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INTEGRATION OF AIR/GROUND DATA LINKS

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INTRODUCTION

The Federal Aviation Administration (FAA) is establishing a new generation of air/ground communications based on the exchange of digital data. This data exchange will be supported by Mode-S for CONUS operations and SATCOM for oceanic operations. The airlines are presently using ACARS, a digital data link network for airline operations that is also a contender for future FAA Air Traffic Control (ATC) data link services.

As E-Systems will present in this paper, there are significant advantages to using Mode-S, SATCOM, or ACARS data links. However, no one medium will be capable of supporting the air/ground communications that will be required by the year 2000. In addition, Mode-S, SATCOM, and ACARS will be the systems found in the cockpit of the future, and air/ground data link communications will be based on those multiple media. The Aeronautical Telecommunications Network (ATN) architecture will support the interoperability of these media both on the ground and in the air. This paper discusses the advantages of utilizing multimedia communications techniques to support and enhance ATN system capabilities.

BACKGROUND

Currently, voice communications is 31% to 43% of the controller's overall workload, as shown in table 1.[1] This overall workload will be reduced by the AAS program with the introduction of the Sector Suites, AERA I, II, and III.[6,8]

Table 1. Radar Controller Activity Profile at Moderate/Heavy Workload

ACTIVITY	SRI STUDY (6)	TSC STUDY (7)
Surveillance monitoring	21%	35%
Conflict detection/ resolution	17%	14%
Communications	43%	31%
Data processing/console operation	19%	20%

The AERA program will change some control concepts resulting in a reduction of controller voice communications, but it is the FAA Data Link Program that will change the way controllers communicate with pilots and significantly reduce the voice communications workload. The Data Link Program will effectively reduce voice communications to "preset quick action keys" and other advanced MMI techniques. These manual entries will represent clearances and general information such as weather to the pilot.

There are three elements critical to the data link program. The first is that while reducing ground controller workload the data link applications should not increase cockpit workload. This issue is being jointly addressed by the FAA and NASA where realtime simulation test beds are being used to develop meaningful solutions.[5] The second critical element is that the communications equipment must not constrain the development of future air/ground communications. The ATN architecture will support this goal. Finally, the communications mechanisms should be transparent to the controller, pilot, ground automation systems, and airborne computers. The ATN routers will provide for this capability.

Mode-S for CONUS operations and SATCOM for oceanic operations are the present FAA approach to support data link communications. The airlines are using ACARS to support carrier operations. ARINC and the airlines have suggested using ACARS and its upgrade AVPAC to provide some subset of ATC data link service. Each of these data links is characterized by performance attributes that make them ideal for certain air/ground communications.

MODE-S DATA LINK

Mode-S represents a significant investment on the part of the FAA that spans almost 20 years.[4] The system concept is mature and effectively integrated with the domestic air traffic control system.[11] Mode-S is capable of providing a secure form of communications with little potential for false messages to be generated from "unofficial" ground stations. Since Mode-S interrogators are FAA-owned systems, the FAA will be the only organization deciding the level of integrity and system availability for the ground interrogators. The level of integrity is a key issue since the services provided by FAA are classified into three broad categories with the following integrity limits:

FAA Services	Integrity	System Availability
Critical	very high	.999 999
Essential	high	.999 99
Non-Essential	practical	>.9

Mode-S data link is the result of improvements in the surveillance function that were required to deal with "fruit" and other ATCRBS limitations. Data link capability is a fall out of the approach to improve ATCRBS performance and not truly a standalone goal of DABS and the resulting Mode-S program. However, Mode-S is a capable communications system for certain classes of messages.

Table 2 shows the relationship between Mode-S system capacity and two message types for a single scenario. The first message type

Table 2. Mode-S System Performance vs. Actual Messages in Cockpit

ASSUMPTIONS	MODE-S
Transmission interval (sec)	10
Bits/frame	112
Frames/transmission	6
Simulation duration (sec)	10
Bits/Msg	112
Planes	100

% MSGS		MODE-S TOTAL	
BROADCAST	PT-PT	SYS TOTAL	PLANE
0	100	600	6
20	80	481	6
40	60	362	6
60	40	244	6
80	20	125	6
100	0	6	6

is a broadcast message and the second message type is a point-to-point message. As can be seen in the table, Mode-S system capacity, which is the total number of messages exchanged by this single site, increases as the message types move from broadcast dominant to point-to-point dominant. This same characteristic of Mode-S is shared as the number of planes increase in the system. Mode-S system capacity increases as required. This is a direct result of the Time and Space Division technique employed. However, even though the ground system capacity appears to increase and accommodate more planes or more point-to-point messages, the number of messages received by any one plane remains constant. In this scenario, the number of messages delivered by Mode-S is six messages per plane. This result is a function of the 112-bit message length and the frame rate, which included six frames of interrogation.

As shown in figure 1, the rotating antenna also limits the worst-case message response time to the rotation of the beacon, which is approximately six seconds. If an interrogation is missed, the response time becomes 12 seconds. Even more important, the response time is not consistent but varies with aircraft azimuth location. For aircraft "A" the controller may experience a very fast communications link response time and for aircraft "B" the same controller may experience a very slow communications link response time even though the same message category may have been transmitted to aircraft "A." Current studies show that response time may not be an issue since cockpit crew response time is ten or more seconds. However, this is a characteristic of Mode-S that does not make it fully transparent to the controller.

Since Mode-S operates in the L band, the signals bounce in an unpredictable fashion on or near the ground. This same characteristic limits coverage in mountainous areas where effective gap filler radars may be cost prohibitive.

Many messages between the air and the ground will be common messages that apply to potentially all the aircraft under coverage as the "party line" may be maintained for some classes of messages. However, Mode-S must rebroadcast the same message to each aircraft that is not in the width of the Mode-S beam.

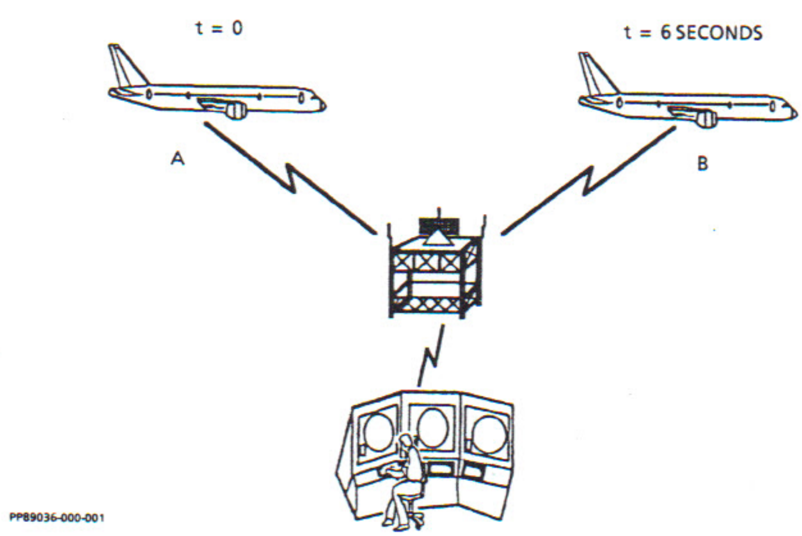

Figure 1. Mode-S Sensor Position at Time of Message Initiated from Cockpit or Sector Suite

An alternative would be to use an omnidirectional communications system for supporting "party line" message communications.

SATELLITE COMMUNICATIONS (SATCOM)

SATCOM has been proposed to support the ADS function for oceanic air traffic control. The oceanic traffic density is relatively low and INMARSAT appears to provide the required coverage. ADS and voice communications could be easily supported for oceanic operations. However, there are issues associated with transition from SATCOM to Mode-S coverage or VHF voice communications when oceanic equipped (ADS) aircraft fly into CONUS regions.

SATCOM equipped aircraft could take advantage of services such as ADS over the continental United States. However, CONUS ADS using SATCOM is subject to the pressures of channel access, bandwidth, and the selection of a CONUS SATCOM system. JPL has developed a concept for an FAA dedicated SATCOM system.[2] That concept could service 86,000 aircraft with 12,186 channels, 59 beams, and 2 FAA dedicated satellites. The development of this data link medium for CONUS operations may require a new, FAA satellite-based infrastructure; however, its development will not be as straightforward as for oceanic air traffic control.

DIGITAL VHF DATA LINK

VHF is a potential medium that could be employed for air/ground digital communications. There are presently two VHF networks in the CONUS. The first is the FAA-owned VHF voice communications network and the second is the ARINC-owned ACARS network.

VHF can be contrasted with Mode-S communications. Because of its omnidirectional characteristics, there is greater capacity to support efficient message broadcasting. As shown in table 3, an omnidirectional broadcast medium may show a smaller ground system capacity than a directional medium, but will provide significantly more broadcast messages to an individual airplane. This observation is critical, since the analysis shows that the performance of the system should consider not only the ground system but also the cockpit. Further, a full analysis of the system from the ground perspective may not lead to a full understanding of actual system performance. If 100% of the messages are broadcast, then the ground system total matches the actual messages received by each plane in the coverage area. Table 3 further shows actual system and individual airplane capacity of a potential VHF network with 40 bits of overhead and an acknowledge protocol associated with each message.

ACARS has been suggested as an alternate medium for air/ground digital communications. ACARS is heavily utilized, processing 3.2 million messages per month and exceeding 99.95 availability at 28 critical airports with an overall system availability of 99.70 in 1987. The system still contains capacity and can be upgraded with additional frequencies if required. ACARS consists of three basic elements:

1. ACARS display, entry, and VHF unit in the cockpit
2. 203 ground stations (VHF transmitters and receivers)
3. A ground digital message network

Although the introduction of an omnidirectional communications medium could significantly increase air/ground communications capacity, ACARS may not have sufficient integrity to handle Critical and Essential Services. As shown in figure 2, the priority of the traffic would have to be negotiated between the FAA and the air carriers. In addition, the ground ACARS infrastructure of the ACARS Data Network System (ADNS) would have to be upgraded if the actual VHF medium had to support the requirements of Critical and Essential services without falling back to workload intensive voice communications. As shown in figure 3, this infrastructure is significant and includes packet switching processors, concentrators, multiplexers, and network controllers. ACARS could be upgraded to achieve any level of required integrity, but there would be a definite cost responsibility associated with such an upgrade.

Table 3. Advantages of Omnidirectional Medium for Broadcast Communications

ASSUMPTIONS	VHF
Transmission interval (sec)	1
Bits/frame	2400
Frames/transmission	1
Simulation duration (sec)	10
Bits/Msg	112
Planes	100

% MSGS		VHF DL TOTAL			
		NO OVERHEAD		WITH OVERHEAD	
BROADCAST	PT-PT	SYS TOT	PLANE	SYS TOT	PLANE
0	100	214	2	79	1
20	80	214	45	79	16
40	60	214	87	79	32
60	40	214	129	79	48
80	20	214	172	79	63
100	0	214	214	79	79

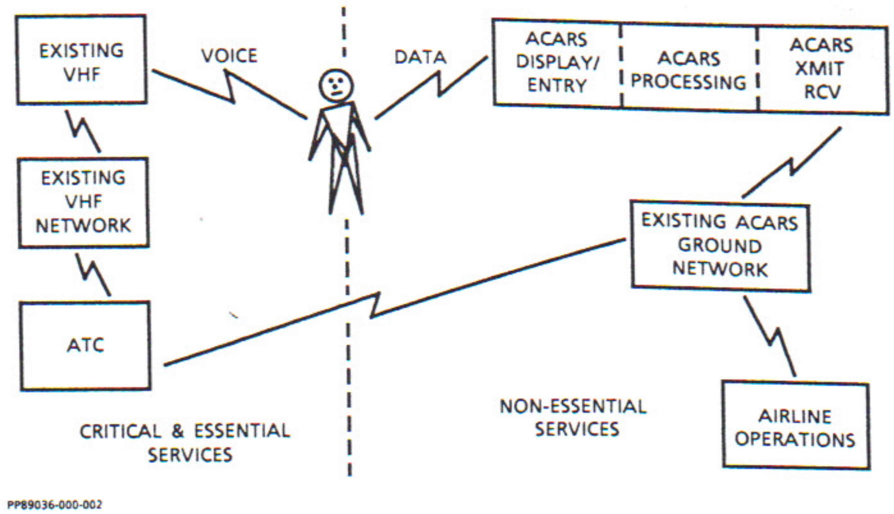

Figure 2. ACARS May Require Significant Expenditures to Support All ATC Services

SUMMARY OF PROBLEMS WITH THE CURRENT DATA LINKS

Each of the media being discussed for ATC data link operations meets one or more requirements for a good air/ground communications system. However, no one individual medium meets all these requirements. The variety of airline equipage, ground/aircraft equipment transition, traffic load, airspace characteristics (Oceanic Enroute, CONUS Enroute, Approach/Departure, Ground), facility characteristics (traffic load, terrain), security, and direct airborne/ground intercomputer communications must be treated from an integrated systems perspective.

Mode-S is an excellent point-to-point communications medium that provides a low-cost solution for the introduction of data link into the cockpit when integrated with the improved

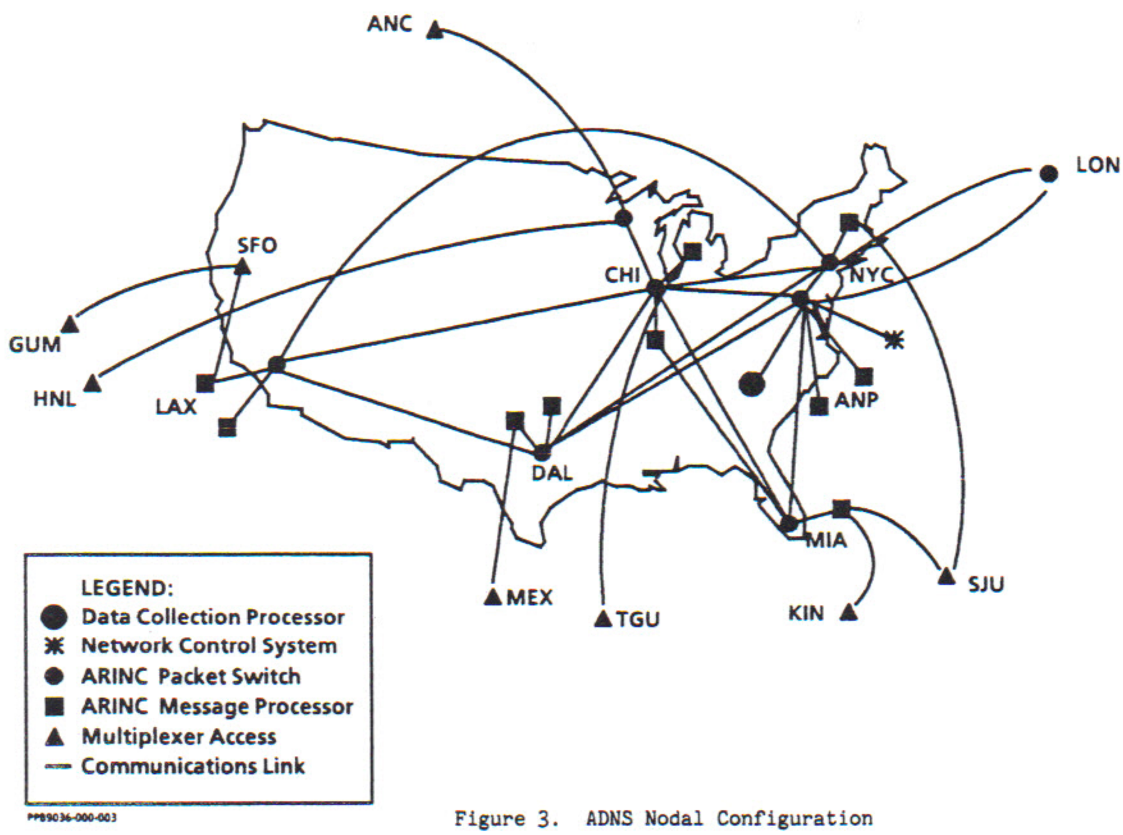

Figure 3. ADNS Nodal Configuration

surveillance functions. However, the Line Of Sight (LOS) communication and multiple reflections cause problems for ground data link services at airports and air data link services over mountainous terrains.

SATCOM is an excellent long range medium for global communications to support international operations. The need for standardization is obvious and individual sovereignties are more willing to cooperate for the development of interoperability.[12] However, SATCOM for CONUS operations, where there are large numbers of aircraft, may be constrained by channel access limitations, propagation delay, and response time.

VHF is an excellent broadcast medium to provide effective communications on the ground as well as most mountainous regions. ACARS in particular is obviously a successful system; however, there are issues associated with certifying the system if Critical and Essential messages are to be supported by ACARS. Specifically, the ground network will need the addition of more hardware and software to provide for the required availability.[7]

THE ATN SOLUTION

Selection of a single medium for ATC data link operations is not the issue. The end state system will consist of a minimum of three data link media in the cockpit. ACARS will continue to provide airline operations support, Oceanic SATCOM will be introduced for ADS, and Mode-S Phase I sites will become operational in the early 1990's. Since the equipment will be in the cockpit and on the ground, all these data link media must be integrated to maximize their utility and provide for interoperability.[9] While multimedia communications is not new, the capability to select in realtime the ideal media capabilities is innovative.

E-Systems has applied this concept in other command and control applications. These media have been integrated by the aviation community as part of the Aeronautical Telecommunications Network (ATN) architecture.[10]

Figure 4 illustrates significant benefits in only one performance area if media interoperability is supported. RTCA SC-162 has drafted a communications architecture definition for the ATN that supports a multimedia data link communication capability between the air and ground. The ATN is based on the international OSI basic reference model, and acknowledges the concept of a generic air/ground communications architecture exclusive of any unique requirements associated with a single application, such as ADS or Pre-departure Clearance. The ATN supports the introduction of new applications, such as the proposed data link applications, without impacting the communications link. Similarly, ATN supports technology insertion, including new data links such as digital VHF, without impacting the applications.[3] Finally, ATN supports interoperability by providing for communications with users outside the FAA ATC community such as the ARINC network.

Voice communications between the Air Traffic Controller and the Pilot is the primary form of air/ground communications in ATC today. Although there may be great resistance from the system operators and users for direct intercomputer communications between the air and the ground, there are applications that will be identified which would require such intercomputer communications if it were available. Mode-C for altitude reporting is an example of effective intercomputer communications. AERA III is developing concepts wherein the flight management computer can access ground flight plan data for airborne modification. Applications such as automatically sending TCAS

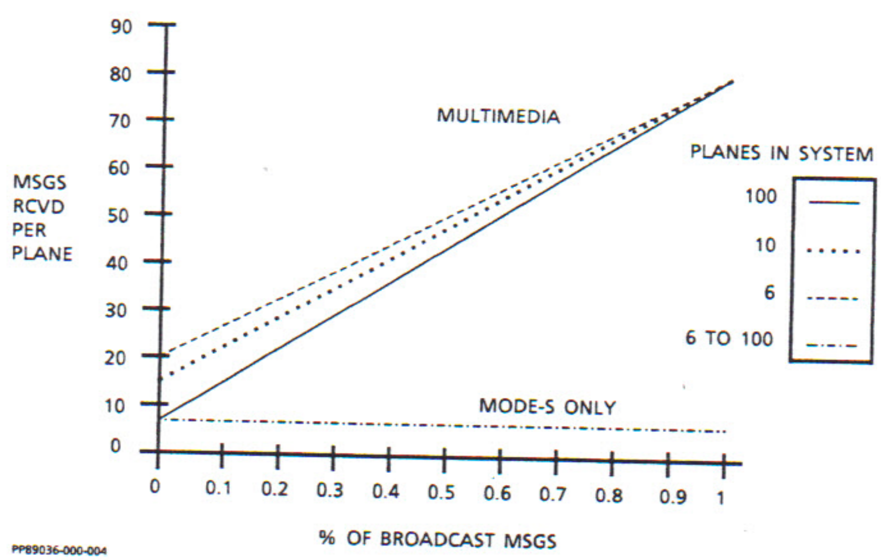

Figure 4. Advantages of Multimedia Communications

alerts or other cockpit alarms to the ground may significantly improve safety. The ATN architecture supports this intercomputer communications.

In both cases, either intercomputer communications or human communications between the air and the ground, the communications should be transparent to the user. Adding operational procedures based on message type or medium should not be required. A router should be able to determine the ideal medium to use to deliver a message to a destination aircraft at the time it is received from the source. For example, if the pilot requests information that is non-essential and SATCOM is unavailable in the cockpit and the Mode-S coverage is poor for that aircraft at that time, then the router should send that message over the ACARS network. If the message were Essential or Critical, then ACARS would not be used but an alternate medium would be used for communications. It is important that the controller and the pilot do not spend time determining which medium to use. The ATN and specifically the ATN routers (ATNR) automatically decide the optimum medium. This concept is illustrated in figure 5.

In addition, routing may change for the same message type as the aircraft location changes. For example, the party line may be more critical in the Terminal Control Area (TCA) than in Enroute airspace. For Clearance Delivery a broadcast medium may be more appropriate in the TCA whereas a point-to-point medium may be more appropriate in Enroute airspace.

CONCLUSIONS

Air/ground data communications will be required to reduce controller workload and provide for increased system capacity. The program in the United States has included all the participants in the community as evidenced by the first symposium on data link at the FAATC. The FAA has established a data link simulation lab and is working with NASA and the airline community to ensure that controller data link automation on the ground is most effectively used in the cockpit. An air/ground communications architecture has been drafted and should be under review by the ATC community. MITRE is developing a simulation capability based on the ATN architecture. UNISYS and Westinghouse are developing the ground Mode-S equipment. The avionics companies have developed Mode-S transponders, SATCOM, ACARS, and GPS equipment. The international community has analyzed SATCOM services and INMARSAT appears to be the solution for Oceanic ADS. In fact, E-Systems has developed the airborne data link system.

Although significant progress has been accomplished to date, several major questions must be answered to make air/ground digital communications a reality. The central question is: Can the routing functionality of the ATN be implemented using the present FAA systems (AAS, NADIN, GDLP, etc.), or is a standalone multimedia controller required at each ACF to support the routing?

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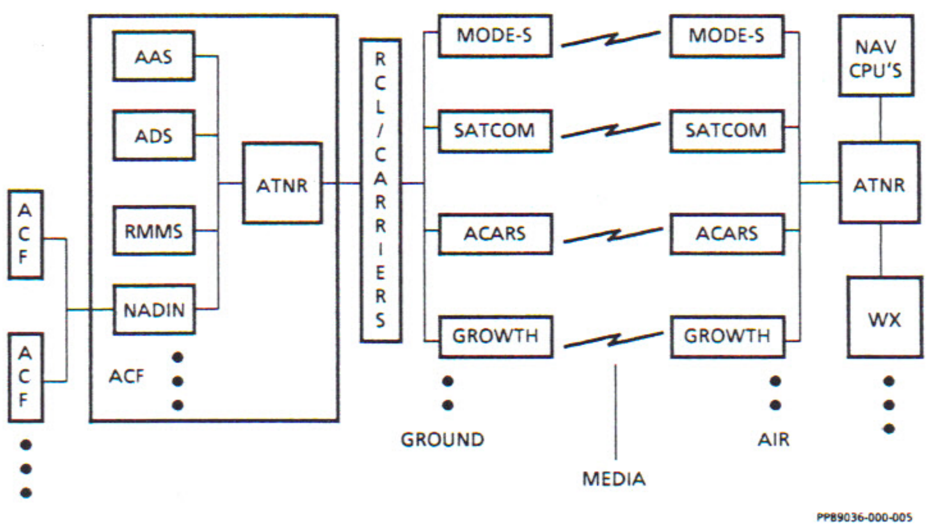

Figure 5. Aeronautical Telecommunications Network Router (ATNR) Concept

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