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# INTEGRATION OF AIR/GROUND DATA LINKS

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# ABSTRACT

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 Continental United States (CONUS) operations and Satellite Communications (SATCOM) for Oceanic operations. The airlines are presently using a digital data link network for airline operations that is a contender for future FAA Air Traffic Control (ATC) data link services.

This paper discusses the advantages and disadvantages of the various media, and develops a comprehensive concept for using the existing FAA voice VHF network for data link operations.

# INTRODUCTION AND BACKGROUND

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

Table I. 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 substantially 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.

### Mode-S Data Link

Mode-S for CONUS operations and SATCOM for oceanic operations is the present FAA solution to support data link communications. The airlines use ACARS to support carrier operations. Aeronautical Radio, Inc. (ARINC) and and the airlines have suggested using ACARS and the Aviation VHF Packet Communications (AVPAC) system upgrade, to provide some subset of ATC data link service. Each of these three data links is characterized with certain performance requirements that make them ideal for certain air/ground communications. However, none of these data links alone will be capable of providing the performance required by the next century.

Mode-S represents a significant investment on the part of the FAA that spans almost 20 years. The system concept is mature and effectively integrated with the domestic air traffic control system. 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 expected integrity requirements:

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

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 the Discrete Address Beacon System (DABS) and the resulting Mode-S program. However, Mode-S is a capable communications system for certain classes of messages.

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

Assumptions	Mode-S % Msgs Mode-		% Msgs		S Total
Transmission interval (sec)	10	Broadcast	PT- PT	Sys Total	Plane
Bits/frame	112	0	100	600	6
Frames/trans mission	6	20	80	481	6
Simulation	10	40	60	362	6
duration (sec)	10	60	40	244	6
Bits/Msg	112	80	20	125	6
Planes	100	100	0	6	6

Table II shows the relationship between Mode-S system capacity and 2 message types for a single scenario. The first message type is a broadcast message and the second message type is a point-to-point message. As can be seen in this table, Mode-S system capacity, which is the total number of messages exchanged by a 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 by Mode-S. 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 6 messages per plane. This is a function of the 112 bit length and frame rate which was 6 frames of interrogation in this scenario.

The rotating antenna also limits the worst case message response time to the rotation of the beacon which can be approximately 6 seconds. If an interrogation is missed, the response time becomes 12 seconds. Even more important is that 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 10 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. An alternative would be to use an omni directional communications system for supporting "party line" message communications.

# Satellite Communications (SATCOM)

SATCOM has been proposed to support the Automatic Dependency Surveillance (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 media for CONUS operations may require a new FAA satellite based infrastructure and 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 omni directional characteristics, there is greater capacity to support efficient message broadcasting. As shown in table III, an omni directional broadcast media may show a smaller ground system capacity than a directional medium, but will provide significantly more broadcast messages to an individual airplane. This is critical since the analysis shows that the performance of the system should consider not only the ground system but also the

Table III. Advantages of Omni Directional 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

		VHF DL Total			
% Msgs		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

cockpit. Further, a full analysis of the system from the ground perspective may not lead to a full understanding of actual system performance. Table III also shows 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 III 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 99.7% in 1987. The system still contains capacity and can be upgraded with additional frequencies if required. ACARS consists of 3 basic elements: ACARS display, entry, and VHF unit in the cockpit, 203 ground stations (VHF transmitters and receivers) and a ground digital message network.

Although the introduction of an omni directional 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 1, the priority of the traffic would have to be negotiated between the FAA and the air carriers. In addition, the ACARS ground infrastructure, ACARS Data Network System (ADNS), would have to be upgraded if the actual VHF media had to support the requirements of Critical and Essential services without falling back to workload intensive voice communications. 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.

As shown in figure 2, that cost responsibility will be significant. The FAA ATC messages will swamp the existing ACARS network such that if full CONUS services were provided, 96% of the message traffic on the ACARS network would be FAA ATC messages. This is based on a load scenario derived from actual

data link test operations [3]. The primary reasons for this significant load on the system are based on the assumption that the FAA would provide services not only to selected existing commercial airliners, but to the entire system.

Figure 3 summarizes the system differences in existing ACARS airline operations and potential FAA ATC requirements.

# 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, 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 surveillance function. However, the Line-of-Sight (LOS) communication and multiple reflections introduce problems for ground data link services and over mountainous terrain.

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. 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

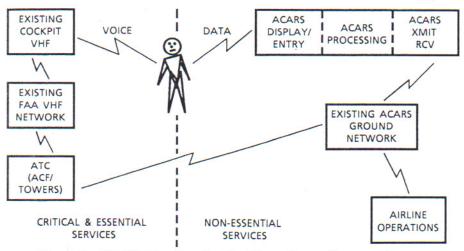


Figure 1. ACARS May Require Significant Expenditures to Support All ATC Services

of more hardware and software to provide for the required availability.

# 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 3 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 1990s. 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. These media have been integrated by the aviation community as part of the Aeronautical Telecommunications Network (ATN) architecture.

## COST OF VHF DATA LINK USING ACARS

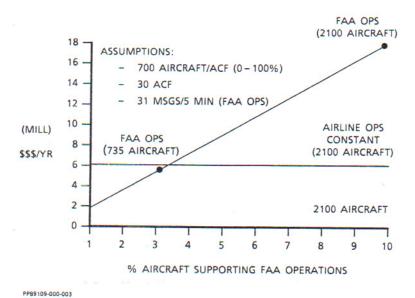


Figure 2. FAA vs. Airline Traffic

		CURRENT AIRLINE OPS	POTENTIAL FAA REQ'S
•	AIRCRAFT SERVICED	4500	21,000
•	DATA LINK TRAFFIC (MIL MSGS/YR)	38.4	1,116
•	GROUND SITES	200	>2,000
•	AVAILABILITY	.95	.99999 – .999 999
•	1987 DATA LINK EARNINGS	6.4	N/A
	(MILL)		
•	COST/ACARS MSG	\$0.17	UNKNOWN

PP89109-000-001

Figure 3. Potential ACARS/AVPAC Upgrade Reg's

Figure 4 illustrates the 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. The ATN acknowledges the concept of a generic air/ground communications architecture exclusive of any unique requirements associated with a single application such as ADS or Predeparture Clearance. Similarly, ATN supports technology insertion with new data links such as digital VHF without impacting the applications. Finally, ATN supports interoperability by providing for communications with users outside the FAA ATC community such as the ARINC network.

As shown in figure 5, the heart of the ATN is the ATN Router (ATNR). The ATNRs will transparently interface ground and airborne application to the ideal communications media.

# ALTERNATE BROADCAST MEDIA SOLUTION

The foundation for the Data Link program is almost complete. The ATNRs will permit the orderly introduction and integration of future ATC data link services. Mode-S will provide excellent point-to-point communications, SATCOM will provide excellent long distance communications, and AVPAC will provide excellent broadcast communications for Non-Essential FAA ATC messages. However, the critical element for future ATC data link includes Essential and Critical services. There is no effective broadcast media to

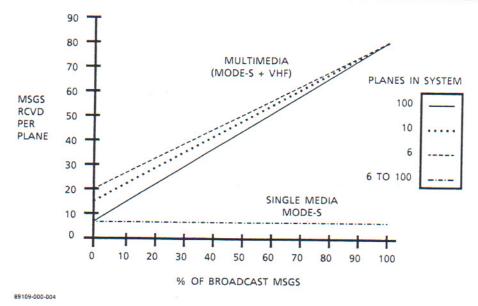


Figure 4. Advantages of Multimedia Communications

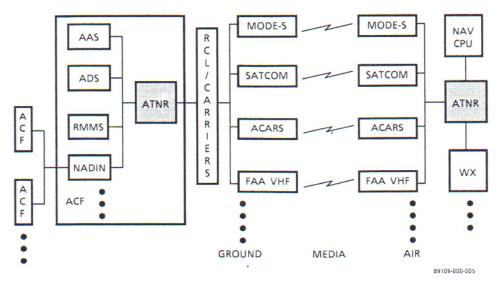


Figure 5. Aeronautical Telecommunications Network Router (ATNR) Concept

support those ATC services at this time. One approach to resolve this issue is to use existing FAA-owned ground equipment that can provide for the integrity of Critical and Essential services and use existing certifiable equipment in the cockpit.

The FAA owns an extensive VHF network (sites number in the thousands) that presently supports voice communications with coverage that exceeds that of Mode-S and SATCOM. In addition, the ground

infrastructure is being upgraded with the RCE, VSCS, and TCS programs. As shown in figure 6, the present FAA-owned VHF network could be upgraded to support both voice and digital data link communications. The modifications in the cockpit and on the ground would be minimal. The cockpit system would use the existing ACARS or AVPAC equipment and would interface to a NAV/COM radio via a Packet Applique. The Packet Applique would manage the voice and data

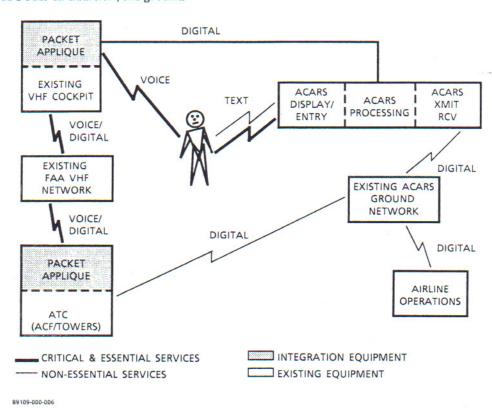


Figure 6. VHF Data Link

communications using a Carrier Sense Multiple Access (CSMA) technique. Data would be routed to the ACARS/AVPAC unit and voice would be routed to the audio channel. The data would be tone modulated and be contained within a 2.5 kHz bandwidth. Data transmission would occur in very short bursts (300 ms) during periods of non-activity on the frequency selected. These short data bursts would be insufficient to open the squelch on radios not equipped with the Packet Applique so that there would be no audible sounds to distract the pilots or ground controllers.

Since the existing VHF voice network is excessively congested, initial services could be established using the existing ATIS channels. Data transmissions could be interspersed with the existing ATIS messages with no operational impacts. As Mode-S, AVPAC, and the VHF data link on the ATIS channel reduce the existing VHF voice congestion, new digital data could even be time-shared with voice on non-ATIS VHF channels using the FAA VHF Data Link (VHF DL) broadcast media.

One of the first services that could be provided is Predeparture Clearance. This service was scheduled for demonstration using ACARS in late 1989. Future services could include ATC clearances in Terminal Control Areas (TCAs) where the party line may be critical to system operations, the broadcast of graphic weather, and other messages that are broadcast oriented and are considered Essential or Critical services.

# RECOMMENDATIONS/CONCLUSIONS

The first recommendation is to evaluate the advantages and disadvantages of the 4 potential data link media for transmitting Critical and Essential ATC messages throughout various flight scenarios:

- MODE-S
- -SATCOM

- -AVPAC
- -VHF DL

The purpose would be not to pick a medium for all present and future ATC services, but to acknowledge that the first 3 media will be part of the ATC infrastructure and to determine the best way to use those media. The operational portions of this work has been initiated at the FAA Technical Center. In addition, the concept of an FAA-owned and controlled ground VHF network that is capable of supporting digital data link and being interoperable with ACARS/AVPAC in the cockpit should be examined in more detail. This analysis should be performed jointly by industry and the FAA.

The second recommendation is to develop a prototype and demonstrate this prototype with the ACARS/AVPAC Predeparture Clearance demonstration. The purpose of this demonstration is to show the advantages and disadvantages of each of the data link media. This effort should be coupled with the ATN prototype being developed by Mitre Corp.

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- 3. ICAO Bulletin, "Prodat/Prosat Data Links Successful in Controlling Test Flight", February 1989, pp 30-32.