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AD-A229 446

Technical Report
Advanced Air Traffic Control System (AATCS)

Phase I
Small Business Innovative Research (SBIR)
Topic AF 87-32

Contract F19628-87-C-0195

prepared for

Electronic Systems Division
Air Force Systems Command, USAF
Hanscom Air Force Base, Massachusetts

31 December 1987

prepared by

Airspace Technology Corporation
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Irvine, Cailifornia 92718

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
1987 Dec 31

3. REPORT TYPE AND DATES COVERED
FINAL

4. TITLE AND SUBTITLE
Advanced Air Traffic Control System (AATCS)
Phase 1 Small Business Innovative Research(SBIR)

5. FUNDING NUMBERS
F19628-87-C-0195

6. AUTHOR(S)
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Hq Electronic Systems Division XR
Hanscom AFB, MA 01731-5000

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for Public Release; Distribution Unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
This report documents the results of a study conducted for the purpose of developing a system concept for the control of air traffic in the post 1995 time frame. The concept has been formulated for a system which would be capable of controlling air traffic over a wide geographical area including multiple terminal airbases. The system will be tactical, highly mobile and will incorporate a high degree of survivability. The concept utilizes a data link technique for aircraft position location rather than conventional radar detection and tracking. This report develops the system concept through a preliminary functional design to a level where specific subsystem elements may be identified or defined. As described herein, the Advanced Air Traffic Control System (AATCS) concept is one approach toward providing the operational capabilities defined for the Automated Tactical Launch and Recovery System (ATALARS) presented in ESD-TR-86-259. The AATCS system is based on ATALARS but with some differences in the operational principles.

14. SUBJECT TERMS
ATALARS, Automated Tactical Aircraft Launch and Recovery System, ATC, air traffic control, concept, architecture, airspace management, battle management

15. NUMBER OF PAGES
80

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAR

Forward

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This study effort was performed under the guidance of Capt. Guy C. St. Sauveur ESD/AVS. The Project Leader was Mr. D.B. Whitney with Mr. T.M. Katanik as the primary contributor. Research was performed by Lt/Col C.H. Metzger, USAF, Ret'd.

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SECTION 1
Introduction

This report contains the results of a USAF contracted study for an Advanced Air Traffic Control Concept. This study effort is Phase I of Small Business Innovative Research (SBIR) Topic, 87-32, and was performed under contract F19628-87-C-0195.

This study is a continuation and expansion of an Air Traffic Control concept system described in *Airspace Technology Corporation* (*AirTech*) Proposal 9122, Automated Air Traffic Control System Concepts.

The AirTech approach for an Advanced Air Traffic Control System (AATCS) evolved as a result of a USAF presentation at the ESD New Horizons briefing in May of 1985. This initial idea was enhanced and refined based on the operational requirements described in ESD-TR-86-259 for the Automated Tactical Aircraft Launch and Recovery System (ATALARS) prepared under the guidance of 1st Lt. Guy C. St. Sauveur, ESD/XRC.

ATALARS, as presented in ESD-TR-86-259, was further refined under a study performed under Contract No. F19628-86-D-0002 by HH Aerospace Design Co.

1.1 Background

The USAF ATC mission has undergone significant changes over the last few years in terms of operational and equipment philosophies. A factor which helped bring about these changes has been a recognition of the vulnerability of the overall ATC system. Considerations for the survivability of tactical ATC facilities are now an accepted requirement in every program. The AN/MPN-14K will probably be the last USAF manned landing control system without some level of survivability as part of the basic system design.

New systems will incorporate high mobility as a paramount survivability feature, as is demonstrated by the Tower Restoration Vehicle (TRV), Surveillance Restoration Vehicle (SRV) and New Mobile RAPCON (NMR) requirements. These systems will incorporate new concepts in processing and display capabilities through the use of rugged compact computers and plasma displays - 1/10 the size of a CRT console. These features alone represent a trend in system design and integration - smaller, more rugged, less power consumption and increased operating capability. All of which will contribute to meeting the mobility requirements.

NMR will add the next step, protection against radiated and conducted electromagnetic energy and provision for operating in a chemical and biological environment. The NMR shelter will also incorporate fragmentation protection.

The next generation system beyond NMR may be a design concept capable of using passive techniques for detection and tracking. It may also still be capable of interfacing with primary and secondary radars. The transition to ATC without a radar will not be without its problems in terms of controller acceptance.

1.2 Scope

The AATCS system described in this report is based on ATALARS but with some differences in the operational principles. The system will be a tactical, highly mobile airspace management and area control facility capable of monitoring large numbers of cooperating aircraft movements over a wide operating area. AATCS differs from ATALARS in two major areas: it would use conventional anti-jam VHF and UHF communications in addition to JTIDS as data links, and it would make provisions for the use of bistatic radar techniques for detection and tracking.

The system described herein is considered as one possible initial approach toward developing the ATALARS. As such, the operation scenario reflects the preliminary ATALARS requirements as described in ESD-TR-86-259 and as further developed under Contract F19628-86-D-0002.

1.3 Basis for the AATCS System Configuration

In order to further develop a system concept which was deemed appropriate for the AATCS requirement, a series of tasks were undertaken. The initial efforts were to develop a set of requirements which were to define what AATCS would provide in terms of capabilities. This system definition phase included a review and assessment of present, near term and future ATC systems and technologies, both civil and military. These were assessed to determine which trends in technologies and operational procedures would be appropriate for the AATCS application.

Specific systems which were investigated included the USAF TRV/SRV and NMR programs, the USMC Marine Air Traffic Control and Landing System (MATCALS) program, the USN AN/FYK-17 (V) Air Traffic Control Tracking System, the AN/FSY-1 Naval Airspace Surveillance and Traffic Control System and the FAA Advanced Automation Systems.

In addition to the ATC systems, battle management and tactical data systems and tactical communication systems were also evaluated. This included Joint Tactical Information Distribution System (JTIDS), Single Channel Ground Air Radio (SINCGARS) and the HAVEQUICK anti-jam radios.

The system review/evaluations considered both the technical aspects of the specific equipments and the ATC performance capabilities. Technical features were reviewed from the standpoint of performance with todays technology and what could be expected from developments which would be available in 5-7 years. The ATC performance, from the controllers perspective, was reviewed with the aim of reducing the level of human intervention and decision making and to set the precedent for control by exception.

From the data gathered through this review, a set of basic operating requirements were developed. These requirements were based on trends in technology which were felt to be appropriate for an evolutionary next-generation ATC system.

Based on this initial effort, and bearing in mind that an AATCS could be fielded early in the 21st century, the system concept incorporates a mix of technologies which are in use today, are potentially available in the near term and others which are felt would be mature in the next 5-7 years. It must be recognized that developments in every area of technology applicable to AATCS are in a continuing state of growth and improvement, and that the conclusions and equipment recommendations of this report can be quickly overtaken by events.

The technologies and equipments for the AATCS concept presented herein is felt to be appropriate for today and for ten years from today. The system can only get smaller, smarter, faster and more capable over time.

SECTION 2
Purpose

AATCS will provide the capability to perform the ATC control function for both enroute and terminal control and to support operations in a combat environment. This capability, much broader in terms of today's systems performance and the operating control area, serves a new type of ATC operation - Airspace Management.

Airspace Management encompasses a wider range of features for the control of aircraft movements. These will include features now considered routine for terminal and enroute control but will also include features associated with tactical air control.

AATCS features which are considered routine by today's ATC standards will include amongst others: aircraft tracking, track and flight plan correlation, track prediction, minimum safe altitude warning, collision avoidance, and emergency procedures. The technologies which support these features will be similar in AATCS to what is in use today.

AATCS will support terminal control operations for a local facility or for airbases located remotely from the AATCS operating site. AATCS will provide approach control service to vector aircraft to an approach point or landing aid threshold. The system will monitor A/C movements and provide metering and spacing criteria to sequence arriving and stacked A/C.

Final approach services will be provided from holding points or pattern entry points. AATCS does not provide all-weather landing capability and therefore must operate with other landing aid assets such as a mobile MLS. AATCS will be able to provide final approach guidance down to TBD landing minimum. Once again this will be a function of the terminal landing aids in operation at the specific airbases. AATCS advisories would be coordinated by the pilot, with guidance being received from the ground based landing aid. The AATCS would also provide advisories for missed approach procedures and guidance for re-entry into the landing pattern.

The departure control function in AATCS will be suitable for operations with or without a local tower facility. With a TRV or other type tower, control of take-off operations would be controlled locally. AATCS would serve a flow control function, coordinated with the tower to safely and efficiently insert A/C into traffic flow. The system would monitor A/C movements against planned or projected flights to minimize changes in departure times or routings due to potential conflicts.

Enroute control will be provided for flights transiting the AATCS controlled airspace and for flights originating and/or terminating at AATCS controlled airbases.

The enroute function will support two major tasks - the creation and maintenance of the flight plan data base and the correlation of actual flight progress against flight plan schedule. The latter function will be used to develop sequenced arrival and departure times for optimum terminal airspace and runway utilization. AATCS will integrate the approach control and departure control functions into the enroute functions for this task.

The support data necessary to perform the terminal and enroute control functions will be input to the AATCS data base. Specifically this will include: flight plan data, airbase and runway status, local and enroute weather data, nav-aid status, and conflict or hazard areas.

AATCS will operate with tactical air control elements to a greater extent than is done today. Procedurally, AATCS will exchange flight operation data with Tactical Air Control Centers and/or Air Support Operations Centers. The system should also be capable of accepting track data from Air Support Radar Teams or other Air Defense radar facilities.

It will be necessary that AATCS be kept current on tactical air operations from the standpoint of safe corridors and the forward edge of battle zones. Therefore, it will be necessary that AATCS facilities be provided with updates on dynamic battlefield movements in order to maintain a realistic assessment of the operating airspace.

2.1 Performance

The AATCS System will provide Air Force Combat Communication Groups with rapidly deployable systems capable of providing terminal ATC services at air bases and alternate landing areas. The system will be used for rapid launch and recovery of aircraft and will include the capability to monitor aircraft movements and maintain a level of positive control, separation, metering and sequencing under routine and extraordinary peacetime and wartime operating conditions. The system will support flight operations, for all types of U S. military aircraft from main operating bases, collocated operating bases, standby bases and contingency airstrips. The system, working in concert with other tactical ATC equipment will provide the capability to handle terminal traffic at more than one airbase.

The system will be tactical, mobile and environmentally tolerant with a high degree of survivability. It will have inherently high mission critical reliability with functional redundancy and graceful degradation.

AATCS must be capable of operation as an autonomous terminal control facility, and with other fixed or mobile ATC assets. It will use passive techniques for acquiring aircraft position data, and process this data to develop an area-wide overview of individual aircraft types, positions, routes, missions and status.

The system must perform a high level comparison of aircraft flight data against static and dynamic data base information relating to terrain, weather, ATC, navaids, tactical mission and flight plan data.

It will use expert system or artificial intelligence techniques to assess the aircraft flight data against the stored data and determine routings, waypoints, separation criteria, emergency and routine procedures. The processor will present a graphics and tabular presentation to the controller showing the overall ATC situation, flight prediction and routing, and potential conflicts and hazards.

The processor system shall consist of rugged high speed computer(s) using VLSI circuit technology, extensive internal high speed primary storage devices and high speed secondary mass storage devices. Off-the-shelf software will be used to the extent possible and will be a higher order language, preferably ADA.

The displays will be compact, rugged, high resolution A.C. gas plasma devices which will function as intelligent terminals. Controller input will be via functional or alphanumeric keyboard, touch screen and position entry devices (trackball, digitizer tablet, capacitive touch pad or mouse). Automated voice recognition techniques will be used for data entry and data update into the processor.

The controller will be able to input variables relating to local dynamic information, i.e., weather, airfield conditions, etc., into the system. The controller will also be able to update and modify A/C data including changes to destination, status or routing and to request recommended routings, predictions or other flight data information. Processor-generated data may be overridden or modified by the controller.

AATCS must have the capability to communicate with aircraft and with other ground-based ATC or tactical facilities. RF communication will be via secure, clear, or anti-jam equipment. Landline communications shall be by wire lines (encrypted or unencrypted), fiber optics or other means.

The system will be self-contained with on-board power generation and environmental control. The system will be designed to operate autonomously in the field for extended periods without replenishment.

AATCS is intended to be survivable primarily due to its lack of a detectable radar sensor and through the use of AJ communication techniques. However, it should be able to take advantage of friendly primary radar facilities which must be operated for air defense purposes. The system concept must then consider the incorporation of bi-static primary and secondary radar receiver-processors as a means of obtaining skin paint or SSR plot data from airborne or ground-based tactical radar transmissions.

SECTION 3
System Definition

AATCS will be comprised of four major elements:

1. The data processing and display subsystem
2. The communications equipment suite
3. The equipment van/transport vehicle
4. The airborne data processing and cockpit information suite.

Each of these systems are, in turn, comprised of subsystems and equipments interfaced into a functional element which supports one or more of the AATCS operational requirements. The concept described in this report will concentrate primarily on the communication, data processing and display and, to a lesser degree, the airborne equipment elements. The design consideration for the ground-based system elements have taken into account the potential packaging, environmental and mobility constraints associated with tactical deployments.

AATCS will provide operational capabilities commensurate with its ATC mission. The basic operational capabilities were developed to meet what was felt to be a realistic operating scenario for the 1995-2005 time frame.

The system must be capable of line-of-sight operations due to the constraints imposed by the uplink/downlink data transmission techniques. The system would therefore be instrumented to cover an area of 360° out to a range of 300 nmi. Assuming optimum link performance, communications could be maintained with aircraft at a height of 60,000 feet at a range of 300 nmi. It is recognized that the majority of the ATC operations would probably be conducted within a range of 60 nmi or less.

The processing and display subsystem would be capable of handling peak loads of up to 600 aircraft within a range of 300 nmi. All targets would be tracked targets. The flight plan data base would store up to 200 flight plans, 100 of which would be active and associated with the aircraft track data.

The various AATCS subsystems interfaced into an operating configuration will perform the AATCS mission. The functional system configuration is shown in Figure 1.

The ground-based operating subsystems, equipment and capabilities will include the following:

a. Operator consoles for three primary controller positions and two assistant controller positions.

b. Multifunction plasma displays for each primary controller position. Each display is capable of providing a dynamic alphanumeric and graphic display of the control area enhanced with map data, special symbols and tabular data displays.

c. Plasma displays for each assistant controller for the tabular display of flight plans and the display of dynamic data including local navaid and airbase data.

d. Processing and software functions to support the primary controller displays including the ATC display and subsystem data base. Also to support the assistant controller displays including the flight plan processor functions. The processor and software functions shall perform all processing associated with the downlinked aircraft position data including but not limited to correlation, tracking, track/flight plan association, and aircraft relative position. The system shall perform predictions and recommended routing and perform conflict monitoring for all aircraft under control and generate data messages to be uplinked to the aircraft.

e. Communications processing and software functions either as a separate processor or, as part of the main system processor, to perform formatting/reformatting, and control of downlinked and uplinked voice and data transmissions.

f. Communication between the AATCS and the aircraft would be of two categories: JTIDS to operate with properly equipped platforms and conventional VHF and UHF tranceivers to operate with aircraft not equipped with JTIDS. A type 2 JTIDS terminal would be the ground-based terminal installed in the AATCS vehicle. The VHF link would use SINCGARS transceivers. The UHF link would use HAVEQUICK radios. Both of these equipments are frequency hopping, anti-jam (AJ) radios with compatible airborne transceivers.

g. Position electronics for operator access and control of the various communication subsystem elements including landline, A/G and intercom.

h. Centralized status and monitoring equipment for each AATCS subsystem including control and BITE.

i. Prime power equipment including redundant power generators with automatic switchover and limited operation emergency back-up battery.

j. Environmental Control Units, closed-loop with chemical, biological filtering/protection.

k. Fiber optic equipment to interface with standard tactical F.O. network.

l. Telephone equipment to interface with digital TRI-TAC network.

m. A single-channel man pack/vehicular or five-channel GPS receiver set for developing a position reference for the AATCS facility.

n. A special purpose, self-propelled, vehicle. To house the AATCS system and equipment and provide working and limited living accomodations for the crew. The vehicle would contain the operations area, an equipment area and a support area. It would be air transportable by aircraft and heavy-lift helicopter. It would also be transportable by rail, ship or landing craft.

o. Expansion capability to enable the incorporation of advances in subsystem technology to include, but not be limited to: voice recognition, point-to-point communications, bistatic primary and/or secondary radar.

The airborne operating subsystem and capabilities are defined for two system configurations. For platforms equipped with JTIDS, the JTIDS terminal in the AATCS should interface directly with no additional capability anticipated.

Platforms not equipped with JTIDS would require equipment and capabilities as follows:

a. An air-ground communication capability based on either HAVEQUICK or SINCGARS equipment.

b. An AATCS processor to process aircraft position data from a GPS and/or INS system (latitude, longitude, heading) and altitude data from a radar altimeter or mode C encoder and format this data for time sequence transmission to the ground station.

c. A cockpit display and/or voice annunciation system to graphically display ATC control information and/or audibly advise the pilot of ground-based directions, instructions or recommendations.

SECTION 4
System Configuration

The subsystem elements which comprise the AATCS are designed to support one or more of the operational or functional tasks which comprise the system's ATC mission.

The system design considerations have incorporated substantial reliance on processor controlled functions for both the basic ATC mission and the subsystem control aspects.

The basic system functions, shown in the functional block diagram in Figure 1, are allocated among the various subsystem elements shown in the system block diagram in Figure 2.

AATCS reliability is enhanced through the use of redundant equipments, extensive built-in-test functions and reductions in the number of mission-critical failure modes. All equipment would be MIL-qualified.

The heart of the AATCS facility will be the System Processor Suite (SPS). The SPS will be comprised of dual processors operating in main/standby mode. One processor would be on-line, the other would be operating in parallel but would be off-line. The processor operation is monitored by a status and control unit. In the event of a fault in the on-line processor the status and control unit would perform an automatic changeover and bring the backup processor on-line.

System data base storage would be resident in both processor memory and external mass storage devices.

Supervision access to the processor system would be provided from one of the assistant controller positions. The Plasma Display and keyboard would function as the terminal device for system initialization, system reconfiguration and system maintenance.

The processing system will handle all of the functions associated with the AATCS surveillance, flight data, training and maintenance modes. Operational processing will be performed for mission-oriented data including the controller displays, display support, system and subsystem control, and input and output data.

Controller display processing will be allocated between the requirements for the primary controller positions and for the assistant controller position. Normal operation for a primary controller position will be the surveillance mode. This will include the presentation of track information, weather and geographic data, preview and processor response information, status information and position entry inputs. Mission oriented data will be presented as a composite display of graphics and alphanumerics.

The assistant controller position will normally operate in the flight data mode. The data presentation will include a tabular listing of inactive and active flight plan data base information, sequenced by estimated activation times. The system will update the flight plan data base by controller action.

Any operator position will be capable of operating in an off-line training mode with simulated instructional scenarios for personnel training.

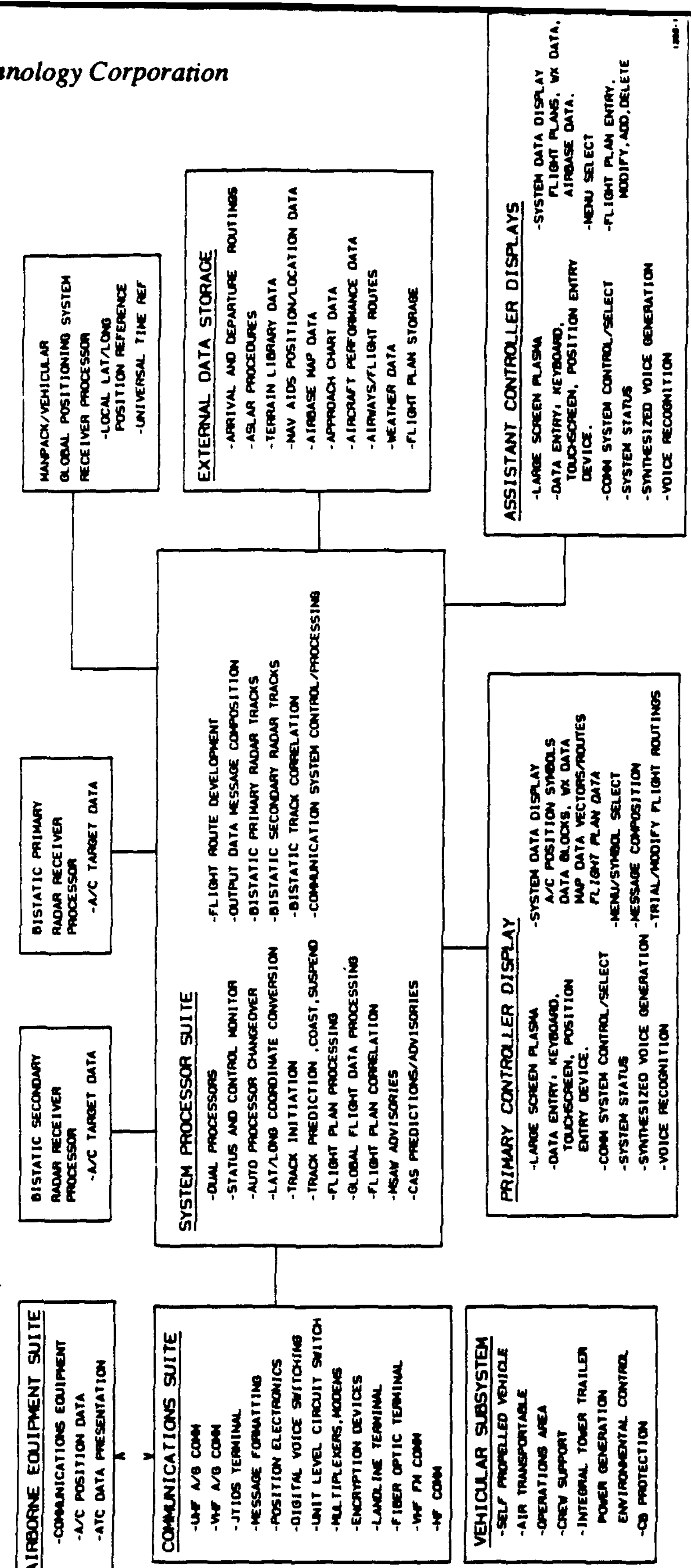

Figure 1. Functional Block Diagram AATCS System

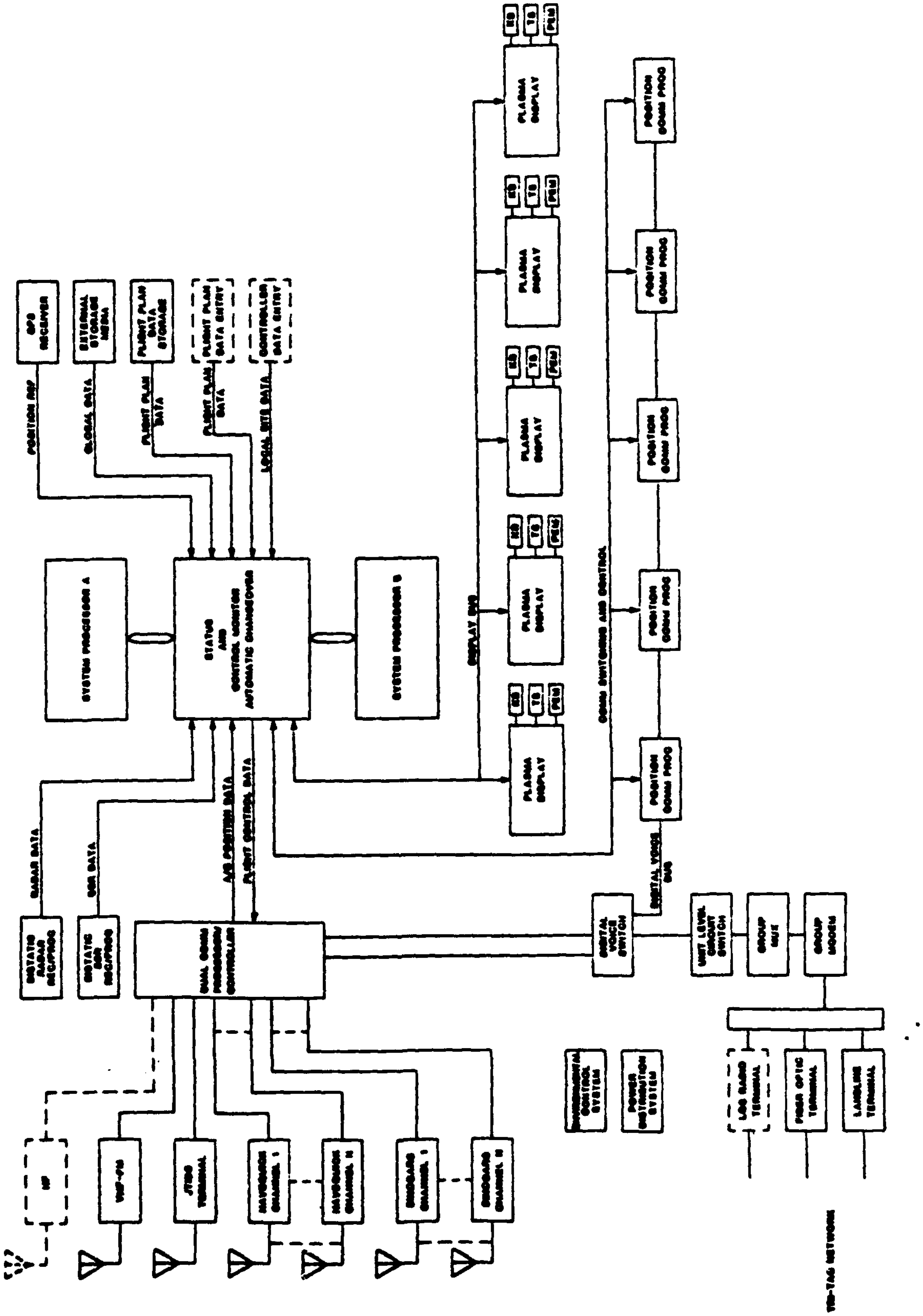

Figure 2. AATCS Preliminary System Block Diagram

Any assistant controller position may be designated as a master position for maintenance purposes. In the maintenance mode the position will support initialized maintenance and test tasks. Tasks would include hardware checks and operability checks. The system will collect and summarize on-line diagnostics and BIT data from each of the AATCS subsystems. It will perform off-line checks of processor operations. This will be used to isolate system errors and equipment faults. The results of performance checks will be displayed as text or graphics.

The input processing function will handle data from the comm suite, the controller consoles and the peripheral equipment. The system checks for transmission errors, message types, format and sequences. It will also perform checks of operator inputs for content, syntax and data content of information fields.

Global and supporting data base information will be handled by the support processing function. This will include: geographic map and terrain data, minimum safe altitude alert profiles, arrival and departure routings, navaid and airbase data, and airways and flight routings. Modifications and changes can be made to this utility data. Data can be input directly into the operational processing data base.

Overall operation and control of the system is provided at the controller display positions. All access, select, control and monitoring functions are controller selectable for presentation on the plasma displays. Functionally this would include:

a. ATC situation display (primary controller display)
   Flight plan/strip listing (assistant controller display)
b. Communication control and select
   - Channel, frequency, hot line, dial line
c. Training/simulation scenarios
d. BITE system, status and monitor
   - System level
   - Individual display units
   - System processor suite
   - Comm system/individual equipment elements
   - Power system
   - Environmental control system

Separate control panels are not required in the control room area for normal system operation.

AATCS will incorporate voice recognition techniques for conversion of controller voice commands into digital data. This capability will be applied toward controller-pilot data link communication and data entry into the AATCS system processor.

Two major benfits are provided: simplified and clearer controller-pilot communications and reduced controller workload for the man-machine interface.

Development of the voice data entry capability for AATCS would closely follow efforts presently underway and planned future research for the FAA Advanced Automation Program. Ongoing efforts in the basic technology are under way at Texas Instruments and are being applied in the development of a controller suite by Hughes Aircraft.

Voice data entry for AATCS is envisioned for a number of controller tasks. Initially, this would include routine tasks of a non-critical nature such as entering or modifying flight plan data, calling up various display presentations or system menus, or positioning or changing the location of a cursor.

Other considerations include digitizing controller commands and advisories for transmission to the aircraft. On-board equipment would, in turn, convert from the digitized format to a synthesized voice output to the pilot's headset or cockpit audio system.

Bistatic primary and secondary radar reception equipment is proposed as an additional capability for AATCS. This equipment would enable AATCS to acquire radar data derived from remotely-located transmitters. The AATCS location would not be compromised by this technique as the system would still be passive.

The communication suite provides all the required capability for data and voice air-ground transmission. The RF communication equipment will provide the ability to operate in the clear or encrypted, normal or anti-jam (AJ), VHF and/or UHF and in a JTIDS net.

Deployment of the AATCS, will be flexible in order to meet a wide range of operations scenarios and missions. The system will be able to operate in conjunction with other TAC or AFCC facilities using various communication methods. Some of the deployment interface configurations are depicted in Figure 3.

Landline capability is provided to tie to a local exchange system or to interface with a TRI-TAC net. Switching, multiplex and modem equipment would be installed to interface with a variety of wire line cables and tactical fiber optic optic cable assemblies. Direct access between the AATCS and other facilities can be made by wire line or fiber optics.

AATCS can be operated with line-of-sight (LOS) radio terminal equipment as a point-to-point link or as an up-the-hill link to a TRI-TAC terminal. The equipment required for the LOS capability may require an additional vehicle or trailer. This is due to the size of the LOS equipment and to also provide the capability to locate the terminal remotely from the AATCS for optimum LOS link path performance.

Additional communications capability is provided by VHF-FM transceivers. These equipments would service a short-range intrabase radio net.

Medium-range and long-range RF comm capability can be incorporated by the addition of HF transceivers. Both the HF and VHF-FM equipment will incorporate AJ operating features.

The vehicle subsystem provides the installation, mounting, transport and support facilities for the AATCS equipment and operating crew. A long wheelbase van-type vehicle and towed trailer contain the AATCS facility. The system is designed to be compact, highly mobile and transportable via various methods. It is self-contained with on-board power generation, environmental control, operating and support facilities. A crew compartment provides an off-duty rest area.

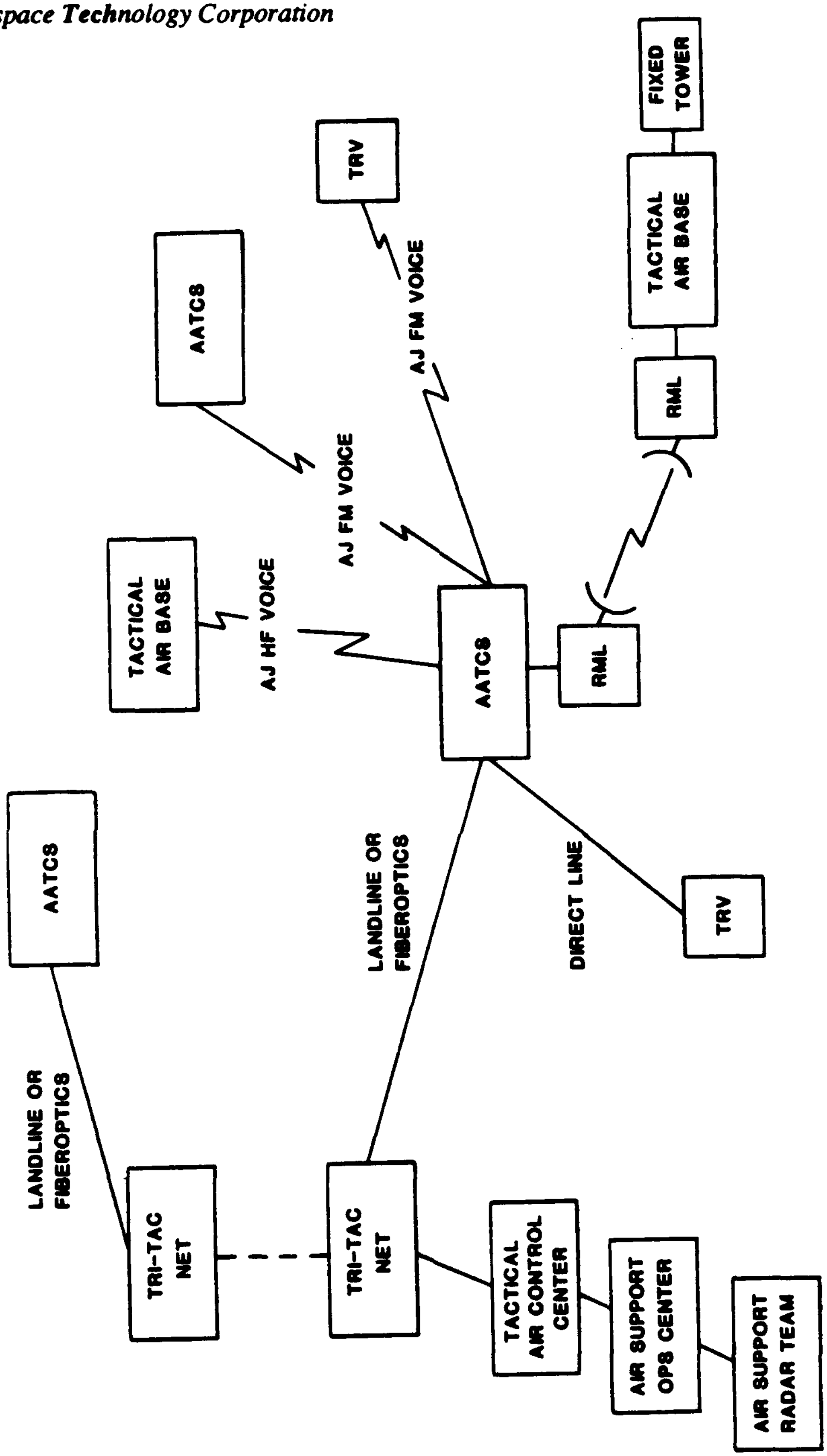

Figure 3. AATCS Deployment and Interface

4.1 AATCS System Processing & Display Suite

4.1.1 General Description

The AATCS mission is an extremely critical one as it concerns itself not only with support to all Air Force air operations, but with the safety of personnel and equipment as well. This mission dictates the use of extremely reliable hardware and software, incorporating redundant/fault-tolerant processing. In addition, the goals set forth in this report and those of preceding ATALARS studies, are very ambitious and involve levels of automation not provided in any current Air Traffic Control system.

As a result of these needs, a modular, flexible architecture is required. It should facilitate a building-block approach to implementing the AATCS functions identified in this report, with the capability of initial feasibility to be demonstrated using a limited subset of functions. The architecture should allow straightforward expansion to include additional higher-level functions as the concept evolves, with minimum impact on previously implemented functions.

Additionally, the hardware should support fault-tolerant processing and BITE functions. It should be reliable, mechanically rugged, have good tolerance to a wide range of environmental conditions, and have good EMC characteristics.

The above demanding requirements can best be met by a multi-processor, bus-oriented design using a standardized circuit card and bus structure with multiple vendor support. Today's technology offers numerous choices which would meet the above needs and offer sufficient processing power "per CPU" to handle the AATCS tasks in a modular, growth oriented fashion.

While several standardized bus structures exist today, one of the best supported for the military market is the VMEbus. It is capable of supporting multiple processors and intelligent I/O cards on the same bus, has a high bus bandwidth capable of supporting 32-bit parallel transfers, has an inherently rugged mechanical design, and is supported by multiple vendor products including a significant number of full MIL-SPEC products.

Additional architectures will continue to evolve during the 1990's. The Navy is currently writing preliminary specs to define their Next Generation Computer Resource (NGCR) to replace the UYK-43/44 series. It will incorporate a 32-bit, multiprocessor, bus-oriented architecture. Similar efforts are under way in other branches of DOD as well. For purposes of this discussion, the hardware design will focus on currently existing VMEbus products wherever possible, however the concepts could be adapted to any similar architecture in the future.

4.1.2 Functional Configuration

The functional configuration of the AATCS System Processor Suite (SPS) and its Input/Output interfaces is shown in Figure 4. The SPS is subdivided into four major areas, as follows:

a. Processing Unit "A"
b. Processing Unit "B"
c. System Monitor & Control
d. I/O Transfer Switching

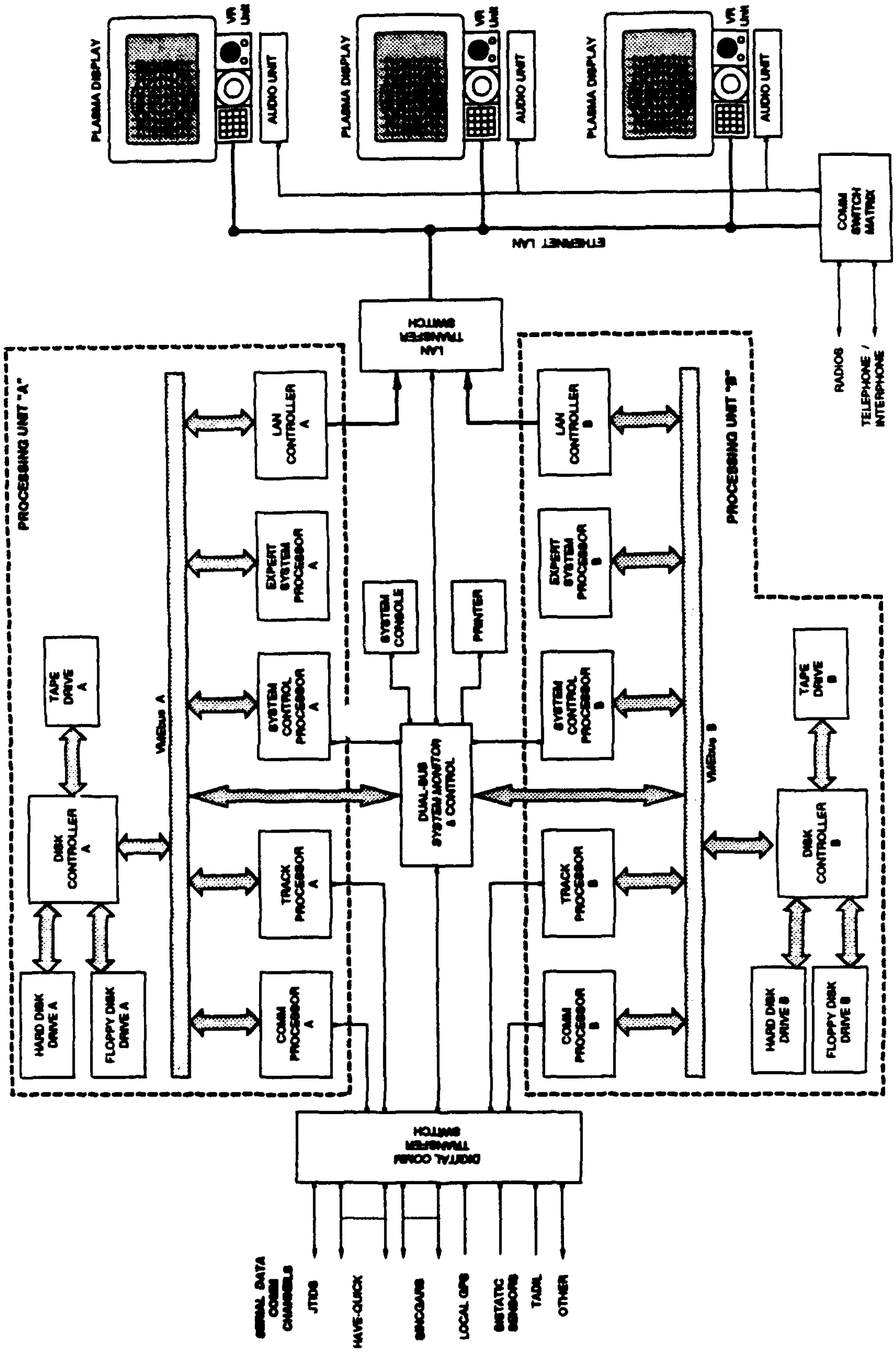

Figure 4. AATCS System Processor Suite (SPS), Peripherals, and Interfaces

In addition, the associated COMM interfaces, displays and controller voice communications subsystems are shown to indicate their relationship to the SPS. The primary interfaces are:

a. JTIDS
b. HAVEQUICK
c. SINCGARS
d. Local GPS
e. Bistatic Sensors
f. TADIL & other ground links
g. Local Ethernet to displays, Comm Switch with expansion provision for other local devices.

4.1.2.1 Processing Units "A" and "B"

These are two identical units which provide all AATCS system processing functions. Physically, they are based on a ruggedized VMEbus chassis and card system. Each processor is fully autonomous and can be operated in a parallel main-standby configuration, or separately with one processor performing prime mission functions while the other performs off-line utility, simulation, diagnostic or training functions.

Each processing unit is housed in a separate enclosure with its own dedicated power supply and peripherals. Use of a battery backup UPS system will be incorporated into the the design of the AATCS vehicle.

4.1.2.2 System Monitor & Control

The System Monitor & Control section is the only processing element which is not fully redundant. This unit connects to the VMEbus in both processing units and performs on-line diagnostics, bus time-out checks, and a variety of status monitoring functions. It is the responsibility of this unit to decide which processing unit should be connected to the I/O devices. Should this unit malfunction, a manual bypass switch is provided.

4.1.2.3 I/O Transfer Switching

This section consists primarily of passive switching devices which can be controlled by either the System Monitor and Control Unit, or by manual selection. In general, most data inputs into the system are not switched but are provided to both processor units in parallel. Outputs from the processor units are selected by the I/O Transfer Switching and applied to the output channels. In this way, both processors can run in parallel and process data as if they were both on- line. However, only the outputs from one processor at a time will be directed to the I/O devices. Additionally, a capability will be provided to disconnect either processor from the input channels as well, however, to preclude a fault on the processor input from disrupting the other processor.

The switching will be configurable on a line-by-line basis to allow system configurations to support the processors operating in separate roles, rather than a redundant mode. This allows each processor to independently control designated data links.

The Ethernet LAN switching will normally allow either processor to access the LAN, with the controlling processor determined by software, since the LAN is designed to operate in a networked environment. A physical disconnect can be made by the System Monitor & Control, or by the operator, should LAN controller problems be identified.

The ability of both processors to access the LAN provides several additional system benefits such as mixing of display data from one processor running simulation/training scenarios and the other processor operating on live data. It also provides a high-speed, inter-processor data channel which can be used for cross-updating of data bases as well as control message passing. This will facilitate the incorporation of additional levels of fault- tolerance and processing element cross-utilization.

4.1.2.4 Data Channel Interfaces

A variety of data channels are connected to the AATCS SPS. They can be broadly classed by purpose as Direct Aircraft (DA), ATC Coordination (AC), and Interoperation Coordination (IC), and Local Utility (LU). These channels carry all information to and from the AATCS SPS. Most of the channels with interfaces outside of the AATCS facility will be implemented as secure channels using various anti-jam and encryption methods. For purpose of this discussion, data encryption is assumed to be handled on a channel-by-channel basis outside of the AATCS SPS functional boundary.

4.1.2.4.1 Direct Aircraft (DA) Channels

The purpose of DA communications is to directly obtain position and status from the aircraft and to transmit advisories and routine control messages directly to the aircraft. The AD message interfaces to the AATCS SPS consist of a combination of JTIDS and SDL links via HAVEQUICK and/or SINCGARS. These will generally be intermediate-speed channels (i.e. 16 KB/S) and may consist multiple channels to allow concurrent interchange via both JTIDS and SDL. Additionally, several SDL channels may be operated in receive mode to monitor air traffic in adjacent control zones.

4.1.2.4.2 ATC Coordination (AC) Channels

The AC channels will initially be primarily low-speed channels providing interchange of flight planning, hand-off, weather, NOTAMS and administrative message traffic between ATC facilities, including AATCS and non- AATCS locations. As ATC network communications evolve, however, these channels will be upgraded to high-speed point-to-point or network configurations requiring the addition of dedicated communications processor boards and/or Intelligent LAN controllers.

4.1.2.4.3 Interoperation Coordination (IC) Channels

The IC channels comprise those necessary to coordinate the ATC mission with other services having a common requirement for data. Such channels will generally be existing TADIL and other links to Air Defense and Tactical Air Control System (TACS) operations, but could also include links to civil air control operations (e.g. FAA, Eurocontrol), NATO operations, etc. In addition, JTIDS may also be cross-utilized in this role.

4.1.2.4.4 Local Utility (LU) Channels

The LU channels consist of AATCS channels necessary for the collection and distribution of data within the AATCS facility and/or host airbase. They consist of a Local Area Network (LAN) channel and several discrete data channels. Communications between the AATCS SPS and the controller display equipment will be via the LAN, which also serves to control the local ATC Communications Switch as well as serves as an inter-processor communications media. This LAN can also be extended to additional on-site or remote communications needs.

Discrete LU channels are also required for inputting information from the local GPS receiver (time and position reference) and from other types of local sensors such as bistatic radars and/or local airbase radar/IFF. Additional channels may also be required for local airfield/NAVAID status as well as status inputs from other AATCS subsystems (e.g. telephone switch, radio equipment, power system, meteorological sensors, etc.).

4.1.2.5 Processor Task Allocation

The AATCS SPS functions are allocated identically in each Processing Unit, to several hardware processors based upon broad functional requirements. These hardware processing functions are chosen to allow a large amount of parallel processing to be done while keeping the functions relatively independent to simplify task synchronization and inter-processor communications. The hardware processor functional allocations are further subdivided into concurrent software tasks, under control of a multi- processing, multi-tasking operating system.

The AATCS Processing and Display functions are allocated to the following seven hardware processing elements, each of which operates in a concurrent, but coordinate manner:

1. Communications Processor
2. Track Processor
3. System Control Processor
4. Expert System Processor
5. Intelligent LAN Controller
6. System Monitor and Control
7. Plasma Displays

The first six of these functions reside physically within the AATCS SPS. Item 7 (Plasma Displays), while external to the central SPS equipment, perform as an integral part of the total AATCS processing function and are included here for completeness.

In addition, each processing unit contains a disk subsystem controller, RAM, ROM and various hardware support functions. RAM and ROM memory are not shown since they are generic, distributed hardware elements associated with each processing function.

The specific subset of AATCS tasks performed by each processing element are shown in the following sub-paragraphs. This subdivision into tasks is accomplished primarily by software. Tasks performed concurrently by software must, however, share the resources of a single hardware processor, whereas functions allocated to independent hardware processors can proceed in true time concurrency, limited only by bus and common memory contention, and task synchronization requirements. The hardware and software architecture selected supports both types of concurrency.

4.1.2.5.1 Communications Processor Tasks

The Communications Processing element will handle all data link control and message buffering functions. Depending on the number of actual channels used in a particular configuration, this task will be performed by one or more intelligent communications processor cards. Some of the tasks performed by the Communications Processor are:

a. Link-specific Protocol control & conversion.
b. Uplink/downlink time sync (HAVEQUICK/SINCGARS only).
c. Downlink time-slot assignments.
d. Message data buffering, formatting & code conversion.
e. Error detection/correction.
f. Raw plot report database maintenance.
g. Local GPS/Time processing.
h. Self-test/diagnostics.

4.1.2.5.2 Track Processor Task

The Track Processing element will handle all tasks associated with processing raw aircraft real-time plots from multiple sources/sensors into a single tracked target database. Raw plot reports are buffered by the Communications processor and sent to the Track Processor. The output database of the Track Processor is use by other processors to assess the current air situation. The Track Processor may actually consist of multiple processor cards if the number of sources of raw plot inputs is large and a large amount of multi-sensor correlation must be done (i.e. SDL, JTIDS, Bistatic Sensors, local/remote radars/IFF, TADIL, etc. Some of the tasks performed by the Track Processor are:

a Plot-to-track correlation.
b. Automatic Track Initiation/promotion/demotion.
c. Coordinate conversion.
d. Ground speed and heading computation.
e. Multiple-sensor correlation.
f. Track prediction, smoothing, maneuver detection.
g. Flight Plan correlation.
h. Track number assignment.
i. Geographic sensor filtering.
j. Air Situation Tracked Target database maintenance.
k. Simulation scenarios.
l. Self-test/diagnostics.

4.1.2.5.3 System Control Processor Tasks

The System Control Processing element functions as the primary controller for the AATCS SPS. It obtains requests for information or action from various processors and, obtains the information or relays the requests/information to other processors. It is the central data/status/command dispatcher for the SPS. It also performs general system housekeeping, data and status table maintenance. Some of the tasks performed by the System Control Processor are:

a. Disseminate air situation database to displays.
b. Process operator requests/data from displays.

c. Status/control processing of Comm Switch matrix.
d. Disseminate Comm Switch status to displays.
e. Request Expert System processing support.
f. Disseminate results of Expert System processing.
g. Prepare uplink messages.
h. Process downlink status or service requests.
i. Process AC and IC coordination messages.
j. Control access to disk and tape peripherals.
k. Overall system management, utility & housekeeping.
l. Self-test/diagnostics.
m. Update various system databases such as Airfield Status, Weather, Flight Plans, Weapons status, Aircraft performance, Geographic maps, NAVAID location status, standard and special approach patterns, ASLAR patterns, etc.

4.1.2.5.4 Expert System Processor Tasks

The Expert System Processing function performs the higher level, decision-making functions. Through access to all system databases, this processor evaluates individual aircraft progress as compared to its flight plan, other aircraft positions, airfield status, active and alternate approach patterns, etc. and issues routine advisories, clearances and routing recommendations directly to the aircraft (via the System Control & Communications processor). It also detects exception handling thresholds and advises controller of actions taken or required.

Implementation of this processing function is the most ambitious undertaking in the AATCS SPS development, from both a hardware and software standpoint. It includes many functions not currently provided in any existing air traffic control system and challenges the state-of-the-art in real-time expert system design.

These specific functions and tasks have been aggregated into a separate functional and physical processing element in order to permit their implementation to be structured in phases as well as to permit the use of unique, state-of-the-art software and hardware designs which are highly optimized for Artificial Intelligence application, but may differ from the designs used in the other SPS processors.

Some of the specific tasks which could be implemented by the Expert System Processing element are:

a. Conflict/collision alerts detection.
b. Minimum Safe Altitude Warning (MSAW).
c. Automatic advisory and clearance generation.
d. Alternate routing advisories.
e. Optimum route selection.
f. Aircraft landing separation and sequencing.
g. Departure sequencing & optimum rondez-vous points.
h. Exception handling/notification criteria.
i. Special ASLAR and emergency procedures.
j. Stack insertion and extraction.
k. Weather, aircraft and airfield status effects.
l. Adjacent control zone hand-offs.
m. Updating of Expert System "rules" database.
n. Self-test/diagnostics.
o. System level diagnostic support.

4.1.2.5.5 Intelligent LAN Controller

The Intelligent LAN controller is responsible for handling all communications on the Local Area Network, in includes message buffering and formatting capabilities as well as link control functions. Some of the specific tasks performed by the Intelligent LAN controller are:

a. Display & Comm Switch Message buffering.
b. Dual processor LAN access control.
c. Inter-processor communication handling.
d. LAN configuration management and utilities.
e. LAN protocol handling & conversions.
f. LAN traffic management.
g. Physical LAN interface.
h. Self-test/diagnostics.

4.1.2.5.6 System Monitor and Control

The System Monitor and Control function monitors the operation of both SPS processor units via direct connection to the VMEbus as well as an alternate connection to each System Control Processor. It is implemented as a dual VMEbus interface card with a CPU and local memory. The system software will be designed such that all system processors periodically execute diagnostic/BITE routines and report their status to the System Monitor and Control card. If any processor reports a fault status or fails to report in the allotted period, the System Monitor and Control can provide operator advisories, initiate degraded mode operations, or transfer all processing to the second processor unit via control of the I/O Transfer Switches. The System Monitor and Control can also proceed automatically to more detailed levels of fault isolation diagnostics to provide a reduced MTTR.

Some of the specific tasks performed the the System Monitor and Control element are:

a. SPS supervisory and maintenance control.
b. System initialization.
c. Fault detection and recovery.
d. System and LRU level fault isolation.
e. System status logging and display.
f. System activity and load factor monitoring.
g. I/O Transfer Switching.
h. I/O Channel configuration and routing.
i. Self-test/diagnostics.

4.1.2.5.7 Plasma Displays

The Plasma Displays, while not technically a part of the SPS, perform a number of controller unique functions which would otherwise have to be performed by the SPS. The Plasma Display incorporates two processing elements internally as presently configured (e.g. Application/Message processing and Graphics processing) and will be upgraded to add voice command processing and touch-screen sensing as a modular expansions. Some of the AATCS tasks performed by the Plasma Displays are the following:

a. Display range and offset scaling.
b. Display filtering (altitude, ID code, etc.).
c. Map drawing and updating.
d. Special Symbology updating.
e. Controller command/message pre-processing.
f. Graphics Processing.
g. Local utility & diagnostics program execution.
h. Touch-screen sensing.
i. Screen layout/configuration setup.
j. Relative range/bearing measurement.
k. LAN interface and message buffering.
l. Synthetic voice comm selector panel display.
m. Voice Recognition & Synthesis processing.

4.1.3 Hardware Design Considerations

While a variety of hardware approaches are potentially suitable for the AATCS application, the requirements for reliability, ruggedness, environmental stability, good EMC, BITE, and fault tolerance coupled with high processor performance significantly restrict the selection of candidate hardware solutions. While not the only suitable system, the VMEbus products from DY-4 System, Inc. are representative of the type of building-block system components which would satisfy the AATCS processing requirements and serve to illustrate the feasibility of the design approach utilizing non-developmental components available today. The DY-4 Inc. VMEbus products incorporate full 32-bit data handling both on-board and on the VMEbus. They also support unique features such as dual-ported RAM, location monitor (mailbox interrupt), BITE and bus-isolation (BI) test mode. These features facilitate the design of fault tolerant, maintainable, multiprocessor systems. All products are available with full MIL-qualified parts and processes.

The following paragraphs identify some the specific hardware which would comprise the SPS, in terms of products manufactured by DY-4 Inc. Similar items manufactured by other vendors may also be suitable, as the VMEbus architecture provides an industry standard which enjoys multiple vendor support.

4.1.3.1 Communications Processor

The Communications Processor could be implemented utilizing one or more DVME-706 Intelligent Communications boards, depending on the specific number of serial channels to be connected. Each board is equipped with a 68000/68010, 8-MHz microprocessor, six channels of RS-232 supporting async data rates up to 19,200 bps and sync rates up to 1 Mbit/sec., a four-channel DMAC, and dual-ported I/O and on- board memory.

4.1.3.2 Track Processor

The Track Processor could best be implemented by the DVME-134 Single Board 32-bit computer. This board provides a 68020 full 32-bit microprocessor, 68881 floating point processor, 1 Mbyte of dual-ported memory with parity, full 32-bit address and data on VMEbus, 64K bytes of PROM, seven-level interrupt support, one serial RS-232 port (not used for track processor), Location monitor (mailbox) with FIFO, BITE circuitry and firmware and bus-isolation capability (BI-mode). The location monitor provides a very efficient method of expediting inter-processor and intertask communications. It occupies specific reserved addresses in RAM and generates an interrupt when written to. Since all on-board RAM is accessible from the VMEbus as well as the on-board CPU, an external processor can write to the location monitor memory to signal a task interrupt without the use of semaphores or other common memory techniques. Equally important is the BITE implementation which includes circuitry to isolate the entire board from the VMEbus to perform fault isolation diagnostics independent of the bus status.

4.1.3.3 System Control Processor

The same hardware could be used to perform this function as for the Track Processor. It may be possible, although not necessarily logistically desirable, to delete the optional floating point co-processor, since the numerical processing requirements are much less than for the track processor. The RS-232 serial port will be used for system console communications with the System Monitor and Control Element.

4.1.3.4 Expert System Processor

The same hardware could also be used initially for the Expert System Processor as for the Track Processor and System Control Processor. This would provide a logistically desirable configuration of identical hardware processors. However, the complex tasks being performed in real- time by this processor may make a totally different architecture more appropriate. Conversion to this more advanced architecture may be necessary to implement some of the higher-level expert system functions in real-time.

Several companies have been engaged in advanced research and development programs aimed at producing special microprocessor designs optimized for AI processing, using concepts such as tagged data architectures to track data types in hardware, as well as other features that support object-oriented, rule-based applications. Texas Instruments and Symbolics Corporation are examples of companies planning to release high-powered microprocessor architectures intended for AI delivery and execution systems in the near future. Intel Corporation's next generation 80486 will also have features specifically designed to enhance AI processing. It is not unreasonable to expect VMEbus-compatible boards based on such processors, coupled with high-density memory chips, to be available in the near future.

4.1.3.5 Intelligent LAN Controller

This function could be implemented with the DVME-750 Intelligent LAN Controller. This board features a Motorola 68010, 10-Mhz microprocessor, LAN interface compatible with IEEE 802.3 Ethernet, TCP/IP protocol drivers in firmware, Manchester encoder/decoder, DMA to on-board memory, 512K bytes of dual-ported DRAM with up to 128K bytes of EPROM, plus standard features such as Location Monitor (mailbox), BITE and bus-isolation circuitry, and on-board firmware monitor and diagnostics.

4.1.3.6 Disk Controller & Peripherals

The DVME-712 Intelligent Disk Controller could be utilized to control a variety of magnetic mass storage peripherals. The recommended complement of mass storage devices would include a 40-80 Mbyte hard disk for on-line database storage and updating, a 5 1/4 or 3 1/2 inch floppy disk for modular software loading and special diagnostics, and a 100 Mbyte cassette tape unit for continuous data and status logging as well as database off-line backup.

In addition, Plessy Ltd. manufactures military-qualified, VMEbus-compatible bubble memory board which could be utilized as a substitute for the hard disk storage if later analysis shows that the data storage capacities can be met cost-effectively. This would provide additional reliability, particularly if the AATCS vehicle is used in the the "operate-while-in-motion" scenario.

4.1.3.7 System Monitor and Control

While this processor would be functionally similar in capability to the DVME-134 common to the other processing tasks, it should be configured to contain dual VMEbus interfaces connectable to a single CPU, and would include on-board dual-ported memory, at least two RS-232 serial I/O ports, a parallel interface to control the I/O Transfer Switches, and a counter-time. It would also be desirable to have a dual-bus DMA capability. Additional research must be done to locate a suitable off-the-shelf product or undertake the design of such a board.

An alternate approach would be to implement this function with a standard single-board computer such as the DVME-107 or DVME-134, in conjunction with a DVME-201 Serial I/O board. The single-board computer would perform all Monitoring and Control functions, while the Serial I/O board would provide all interfaces. This approach would eliminate the dual VMEbus connections, requiring information relative to the system's operational status to be obtained via the System Control Processors, rather than through direct access to each individual processing element via the VMEbus. Additional serial I/O would be used to communicate with the System Control Console and printer. The DVME-201 Serial I/O board also contains two, 8-bit parallel I/O ports which could be used to control the I/O Transfer Switches.

The System Monitor and Control card(s) would be contained in a separate enclosure including its own power supply. This would maintain the independence of this element from both Processor Unit "A" and "B." Manual bypass switches would also be provided to allow control of the I/O Switching Matrix modules should the System Monitor and Control fail.

4.1.3.8 Memory

While it is anticipated that sufficient memory will be available on-board the processors identified above, extra add-in memory is available in both static and dynamic configurations.

4.1.3.9 Chassis and Power Supply

The reliability, ruggedization, environmental, and EMC requirements can be met through the use of either the DVME-923S 20-slot or DVME-939 9-slot VMEbus Chassis and Power Supply Unit. The initial configuration of each Processor Unit would contain approximately seven (7) VMEbus cards, as describe in the preceding paragraphs. Since provisions should be made for additional Communications and Track Processors, the 20-slot chassis is preferred. Some of the features of this extremely rugged unit are:

a. Chassis size is 14"H X 17"W X 15"D.
b. Power Supply is 5.25"H X 17"W X 15"D.
c. Mounting designed for standard 19" EIA rack.
d. 20-slot VMEbus capacity.
e. Power Supply: 5 V, 100 A., +/-12 V, 3A.
f. Environment Standards to RTCA DO-160B.
g. Altitude: 0-15,000 ft.
h. Temp. (Operating): -15 to +55 deg. C.
i. Temp. (Operating, short term): to +70 deg. C.
j. Temp. (Storage): -55 to +85 deg. C.
k. Humidity: 20-95% (non-condensing)
l. Vibration: 0.010" double-ampl, sine, 0-55 Hz.
m. Input Power: Per MIL-STD-704 (22 - 29.5 VDC).
n. EMI: Meets MIL-STD-461 (Notice 6).

4.1.4 Software Considerations

A significant portion of the development effort associated with the AATCS system will be associated with software. The hardware architecture described above is intended to support and simplify the job of developing software in a multi-processor, multi- tasking real-time system.

4.1.4.1 Software Task Allocations

The decomposition and allocation of the AATCS processing requirements into the functional processes described in section 4.1.2, and their further decomposition into task areas also discussed that section, provides the basis for initial software tasks allocations. Further specific task segmentation, database specifications and detailed man-machine interface requirements need to be further developed during the feasibility demonstration phases of the AATCS program.

4.1.4.2 Operating System Software

In addition to these tasks, a real-time, multi-processing, multi-tasking Operating System is required to control and manage all other processes and to allocate system resources as required. Selection of an appropriate operating system is an involved process with numerous tradeoffs. Several potential solutions exist today, with additional choices to be available soon.

An excellent real-time, multi-tasking operating system is VRTX, provided by Ready Systems, Inc. This operating system is configurable to support virtually any real-time, embedded system hardware environment. It also can be interfaced to numerous high-level languages, including C and Ada.

Another candidate operating system is HARMONY, offered by DY-4 Inc., to support their line of VMEbus boards. While it does not provide as broad a range of functions and language interfaces as VRTX, it is highly optimized for the Motorola 68000/10/20 microprocessors and fully supports both multi-tasking and multi- processor configurations. Drivers are available for most of the DY-4 line of VMEbus boards. It includes a distributed Kernel for multiprocessor configurations, and is fully PROM resident. It uses a relatively simple, synchronous message-passing scheme for inter-task communications and synchronization that is independent of whether the tasks are running on single or multiple hardware hardware processors, as far as the application software is concerned.

The task of selecting the optimum real-time operating system should be attempted only after a more detailed definition of all processing requirements has been developed.

4.1.4.3 Programming Language Considerations

Since most future DOD programs will mandate the use of the Ada language for embedded software, it should be the primary language considered for the development of the AATCS system software. Unfortunately, the availability of an Ada development environment with strong support for multi-vendor, real-time embedded systems using multiple processor architectures is somewhat limited at this time. One of the most flexible and complete Ada development environments for embedded microprocessors is the VERDIX system. The VERDIX Ada development system can be hosted on Digital Equipment VAX minicomputers and real-time embedded software cross-targeted for Motorola 68000/10/20 or Intel iAPX-86 series microprocessor in embedded systems. VERDIX Ada provides a complete operating environment in the target system, including many traditional real-time operating system functions. It also provides the capability to import code written in assembler and/or numerous high level languages.

The capability of VERDIX and/or other Ada development environments to support real-time, fault-tolerant, multi-tasking, multi-processing software development for embedded systems is continuing to improve daily. The task of selecting the optimum Ada development environment should, however, be attempted only after a more detailed definition of all AATCS processing requirements has been developed and additional experience is available from industry on the benefits of Ada in this environment.

Consideration should also be given to the C language for software development. This language provides a well-structured development environment and offers some of the advantages of both assembly language as well as higher level languages such as Ada and Pascal. The C language is widely supported on nearly all computers in use today, including embedded, real-time applications, and is the language of choice for most commercial software development. Additionally, the HARMONY operating system design specifically for multi-processor configurations, is fully compatible with the C language.

An additional consideration in the selection of languages arises from the requirement to incorporate expert system processing into the AATCS. While simplified expert system AI processing can be implemented in conventional languages, on conventional processor architectures, the complexity and real-time response nature of the tasks identified for AATCS may require a more sophisticated approach. Such an approach may involve the use of AI optimized processor hardware architectures and software written in LISP, PROLOG, or similar languages. This processor and software must be linked with conventional software and processors running elsewhere in the system, in a real-time environment. This further complicates the task of selecting the optimum programming language and operating system.

4.2 AATCS Display Consoles

The display technology to be used in the AATCS will be AC Gas Plasma. These displays are high resolution, high brightness presentations, mechanically compact and rugged with low power consumption and inherently high reliability.

The display would be the next generation to the systems presently in development for SRV and NMR. As such they would be larger in display area and configured to provide more features and system-level control functions to the operator.

The controller positions make up the operational keystone for the AATCS facility. As such, they are designed to place all relevant data and system control directly, and literally, at the controller's fingertips. The display becomes the medium for presenting the overall ATC picture and also provides the ability for the operator to access, select and control the various subsystems which comprise the AATCS.

Each display will be equipped with data entry devices to access the system processor. These will include infra-red (IR) touchscreen, a functional or alphanumeric keyboard and a capacitive touch pad. The IR device will be a standard X-Y, LED source/detection matrix. The keyboard will be a standard type, configured for the specific requirements of AATCS.

The capacitive touch pad is a recent development, not yet available in the open market but which may be part of the sector suite for the FAA Advanced Automation Program. It performs the function of a trackball, joystick or mouse for positioning a cursor. The unit is a small metallic plate, approximately 3x3 inches. Positioning a finger on the plate and moving it to the desired area, relative to the display screen, causes the cursor to move to the corresponding display location. The unit is compact and very effective.

The AATCS displays will be of two sizes. The primary controller display will have a display area of 28 x 28 inches arranged in a matrix of 2048 x 2048 pixels. The assistant controller display will have a display area of 14 x 24 inches, 1024 x 1752 pixels. Both displays will have the same basic performance characteristics.

Screen brightness will be at least 25 footlamberts at full brightness setting, and will be operator-adjustable (up to 16 levels), including the effects of an anti-reflective filter. The contrast ratio will be at least 10:1 with an ambient light level of 5 foot candles. The presentation will be flicker-free and useable up to at least an ambient light level of 20 foot-candles.

The display tasks associated with the primary controller display are the most complex in that it is a highly dynamic display, handling a large number of aircraft presentations, maps and vectors and system control functions. The assistant controller display requires a lower performance level in that it is primarily concerned with a more static tabular data presentation.

The display drive electronics and graphics processing provide high speed dynamic display updating which completely eliminates such anomalies as smear, flicker, bright flashes, and perceived sequential writing and erasing from top to bottom (window-shading).

4.2.1 Controller Display Configuration

4.2.1.1 Primary Controller Position

The primary controller position display presentation will be flexible and able to be set up in various configurations. One possible configuration is shown in Figure 5. This presentation includes the overall ATC situation display and subset displays for various types of supporting data. The display will also provide the means to select and control other AATCS functions by means of the touchscreen data entry and keyboard.

The ATC situation display will be presented as a plan position indicator. Display ranges, range marks, cursor position and display offset are selected from the panel. Maps, symbols and other types of graphics may be displayed to set up the presentation to reflect the ATC operational environment.

In addition to the situation display, tabular data lists and control panel layouts are presented. These will include:

a. Arrival list (processor generated)
b. Departure list (processor generated)
c. NOTAMS (controller entry)
d. Preview area
e. Preset function/select list
f. Airbase weather (controller entry)
g. Preformatted system status and control
h. Preformatted comm control and select
i. Flight strip data (processor generated)

The situation display will provide the following types of information display:

a. Aircraft Position Symbol. Five types of position symbols are proposed. These would provide an indication of routine or abnormal aircraft status: Normal, low fuel, damage, wounded on board, and emergency.

   Other symbols can be used to widen the range of aircraft status or condition data reflected in the position symbol. Position symbols, data block configuration and special message types are shown in Figure 6.

b. Data block information. Five lines of data block information would be provided. It is intended that the data presented here would provide to the controller as much specific flight information as possible.

   The first line of the data block will contain two elements: the four-digit A/C ident and a three digit A/C heading. The second line contains the four digit A/C groundspeed in knots and three-digit aircraft altitude in hundreds of feet. Line three will contain a four-alpha character A/C designation (if applicable) and an arrow indicating whether the aircraft is in level flight, climbing or descending.

   Line four will be used for controller entered special messages relating to special operations, type flight, widebody, VIP etc. A fifth line could be for special messages entered by the pilot and downlinked as part of the aircraft data message.

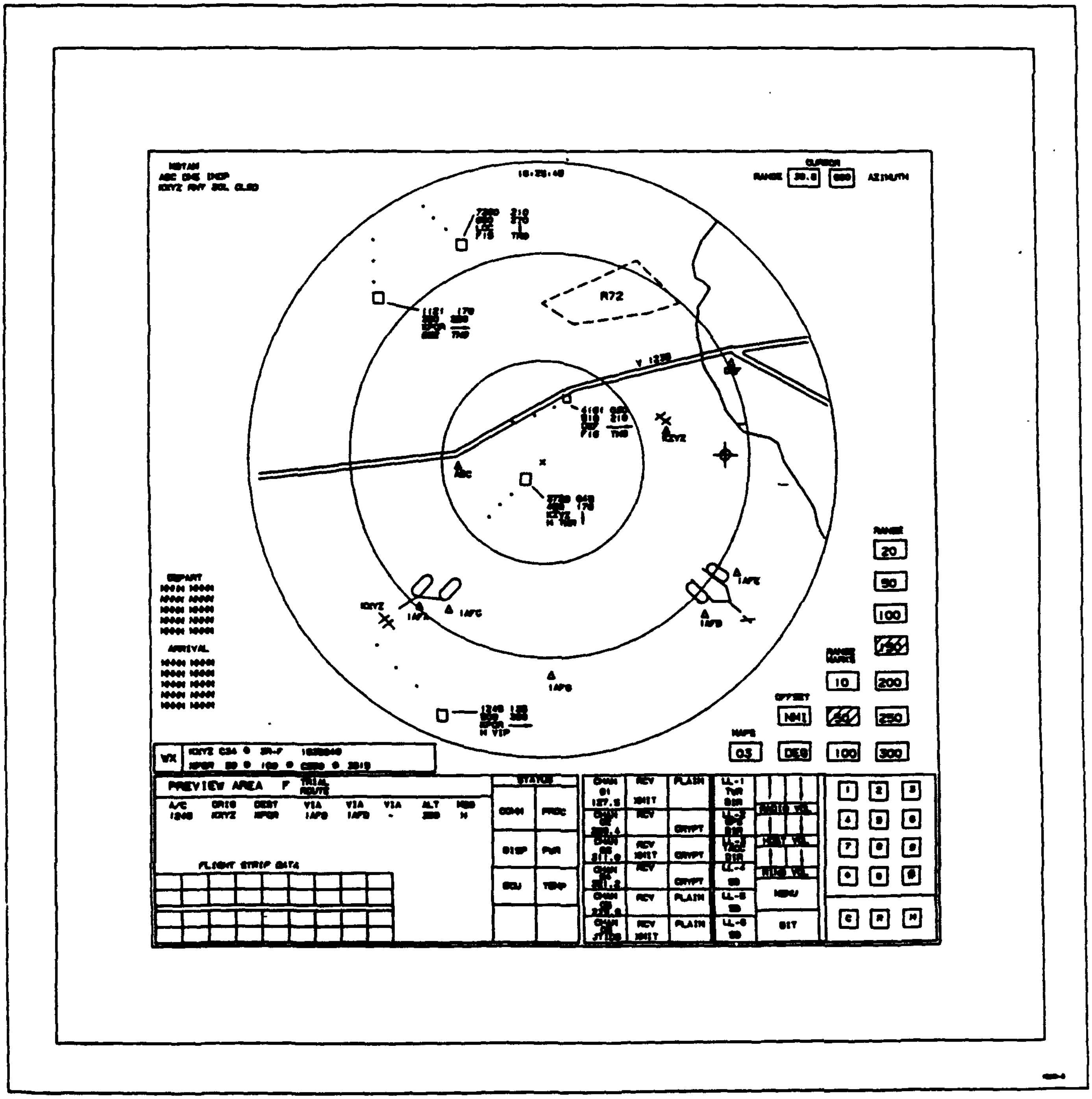

Figure 5. Preliminary Layout, Primary Controller Display

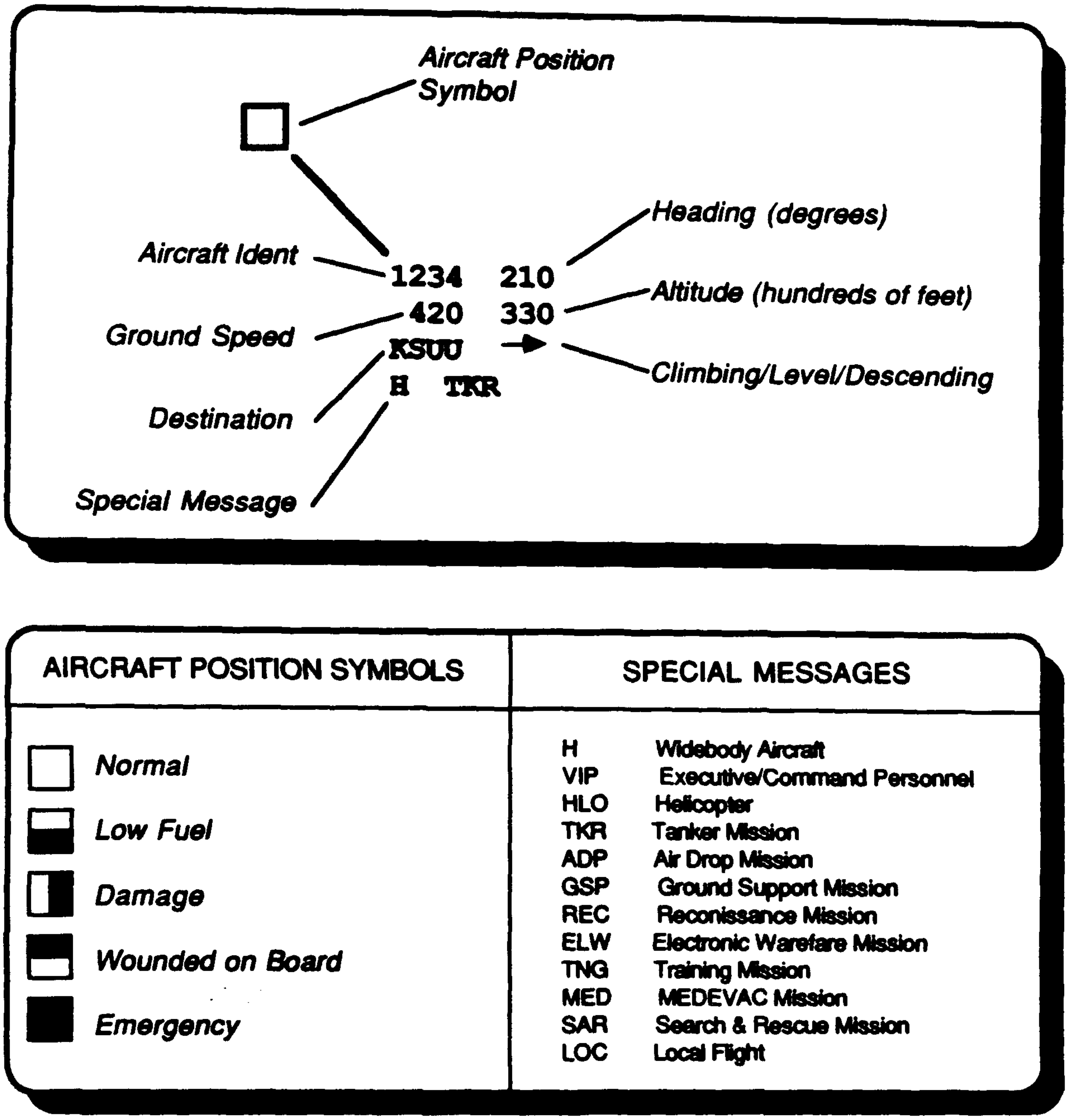

Figure 6. Primary Controller Display Symbology

The data block and leader line may be offset in any of eight directions under operator or system control to eliminate overlapping data blocks. The entire data block will blink for emergency situations.

c. Lines, special symbols and other fixed map elements can be designed into geographic maps or to outline hazard areas or other special airspace. Storage would be provided for pre-defined maps which could be displayed on controller command. Map composition and alignment would be performed by the operator using the keyboard and position entry devices.

d. Cursor Position will be indicated by a numeric readout of cursor azimuth and range mark position. The cursor position on the display would be indicated by a cross-hair/circle.

e. Arrival and Departure Lists. Tabular listing of scheduled A/C movements would be displayed. Each list would contain entries for N A/C and would show A/C ident and scheduled arrival or departure items sequenced by scheduled activation time.

f. NOTAM Data. A listing of NOTAM or other operational/status data will be provided. This would be two or three lines of 24 characters which would be entered by the controller.

g. The preview area would be allocated as a space of X by Y inches and used for message composition, menu selection, and other special-purpose displays.

h. Status and Control. Subsystem BIT status instructions will be displayed, either as a standard part of the overall display presentation, on operator selection, or forced on the display on detection of a system fault.

i. Comm Control and Select. The control and select panel function will be included as part of the controller display presentation. The function is described in Paragraph 4.2.1.

j. Airbase Weather Data. Terminal weather data for up to N airbases can be displayed. Data entry would be by controller action. Weather data can be called up by individual airbases for display at any position.

k. Flight Strip Data. It will be possible to call up and display flight strip data for up to N aircraft on the primary controller display.

The nature of the plasma panel with its touchscreen data entry will allow the screen configuration to be extensively changed during the AATCS system design. It could be designed to enable a controller to adapt or modify his display presentation to meet his particular operational requirements.

The presentation shown as the example in Figure 5 is representative of what can be done.

4.2.1.2 Assistant Controller Position

The display at the assistant controller position is primarily associated with tabular data. The major function at this position is flight data management, with system support data control and entry as a secondary function.

The display presentation, shown in Figure 7, shows some of the data which would be presented at this position. Up to N flight strips can be displayed, which would be the majority of the data. Information contained in each strip presentation is described in paragraph 4.2.5.

The assistant position will also display certain of the same data as was described for the primary controller display. This includes: comm control and select, system status, airbase weather, NAVAIDS status and a preview area.

4.2.2 Primary Controller Display

The high-speed drive electronics are capable of supporting a continuous 25-Hz, full-panel raster scan update rate, using a line-at-a-time erase/write cycle which writes an entire horizontal line at one time. The data is transferred from the frame buffer memory by the graphics processor, as 16-bit parallel words and held by a FIFO buffer on the display logic/interface board. This buffer acts as a synchronizer, and makes the display driver operation essentially independent of the frame buffer so long as the maximum data rate is not exceeded.

A Plasma Display does not require continuous refresh like a CRT. Static data on the display is completely flicker-free even if the update rate is reduced. The cursor is updated at a high rate and moves continuously without appearing to step, flicker or jitter. Aircraft position symbols do not move continuously due to the discrete plot-per-update nature of the downlink data cycle. Aircraft position symbols are drawn and redrawn very rapidly, creating the effect of targets being updated continuously rather than in blocks or with visible erase and redraw of data areas.

The design also provides for the bit image in the frame buffer memory to be rapidly updated. This requires the use of a dedicated high-speed drawing processor and associated memory. The drawing processor updates the frame buffer bit map at over 50,000 vectors-per-second, and can write approximately 20,000 characters-per-second. By segregating static and dynamic data into separate bit planes, all target symbols, limited data block, trail dots, and the cursor are fully redrawn every panel update. The 32-bit programmable graphics processor contains all control circuitry necessary to receive display list information from the Application Processor, perform all drawing operations into the frame buffer, as well as perform frame buffer to Plasma Display data transfer and RAM memory refresh.

The drawing processor and the display update functions both access the frame buffer. A dual-ported video RAM is utilized to minimize memory contention and maximize available memory bandwidth. Video RAM's contain an internal 256-bit shift register which, once loaded, is shifted out serially to the display. This makes more than 98% of the memory bandwidth available to the drawing processor, allowing it to achieve full predicted drawing speed.

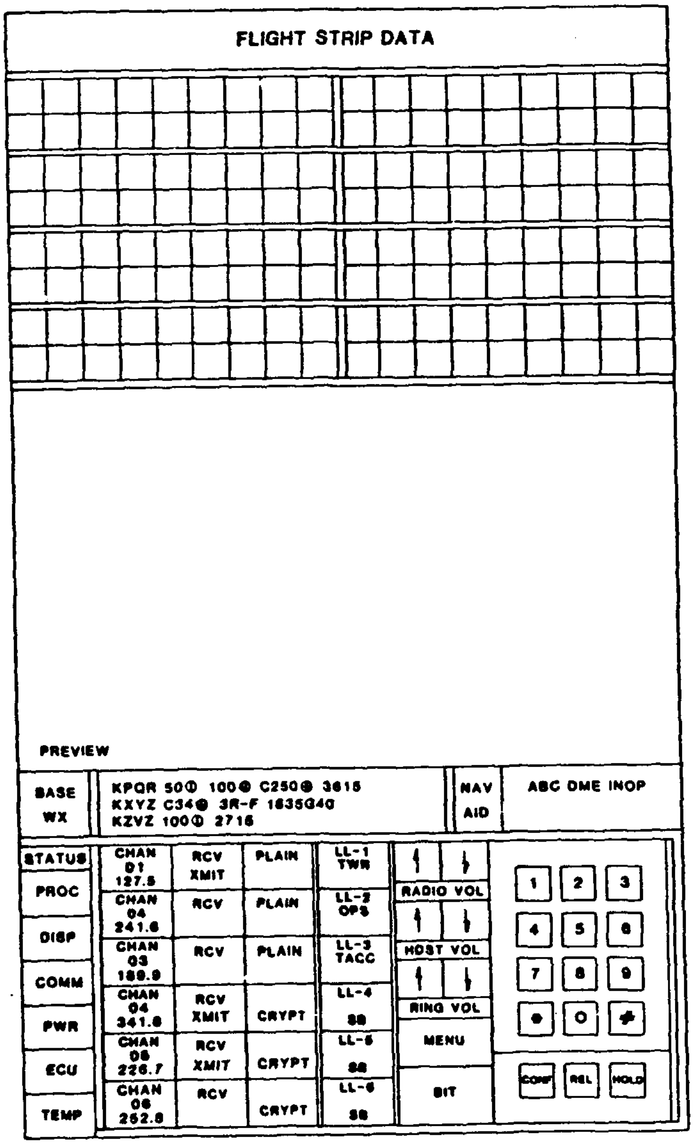

Figure 7. Preliminary Layout Assistant Controller Display

The net result of the video rate update capability of the panel, combined with an extremely fast graphics drawing processor, is a highly dynamic display presentation. The display has all of the benefits and performance of a CRT while retaining the reliability, maintainability, ruggedness, short-depth, high-brightness and readability of a flicker-free plasma display.

4.2.2.1 Multiple Bit-Plane Frame Buffer

The frame buffer is organized as a pixel bit map at four bits per pixel. Two bits-per-pixel are treated as separately maskable bit-planes for static and dynamic data. The second two bits are used to control the transparency and blink characteristics of the dynamic bit-plane.

The static data bit-plane contains data such as map data, range marks, tabular lists, menu selection block, etc. Data elements are written and/or erased selectively from this bit-plane in response to operator and bit status inputs. Continuous update of this information is not required. For example, all map and range mark data elements are rescaled and redrawn upon a change in range or offset settings in less than 0.1 seconds. Updating this bit-plane only when necessary significantly reduces the data load on the graphics processor.

The dynamic bit-plane contains all rapidly changing data; that is, all data which is updated and redrawn continuously. This consists of data such as target symbols, leader lines, limited data blocks and associated symbology, trail dots, and the cursor. Segmenting of the data into different bit-planes allows the graphics processor to update the target position symbols and data blocks to create a smooth update pattern that is free of display-induced spoking.

The other two bits-per-pixel control dynamic data overlay transparency and data blink functions. The blink bit is used to signal a hardware gate to enable/disable the dynamic bit-plane pixel data at a one-hertz rate to perform functions such as displaying emergency situations. Performing hardware blink further off-loads the graphic processor.

If the transparency bit is set, the data from the static and dynamic bit-planes are logically OR'd prior to being sent to the display. When dynamic data is written to the same coordinates as static data, then subsequently erased, the bits in the static plane remain unchanged. Therefore no holes, discontinuities or missing pixels result from such an operation. This situation commonly occurs when a data block or position symbol cross a map line or range mark, for example.

To further enhance readability, the transparency bit can be reset. This causes the bit in the static map to be ignored and overridden by the dynamic map bit for that pixel. This is used to create a dark area background field upon which each character of the data block is overlayed. This is accomplished by transferring a rectangular block of pixels from the font map to the dynamic map, with the transparency bit reset. In this case as well, there is no destruction of the underlying static data when the dynamic bit-plane is erased and redrawn.

4.2.2.2 Target Updating and Aging

Target position information is sent directly to the display application processor by the system processor. The latitude and longitude data are then converted to coordinate data relative to the AATCS site.

Once a target plot has been displayed, it must be removed (aged out) on the next update cycle to prevent duplication. The actual aging time can be varied as a display setup function to suit operator preference.

A protective feature is also provided by the target-aging software. If no valid plot messages are received from the system processor for a full update cycle, or a BITE message is received indicating a failure of the processor or comm line, the aging process will be suspended, freezing the last set of valid targets on the display. Targets which are aged out are normally moved into a trail dot queue, however sufficient storage is provided in the main target queue to hold at least two update cycles of full target data. Upon detection of a full update cycle target dropout, target data from one complete prior cycle will be restored to the display and a warning message sent to the operator. This is necessary since the previous scan's targets will all have aged out to trail dots by the time the problem can be detected.

4.2.2.3 Data Overlap Resolution

There is no interaction of target data and tabular lists due to physical segregation of these data areas. The only remaining interaction is overlapping data from multiple target data blocks. The graphics processor performs logical operations on data as it is written into each bit-plane (referred to as Raster Ops). Each dynamic target will be assigned a priority level, with emergency targets having top priority. When the dynamic bit-plane is updated, it is first erased completely, then built up in reverse priority sequence with highest priority targets drawn last. For example, the highest priority targets will overlay and blank out areas in common with lower priority targets.

4.2.3 Display Unit Architecture

The primary controller display consists of individual LRU's packaged in a compact, rugged package approximately 34 x 34 x 6 inches. The Plasma Display glass panel and matrix sustainer boards are assembled as an integral unit. The graphics processor, application processor and display logic assemblies are mounted on the rear of the display unit assembly. The power supply is a separate unit.

The assistant display is configured with the same compliment of LRU's, the package is smaller, and approximately 21 x 31 x 6 inches.

The display units interface to the system processor is via a serial RS 449/RS 423 34.8 Kbaud bi-directional line. Links between display units are 9600 baud, RS 232.

4.2.3.1 Plasma Display Head

The Plasma Display Head (PDH), consists of specialized drive and sustain electronics and a high speed parallel digital interface. High-speed parallel digital data is stored by a FIFO buffer and loaded into the plasma panel driver IC's with integral 32-bit shift registers. This allows full pixel line-at-a-time updates at video rates (25 Hz).

4.2.3.2 Applications Processor

The Applications Processor architecture is based on the Intel 80186-8 high integration 16-bit microprocessor supported by 256KB of DRAM (dynamic databases and message queues/buffers), 128KB of EPROM (program and fixed tables), and 16KB of EPROM (non-volatile storage of maps and site/display setup parameters). In addition, four serial I/O channels and a keypad interface are provided. Also supported as a memory mapped I/O port, is a 16-bit parallel interface to the Host Bus port of the Graphics System Processor (GSP).

The 80186 CPU combines numerous support functions on a single chip, including a clock generator, two independent high-speed DMA channels, a programmable interrupt controller, three programmable 16-bit timers, programmable memory and peripheral chip-select logic, programmable wait-state generator and a local bus controller.

The operation of the 80186 is supported by the 8207 Dynamic RAM controller which supports zero wait-state memory operation utilizing 150-ns dynamic RAM's. Program memory is supported by 200-ns 27512 EPROM's, also operating with zero-wait states. Sixteen K-bytes of non-volatile storage is provided by two 2864A EPROM IC's. These devices are designed with an internal 16-byte page buffer which looks like static RAM to the processor. Data is read from the device in the same manner as any RAM device. To write data to non-volatile storage, the processor writes 16-bytes as it would for static RAM. The EPROM then automatically completes the write-cycle internally in 5 milliseconds. The device also incorporates power on/off protection.

4.2.3.3 Graphics Processor

The Graphics Processor (GP) architecture is based on the Texas Instruments Advanced Graphics processor, the TMS34010. Its high level of integration and programmable graphics command set greatly simplify the task of designing a graphics controller and customizing the commands to the Air Traffic Control environment.

The TMS34010 is capable of handling six million instructions-per-second (6 MIPS) and offers a draw rate of up to 48-million pixels-per-second. It is an advanced, high-performance, 32-bit CMOS microprocessor optimized for graphics system applications. It is supported by a C-language compiler, CGI Graphics standards, realtime emulation and a large library of pre-written graphics routines covering all commonly used graphics primitives.

The GP instruction set is optimized for graphics operation, providing full XY addressing and pixel array transfer with boolean and arithmetic raster operations. It also includes a full set of general purpose microprocessor instructions, making it a fully capable 32- bit stand-alone processor. It supports bit, pixel, byte, word and field (user defined) data types, and both linear and XY addressing modes. An on-chip 256-byte instruction cache speeds execution of most graphics algorithms significantly. Instructions located in the cache and which do not require memory operands, can execute as fast as 6 MIPS.

Three types of memory are used on the graphics processor board. The EPROM and DRAM are of the same type and size as used for the Applications Processor. This memory is local to the GSP and is used for storage of the graphics algorithms, font tables and display lists. In addition, 512-Kbytes of Video RAM (VRAM) are used as a display frame buffer bitmap.

The GP has three basic specialized input/output interfaces: (a) the host bus interface, (b) the display interface, and (c) the position entry device interface.

The host bus interface is a high speed DMA supported 16-bit port for transferring display list and other information rapidly between the application and graphics processor local memories.

The display interface combines the serial outputs of the VRAM shift registers for each bit-plane into 16-bit parallel words. It provides the necessary logic to compress the 4 bits-per-pixel memory into one bit per pixel for the display. It also includes all timing and handshaking with the logic board FIFO.

The position entry device interface is a memory-mapped parallel I/O port which is read by the GSP to determine the current location of the cursor. The I/O port includes X and Y pulse up/down counters which follow the direction of the position entry device.

4.2.4 Computer Programs

Four separate computer programs will be utilized in the design of the AATCS display subsystem, the (a) AATCS ATC Operational Program, (b) Versatile Real-Time Executive (VRTX), (c) AATCS System Processor Simulation Program, and (d) Plasma Graphics Command Interpreter. Only items (a), (c) and (d) will require some level of development. Item (b) is an off-the-shelf real-time executive developed by Hunter & Ready, and provides a common software interface across numerous software languages (including C and Ada) and processor architectures (including Intel apx-86 and Motorola 68000 families). Only hardware environment-specific drivers will require development effort. Item (d) is currently in development for SRV and will require upgrading and extensive modification for the AATCS application.

The AATCS Operational program will provide the processing necessary to interpret the messages from the system processor and display the information to the operator on the Plasma Display screen. It will also provide the capability to prepare geographic maps upon which aircraft position data can be overlayed.

VRTX, produced by Hunter & Ready is a general purpose real- time executive designed specifically for embedded firmware applications. It supports real-time multitasking and controls all inter-task communications and scheduling. In addition, it provides dynamic memory management, support for real-time clock and character I/O, and interrupt handling services. VRTX is available for all popular 16 and 32-bit microprocessors, insuring portability and growth capability. It is an off-the-shelf package in widespread use throughout the commercial and military environment.

Simulation software will be developed to test the capability of the display subsystem to process real-time inputs from the AATCS system processor. The program will be designed to generate pre-stored scenarios and to exercise the display subsystem for training and to execute system performance tests. The program will operate in one of two modes; one being an off-line mode for composing and generating scenario scripts, and the other will be a real-time mode for running the scenarios.

The Plasma Graphics Command Interpreter (PGCI) contains a graphic algorithm library for both standard and customized graphics commands as well as a command interpreter, control executive, position entry/cursor interface driver, interrupt handler, and self-test BITE routines. Data transfers to/from the host bus are handled by the host and are transparent to the PGCI. The PGCI is a generic graphics program capable of extension to support many additional custom commands and can be utilized for many different high performance graphics applications.

4.2.5 Flight Plan Processing

The flight plan processing function will handle flight plan data - scheduled/repetitive flight plans, filed flight plans and in-flight reported flight plans - and display this data on the assistant controller displays.

Flight plan data would be stored on an external storage media accessed and controlled by the system processor. The data file will include a basic data base, established for the specific AATCS operational area. Data files would include:

a. Airbase data
b. Aircraft type
c. Regional or sector data
d. Geographical reference points
e. Entry and exit points
f. Flight routes

Flight data can be entered, modified, deleted and added by operator-action from each controller position.

The processing system provides the ability to create and maintain the flight data base and specific flight route information. This could include airbase names/locations/entry-exit fixes, airways/routes with sequential fixes and interfix distances, and a data base of pre-defined routes.

The AATCS system could also be designed to incorporate the capability to process and distribute flight plans to other ATC facilities by land line or radio.

The system will allow selected controller positions to modify data bases and system control through keyboard or position entry device operation.

The system is initially intended to operate with flight plan data being entered by the controller using his position keyboard. It would be possible for the system to be able to accept flight plan data via landline or RF comm link from an AFTN.

The system will be able to create and maintain the flight data base. Each data base entry will be capable of accepting the following types of data:

a. Aircraft Identity (ACID) - same as his discrete beacon code or the A/C tail number

b. Aircraft type

c. Type of flight: departure, arrival, enroute

d. Origin airbase

e. Destination airbase

f. Entry fix or departure airbase

g. Exit fix or arrival airbase

h. Estimated time of departure or over first entry fix

i. Speed

j. Flight level

k. Flight plan class

l. Route definition
   i. list of routes and crossing fixes
   ii. predefined route entry

The system provides the ability to enter flight plans from any controller position via keyboard or position entry.

This data will be used in creating the flight strip presentation at the assistant controller position.

A possible strip configuration, shown in Figure 8 as it would be displayed, consists of two lines of information.

Line number 1 would contain the A/C identification number, type A/C, airspeed, requested flight level and space for controller entries of altitude changes. Space would be available for entering estimated time over (ETO) up to N navigational fixes.

Line number 2 would contain date of flight, origin, estimated time of departure, and destination.

The global data base will contain position location data for all navigational aids, way points, fixes and airbases. The system processor will be monitoring aircraft movements relative to these fixed reference points and against the filed flight plans. It will be possible to correlate aircraft movements between fixes and destination and automatically update the flight plan data base with actual departure, time over fix and arrival time. The processor is then able to update waypoint estimate, based on actual time and ground speed. Flight strip presentation at the assistant positions would be revised along with arrival lists at the primary controller positions.

This capability allows AATCS to perform a mini flow control function for enroute metering and spacing and to automatically perform a terminal traffic activity estimate. This, in turn, would be used to make recommendations for modifying specific flight plans to schedule arrival and departing traffic so as to fit the runway capacity for specific airbases.

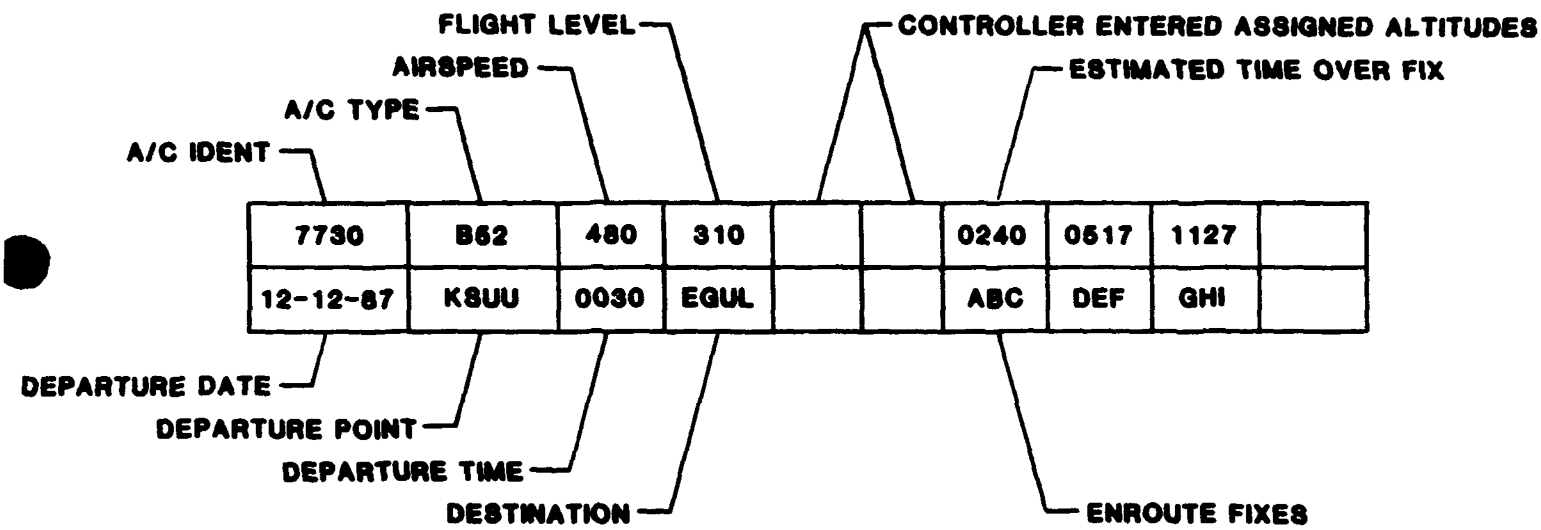

Figure 8. Preliminary Configuration Flight Strip Data Display

4.2.6 AATCS Position Reference

The mobile aspect of the AATCS facility, coupled with the requirement for a common grid reference between the ground based and airborne equipment, necessitates a highly accurate position reference.

A Global Positioning System (GPS) receiver will be installed in the AATCS vehicle to provide the position reference. Two versions of GPS receiver are suitable for the AATCS application, the single channel manpack/vehicular (M/V) configuration, and the five-channel aircraft (A/C) configuration. Either configuration will provide precise three-dimensional position and velocity and coordinated universal time.

The M/V unit is designed for ground vehicle applications with low maneuverability. The A/C configuration is designed for applications with higher maneuverability and which may require uninterrupted four-satellite tracking and greater immunity to jamming. Both configurations provide specified position accuracy of 16 meters, however extensive testing has demonstrated accuracies to better than 7 meters.

The M/V version shown in Figure 9 is designed as a standalone unit consisting of antenna, single channel receiver/processor and control display unit. The antenna is a fixed reception pattern and would be mounted on the AATCS vehicle. The receiver-processor is a single unit containing the receiver, computer, memory and power. The control display unit is a liquid crystal, alphanumeric display with keyboard. Reaction time from power-on to first accurate output is 10.5 minutes. Position data developed by the system would be input into the AATCS computer processor by operator-entry.

The A/C configuration is designed as a rack-mounted unit with either a fixed reception pattern antenna or a conformal controlled reception pattern antenna. The receiver consists of five paralleled tracking channels. The control display unit is a multifunction CRT designed for rack mounting. Control and data entry is provided by a keyboard and function switches. A 60/400 Hz power converter would be provided to operate the A/C configuration.

Reaction time from power on to first accurate output is 4.5 minutes. Position data from the receiver would be interfaced directly into the AATCS processor.

The AATCS system as initially conceived is not designed for operation while underway. Either of the two GPS receivers could provide accurate position updates to allow underway operation.

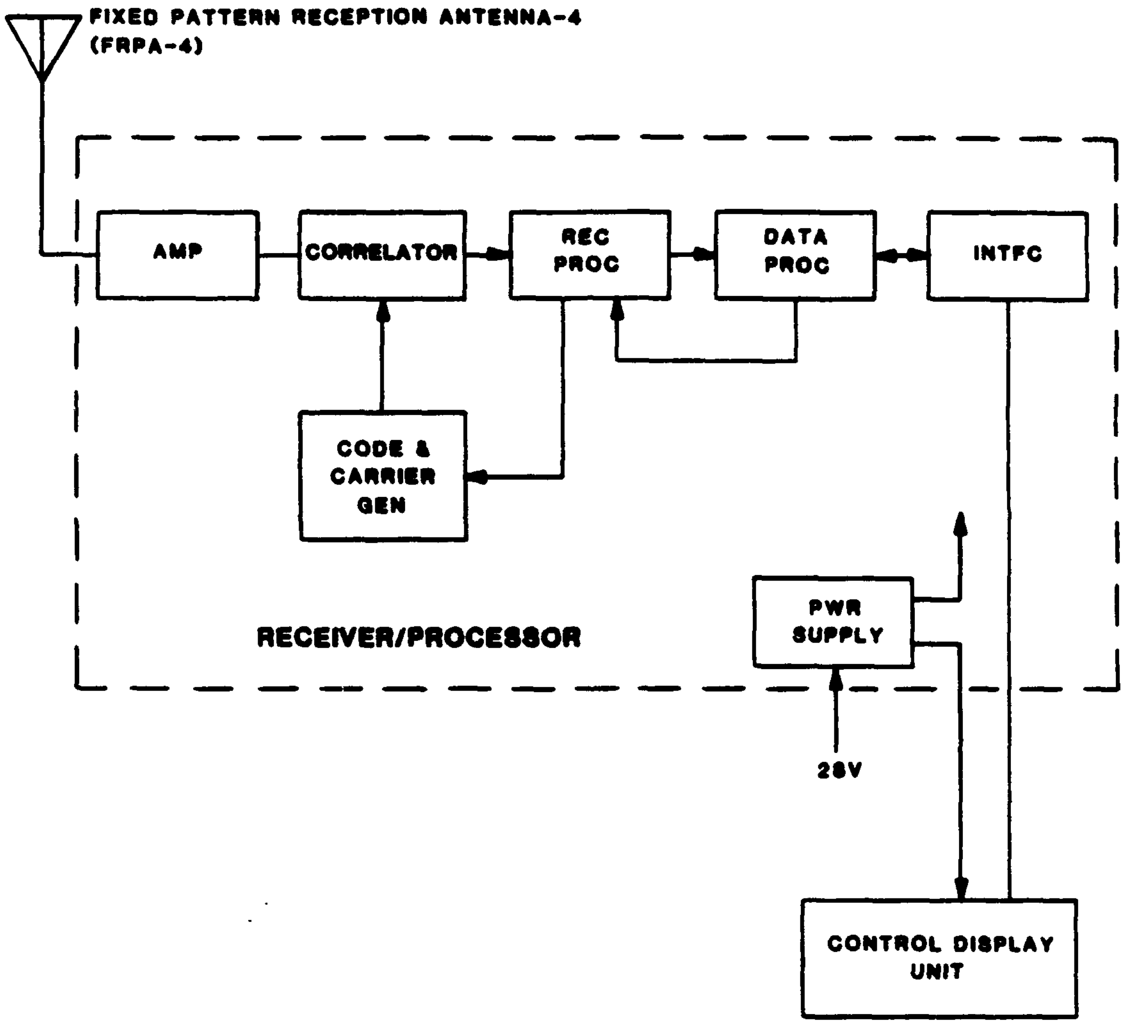

Figure 9. Global Positioning System Manpack/Vehicular Receiver

4.3 AATCS Communication Suite

The Comm Suite will be comprised of subsystem elements to perform the following functions:

a. Voice and data uplink and downlink
b. Operator control and select
c. Communication processing
d. TRI-TAC landline interface
e. Intrabase radio comm

As presently configured, the RF and landline comm portions of the AATCS Comm Suite utilizes off-the-shelf equipment.

A preliminary functional block diagram of the comm subsystem is shown in Figure 10. The subsystem performs three functional tasks: RF transmission and reception, digital processing and control and digital/analog switching.

As was discussed earlier, the AATCS will utilize both JTIDS and conventional AJ comm for data and voice links to the aircraft. This is deemed appropriate in that it appears highly unlikely that all aircraft would be equipped with JTIDS terminals. AATCS will have to handle all types of aircraft presently in inventory and those slated for introduction within the next 10 years.

Of specific concern are attack and observation type (A7D, OV-10, A-10, OA-37 etc.), older fighter types (F-4, F-5, etc.) transport and tankers (C-9, C-20, C-21, C-23, C-130, etc.) trainers (T-37, T-38, T-41, T-43, etc.) and all the rotary-wing aircraft (UH-1, CH-3, HH-3, HH-53, UH-60, etc.). It is believed that few of these types are candidates for JTIDS installations. However all of those aircraft could be equipped with UHF and/or VHF AJ comm equipment.

The recommended VHF ground-based comm transceivers are the AN/VRC-90 Vehicular Long Range SINCGARS radio. The radio operates in the 30-88 MHz band with an output power of 50 watts. The system uses 25-KHz channel separation and incorporates frequency hopping, spread-spectrum technique for ECCM. It handles 16-Kbps throughput for both analog and digital modulation. The transceiver is compatible with the AN/ARC-201 airborne system, both of which are in production.

In the digital mode the radio operates at bit rates from 75-bps to 16-Kbps. It can be used with narrowband FSK modems (TADIL B or Link 1) and with multiphase DPSK modems, or with TACFIRE type FSK signals. It will operate in plain text and cipher text modes with the KY-57. Although the VHF-FM band has a short range (35 Km), the SINCGARS equipment would be compatible with certain aircraft who would be controlled by AATCS in the terminal area.

The UHF ground equipment can be the AN/GRC-171A(V)4, HAVE QUICK transceiver. The GRC-171 provides AM and FM operation in the 225- to 400-MHz band, output is 20 watts AM and 50 watts FM carrier output. Modes of operation include AM voice, AM AJ voice, AM secure voice (with or without AJ), FM voice, FM AJ voice, FM TADIL A (Link 11) data, FSK TADIL C (Link 4) data.

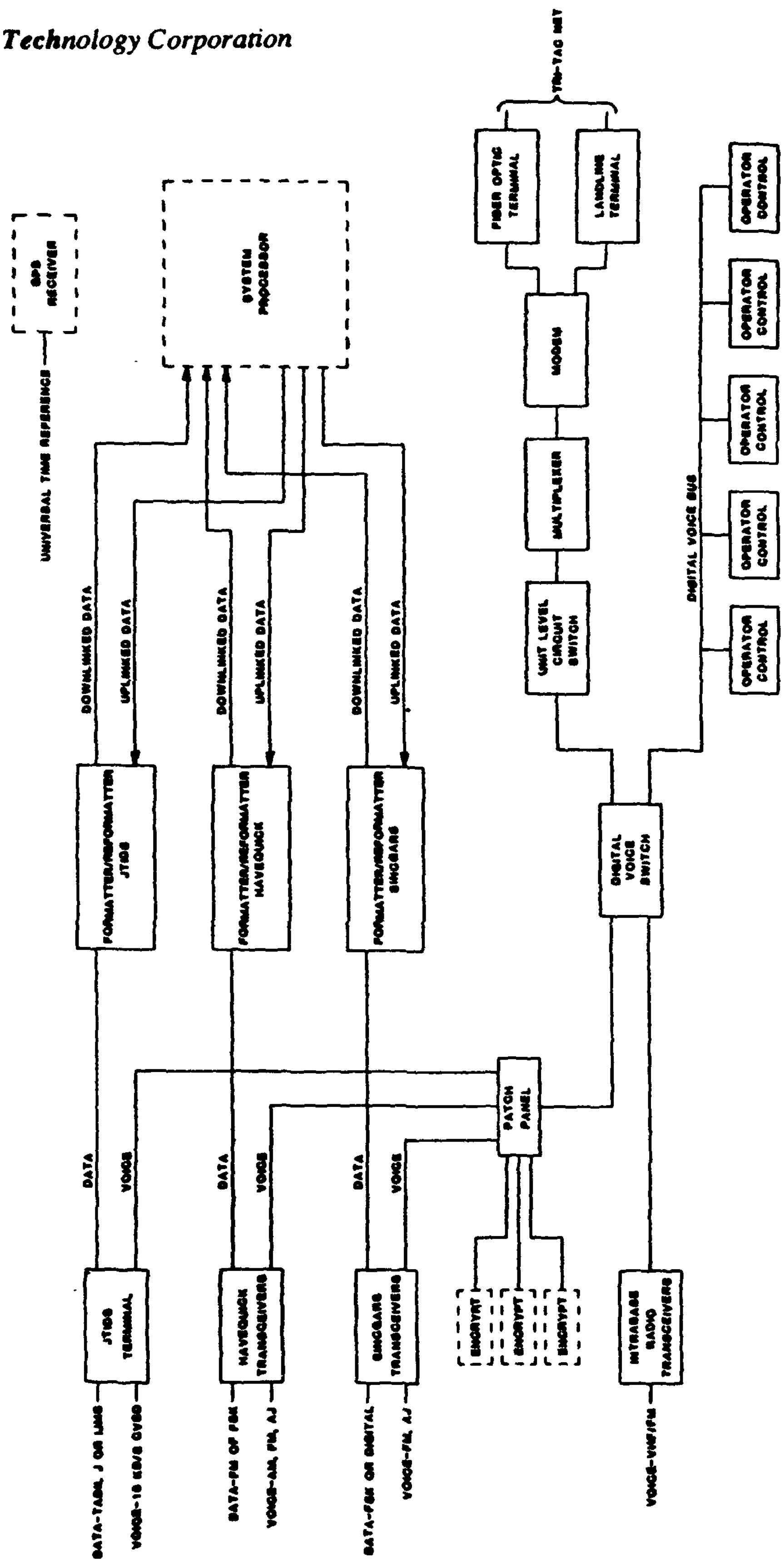

Figure 10. Preliminary Functional Block Diagram, AATCS Comm Subsystem

The recommended JTIDS terminal is the AN/VRC-107(V), a class 2 terminal consisting of a receiver/transmitter (R/T) unit and a data processing unit (DPG). The R/T provides time division multiple access (TDMA) signal transmission and reception into a JTIDS net and also performs TACAN signal processing. Power output is 200W TDMA, and 500W TACAN.

The DPG consists of four elements -- the Digital Data Processor (DDP), the Interface Unit (IU), the Secure Data Unit (SDU), and the Battery.

The DDP is a common terminal element which performs the message processing, scheduling, and network protocols required for the terminal to operate in the JTIDS community. The IU provides the interface between the terminal and AATCS comm processor. Any processing which is peculiar to a given user is performed in the IU. The Secure Data Unit is GFE which provides the codes for encryption and decryption of data. The Battery provides power to portions of the terminal memory to maintain Initialization Data during Standby mode and power interruptions, and to the SDU during loading of the crypto variables.

The terminal will handle two 16 Kbps CVSD voice channels. Message formats are TADIL J and Improved JTIDS Message Standard (IJMS).

Message transmission within the JTIDS net will be controlled by the basic TDMA architecture. This will provide non-interfering net operations in the presence of transmissions from multiple JTIDS terminals.

The VHF and UHF transceivers would also perform the voice transmission and reception function either clear or cipher, with or without AJ.

4.3.1 Controller Display Panel

Each controller position will be equipped with a control and select panel for access to the air-ground voice circuits and for intercom and landline functions. The comm panel functions will be integrated with the Plasma Display and will be controllable by finger action on the plasma touch screen.

Integration into the Plasma Display deletes additional comm hardware from the system with a resultant improvement in the overall AATCS reliability.

The comm select panel, provides the controller with all the required access, control and select functions to operate the AATCS comm suite. Three operating modes are envisioned: 1) menu/initialization/set-up, 2) BITE/status function and 3) Normal operation.

The basic operating configuration, Figure 11, provides a ready assessment of the selection of comm assigned to the specific position and the status of the overall comm system. The number of A/G, landline and intercom channels assigned to a position may be varied dependent upon the requirements of the position.

In the example shown six A/G, three direct access (Hotline/ringdown) and three dial lines are assigned to the position. Each A/G channel is identified by channel number and frequency. A select function is provided for monitor (RCV) or transmit (XMIT) for each channel. Associated with each channel is a select function for plain or encrypted operation. Selecting a direct-access line causes a ringdown to the indicated location. Selecting a switchboard line (SB) accesses the on-board unit level circuit switch (ULCS). The DTMF pad is then used to dial the desired number. Incoming calls are indicated by an illumination of the appropriate line indicator and an audible signal.

A finger on the appropriate volume control - up or down, adjusts the volume for the speaker, headset or ring.

The menu function will call up the prestored menus - initialization/set-up, BITE/status or other to be determined.

Conference, hold and release are provided for the landline and intercom functions. The BITE indicator will show a fault somewhere in the system. The BITE/status menu function would be used to isolate the fault.

The Menu/initialization/set-up function would be used to set-up a position and assign specific operational capabilities. By stepping through each A/G channel and assigning a specific radio and entering its frequency through the use of the DTMF pad, the operator will have his A/G comm defined.

Landline channels are assigned by stepping through the LL entries. Activating the SB (switchboard) select assigns the line to the ULCS. Activating the DIR (Direct) select and then selecting the specific hotline destination from the DIR sub-menu transfers the destination indicator form the sub-menu to the DIR indicator block. This will establish the direct ringdown destination for that landline channel.

Interface to an external TRI-TAC network is provided by a unit level circuit switch (SB-3865 or equal) multiplexers and modems. Specific equipment would be selected from the TRI-TAC system manual, TT-SM-HB-001A, to best meet the anticipated external communication network and circuit switches. The design of the comm system will include transmission capabilities for field wire, CX-4566 tactical 26 pair cable, CX-11230 coax cable and fiber optic cable assemblies.

Short range wideband radios, (line-of-sight) could be used as an alternative to the cable transmission method. The AN/TRC-175 terminals are compact radios which could be shelterized, mounted on mobilizers and towed behind the AATCS vehicle.

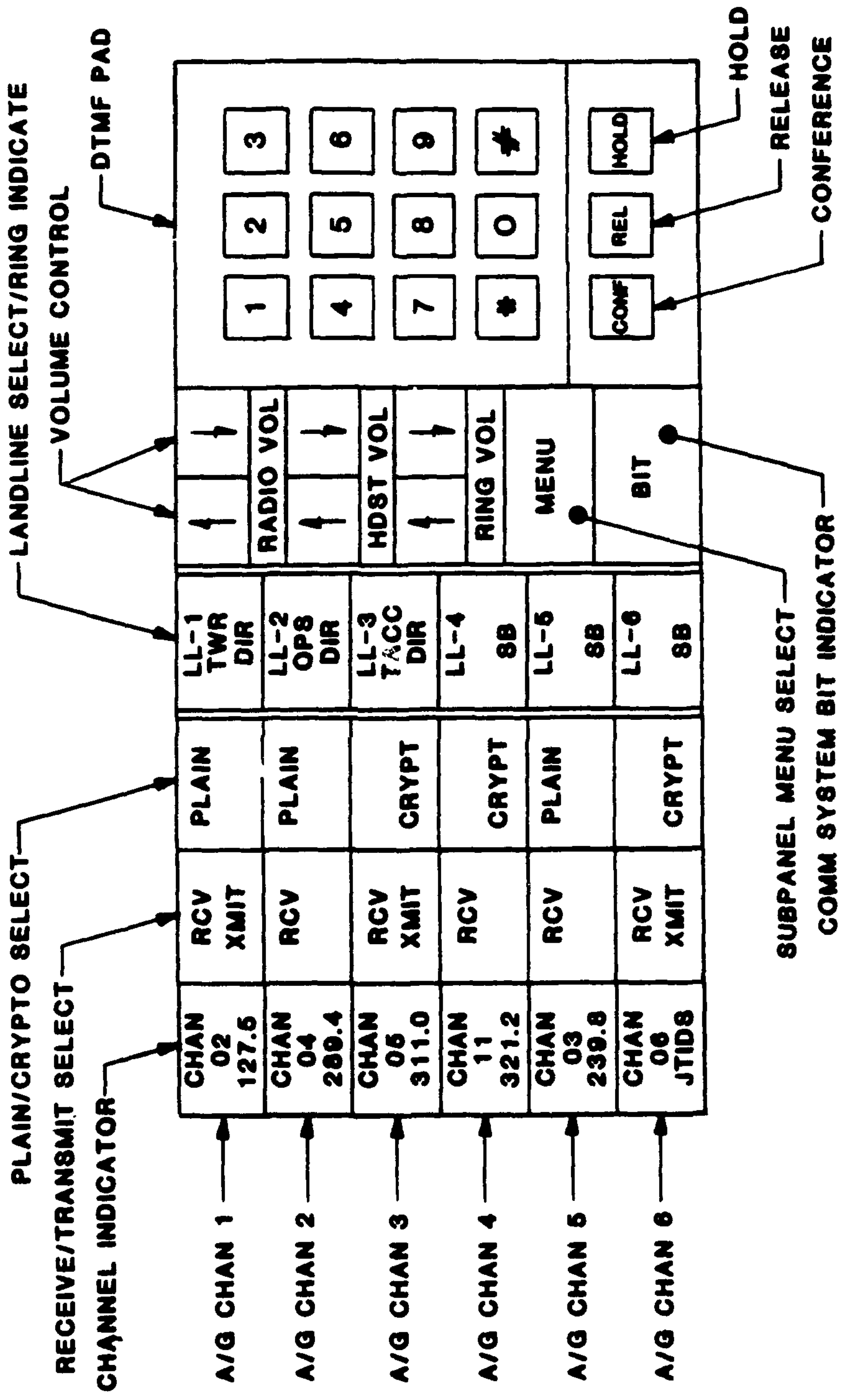

Figure 11. Comm Select Subpanel, Normal Operation Display

4.3.2 Secure ATC Radio Data Link (SDL)

4.3.2.1 Purpose

One of the key elements of the AATCS system is the digital communications link which transmits aircraft position, identity, and other status information from the aircraft to the AATCS ground-based control center as well as transmitting advisories, commands and information requests from the ground station to the aircraft. Since many aircraft will be geographically disbursed over a wide area, the SDL must also perform a network control and synchronization function to permit an orderly and non-interfering exchange of data. It must also support a data rate rapid enough to support the real-time target tracking and decision-making functions of the processing & display system. All this must be accomplished while maintaining a secure, anti-jam communications channel.

4.3.2.2 Requirements

In order to determine what design approaches might satisfy this basic purpose, a list of general requirements were developed based on the desired traffic-handling capacity, data update rates, the amount of information to be transmitted, and other factors such as network synchronization, inter and intra-network interference, and ECM resistance. It should be noted that these requirements are not intended to be comprehensive at this time, but serve primarily to permit evaluation of the general feasibility of various design approaches to satisfy the basic need.

4.3.2.2.1 Target Capacity

Based on ATC systems in current use, as well as guidance provided in the ATALARS reference documents, a peak load of 600 aircraft within a 300-nmi radius should be supported. This is somewhat in excess of the ATALARS recommendations which envision a 100-nmi radius and up to 300 aircraft. The higher limits are set as goals for the purpose of this analysis to provide good operating margins as well a growth capacity.

4.3.2.2.2 Data Update Rate

Data update rates must be considered separately for the uplink and downlink. The worst case requirement will be defined by the downlink requirement, since each aircraft must routinely report its position on a regular basis to permit accurate ground-based tracking and real-time display to be performed. The uplink will be used only when specific advisories or requests for information must be transmitted to an aircraft. Current ATC systems require a three- to five-second update rate for terminal area traffic (less than 60 nmi from the airfield) and ten-to-fifteen second update rates for long range, enroute aircraft (60-300 nmi). The ATALARS reference documents envision a two- to five-second update rate for targets in the range of 0-100 nmi.

For purposes of this analysis, we will establish minimum position reporting intervals of 3 seconds for targets less than 60 nmi, 6 seconds for targets between 60 and 120 nmi, and 12 seconds for targets between 120 and 300 nmi.

4.3.2.2.3 Message Size

Since the type of data and transmission rate are quite different for the uplink versus the downlink, they will be considered separately. Additionally, the downlink message rate will be relatively constant for a given number of aircraft, whereas the uplink rate will vary considerably depending on the amount of advisory and control information required to be sent to specific aircraft.

4.3.2.2.3.1 Downlink Message

The primary information to be transmitted on the downlink consists of aircraft position (latitude, longitude and altitude), unique aircraft identity code, and status codes, and service request/acknowledge codes. Additional information could be added such as airspeed, heading, and limited text messages, at the expense of data handling capacity. Information such as speed and heading can be derived by the ground-based tracking systems similar to the method used in today's radar based systems.

The status code and service request/acknowledge code fields are intended to provide a shorthand method of transmitting common status information such as low fuel, weapons status, damage status, etc., and service request/acknowledgment such as alternate routing, weather, airfield status, message confirmation, etc. Special service-request codes could even be used to request more network time be allocated to a particular aircraft to allow transmission of longer text messages on a non- routine basis.

For purposes of the analysis the following downlink message structure will be utilized:

Information	*Digits*	*Bits*	*Data Capacity*
Latitude	7 (BCD)	28	Deg., Min., Sec.
Longitude	7 (BCD	28	Deg., Min., Sec.
Altitude	3 (BCD)	12	0-99,000 ft (100's)
Aircraft ID	4 (OCT)	2	4096 codes
Net ID	2 (HEX)	8	256 nets
Status	2 (HEX)	8	256 codes
Service Req./Ackn	2 (HEX)	8	256 codes
TOTAL INFO BITS		104	
Checksum/Error Detection		8	
Synchronization		10	
TOTAL BITS/MESSAGE		122	

4.3.2.2.3.1 Uplink Message

The uplink messages will vary in quantity and content depending on the number of aircraft, frequency of update and nature of the message traffic. The following generalized, variable length message structure will be utilized for this analysis:

Information	Length	Bits	Data Capacity
Net ID	1 (byte)	8	256 Nets
Message Type Code	1 (byte)	8	256 Message Types
Aircraft ID	4 (OCT)	12	4096 Codes
Length Code	1 (byte)	8	Up to 256 data bytes
Data Fields	variable	88	Typical 10-byte message
TOTAL INFO BITS		116	
Checksum/Error Detection		8	
Synchronization		10	
TOTAL BITS/MESSAGE		134	

4.3.2.2.4 Other Factors

A number of other factors should be considered in establishing the SDL requirements, in addition to supporting the necessary data exchange rates and capacities. While objective, parametric requirements could be established in these areas, it is adequate to treat them only subjectively for purposes of this analysis. Some of the factors to be considered in selection of a design approach to the SDL, are as follows:

a. The link must have both anti-jam and low probability of intercept characteristics. This dictates the use of some combination of spread-spectrum, frequency-hopping, and data encryption.

b. The ground station should minimize the amount of time during which it actively radiates energy, to enhance item (a) above.

c. Aircraft Position Reports should be synchronized in such a way that they do not overlap in either the airborne or ground station environment. This will facilitate reading of the aircraft position/status reports by other aircraft to permit some level of ATC processing to be performed on the aircraft and provide a limited air situation display capability.

d. A capability should be provided for the ground station to discretely address individual aircraft as well broadcast information of interest to all aircraft.

e. A capability should be provided for aircraft to randomly enter the system without benefit of pre- assigned identity codes or time slots.

f. Provisions should be made for ground stations to monitor aircraft position/status reports sent to adjacent ground stations. Additionally, a capability should be provided to smoothly transition aircraft from control of one ground station to another (hand-off).

4.3.2.3 Candidate Approaches

Based on the somewhat simplified requirements developed above, several candidate system/design approaches are presented and evaluated below.

4.3.2.3.1 JTIDS

Virtually all of the above requirements could be met utilizing JTIDS terminals in both the airborne and ground equipment. It provides the necessary levels of security, network synchronization, data rates and capacity. The message traffic generated into the JTIDS network based on the above number of aircraft, update rates and message sizes would utilize less than 10% of typical JTIDS network capacity. This is further reduced in actual practice due the probable existence of aircraft derived position data on an operational JTIDS network for purposes other than Air Traffic Control. JTIDS has a flexible slot assignment protocol which allows a wide variety of update times to be supported.

One of the problems in using JTIDS for the AATCS SDL function is jurisdictional in nature. There may be situations where the position update rate from the JTIDS network is not sufficiently high to support high density, close-in Air Traffic Control Operations such as ASLAR. The JTIDS network uses a basic cycle of 12 seconds, whereas ATC operations can require a 3- to 5- second update rate. JTIDS can be configured to allow multiple TDMA slots-per-aircraft per-cycle, however this may not be compatible with the JTIDS primary mission requirements and could overload the network in the presence of other higher priority traffic. The potential degradation of the AATCS position data rate due to JTIDS network loading restrictions imposed by non-ATC operational requirements may be unacceptable and favor the use of an autonomous system for AATCS, rather than shared use of the JTIDS network.

The main problem associated with using JTIDS, however, is one of cost. As a result of the relatively high cost of JTIDS terminals, some sort of cost-driven priority system will ultimately govern which air vehicles are equipped with JTIDS terminals and which are not.

In order for any Air Traffic Control system to be both safe and effective, all aircraft in the airspace must be detectable and controllable by the ground station. This calls for multiple aircraft tracking methodologies to be employed in AATCS. Other portions of this report address methodologies not dependent on aircraft self-derived position data (i.e. TACS interfaces, bistatic radar/IFF, etc.). This section concer itself exclusively with methods of obtaining aircraft self-derived position data. While JTIDS serves this purpose well, technologically, it may not be cost effective for all platforms. Additionally, data rate conflicts may occur as a result of the differing operational needs of various users of the shared JTIDS network. Therefore, additional approaches are evaluated below. It is intended that these other approaches be considered to augment, not necessarily replace, JTIDS in the SDL role.

4.3.2.3.2 HAVEQUICK/SINCGARS

Other methods for secure radio data communications currently exist in addition to JTIDS. Frequency hopping UHF and VHF radios employing HAVEQUICK and SINCGARS, respectively, are currently available in both airborne and ground-based versions, and support both secure voice and wideband (16 KB/S) digital data. Both anti-jam and data encryption are available as standard features associated with these radios and are transparent to the source and destination terminals. These devices also have the capability to operate on multiple, non-interfering nets. The cost, weight, size, and complexity of these radios are considerably less than class 2 JTIDS terminals. In addition, existing aircraft radios such as the AN/ARC-164 and AN/ARC-171 have off-the-shelf mod kits available to upgrade to HAVEQUICK.

These systems, however, rely on manual network control methods and do not implement user-specific time slots. Anti-jam operation is achieved by a pseudo-random frequency-hopping pattern which is determined by a Word-of-the-day (WOD) and synchronized by the precise Time-of-day (TOD). At least one node in the network must have access to precise time-of-day data, and can disseminate that data to other nodes in the network. However, this frequency-hopping is transparent to the data link, with all stations in a network changing frequency simultaneously, and in the same pattern.

Therefore, some means of user-unique time-slot assignment and synchronization must be employed external to the secure radio equipment. Three different approaches to time-slot synchronization will be explored below. Common to each of these approaches is the need to establish a basic user time-slot interval based on the capacity requirements established above.

Both the HAVEQUICK and SINCGARS are capable of supporting data rates up to 16 KB/S. The 136-bit downlink position reports described above, would then require 7.6 milliseconds-per-report. Allowing a 1.9 millisecond propagation guard band (300 nmi) and a 0.5 millisecond jitter/error allowance, a slot time of 10-milliseconds per user report/message can be established.

4.3.2.3.2.1 TOD Referenced TC-RC

This approach would use a coordinated time based technique whereby each user in the net operates within a common transmit and receive cycle. The basic net time synchronization reference would be the GPS or HAVEQUICK TOD derived time base which would be common to the AATCS ground station and each airborne platform.

The cycle time would set the update rate for data exchange between the ground and the aircraft. Each user would time-share the same randomly-hopping frequencies within the net structure.

Two sub-cycles of 3 seconds seconds in length would be established. Within this sub-cycle would be assigned 300 time slots of 10 milliseconds each in length. The two complete sub-cycles (transmission cycle - TC and receive cycle - RC) would constitute a full up/down data exchange; one for downlinked traffic and one for uplinked traffic.

Each aircraft would be assigned a specific time slot within each system time cycle. Downlinked messages would be transmitted from the aircraft in his assigned slot in the RC cycle. Uplinked messages would be transmitted from the AATCS ground station to the aircraft in the same time slot in the next TC system time cycle. Specific time slots would be assigned at the start of a mission, or assigned dynamically as aircraft enter the system.

Basic system timing could be derived from GPS and output as a special message in the normal AATCS transmit cycle, or locked with the Time-of-Day (TOD) input into the HAVEQUICK or SINCGARS transceivers.

An all aircraft mode would be used to allow aircraft not part of the pre-assigned net structure, to enter the system. This mode would be part of the normal TC transmit and RC receive cycles and would use special purpose slots near the beginning and end of each cycle. The first slot in the AATCS ground station transmission, T1, would be an all-call message, as shown in Figure 12. This message would include a time sync which would be used by the aircraft to obtain a lock with the basic system timing. A special message slot or series of slots, TN, would be established near the end of the AATCS receive time cycle.

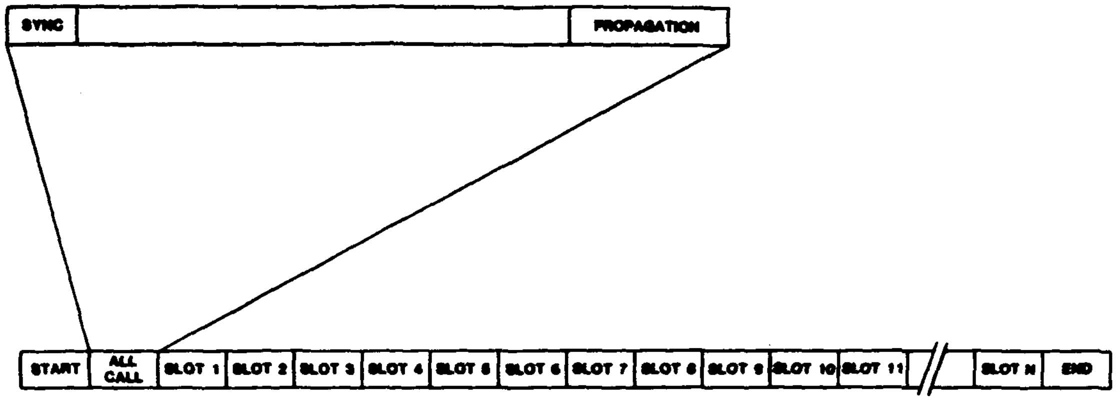

Figure 12. TC Uplinked Data Message Format. All-Call Sync Message

The aircraft desiring to enter the AATCS net would sync with the system with the all-call T1 message in the uplinked transmission. They would then transmit their data message and identity in the special message TN slot in the downlink cycle, Figure 13. The AATCS data processor would enter the new aircraft data into the system data base and assign a specific time slot in the transmit and receive cycle to that aircraft. That information would be transmitted to the aircraft in the TN special slot position during the next transmitted TC cycle, Figure 14.

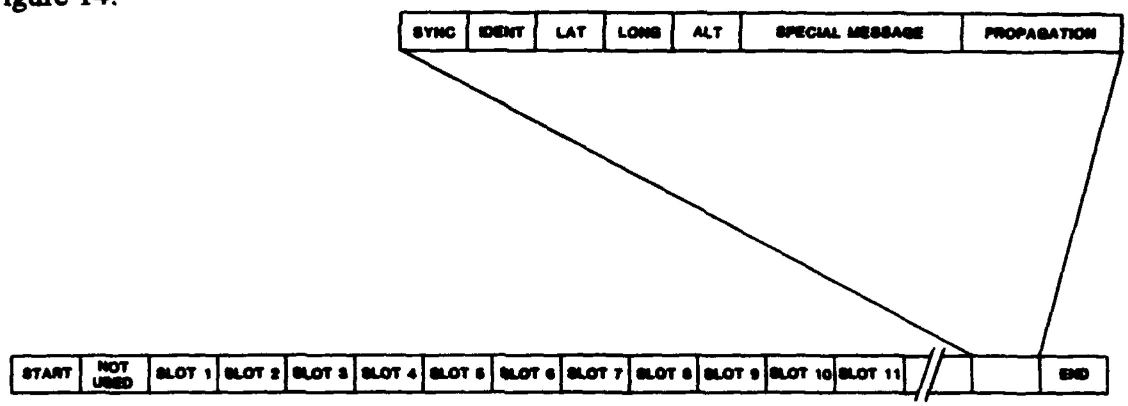

Figure 13. RC Downlinked Data Message Format. Aircraft Entering AATCS System

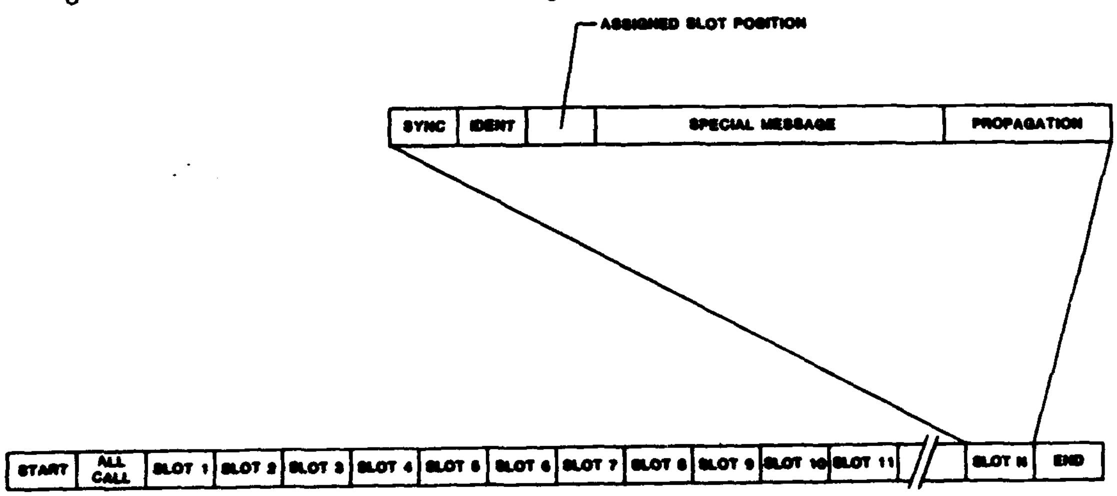

Figure 14. TC Uplinked Data Message Format. Assigning Aircraft Specific Slot Position

The aircraft processor would then reset the timing for his on-board AATCS processor corresponding to his transmission and reception periods. Further transmissions would be in this time slot, Figure 15 and 16.

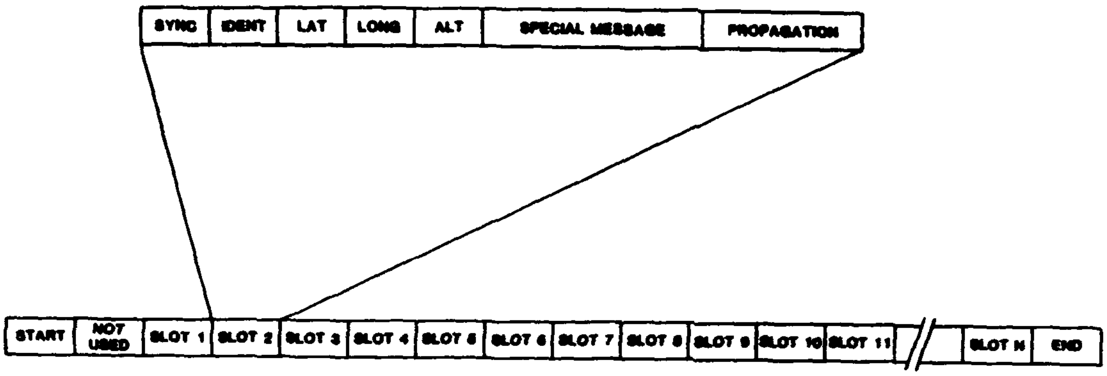

Figure 15. RC Downlinked Data Message Format. Aircraft Assigned Message Slot Position No. 2.

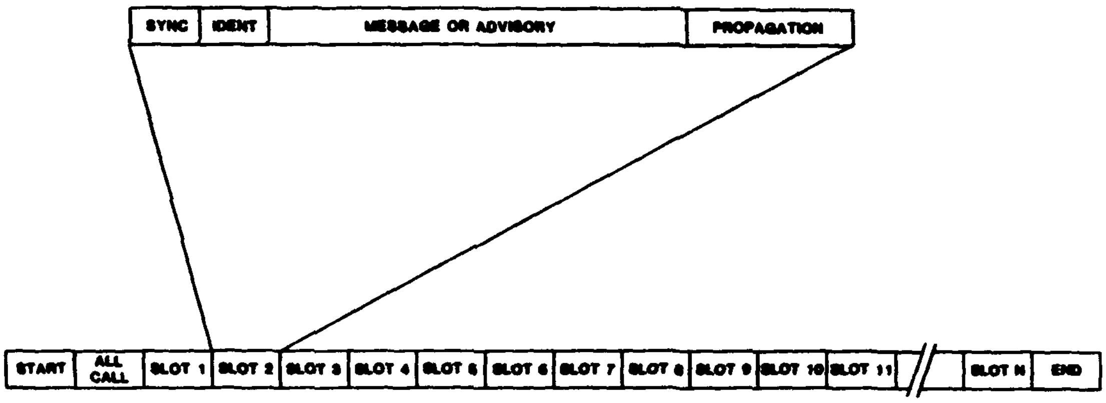

Figure 16. TC Uplinked Data Message Format. Aircraft Advisory Message.

This method of uplink-downlink net control provides a simple method of utilizing the AJ common equipment as the communications element of the AATCS. The use of a fixed TC and RC cycle, however, is wasteful of transmission time, however, as the volume of message traffic is higher on the downlink than the uplink. Also, both the traffic capacity of 300 aircraft and data rate of 6 seconds, both fall short of the goal of 600 aircraft and a 3- to 6-second update rate for terminal area traffic. A method of optimizing the data transmission rate is needed.

4.3.2.3.2.2 SELCALL

A second consideration for the net control technique was the feasibility of variable or multiple update rates. The thinking here was that aircraft at long ranges, i.e. 100 nmi would require position updating at a lower rate than aircraft which were closer to the AATCS facility, i.e. 40 nmi.

One concept for accomplishing this was to use an interrogation-response technique, similar to Selective Call (SELCALL). This approach would also use the AJ comm equipment but specific uplink and downlink data would be transmitted on demand under control of the system processor. The aircraft would then respond to that uplinked interrogation.

The TC-RC technique and the SELCALL technique would have some commonality. The data message formats would be the same. Each aircraft would be assigned a unique identification number, either the same as his discreet beacon code or the aircraft tail number. The SELCALL technique would use an additional message type for A/C interrogation purposes.

In the SELCALL technique the rate at which data was exchanged between the AATCS and the aircraft would be a function of the aircraft range to the facility or the aircraft maneuvering rate.

Aircraft entering the AATCS net would downlink a message in the RC format. The system would treat this transmission the same as a conventional ATC system would treat a discreet beacon code input. The system would enter the aircraft into the data base, correlate the data with the stored flight plan data and start a track.

Based on the aircraft's position relative to AATCS, or to a defined area of interest, i.e. hazardous area, air base or other navigation point, the system or the controller would establish the initial update rate.

Requests to update the aircraft position data would be in the form of an Interrogation Message (IM). Upon receipt of this message, and after decoding the proper aircraft ident, the airborne processor would reply with an RC format message. The message exchange would be half-duplex.

The AATCS processor would maintain the track, initiating IM transmission at a fixed rate or at an accelerated rate depending on the flight profile or other variable factors. Advisory messages to the aircraft would be transmitted in the TC format at a rate commensurate with the aircraft position and flight status.

Among the advantages of the SELCALL technique is a removal of the requirement for a common system time base and the incorporation of a simplified transmission and reception processing scheme. It also allows the system to update the tracks on an as-needed basis and transmit advisories when they are most appropriate.

In both the TC-RC and SELCALL techniques, the survivability aspect of the AATCS concept are retained. The AJ comm will still provide protection against self-interference and jamming. The frequency hopping capability provides an inherently high tolerance for ECM environments and the ability to deny knowledge of the facility location to direction-finding equipment.

The above approaches still suffer, to a degree, from a non-optimum data interchange protocol. At saturation, the SELCALL approach still utilizes an excessive amount of overhead requesting discrete position reports from each aircraft, plus the time required to uplink messages. In addition, the higher than necessary uplink duty cycle causes the ground station to be more susceptible to detection. A method is needed which will combine the low ground station duty cycle of the TOD referenced TC-RC method with the variable data rate and time-code independence of the SELCALL method, while increasing the total aircraft handling capacity. Such a method is described in the next section.

4.3.2.3.2.3 Multiple Update Rate, Self-Synchronized SDL (MSDL)

This approach establishes a full uplink/downlink cycle of 12 seconds, which is further subdivided into four sub-cycles of three seconds each, i.e. SCA, SCB, SCC, and SCD (see Figure 17. Each three second sub-cycle consists of 300 slots of 10 milliseconds each for a total of 1200 slots/cycle. Each slot includes data, synchronization, checksum, jitter and propagation guard bands, as described in paragraph 4.3.2.2.3 above. Slots can be dynamically allocated by the ground station as transmit or receive, depending on the data loading.

4.3.2.3.2.3.1 Network Synchronization

Network synchronization is provided by a special message code from the ground station which transmits the ground station coordinates, net identity, as well as a cycle start time reference mark. In order to minimize propagation and jitter guard band times, the aircraft end of the link computes propagation delay based on knowing its own position and the uplinked position of the ground station. All downlink transmission slot start times are offset by this delay, such that signal arrival times are synchronized to the ground station reference.

Each aircraft synchronizes an internal clock to the uplinked cycle start mark (offset by the computed propagation delay) at the beginning of each cycle, and counts through all 1200 slots. This timer is used as a reference by the aircraft to determine when its assigned slot time starts. The accuracy of the clock required to perform this timing is not critical and can be easily obtained from a variety of low cost crystal clock oscillators. For example, timing stability should be at least 0.5 milliseconds over the 12-second cycle period, which is approximately 42 ppm stability. Specifying an accuracy and stability of 0.001% (10 ppm) will provide adequate margin and is easily obtainable.

4.3.2.3.2.3.2 Functional Slot Allocations

The first slot(s) of each sub-cycle are allocated to uplink traffic, with the remainder for downlink traffic. The first four downlink slots are reserved for aircraft entering the net. Such an aircraft will randomly transmit a position report in one of these four slots during one of the four subcycles (i.e. one of 16 possible slots every 12 seconds). The ground station will log the aircraft ident into the database and assign it a discrete time slot on the next uplink message slot open. Subsequent reports by the aircraft will be transmitted in its assigned slot. The use of multiple slots for new aircraft minimizes the probability of message collisions during the initial login process. If two aircraft should coincidentally select the same random slot to transmit a login message, the garbled reply will not be responded to by the ground station. On the next cycle, the two aircraft will randomly select two other slots for login. This process is continued until one of the messages is received in a clear slot, and the aircraft is assigned its permanent slot in the net. Since this login will generally be accomplished within one cycle, a sustained rate of 5 aircraft per minute can enter the system automatically. The probability of being granted entry to the system within one cycle falls to approximately 78% for 20 aircraft per minute and to 60% for 40 aircraft per minute. At 20 aircraft per minute requesting entry into the system, 95% will be granted entry within two cycles (24 seconds).

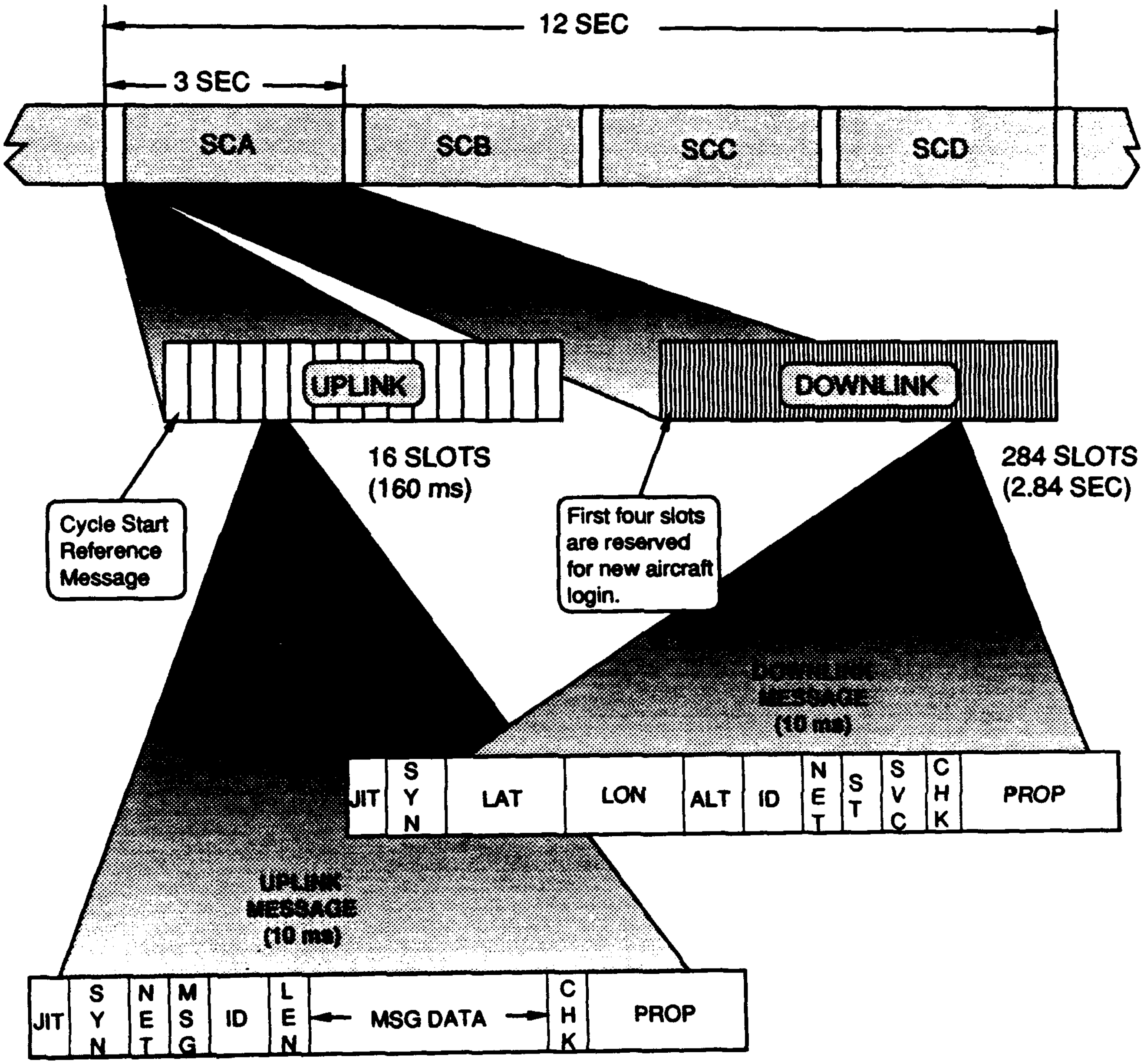

Figure 17. Multiple Update Rate, Self-Synchronized Secure ATC Radio Data Link (MSDL)

4.3.2.3.2.3.3 Multiple Update Rates

In order to provide multiple position update rates, aircraft would be assigned subcycle patterns as well as specific slots. Aircraft at close ranges would be assigned an ABCD pattern resulting in a report every three seconds (once per subcycle). Intermediate range aircraft would be assigned an AC or BD pattern resulting in a report every six seconds (every other subcycle). Long range aircraft would be assigned a single subcycle pattern, i.e. A, B, C, or D resulting in a report every 12 seconds (once per cycle).

If we assume a distribution of uplink messages shown below, the resulting average uplink rate is 260 messages per minute, or about 52 messages per 12-second cycle.

Range (nmi)	Message Interval	No. of Aircraft	Total Msg Rate
< 40	30 seconds	100	200 msgs/min.
40-100	2 minutes	200	100 msgs/min.
100-300	5 minutes	300	60 msgs/min.
TOTAL		600	260 msgs/min.

This will require that the first 13 slots of each subcycle be reserved for uplink traffic. Adding three slots for synchronization data and broadcast messages, the first 16 slots of the 300 slot subcycle would be reserved for uplink traffic. This leaves 284 downlink slots per subcycle, or 1136 slots per 12 second full cycle (approximately 95 slots/second). Various distributions of short, long and medium range aircraft can be accommodated by dynamically assigning either a 3, 6 or 12 second reporting interval to aircraft based on criteria such as range, mission criticality, emergency status, etc. A typical scenario is shown below.

Range (nmi)	*No. of A/C*	*Reports/ cycle*	*Time Used*	*Report Interval*
< 40	100	4	4.2 sec	3 sec
40-100	200	2	4.2 sec	6 sec
100-300	300	1	3.2 sec	12 sec
TOTAL	600		11.6 sec (out of 12 sec.)	

The ratio of uplink to downlink slots could be increased or decreased dynamically as well,. depending on the data load by reassigning discrete aircraft reporting slots to make more or less slots available to the uplink traffic. If additional uplink time is required without compromising traffic capacity, target update rates can be reduced, or a second uplink channel could be added to permit full duplex operation.

4.3.2.3.2.3.4 Multiple Nets & Hand-offs

This system also provides the capability for AATCS ground stations to monitor aircraft under the control of adjacent ground stations by incorporating multiple HAVEQUICK or SINCGARS radios within a single ground station. The primary net radio for the ground station would transmit and receive. Other radios would be tuned to adjacent net numbers and operate in receive-only mode. Since the controlling net number is transmitted as part of each aircraft position report, the ground station display processor could merge reports from the primary net, with those from adjacent nets, and display the controlling net number for each aircraft within radio reception range. Each aircraft would, however, be tuned to only one net at a time thus avoiding conflicting uplink commands from, or multiple position reports to, more than one ground station at a time.

Hand-off could be accomplished manually by the aircraft entering the new net, a login slot and wait for a fixed slot assignment, or ground data links could exchange flight plans of aircraft transitioning control zones and provide pre-assigned slot numbers in the destination net to avoid congestion in the login slots.

4.3.2.3.3 Other SDL Approaches

Several other approaches to satisfy the SDL requirement were also considered, however they were rejected due to shortcomings that prevented them from meeting critical requirements. Various approaches to encoding the uplink and downlink data onto the existing TACAN or IFF signal were considered. While approaches such as pulse phase coding, pulse position coding, etc., are technically feasible, neither system provides secure communications, minimal ground station emission, anti-jam features, or mobile operation capability of the ground station.

Another system considered is the CP-1516/ASQ Automatic Target Hand-off System (ATHS). This unit is basically a battlefield- mission computer with the capability of burst-mode secure data communication with remote units, and is HAVEQUICK, SINCGARS, and KY-57/TSEC compatible. Typical data transmitted and displayed include geographic coordinates, fuel remaining, and battle damage assessment as well as free text capability. However, its standardized message encoding scheme and its low data rate (1200 bps) prevent it from supporting the traffic capacities and update required by the SDL function. In addition, its capability to operate in a precisely synchronized time-slot network environment is extremely limited.

4.3.2.4 Recommended Approach

The recommended approach is the Multiple Update Rate, Self- synchronized SDL. It satisfies all of the requirements developed above, is fully autonomous, and is a lower cost approach than JTIDS. The SDL approach described above should be considered for platforms which do not have a JTIDS terminal but are expected to be a part of the secure Air Traffic Control environment. If a platform requires a JTIDS terminal for reasons other than Air Traffic Control, however, it is more cost effective for the AATCS system to "piggy-back" its unique data needs onto that system, and to make use of position and status data already resident on the JTIDS network. It should be recognized, however, that varying user demands from different operational commands sharing the JTIDS network may, under certain conditions, adversely affect the position reporting data rate necessary to support AATCS operations.

The recommended approach also has the flexibility to be dynamically configured by the ground station to handle wide variations in target loads, update rates and uplink/downlink traffic ratios, making the most appropriate trade-off for the existing conditions. Additionally, it is independent of TOD information derived from GPS or HAVEQUICK/SINCGARS. While TOD must be available to the anti-jam radios, it does not have to be input to the airborne AATCS equipment, thus simplifying the system architecture. It also allows the same network synchronization scheme to be employed over non-secure links and using INS or RNAV aircraft position data. In such a non-secure environment, TOD would not be available on the aircraft and any radio data link capable of supporting 16 KB/S could be utilized.

4.3.2.5 Method of Implementation

The recommended MSDL-SDL approach could be implemented using a combination of off-the-shelf HAVEQUICK or SINCGARS radios and data encryption equipment. Typical radios would be the AN/ARC-164 for aircraft and AN/GRC-171 for the ground station. These would be combined with data encryption devices as required, and controlled by a formatter-processor as described elsewhere in this report. The airborne formatter-processor would have access to the aircraft MIL-STD-1553 data bus to obtain NAV, GPS, and INS data and interact with the aircraft commander via the situation displays and data entry panels. The ground-based formatter-processor would, in all likelihood, be integrated into the central multi-processor computer system.

Some consideration was given to shared usage of radios for AATCS data as well as voice communications. This is not recommended, however, due to the high bandwidth of AATCS data flowing from widely disbursed aircraft. Intermixing voice and data on the same network would severely degrade the aircraft handling capacity and data rate.

A net switching scheme could be investigated, wherein the radio is tuned to the AATCS data network only during the uplink slots and its own downlink slot. During the rest of the time, it would be tuned to a voice network. The network changing would be under the control of the AATCS processor. Since the uplink slots and the single downlink slot consume only about 6% of the total cycle time, the radio would be tuned to the voice net for about 94% of the time, neglecting switching and synchronization times. It has been demonstrated that companded, digital voice can be transmitted at 9600 baud with little degradation. Since the radios will support a maximum data rate of 16 KB/s, voice transmission could be made in the digital mode with sufficient data buffering to regenerate a continuous audio signal in the presence of the 6% loss in throughput due to the time required to access the AATCS network. This approach would preclude the capability of the airborne system to receive and decode position reports from other aircraft, for the purpose of generating an airborne air situation display.

Such a scheme would involve additional study and possible modification to the anti-jam radios, as well as analog-digital- analog conversion of voice information. Therefore, it is not clear that this is a more desirable approach than adding an additional radio dedicated to the AATCS data function.

4.3.2.6 Limitations & Restrictions

Certain areas require additional study and analysis before feasibility can be concluded. The effect of the HAVEQUICK and SINCGARS frequency-hopping on the data throughput rate requires access to classified information to evaluate. While it is presumed that data buffering would insure error-free data transmission during frequency switching intervals, some degradation in throughput may result. It is anticipated that this should be minimal (i.e. less than 5%), however it will directly affect the aircraft capacity and/or data rate to a similar degree.

In an attempt to minimize this effect, it would be desirable to have the AATCS time slots synchronized to the frequency-hopping interval such that the frequency changes always occur during the propagation guard time. This would result in no loss of data throughput, since the propagation guard time is already considered "lost" time in the present analysis. The feasibility of this, including the availability of frequency-hop triggers external to the radios and the frequency-hop durations, also requires access to classified information, and has not been addressed in this report.

The propagation guard time provided will permit non-overlapping downlink messages to be received by ground stations within a 300-nmi radius. However, a more detailed analysis is required to evaluate the potential for overlapping messages to occur in the air-to-air monitoring mode due to the ground station arrival time referenced slot times. Since this is a secondary function, however, some level of non-optimum performance can be tolerated. It may be necessary to widen the guard times slightly to eliminate such interference. This should have only a very minor affect on system capacity, however.

It should also be noted that downlink and uplink message lengths used for this analysis were not optimized for packing density. It would be possible to encode latitude and longitude, for example, as binary degrees, minutes and seconds, rather than BCD characters. This would reduce these field lengths from 28 bits to 21 bits, reducing the overall message length by 11%. Similar encoding optimizations could be made in other parts of the messages as well, offsetting some of the negative factors listed above.

4.4 Bistatic Radar

AATCS is designed as a passive system; one of its main operational considerations being the deletion of a primary radar for aircraft detection. The AATCS concept as described here will be able to function without radar data.

However, if AATCS is operating in an area where other tactical radars must operate for air defense purposes, could not AATCS utilize this radar data? The availability of primary radar target data could enhance the AATCS operability for both ATC and defensive/survivability purposes.

The bistatic radar technique uses separate transmitter and receiver sites. AATCS could be a receiver site with receiving equipment compatible with a remotely located tactical air defense radar, i.e , AN/TPS-43, AN/TPS-70 etc. Detection of aircraft targets would be based on target reflections, from the remote transmitter, which are received at the AATCS receiver.

With compatible equipment, AATCS could provide plot data to the processing system on unknown or hostile aircraft.

Operationally, the scheme will involve a coordinated effort in the field, to establish and operate the system. AATCS would need to be sited at an optimum location relative to the radar transmitter in order to assure coverage of the area of interest. The two sites will require the establishment of a common time reference relative to the transmitter timing. This could be through a data link between the two sites or be based on a stable clock system. AATCS would need to establish the precise location of the radar transmitter.

With these factors established, the total propagation time and the elevation and azimuth angles measured at the AATCS receiver site would provide the target location information.

Bistatic techniques are by no means a simple approach for radar detection. Resolution and precision are not as good as that obtained from a colocated radar transmitter and receiver.

The requirement to perform angle measurements on received data may make targets at long ranges difficult to resolve. The AATCS site equipment would be complex, requiring significant special purpose processing capability.

The efforts required to develop a bistatic radar approach for AATCS are beyond the scope of this SBIR effort. Limited data is available on the status of bistatic radar development. Activities which may be applicable to AATCS are classified or proprietary. However, development efforts are underway on both primary and secondary bistatic radar systems.

4.5 AATCS Vehicle

The AATCS mission requires that the system be highly mobile and capable of self-contained autonomous operations. To accomplish this, the system will be installed in a self-propelled vehicle which will house all equipment and crew and provide technical and personnel support.

To meet the air transportability requirement, the unit would be very compact with approximate maximum dimensions of 40 feet long by 8.5 feet high by 8.75 feet wide. An outline configuration is shown in Figure 18.

The vehicle would consist of a van configured with an operations area and crew compartment and a towed trailer with power and environmental control equipment. A preliminary layout for the facility is shown in Figure 19.

The vehicle would be of a special design with a front-end drive diesel engine. Rear axles would be single wheel, tandem. The front-end drive will remove the requirement for a drive shaft, which will aid in keeping a low overall vehicle height while allowing sufficient head room in the manned spaces.

The vehicle will be insulated to reduce the heating and cooling loads on the ECU.

4.5.1 Operations Area

The operations area houses the five operator positions and equipment racks containing the communications system processing support electronics equipment. All equipment is rack-mounted with shock isolation.

The area is planned as a space 192 inches (16 ft) long, 74 inches (6.2 ft) high and approximately 96 inches (8ft) wide. The controller positions would be on the curbside, with the equipment racks on the roadside, as is shown in Figure 20.

Controller operating positions are 38 inches wide, and contain the multifunction Plasma Display unit, with keyboard and position entry device.

Each assistant controller position is 30 inches wide, and contains a tabular Plasma Display unit with keyboard and position entry device. Each position has headset jacks and a speaker module.

Interior lighting is from dimmable overhead and floor-level lights and individual position lights.

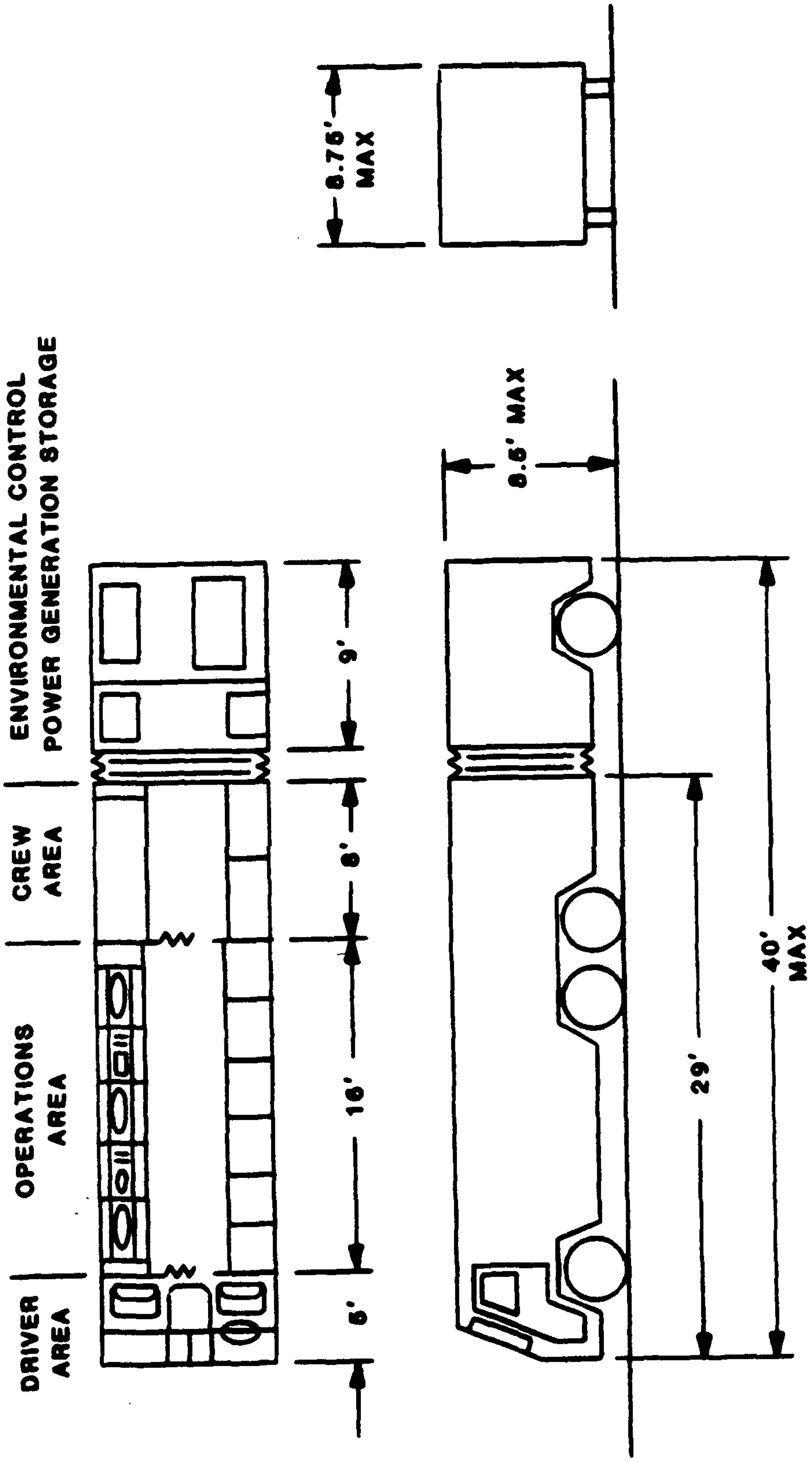

Figure 18. AATCS Vehicle Outline Dimensions

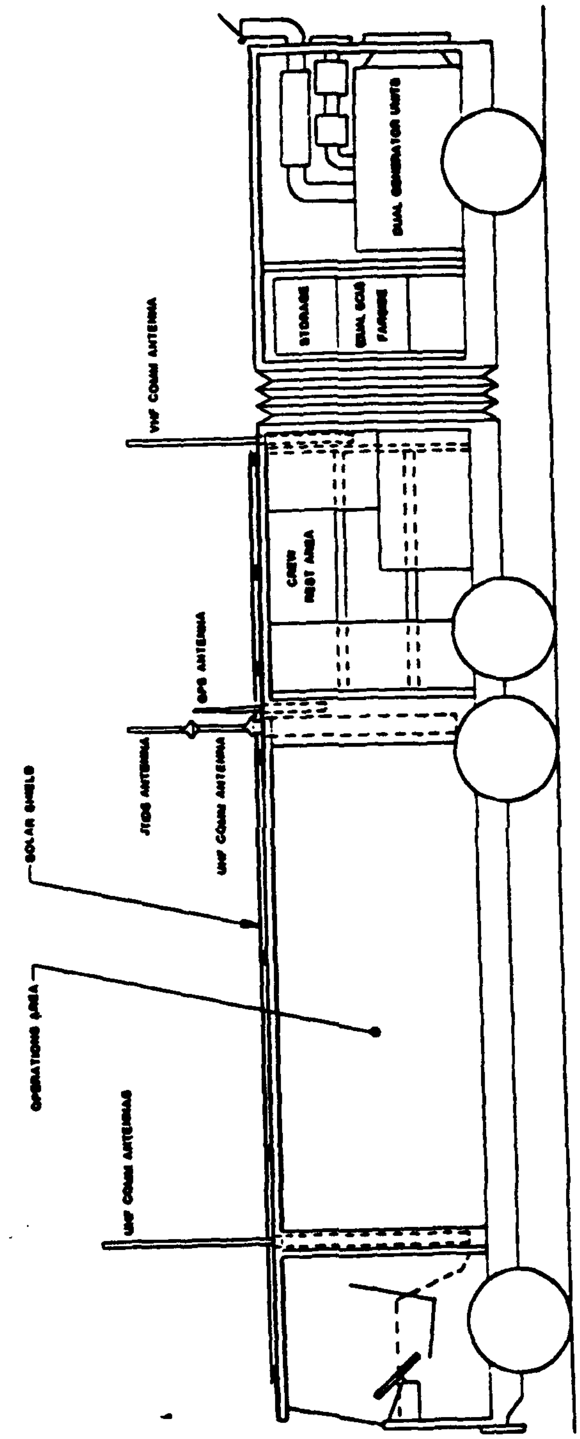

Figure 19. AATCS Vehicle Layout

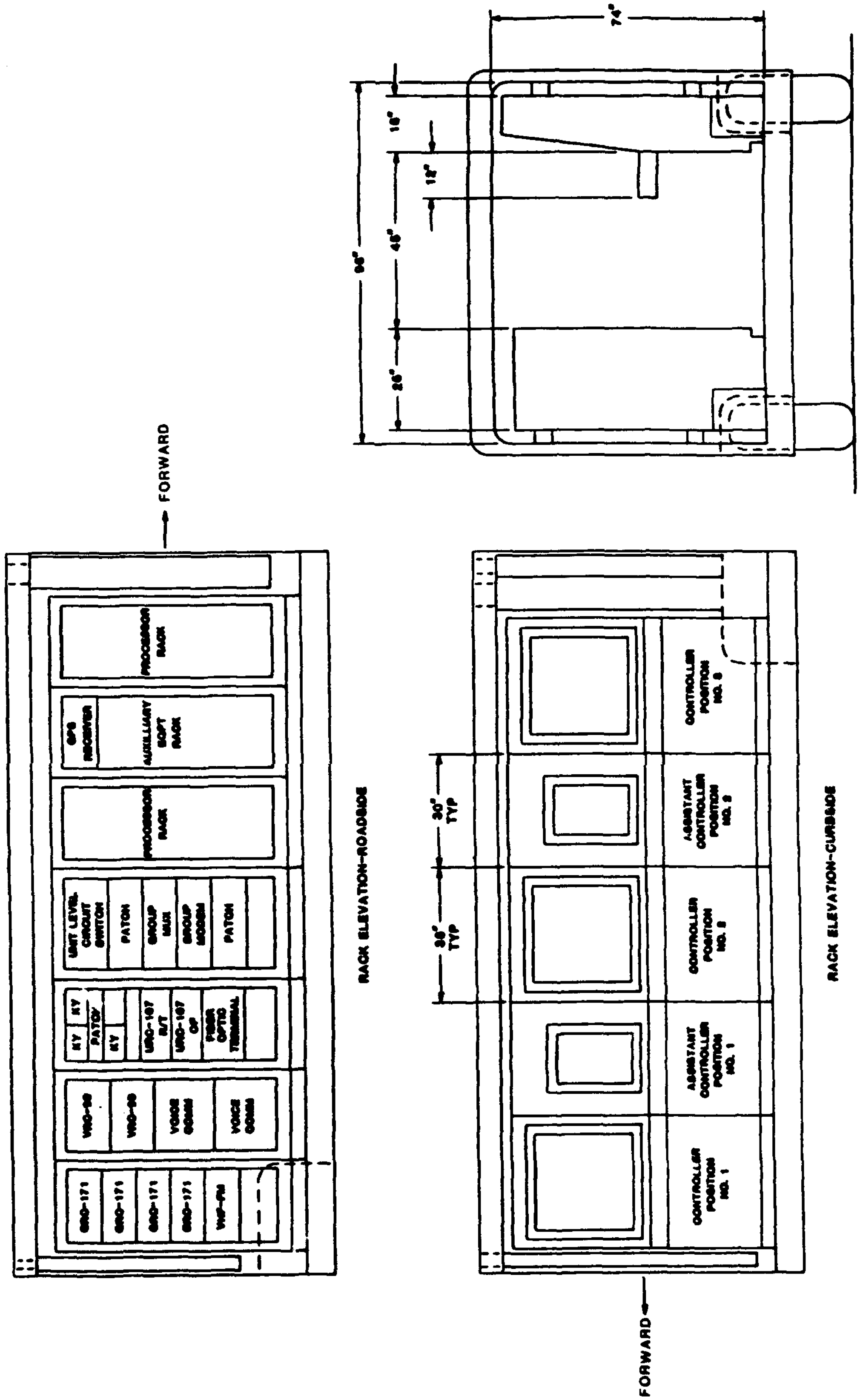

Figure 20. Preliminary Layout, AATCS Operations Area

4.5.2 Crew Area

Space is provided for an off-duty crew rest area. This space, approximately 8 feet long, will contain bunks, food storage and preparation facilities (refrigerator, microwave oven) and marine toilet facilities.

Storage tanks for water and waste would be mounted low in the vehicle, integrated into the chasis/frame structure.

4.5.3 Environmental

The facility will be designed for operation in a chemical and biological environment. As such, the internal environment would be tightly controlled with limited exchange of air to the outside. Access to the trailer would be through an accordion-type butting fixture which will provide a level of protection and retain filtered air between the units. The ECU would operate in a closed-loop configuration with minimum replenishment air required.

The design of the overall facility will incorporate protection against radiated and conducted electromagnetic energy. Conductive shelter penetrations will be hardened against radiated energy.

Fragmentation protection will be provided against threats of up to 70 grains at velocities up to 360 m/sec.

A solar shield mounted on the top of the vehicle will provide protection against solar radiation directly on the roof of the van. This will aid in reducing the solar heat load on the ECU system.

4.5.4 Towed Trailer

The towed trailer will be a single axle, enclosed cargo van type unit. The trailer is divided into two compartments, one having the environmental control units (ECU) and storage facilities, and the rear compartment housing the power generation equipment. The two compartments would be designed to preclude air exchange between the spaces. Air intakes for the ECU and power compartments would be equipped with micron particulate filter units.

The trailer will be insulated with sound absorbent material to reduce the ambient noise level within the operations area and external to the trailer.

A hook and pintle hitch will connect to the tow vehicle. Trailer brakes will be operated by the tow-vehicle braking system.

Fuel tanks for the generators will be mounted low in the trailer, integrated into the chassis/frame structure. Protection against rocks or contact with high ground points will be provided by steel shield plates.

A fire/high temp/carbon monoxide detection and alarm system and a halon fire extinguisher system will be incorporated into the power generation compartment.

4.5.4.1 Power System

Dual power generator units will operate in a main/standby mode. The generators will be diesel engine driven and sized such that one unit will carry the electrical load for the AATCS.

The system will also operate from base mains power. Connection points and stepdown transformer will enable the system to operate from 120/208V 60Hz, 3 phase, 4 wire; 220/380V, 50Hz, 3 phase, 4 or 5 wire and 240/416V, 50Hz, 3 phase, 4 or 5 wire. A transfer panel would control and sequence between the generators and the input mains power.

The compact nature of the AATCS system dictates that the generators be small and efficient. As such, standard military generators from the Mobile Electrical Power (MEP) series are not suitable due to their size and weight. Other models would need to be researched for a more appropriate type for the AATCS mission.

4.5.4.2 Environmental Control Units (ECU)

Two ECU units would be installed and operated in an on-demand configuration. One unit would normally be on line with the other unit brought up as a second stage to handle higher heating or cooling loads. This sequential load handling capability will enable the design of the ECU system to be scaled back slightly in terms of the size of the individual units. One unit would not have to be sized to handle the whole AATCS facility under worst-case high or low ambients.

Selections of specific ECUs for the AATCS application would be done following a detailed engineering investigation of the vehicle design and construction, and a complete heating/cooling analysis.

4.6 AATCS Airborne Equipment Suite

The AATCS concept has been developed whereby two types of up/down data links would be necessary in order to accommodate all potential aircraft types.

Those aircraft equipped with JTIDS will use the JTIDS net for the data link function. AATCS advisory data would be adapted to interface to the pilot's control and display unit to become a part of the overall situation display. The inherent AJ capability of JTIDS would also enable the AATCS ground controller to communicate directly with the pilot using the JTIDS voice channels.

For aircraft not equipped with JTIDS, AATCS would utilize the capabilities of the existing on-board VHF or UHF AJ comm and RELNAV/GPS equipment. Two functions must be performed for AATCS operation, acquiring aircraft position data for downlinked transmission and developing a suitable scheme for uplinking and presenting flight advisory data to the pilot.

The ground-based and airborne transceivers provide the means to transmit the data. The transmission cycle techniques described in Paragraph 4.2.1 will provide the ability to sequence and control the message traffic. To implement the AATCS control function in the aircraft will require the addition of an on-board formatter/processor to the airborne equipment.

The airborne subsystem shown in Figure 21 would be an interface between the aircraft transceiver, RELNAV/GPS equipment, heads-up-display (HUD) or other tactical display and cockpit audio system.

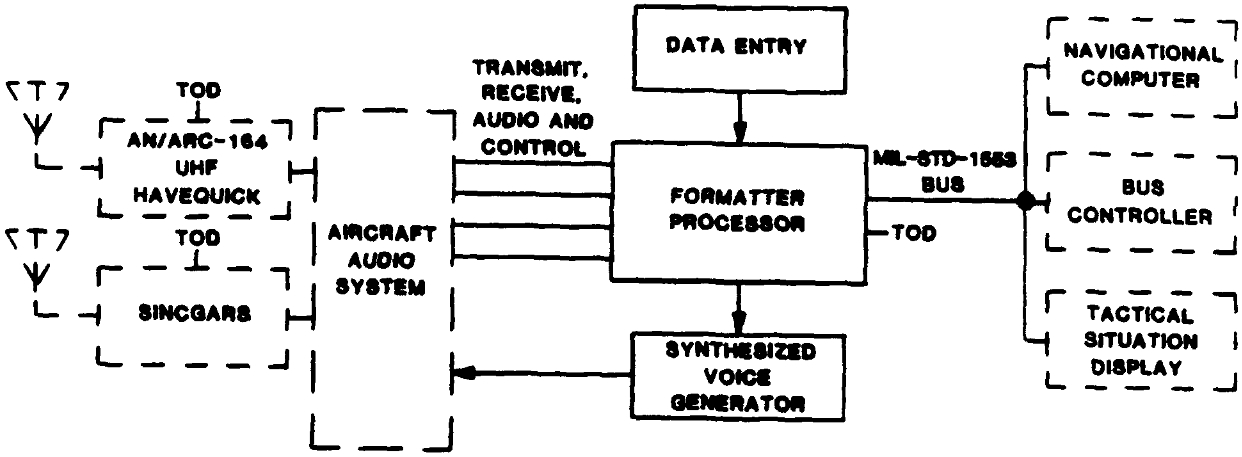

Figure 21. Functional Block Diagram, AATCS Airborne VHF, UHF Comm Suite

Aircraft position data would be provided by the RELNAV/GPS equipment and input to the formatter-processor (FP). The FP would add the A/C ident and format the position data for transmission. If the TC-RC technique is selected as the method for AATCS comm control, the transmission timing would be under control of the system clock. This could be derived from GPS, HAVEQUICK or SINCGARS TOD or a reference signal from AATCS.

If the SELCALL technique is incorporated, transmissions would be on demand.

Flight advisories would be transmitted from AATCS to the airborne transceiver and output from the receiver into the FP. The FP would reformat the data message from the transmission format, confirm the A/C ident bits and output the message to the visual display and/or the synthesized voice generator.

The AATCS advisory message would be adapted to operate with the cockpit display, both in terms of the digital interface and the display format and presentation.

The message would also be input into the voice synthesizer which would output digitized voice to the pilot's headset or cockpit intercom net. It is anticipated that the required word repertory to provide ATC advisories would be limited in number and that many would be standardized phrases.

A capability would be provided to input special messages into the downlinked message, this could include emergency situations, damage, wounded, low fuel etc. This feature could be a function keypad or other device or could even be a voice input into a digitizer.

SECTION 5
Conclusions and Recommendations

AATCS incorporates a number of features and capabilities which are deemed appropriate for the USAF ATC mission early in the 21st century. The system concept incorporates equipments and technologies which will perform the ATC mission while, at the same time, provide a high level of survivability for the system.

AATCS will be highly mobile and able to perform its ATC operations from locations remote from airbases and landing strips. The system will not require the use of a colocated primary radar sensor and communications between AATCS and other facilities will rely extensively on AJ techniques. The vulnerability of AATCS to detection and hostile action is therefore reduced. However, A/C landing areas will still be easily locatable and subject to direct attack.

The extensive use of frequency-hopping anti-jam radios will aid significantly in masking the AATCS operation. However, it is entirely possible that within the next ten years the HAVEQUICK and SINCGARS technologies may be compromised by the development of advanced ECCM techniques.

The operating environment envisioned for AATCS would not normally place the system in areas where ground actions were probable. The AATCS transporter, while not presently planned as a combat vehicle, could be designed with armor protection; perhaps similar to an Armored Personnel Carrier (APC).

The trade-offs would be higher AATCS vehicle road speed, lower vehicle weight, better mobility and C-130 transportability versus improved all-terrain operations and greater protection against small arms fire for an APC.

The C-130 transportability issue is felt to be a strong consideration in the overall system design. The system, as configured, is designed to house five controller positions and all of the supporting equipment in one C-130 transportable vehicle. It would be possible to expand the system by the addition of another van and relocating and enlarging the operations areas and support areas between the two vehicles.

The system concept presented here uses conventional landline and RF communications techniques to interface AATCS to other tactical and ATC facilities.

AATCS should be considered as a candidate user/terminal in a satellite communication network, such as MILSTAR. This would exploit the autonomous operating features of the system and limit or delete the need for direct connection into a conventional switching system.

The AATCS is not without its limitations. From a performance standpoint, the VHF/UHF uplink/downlink comm system will be subject to terrain masking and communications horizon limitations for low flying A/C. This problem would exist with a radar-based system. Utilization of the JTIDS network will alleviate this problem through JTID's ability to utilize the airborne terminals as repeater stations.

The AATCS processing and display system is by far the most ambitious and innovative aspect of the system concept. The system performance in terms of aircraft traffic density and the number of operations and tasks to be performed for those aircraft are well within the capabilities of a number of processor systems. The system must perform a large number of operations to support each aircraft track, however the update rate for this data will be commensurate with the update rate for a primary radar processor.

The AATCS system concept is based on a mix of mature technologies and near-term technical developments. Candidate subsystems for various functional elements are presently in inventory. The overall system is innovative in its configuration and application, but not in terms of hardware development.

By far, the most ambitious effort to be required in the development of AATCS will be the processor system software. The hardware architecture described in this report is intended to support and simplify the software development for the multi-processor, multi-tasking real time system. The initial allocation of the AATCS processing requirements into functional processes and task areas has provided a basis for the preliminary software task allocations. Additional task segmentation, including the generation of detail man-machine interfaces and database specifications, would need to be developed during any feasibility demonstration phase of the AATCS development.

As important as the software generation, and possibly more critical to the overall AATCS concept development, will be the definition and determination of the airborne equipment suite. The techniques and methodology to be used to replace today's use of voice communication for ATC purposes will require significant consideration for the human factors element. The man-machine interface in the cockpit of a high-performance fighter aircraft will be heavily impacted by workload considerations and on-board mechanical and physical constraints. Any effort toward the development of the airborne AATCS suite must be closely coordinated with ongoing USAF developments toward a Standard Cockpit Design.

The design of the ground-based AATCS facility will be a challenging effort in mobility, packaging and environmental control. The preliminary AATCS vehicle configuration incorporates some innovative approaches in terms of the vehicle itself and the layout and configuration of operations and support areas. The ATCS vehicle will be a good area for creative design approaches.

On balance, AATCS is a viable concept for a highly effective Airspace Management System. The basic operational premise meets the spirit and intent of the ATALARS concept by providing the capabilities to monitor and control a high number of aircraft movements over a large area under ordinary and extraordinary peacetime and wartime operating conditions.

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GLOSSARY

A/C	Aircraft
AATCS	Advanced Air Traffic Control System
ADP	Automated Data Processing
AJ	Anti-Jam
ASOC	Air Support Operations Center
ASRT	Air Support Radar Team
ATALARS	Automated Tactical Aircraft Launch and Recovery System
ATC	Air Traffic Control
ATDS	Air Tactical Data System
AWACS	Airborne Warning and Control System
AWS	Air Weather Service
BIT	Built In Test
BITE	Built In Test Equipment
C^2	Command and Control
CAFMS	Computer Automated Force Management System
CBR	Chemical Biological Radiological
COTS	Commercial Off-the-Shelf
CPU	Computer Processor Unit
CRC	Control and Reporting Center
CRP	Control and Reporting Post
CRT	Cathode Ray Tube
DBMS	Data Base Management System
DDP	Digital Data Processor
DOD	Department of Defense
DRAM	Dynamic Random Access Memory
ECU	Environmental Control Unit
EMC	Electromagnetic Compatibility
EMP	Electromagnetic Pulse
ESD	Electronic Systems Division
ETA	Estimated Time of Arrival
ETO	Estimated Time Over (Fix)
FAA	Federal Aviation Administration
FACP	Forward Air Control Post
FEBA	Forward Edge of Battle Area
FLOT	Forward Location of Troops
FM	Frequency Modulation
FO	Fiber Optic
FSED	Full Scale Engineering Development
FSP	full Scale Production
GFE	Government Furnished Equipment
GPS	Global Positioning System
HF	High Frequency
HQ TAF	Headquarters Tactical Air Forces
ICAO	International Civil Aviation Organization
ID	Identification
IFF	Identification Friend or Foe
INS	Inertial Navigation System
JTIDS	Joint Tactical Information Distribution System
KB	Keyboard
LAN	Local Area Network
LOS	Line of Sight

LPI	Low Probability of Intercept
LRU	Line Replaceable Unit
MATCALS	Marine Air Traffic Control and Landing System
MCE	Modular Control Element
MLS	Microwave Landing System
MMI	Man-Machine Interface
MMLS	Mobile Microwave Landing System
MPC	Message Processing Center
MSDL	Multiple Update Rate, Self Synchronized Secure ATC Radio Data Link
NATO	North Atlantic Treaty Organization
NMR	New Mobile RAPCON
NTDS	Naval Tactical Data System
OM	Operations Module
OTS	Off-the-Shelf
PEM	Position Entry Module
PME	Prime Mission Equipment
QWROTES	Quick Wartime Restoral of TRACALS Equipment and Services
RAM	Random Access Memory
RAPCON	Radar Approach Contol
RELNAV	Relative Navigation
RFP	Request for Proposal
RML	Remote Microwave Link
ROM	Read Only Memory
SDL	Secure ATC Radio Data Link
SE/PM	Systems Engineer/Program Management
SINCGARS	Single Channel Ground Air Radio
SPS	System Processor Suite
SRV	Surveillance Restoral Vehicle
SSR	Secondary Surveillance Radar
TAB	Tactical Air Base
TACC	Tactical Air Control Center
TACS	Tactical Air Control System
TADIL	Tactical Digital Information Link
TAOC	Tactical Air Operations Center
TR	Technical Report
TRV	Tower Restoral Vehicle
TS	Touchscreen
U/I	Unidentified
UHF	Ultra High Frequency
UPS	Uninterruptible Power System
VFR	Visual Flight Rules
VHF	Very High Frequency
VLSI	Very Large Scale Integrated
WOC	Weapons Operations Center