FAA-72-29
REPORT NO. FAA-RD-73-34

SIGNAL ANALYSIS FOR AEROSAT

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AUGUST 1972
FINAL REPORT

Prepared for
DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
Office of Systems Engineering Management
Washington, D.C. 20591

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No. FAA-RD-73-24	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle SIGNAL ANALYSIS FOR AEROSAT		5. Report Date August, 1972
		6. Performing Organization Code
7. Author(s) L. A. Frasco		8. Performing Organization Report No. DOT-TSC-FAA-72-29
9. Performing Organization Name and Address Department of Transportation Transportation Systems Center 55 Boradway Cambridge, MA 02142		10. Work Unit No. R-2152
		11. Contract or Grant No. FA211
12. Sponsoring Agency Name and Address Department of Transportation Federal Aviation Administration Office of Systems Engineering Management Washington, D.C. 20591		13. Type of Report and Period Covered Final Report Jan. 1972 - June 1972
		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract This report addresses signal design for the AEROSAT system. Candidate data and surveillance modems are analyzed for L-Band avionics. Detailed theoretical analyses are presented of the effects of the oceanic satellite-aircraft channel on data modem performance. In addition, an L-Band avionics transceiver is proposed to meet the requirements of the Experimentation and Evaluation Phase of AEROSAT. The proposed avionics is flexible and easily adaptable to a variety of operational and access control concepts. A task plan outline is presented for an improved modem task for the following year.

17. Key Words Signal Design, Multipath, AEROSAT, Avionics	18. Distribution Statement DOCUMENT IS AVAILABLE TO THE PUBLIC THROUGH THE NATIONAL TECHNICAL INFORMATION SERVICE, SPRINGFIELD, VIRGINIA 22151.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	80	

Form DOT F 1700.7 (8-69)

PREFACE

The work documented in this interim report is part of an advanced technology task performed by both the Electromagnetics and Information Sciences Divisions of the Technology Directorate of the Transportation System Center in support of the Federal Aviation Administration AEROSAT Program.

Technical associations with H. David Goldfein and Dr. Sherman Karp are hereby acknowledged. Mr. Goldfein wrote Appendix A of this report and was a major contributor to Section 3.1. Dr. Karp's experience with the statistical analysis of AEROSAT channel data and his time spent reading the first draft of this report are greatly appreciated.

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1.0 INTRODUCTION

Aeronautical satellite systems are being considered for air traffic control of transoceanic aircraft. In the second half of this decade, satellite ATC systems may replace the present outmoded system which is primarily based on HF transmission for voice communication with position reporting for dependent surveillance. In terms of operational requirements, the aeronautical oceanic satellite ATC system (AEROSAT) will use satellites primarily for improved communication performance and coverage in the interest of improving safety for the expected traffic volume. The following functional requirements for AEROSAT (in order of priority) are: (1) voice and data communication including dependent surveillance by position reporting; (2) independent surveillance by ground stations. A system concept for AEROSAT has been proposed but will undergo further definition as development progresses. Consequently, subsystem specifications (i.e., for the satellite, avionics, and ground facilities) have not been finalized since details of this kind are expected to be iterated with system design and implementation. Care must be taken, therefore, to coordinate system/subsystem definition to achieve an optimal system. System concept selection, subsystem specification, and engineering development are by necessity being done in parallel.

The development phases of the AEROSAT program will be initiated with an Experimentation and Evaluation (E&E) Phase followed by various operational phases. It is intended that most of the Experimentation and Evaluation hardware be the forerunner of operational system hardware. This approach has been stimulated by an eagerness to get an operational system on the air as soon as possible.

In the following sections, signal design issues for AEROSAT are discussed. In the course of this discussion, the impact of the signal design task on ground control and accessing; and, its interfaces in general with other tasks and AEROSAT system integration will be clarified.

The work effort on this task can be divided into three principal areas: (1) recommendation of data communications and surveillance modems for AEROSAT Experimental avionics and preparation of the relevant portions of the AEROSAT avionics specification; (2) planning and initiation of a technical support effort in AEROSAT modem design and evaluation; (3) quantification of the impact of the signal design task on AEROSAT access control concepts.

Candidate modems are recommended and specifications prepared in the support of L-Band avionics developments. For data communication, incoherent binary FSK is the recommended choice over others such as CPSK and DPSK. The analysis described in this report demonstrates the marginal performance of DPSK over the AEROSAT channel. The surveillance modem is less rigidly defined although tone ranging is recommended in a 50 KHz bandwidth with specified acquisition times and ambiguity resolution. However, since extensive surveillance experiments are planned, waveform design, bandwidth and modulation are still open issues. The details of the rationale used for modem recommendation are included in this report.

Considerable effort has been devoted to planning a technical support role for continuing AEROSAT avionics development and experimental evaluation in the laboratory and in the field. Of primary interest is channel characterization and modeling of the AEROSAT aircraft to satellite link. The results of these studies will be important in evaluating recommended avionics designs especially those developed during the initial phase of the AEROSAT avionics hardware development. The channel characterization studies will also be of extreme value during laboratory channel simulation and field tests leading to signal design recommendations for AEROSAT as well as for future CONUS Satellite ATC R&D efforts.

In recommending data and surveillance modems it became necessary to specify the avionics as an integrated system package. A modular description of the avionics system was prepared and a general access control interface defined.

A baseline operational concept was defined to aid in avionics specification as well as to help define operational system tests.

A fundamental issue is the flexibility required in the avionics to support access during the E&E Phase. More specifically, the requirement for multiple simultaneous channels on receive versus a single channel has been established.

In the next section, a description of a baseline AEROSAT system is presented.

2.0 A BASELINE AEROSAT SYSTEM

AEROSAT development efforts must be as flexible as possible to allow for changes in system configurations and for a wide range of system tests. However for signal design purposes some assumptions must be made regarding the system configurations. One possible AEROSAT baseline system concept postulates a polled data link, computer scheduled communication (data/voice) channels, an emergency channel, and an experimental channel for independent surveillance. The system data flow is shown in Figure 1. The Aeronautical Satellite Control Center/Aeronautical Satellite Earth Terminal (ASCC/ASET) interface provides for the control of the transfer of information between ground and air. The system control concept including supervision, scheduling, interrogation and information collection and distribution for surveillance and communications is exercised from the ASCC. The ATC/ASCC interface is interpreted in the concept description as generating requirements (with their associated priorities) for surveillance data and communication access to airborne units.

Necessary to the definition of the ASCC/ASET structures is the determination of the class of operational/access control strategies which the avionics (and, of course, the rest of the AEROSAT System) should support for experimental/operational tests. The following sections will describe the proposed system in terms of its ATC operational requirements. Finally, the interrelationship between the system elements and interfaces will be described in terms of the operational control concept.

2.1 SYSTEM ENTRY AND EGRESS

There are two ways to enter and leave the system: scheduled and unscheduled.

A. Scheduled

1. Flight plan filed with Oceanic ATC
   Placed in pre-flight queue and assigned ID code

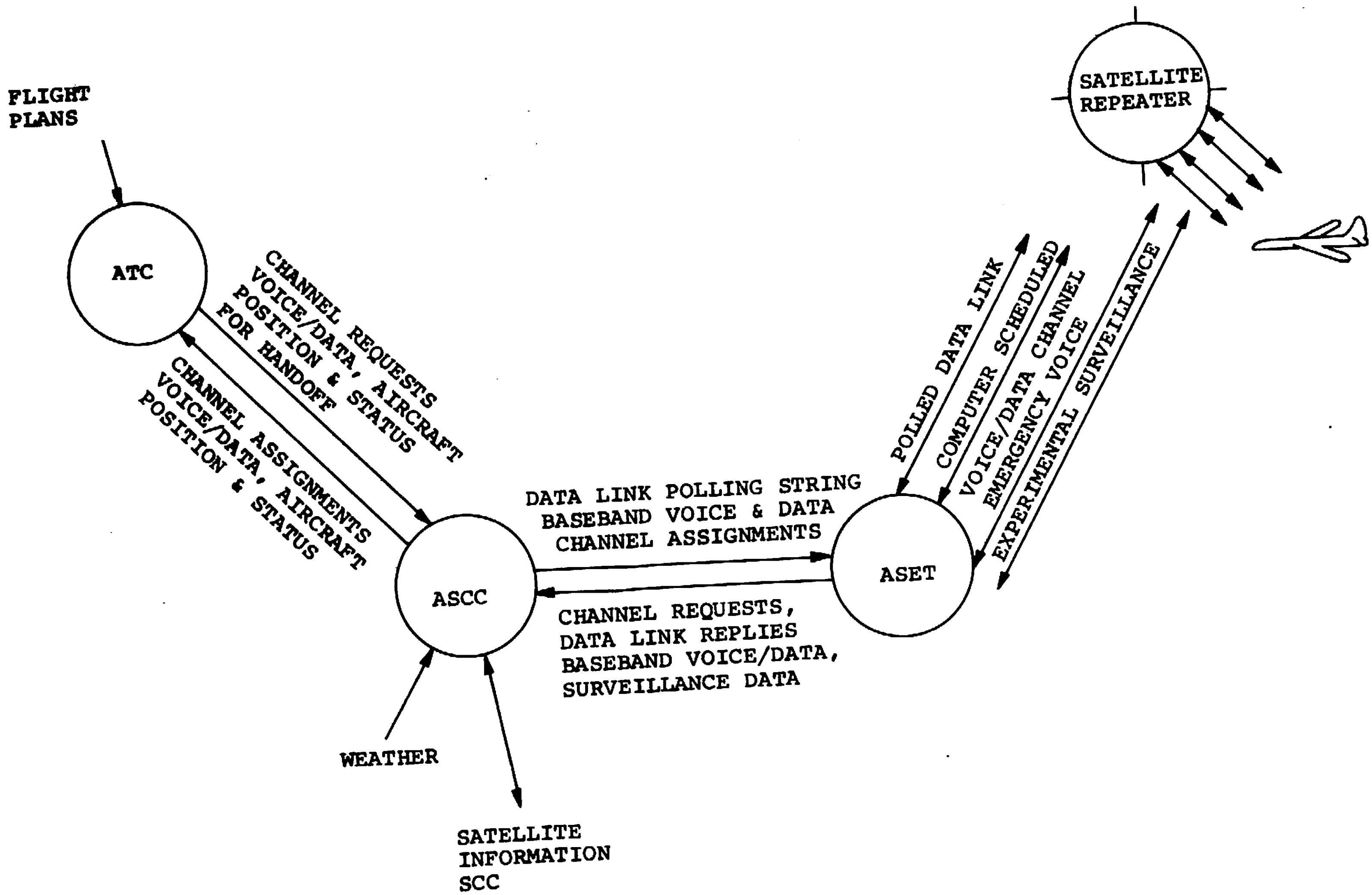

Figure 1. Candidate AEROSAT Operational Concept and Data Flow

for polled data link. At flight time, placed in track table at ASCC with any initial state parameters available. After initial acquisition completed, verification provided to ATC

2. Hand-off between CONUS ATC and Oceanic ATC CONUS flight plan information and track table entry transferred to Oceanic ATC. Placed in ASCC's track table with present state vector (e.g., flight, ID code, present position, time, etc.). Aircraft is acquired and verified as in 1a. During egress (Oceanic to CONUS ATC), ASCC track table entry is transferred to CONUS ATC along with any additional flight information required.

B. Unscheduled

1. Pop-ups (i.e., unidentified flights which have somehow gained entry into the controlled airspace.

   a. Entry Initiated by Aircraft
      Aircraft calls ground on voice link using communication accessing procedures (See Section 2.2 following). Gives identity and navigated position and in turn is assigned ID polling code. Verification is received via the polled data link.

   b. Entry Initiated via Ground Control
      Ground uses universal addressed polling mode with tracked aircraft suppressed. Aircraft transponds untracked mode message containing identity and navigated position. Assigned polling code via data link or voice.

2.2 SYSTEM COMMUNICATION ACCESSING

As can be seen from Figure 1, the data flow between ground and air is accomplished using a polled data link, computer scheduled communication (data/voice) channels, an emergency channel, and an experimental channel for independent surveillance. All data exchange is accomplished under a priority scheduling structure.

A. Uplink

1. Data

   Adaptivity polled (discretely addressed) data link scheduled under ground control.

   a. Polled surveillance data derived from aircraft's navigated position (e.g., INS, Loran C, Omega) data linked to ground with an update rate of ≈ 1 min. Update rate is under ground control and variable for each flight.

   b. Command data transmitted to specific aircraft as necessary (with return verification depending on message)

   c. Common data transmitted to all aircraft via universally addressed poll (e.g., weather advisories, etc.)

   d. Canned messages and segmented long data strings (e.g., teletype) transmitted to specific aircraft as required.

   e. Voice/Data channels assigned via data link as required.

2. Voice

   Voice channels assigned based on priority.

   a. Channel assignments data linked to aircraft. Aircraft receiver and transmitter are manually or automatically tuned to proper frequencies.

   b. In case of emergency, emergency channel used. If loaded, the entire system communication capacity is rescheduled by the ground to accommodate emergency priority.

B. Downlink

1. Data

   a. Ground initiated downlink via polled data link; aircraft can add short canned message as part of transponded reply.

   b. Request data channel (with priority) via polled data link if required reaction time is greater than 1 minute.

   c. If reaction time less than 1 minute is required, channel may be requested using access procedures described under downlink voice, b.

2. Voice

   a. Ground initiated downlink channel assigned for reply to ground voice message.

   b. User initiated channel requests based on priority.

      1. Low Priority (Reaction time greater than 1 minute)
         Channel requests are made via polled data link and placed by ground control in scheduled queue; aircraft may assign priority which increases as a function of time.

      2. High Priority (Reaction time less than 1 minute)
         Aircraft listens (manually or automatically) for voice channel availability; if no busy signal heard, a channel request tone is transmitted. If no ground generated busy tone heard in reply, aircraft takes channel.

      3. Emergency
         Use emergency voice channel. If loaded, transmit emergency tone on all channels.

2.3 SYSTEM SURVEILLANCE

Surveillance information is provided in two ways:

A. Navigated position information is data linked to ground from the aircraft via polled data link (See Section 2.2). Data is processed and used to update track table at the ASCC.

B. Independent surveillance is provided by polled link similar to the data link described in Section 2.2 but with increased range resolution using an experimental channel. Excess capacity on this link can be utilized to increase communication capacity of the system. Aircraft position is computed using point and tracking algorithms at ASCC and used to update track table.

2.4 SYSTEM CALIBRATION, CHECKOUT, AND FAULT DETECTION

This section describes procedures for dynamic/real time operational system verification and isolation of subsystem failures.

A. User Initiated

1. Uplink Tests
   Via data link or voice (depending on priority), aircraft requests transmission of test signals, messages, etc. Receipt of transmitted signals is used to verify uplink performance.

2. Downlink Test
   A user requests channel slots on downlink and transmits prescribed test signals, messages, etc. Acknowledgement of observed downlink performance is provided by the ground.

3. Other Tests
   Other tests include transmission of signals by ground which allows aircraft subsystem test (e.g., antenna, reciever, etc.) and verification of performance.

B. Ground Initiated

Link performance tests are performed similar to those initiated by the airborne element (See preceding paragraph). Excess system capacity can be utilized to test both link performance to individual aircraft as well as overall system performance. This includes procedures for periodic check out of the satellite supported by information from SCC. To a large degree, fault detection is implicit in ground interrogation and scheduling strategies. In all these tests, ground calibration stations (i.e., transponders on the ground at fixed geodetic points) can be utilized to verify link parameters as well as surveillance subsystem performance.

2.5 SYSTEM FAILURE MODES

In the preceding sections the selected concept has been described in terms of operational procedures. In this section the contingencies which have been made for system failure are presented.

A. Airborne Detected

After the aircraft has not been interrogated for a predetermined time period, it reverts to an untracked mode. Aircraft calls on voice link with priority which depends on elapsed time since last interrogation (See communication accessing) and asks for information on nature of failure utilizing detection and fault isolation procedures of Section 2.4. Meanwhile, aircraft transmits position information using alternate voice/data channel assigned by ground. If all AEROSAT avionics are dead, the aircraft must follow some predetermined emergency flight plan and try to contact the ground via backup links such as HF.

B. Ground Detected

1. Loss of single track (based on number of missed interrogations and estimated accumulated position error) is determined by the ground. Ground initiates call to aircraft via voice link with appropriate priority. Aircraft position is updated via assigned voice/data link. Fault detection and subsystem isolation proceeds as in Airborne Detected, 1. An alternate procedure is to initiate a general interrogation with tracked aircraft suppressed.

2. Power failure or other failure of ground equipment if aircraft have not been interrogated for a predetermined amount of time, they revert to an untracked mode. After failure has been remedied, the ground initiates a universal interrogation with tracked aircraft suppressed. Untracked aircraft respond and reply with delays proportional to their last interrogation (or some other scheme which spreads their returns out in time).

2.6 SYSTEM ELEMENTS, INTERFACES, AND GROUND CONTROL CONCEPT

This section describes the interrelationship between the AEROSAT system elements and interfaces in terms of the operational control concept. The major ground control system elements are:

A. Aeronautical Satellite Earth Terminal (ASET)

Performs all transmission and reception of radio signals between ground (ASCC) and satellites. It contains all the required antennas, transmitting and receiving electronics, modems, ranging equipment for the ground to aircraft to ground links; and interfacing equipment for ground communications and information transfer from the ASET to the ASCC.

B. Aeronautical Satellite Communication Center (ASCC)

Houses operational ground control equipment. It provides control of all messages handled by its associated ASET and coordinates the transfer of message traffic to and from its associated ATC center and other terminals (e.g., airlines, weather, experimental facilities). The ASCC receives baseband communications and digitized range information from the ASET. It will have the capability to perform surveillance computations and other general data management tasks as well as interfacing with the satellite control center for tracking information, and satellite channeling and switching functions. Although the ASET and ASCC are functionally separate, they may be physically collocated.

C. Air Traffic Control Center (ATCC)

Performs ATC functions: requests appropriate ground-to-air communication, surveillance information and passes these requests to ASCC for scheduling and system control; in general, monitors all equipped aircraft within its area of interest and establishes communication as necessary.

2.6.1 Man/Machine Interfaces

Using the baseline operational concept definition, this section establishes operational procedures for the controller and pilot system interfaces. Effort has been made to keep the ASCC/ASET transparent to controller and pilot. Examples of the operational procedures presented here are summarized in Table 1.

2.6.1.1 <u>Controller Procedures</u> - The procedures described here attempt to keep controller system interaction simple and to limit that interaction to strictly control rather than housekeeping functions.

TABLE 1. ATC OPERATIONAL PROCEDURES FOR MAN/MACHINE INTERFACE

PROCEDURAL CLASS	CONTROLLER	PILOT
System Entry and Egress	Scheduled Entry - Controller notified of flight entry request and flight information displayed to him. Acquisition verification exchange between controller/system. Scheduled Handoff - Similar to entry. Unscheduled Entry - Enters into system identity and navigated position provided by pilot via voice. ID cards displayed to controller and transmitted to pilot. Verification via polling link and visual track on display.	Scheduled Entry - Files flight plan and assigned ID code. Scheduled Handoff - Receive Knowledge of changes in ground control. Unscheduled Entry - Ground controller called by voice and given identity and navigated position. Assigned ID code and reciever acquisition verification from avionics.
System Communication Accessing	Controller presented with a continually updated situation display with track and status of all controlled aircraft. All communication on priority scheduled basis. ATC functions which require controller/pilot exchanges and occur often are implemented as function switches. Provision exists for entry of general data communication. Channel requests require priority and destination tags. Channels may be dialed-up or, for faster entry, light pen destination identification from display. Incoming communication from controlled aircraft presented as flashing signatures on display.	Low Priority - Pick up mike (or flick switch); initiates channel request on polled data link. Messages may be placed in data buffer for transmission on data link when aircraft is next interrogated. Up and down link channel assignments automatically switched in. High Priority - Avionics automatically scans channels, sends a request tone, and listens for busy signal; if none, switches down link to this channel. Pilot initiated by switch with notification by buzzer/lit. Emergency - Pilot presses red button on mike or control panel. Uplink assignments are automatic with light/buzzer notification. Function keys, a general data entry device and a simple display provides for data entry and display.

A. System Entry and Egress

1. Scheduled Entry
   Prior to system acquisition, specific oceanic controller is notified of impending flight entry into system and relevant flight information displayed to him. Controller has the option of looking at complete pre-flight queue at any time. Acquisition indicated under system control. Verification of acquisition provided to controller (e.g., flashing signature on display, etc.)

2. Scheduled Hand-offs
   As in System Entry and Egress, specific oceanic controller notified of CONUS to oceanic transfer request. System automatically receives flight plan information and track table entry from CONUS and acquire aircraft. Acquisition verification provided to oceanic controller and to CONUS ATC. Similar procedures for hand-offs to CONUS.

3. Unscheduled Entry

   a. Aircraft Initiated
      Controller called by pilot on voice link. Controller enters into system identity and navigated position provided by pilot. System assigns ID polling code by displaying it to controller who in turn transmits it to pilot. Correct receipt verified via polled data link using assigned ID code; displayed to controller visually as acquired track on display.

   b. Ground Initiated

      System automatically interrogates periodically for untracked aircraft. These aircraft transpond with untracked message format (see Section 2.1). System assigns polling code and notifies controller by display. Verification as before.

B. System Communication Accessing

Ground control automatically polls aircraft, monitors track and status of all controlled aircraft and presents this information in a display to the controller. Controller communicates with airborne units on a priority basis as described in Section 2.2. For simplicity this priority structure has been made implicit in controller accessing procedures. For example, a variety of ATC functions can be listed requiring controller/pilot exchanges. The most common of these can be incorporated on the controller's panel as function switches or buttons; the different priorities of these functions will be handled automatically by the system. There will also be provision for entry of more general requests (e.g., keyboard entry). Channel requests require the controller to specify a priority (maybe implicitly) and a destination. The channel may be dialed up like a telephone or using keyboard entry of the ID code; both of these methods imply fairly low priority due to slow entry. Faster entry can be accomplished for example by light pen identification of destination on the tracked aircraft display.

Actual assignment of specific channels and line switching is performed by ASCC (Section 2.6.2). Messages transmitted to controller via ASCC are recognized by flashing signatures, lights, buzzers, etc., and displayed as required.

C. System Surveillance

Minimal controller interaction. Controller may request aircraft position verification, surveillance update rate increase or display of aircraft location.

D. System Calibration, Check out and Fault Detection

Whenever possible check out and fault detection has been incorporated into the operating procedures in the form of procedural verification and generation of procedural verification and generation of redundant information.

Also, controller may request calibration and check out tests; receives verification on their completion. Controller notified of detected system faults. General system log prepared listing all tests and their status; hard copy output generated.

E. Failure Modes

Controller notified of subsystem failure by pilot (e.g., avionics failure) or by ground system fault detection techniques. Procedures described in Section 2.5 with appropriate accessing described in Section 2.3 and in System Communication Accessing, B.

2.6.1.2 Pilot Procedures - Emphasis is once again to keep pilot interaction simple and free from housekeeping.

A. System Entry and Egress

1. Scheduled Entry
   Files flight plan and is assigned ID code.

2. Scheduled Handoff
   Pilot receives knowledge of changes in ground control (e.g., Oceanic to CONUS interchange).

3. Unscheduled Entry
   Pilot calls ground controller on voice link (see accessing) giving identity and navigated position. Aircraft assigned ID code. Pilot receiver verification of polled interrogations (untracked mode light goes off).

B. System Communication Accessing

As in controlled procedures, priorities are implied by pilot procedure:

1. Low Priority
   Pilot picks up mike (or flicks switch) and thereby initiates channel request on polled data link. Low priority messages may be placed in data buffer

to be sent on polled data link whenever aircraft is interrogated. Up and downlink channel assignments are automatically switched in.

2. High Priority
   Avionics automatically scans channels, sends a request tone, and listens for busy signal; if none, switches downlink to this channel. Pilot initiated by switch with notification by buzzer/light.

3. Emergency
   Pilot presses red button on mike or control panel. Uplink assignments are automatic with light or buzzer notification. Function keys, a general data entry device and simple display are available for pilot data entry and reception.

C. System Surveillance

No pilot intervention except upon subsystem failure.

D. System Calibration, Check Out, and Fault Detection

Pilot requests with the press of a button or via voice, the transmisstion of test signals for uplink check. Pilot presses calibrate mode; channel automatically requested, test signals sent and verification received automatically. Fault detection circuitry notifies pilot of avionics malfunction. In addition to these tests, there is automatic system testing periodically undertaken without pilot in loop. He is notified immediately of any detected subsystem failures.

E. System Failure Modes

Automated system procedures are described in Section 2.5. Pilot notified of untracked mode by light or buzzer. Pilot calls ground controller via voice channel. If possible, aircraft transmits position and identity information using alternate channel assigned by ground.

If avionics failure, pilot tries to access ground via backup links while maintaining emergency flight plan.

2.6.2 Operational Ground Control System Configuration

The ASCC houses the operational control system configuration. Paragraph 2 of Section 2.6 specifies the system control functions which must be performed. The purpose of this section is to present a skeleton description of the control system configuration. This will be helpful in providing a better understanding of the baseline operational ATC system concept and it will allow some preliminary equipment sizing to be done.

Figure 2 contains a block diagram of the ground control system configuration. The system work load is divided into a set of tasks. Control is handled by the system monitor which supervises the execution of the individual tasks; tasks are serviced based on a priority interrupt structure. These tasks include: 1) message routing; 2) interrogator scheduling, (polling); 3) surveillance computations; 4) system calibration and fault detection; 5) failure modes. As can be seen from the diagram, the message routing task plays a central role in data interchange. The aircraft track and status table provides a centralized data base containing the "state" of the airspace. It is continually being updated and scanned for information (e.g., priority requests, polling string, update of airspace "state" for ATCC, etc.)

In Figures 3 and 4 representative examples of pilot and controller I/O are presented. The controller I/O configuration shown was taken from the NAS Stage A Enroute System Description Document. The I/O configurations are presented only as a portrayal of the man/machine interfaces and are not to be construed as defining these interfaces.

As can be seen from Figure 2, there will be a message routing, storage, and switching function which will be performed by the ASCC. This function is the principal controlling element in the system. The program to perform this function is very similar to the communication software packages provided by several computer

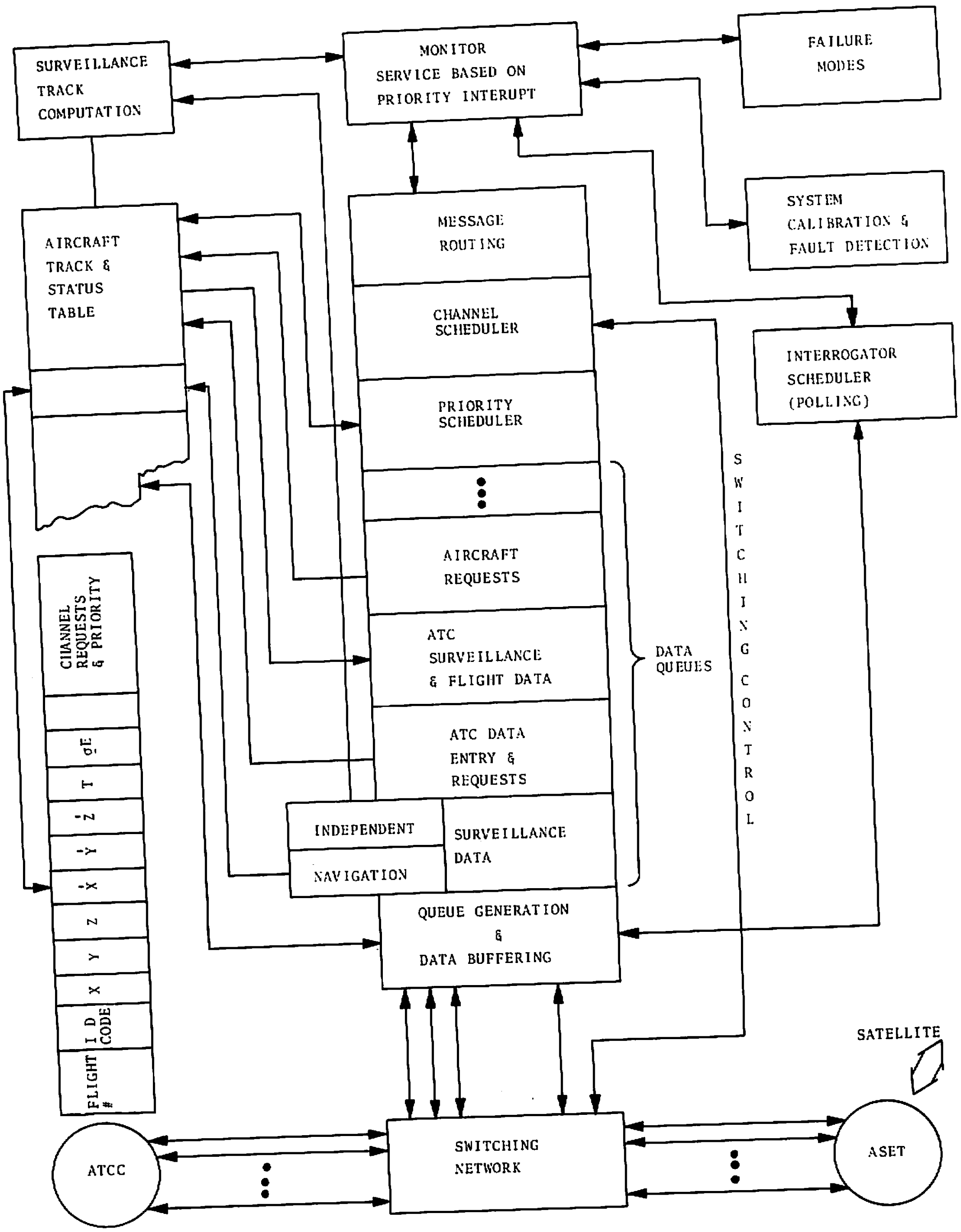

Figure 2. Ground Control System Configuration

manufacturers and, therefore, a minimal development effort should be necessary. The other major software element will be the scheduling of AEROSAT channel usage.

3.0 AEROSAT AVIONICS

In this section AEROSAT avionics design and modem recommendations will be discussed.

3.1 AVIONICS SYSTEM ENGINEERING RECOMMENDATION

The basic approach in developing avionics will be to ensure flexibility with regard to modems and access control approaches. The avionics must be adaptable to a variety of operational concepts and access control philosophies. This flexibility means increased cost and complexity of the initial avionics package. However, this approach will permit a wider range of tests during the evaluation and development phase of AEROSAT.

The avionics system discussed here which may be incorporated in the AEROSAT L-Band transceiver specification consists of an L-Band integrated multi-channel transceiver including modems and access control logic, a control panel, and pre-amplifier/power amplifier/antenna assembly. Figure 5 presents a component block diagram of a proposed avionics package. A modular design is recommended to facilitate technological developments especially improved prototype modems. A more detailed description of the package is presented in the following paragraphs.

As can be seen from Figure 5, the avionics package has been divided into four basic building blocks or modules: 1) wideband RF transmitter and receiver; 2) IF variable band-pass section; 3) modems; 4) interfaces, control logic, and control panel.

Module (1) is composed of a wideband 15 MHz RF receiver front-end with high dynamic range (dependent on the maximum number of simultaneous active received channels at the front-end) and a wideband 15 MHz hardlimiting transmitter.

Module (2) is made up of two different types of submodules (channels): 1) independent frequency tunable across the entire receive band by electronic/manual synthesizer control 2) frequency tuned (e.g. with a crystal oscillator for receipt

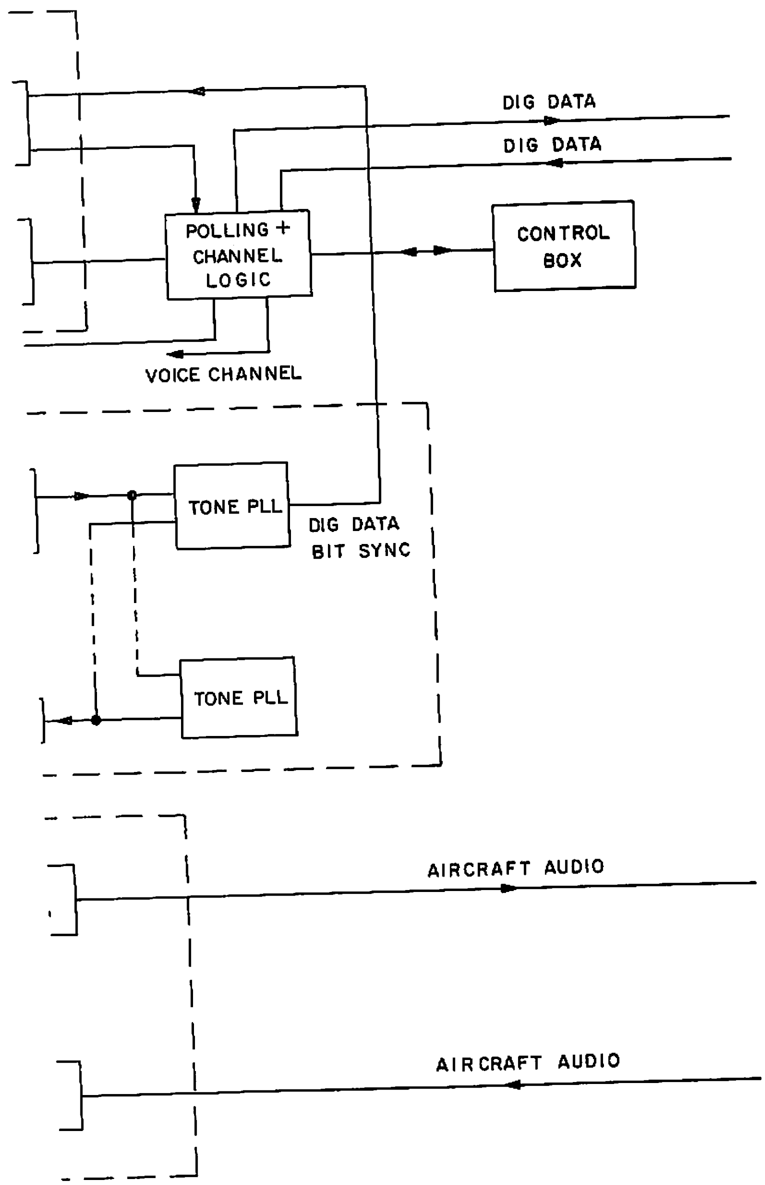

Figure 5. A Proposed AEROSAT L-Band Transceiver