancy is planned into the system, the primary and secondary radar systems could be eliminated if either the GPS or modified TACAN approaches are selected. Also, Synchro-DABS could also evolve to a state where most or all directional, rotating antennas are eliminated.

SECTION III

AIR FORCE AVIONICS CAPABILITIES, PLANS AND INTERFACE PROBLEMS

In this section the avionics functions currently provided on USAF aircraft to ensure NAS compatibility are reviewed. Major USAF avionics development plans are then discussed and, in light of the NAS plans in Paragraph 2 of Section II, the future NAS interface problems are identified.

1. PRESENT AVIONICS REQUIREMENTS OF USAF A/C OPERATING IN CIVIL AIRSPACE

Present avionics requirements of USAF aircraft, over and above those systems carried for USAF purposes, are quite minimal in order to be compatible with the NAS environment. The exceptions are the transport category aircraft which carry fully IFR-certified avionics, due to their heavy involvement in high density areas. In general, requirements for unique avionics are minimal for the following reasons:

1) The FAA supports UHF comm channels for military users
2) The domestic TACAN airways system is virtually identical to the VOR airways, and TACAN may be used as an approach aid
3) The civil and military ILS systems are common
4) Compass locators and ADF beacons may be used with any ADF equipment

The only accommodation of any real significance was provision of the ATCRBS Mode A and C transponder functions, which required further embellishment to the IFF system or independent transponder equipment. An encoding altimeter is also required to support the Mode C function, although this would apply primarily to the transport type aircraft.

The Air Force is currently developing several new, highly sophisticated avionics systems. Of these, four major programs are of interest here due to the fact that they will affect Air Force NAS operations since they involve the communications, navigation, identification and landing functions. These programs, described in detail in the following section, are:

- Joint Tactical Information Distribution System (JTIDS)
- NAVSTAR Global Positioning System (GPS)
- Microwave Landing System (MLS)
- 4D Integrated Control and Display System (4D INCADS)

Each of these programs are designed to satisfy military operations requirements. Their utility in the NAS environment has been considered in each case, but was not a major factor influencing their design. MLS is a joint DOD/FAA program, and so it has been designed to satisfy civil requirements. However, this does not insure compatibility in complex civil terminal environments, as will be seen later. Each of these four programs diverges, to a greater or lesser extent, from the UG3RD plans described in Section II, and in most cases they also diverge from the potential 4GATC plans introduced in Paragraph 3, below.

2. AVIONICS SYSTEM DEVELOPMENT PLANS AND PROGRAMS

In this section the four major USAF avionics development programs related to the communications, navigation, identification and landing functions are described in sufficient detail to permit identification of NAS interface problems and to investigate solutions.

a. Joint Tactical Information Distribution System

The JTIDS (Reference 17) system is designed to fill a very significant military requirement for secure, timely communication and distribution of data among all forces engaged in a tactical theater environment. All users participate in transmitting and receiving data over what amounts to a secure party line. The coverage of a JTIDS net is regional, e.g., within line of sight range of an AWACS aircraft (500 nm range). More than one net can be operating in an area, and communications between nets is possible. JTIDS is a true ICNI (Integrated Communications, Navigation and Identification) system: navigation is provided through an integrated TACAN capability, and identification is provided as a part of the communications function. Also, the relative navigation function is provided for coordinating maneuvers and collision avoidance.

JTIDS operates as a time division multiple access (TDMA) system, where only one user transmits at any instant, followed by blanking which allows the transmission to propagate across the coverage volume. Users are all synchronized and are assigned time slots in accordance to their data rate requirements. Communications security is achieved through data encryption and through frequency hopping techniques. Jam-resistance is provided through frequency hopping and through allocation of time slots such that transmissions are uniformly distributed, rather than bunched up. The frequency-hopping scheme is central to the JTIDS concept, as it provides jam-resistance as well as security. JTIDS can operate in a single frequency "narrow band" mode when these features are not needed. JTIDS operates in the L-band from 960 to 1215 MHz. This band also contains ATCRBS (1030 and 1090 MHz) and TACAN/DME. Together these two utilize essentially 100% of the band, but only on a part time basis since they are pulse systems. JTIDS operates throughout the band, with the exception of the regions around 1030 and 1090 MHz. The frequency requirements of JTIDS are illustrated in Figure 8. Operating frequencies are uniformly spaced and selected in a psuedo-random sequence which is known only to participants in the net. Each JTIDS pulse is 6.4 μsec long and transmits one symbol or character. Each pulse is transmitted at a different frequency, and a total transmission time of 7.8125 milliseconds constitutes a message. There are 1536 messages or time slots within a 12 second time frame, and 64 time frames within the basic 12.8 minute cycle of the system. This time-division structure is illustrated in Figure 9. Since only the

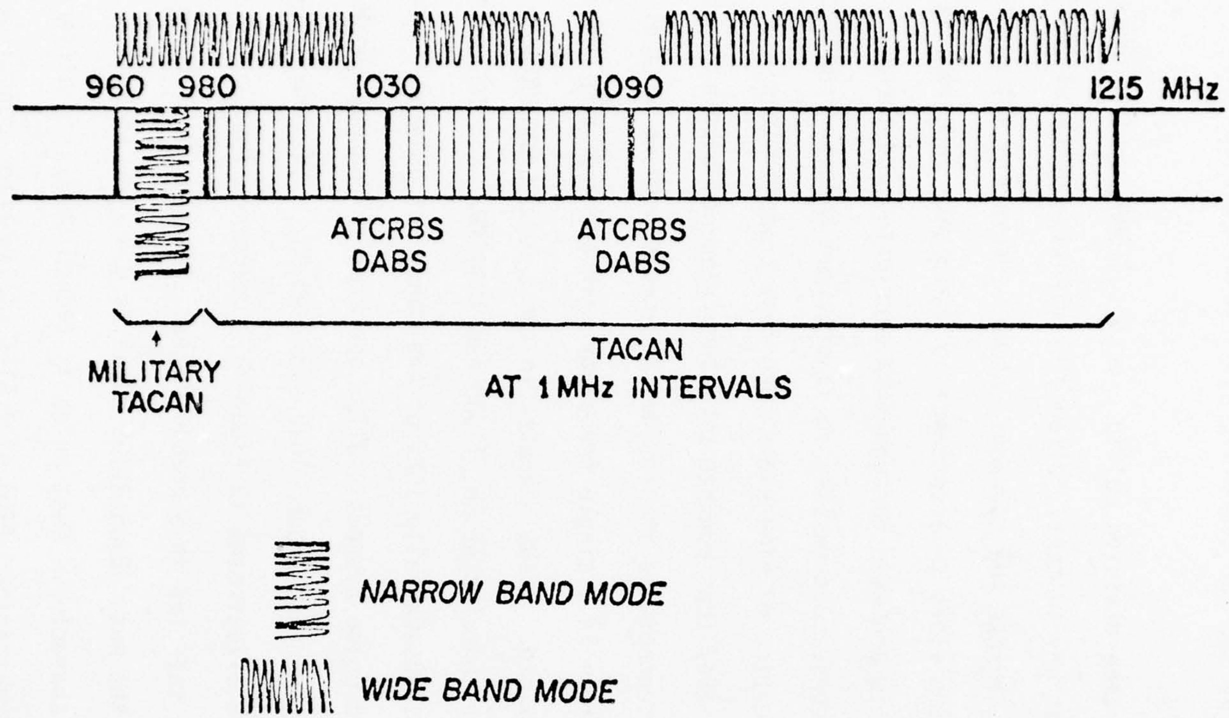


Figure 8. - JTIDS Operating Frequencies

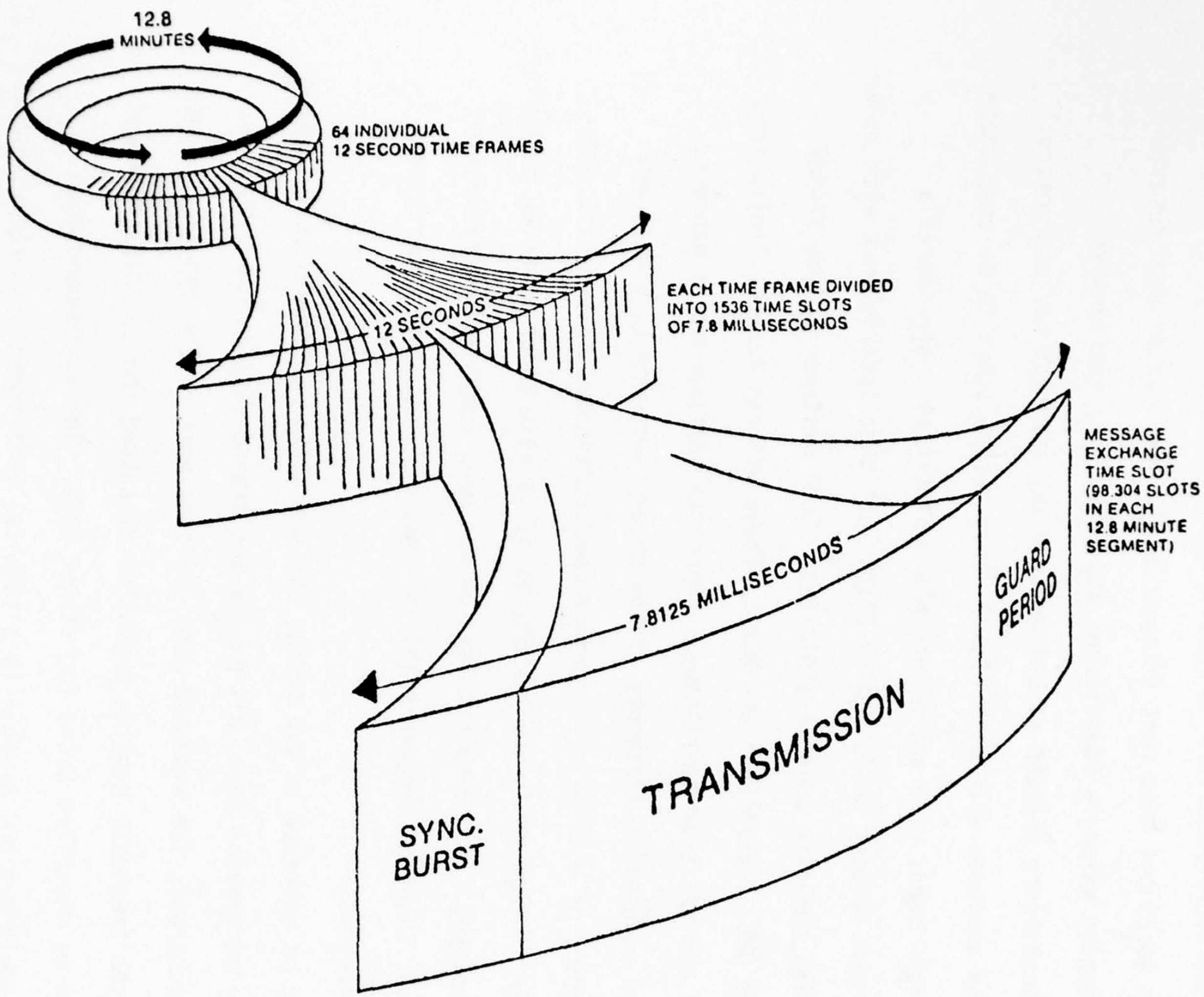


Figure 9. - JTIDS Time Slot Structure

net participants know the psuedo-random sequence, only they can tune their transmitters/receivers to receive an intelligible set of data. Also, the enemy would not know what frequencies to jam, and so must resort to broadband jamming which is inefficient and relatively ineffective.

JTIDS transmitters operate at 200 watts peak, although certain control aircraft will be equipped with much higher power transmitters to be used under jamming conditions (this will not affect NAS operations). Considerable attention has been devoted to designing JTIDS such that interference with other systems utilizing the same band is minimized. Such systems include TACAN/DME, MLS L-band DME, DABS/ATCRBS and BCAS. These efforts include limitations to pulse width, and spectrum confinement. Spectrum confinement is achieved by limiting the modulation frequency of the binary sequence to 5 MHz, and through the choice of modulation technique used (continuous phase-shift modulation-CPSM, or minimum shift keying-MSK, as it is also known). Notch filtering may also be employed. The resulting system has been subjected to extensive bench and flight testing (Reference 17) in order to prove that interference problems are minimal.

JTIDS can be operated in two modes, the so-called narrowband and wideband modes. In the narrowband mode, all pulses are transmitted on one frequency, 969 MHz. In contrast, the wideband mode utilizes most of the 960 to 1215 MHz band through the frequency hopping technique discussed above. Data rate and modulation are as described above for either mode. The narrowband mode is jammable and therefore not usuable in a tactical environment, so the wideband mode would be prevalant. The narrowband mode may find some applications in the NAS environment.

In addition to the basic JTIDS capability discussed to this point, there is also a plan for a Phase II JTIDS. These plans are certainly not firm, and would probably come to pass only if a very definite need is demonstrated. Phase II JTIDS would operate using the Distributed Time Division Multiple Access (DTDMA) technique. The difference is that, whereas in the TDMA concept each user transmits his entire message consisting of frequency-hopped pulses in one burst, in the DTDMA concept the pulses comprising one message are pseudo-randomly distributed in time so that pulses from many users are interleaved. This further improves jam-resistance. A further, and very important, feature of Phase II JTIDS is that it includes an avionics integration function whereby the following systems (besides TACAN) would be integrated within JTIDS:

- IFF
- ATCRBS
- DABS
- GPS

Presumably it would also be possible to integrate BCAS or Synchro-DABS if either are implemented by the FAA.

b. NAVSTAR Global Positioning (GPS)

The GPS navigation system is designed to fulfill tactical, airlift and transport navigation aid requirements and become a universal military positioning system (air, sea, land) except for undersea usage. It is intended specifically to take over the role which Loran-C has played in tactical operations; e.g., in Southeast Asia. It has the advantages of higher accuracy as well as worldwide coverage, eliminating the need to set up Loran chains as has been the case before. The GPS system is intended to be widely utilized by USAF as they transition operations from the use of several nav systems to just three systems: INS, GPS and radar (Reference 18).

Three levels of avionics system complexity have been specified (Reference 19) and will vary considerably in cost and performance (particularly dynamic performance). These will be discussed subsequent to introducing the concept of operation of GPS. The GPS receiver discriminates a measure of psuedo-range and range rate from at least three (to get 2D position and Time) or four (to get 3D position and time) satellites out of the (eventual) constellation of at least twenty-four satellites circling the earth. By measuring psuedo-range from four satellites, three-dimensional position and time can be accurately determined unambiguously (Reference 20).

The psuedo-range measurements are achieved in the following manner. Each satellite transmits two signals, one called the clear/acquisition (C/A) signal and the other called the precision (P) signal. The P signal is secretly coded and can only be utilized by authorized users. It provides the highest positioning accuracy ($\sim$10 m). The C/A signal is usable by all, but provides fixes at approximately ten times the error. The lowest cost user equipment would suffer further degradation. GPS operates on two frequencies: L_1, 1575.42 MHz, and L_2, 1227.6 MHz. The L_1 signal contains both the C/A and P signals; they are both transmitted continuously as Psuedo Noise Biphase Shift Keyed (PN/BPSK) continuous sinusoidal carriers. "Psuedo Noise" relates to the fact that each signal is transmitted as a sequence of a fixed number of bits generated by a shift register with feedback taps. Arrangement of the taps provides unique code sequences. Each of the twenty-four satellites transmits one sequence of 1023 bits as the C/A signal (from a 10-bit shift register) and one sequence equivalent to 2×10^{14} bits which is generated from a combination of two 24-bit shift registers. The C/A signal is modulated at 1.023 Mbps and thus repeats one-thousand times per second. The P signal is modulated at 10.23 Mbps and, since the code sequence is so long, it repeats once every 267 days. The C/A code sequence is fixed, unique to each satellite, and available to all users. The P code sequence is unique to each satellite at any given time and requires privileged knowledge to reconstruct it in the receiver.

The C/A and P code sequences do not of themselves convey data, but are used to uniquely identify each satellite and to provide the psuedo-range measurement. "Biphase Shift Keying" refers to the fact that the method of modulation used is to phase-shift the carrier 180° to indicate changes in digital state (zero or one). The two signals simultaneously modulate the carrier in phase quadrature at constant amplitude. Each modulator results in either no phase shift, or a 180° phase shift; thus any of four carrier phases may exist at any point in time, indicating the state of the two modulating signals.

The L_2 channel also contains either the C/A or P signals, but not both. Its sole purpose is to provide information by virtue of its different carrier frequency to determine ionospheric propagation characteristics so that corrections may be made. Lowest cost user equipment would not receive this signal.

Each signal (C/A and P) also conveys digital data required for the operation of the system (satellite ephemerides, clock corrections, and handover data). Handover data is acquired from the C/A signal by P-signal users in order to initialize the code sequence so that the P signal may be acquired. The digital data frames are 1500 bits long and are modulated at a rate of 50 bps. Note that this data rate is <u>extremely</u> slow relative to the modulation rates (chipping rates) of the C/A signal (1.023 Mbps) and the P signal (10.23

Mbps). The modulation is accomplished by modulo-2 summing (exclusive OR) of the data bit stream and the C/A code sequence stream. Note that the C/A code repetition rate (1000/sec) is exactly twenty times the data bit rate. Thus, a data bit set to one simply causes the received code to assume the two's complement of the original 1023 bit code for twenty cycles.

All satellites transmit at the same two frequencies continuously. The received power levels are extremely low (minimum of -163dBw for the P signal, and -160dBw for the C/A signal). Also there is a significant amount RF noise and receiver termal noise complicating the signal detection problem. The different satellites are differentiated by the doppler shift of the carrier (due to relative velocities) and the unique signal code sequence (which is known to the receiver). The acquisition of the signal is accomplished through two steps: code lock, followed by frequency lock. Code lock is accomplished by comparing the output of an internally-generated signal code replica which is compared to the received signal while the code is being shifted one-half chip at a time, until the correlation peaks. Through the use of the correlation technique, the desired signal is thus separated from the other satellite signals (which may be of higher amplitude) and background noise, even though the desired signal would be otherwise indistingishable from the noise. The phase of the code generator is then fixed and locked to the received code phase. The signal carrier phase is then acquired and tracked using a Costas loop which varies the frequency of the internally generated signal until lock is achieved (this is called the Pull-In Mode) (Reference 20). Once locked, normal loop tracking occurs.

Four satellites are acquired and tracked by four separate channels (or one time-multiplexed channel) in the receiver. The relative delays required to achieve code lock are proportional to the relative ranges of the four satellites. Since the satellite positions are known (from the 50bps data), receiver position and exact time of day may be determined. The doppler shifts of the received signals are proportional to relative velocities. Since the absolute velocities of the satellites are known, the velocity (in three dimensions) of the receiver may be calculated.

The most sophisticated type of receiver, referred to as the "X" receiver (Reference 19), contains at least four independent tracking loops, and acquires the highly accurate P-signal after having first acquired the C/A signal and decoding handoff data from that signal. The "X" receiver also tracks both the L_1 and L_2 channels and performs ionospheric delay corrections to the range measurements. The "X" receiver is most able to respond to dynamic situations since all four satellites are continuously tracked, and thus range and velocity data are updated continuously. Maintaining tracking within the receiver during highly dynamic maneuvers can be a significant problem (Reference 20) unless inertial aiding is provided so that changes in inertial velocity and acceleration are used to bias the tracking loops. In transport type missions this is apparently not a problem.

The other two receiver classes (Reference 19) are "Y" and "Z" types. The basic characteristics of all three classes are summarized in Table 8. Both receivers track only one satellite at a time. Thus a complete solution is available only once every two minutes. Successful operation in an aircraft will require integration of heading/air data signals (when available) such that the system becomes an updated DR system. The "Y" receiver tunes both the L_1 and L_2 signals, and performs ionospheric delay correction. It can also track either the C/A or P signals. The lowest cost, "Z" receiver receives L_1 only and tracks only the C/A signal, and would therefore be considerably less accurate.

TABLE 8

USER EQUIPMENT SET ATTRIBUTES AND OPERATING MODES (REFERENCE 19)

Equip-ment Set	Operating Frequency	Signals		Simul-taneous Signals	Ionospheric Correction Method		Auxiliary Sensor Set		
		AQC	NAV		Direct RF	Static Model	Inertial Measure-ment Unit	Air Mass Unit	External Time Reference
X	L_1 and L_2	P and/or C/A	P or C/A	≥ 4	Yes or No	Yes or No	Yes or No	Yes or No	Yes or No
Y	L_1 and L_2	P and/or C/A	P or C/A	≥ 1	Yes or No	Yes or No	Yes or No	Yes or No	Yes or No
Z	L_1 only	C/A	C/A	≥ 1	No	Yes	No	No	No

*The Yes or No entries are defined as follows:

a. For each of the operating modes, the operator shall be able to select (yes) or not select (no) the mode.

b. When the operator has selected Yes for both the direct RF mode and the static model mode for ionospheric correction, the direct RF shall be the preferred mode and the system shall revert to the static model mode only when L_2 is unavailable.

c. Microwave Landing System (MLS)

The Microwave Landing System is designed to eventually replace civil ILS and military ILS and PAR systems (Reference 7). There are two major motivations for its development: operational and economic. It is infeasible to install ILS at some sites due to multipath problems and overwhelming site preparation costs. It is also highly desirable to have a landing system which allows selection of descent gradients and approach paths, rather than the fixed path which ILS provides. Descent gradients can be selected to match aircraft approach performance, which can be of importance for STOL and VTOL aircraft. Approach path selection can be very useful for several purposes: obstacle clearance, noise abatement and to avoid airspace restrictions. Other advantages to MLS include the fact that a large number of channels would be available (200), that it is suitable for tactical (replacing PAR) and shipboard use, it rejects multipath effects, and eventual lower ground site support costs will result.

The MLS system provides lateral guidance of either ±10, 20 or 40 degrees in width, vertical guidance up to 20 degrees, DME service, flare guidance and missed approach guidance. It is modularly configured so that only minimal capabilities (lateral and vertical guidance) would be provided where economics do not justify the more complex systems. The system is based on the Time Reference Scanning Beam (TRSB) principal, where a narrow microwave beam is scanned back and forth, and thus time interval measurements are used to measure angles by the receiver. The system operates in the C-band (5 MHz), except for the DME which will be in the L-band (TACAN). Civil usage of MLS for Cat II/III operations will utilize the L-band DME, flare guidance and radio altimeter for flare and touchdown guidance (Reference 5). In many cases military requirements prevent use of the radio altimeter, such as for tactical field landings and carrier landings, and so a more accurate DME is required (Reference 7). In particular, the Navy is supporting a requirement for C-band DME. However, this would be considerably more expensive for civil users. Therefore, the Navy may have to provide a non-standard DME for their own use.

Besides being useful for the flare and touchdown maneuvers, the DME will also serve a useful function in the operation of MLS as an area coverage, or RNAV, system within the regions of coverage of the lateral, vertical and DME signals at a given installation. This capability can allow complex approach procedures to be executed. These may have significant applications in the civil environment, and are a part of the 4D INCADS program discussed below. However, for more routine and permanent-base operations the initial Air Force requirement is simply to substitute for existing Cat II straight-in approach capability (Reference 7). According to Reference 5, the probable Air Force MLS implementation strategy would be as follows:

1) For tactical airlift fleet usage, replace TALAR with MLS. Begin installing MLS at both tactical and strategic airlift bases, as well as in all airlift aircraft.
2) Equip undergraduate pilot training bases and aircraft with MLS as early as possible.
3) Then begin installing MLS at bomber and tanker bases, and in bomber and tanker aircraft. Also begin MLS installation at fighter and attack aircraft bases.

4) Once fighter and attack aircraft bases are equipped, and 75-80% of all Air Force bases have MLS, equip fighter and attack aircraft with MLS. This sequence is necessary since aircraft space limitations preclude installation of both ILS and MLS avionics at the same time.

5) The Air Force would assume that by the time step 4 is started, that the FAA would have MLS installed at those civil airfields utilized by the Air Reserve Forces.

Equipment complements envisioned for civil and military users are listed in Table 9, which is taken from Reference 5.

d. 4-D Integrated Control and Display System (4-D INCADS)

This development area concerns efforts oriented towards integrating aircraft flight control, displays and navigation into a single airborne system. The intent is to transform the role of the pilot from that of direct controller of the aircraft to a role as systems manager and decision maker. This becomes necessary in a hostile tactical environment as more advanced navigation and reconnaisance sensors (Loran-C, GPS) and digital communications systems (JTIDS) supply the pilot with more data than can be dealt with without automated aids. The following advanced flight management capabilities are to be provided by the 4-D INCADS system:

- Airborne computer synthesis of nonlinear four-dimensional profiles (3D trajectories plus time)
- A control law (with automatic and manual modes) to track the synthesized 4-D profiles
- Mission-oriented information displays and controls

TABLE 9

MLS AND RELATED AIRBORNE OPERATIONAL CAPABILITIES (REFERENCE 5)

	CIVIL ELEMENTARY CAPABILITIES	CIVIL INTERMED CAPABILITIES	CIVIL ADVANCED CAPABILITIES	MILITARY INTERMED CAPABILITIES	MILITARY ADVANCED CAPABILITIES
1. Equivalent Operational Categories	I	I, II	I, II, III	I, II	I, II, III
2. Azimuth Path	Fixed	Selectable	Complex	Selectable	Complex
3. Elevation Path	Fixed	Selectable	Complex	Selectable	Complex
4. Missed Approach/ Departure	No	Optional	Yes	Optional	Yes
5. Approach Fixes	Markers and/or DME	Markers and/or DME	DME	DME	DME
6. Terminal Nav Capability	Limited to Straight-In	Sector Coverage with Range & Altitude	Sector Coverage with Range, Altitude & Time	Sector Coverage with Range & Altitude	Sector Coverage with Range, Altitude & Time
7. Autoland	No	Optional	Yes	Optional	Yes

The 4-D profile capability is designed to improve operational efficiency on missions requiring tactical assaults, tactical airlifts and in-air rendezvous, and to provide a complex, flexible 3-D approach capability for avoiding traffic, military threats, geographic and man-made obstacles and weather for transport aircraft. The 4-D capability will promote higher landing rates and will allow aircraft schedules to be coordinated with other aircraft, combat troops, etc. Also included is an objective to gain a night/all-weather capability based on a navigation technique comprised of inertial sensors and either Loran-C, differential Loran, or GPS.

The system design which resulted from the INCADS tasks so far (Reference 21) consists of a strapped-down inertial system integrated with Loran (or differential Loran where differential transmitters are provided), where Kalman filter techniques are used to combine the sensor data. Also considered are the techniques required to integrate GPS data, rather than Loran, in the system. Also considered is the integration of JTIDS data in the system, such that the system responds with alternate routings for pilot approval when threat data are received from the JTIDS link. Also, the subjects of integration of MLS and Omega data are addressed, although detailed designs are not provided as they were for Loran and GPS.

The 4-D profile generation capability of the INCADS system is quite sophisticated. It allows profiles (or routes) to be totally defined by the pilot, or it can generate route data ranging from minor parameters (such as bank angles or turn radius) to specifying a major portion of a route, based on criteria supplied by the pilot or JTIDS net. These criteria include specification of arrival times and aircraft velocities at certain waypoints, and specification of avoidance areas (to accommodate military threats, traffic, obstacles or weather). The system then synthesizes profiles in four dimensions which consider the operating envelope of the aircraft, which are then presented to the pilot for approval. Upon receiving approval of the profile, the system flies the aircraft to match the profile automatically, or drives the EADI and throttle setting displays such that the pilot may fly the profile manually.

This work is presently continuing, and is now oriented towards fighter aircraft applications.

3. IDENTIFIABLE AND POTENTIAL INTERFACE PROBLEMS

In this section the UG3RD plans and 4GATC possibilities outlined in Section II and the USAF avionics development plans in Paragraph 2 above are compared in order to determine the avionics interface problems of the future. Some of these problems may be solvable through minor changes in system specifications, whereas others will entail provision of new equipment or, due to cockpit space limitations, the integration of NAS functions into planned equipment. These avenues for solution are pursued in Section IV.

One interface problem which involves most of the areas discussed below is the fact that JTIDS will share the L-band with each of these new UG3RD systems: DABS, BCAS, RNAV (TACAN/DME) and MLS L-band DME. The JTIDS signal format has been designed to minimize interference potential. An extensive analysis and test program (Reference 17) has been carried out in order to verify the level of interference to be expected. The general conclusions of that study are presented below. More specific conclusions are presented in each of the following subsections. One caveat mentioned several times in the study is that the results are valid only if both the JTIDS plan and UG3RD plans remain fixed; any changes in either would require additional testing or analysis.

General Conclusions Regarding JTIDS Interference (Reference 17):

1) The test and analysis efforts show that the Phase I JTIDS signals have either no effect or only minimal operational effects on current designs of existing and firmly planned ATC systems. Minimal effects occur only when the ATC systems are receiving desired signals at or near their performance limits (near threshold) while simultaneously receiving maximum strength JTIDS signals.

2) If recognized flight-separation requirements are observed, the mobility of airborne JTIDS terminals makes the probability of experiencing these minimum operational effects very low. However, care must be taken to assure that ground-based JTIDS terminals are sited to keep JTIDS signal levels below those that affect ATC system performance.

3) When JTIDS terminals and ATC equipments are collocated on airborne platforms, the DOD should assure that isolation between avionics is provided to maintain required ATC system performance.

4) The present level of JTIDS/ATC system technical compatibility can be continued provided current design features and operating conditions are maintained. This implies that compatibility-related features of JTIDS will not change, and that modifications to or new models of ATC systems will continue to incorporate features that promote compatibility.

5) If JTIDS-compatible features are retained in the design of new and firmly planned ATC systems, then all data developed during this investigation substantiates the conclusion that equipment compatibility is no longer an unresolved issue regarding JTIDS spectrum support.

a. UG3RD Interface Problems

Discrete Address Beacon System

The DABS system will maintain compatibility with ATCRBS transponders for a suitable transition time period. However, it is the intention of the FAA that all controlled aircraft be eventually equipped with DABS transponders. Even if airborne data link displays, or even the ATARS display, are not furnished, the DABS beacon function itself is of great importance to ATC since many of the planned automation features will depend upon the highly reliable, accurate DABS surveillance data for all aircraft in order to properly automate many decision-making functions. Thus DABS transponder capability, with the attendant encoding altimeter and control/display panel, would be required of all USAF aircraft operating in the NAS environment, with the possible exception of trainers operating in restricted areas. Due to space limitations, particularly in fighters, this can create a serious problem if some existing equipment cannot be completely replaced by a new unit which performs the DABS function.

Two other DABS functions are of critical importance here: ATARS and DABS data link control message displays. ATARS is intended as a very low cost incremental addition to the airborne DABS unit. All aircraft operators operating in controlled airspace will be strongly encouraged to adopt ATARS in order to reduce the VFR and VFR/IFR mid-air collision risk. The interface problem for USAF aircraft (particularly fighters) in this case is certainly not expense, but panel space required for an ATARS display. The DABS data link display poses the same problem. It would not be nearly as strongly encouraged by FAA for VFR aircraft, but will be encouraged for IFR aircraft. It is important to note, however, that while the basic DABS transponder capability is necessary to the operation of the advanced automation systems, the data link display serves only to improve controller productivity and therefore improve system capacity.

The conclusions of the JTIDS interference study (Reference 17), regarding DABS are as follows:

> The following conclusions are based on flight-test measurements on prototype DABS equipment without notch filters being employed in JTIDS equipment, supplemented by theoretical analysis and ATCRBS bench test measurements. These findings apply to DABS equipment with specifications similar to the units tested.
>
> 1) The DABS flight-test measurements and analysis indicate that a JTIDS aircraft at minimum ATC operational altitude separation from a DABS aircraft, or near a DABS interrogator, would not affect DABS performance.
>
> 2) The above conclusions also apply to an environment containing multiple DABS transponders, DABS interrogators and JTIDS terminals. Increases in the number of DABS equipments would not make the DABS more susceptible to JTIDS signals.
>
> 3) Flight tests indicated that DABS performance would not be affected even if JTIDS transmitters without notch filters and DABS transponders were installed on the same aircraft and both antennas were mounted on the bottom of the aircraft.

Beacon Collision Avoidance System

The BCAS system will be more of a near-term solution to the collision avoidance problem since it is designed to operate with conventional ATCRBS (it will probably evolve to also operate with DABS). Airborne BCAS units will be expensive, relative to the cost of an ATCRBS transponder, and no attempt will be made by the FAA to encourage wide proliferation. Instead, airline, commercial and corporate operators will be encouraged to equip. The result will be that heavy aircraft will be protected from most other aircraft, while light aircraft would only be protected from equipped aircraft. Thus the probability for major accidents would be reduced. Along with this, Air Force transports (and other heavy aircraft operating in the NAS environment) would also equip in an effort to prevent major civil/military accidents. Fighters, which would suffer from a major space problem as well as expense, would probably not be so affected. However, it may be in the interest of the Air Force to equip fighters in order to further reduce the civil/military accident potential.

BCAS presents a problem for all equipped users as DABS/ATARS is introduced. If the ATARS and BCAS systems are left as separate functions, the potential exists that their displays could show different threats, or indicate different resolution commands, creating high confusion potential.

The conclusions of the JTIDS interference study (Reference 17) regarding BCAS are as follows:

> The following conclusions are based on flight-test measurements and theoretical analysis using feasibility BCAS equipment operating in the passive mode. They are applicable to BCAS equipment with similar technical characteristics.

1) The BCAS flight-test measurements indicated that a JTIDS aircraft with minimum ATC operational altitude separation from a BCAS aircraft would not affect BCAS performance. The theoretical analysis indicated that JTIDS coupling levels at the minimum BCAS aircraft-to-aircraft operational separation distance would not effect BCAS/ATCRBS transponder reply efficiency, and would provide only a negligible contribution to fruit on 1090 MHz in congested terminal areas.

2) No measurements were performed on the BCAS active mode. However, based on measurements of the passive mode ATCRBS transponders with similar technical characteristics, and on analysis results, JTIDS would not affect BCAS performance in the active mode.

3) Collocating a JTIDS transmitter and a BCAS interrogator aboard the same aircraft may require engineering to assure adequate isolation between the two equipments.

Area Navigation

The FAA is expected to begin the implementation of RNAV (Reference 22 and 10) in the near future, with full implementation essentially complete in 1985. It is expected that airlines and other commercial operators will voluntarily equip virtually 100% of their aircraft in order to take advantage of the very significant payoffs (Reference 6) available to RNAV-equipped users. General Aviation operators are also expected to equip in large numbers, although not nearly to the 100% point. It is not clear at this point whether RNAV capability will become a requirement in certain terminal areas. However, it will be strongly encouraged at the approximately sixty RNAV-configured terminal areas because the following advantages to ATC performance are gained (among others):

- Significantly reduced controller workload (Reference 8)
- Improved M&S System Performance (Reference 6)
- Improved 4-D M&S System Performance and Airport Capacity (Reference 6)

As a result, USAF navigation systems which possess an intrinsic area navigation capability (GPS, 4-D INCADS) should be configured to meet civil requirements for RNAV, VNAV and 4-D operations. These requirements (which would apply to all high altitude airspace users, and to transports operating in major terminal areas) include the following:

1) Multi-waypoint route storage
2) Parallel offset and direct-to-waypoint capabilities
3) Automatic turn anticipation
4) VNAV performance meeting AC 90-45A criteria
5) 4D performance meeting as yet unspecified criteria
6) VNAV maneuver anticipation
7) 4D operations along fixed routes (using speed control only -- no automatic trajectory generation)
8) While not a requirement, the bulk storage of a route structure and approach procedure data base for computer access is a highly desirable feature, particularly for the transport application.

Most GPS aircraft system development work performed to date has concentrated on the signal acquisition and tracking function, rather than the performance of the system as a navigator. A recent study (Reference 23) has considered the integration of GPS as a sensor replacing Loran in the AN/ARN-101 Navigation and Weapon Delivery System for the F-4. However, this treated GPS as a sensor and not a unique stand-alone aircraft navigator. Thus the problem remains of specifying the performance capabilities of, and developing, the complete GPS navigator for civil and military environment usage.

The 4-D INCADS system is much closer in performance to the civil requirements since VNAV and 4D features are provided, multi-waypoint routes, turn anticipation and VNAV maneuver anticipation are provided. However, the problems of providing parallel offset and civil 4-D maneuvers remains.

Two civil requirements which must be met by USAF RNAV systems in general are:

- Demonstration that USAF systems will meet AC 90-45A (Reference 25) route width requirements (the accuracy requirements are reviewed in Paragraph 2 of Section II), and
- Demonstration that the remaining requirements of AC 90-45A, or its successor, are met.

The remaining requirements are in the areas of environmental limits, failure mode analysis, provision of required RNAV functions, failure warning, non-derrogation of operation of interconnected equipment, built-in test, and electromagnetic interference. Accuracy should be demonstrated in bench testing and flight testing. Accuracy performance in flight tests should show that (enroute) cross track error exclusive of flight technical error, and along track error, is less than 1.5 nmi (2σ). This includes the use of radio updates for systems which require updates.

The conclusions of the JTIDS interference study (Reference 17) regarding TACAN/DME, which could be used by some RNAV systems, are as follows:

1) Measurements indicate that JTIDS signals will not cause false range, bearing or velocity indications, or affect the quality of the identification tone.

2) When JTIDS signal levels are coupled into the TACAN/DME system, the only effect is to reduce the interrogator acquisition range by a few nautical miles (maximum of 7 nmi). This will occur only when the interrogator is attempting to acquire the TACAN/DME signal at the service limits while a JTIDS aircraft is either near the TACAN/DME ground beacon or at a minimum ATC separation distance from the interrogator. Analyses indicate that this low-probability event produces range-acquisition changes that are less than the normal TACAN/DME system variability observed during the test program.

3) JTIDS ground-based units require site engineering to ensure that the JTIDS signals do not affect the performance of TACAN/DME beacon receivers. The separation distances required will vary according to particular terrain conditions, but will be on the order of 3 to 5 nmi for line-of-sight conditions.

4) If JTIDS ground terminals are properly sited, these results indicate that JTIDS operations will produce no harmful operational effects in the TACAN/DME system.

Microwave Landing System

The fact that MLS is a joint civil/military effort assures basic overall compatibility. The problems which remain are the provision of complex approach procedure capability for use at terminals where such procedures will be required, and the integration of MLS with the existing (or planned) Area Navigation system. The complex approach path capability involves what are essentially area navigation route definitions and navigation computations. These are not required of a basic Cat II MLS system which would provide selectable gradients and approach paths. It is therefore advantageous to integrate the MLS data with the RNAV system to avoid unnecessary functional redundancy. The integration of MLS with GPS computers has not been seriously considered yet (Reference 7). The 4-D INCADS study (Reference 21) explores the integration of MLS with INCADS, but does not go into detail.

The conclusions of the JTIDS interference study (Reference 17) regarding MLS L-band DME are as follows:

> The conclusions are based on flight tests of experimental MLS/DME equipment supplemented with theoretical analysis. The MLS/DME equipment tested consisted of a terminal ground beacon and an airborne interrogator, both modified to tentative MLS/DME specifications. The following results are indicative of the electromagnetic compatibility to be expected if this type of MLS/DME design is operationally implemented.
>
> 1) All measured operational conditions indicate that JTIDS would not affect MLS/DME performance. However, no measured data is available concerning the performance of collocated JTIDS terminals and MLS/DME equipment.
>
> 2) The effect of collocating an MLS/DME interrogator and a JTIDS terminal aboard the same aircraft requires further evaluation. This collocation should be engineered to preclude interference in the interrogator receiver. The required minimum separation distance between the ground beacon receiver and a JTIDS-equipped aircraft on the glide slope should be determined.

b. Potential 4GATC Interface Problems

All of the potential directions which 4GATC could take which were identified in Paragraph 3 of Section II would involve new avionics functions for USAF compatibility. The Synchro-DABS concept actually only requires standard DABS capability for other aircraft to perform the collision avoidance function of Synchro-DABS. If the DABS rotating surveillance antennas are retained by ATC, no USAF modifications of DABS would be required to remain compatible, although those aircraft would not have the benefit of Synchro-DABS CAS capability. A pre-existing BCAS capability, if designed to operate with DABS, could continue to serve that purpose. If a decision is made to eliminate the rotating surveillance antennas and substitute triangulation, air/ground data link of air-derived position would be required for cross-check purposes. This could just as well be GPS as Synchro-DABS-derived position data.

If an ASTRO-DABS concept (or similar) using surveillance satellites were adopted, new airborne DABS equipment, including new antennas, would be required. Also, ASTRO-DABS does not directly solve the CAS problem.

ATC techniques which would utilize GPS-derived position coupled with an air/ground data link of some kind could use existing GPS equipment in USAF aircraft, but would probably involve providing new data link equipment. JTIDS could be used as the data link, except that then all civil users would have to also use JTIDS, which would be far more expensive than a data link developed for civil users. That link would probably be a low cost single-frequency system using a TDMA technique. CAS service would be provided by listening in to position reports, cross checked by one-way range measurements through the TDMA system.

SECTION IV

RECOMMENDED SOLUTIONS

This section presents the recommended solutions to those NAS interface problems identified in the previous section, and suggests the research tasks which would be required in order to complete the study of the NAS interface problems. Finally, the major study conclusions are presented.

1. RECOMMENDED INTERFACE PROBLEM SOLUTIONS AND ALTERNATIVES

a. Discrete Address Beacon System

Provided that the FAA implements the DABS feature as planned, Air Force aircraft operating in the NAS environment will have to be DABS transponder-equipped, with the possible exception of jet trainer aircraft operating in restricted areas. The question becomes how this is to be accomplished, and what DABS features should be supported. Transport aircraft should also support the ATARS and DABS data link display functions, replacing existing ATCRBS equipment. This results in order to optimize ATC controller productivity and capacity in busy terminal areas to the greatest possible extent by fully supporting the advanced automation programs of the FAA. The ATARS function also provides needed insurance against collisions with VFR aircraft which will be operating in terminal areas which military aircraft will be traversing. Cockpit panel limitations, while always a problem, should not be a major obstacle since the ATARS/data link display will be quite small. Phase II JTIDS may provide the DABS functions. However, plans are so nebulous concerning Phase II at this time that it should not be considered as an alternative for providing the DABS function at this time.

Fighter aircraft other than trainers operating in restricted areas should be DABS equipped. The present ATCRBS would be removed and replaced with a DABS/IFF unit. It is highly recommended that the ATARS capability also be included in order to eliminate VFR aircraft/military jet conflicts and accidents. The ATARS display used will be of necessity considerably smaller, or even differently configured, than the conventional civil unit, but will nonetheless be useful. It is desirable to also have the data link ATC command display; however, if a design compromise must be made, it should be the elimination of the data link display, not ATARS.

b. Beacon Collison Avoidance System

BCAS capability will probably not be made a requirement for entry into airspace by the FAA. However, equipage by heavy aircraft operators will be strongly encouraged. Air Force adoption of BCAS capability would entail development of a replacement ATCRBS/IFF unit with built-in BCAS computational capability and display. The system would have to also have a tunable transmitter (1030 and 1090 MHz), and receive on both channels simultaneously. As stated in Section II, the computational requirement is extensive, although no extra controls are required for its operation. These requirements may actually prohibit the installation of BCAS systems on fighter aircraft due to space (rack and panel) considerations alone, regardless of cost and other considerations. Due to the fact that this prohibition would not apply to the case of transport aircraft, and due to the potential large benefit the Air Force could realize from reductions in potential future accidents, the adoption of BCAS capability in transport aircraft would be very much worth while. Since this would be a new system, it could also embody DABS, ATARS and data link display capability (becoming a combination ATCRBS/IFF/BCAS/DABS/ATARS/data link system). For near term installations a simplified display head (ATCRBS/IFF/BCAS-only) could be utilized, which would be replaced with the full DABS unit as DABS is implemented.

In the fighter aircraft case, possibly the only avenue for producing a physically realizable system is through integration of BCAS with another system which shares some functional capability, such as JTIDS. Through moderately increased receiver complexity and significantly enhanced computational capability, the JTIDS system might be able to perform the ATCRBS/IFF/BCAS functions as well as the JTIDS/TACAN functions. This subject is further explored in Paragraph 2 below.

c. Area Navigation

In all probability, Area Navigation will be implemented to the point where USAF operations would be significantly affected before 1985, which is the same time frame in which GPS will become fully operational. In Section III the seven probable requirements for RNAV operations in the high altitude airspace and dense terminal areas are listed. USAF GPS systems should be configured to meet these requirements. Five of these requirements (multiple waypoint storage, parallel offset and direct-to-waypoint capabilities, turn anticipation, VNAV performance requirements and VNAV maneuver anticipation) will be confirmed (or modified) by the now-forming RTCA Special Committee on RNAV (Reference 24) and the revisions to AC 90-45A (Reference 25) now being considered within the FAA (Reference 26). Four-dimensional (time control) system performance and functional requirements will be established in the future.

The other capability which transport GPS systems should have integrated for operational reasons is route structure data base capability, where all commonly-flown (domestic and international) routes, SIDs, STARs and IAPs are stored and are manipulatable through an interactive call-up system by the flight crew.

GPS systems for fighters, except in special cases, may have no need for the data base capability; they would operate in conjunction with the JTIDS data net. They should, however, possess the other capabilities discussed above.

The 4-D INCADS system (Reference 21) is very close to providing the functions necessary for civil RNAV operations. Modifications required include providing an explicit civil operating mode whereby the parallel offset, direct-to-waypoint, and restricted 4-D capability along fixed route functions would be available for pilot selection. Route structure data base capability, which is mentioned in Reference 21, should be provided in the transport aircraft installations.

d. Microwave Landing System

All future USAF navigation systems which are configured as Area Navigation systems should also be designed to accept MLS sensor data so that complex approach procedures may be navigated. Then in cases where aircraft are RNAV-equipped, complex or fixed-gradient approach paths would be flown using the RNAV system since it could provide smooth transitions from conventional RNAV guidance to MLS guidance. The RNAV/MLS guidance interface problem is discussed in detail in Appendix D of Reference 6 and Volume II of Reference 27.

e. Potential 4GATC Interface Problems

It is too soon, due to the preliminary nature of FAA 4GATC plans, to take any positive action regarding avionics planning by the Air Force. The one certainty of the 4GATC system is that a data link will be involved, either DABS or a TDMA concept. However, the TDMA system will not be JTIDS-compatible. For navigational purposes, GPS should serve any 4GATC requirement, as will MLS for any landing system requirement. Any unique requirement will arise from changes to the surveillance system, as discussed in Paragraph 3.b of Section III.

2. AREAS REQUIRING FURTHER RESEARCH OR CONSIDERATION

a. DABS Features Evaluation

In the previous paragraph it is explained that it is desirable to furnish all DABS features (beacon, data link, ATARS display and ATC message display) for all aircraft operating in the civil environment, but that cost and space limitations may prevent the widespread installation of all features. It is therefore of interest to review the factors pertinent to this subject (operational need, aircraft type, NAS operations performed, installation space, installation cost) and formulate a recommended installation program and schedule unique to each aircraft type.

b. Fighter ATARS/ATC Display Configuration

Paragraph 1 mentions the fact that it may be possible to develop a much more compact ATARS or combination ATARS/ATC display appropriate to the fighter aircraft environment. Standard display configurations are illustrated in Figure 5. This task would consist of an operational evaluation of the fighter cockpit environment and a human factors study in order to design a compact display.

c. BCAS Deployment Tradeoff Analysis

This study would evaluate the costs of equipping the several classes of USAF aircraft operating in the NAS environment individually, and estimate the cost savings likely to result due to the reduction in accident potential, both military/civil and military/military. The result would be a recommended BCAS implementation plan and schedule for each aircraft class.

d. RNAV Avionics Standards Requirements

The objective of this study would be to analyze in detail the currently planned USAF avionics systems, plus those likely to be developed in the future, which are to have an area navigation capability, and to determine what problems will be involved in demonstrating compliance with civil RNAV avionics standards (AC 90-45A, Reference 25, or its successor, Reference 26). Investigations would include compliance in the areas of accuracy, functions, environmental qualification, failure modes, failure enunciation, non-derrogation of inter-connected equipment, built in test and electromagnetic interference. The result would be recommendations for correcting deficiencies, and test procedures for demonstrating compliance.

e. JTIDS/4GATC Interactions Study

As stated in Section III, the JTIDS interference study (Reference 17) was only concerned with present JTIDS plans and the UG3RD system. Future ATC techniques, including Synchro-DABS, satellite surveillance, and TDMA data link systems, may involve further interference problems. The objective of this study would be to identify all such potential problems and determine the laboratory and flight test procedures required for their resolution.

f. USAF Avionics Integration Techniques

One of the primary findings of this study is that, as a result of the new Air Force avionics development plans and the FAA plans for NAS operators, USAF aircraft will in the future carry more separate pieces of avionics equipment than they do at present. In the case of fighter aircraft, this presents a critical situation since not enough "holes" will be created in the panel by removal of obsoleted equipment for the new equipment to fit into. This fact is illustrated by the table below:

New Systems	Obsoleted Systems
JTIDS	TACAN
GPS	None
MLS	ILS
DABS/IFF	ATCRBS/IFF
BCAS*	None
RNAV*	None
4-D RNAV*	None

*These last three items may be optional, as indicated earlier.

Even without the optional functions, four complex systems must fit where three relatively simple systems now reside. This situation is not likely to be helped by future developments in other aircraft systems (flight control, weapon delivery, stores management, ECM, etc.), all of which compete for available space. Therefore, the avenue for solving this problem with the greatest promise is through functional integration.

It is recommended that further study, conducted on a hardware as well as systems level, be conducted in order to determine the best combinations of functions to integrate and best means to achieve that integration. Integration should be achievable for two primary reasons:

1) Several systems operate in the same radio frequency band
2) They all (with the exception of DABS) involve extensive computational requirements, which leads to the conclusion that computations can be centralized in fewer, more powerful computers.

The determination of the required transmitter/receiver configuration, signal processing requirements, computational requirements, and integrated controls/displays would be a primary objective of this study.

Several recent and ongoing studies are being conducted by the Air Force which bear directly on this problem, and would serve as the major source of information for the study:

- DABS/JTIDS integration study (ARINC, Lincoln Laboratories) conducted for ESD (Reference 28)
- C-135 Control/Display/Navigation System Integration study conducted by AFFDL
- AN/ARN-101 GPS Interface Study (Lear) conducted for ESD (Reference 23)
- 4-D INCADS Transport and Fighter Program, JTIDS and GPS interface studies (Lear) conducted for AFFDL (Reference 21)
- JTIDS Phase II development program conducted by ODDR&E and AF/RDPE
- Digital Avionics Information System development program conducted by AFAL

In addition the Naval Air Systems Command is conducting an ICNI study. All of these studies are of interest to this suggested research area, either because they directly address the integration problems of interest, or because they may offer useful integration techniques. The result of the study will be a recommended avionics system configuration, and a development program outline for realizing the integrated avionics configuration.

3. STUDY CONCLUSIONS

The major findings of this study are as follows:

- For the most part, USAF avionics development programs have not explicitly considered the future requirements for NAS operations, and so functions such as ATARS, DABS data link, BCAS and civil RNAV functions have not yet been directly addressed.
- All USAF aircraft regularly operating in NAS airspace should be equipped with DABS transponder beacons (when DABS is implemented) to support FAA automation efforts. ATARS and data link functions should be provided on transport aircraft, and also on fighter aircraft if space limitations may be overcome.
- The FAA in all probability will promote the BCAS technique as the answer to the independently-derived CAS problem. Heavy USAF aircraft will be strongly encouraged to equip. It is in the interest of the Air Force to also equip fighter aircraft, again if the space limitations can be overcome. The computational requirements of BCAS are such that equipage of the fighter fleet could be quite expensive.
- All navigation systems which will operate in the NAS environment and which will use an area coverage aid (Loran, GPS, etc) should be configured to perform the functions to be expected of civil Area Navigation systems. Similarly, 4-D RNAV systems should also be compatible with expected 4-D procedures.

- All area coverage navigation systems should have provisions for accepting MLS system inputs, so that complex approach procedures may be executed.
- A critical problem concerning equipage of fighter aircraft with the new avionics systems being developed by the Air Force, and those which will be required for NAS operations, is the severe space limitations of such aircraft. Therefore, a vigorous avionics integration program should be pursued.

REFERENCES

1. Final Report of the Air Traffic Control Advisory Committee, December 1969.

2. An Overview and Assessment of Plans and Programs for the Development of the Upgraded Third Generation Air Traffic Control System, FAA-EM-75-5, Office of Systems Engineering Management, Federal Aviation Administration, and the MITRE Corp., March 1975.

3. Drouilhet, P.R., DABS: A System Description, FAA-RD-74-189, MIT Lincoln Laboratory, 18 November 1974.

4. "Proposed U.S. National Aviation Standard for the Discrete Address Beacon System", Federal Register, Vol. 43, No. 59, March 27, 1978.

5. Microwave Landing System (MLS) Implementation, Document DO-166, Special Committee SC-125, Radio Technical Commission for Aeronautics, July 1977.

6. Bolz, E.H., et al, Systems Integration: RNAV and the Upgraded Third Generation System, FAA-RD-77-22, Systems Control, Inc. (Vt), for Systems Research and Development Service, Federal Aviation Administration, December 1976.

7. Conference with Major Robert Heath, AF/RDPE, Pentagon, 20 December 1977.

8. Bolz, E.H., Impact of Area Navigation on Controller Productivity and ATC System Capacity, FAA-RD-78-51, Systems Control, Inc. (Vt), for Systems Research and Development Service, Federal Aviation Administration, January 1978.

9. Adams, R.J., Preliminary RNAV Avionics Standards, FAA-RD-75-178, Systems Control, Inc. (Vt), for Systems Reasearch and Development Service, Federal Aviation Administration, July 1974.

10. Clark, W.H., Bolz, E.H., et al, Implementation of Area Navigation in the National Airspace System: An Assessment of RNAV Task Force Concepts and Payoffs, FAA-RD-76-196, Systems Control, Inc. (Vt), for Systems Research and Development Service, Federal Aviation Administration, December 1976.

11. Harris, R.M., et al, An Advanced Air Traffic Management Concept Based on Extensions of the Upgraded Third Generation ATC System: Summary Report, FAA-EM-73-10A, MITRE Corporation, for Office of Systems Engineering Management, Federal Aviation Administration, March 1974.

12. Amlie, T.S., "A Synchronized Discrete-Address Beacon System", IEEE Transactions on Communications, pp 421-426, May 1973.

13. Solicitation #77SS-111, "Provide a Study of the Feasibility of a Satellite-Based Air Traffic Control (ATC) System as a Practical Alternative to the Existing Domestic Air Traffic Control System" U.S. General Accounting Office, 10 September 1977 (RFP later canceled).

REFERENCES
(Continued)

14. Erwin, R.L., et al, Strategic Control Algorithm Development, DOT-TSC-OST-74-3, Boeing Commercial Airplane Co., for Transportation Systems Center, Department of Transportation, August 1974.

15. Schuchman, L., The ASTRO-DABS Concept, MTR-6287, MITRE Corp., for the Office of Systems Engineering Management, Federal Aviation Administration, November 1972.

16. Simolunas, A., The "New" Navigation System; How Do We Transition?, Systems Research and Development Service, Federal Aviation Administration, April 1976 (draft).

17. EMC Analysis of JTIDS in the 960-1215 MHz Band, Office of Telecommunications Policy, Department of Commerce, 1977 (draft)

18. Conference with Major Thomas Swartz, AF/RDPV, Pentagon, 19 December 1977.

19. System Segment Specification for the User System Segment of the NAVSTAR Global Positioning System, Phase I, SS-US-101B, Space and Missile Systems Organization, 30 September 1974.

20. Raab, F.H., et al, "An Application of the Global Positioning System to Search and Rescue and Remote Tracking", Journal of the Institute of Navigation, Fall 1977, pp. 216-228.

21. Final Report: Feasibility Study for Integrated Flight Trajectory Control (Airlift), GRR-008-0177A, Instrument Division, Lear Siegler, Inc., for Air Force Flight Dynamics Laboratory, Wright Patterson Air Force Base, January 1977.

22. RNAV Policy Statement by the Administrator, Federal Aviation Administration, Federal Register, 13 January 1977.

23. Final Report: Feasibility Study of Global Positioning System Interface with the AN/ARN-101 Digital Modular Avionics System, Report #6344-042, Instrument Division, Lear Siegler, Inc., for Electronic Systems Division, Air Force Systems Command, April 1977.

24. Special Committee currently being formed by the Radio Technical Commission for Aeronautics, for purpose of establishing RNAV Minimum Operational Performance Standards.

25. Approval of Area Navigation Systems for Use in the U.S. National Airspace System, Federal Aviation Administration Advisory Circular 90-45A, 21 February 1975.

26. Installation and Approval of Airborne Equipment for Area Navigation, International Federal Aviation Administration working draft for an Advisory Circular, Flight Standards Service, AFS-130.

REFERENCES
(Continued)

27. Scott, R.W., et al, An Avionics Sensitivity Study, CR-145107, Systems Control, Inc. (Vt), for Langley Research Center, National Aeronautics and Space Administration, September 1976.

28. Draft reports by Aeronautical Radio, Inc., and MIT Lincoln Laboratory concerning DABS/JTIDS Integration, for Electronic Systems Division, Air Force Systems Command, 1977.

29. McColl, David R.S., "The Military and Air Traffic Control", IEEE Transactions on Communications, pp 501-516, May 1973.

30. A New Guidance System for Approach and Landing, Document DO-148, Special Committee SC-117, Radio Technical Commission for Aeronautics, December 1970.

31. Application of Area Navigation in the National Airspace System, Report of the FAA/Industry RNAV Task Force, February 1973.

32. Mark 2 Air Transport Area Navigation System, ARINC Characteristic 582, Aeronautical Radio, Inc., August 1970.

☆U.S.Government Printing Office: 1978 — 657-002/211