FAA-76-18

REPORT NO. FAA-RD-76-112/DOT-TSC-OST-76-20

AEROSAT ACCESS CONTROL SUMMARY

H.A. Blank
G.V. Kinal
Computer Sciences Corporation
6565 Arlington Blvd.
Falls Church, VA 22046

L. Klein
U.S. Department of Transportation
Transportation Systems Center
Cambridge MA 02142

OCTOBER 1976
FINAL REPORT

Prepared for

U.S. DEPARTMENT OF TRANSPORTATION

OFFICE OF THE SECRETARY

Office of the Assistant Secretary for Systems Development and Technology
Office of Systems Engineering
Washington DC 20591

FEDERAL AVIATION ADMINISTRATION

Systems Research and Development Service
Washington DC 20590

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No. DOT-TSC-OST-76-20 FAA-RD-76-112	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle AEROSAT ACCESS CONTROL SUMMARY		5. Report Date October 1976
		6. Performing Organization Code
7. Author(s) H.A. Blank, G.V. Kinal, L. Klein*		8. Performing Organization Report No. DOT-TSC-FAA-76-18
9. Performing Organization Name and Address Computer Sciences Corporation** 6565 Arlington Boulevard Falls Church, Virginia 22046		10. Work Unit No. OS 521, FA611/R6129
		11. Contract or Grant No. DOT-TSC-1079
12. Sponsoring Agency Name and Address U.S. Department of Transportation Office of the Secretary Office of the Assistant Secretary for Systems Development and Technology Office of Systems Engineering Washington D.C. 20590 and Federal Aviation Administration Systems Research and Development Service Washington D.C. 20591		13. Type of Report and Period Covered Final Report July 1975 – May 1976
		14. Sponsoring Agency Code
15. Supplementary Notes * DOT/TSC **Under contract to: U.S. Department of Transportation Transportation Systems Center Kendall Square Cambridge MA 02142		

16. Abstract

The purpose of this report is to summarize U.S. Department of Transportation activities with regard to the AEROSAT access control studies that have been conducted in the recent past and to make recommendations for future efforts. In particular, this report concentrates upon the studies conducted by Aerospace Corporation, Bell Aerospace Company and Computer Sciences Corporation on behalf of the Department.

The report consists of three basic sections. Section 2 is a discussion of the communications concepts germane to AEROSAT access control. It defines and reviews the principles of multiplexing, multiple access, demand access, and access control and relates them to the system parameters of AEROSAT. Section 3 is a complete summary of the three AEROSAT access control studies. The evaluation approach taken, the access control techniques considered, and the conclusions reached by each study are summarized. No attempt is made to critique these results or to combine them into a common set of recommendations. Section 4 presents the recommendations for AEROSAT access control techniques, mainly based upon the results of the three studies and the access control techniques defined in appropriate AEROSAT documentation. Also included are recommendations for AEROSAT test and evaluation, as well as future simulation efforts.

17. Key Words Satellite communications, AEROSAT, access control, multiple access, multiplexing		18. Distribution Statement Document is available to the public through the National Technical Information Service, Springfield, Virginia 22161	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 90	22. Price

Form DOT F 1700.7 (8-69)

PREFACE

The purpose of this report is to summarize U.S. Department of Transportation activities with regard to the AEROSAT access control studies that have been conducted in the recent past and to make recommendations for future efforts. In particular, this report concentrates upon the studies conducted by Aerospace Corporation, Bell Aerospace Company and Computer Sciences Corporation on behalf of the Department.

This report presents the recommendations for AEROSAT access control techniques, mainly based upon the results of the three studies and the access control techniques defined in appropriate AEROSAT documentation. Also included are recommendations for AEROSAT test and evaluation, as well as future simulation efforts.

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

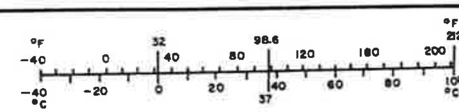

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF ILLUSTRATIONS

Figure

LIST OF TABLES

Table

SECTION 1 - INTRODUCTION

The purpose of this report is to summarize DOT activities with regard to the AEROSAT access control studies that have been conducted in the recent past and to make recommendations for future efforts. In particular, this report will concentrate upon the studies conducted by Aerospace Corporation, Bell Aerospace Company and Computer Sciences Corporation on behalf of DOT. The final reports submitted by these three organizations are entitled:

- Analysis of an Aeronautical Satellite Evaluation and Development System (FAA-RD-74-41) (by Aerospace Corporation)
- System Access Control Study (FAA-RD-74-107) (by Bell Aerospace Company)
- Access Control and Processing Studies for Ground-Satellite Mobile Communications/Surveillance Systems (FAA-RD-74-106) (by Computer Sciences Corporation).

This report consists of three basic sections. Section 2 is a discussion of the communications concepts germane to AEROSAT access control. It defines and reviews the principles of multiplexing, multiple access, demand access, and access control and relates them to the system parameters of AEROSAT. Section 3 is a complete summary of the three AEROSAT access control studies. The evaluation approach taken, the access control techniques considered, and the conclusions reached by each study are summarized. No attempt is made to critique these results or to combine them into a common set of recommendations. Section 4 presents the recommendations for AEROSAT access control techniques, mainly based upon the results of the three studies and the access control techniques defined in the Technical Requirements for AEROSAT L-Band Test Avionics System (TSC, December, 1974). Also included in Section 4 are recommendations for AEROSAT T&E, as well as future simulation efforts. Note that the access control techniques considered apply to the VHF as well as to L-band. The same methods would be used at either frequency and the same general design considerations apply to both.

SECTION 2 - COMMUNICATIONS CONCEPTS FOR AEROSAT

2.1 INTRODUCTION

The designer of a satellite communications system for aircraft users must consider the following:

- Large number of aircraft users
- Low communication duty cycle per user
- Limited satellite capacity especially in ground-to-air direction
- Low gain mobile user antenna
- Potential multibeam satellite antenna
- Requirement to minimize avionics cost and crew workload
- Potential requirement for independent surveillance
- Relatively severe Doppler environment.

The first three points provide the basis for the problem of access control, i.e., the method whereby a limited satellite capacity is shared and used by a large number of users. The other points influence how this might be done, and directly affect the capacity of the system, in some cases.

Later sections of this report treat access control for AEROSAT in detail. This section will be devoted to providing a general background on the subjects of multiple access, multiplexing and access control including a brief discussion of the multiple beam problem potentially related to Aerosat.

First, a few definitions:

Multiplexing is the process whereby a number of channels of information (voice or data or combinations) are combined so that they can be collectively modulated onto a single carrier for transmission. The individual channels are generally not recoverable at the receiving point until the entire multiplex is demodulated. Demultiplexing is the process of breaking the composite multiplex signal down into its constituent information channels. Multiplexing can be done in the time and frequency domains (TDM and FDM respectively).

Multiple Access is used to describe techniques that permit several separated users to "simultaneously" communicate via some common medium, in our case a repeater (or transponder) channel of a communication satellite. The users each access the repeater channel with a modulated carrier (which might have been multiplexed at the earth terminal). It can be viewed as a resource sharing technique since the available resources of bandwidth, time or power are divided up between the accessing carriers.

Access Control refers to the methodology used to allocate the communication resources of the system, i.e., the assignment of users to channels of the system. Access control provides a similar function whether the communication channels are to be full-time assigned* or demand assigned*. The access control subsystem of a communication system is responsible for controlling the capacity of the system by use of an efficient and ordered set of techniques. The case of demand assigned usage is more important to AEROSAT because of the low duty cycle of the users.

2.2 MULTIPLE ACCESS TECHNIQUES

2.2.1 Signal Design Techniques

As previously discussed satellite communication systems generally have the problem of multiple access. The satellite repeater, in conjunction with the modulation employed and the procedures followed at the ground station, must allow the repeater output power to be shared between two or more signals. The number of users that must be served or signals that must be processed simultaneously is, of course, a function of the system requirements.

---

* See discussion in Section 2.2.2 for a detailed explanation of these terms.

The multiple access method or multiple access modulation is designed to accomplish two main purposes: (1) it must make possible separate reception of each signal passing through the satellite by any receiving station possessing the requisite demodulator, and (2), it must minimize the signals' interfering with each other as they pass through the satellite repeater. The three most common methods are frequency division, time division and code division multiple access.

Three resources are available in a satellite repeater: time, frequency and power. The three cited multiple access methods can be visualized as fitting into a three-dimensional domain of these resources as shown in Figure 2-1.

In frequency division multiple access (FDMA), the signals are maintained at different center frequencies so that a simple filtering operation will separate them at the receiver. Therefore, the signals can be present simultaneously but they must share the available power and bandwidth. In time division multiple access (TDMA) the signals from different sources are interleaved in time at the satellite; therefore each occupies the total available bandwidth and receives the total satellite power when present. Code division (or spread spectrum)* multiple access (CDMA or SSMA) uses specially designed, simultaneously present signals, each of which totally occupies the available bandwidth.

It is also helpful to consider the multiple-access modulation as a means of addressing the signal to the receiver. For example, in TDMA, the multiple-access modulation is a time-gating function which correctly locates each transmission burst relative to those of the rest of the network. The repeater output signals can then be separated by time gating. In constant-envelope SSMA, or CDMA, a wideband phase or frequency coding is inserted to provide carrier addressing. The different carrier entries into the repeater channel can coexist in the same channel with only minor interference by the selection of nearly orthogonal codes, that is, codes that exhibit a low cross-correlation. The repeater output signals are separated at a receiver by correlating them with a perfectly synchronized code identical to that used at the transmitter.

* Pseudonoise techniques represent one way of spreading the spectrum of a signal.

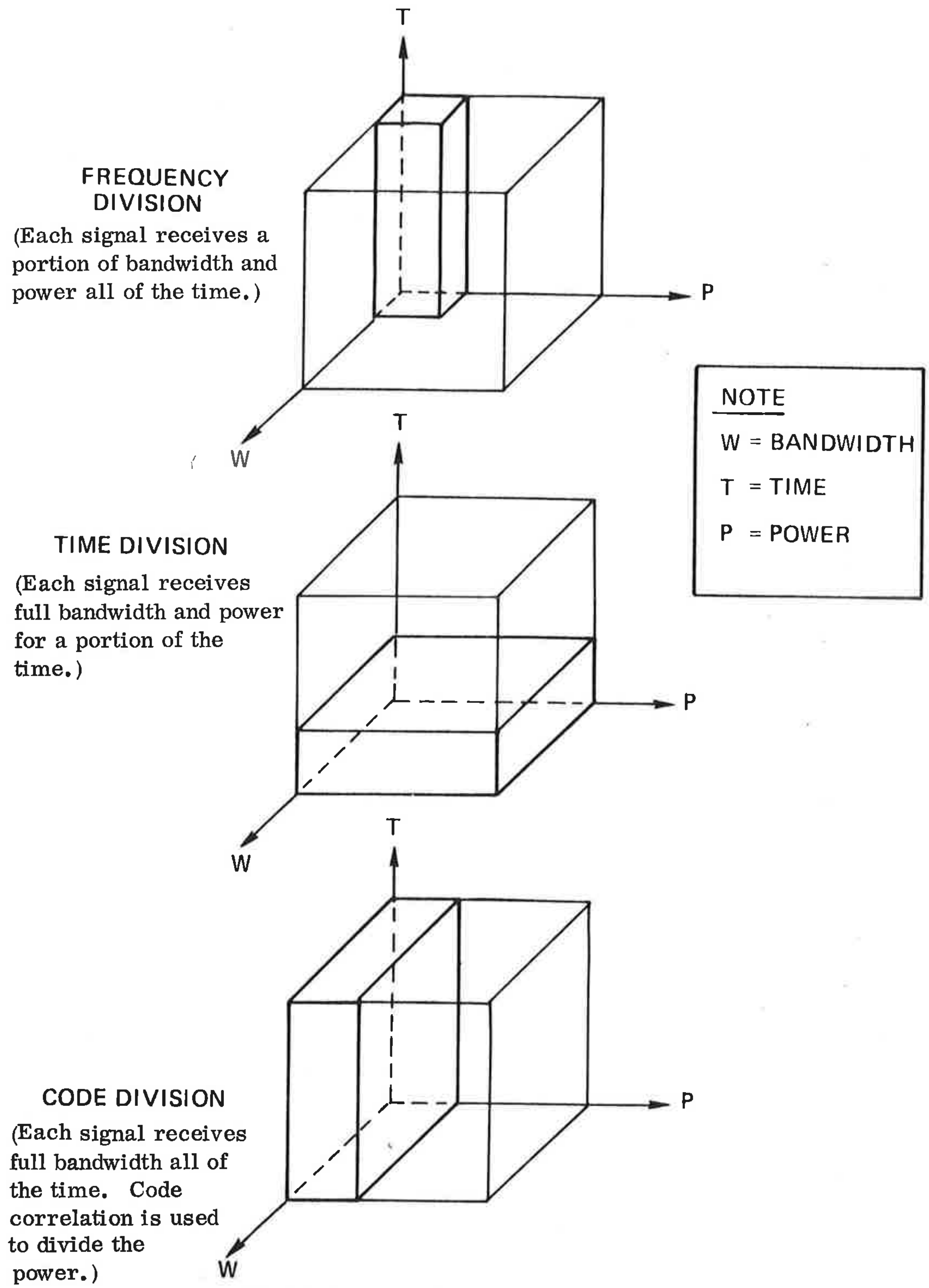

Figure 2-1 Multiple Access Domains

Each figure shows the distribution of resources to one signal under the appropriate method of multiple access.

When the wideband code is accomplished by phase shift keying the carrier it is often referred to as pseudonoise, and when frequency shift keying is employed the term frequency hopping is used.

In FDMA, the multiple-access modulation is not really a modulation in the strict sense; it is an a priori choice of carrier center frequency.

Just as in the discussion of message modulation, many factors influence the final decision in selecting the multiple-access modulation. The first and perhaps most important factor is the efficient use of the available satellite power. The cost of launching the satellite repeater is a function of the transmitter power. Thus, it is important that a multiple access technique be selected that uses the repeater power efficiently. The efficiency must be considered in terms of the overall capacity with multiple entries as well as with a single signal.

The second factor relates to the mechanics of how multiple access is achieved and maintained. FDMA or CDMA systems require control of the relative satellite input signal levels (not necessarily all equal), and TDMA requires that the transmission time of each entry be controlled accurately.

The total number of signal entries that the particular system is required to handle is also an important factor. For example, FDMA through a linear repeater could handle as many non-overlapping signals as the overall repeater bandwidth would permit, but a nonlinear repeater generates intermodulation products which can interfere severely unless special precautions are taken. To minimize interference from intermodulation, frequency assignments for an FDMA system can be chosen so that the spacing is unequal. This is only possible, of course, when the repeater bandwidth is large enough to permit such spacing. An alternative approach which is more bandwidth-efficient but less power-efficient is to linearize the satellite transmitter.

Another factor influencing the selection of multiple-access modulation is the performance that can be obtained with a mixture of transmitting terminal sizes. It may be necessary, for example, for the large terminals to reduce their output power to allow the small terminals to operate.

A factor related to communications requirements and operational flexibility is connectivity. The operation of any multiple access system requires some form of network control. This means that terminals must be able to communicate with one another as well as with a control station. This is especially the case if some degree of demand access is desired. Demand access is here defined as the situation in which there may be more users than available satellite entries, requiring that a user request entry into the system from the network controller. The requirement for interlink connectivity can very heavily influence the choice of multiple access technique.

Table 2-1 summarizes multiple access techniques.

2.2.2 Channel Access Principles

"Multiple access" is used to connote signal design techniques that permit a member of users simultaneously to communicate via some common medium. The multiple-access techniques considered in this report do not rely upon avoidance measures such as narrow-beam antennas and/or geographical isolation among different communication links, but rather on efficient spectral occupancy by a group of users who, by design, share some common spectrum in a satellite repeater channel. Channel access refers to the philosophy of useage of the communications channels.

To illustrate the tradeoffs that exist, it is convenient to define three basic forms of channel access:

a. Controlled access on a full-time assignment basis (hereinafter called Full-Time Access).
b. Controlled access on a nonpermanent allocated basis (hereinafter called Allocated Access or Demand Access).
c. Random Access.

"Full-time" accessing refers to those techniques in which each user is permanently assigned a transmit channel. Such assignments can be made on a noninterfering basis if appropriate signal design techniques are used so that in principle, one user

Table 2-1. Summary of Multiple Access Technique

TECHNIQUE	CHARACTERISTICS	ADVANTAGES	DISADVANTAGES
FDMA	CONSTANT ENVELOPE SIGNALS SIGNALS CONFINED TO NONOVERLAPPING FREQUENCY BANDS MA DEMULTIPLEXING BY FILTERING MESSAGE INFORMATION BY ANGLE MODULATION	NO NETWORK TIMING	INTERMODULATION IN REPEATER REQUIRES UPLINK POWER CONTROL
TDMA	SIGNALS FROM DIFFERENT LINKS NEVER PRESENT SIMULTANEOUSLY IN SATELLITE MA DEMULTIPLEXING BY TIME GATING MESSAGE INFORMATION BY ANGLE MODULATION WITHIN CARRIER BURST	HIGH EFFICIENCY IN USING SATELLITE POWER DOES NOT REQUIRE UPLINK POWER CONTROL PEAK POWER TRANSMITTER BANDWIDTH EFFICIENCY	NETWORK TIMING REQUIRED ANALOG TO DIGITAL CONVERSION REQUIRED
CDMA SSMA	CONSTANT ENVELOPE CARRIERS TRANSMITTED SPECTRUM IS SPREAD OVER SATELLITE BANDWIDTH MA DEMULTIPLEXING BY CORRELATION WITH LOCAL REFLICA OF CODE MESSAGE INFORMATION BY ANGLE MODULATION	NO NETWORK TIMING REQUIRED CAN USE FIXED-ADDRESS ASSIGNMENTS INTERFERENCE RESISTANT	LINK SYNCHRONIZATION REQUIRED UPLINK POWER CONTROL REQUIRED BANDWIDTH INEFFICIENCY

Table 2-2. Channel Accessing Characteristics

Type	Mutual Interference	Access Delays	Access* Control Required
Full-Time	NO	NO	NO
Allocated	NO	YES	YES
Random	YES	NO	NO

Type	Nature of Performance Tradeoff
Full-Time	Large total bandwidth required for low duty cycle users
Allocated	Large total bandwidth required for high probability of immediate access
Random	Large total bandwidth required for low interference (high SNR output or low P_e)

* The term specifically refers to the requirement for all nodes of a multiple-access network to be continually informed of the access assignment status of all other nodes (decentralized control) or for a master control node to make all assignments.

2.2.3 Demand Access Variability

Demand access as defined above and applied to allocated satellite multiple-access systems can now be examined in greater depth to bring out some other interesting characteristics resulting from a further subdivision of the general term. The subdivision occurs in accordance with the way the originating and destination channel connections are made in the satellite network and can be stated as:

- Semivariable
  - Variable Origin
  - Variable Destination
- Fully Variable.

The various types are illustrated in Figure 2-2. A variable origin configuration consists of receiving stations permanently assigned to a return satellite channel, and the transmitting stations are assigned to a forward satellite channel on demand according to the destination of the traffic being served. A variable destination configuration is one where the uplink channels are permanently assigned to a transmitter station, and the downlink channels are demand assigned to the receivers, according to the destination of the traffic being served. A fully variable configuration has both the uplink and downlink channels assigned on demand, as needed.

A comparison of the fully variable demand-access scheme with the other two semivariable schemes yields the following advantages for the fully variable:

a. The forward and return circuits may be permanently paired. This simplifies the selection process.
b. Implementation of a. insures that blocking will not occur by failure to find both a forward and return channel.

Contrasting these points, it can be argued that the other two demand-access schemes have an advantage over the fully variable scheme in that a number of channels is allocated to each ground terminal for its own exclusive use. However, there is little sense to insuring, say, the forward channel, if the corresponding return channel cannot be attained due to blocking. In general, the fully variable demand-access scheme offers more advantages than either of the semivariable or the preassigned schemes.

2.2.4 Control Philosophy for Demand Access

Demand-assignment systems require network control and coordination to monitor and assign the available channels from the network pool of channels. Two approaches are possible: centralized and decentralized (or distributed). In decentralized control for a generalized satellite system, each earth terminal contains a computer that contains the status of channel pool assignments in use and available for use. A network control orderwire is required to continually communicate changes in network status to all earth terminal computers. This approach to system control, although costly, prevents any one terminal or location in the network from assuming autonomous network control (important in some military systems). The COMSAT SPADE system uses such a decentralized control scheme.

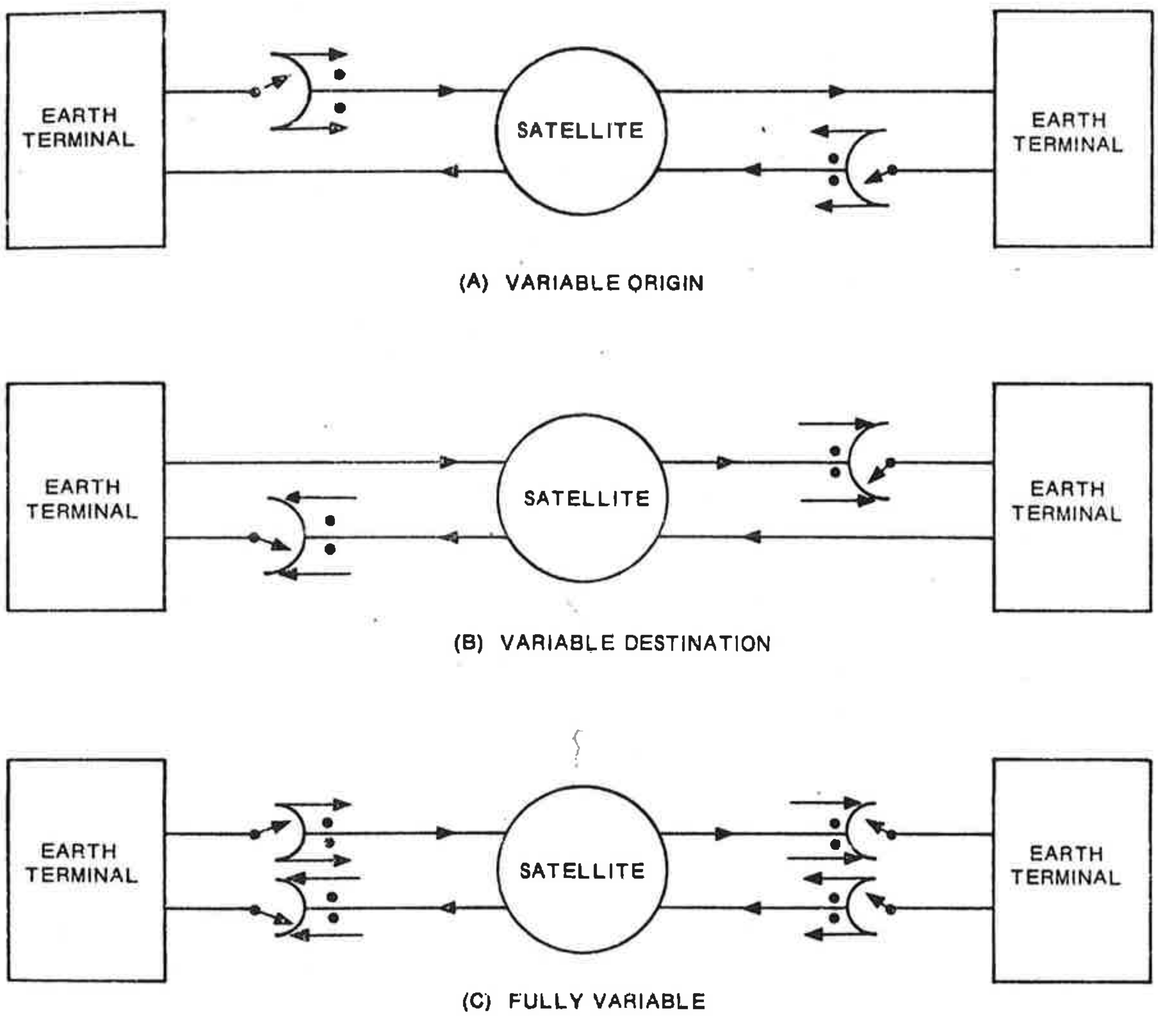

Figure 2-2. Demand Access Types

In centralized control as the name implies, each earth station must request channel assignments from a master control terminal.

For AEROSAT, the situation is somewhat unusual among satellite systems. The cost of the equipment on the aircraft is an important factor. The communications connectivity needed is largely a fan-in, fan-out situation between ATC centers and the aircraft in the system. In addition, surveillance is included in the system. These three factors combine to make centralized control the logical choice for channel assignment to aircraft and ground users.

There are, however, several factors which make the use of a single master control center impractical in the AEROSAT system. Thus, at least two and possibly three Aeronautical Satellite Control Centers (each having the channel control jurisdiction over a specific group of aircraft) will exist in the system. These centers (ASCCs) must must also share the satellite capacity in some manner. Centralized and decentralized methods are possible. In the centralized method one ASCC would act as master and the others would request channels as they needed them, in turn, to assign to their aircraft and ground users. These requests can be structured on a short term message by message basis (applicable for voice) and a long term basis as overall demand varies (applicable for short messages such as data). It is also possible to request on a message by message basis for data but this implies the use of one ASCC to transmit all data messages with all other ASCC's routing data messages through it.

In the decentralized method, each ASCC is semi-permanently allocated a specific portion of the available channels which they independently assign to their users. The allocated portions can be varied with time as the ASCC loads change with traffic conditions on a long-term basis. The decentralized method, although simpler to implement, can seriously affect the queuing time under certain conditions.

Therefore, AEROSAT may use a combination of centralized* (intra-ASCC) and decentralized (inter-ASCC) access control methods.

* Actually some of the seizure methods of access control are simplified methods of decentralized control.

the header and channel dwell times must be appropriately oversized to assure reliable detection. Channel scanning is most appropriate to time division systems. Upon receipt be an aircraft of its address and a channel identification code, the system proceeds as in the semipermanent assignment case.

2.3.2.3 Supervisory Channel Assignment

This method uses a supervisory channel apart from the communication channels which all aircraft monitor. Aircraft are addressed over this channel and are told over which channel a message is coming and the message type (voice or data). It is also possible to include within the supervisory channel, at the expense of channel capacity, short messages. In this case, an ARQ strategy could be used via a return supervisory channel. After aircraft tuning is accomplished, the aircraft transmits an acknowledgment over the paired return communication channel, and either voice or data (possibly using a block ARQ strategy) transmission commences.

2.3.2.4 Method Selection

The choice of these methods depends upon:

- The particular system configuration; i.e., whether multibeam or not, whether a global coverage antenna is available
- The multiple access method (e.g., TDMA beam-hopping methods can easily incorporate a channel scanning doctrine)
- The expected message length distribution
- Whether or not surveillance is included in the system
- The channel and resulting constraints imposed on message block length due to burst errors.

2.3.3 Access Control Methods for Air-Originated Traffic

Table 2-3 presents a number of methods by which a field of aircraft users can gain access to the capacity of a satellite system. These methods apply mainly to access of two-way channels. In this table, a message consists of a transmission of information to be transferred (with routing information) or a signal designed only to cause a route connection to be made at the ground complex (e.g., to set up a voice conversation). On the other hand, a call is a transmission designed to enter the desire to establish communications into a system control function. In some of the methods in Table 2-3, both messages and calls relating to other messages (for example, voice or long data messages) can be combined.

The methods are broken into two groups: those which permit direct communication channel entry and those which use an access control or calling channel to indicate a desire to communicate.

Acknowledgment of a message or response to a desire to establish two-way communications (for example, voice) in the seizure approaches, and response to a call in the calling approaches, would use a forward communication channel or supervision channel, depending on how the ground-originated access control is organized. In the calling approaches, this response could include channel assignment or estimated waiting time. The latter gives the aircraft the option of waiting or requesting again under a higher priority.

In the calling approaches, the call may include channel-type needed (one-way or two-way) message type (voice or data), and message priority (routine or urgent), in addition to addressee and originator identifications.

It is possible to use hybrid methods wherein approaches are combined and/or augmented with certain features of each other.

2.4 UNIQUE AEROSAT CONSIDERATIONS

The AEROSAT operational environment and the potential configuration of the AEROSAT L-band antenna require that additional factors be considered in the solution of the access control problem. These considerations involve coverage and connectivity.

The discussion of system connectivity will be limited to the functions of and interrelationships among the spacecraft, aircraft and ASET(s).

The general connectivity needed is shown in Figure 2-3. Each Air Traffic Control Center (ATCC) must be able to access via the satellite any aircraft located within

Table 2-3. Communication Channel Access - Control Methods for Aircraft Originated Traffic

METHOD	DOCTRINE	OPERATIONAL IMPLICATIONS	COMMENTS
Seizure Methods			
Channel Seizure Without Observation	Aircraft seizes and transmits message on any channel selected at random without regard to occupancy of channel.	Simple method, but interference probability is high for a heavily loaded system. Therefore, inefficient channel usage is necessary for acceptable performance.	This method will not be considered.
Channel Seizure With Observation - Type 1	Channel occupancy observations are made by tuning through received channels. User then transmits message on an unused channel. Acknowledgment or response comes by some forward channel.* Cross band repeater implementation may require introduction of an occupancy signal on forward half of channel or A-G message turnaround or equivalent.	Simple, but workload on operator is greater unless tuning can be automated (i.e., a scanning receiver). Interference probability is still high for a heavily loaded system where users are waiting to access system due to the round trip propagation delay.	This method is most easily applied to Configuration C and C-1 TDMA approaches because channel scanning is inherent in the system, and a relatively large number of channels are available.
Channel Seizure With Observation - Type 2	Channel occupancy indicators are included in a broadcast transmission. User chooses a clear channel at random and transmits message. Acknowledgment or response comes by some forward channel.	This obviates need for automated receiver scan but interference problem is the same as Type 1. The broadcast transmission can be used to resolve interference problems.	The broadcast transmission requires satellite power, whereas the Type 1 occupancy signal uses unused communication channel access.
Calling Methods			
Random Calling	Aircraft enters a calling channel at random with a short calling message. Acknowledgment and channel assignments come by forward channel.*	If random channel is properly designed, waiting time to introduce call can be made to approach channel delay. If a forward supervisory channel is used, random calling minimizes its load for channel supervision.	Call must be short and relatively infrequent for random channel to work acceptably. Particularly useful for emergency channel access.
Ordered Calling - Type 1	All aircraft periodically enter the calling channel with a calling message designating whether or not a channel is needed.	Interval between calls determines maximum time to introduce a call. Of interest when surveillance is included because surveillance report or waveform sample can be combined with calling message.	A synchronization method is needed which, in general, can be derived from a forward supervisory channel. Means can be devised to make calling interval flexible for some limited fraction of the aircraft; particularly useful for surveillance purposes.
Ordered Calling - Type 2 (Poll)	Same as Type 1 except that the calling message is generated in answer to a forward poll.	The interval between polls determines maximum time to introduce a call. Also of interest for surveillance applications. Polling channel usage is low because of low-duty cycle of users (i.e., answer to poll is no most of time). If poll interval is lengthened to reduce percentage of "no's," waiting time to introduce a call increases.	The forward poll serves as the synchronization waveform needed in Type 1. This inherent ground control of synchronization leads to significant flexibility in calling interval, surveillance update, etc.

*Depending on how ground-originated access control is organized.

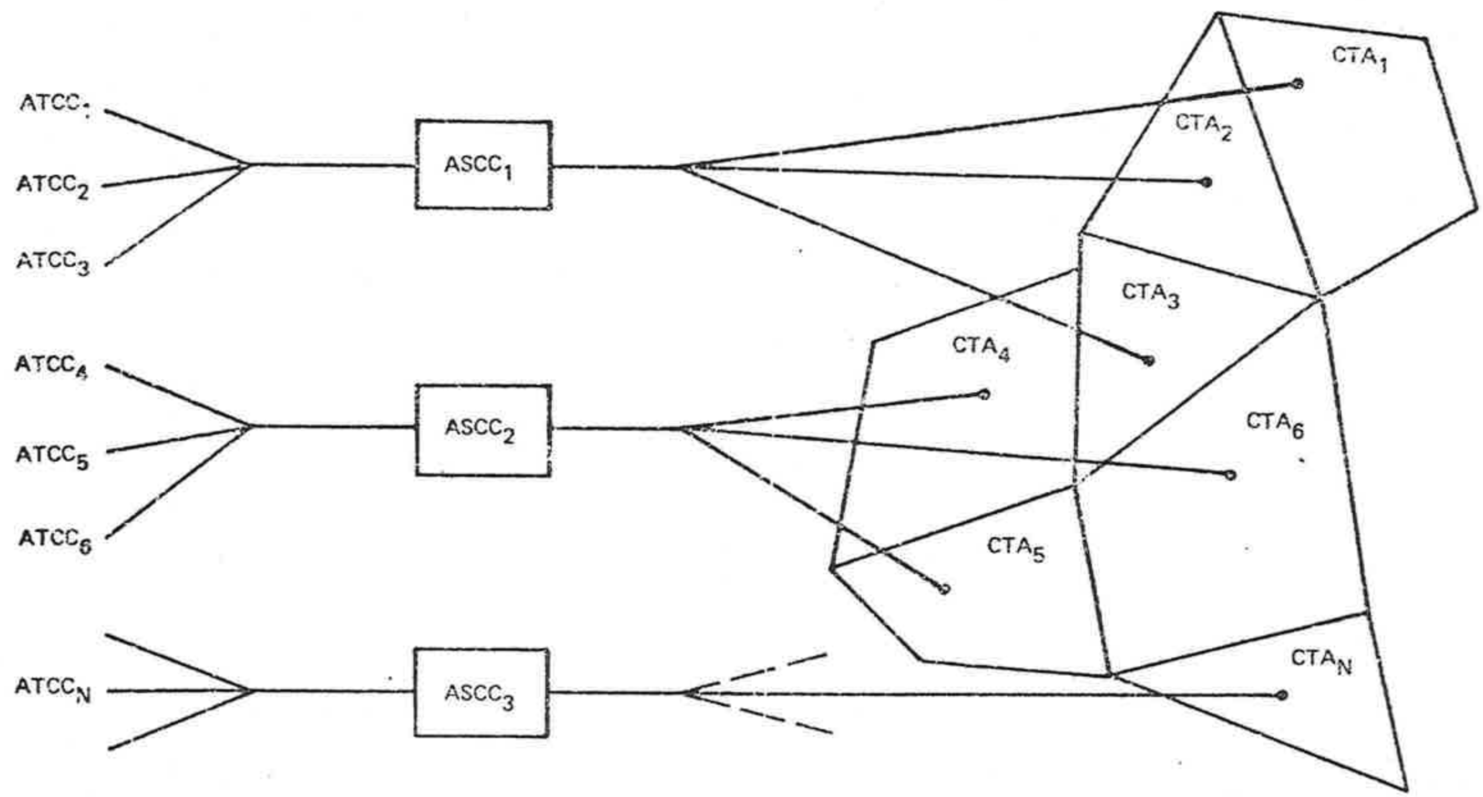

Figure 2-3. General System Connectivity

its CTA/FIR.[1] In this diagram, neither the satellite nor ASETs are shown because their number and relationships are unspecified in the basic connectivity. It is assumed, however, that some data processing functions are done by some number of ASCCs. There is no apparent requirement for more than one ATCC to access any given CTA. (In any practical system, coverage of any CTA will extend to some extent into adjacent ones so that surveillance and communications, if necessary, are available before handover is effected.)

The design of spacecraft antenna radiation patterns to provide coverage of aircraft within the field of view can be done under several philosophies:

1. Use of one antenna to cover the entire field of view of interest
2. Use of one or more spot beams to cover route areas of highest traffic density superimposed on a broader beam covering the entire field of view of interest.
3. Use of a cluster of spot beams arranged and oriented so that a few of them cover high-density route areas and the rest cover the balance of the field of view.

The advantage of the first philosophy is spacecraft simplicity but the resultant low antenna gain requires very high RF power per channel. The second philosophy improves the situation for those routes included within the high-gain coverage. An antenna aperture is needed on the spacecraft commensurate with the narrowest beam dimension desired. The provision of capacity via the wide-coverage antenna to other areas within the field of view still requires higher RF power as in the previous situation. Although complicating the spacecraft communication subsystem somewhat, the beam cluster approach (properly oriented) has the advantage of potentially lowering the RF power requirements on both the spacecraft and aircraft for the same capacity. The latter two coverage philosophies, and their extensions to very large numbers of beams, are most applicable to the nonbroadcast situation, that is, where each aircraft in the

[1] We will assume that FIR (Flight Information Region) and CTA (Control Area) are identical.

field of view receives a different message. Broadcast applications can also be served, but with some power and bandwidth penalties and are, therefore, in general best served by broader, full-coverage antenna patterns. The only true broadcast function relating to the aeronautical communications problem is possibly the surveillance channel.

One can see that the relative relationship between the connectivity needed from any given ATCC and/or ASET and the coverages provided by the Aerosat antenna configuration has a large influence on the design of access control methods, particularly the use of supervisory channels.

SECTION 3 - SUMMARY OF ACCESS CONTROL STUDIES

This section presents the results of the three access control studies considered in this report. These results are presented factually as they were originally reported by the study teams, and no attempt has been made here to recommend AEROSAT access control techniques. Such recommendations will be presented in Section 4. For each study, a summary of the methodology utilized, the access control techniques considered, and the conclusions obtained are presented in this section.

3.1 SYSTEM ACCESS CONTROL STUDY (BELL AEROSPACE)

This section presents a summary of the work accomplished during the study on System Access Control by the Bell Aerospace Company. The objective of the study was to obtain detailed descriptions of equipment and interfaces for promising access control techniques which are applicable to an aeronautical satellite system.

3.1.1 Methodology

Emphasis in the study was placed on systems capable of providing voice, data and independent surveillance services. Six candidate configurations using either frequency division or time division techniques were investigated. The basic method of operation and sets of flow diagrams were developed so that comparative evaluations could be made of workable systems. Provisions were made for different types of entry, beam switching, and for setting up communications between mobiles anywhere over the oceanic area and various ground terminals. The interactions of the access control techniques with signal designs were considered wherever appropriate.

A queuing simulation and supporting analysis was carried out simultaneous with the formulation for the systems concepts. The simulation verified that results obtained from the application of conventional queuing theory are valid. A set of charts developed from the theory is useful as a design tool helpful in evaluating and comparing channel management strategies.

Descriptions of all the candidate configurations were presented in the final report. However, based on a comparative evaluation an FDMA concept, identified in the study as System C, and a TDMA system, identified as System F, rated highest and were presented in greatest detail. Preliminary designs of the avionics instrumentation for these two systems and a summary listing of avionics element costs were included.

The format of the Universal Digital Data Link (UDDL) was used in the selected FDMA system instrumentation to provide for the transmission and reception of all supervisory data required for channel accessing. The data-link channel was also used for surveillance polling with the surveillance signal multiplexed in quadrature with the data carrier. Full duplex channels were used for both data and voice.

A separate supervisory channel multiplexed with a surveillance signal in a single framing burst was used in the selected TDMA system. All other bursts represented communications channels which can be used for either voice or data. The air-ground transmissions are handled as FDM. Corresponding to each burst in an uplink frame, there is a downlink frequency channel.

The main advantage of the TDMA is the elimination of intermod products and operation of the satellite power amplifier at maximum efficiency. However, much of the advantage is lost because of the increased channel overhead associated with each burst.

The selected FDMA and burst TDMA systems described are comparable in operational capability. Access capability from any ASCC/ASET to any mobile anywhere over the ocean is provided. In the TDMA system, time synchronization of each ASCC/ASET to the master which transmits a framing burst is required. This is achieved by monitoring the L-band transmission from the satellite. Rapid beam switching on a burst-to-burst basis is also required. Therefore, a command channel to the satellite which furnishes a timing reference and the switching sequence must be supplied. For FDMA, the satellite must have the capability of switching individual channels to various spot beams. Precise timing is not a requirement.

3.1.2 Access Control Techniques

3.1.2.1 FDMA Systems

In this section the FDMA systems analyzed during the Bell study program are described. The three frequency division multiple access systems all provide voice, data and surveillance services under fully loaded conditions. The differences between the three systems are associated primarily with the manner in which the supervisory control data is handled, and secondarily the manner in which channels are allocated among the ASCC's of the system. The variations may be summarized as follows:

System A. Separate supervisory channel transmitted via an earth coverage antenna; central management of voice channels.

System B. Separate supervisory channel transmitted via spot beams; central management of voice channels.

System C. Supervisory data for AEROSAT integrated into standard data-link; distributed management of channels.

It is apparent that the differences are evolutionary rather than revolutionary. In System A, the supervisory data, in digital form, is multiplexed with the surveillance signals on a separate carrier and transmitted from the master ASCC to all aircraft on an earth coverage beam. Quadrature modulation is one efficient technique for combining the two signals, which conserves satellite power. System B is similar to System A except that the surveillance and supervision (S&S) signals are transmitted via spot beams, thereby taking advantage of the extra antenna gain. The S&S signals are sequentially switched from beam to beam to obtain oceanic coverage. In System C, the supervisory data is transmitted in combination with other data on a "standard format" data channel. Each aircraft continuously receives an assigned data channel and monitors a sequence of fixed length messages transmitted thereon for self address signifying independent surveillance polling commands and a normal data-link interchange. Surveillance signals are multiplexed onto the data-link carrier. By multiplexing both the supervision and surveillance onto the data-link channel, satellite power usage for these functions is minimized. Each ASCC manages its own channels and performs its own surveillance.

Method of Operation of System A

The distinguishing feature of System A is the use of a separate supervisory channel on which are transmitted low data-rate signals for channel access control and surveillance polling. The supervisory signal is multiplexed with the surveillance signal and transmitted via an earth coverage antenna for simultaneous reception by all mobiles. The ASET/ASCC, designated as the Master, transmits and receives the supervision/

surveillance signal to and from all mobiles equipped to utilize the service. Uplink transmission is continuous. All aircraft in the system continuously monitor this S&S channel, maintain lock-on and synchronization and respond when sequentially polled via a system address. Fixed length polling slots are used in the supervisory data channel with a duration which is compatible with the surveillance signal processing requirements and the information to be transmitted. The data rate is selected to minimize satellite power requirements.

The communication channels in the system are designated by the master ASCC as either data or voice. They are transmitted G-A via spot beams in each of the satellites to the areas of the ocean requiring communication service in response to switching commands received by the satellite control facility (SCF) from the ASCC. In the A-G direction, either earth coverage or spot beams are used depending on the particular satellite design.

Digital data links are assigned to each of the ASCC's for relatively long periods and are managed separately at each center. All aircraft are assigned a data link channel to monitor, corresponding to the ATCC-ASCC having responsibility for their control. The message formatting and queue management are accomplished by the local ASCC. However, queue status information is transmitted to the master from each local ASCC for overall system management. Data channels can be assigned or reassigned based on overall demand. All data transfer is handled on a priority basis in accordance with standard data-link practices. Ground requests and messages funnel directly into the ASCC while airborne requests for data transmission are received by the master and forwarded to the appropriate ASCC for entry into the queue.

Because of the existence of the separate supervisory channel, periodic polling via the data-link is not required. Message traffic is handled purely on a demand assignment basis. Either variable length or fixed block length messages can be used.

The uplink data transmission is continuous so that all aircraft can stay locked-on and synchronized, and reply when the correct address is received. In the downlink transmission, provision is made for guard time, acquisition and synchronization. The acquisition time can be held to a minimum if the supervisory/surveillance signals are coherent with the data transmission so that doppler information obtained from the former can be used.

Voice channels are allocated on a request/grant (with priority) basis entirely under control of the master ASCC. Thus, a central queue is maintained for all the voice channels in the system. The ground-to-ground link is used to receive and transmit requests and make temporary assignment of voice channels among the ASCC's of the system. The actual voice transmission takes place between the local ASET/ASCC to the mobile involved.

Description of System B

System B differs from System A in the manner in which the supervisory and surveillance (S&S) signals are transmitted to, and received from, the aircraft in the system. In System A, the S&S signals are transmitted and received via an earth coverage satellite antenna. To enable some savings of satellite power and/or provide additional margin for the G-A link, a system instrumentation was investigated wherein the S&S signal at one unit of power level is transmitted sequentially via the contiguous spot beams to all areas of the ocean. The capability of switching the S&S channel amplifier in the satellite to the individual spot beams is assumed. The S&S signal is received in only a single spot beam area at any given time at an adequate power level. The need for an earth coverage antenna in the satellite for surveillance signal transmission is eliminated. The principal drawback in this instrumentation is that quite frequent beam switching is required to provide high rate polling to several aircraft each of which may be in a different spot beam. This results in attendant delays while aircraft in an area reestablish synchronization. The lengthening of total S&S servicing time (epoch) for all aircraft, with a typical distribution of aircraft communicating at a high message rate is, however, not severe and the concept is quite workable. It was felt that since regular surveillance polling would not optimally be programmed in one or more areas any more frequently than once per epoch (no aircraft in area on high polling rate), that it would be best to provide emergency signalling over a separate low speed A-G channel. An earth coverage receiving antenna in the satellite is utilized.

The supervisory data channel format for System B is essentially identical to that for System A, except that an emergency signalling channel is added.

Description of System C

The design of System C follows as a logical extension to Systems A and B described in previous sections and is based on the following rationale.

The Universal Digital Data-Link duplicates within its format many of the channel management functions required of the supervisory signal and is transmitted via spot beams. Since, as in System B, the supervisory signal is also transmitted via spot beams, it is efficient to combine the two signals into a single 1200 bit per second stream based primarily on the UDDL format. Most of the communications to and from a mobile will be to a particular control center via a local ASCC. If that ASCC is allocated, a group of voice channels in addition to a data-link/supervisory channel for management most ground or airborne requests can be handled on a local basis. This distributed control will eliminate the necessity for processing of all ring-up and grants from the master ASCC and reduce G-G supervisory message traffic. If the waiting time allowances are not too restrictive, the implementation of a distributive control discipline does not impose severe penalties on the allowable message loading per channel. If the surveillance signal is quadrature modulated on the data-link carrier, the additional satellite power for this signal is negligible.

Each local ASCC designates at least one of the channels assigned to it as a supervisory/surveillance/data (SS&D) channel and uses it to manage the allocated voice channels, transmit and receive digital data, and control surveillance polling. The aircraft under control of the oceanic air traffic control centers (OATCC) which interface with a given ASCC continuously monitor the data-link channel emanating from that ASCC, thereby maintaining lock-on and synchronization. The SS&D signal is transmitted as a continuous 1200 bps bit stream which is subdivided into fixed block-length messages whose minimum duration is compatible with the surveillance signal.

The local ASCC's may compute position location for the aircraft under their individual supervision. Each time an aircraft is polled, it replies on a single frequency with multiplexed SS&D information.

All A-G SS&D messages are transmitted via two paths providing full downlink supervisory and data message redundancy. While each transmission of an SS&D message contains its own error checking, the redundant transmission of supervisory and data message will considerably enhance the probability of receiving correct messages.

Beam or channel switching in this system is minimized. For the SS&D channel, it is only required where the oceanic area serviced by a particular ASCC is covered by more than one spot beam and it is not resource effective to put a channel in each beam.

3.1.2.2 <u>TDMA Systems</u>

This section presents a review of the general category of time division multiple access (TDMA) types of instrumentation evaluated during the study. Although time division techniques were considered for both up and downlink transmission, they are used uplink only. This is because of the complexity in synchronizing the transmissions from the mobiles. Thus, the options described are hybrids using time division uplink and frequency division downlink.

Two basic types of time division techniques were considered. These are a bit-by-bit multiplex and a burst multiplex. Two different instrumentations for the bit-by-bit multiplex and one burst concept were detailed to permit comparison. The burst multiplex instrumentation ranked highest in the comparison. The two bit-by-bit multiplex concepts are presented first in this section while a more comprehensive description of the selected burst TDMA concept is presented last.

<u>Single Multiplex Per Satellite (System D)</u>

The basic uplink digital multiplex consists of a bit-by-bit multiplex of a number of communication channels and is framed by a synchronization, surveillance and supervision (SS&S) channel. A separate supervisory signal is thus used for channel management. The bit rate per channel is 19.2 kilobits per second corresponding to that used in delta voice modulation systems being proposed for AEROSAT. A channel used for data is transmitted at 16 chips per information bit to provide 1200 bits/sec with the same power as a voice channel. The uplink multiplex is formatted at the ASCC. It is composed of the voice and data inputs forwarded to the ASCC from the ATCC and company terminals connected to it.

Corresponding to each multiplexed uplink channel, including SS&S, there is a separate downlink frequency channel to provide a full duplex capability. Voice and data are transmitted downlink on separate carriers using the same type of digital modulation system. A typical S&S reply consists of a multiplex of supervisory data and a ranging signal. The basic features of the system are:

- One communications and surveillance multiplex per satellite, or a total of two, each on different frequencies, are available during noneclipse times. Each multiplex uses full satellite power.
- Each uplink multiplex carries a combination surveillance, supervision and multiplex-synchronization (SS&S) channel plus a fixed number of communication channels dependent on satellite power available. Each communications channel may be used for either voice or data information and has a quality of at least 43 dB-Hz.
- The two multiplexes can conveniently be transmitted from at most two ASCC's. Therefore, all ATCC's and company terminals in an oceanic area must interface with one of the ASCC's which generate the multiplex.
- Each aircraft is assigned a multiplex frequency/channel to tune to while in a given area. Additionally, each aircraft is assigned a digital channel within the multiplex to monitor.
- All aircraft in the oceanic area would be provided with a rapid access channel that could be used to signal either a desire to enter the system on a random (pop-up) basis or to signal an on-board emergency situation.

- During eclipse the single remaining multiplex services the entire oceanic area.
- Each of the two multiplexes transmitted uplink, and containing one SS&S channel, has a companion downlink frequency channel for transponding SS&S information from the aircraft.
- The uplink supervisory data message provides for initial acquisition discrete address polling as well as regular repeated discrete address surveillance polling.
- Each ASET/ASCC, transmitting and receiving its own SS&S signals, processes the returns and computes the position of all aircraft under its jurisdiction.
- The multiplex area is related to the FIRS associated with the ATCC's interfacing with the ASCC generating the multiplex.

Two Multiplexes Per Satellite (System E)

Use of a single bit-by-bit multiplex per satellite requires that all of the facilities of a satellite be beamed to a single area of the ocean. In some cases this results in more channels than are required in some of the sparsely populated areas of the ocean at a given time. When voice communication is involved, the multiplex could reside in a location for relatively long periods of time with many of the channels idle while other areas not then receiving service may experience heavy queuing.

To minimize the total number of channels switched and to permit greater overall flexibility, two uplink multiplexes per satellite are provided for the second bit-by-bit multiplex studied. They are similar to the first multiplex scheme except that each uses approximately half the satellite power. Each contains its own supervision, surveillance and synchronization channels. Thus, there are available a total of four multiplexes and these can be allocated to up to four ASCC's. For many allocations the multiplexes can be dedicated to particular beams where the aircraft population is high, thereby minimizing the total switching required. During any period when a multiplex is switched, only half the satellite capacity is changed. This is advantageous during eclipse operation when a single satellite services an entire ocean. On the other hand, during some situations when both multiplexes in a satellite service a common oceanic area, and with transmission through a common amplifier, intermod products are not completely eliminated.

The basic features of the system are:

- Two communications and surveillance multiplexes per satellite, or a total of four, are available during noneclipse times. Each multiplex operates in a separate frequency channel.
- Each multiplex carries a combination surveillance, supervision and multiplex synchronization (SS&S) channel plus communication channels that may be used for either voice or data information.
- Each aircraft is assigned a frequency/channel to tune to while in a given area. Within a multiplex each aircraft monitors a data link channel.
- System supervision can be distributed among up to four ASET/ASCC's or contained within a single ASET/ASCC depending on whether or not the multiplexes are transmitted uplink from a single ASET/ASCC.
- The downlink SS&S return would typically consist of a 19.2 kilochip bit stream carrying a sequential multiplex of synchronization, surveillance and supervisory return information.
- Each ASET/ASCC, transmitting and receiving its own SS&S signals, also processes them and computes the position of all aircraft under its jurisdiction.
- Random entry or emergency signalling would be done in a manner essentially identical to that for the single multiplex per satellite.
- Discrete address polling is used for normal entry polling.

Description of Burst TDMA System (System F)

A burst TDMA concept is presented in sufficient detail to permit study of the system access characteristics. It is adapted to the peculiar requirements of AEROSAT. The concept utilizes a single burst TDMA per satellite incorporating in each a means for TDMA system supervision, a means for surveillance ranging and a means for communicating between any ground station to any aircraft located anywhere. A typical signal format is presented in the study to illustrate operation of the concept.

3.1.3 Conclusions

3.1.3.1 General

The systems described in this report indicate that there are several approaches which could be used effectively for surveillance and communications facilities management in the AEROSAT system. Although each of the systems is workable, they all have relative advantages and disadvantages. To aid in system evaluation, a comparison matrix was constructed during the early phase of the study. This is shown in Table 3-1. A set of numerical evaluation factors indicating relative ranking are included. Grading from 0 to 4 was used with 4 representing a highest score.

The five major parameters chosen for the matrix are:

	Relative Weighting
Avionics Complexity	5
Operational Capability	4
System Flexibility	4
Satellite Complexity	3
Ground System Complexity	2

Each of these is broken down into several factors which characterize each parameter.

To obtain an overall rating, the subparameter numbers in each category were multiplied by the category weighting factors. The following results were obtained.

Table 3-1. System Evaluation Matrix

	A FDM SEP SUP EC	B FDM SEP SUP SWITCH BEAM	C FDM DATA/SUP	D TDM/FDM 1 MULTI/ SAT	E TDM/FDM 2 MULTI/ SAT	F BURST TDMA/FDM
Avionics Complexity (Wt = 5)						
R-T Assembly	2	2	3	4	4	4
Communications Modem	3	3	4	2	2	1
Supervisory Processing	3	3	4	3	3	3
Surveillance Processing	4	4	4	3	3	2
Operational Capability (Wt = 4)						
Channel Access Capability	4	4	4	2	2	4
Channel Request Times	2	1	4	3	4	3
Access Thruput	2	2	4	3	4	3
Busy Probability/Waiting Time	4	4	2	3	2	3
Effective Channel Utilization	4	4	3	1	2	4
System Overhead	1	2	4	2	2	3
Spectrum Utilization	2	2	2	4	3	4
Degraded Operation	4	4	4	1	2	3
Eclipse Operation	2	3	4	2	3	4
System Flexibility (Wt = 4)						
Designation of Channels Voice/Data	4	4	3	4	4	4
Allocation/Reallocation of Channels	4	4	3	1	2	4
Adding/Subtracting Channels	4	4	4	2	2	3
Changing Bit Rate	4	4	4	3	3	3
Satellite Complexity (Wt = 3)						
Beam Channel Switching	4	2	3	4	3	2
Antenna Coverage	3	4	4	4	4	4
Ground System Complexity (Wt = 2)						
ASCC Interfaces	2	2	4	3	4	4
ASCC/ASET Complexity	4	4	3	3	3	2

System A	245
System B	258
System C	291
System D	220
System E	235
System F	260

System C rated best primarily because of operational capability and avionics simplicity. System F was rated second and slightly above System B. The overall operational capability of the burst TDMA is comparable to that of System C. However, it rated lowest in avionics complexity. Nevertheless, it should be remembered that the total cost differential is not excessive. It is pointed out that the ratings used in the evaluation are subject to variations which depend on the relative importance attached to the parameters and tend to be highly subjective.

The following paragraphs discuss the parameters involved in the system comparison.

3.1.3.2 Avionics Complexity

Avionics complexity is considered the most important evaluation parameter. Complexity has been chosen rather than cost because it is felt that the overall avionics cost for all systems tends to be about equal. This is because the relative cost for antennas and RF components tends to be high while the production cost of signal processing components (particularly digital modules) tends to be low. Complexity is more of a measure of the total number of circuits or active elements. It reflects initial design difficulty and ease of checkout and maintenance.

R/T Assembly

The FDMA systems use a double conversion receiver and are identical for all systems. The TDM systems use only a single conversion receiver and are identical for both types of TDM configurations studied. However, a double conversion receiver is equally usable and may have some tuning advantages.

It is concluded that a single R/T design is usable and valid for all configurations. The only difference between the various configurations is the number of channels supplied at the output of the second conversion. The number of independently tunable receiving channels is listed as follows:

Systems		
A, B	C	D, E, F
1 Voice	1 Voice	1 Digital Multiplex
1 Data	1 Data/Surveillance	
1 Supervisory and Surveillance		

Simultaneous reception is provided with an overall noise temperature of $1000^{\circ}K$. In the FDMA systems the number of channels can be reduced if the communications services supplied are reduced along with a reduced channel management capability. On the other hand, in the TDM systems the number of channels is increased if it is desired to monitor the output of both satellites.

The number of transmitting channels is:

A	B	C	D, E, F
1 Voice	1 Voice	1 Voice	1 Voice
1 Data	1 Data	1 Data/ Surveillance	1 Data
1 Supervisory and Surveillance	1 Supervisory and Surveillance	1 Rapid Access	1 Supervisory and Surveillance
	1 Rapid Access		1 Rapid Access

Transmission of only one carrier at a time is implied, thereby permitting use of a Class C amplifier. It is assumed that a surveillance reply preempts data and transmission of either of these interrupts voice. A missing data reply will automatically cause a ground request to repeat. An EIRP of 23 dBW is used in all systems.

Communications Modems

FDMA

The FDMA systems use separate modems for each received subcarrier. In Systems A and B, therefore, a separate modem is provided for the voice, data and supervisory and surveillance signals. The configurations identified in the study permit use of any AEROSAT compatible modulation technique for the voice or data channels. The S&S modem is designed for 300 bit/second data which is quadrature modulated with a surveillance signal. Phase-locked loops are required in the data modem and the S&S modem, and these permit search and acquisition of the carrier and bit sync within a 1-second time period when a special preamble is transmitted.

System C requires only two modems. These are an AEROSAT compatible voice modem and a surveillance and data modem. The latter is designed for 1200 bit/second data quadrature modulated with a surveillance signal. Search requirements can be met using phase-locked loops.

TDM

The time division systems are constrained to the use of digital modulation for all signals. In all of these, a comparatively wideband phase-locked loop is used.

In Systems D and E, the bit sync loop tracks a continuous incoming bit or chip stream. The rate is about 100 kHz. A special code is used in the SS&S channel to identify it and permit demultiplexing of the communications channels. The output of the demultiplexer provides 19.2 kchip/second delta mod voice or 16 chip/bit, 1200 bit/second data at the selected channel outputs. Subsequent demodulation is standard. Modulation for downlink transmission is accomplished in standard AEROSAT digital voice and data modulators.

Burst TDMA

In the burst TDMA system acquisition of phase and bit sync within every burst is required subsequent to initial frequency search. Three milliseconds of preamble is provided for this in the burst. In addition, memory is required to reduce drift, frame-to-frame, for those aircraft operating in remote areas. Typical loops are discussed in Appendix E of the Bell final report referenced earlier.

The modulators for downlink transmission are standard AEROSAT digital voice and data modulators.

Supervisory Processing

All systems except System C use a separate two-way supervisory channel. In Systems A and B, a 300 bit per second data channel is used to perform the functions. In Systems D and E, the same type of information is multiplexed into the communications bit stream, while in System F it is contained in the framing burst. The downlink supervisory information for the TDM systems is transmitted in a surveillance reply sequence.

Surveillance Processing

FDMA

Analog or digital ranging can be used in the FDMA systems. In Systems A and B, the signal is multiplexed with the supervisory data. In System C, the signal is multiplexed with the data-link signal. A signal quality of about 30 dB-Hz is assumed for System A while 36 dB-Hz is assumed for Systems B and C.

Processing involves lock-on and synchronization to the incoming signal and generation of a reply signal.

TDMA

TDM systems are constrained to the use of digital ranging techniques. In Systems D and E, a precision clock is locked to the incoming bit stream. A 32 chip code provides coarse ranging and ambiguity resolution. The TDMA system uses the same principle except that the precision clock is synchronized during the framing burst.

Operational Capability

This parameter is concerned with the effect of the multiple access scheme and channel management discipline on the overall ability of the AEROSAT system to provide communications and surveillance services.

Channel Access Capability

In Systems A, B, C and F, every ASET/ASCC can access every available satellite channel. In Systems D and E, G-A access must occur via the center generating the multiplex.

In the FDMA systems, access to a mobile is possible via any satellite channel subject only to channel (or beam) switching limitations in the satellite. In TDM and TDMA systems, access to a mobile is achieved only via one of the channels in the multiplex which the mobile is monitoring.

Since all systems use FDMA A-G, all ground terminals can be accessed from any mobile, subject only to satellite antenna arrangement.

Channel Request Times

This refers to the time required for requesting and obtaining use of a channel, not including the queueing time.

The major time delay in downlink access is the polling epoch time. This is greatest for System B and is about 20% less in System A. In Systems D and F, the polling epoch is cut in half while in Systems C and E multiple polls are used reducing the epoch time even more. Additional downlink access delays may occur due to G-G link delays in granting channels by the ASCC. However, this is on the order of seconds rather than minutes as in the above.

The delays in uplink access are minimal because of the direct connection via terrestrial links between the ATCC's and the ASCC's.

Emergency access, via dedicated A-G channels on a random access basis, is about equal in all systems. In distributed control, granting of channels requires smaller delays since all the ASCC's monitor the emergency channel.

Access Throughput

An important aspect of the channel management concept is the number of interchanges involved in processing a request. When a single supervisory channel is used with centralized control, as in Systems A and B, all requests are processed through the master ASCC. All channel requests initiated from ground terminals associated with an ASCC other than the master are transferred to the master via the G-G links. The grant is transmitted back over the G-G link. A similar situation exists for airborne requests to a terminal not connected to the master. The call to the ASCC must be transmitted via G-G links.

In Systems D and F, the number of such interchanges is reduced because of the use of two supervisory channels. Systems C and E have greatest flexibility in allocating channels to ASCC's for direct control.

Busy Probability/Waiting Time

A key parameter which is a measure of how effectively the available channels are used by the various centers to handle the message traffic is the queueing time. It pertains primarily to the voice channels and is a function of whether the channels are all kept in a common pool or whether they are allocated among the centers. Allocation among centers (or distributed control) represents increased queueing time. Systems A and B use centralized control while System C (as presently described) uses distributed control. In Systems D, E and F, the channels are split into separate multiplexes. Systems D and F represent a 2-way equal split of channels while System E represents a 4-way equal split of channels. In System C, the channels are allocated to the various ASCC's in accordance with message traffic.

Effective Channel Utilization

This parameter is concerned with how messages and/or conversations are packed into the channel. All systems use the voice channels on a demand assignment basis. Therefore, the only loss in utilization comes about because of the set-up and ring-up time between conversations. In terms of message durations, this time is expected to be small in all cases. Channel switching capability affects efficiency in the following manner. In the FDM and TDMA systems, individual communications channels can be switched on a demand basis to antenna beams covering sparsely populated areas. In System D, an entire multiplex must be switched, so that needed capacity may be removed from one area while providing excess capacity in another area. System E mitigates this effect.

For data channels all systems use demand assignment without polling except System C. Therefore, variable length messages are transmitted on these channels. By utilizing the message length information, efficient message packing may be obtained by the ASCC formatting the data stream. However, there may still be gaps. In System C, fixed block length messages are used in polled sequences. Therefore, transmissions occur to particular aircraft regardless of whether data is to be sent or not. Some loss in channel utilization is therefore incurred.

For air traffic control application, most messages are expected to be fixed length. The difference between use of variable length and fixed length messages is apt to be small.

System Overhead

This parameter is used to characterize the magnitude of the system power lost because of the access and channel management discipline. It is observed that in System C, there is a substantial savings in satellite power by absorbing the supervision and surveillance signals into the data-link channel. The TDM systems generally do not have any intermod losses. In the burst TDMA substantial improvement in overall efficiency can be obtained by reducing the preamble preceeding each burst transmission. One approach for doing this is to maintain chip synchronization between bursts among all the ASCC's in the system.

Spectrum Utilization

In addition to the intermodulation power losses associated with FDMA systems there are also interference problems to be considered. Signal frequency plans have to be designed to ensure that any intermodulation product which falls on a signal frequency is sufficiently small that the interference is negligible. This generally requires that a greater portion of the electromagnetic spectrum is required for an equivalent number of channels in the FDMA Systems A, B and C than for the TDM Systems D and F. System E, which is in a sense a hybrid, falls in the middle.

Degraded Operation

Factors to consider here are decrease in satellite power, extraordinary fading or scintillation. Systems which do not threshold, as is the case with some analog modulation techniques, are desirable under the above circumstances. Thus, this favors FDMA systems. In FDMA systems, channels can be easily dropped if there is an overall loss in satellite power. In Systems D, E and F which require digital techniques, there is more of a tendency toward thresholding. In System D, the entire multiplex degrades when the satellite power decreases. In System E, a multiplex can be dropped. In the burst TDMA, channels can be dropped by simply not transmitting during a burst if the power supply can adjust to the above.

Eclipse Operation

During an eclipse, the available channels are reduced to $\frac{1}{2}$. In Systems A and B, if surveillance service is to remain unchanged, the available communication channels are less than $\frac{1}{2}$ normal. In System C, a reallocation of data-link/supervisory channels may be required to provide sufficient voice channels for the message traffic. In Systems D and F, one of the two multiplexes is disabled resulting in single ASCC control of the SS&S channels. In System D, all communications are curtailed in oceanic areas other than that covered by the single multiplex. In System F full area coverage is provided but with fewer channels. In System E, one of the two remaining multiplexes can be continuously used in the principal North Atlantic area and the other can be switched to other areas as needed.

System Flexibility

Designation of Channels for Voice or Data

All systems have this capability. However, in System C one or more channels are dedicated for combined data and supervision.

Allocation/Reallocation of Channels to ASCC's

Greatest flexibility for channel allocation on an individual channel basis is obtained with the FDMA and burst TDMA systems. As long as the master ASCC maintains queues or is appraised of queue status by other ASCC's channels can be allocated to relieve build-ups. In Systems D and E, an entire multiplex must be reallocated.

Adding or Subtracting Channels

Adding or removing individual channels is easy in the FDM systems. It is not feasible in Systems D and E. Individual channels can be deleted in System F but it does not have the flexibility for adding channels as in A, B or C.

Changing Bit Rate

The bit rate can be changed from 1200 bits/second to 2400 bits/second by providing 2 units of power in a given FDMA channel. In TDM systems, two channels must be combined on a time basis resulting in a non-uniform bit stream which can be handled if provision is made beforehand in the avionics.

Satellite Complexity

This parameter refers to design and/or control aspects of the satellite which may be peculiar to a particular access scheme. (NOTE: Additional satellite design data may influence some of the ratings).

Beam/Channel Switching

Because spot beam coverage has been postulated, all systems require some degree of channel switching to provide full oceanic coverage. In System A, only individual communications channels need to be switched and only on the basis of demand.

In System B, in addition, the supervisory and surveillance channels need to be switched perhaps as often as 15 to 20 times per two-minute epoch. Furthermore, switching of the S&S channel must be accomplished such that it adds capacity to the communications channels already connected to a particular beam. In System C, the switching is minimized for the supervisory because multiple/data supervisory channels are used. Hence, one or more may be dedicated to a beam. Although beam switching is required in System D, the switching function consists of moving the entire power amplifier output from one beam to the next. The System E switching function is minimized because of the availability of more multiplexes as in System C.

In System F, beam switching is required on burst-to-burst basis. Therefore, a rapid beam switching capability is required along with the means for processing the instructions for switching sequence contained in the framing burst.

Antenna Coverage

As stated previously, all systems use spot beam coverage. An earth coverage antenna is required in the G-A link in System A to transmit supervision and surveillance. No uplink EC antennas are required in the other systems. All systems use earth coverage antennas A-G for emergency access. System F employs earth coverage for the communications reply channels. It can, however, be used in all other systems.

3.1.3.3 Ground System Complexity

ASCC Interfaces

Systems using centralized control (such as A and B) require processing of all requests and grants for voice channels at the master ASCC. The G-G links must be used for transmitting this information among the various ASCC for completing the circuit connections. With decentralized control, each ASCC manages its own channels and only queue status needs to be transmitted for possible periodic reallocation. Aircraft doppler must also be transmitted from the master to the local ASCC's to aid in data link lock-on and acquisition. In Systems C, D, E and F each ASCC having control determines aircraft doppler on its own. Position location is generated locally in Systems C, D, E and F while for Systems A and B the position data is transmitted via the G-G links.

Information transfer between the ATCC and the ASCC is comparable for all systems. In System D where only two ASCC's are possible, the links between some of the ATCC's may have to be quite long.

ATCC/ASET Complexity

The FDMA systems using single channel per carrier tend to require less information handling. Voice is transmitted straight through from the ATCC to the ASET at baseband. Data messages are handled on a store and forward basis. The ASCC formats the data stream. In TDM systems, the separation between the ASET and ASCC becomes less clear. The ASCC must multiplex all the channels together before transmission of the baseband signal to the ASET. This includes incorporation of the surveillance signal and supervisory information into the multiplex.

3.2 CSC REPORT

3.2.1 Methodology

The CSC study applied a system oriented approach to the access control problem. The authors went back to the fundamental requirements-oriented driving function of the system, namely the communication channel requirements in each AEROSAT coverage area. These requirements could be met with a number of different satellite antenna beam configurations. These antenna beam (coverage footprint) configurations thus became the fundamental distinguishing elements for the synthesis of five different baselines for comparison. These five configurations were as follows:

A	Global beam
B	Three beams (diverse sizes)
C	7-beam cluster
B-1	B plus a global beam
C-1	C plus a global beam

Within the constraints of available cost-effective launch vehicles, the communication capacity of each of these configurations was analyzed. The capacity feasible plus the nature of the antenna coverage then implied the most appropriate modulation, multiple access, and detection techniques. For example, technological factors in satellite repeater design make TDMA more appropriate to the multiple-cluster-beam configuration C than FDMA. The configurations and capacities are shown in Table 3-2.

Next, the access control techniques best suitable for each were selected. For example, configurations of lesser capability were assumed to require "tighter" or more stringently controlled access than those with more capacity.

The five selected system approaches were then analyzed in detail. Simulation techniques were used where necessary. In particular, a bit error rate modulation/detection simulator was used to ascertain the performance of various modulation techniques which could be applied. Then, an overall oceanic communication simulation was performed. This simulation applied a specific traffic requirements model (of North Atlantic air traffic) to each of the five selected systems, and provided

Table 3-2. Systems Analyzed

	SATELLITE TRANSMIT COVERAGE	MULTIPLE ACCESS	G-A CAPACITY	MODULATION/ DETECTION	SURVEILLANCE* CAPABILITY
A	Global Beam	FDMA	3	DPSK**/Costas	Dependent Independent
B	Triple 8 x 13 x 13 Beam	FDMA	3 →8° Zone 1 →13° E. 2 →13° W.	DPSK/Costas	Dependent Independent
C	Seven Beam Cluster	TDMA	11 + 1	Carrier Burst/ Mod. Costas and DPSK/Costas	Dependent Independent
B-1	Global + B	FDMA or TDMA	4 →8° Zone 0 →13° E. 1 →13° W.	Same as B	Dependent Independent
C-1	Global + C	TDMA	8	Same as A and C	Dependent Independent

*This is the assumed requirement. The provision of independent surveillance in configuration C requires more study.

**This will be referred to as differentially-encoded PSK (DEPSK) to distinguish it from the scheme where carrier phase during a bit is used as a detection reference for the following bit.

communication performance outputs such as delays and queue parameters. The five configurations were refined slightly on the basis of these results, and recommendations were made.

In support of the system study effort, side studies were performed as follows:

Avionics configuration study

Signal design in a multipath environment

Automatic Repeat Request (ARQ) analysis.

3.2.2 Access Control Techniques

3.2.2.1 Introduction: General Techniques Considered

The CSC Report emphasized the control of access to the AEROSAT system by the airborne users; it did not treat contention among ground users, the ASCCs, or the ASETs. The access control problem was separated into a forward (ground-air) and a return (air-ground) element. The former relates to which channels an aircraft listens to, and how. There were three methods considered: semipermanent channel assignment; channel scanning; supervisory channel. The return direction involves control of which channel an airborne user should transmit into. The techniques are summarized in Table 3-3.

3.2.2.2 Specific Application to Specific Configurations Analyzed

As mentioned, the CSC authors went on to select from the dozens of possible access control technique combinations those most applicable for each of the five system configurations previously developed. The matching of configuration and techniques is shown in Table 3-4. Note that in most of the cases a poll or control message of some kind was specified in the forward direction. Also note that it is in general necessary to explicitly treat on a separate basis the forward and return directions, the issue of emergency or pop-up access, and voice as opposed to data utilization.

3.2.2.3 Access Control Delay Analysis

A computerized simulation was applied by the CSC group in order to assess the performance of the five configurations. The results in terms of access control delay are shown in Table 3-5. It should be noted that these delays apply to a specific requirements model, and to the calculated system capabilities derived under a launch vehicle constraint. Thus it is not surprising that System C performs better than A, given its greater capacity (channels available).

A study of the results obtained using the assumed analog requirements reveals the following observations:

Table 3-3. Communication Channel Access - Control Methods for Aircraft-Originated Traffic

METHOD	DOCTRINE	OPERATIONAL IMPLICATIONS	COMMENTS
Seizure Methods			
Channel Seizure Without Observation	Aircraft seizes and transmits message on any channel selected at random without regard to occupancy of channel.	Simple method, but interference probability is high for a heavily loaded system. Therefore, inefficient channel usage is necessary for acceptable performance.	This method will not be considered.
Channel Seizure With Observation - Type 1	Channel occupancy observations are made by tuning through received channels. User then transmits message on an unused channel. Acknowledgment or response comes by some forward channel.* Cross band repeater implementation may require introduction of an occupancy signal on forward half of channel or A-G message turnaround or equivalent.	Simple, but workload on operator is greater unless tuning can be automated (i.e., a scanning receiver). Interference probability is still high for a heavily loaded system where users are waiting to access system due to the round trip propagation delay.	This method is most easily applied to Configuration C and C-1 TDMA approaches because channel scanning is inherent in the system, and a relatively large number of channels are available.
Channel Seizure With Observation - Type 2	Channel occupancy indicators are included in a broadcast transmission. User chooses a clear channel at random and transmits message. Acknowledgment or response comes by some forward channel.	This obviates need for automated receiver scan but interference problem is the same as Type 1. The broadcast transmission can be used to resolve interference problems.	The broadcast transmission requires satellite power, whereas the Type 1 occupancy signal uses unused communication channel access.
Calling Methods			
Random Calling	Aircraft enters a calling channel at random with a short calling message. Acknowledgment and channel assignments come by forward channel.*	If random channel is properly designed, waiting time to introduce call can be made to approach channel delay. If a forward supervisory channel is used, random calling minimizes its load for channel supervision.	Call must be short and relatively infrequent for random channel to work acceptably. Particularly useful for emergency channel access.
Ordered Calling - Type 1	All aircraft periodically enter the calling channel with a calling message designating whether or not a channel is needed.	Interval between calls determines maximum time to introduce a call. Of interest when surveillance is included because surveillance report or waveform sample can be combined with calling message.	A synchronization method is needed which, in general, can be derived from a forward supervisory channel. Means can be devised to make calling interval flexible for some limited fraction of the aircraft; particularly useful for surveillance purposes.
Ordered Calling - Type 2 (Poll)	Same as Type 1 except that the calling message is generated in answer to a forward poll.	The interval between polls determines maximum time to introduce a call. Also of interest for surveillance applications. Polling channel usage is low because of low-duty cycle of users (i.e., answer to poll is no most of time). If poll interval is lengthened to reduce percentage of "no's," waiting time to introduce a call increases.	The forward poll serves as the synchronization waveform needed in Type 1. This inherent ground control of synchronization leads to significant flexibility in calling interval, surveillance update, etc.

*Depending on how ground-originated access control is organized.

Table 3-4. Access Control Doctrine for Systems Analyzed

CONFIGURATION	A/C RECEIVER OPERATION	GROUND-AIR METHOD/ SIGNAL RECEIVED	INFO. ON POLL	HIGH PRIORITY A/C ACCESS	AIR-GROUND METHOD	COMMENTS	SATELLITE BEAM FOR A-G SIGNALS			Sattelite Beam for G-A Polling Signals
							Poll Response	Communi-cation	Random Access	
A	Semipermanent assigned to one of two channels	Poll with response on return channel	Relatively short messages (80 char.)	Random	Response to poll with short mes-sages	Long messages and voice use third channel	EC	EC	EC	EC
B	Semipermanent assigned to one of N channels	Addressed messages in block format	N/A	Random	Random	Channel held until voice or message completed	NB	NB	EC	NB
C	Scans through all comm. channels	Addressed messages in block format	No	Random	Seizure with observation. Poll in 0 capacity beams		NB	NB	EC	Not applicable*
B-1	Assigned to supervisory channel	Poll with response on return channel	Channel assignment, Comm. to 13°F.	Random	Response to poll		NB	NB	EC	EC
C-1	Assigned to supervisory channel	Poll with response on return channel	Channel assignment	Random	Response to poll		NB	NB	EC	EC

EC - earth coverage

NB - narrow beam

*Except for the single supervisory time slot used as a poll in zero capacity beams.

Table 3-5. Access Control Delay Performance Comparisons

	System	Total Delay (Seconds)			
		Median		90% Point	
		G-A	A-G	G-A	A-G
Analog Requirements					
	A	---	--	---	---
	B	325	10	455	18
	C	79	15	170	19
	B-1	275	64	442	105
	C-1	210	50	260	87
Digital Requirements					
	A	114	58	210	106
	B	<1	<1	<1	6
	C	<1	2	5	8
	B-1	46	46	82	82
	C-1	46	46	82	82

1. All delay performance results in the ground-to-air direction represent operationally unacceptable delay times to access and use the facilities of the system. This holds even for System C. The assumed requirements thus exceed the capabilities of satellites launched by Delta 2914* boosters.

2. Systems B and C have marginally acceptable delay times in the air-to-ground direction, whereas Systems B-1 and C-1 have unacceptable delay times.

3. As the satellite capacity increases from three channels in the North Atlantic beam of System B, to four channels in System B-1, to eight universally available channels in System C-1, to 11 in System C, we see the almost fourfold decrease in system delay performance in the ground-to-air direction.

4. The excessive delay times of Systems B-1 and C-1 in the air-to-ground direction are primarily associated with the poll. The poll frame length is 91 seconds, yielding a median delay of 45.5 seconds. Add to this the median service delay of about 1 second in the air-to-ground direction, and it can be seen that System C-1 has almost no queueing delay (i.e., waiting for the next available satellite channel), whereas only about one third of the System B-1 total delay can be attributed to the queueing delay.

5. The channel capacities of Systems B, C, B-1, and C-1 appear to be adequate enough to handle the assumed air-to-ground analog requirements, although the access control doctrine of Systems B-1 and C-1 does not yield acceptable performance with respect to delay. However, both the random access (System B) and random seizure (System C) doctrines give acceptable results. The random access doctrine gives better absolute results than does the random seizure doctrine, even though the latter is on a system that has considerably greater capacity than is available for the system of the former.

A study of the results obtained using the assumed digital requirements reveals the following observations:

* Current plans are to use a Delta 3914, using the excess capacity over the 2914 to provide the VHF capability.

1. System A yields the longest total delay results. The low capacity of System A may preclude it from being seriously considered for Aerosat.

2. Systems B and C show performance delay times that indicate that little or no delay is incurred in accessing the system or waiting for an available satellite channel. Almost all the delay is associated with the service distributions. In fact, from the population analysis results, neither system ever required more than three satellite channels simultaneously. Thus, System B, and particularly System C, have excess satellite capacity to meet the assumed requirements.

3. Systems B-1 and C-1 also have excess satellite channel capacity since System B-1 has more than three available ground-to-air channels in the North Atlantic beam and System C-1 has eight universally available ground-to-air satellite channels. The median total delay of both systems is 46 seconds. About 0.5 second of this results from the digital requirements service distributions, and almost all the remainder occurs as a result of the delay incurred in accessing the system via the polls.

4. The results of the digital requirements simulations indicate that, with the possible exception of the ground-to-air direction of System A, all other systems tested (i.e., B, C, B-1, and C-1) have adequate or excess capacity to handle the offered traffic load.

5. The results of the digital requirements simulations further indicate that the random access, random seizure access, and semipermanent assignment access control doctrines provide equally acceptable system delay performance, whereas polling, with, or without, message information will not provide acceptable system delay performance.

Of all the access control subsystems conceptualized and of those actually tested via computer simulation, the random access, random seizure, and semi-permanent assignment doctrines are best suited for aeronautical mobile application. The random seizure doctrine is well suited to large capacity system configurations, such as

System C, but may not work well for smaller capacity system configurations, such as Systems B, B-1 and C-1, due to the possibility of mutual interference on the communication channels. A properly designed random access control subsystem will slightly out-perform a random seizure access control subsystem, particularly with a small communication channel capacity system.

Since the global channels of Systems B-1 and C-1 are not needed for air-to-ground access control purposes with a random access channel(s) serving this function, and may only be used "as needed" for ground-to-air access control, their main purpose can be relegated to the surveillance functions.

A revised set of configurations was developed by CSC after the simulation results were studied. The main difference between this list, shown in Table 3-6, and the previous list were that random access was favored in most A-G cases, and semi-permanent assignment was favored for G-A with FDMA systems (with TDMA, monitoring of all channels or slots is elementary and so this approach was selected for G-A/TDMA systems.)

3.2.3 Conclusions

Conclusions with regard to access control were as follows:

1. The polling access doctrines investigated incurred long access delays for both analog and digital air-to-ground traffic.

2. The use of random access calling channels for air-originated air-to-ground traffic results in high reliability and in insignificantly low access times if signaling is properly optimized.

3. The semipermanent assignment and channel scanning methods for use on ground-to-air channels are equivalent to single-server and multiserver queues, respectively, with the ability to dynamically aportion the user population. Thus, in the long term steady state, their performances are equal. The additional overhead involved in reassigning users to channels in semipermanent assignment is not expected to be significant.

Table 3-6. Revised System Access Control Doctrines

		Access Control Doctrine		
System	Multiple Access	G-A	A-G	Remarks
A	FDMA	Semi-Perm Assignment	Random Access	
B	FDMA	Semi-Perm Assignment	Random Access	
B-1	FDMA	Semi-Perm Assignment	Random Access	EC Poll for Surveillance & G-A Access Control
B-1	TDMA	All-Channel Monitoring	Random Access	EC Poll for Surveillance
C-1	TDMA	All-Channel Monitoring	Random Access	EC Poll for Surveillance
C	TDMA	All-Channel Monitoring	Random Monitoring	

4. The seizure with observation doctrine simulated in System C apparently does result in a significant number of simultaneous seizures by aircraft desiring to gain access, for the requirements assumed.

5. Semipermanent assignment, when used with simple avionics, locks out the aircraft communicating on the channel under certain circumstances. It also requires all aircraft assigned to the channel to reacquire after an analog voice transaction.

6. The use of a two-step poll significantly lowers the access time for air-to-ground traffic when used with System A. This procedure provides a better match of slot length to message length distribution (assumed), and performs almost as well as a fully variable slot.

3.2.3.1 System A

System A does not present any major technical problems in access control. However, because of the assumed launch vehicle constraint, the capacity is low and it was felt that the access delays incurred in this system (for the requirements used) could seriously jeopardize the eventual operational acceptability of the system.

3.2.3.2 System B

System B requires the minimum and therefore the least expensive avionics package. A single channel receiver and a switched (not diplexed) antenna are sufficient. Because the ground-to-air channels themselves are used for management purposes, analog requirements result in extremely long delays in delivering ground-to-air messages to the aircraft users. The use of four random access supervisory channels in the air-to-ground direction results in significantly lower, and probably acceptable, access delays for air-to-ground analog messages. Digital traffic can be adequately handled in both directions with this management doctrine and the resources available from System B.

System B also suffers from a number of operational disadvantages which further discourage its adoption:

1. Independent surveillance waveforms must be separately provided on all channels, thereby increasing ground station and satellite costs (since each waveform must be generated, relayed in the air-to-ground direction, and phase compared at the ground facility).

2. Since a number of aircraft are monitoring each channel for both access information and messages during voice transmissions, no other aircraft can receive any but emergency messages.

3. After each voice transaction on a channel (assuming an analog modulation) every aircraft assigned must reacquire phase for address recognition purposes.

4. In the lower capacity beams, the failure of a satellite channel amplifier may cause severe access delays (or no capacity at all) in that beam. The use of a global coverage pattern with some minimum capacity provides backup in such cases.

3.2.3.3 System C

Even though System C has a large capacity, its analog access performance in the ground-to-air direction is poor. This can only be attributed to the high message arrival rate dictated by the requirements used, and the seizure access doctrine used in this system. As in System B, the absence of a global beam on the satellite compromises its reliability if any normal beam fails. In the case of System C, the beam switching mechanism on the satellite might be most susceptible to failure.*

3.2.3.4 System B-1

Since in System B-1 both the ground-to-air and air-to-ground channels are controlled by using the poll, the access delay is dominated by the poll interval. For the requirements assumed, the analog delays are unacceptable in both the ground-to-air and air-to-ground directions. The overall performance of this system would be

*Aerosat is an experimental system but it is felt that most experimentation will be concerned with the technical aspects of communication and the operational aspects of system control and usage rather than the development of satellite technology per se.

improved, and the system would be preferred over all others studied, if the access control performance could be improved.

3.2.3.5 System C-1

Similar conclusions can be drawn for System C-1 as for B-1 with the additional observation that advances in satellite and overall system technology must be made before this type of system can be actively pursued and fully evaluated operationally.*

3.2.3.6 Preferred Method

When all the results of this study are considered, assuming that independent surveillance is required, it appears that the most desirable system uses system configuration B-1 (i.e., multiple beams for most communications, plus a global beam) with the access control procedure described below. Each of the communication beams has from one to four channels, depending on the geography it covers, and the global beam provides a supervisory channel which all aircraft monitor. This channel also provides coverage to areas not covered by the multiple beams, and provides backup communication coverage to areas if satellite failures occur. The narrow multiple beams are used by the aircraft for all air-to-ground transmissions except for the random access calling channel(s) described below. The satellite equipment serving this channel(s) is made redundant to ensure extremely high reliability.

The access control procedure uses:

- Semipermanent assignment of forward (G-A) downlink channels to A/C receivers.
- Random access calling channels to signal for access by aircraft.
- A global broadcast supervisory channel, also used as a reference to aid acquisition of assigned channels and for Doppler correction of all aircraft transmissions.

---

*See footnote on previous page.

In most instances, the channel assignment to each aircraft is made well in advance of the need, either before takeoff or via other than satellite means. If not, the supervisory channel can be used.

To obtain access to a channel (one way or two way) an aircraft proceeds as follows. One of the random access calling channels is entered with a short pulsed transmission (containing identification and channel type needed), repeated every few seconds until acknowledged as follows:

1. If a two-way channel is requested:
   - The aircraft is called over its assigned channel (if available or if the wait is not too long), or
   - It is called on the global supervisory channel and told either the waiting time or to tune to another channel (change in assignment) over which it is called after acknowledging change over random access channel
   - ACK/NAK for digital transmission is received over the paired communication channel for both directions.
2. If a one-way air-to-ground channel is requested:
   - The aircraft is called over the global supervisory channel and told which one-way air-to-ground channel to use
   - ACK/NAK comes over the global supervisory channel.

   For the ground system, to reach one particular aircraft:
   - The aircraft is called on its assigned channel, or
   - It is called on the global supervisory channel and an assignment change is made.

   The global supervisory channel is also used for:
   - Requesting surveillance returns from aircraft
   - Synchronizing periodic data reporting transmissions (including position reports and surveillance returns)

- Emergency calling when assigned channel cannot be used or preempted
- General broadcast messages through the use of appropriate message labels in the addressed transmission.

Other rules are:

- Aircraft in flight enter the system using the random access channel, after acquiring the global supervisory channel, and are acknowledged and assigned their channel and satellite over the supervisory channel.
- The supervisory channel being monitored is used as an indication of satellite health. If it fails, the crew performs appropriate backup procedures.
- The satellite supervisory channel to be monitored is assigned along with channel assignment. In the case of pop-up or in-flight system entry, the crew randomly selects a satellite and is told to change if necessary.
- If only the supervisory channel of a satellite fails, the satellite is operated in a backup mode with all supervisory channel functions picked up on one channel in each beam. This channel is cleared and operation continues as before.
- If all random access channels of a satellite fail (which is highly unlikely because the simulations indicated that two per satellite are required), all aircraft will use the second satellite, thereby slightly increasing its random access load and access delay characteristics.

Almost all receiver functions are accomplished automatically either in response to signals/commands on the global supervisory channel or its carrier, signals/commands generated internally to the receiver, or those received over the assigned communications channel. The aircraft crew initiates only communication need (if not an automatic report), desire to enter the system, the message itself (if not an automatic report), and the global supervisory channel to be monitored (which depends on satellite assignment).

3.3 AEROSPACE REPORT

3.3.1 Methodology

The Aerospace report treats more than just access control techniques. At the same time, however, it does not present actual performance predictions for the various alternatives given.

The approach taken is to describe a set of viable operational concepts to be evaluated. The various operational concepts have to do with particular service modes, i.e., particular combinations of voice, data, dependent surveillance and independent surveillance operation. Given these operational concepts, a set of test configurations is then developed which allows actual evaluation of the concepts. Inherent in the detailed descriptions of these test configurations are access control techniques. The last portion of the report describes a proposed system which would support the experimental evaluation program implied by the test configuration listing. Thus it would be more accurate to treat the Aerospace report as a test program description than as an analytic effort.

3.3.2 Concepts, Configurations, and Techniques

3.3.2.1 Operational Concepts

The operational concepts considered by the authors total nine, as follows:

1. Voice communications only
2. Voice communications with dependent surveillance
3. Voice communications with independent surveillance
4. Voice communications with dependent and independent surveillance
5. Data communications with dependent surveillance
6. Data communications with independent surveillance
7. Data communications with dependent and independent surveillance
8. Voice and data communications with dependent surveillance
9. Voice and data communications with dependent and independent surveillance.

Note that at the time this work was performed the data communication and dependent surveillance functions were distinct, a distinction which has pretty much disappeared in most system concepts developed since.

These concepts were then further refined and detailed by considering the voice channel access techniques applicable for ground users and for airborne users, and the type of connection or routing employed for data. Specifically, ground users would contend for available channels either via "seize when available" (SWA) or "request" (REQ) modes. Aircraft access control could be SWA or REQ (via a data link message); with SWA, some concepts allow for an availability indication to the pilot (a status tone package broadcast, for example). Data connections or transfer could be either channel switched (CH. SW.) mode or terminal store and forward (TSF) mode. These modes are summarized in Table 3-7.

3.3.2.2 Test Configurations

The Aerospace authors have developed so-called "Test Configurations" which could be used to test, in an actual, on-line manner, the concepts postulated. These are shown in Table 3-8, with notes. For some cases, more than one variation has been postulated. As an example, voice only operation (#1) was previously separated into 1A, 1B, and 1C variants. Now, 1C is tested under two test configurations, 1C1 and 1C2.

3.3.2.3 Access Control Considerations

The access control considerations are not explicitly brought out in the Aerospace report, but can be extracted by a detailed perusal of the sixteen different arrangements or variations involved. It is significant to point out that the queueing or access contention of ground users has been addressed in this report, perhaps with more emphasis than the aircraft access control. On the other hand, there is no consideration of how an airborne user is assigned to a given channel (many modes have only one channel in operation, however).

Table 3-7. Summary of Operational Concepts

CONCEPTS FOR COMMUNICATIONS SERVICES			MODES OF OPERATION					
				Voice Channel Access				
				Gnd-to-A/C Channels	Aircraft-to-Ground Channels			
ATC Communications (except Surveillance)	Airline Company Communications	ATC Aircraft Surveillance	Case Identifier	Access Mode	Access Mode	Availability Indication to Pilot	Ground Monitor	Data Link Ground Message Routing
VOICE	Voice	Voice Position Reports	1A 1B 1C	SWA or REQ	SWA	None Yes Yes	(1) SWBD SWBD Controller	
	Voice and Data Link	Dependent	2A 2B	SWA or REQ REQ	SWA REQ (Data Link)	Yes	SWBD	(2) CH.SW.&TSF CH.SW.&TSF
	Voice	Independent	3A 3B	SWA or REQ REQ	SWA REQ (DRR)	Yes	SWBD	
	Voice and Data Link	Dep. & Ind.	4	REQ	REQ			TSF
DATA LINK		Dependent	5A 5B					CH. SW TSF
	Data Link	Independent	6					TSF
		Dep. & Ind.	7					
VOICE AND DATA LINK	Voice and Data Link	Dependent	8	REQ	REQ (Data Link)			TSF
		Dep. & Ind.	9	REQ	REQ			

DRR - Data Returned with Ranging
SWBD - Switchboard
CH. SW. - Direct Channel (circuit) Switching
TSF - Terminal Store and Forward
SWA - Seize when Available
REQ - Request

Table 3-8. Summary of Desired Test Configurations*

Concepts for ATC Services		Case Identifier	Ground Configuration		Voice Channels		A-G Avail. Ch.[b]	Data Channels		Data Modes		Ind. Surv. Channels		Ind. Sur. Poll Control	Total Channels[i]		
Comm.	Surveillance		No. ASCC	No. OCC	G-A	A-G	G-A	G-A	A-G	A-G Modes Channel Mgmt.	Poll Control	G-A	A-G		G-A[b]	A-G	G-G[i]
Voice	Voice Position Reports	1A 1B 1 C.1 1 C.2	1 1 1 1	1+ 1+ 1[a] 2[a]	2 2 1 2	2 2 2-4 4-8	1 1 1								2 3 2 3	2 2 2-4 4-8	
	Dependent	2A 2B	1 2	2+ 2+	2 2	2 2	1	1 1	3 3	Test c,d Pick c or d	e f				4 3	5 3	1
	Independent	3A 3B	1 2	2+ 2+	2 2	2 2	1					1 2	4 4	g Test g.h	4 4	6 6	1
	Dep. & Ind.	4	1	2+	1	1		1	2	d	e	1		e	3	7	
Data Link	Dependent	5A 5B.1 5B.2	1 2 2	1+ 2+ 2+				1 2 1	3 6 6	c d d	e e f				1 2 1	3 6 6	1
	Independent	6	1	1+				1	3	d	e	1	4	e	2	7	
	Dep. & Ind.	7	1	1+				1	3	d	e	1	4	e	2	7	
V & D	Dependent	8	2	2+	1	1		1	3	d	f				2	4	1
Link	Dep. & Ind.	9	2	2+	2	2		2	4	d	e	2	4	e	6	10	

* The small letters refer to the notes of this figure

Notes for Table 3-8

a. Multiple aircraft-to-ground voice channels are assigned to respective controllers. ASCC assigns correct (sector dependent) frequency to each aircraft.

b. The availability indication for aircraft-to-ground voice channels is identified herein as provided by the equivalent of a separate ground-to-aircraft channel. However, the indication could be multiplexed onto ground-to-aircraft channels used mainly for other purposes.

c. Multiple aircraft-to-ground data channels are assigned to and terminate at respective OCCs. ASCC assigns correct (OCC dependent) aircraft-to-ground data channel to aircraft. The ASCC controls channel switching only. This is the CH. SW. method referred to in the text.

d. Multiple aircraft-to-ground data channels are assigned to aircraft without regard to OCC to permit best use of available return communications capacity. ASCC terminates data link messages and forwards them to respective OCCs. This is the TSF method referred to in the text.

e. Each ASCC polls the aircraft for its respective OCCs via data link ground-to-aircraft channels.

f. Master ASCC polls all aircraft for all OCCs via the data link ground-to-aircraft channel. Secondarly ASCC sends poll requests to master ASCC via a ground-to-ground data channel.

g. Each ASCC polls the aircraft for its prespective OCCs via a polling signal multiplexed onto the ranging signal transmitted on the independent surveillance ground-to-aircraft channels.

h. Master ASCC polls the aircraft for all OCCs on one ground-to-aircraft independent surveillance channel and uses the other ground-to-aircraft independent surveillance channel for transmitting the surveillance ranging signal. Secondary ASCC sends poll requests to master ASCC via a ground-to-ground data channel.

i. The ground-to-ground data channel between ASCCs does not need to be provided by the Aerosat satellites.

j. Tests can be feasibly conducted with considerably fewer channels and an acceptable reduction in scope using reasonable simulation.

The following access control elements are implicit in the Aerospace work:

1. Airborne User Access Control

    Random Access (Voice)

    Seizure, based on status tone broadcast (Voice)

    Data Link (poll responses)

    Requests for voice channels via data link message

    Requests multiplexed with indepedent surveillance response

2. Ground User Access

    Seizure (voice) based on status, loopback, or key system approach

    Requests to a manual switchboard (voice)

    Requests (automated) (voice and data)

    Store and Forward data message service (data link)

    Master/Slave ASCC concept. The master runs a forward poll.

In the light of more recent developments, it is seen that the key elements throughout are:

Manual switchboard voice operation

Status tone broadcast to aircraft

Data link poll operation

A means for ground user contention, e.g., conference bridge and key system.

3.3.3 Conclusions

The Aerospace work does not evaluate the relative merits of various approaches. It does present designs for system elements which would allow the test program to be carried out. The intention was to defer conclusions until after collection of experimental/evaluation data.

SECTION 4 - ACCESS CONTROL RECOMMENDATIONS

4.1 INTRODUCTION

The choice of access control techniques for testing during the Aerosat E&E program is influenced by:

- Their feasibility and suitability for operational use as demonstrated by previous studies
- The configuration of the satellite to be procured for the program.

It may be argued that potential future operational satellite configurations should also influence the choice. However, it is felt that if a technique or configuration is not tested and evaluated during the E & E phase then it is an unlikely candidate for a first operational system.* Thus, we limit ourselves to access control techniques which are compatible with the E & E satellite configuration. This does not preclude pseudo-simulation type scenarios where the E & E configuration is used in such a way as to simulate an access control scheme on a smaller scale and under slightly different conditions than might be used operationally.

4.2 SATELLITE CONFIGURATION ASSUMPTIONS

As of this writing, it appears that the pertinent satellite configuration will as follows:

- Three beam transmit antenna at L-band (i.e., no global coverage) each beam covering one NAT area
- Global coverage receive antenna at L-band (i.e., no reception via three narrow beams)
- A maximum of five L-band transmit channels via the three beams during eclipse
- Beam (area) A can have up to 3 channels, beams B and C up to 2 channels

*The E & E satellites themselves may well be the first operational ones also.

- Transfer of channels (power) between beams will be done relatively slowly in response to ASCC requests (30 seconds of elapsed time)
- A limited number of channel transfers per day are possible (about 5 or 10) on the average but the peak number during a few days of testing could be much higher.

4.3 SYSTEM CONFIGURATION ASSUMPTIONS

In order to set up test scenarios for the E & E program that relate to meaningful systems, it is necessary to establish at least a few basic principles of system configuration. Without these, the number of test scenario possibilities is very large. The basic principles which have been adopted (at least for now) are as follows:

- All scenarios will primarily make use of the satellite configuration as it is envisioned. This implies that concepts such as earth coverage, switching, and others not directly included in the satellite configuration will have to be evaluated by simulation/emulation.
- In line with the idea that entire system concepts are being tested and evaluated, a single access control scheme should be applicable over the entire system to simplify pilot procedures as much as possible.
- Air-initiated access in a beam cannot depend on the current existence of a ground-air channel since some beams have zero G-A capacity at times.
- Ground-initiated access control must work with a minimum of one ground-air channel in a beam area.
- A few of the L to C band channels in the satellite can be set aside as calling channels for access control purposes.

4.4 RECOMMENDED TEST AND EVALUATION SCENARIOS

4.4.1 Introduction

The scenarios or test/evaluation modes recommended here have been selected according to the services they are assumed to provide. This set is not entirely exhaustive or comprehensive, but provides scenarios which are consistent with the assumptions presented previously, and shows a meaningful cross-section of concepts such that the data obtained will be useful in defining follow-on operational systems. As concepts have been developed and debated, it has become evident that functionally a distinction between data and dependent surveillance readout is not necessary. Furthermore, the operational desirability (to users) of voice means that while voice only modes of operation are meaningful, and voice and data is also reasonable, data only operation is not viable and therefore unlikely. Thus, there are three general service categories to consider:

- Voice only
- Voice + data (and dependent surveillance)
- Voice + data + independent surveillance.

The first two can be provided even by only one satellite; the third of course requires two satellites. The last area of distinction with regard to access mode or access control concerns the forward capacity available in each area. If normally there is no forward channel capacity provided to an area, differences in exact access mode may be necessary relative to the other areas which do have forward channel capacity directed into them. The significance of these distinctions will be evident in the sequel. The modes are summarized in Table 4-1.

4.4.2 Voice-Only Operation

Voice-only operation can be supported by a one or a two satellite system. The backbone of access control in this case is the earth-coverage air-to-ground calling channel(s). In an area with no forward (G-A) capacity normally allocated, the availability of this return calling channel allows potential users to gain access on a random access basis. This can be random access using calling tones, for automated or semi-automated operation, or manual voice calling, intercepted by a monitoring operator not unlike HF radio operation.

Similar random-access calling channels would also be used in areas which are served with forward downlink channels, but only on an emergency or special basis. Normally, random access would not be necessary since the existence of forward channel

Table 4-1. Summary

Service Mode	Number of Satellites	Access Control in Areas With Forward Capacity	Access Control in Areas Without Forward Capacity
I Voice Only	1 or 2	G to A: Semi-permanent assignment. SELCAL A to G: Seizure with observation (of status tones). Use of calling tones.	Earth coverage calling channel(s) on random access basis: a) calling tones b) voice call-in to operator
II Alternate Voice/ Data (includes dependent surveillance)	1 or 2	ARINC 586 Data Link for data and all requests and responses.	Random access of E.C. calling channels using data link. Also position readouts.
III Voice, Data, and Independent Surveillance	2	Same as above. (Surveillance Waveform is multiplexed with communications modulation)	Same as above. (No independent surveillance in these areas on a regular basis.

capacity allows status tones to be broadcast, so that air-to-ground access becomes seizure with observation rather than random. The forward channels are semi-permanently assigned, and SELCAL-like signalling is employed to reach specific aircraft.

4.4.3 Voice and Data Operation

The provision for data-link operation is very unlikely to remove the desirability of voice for the airborne community, so the next service level beyond voice only is voice and data operation. This can be supported even with only one satellite. Data link transmission includes the opportunity for dependent surveillance readout.

Once again, areas which do not usually have forward channel capacity directed to them still have available on a random access basis a return channel(s) for requesting service. Since the system is set up to accommodate data transmission, one-way (unacknowledged) position reports can also be sent in this way. In all cases, requests for voice operation will be accommodated by the sending of a data link request message by the airborne user.

In areas with forward channel capacity, ARINC 586-based data link and voice service are supported. Since some areas might only have one forward channel, however, provision should be made to allow alternate voice and data operation using the same forward channel. This excludes the consideration of rigid polling structures for access control.

Semipermanent channel assignment will be used to permit ground-originated calling of aircraft using either SELCAL* (tone coding) or data messages for voice access and data messages for data access.

4.4.4 Voice, Data, and Independent Surveillance

The addition of independent surveillance means that two satellites are required. Areas with no forward capacity (normally) will be supported by means of random access call-in over the earth coverage return channel(s), as before.

*In an evolving system assuming voice only service in the beginning, SELCAL will probably be preferred.

and signal design must be considered in determining the range of surveillance system performance attainable. The ability of the AEROSAT system to achieve desired position location accuracy and update rates should be determined. The effects of unified signal formats will be considered.

4.5.6 Simulation of Configuration Changes

The access control simulation model should be altered to incorporate recent changes in the AEROSAT system concept. Two main topics shall be considered. The partitioning of the North American earth station into two facilities, one in Canada and the other in the United States, will be incorporated into the simulation model, including the requirement for terrestrial data communications between them. The second configuration change is the inclusion of VHF into the satellites and U.S. portion of the ground facilities. Investigate the impact of the inclusion of the VHF communications channels on the access control subsystem. Investigate the advantages of a single access control subsystem to control channels in both VHF and L-Bands as compared with a separate subsystem for each band. For the former case consider the effect of error rate differences at the two frequencies on aircraft queue formation. For the latter case investigate the loss of efficiency caused by necessary coordination between the two access control subsystems.

4.5.7 Random Access Simulation

Based on their delay performance as discussed in Paragraph 3.2.2.3, random access methods appear to be prime candidates for AEROSAT consideration. However, the kinds of behavior encountered in a random access system make its design considerably more complex than the design of a polling system. Therefore, it is recommended that simulation studies be performed to establish a more extensive data base on the performance and behavior of random access systems to serve as guidance for later decisions on experimentation and design.

4.6 COMMON SYSTEM OPERATION

Given the international aspect of the component parts of the AEROSAT System there is a need to specify a commonality of equipment and operations to ensure a basic degree of compatibility between the various ASCCs and the different types of avionics equipments. This is required so that the equipment which will be provided by the different partners in the AEROSAT program can operate in common system experiments.

4.6.1 Common System Options

A. Define a standard set of modems, procedures, and access methods that all aircraft will be equipped to use.

B. Permit each aircraft to be equipped with an arbitrary modem/set provided that each ASET has the same modem set. Each ASET maintains a record of which aircraft carries which modem/set and has the ability to switch modems.

C. Use option B except specify a common data modem, which can also be used for surveillance polling and voice access control.

Option (A) above of achieving common system operation suffers from the disadvantage that it requires each aircraft to carry up to three additional modems. Option (B) requires no additional airborne modems but involves the keeping of complex aircraft files in the ASCC computer and introduces substantial complications in procedures required to handle pop-up aircraft. Option (C) requires only up to one additional airborne modem with none of the ground problems.

APPENDIX - REPORT OF INVENTIONS

The contract work reported here consists of a review of general background material and a presentation in summary form of the studies pertinent to AEROSAT channel management and access control carried out under previous contract. Thus the results presented here do not constitute inventions or discoveries, but rather are a summary of a substantial body of material in a form useful to those taking part in the implementation of the AEROSAT program.