DOT/FAA/SE-93/2

Project Report
ATC-200

# ADS-Mode S: Initial System Description

V.A. Orlando

2 April 1993

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16. Abstract

Dependent Surveillance and the Mode S beacon radar. The result is an integrated concept for seamless surveillance and data link that permits equipped aircraft to participate in ADS or beacon ground environments. This offers many possibilities for transition from a beacon to an ADS based environment.

The ADS-Mode S concept is based on use of the Mode S squitter. The Mode S squitter is a spontaneous, periodic (once per second) 56-bit Mode S broadcast containing the Mode S 24-bit address. This broadcast is provided by all Mode S transponders and is used by the Traffic Alert and Collision Avoidance System (TCAS) to acquire Mode S equipped aircraft. For ADS-Mode S use, this squitter broadcast is extended to 112 bits to provide for the transmission of a 56-bit ABS message field. The ADS squitter is transmitted in addition to the current TCAS squitter in order to maintain compatibility with current TCAS equipment.

This paper defines the ADS-Mode S concept, describes its principal surveillance and data link applications and provides estimates of expected performance.


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The original concept for ADS-Mode S was first proposed by Paul R. Drouilhet, Assistant Director of Lincoln Laboratory.

Under FAA sponsorship, Lincoln Laboratory established a small study team to further define the characteristics and performance of ADS-Mode S. This study team was lead by the author and included the following Lincoln Staff members:

Edward T. Bayliss
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William H. Harman
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Loren M. Wood

Valuable contributions to the development of the concept were also made by P. Douglas Hodgkins of the FAA.

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# INTRODUCTION

The International Civil Aviation Organization (ICAO) has defined a concept for communications, navigation and surveillance for the next century known as the Future Air Navigation System (FANS). A cornerstone of the FANS is the increasing reliance on the use of satellite-based navigation systems such as the Global Positioning System (GPS). A second thrust of the FANS is surveillance based on the down linking of aircraft-derived satellite position information. This technique is known as Automatic Dependent Surveillance (ADS).

The general application of ADS will require that all aircraft in a region of airspace be equipped with satellite navigation and some form of data link. Since such general equipage will take many years, early implementation is expected to take place in regions where other surveillance techniques are not practical, e.g., over ocean and in remote areas.

Planning is currently underway for ADS to support Air Traffic Control (ATC) management of oceanic routes. Significant economic benefits are anticipated due to the reduction in separation (and the resultant capacity increase) made possible by ADS. This form of ADS connects an aircraft via a point-to-point link with the controlling oceanic ATC facility.

The application of ADS in other areas requires a more general form of ADS in which the aircraft broadcasts its position in an omni-directional fashion. This makes it possible for one ADS transmission to simultaneously serve the surveillance needs of multiple ground ATC and airborne collision avoidance activities.

ADS-Mode S is a system concept that merges the capabilities of Automatic Dependent Surveillance and the Mode S beacon radar. The result is an integrated concept for seamless surveillance that permits equipped aircraft to participate in ADS or beacon ground environments. This offers many possibilities for transition from a beacon to an ADS-based environment.

This report provides an initial system description of the ADS-Mode S concept. It is anticipated that this report will be updated and reissued as progress is made in the development of this concept.

## REPORT OVERVIEW

The overview of the report will present the ADS-Mode S concept together with its principal surveillance applications. Next, answers are given to fundamental questions that determine the feasibility of the concept. This is followed by a description of other surveillance applications together with a preliminary list of implementation issues. The report ends with a summary which includes the identification of actions needed to further the development of the concept.

The technical details of supporting studies conducted to obtain answers to the fundamental questions are provided as an appendix to this report.

# OUTLINE

- OVERVIEW
- FUNDAMENTAL QUESTIONS
- OTHER ADS APPLICATIONS
- IMPLEMENTATION ISSUES
- SUMMARY
- SUPPORTING STUDIES

# BACKGROUND

The FAA is evaluating alternatives for a planned second buy of beacon radars. The availability of GPS/GLONASS will provide the basis for a worldwide capability of Automatic Dependent Surveillance (ADS). Hence the second buy study included ADS as one of it alternatives.

A data link is required for the implementation of ADS in order to transfer the aircraft-derived position to the ground. The initial study for the second buy focused on the use of the VHF data link for the ADS alternative.

The use of the VHF data link raised a number of concerns relative to its capacity to support ADS within the required delivery delay as well as the availability of sufficient spectrum for a national implementation. A further concern was how to accommodate the Traffic Alert and Collision Avoidance System (TCAS) into such a concept.

As a result of these concerns, the FAA requested that Lincoln Laboratory investigate the use of the Mode S data link to support the implementation of ADS, a concept that had been previously proposed by the Laboratory. The Lincoln approach contained in this report bases support for ADS on the use of a modified Mode S squitter.

# BACKGROUND

- **FAA EVALUATING SECOND BUY ALTERNATIVES**
- **GPS/GLONASS PROVIDES BASIS FOR ADS**
- **AIR/GROUND DATA LINK REQUIRED**
  - INITIAL STUDY FOCUSED ON VHF DATA LINK
- **VHF FOR ADS RAISED CONCERNS:**
  - CAPACITY
  - DELIVERY DELAY
  - SPECTRUM AVAILABILITY
  - SUPPORT FOR TCAS
- **LINCOLN PROPOSES ADS-MODE S**
  - BASED ON MODIFIED MODE S SQUITTER

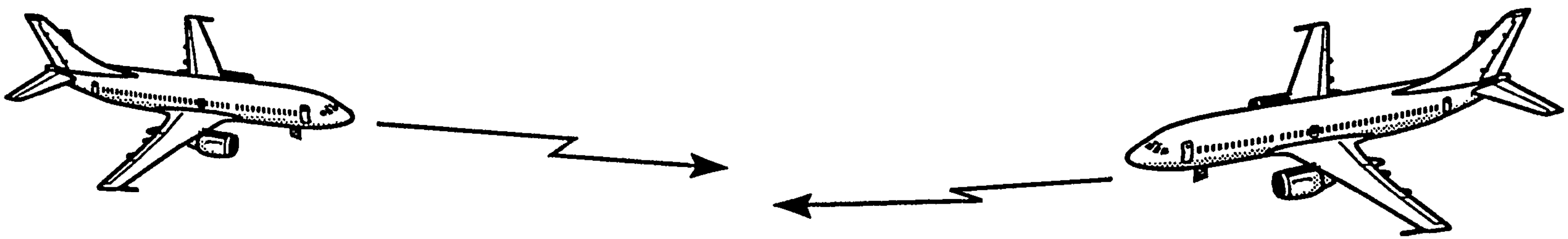
## CURRENT MODE S SQUITTER

In the current Mode S design, the squitter is a 56-bit transmission, broadcast on the Mode S transponder reply frequency (1090 MHz). It is transmitted in an omni-directional fashion once per second.

This squitter is used by TCAS to detect the presence of Mode S equipped aircraft. In operation, TCAS listens for squitters, extracts the 24-bit Mode S address contained in the squitter data and uses this address as the basis for discrete interrogation as required to perform surveillance on Mode S equipped aircraft.

Note that the squitter is in operational use with TCAS. Its performance is well understood from the design and validation of TCAS as well as the substantial experience with TCAS as an operational system.

# CURRENT MODE S SQUITTER
# (FOR TCAS ACQUISITION)



**56-BIT SQUITTER**

## ADS-MODE S SQUITTER FORMAT

The format of the current 56-bit format is shown in the figure. Since the Mode S message protocol defines both 56-bit and 112-bit replies, the proposed approach is to define an additional squitter for ADS that uses a 112-bit format. This creates a 56-bit message field for ADS data. All other fields remain the same as in the original squitter.

# ADS-MODE S SQUITTER FORMAT

**CURRENT (56 BITS)**

| | | |
|---|---|---|
| CONTROL | MODE S ADDRESS | PARITY |

**ADS-MODE S (112 BITS)**

| | | | |
|---|---|---|---|
| CONTROL | MODE S ADDRESS | ADS MESSAGE - 56 BITS | PARITY |

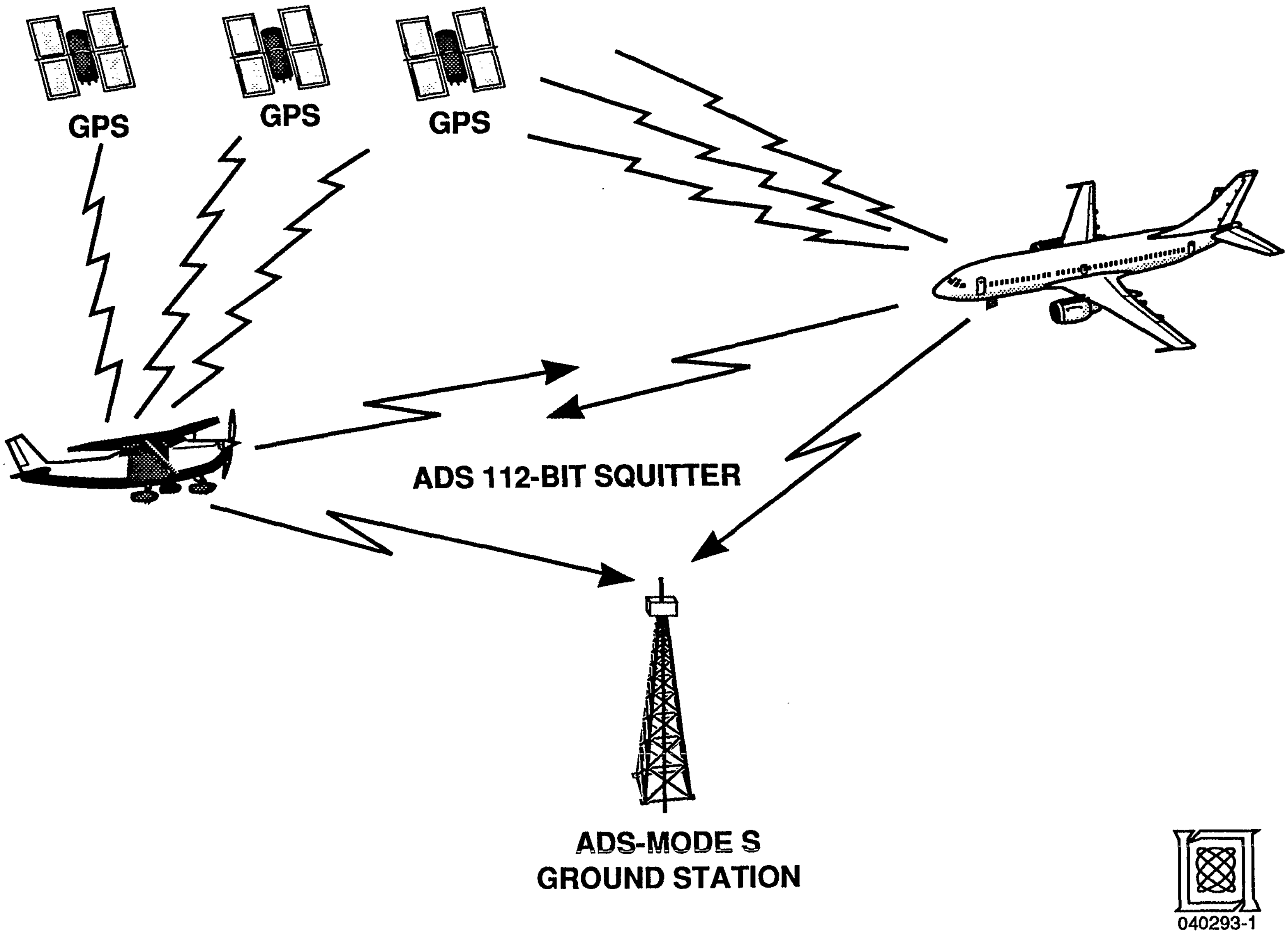
## ADS-MODE S CONCEPT

In operation, equipped aircraft use GPS to determine their position once every second. This position information is inserted into the 56-bit ADS message field of the 112-bit squitter and broadcast twice every second to increase the probability of a successful reception. The current 56-bit squitter is broadcast once per second for continued compatibility with TCAS.

Simple omni-directional or sector beam ground stations can receive the squitter to provide for ground-to-air surveillance requirements.

The squitter can also be received by TCAS aircraft to support acquisition of Mode S aircraft as with the current squitter. As will be shown later, the ADS-Mode S squitter can provide other benefits to TCAS operation.

# ADS-MODE S CONCEPT



## ADS-MODE S SURVEILLANCE APPLICATIONS

As ADS-Mode S was being developed, it became obvious that it had applicability to surveillance activities beyond those required for the second buy of beacon radars. A list of the most important surveillance applications identified is shown on the figure. Each of these applications will be described in greater detail later in the report.

In addition to the en route and terminal coverage required for the second buy, ADS-Mode S also has the ability to support Precision Runway Monitoring (PRM) surveillance requirements if the derived position is based on a special form of GPS known as differential GPS.

On the surface, the concept (also using differential GPS) supports surveillance on runways and taxiways.

Air-to-air use of ADS-Mode S squitters includes improved performance for TCAS as well as support for Cockpit Display of Traffic Information (CDTI).

# ADS-MODE S SURVEILLANCE APPLICATIONS

- AIR-GROUND
  - EN ROUTE
  - TERMINAL
  - PRECISION RUNWAY MONITORING (PRM)
- SURFACE
  - RUNWAY AND TAXIWAY
- AIR-AIR
  - IMPROVED TCAS
  - COCKPIT DISPLAY OF TRAFFIC INFORMATION (CDTI)

## RELATED DATA LINK CAPABILITY

Although not part of the ADS-Mode S concept, the inclusion of a Mode S transponder as part of the ADS-Mode S avionics means that access is available to the Mode S data link.

This includes the data link service provided by the conventional Mode S ground sensors currently being procured. These sensors will provide data link service in the en route and terminal areas.

An additional form of Mode S data link device can be foreseen that provides service using simple omni-directional or sector beam antennas.

One particular application of this technique is currently under development by the RTCA. This application uses the Mode S uplink broadcast capability to deliver the ground-derived differential GPS corrections, using simple omni-directional transmitters.

# RELATED DATA LINK CAPABILITY

- MODE S SENSOR DATA LINK
  - TERMINAL AND EN ROUTE
- MODE S OMNI DATA LINK
  - SURFACE
  - TERMINAL AND EN ROUTE
  - DIFFERENTIAL GPS BROADCAST

## AIR-TO-GROUND SURVEILLANCE

The proposed concept for air surveillance in the en route area uses 100 NM ground stations. Multiple stations will be required to replace a 200 NM beacon radar. This will provide better low altitude coverage than the beacon radar.

The 100 NM range of these ground stations provides flexibility of implementation and thus makes it possible to collocate these units with existing FAA facilities, eliminating the need for the acquisition of additional sites.

In the terminal area, a 50 NM ground station will be able to replace a terminal beacon radar on a one-for-one basis.

# AIR-TO-GROUND SURVEILLANCE

<u>EN ROUTE</u>

- USE MULTIPLE 100 NM ADS-MODE S GROUND STATIONS
  - PROVIDES BETTER LOW ALTITUDE COVERAGE
- LOCATE RECEIVERS AT EXISTING FAA FACILITIES
  - RCOs, VORs, ETC.

<u>TERMINAL</u>

- USE 50 NM ADS-MODE S GROUND STATIONS

## ADS-MODE S AIR SURVEILLANCE

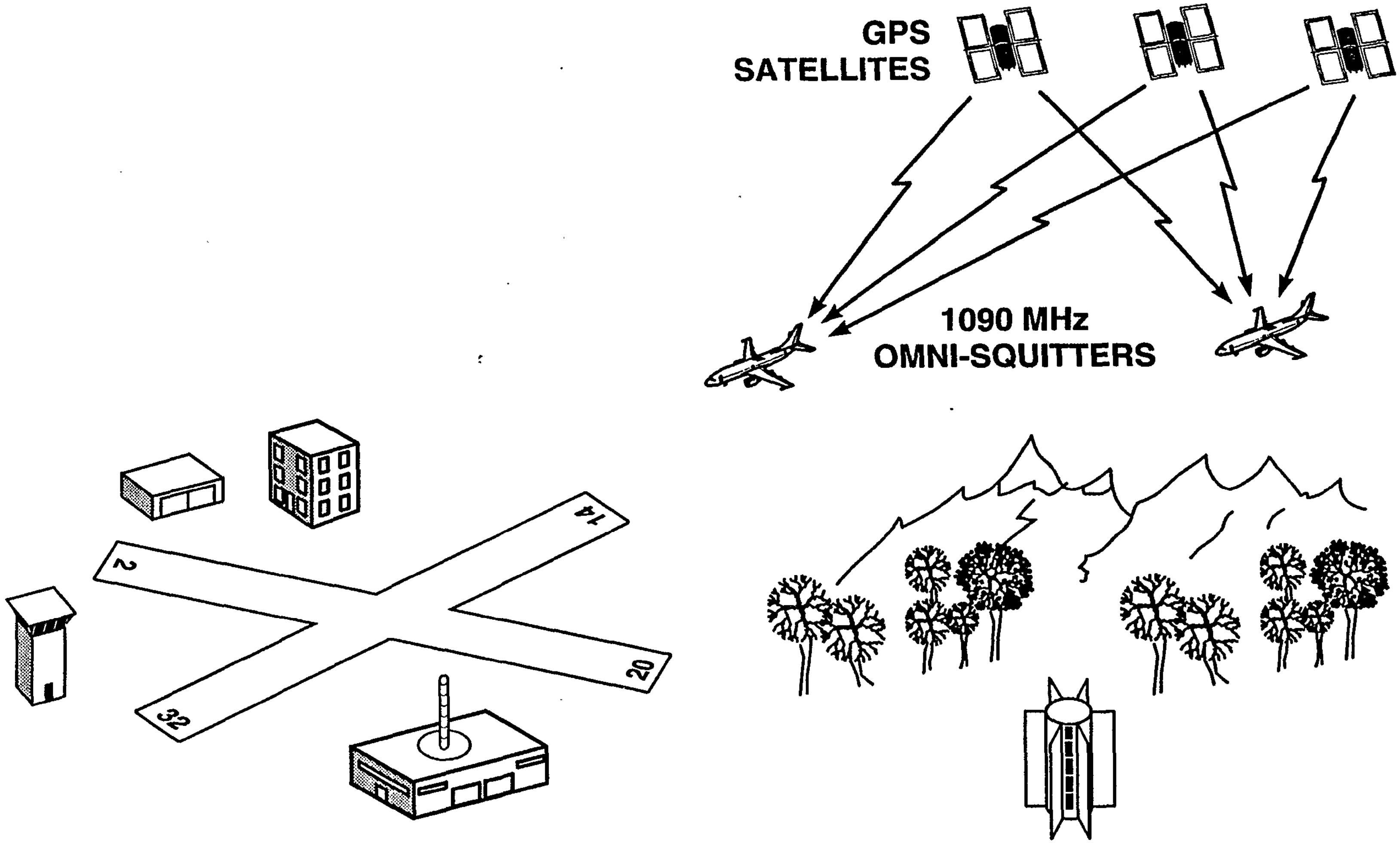
The concept for ADS-Mode S air surveillance is shown in the figure.

Aircraft determine their position using GPS and broadcast this position using the ADS-Mode S squitter.

The squitter is received by terminal and en route ground stations. The terminal antenna is shown as a single element omni, which is compatible with the required 50 NM range. The figure shows the use of a 6-sector antenna (with 6 receivers) in order to obtain the required 100 NM range. The 6-sector antenna is required to provide the antenna gain needed for 100 NM operation. It is also needed to limit the number of aircraft being processed by any one receiver in order to operate into higher traffic densities.

The example shows that the ground stations are also able to transmit on 1030 MHz in order to provide Mode S data link service. For the terminal ground station, this will include the uplink broadcast of differential GPS (DGPS) corrections to support PRM and the use of GPS-based non-precision approaches.

# ADS-MODE S AIR SURVEILLANCE




TERMINAL
OMNI-ANTENNA
RECEIVE SQUITTERS 1090 MHz
TRANSMIT DGPS 1030 MHz

EN ROUTE
6-SECTOR ANTENNA
RECEIVE SQUITTERS 1090 MHz
TRANSMIT DATA LINK 1030 MHz

217615-2

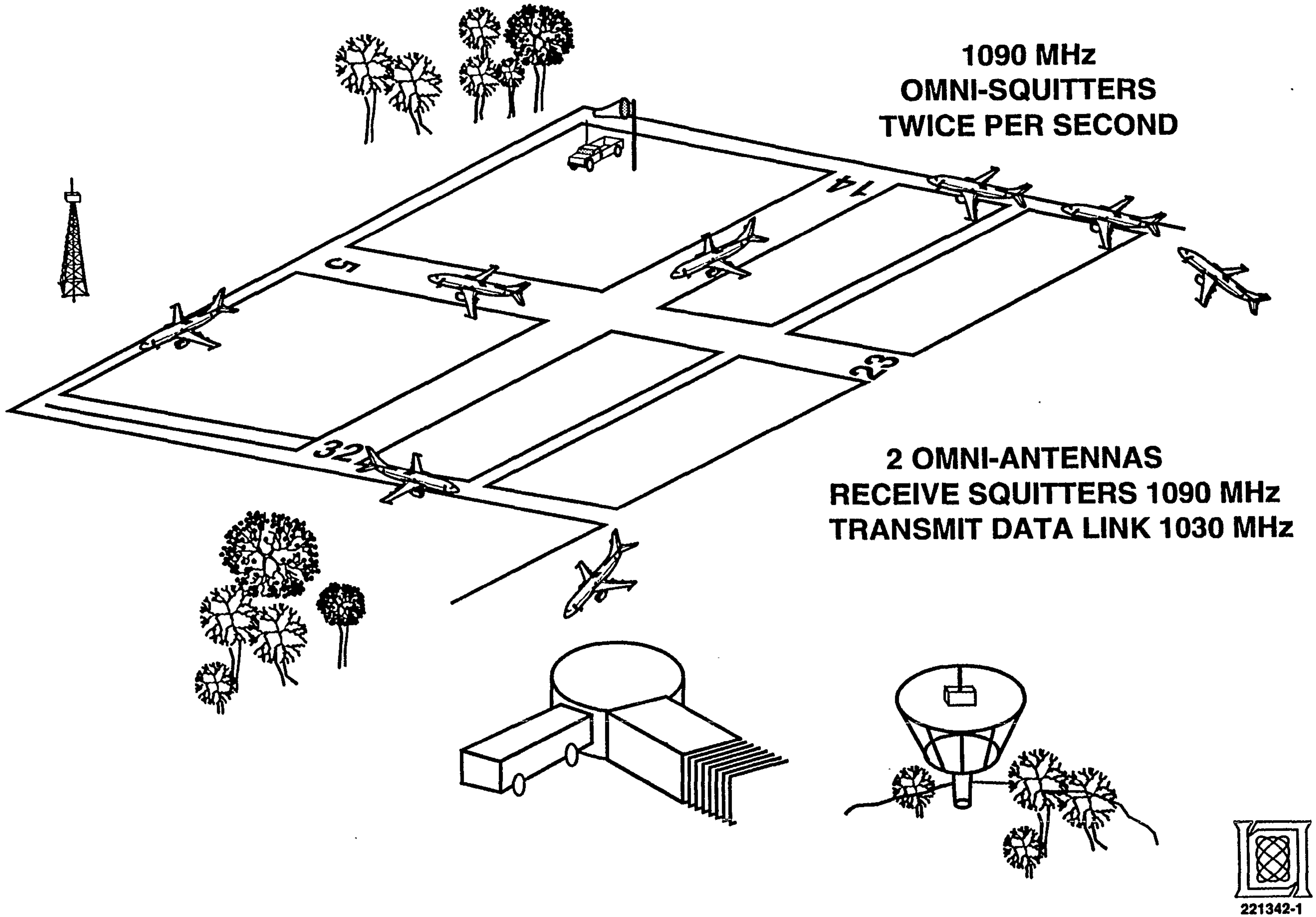
## ADS-MODE S SURFACE SURVEILLANCE

Operation on the airport surface is shown in the figure.

Aircraft squitter their GPS derived positions while operating on runways and taxiways. These squitters are received by omni-directional receiving stations around the periphery of the airport. Two stations for this purpose are shown in the figure. The exact number will be determined by squitter reception performance in the multipath environment of the airport surface. Additional measurements will be made on the airport surface in order to better estimate this performance.

Surface surveillance requires the use of DGPS in order to obtain the required position accuracy. This correction is broadcast to surface aircraft using the same ground stations as used for squitter reception. The availability of a transmit capability in the ground stations means that Mode S data link service can be used to provide a general purpose data link in support of surface automation.

# ADS-MODE S SURFACE SURVEILLANCE



## TCAS WITH ADS-MODE S

The availability of position data in the ADS-Mode S squitter makes it possible to significantly improve the operation of TCAS.

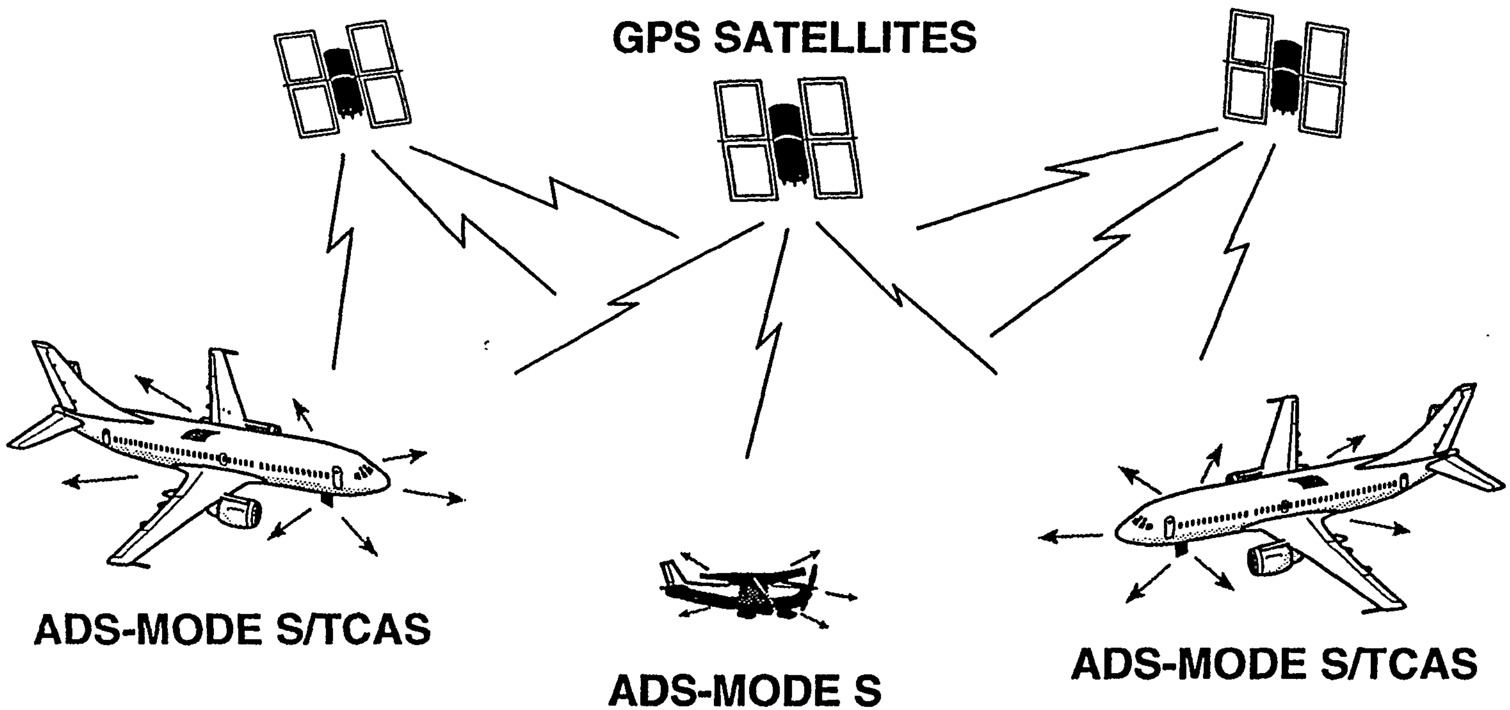
For security reasons, the Air Force intentionally perturbs the accuracy of GPS through a technique called "Selective Availability" or SA. Analysis of TCAS operation indicates that ADS-Mode S will be able to support passive surveillance of Mode S aircraft to a Tau of 40 seconds if SA is turned on (as it is today). Tau in TCAS terms is the time to closest approach. Operational experience indicates that an intruder with a Tau of about 40 seconds is observed on an average of once per hour per TCAS. Thus TCAS will be able to perform most of its surveillance passively.

If SA is turned off, TCAS will be able to perform all of its surveillance of Mode S aircraft passively. The only time that TCAS will be required to transmit is when it is performing coordination for an avoidance maneuver. Experience indicates that this occurs only once every 45 hours per TCAS.

In addition to surveillance benefits, the use of the ADS position information can reduce the alert rate for TCAS 2 through the use of miss distance filtering.

An additional benefit is that ADS-Mode S provides the basis for TCAS 3, the version of TCAS that uses horizontal avoidance maneuvers. The use of ADS position information from intruder aircraft appears to provide a more achievable basis for TCAS 3 than the alternative of precision antennas to measure bearing angles.

# ADS-MODE S
# TCAS WITH ADS




- ADS CAN SUPPORT PASSIVE TCAS SURVEILLANCE
  - TO A TAU OF 40 SEC IF GPS SA IS ON
  - FOR ALL SURVEILLANCE IF GPS SA IS OFF
- CAN REDUCE THE ALERT RATE FOR TCAS 2 THROUGH THE USE OF MISS DISTANCE FILTERING
- PROVIDES A BASIS FOR TCAS 3

## TCAS AIR-AIR INFORMATION

Current Mode S transponders have the capability of storing airborne data in up to 250, fifty-six bit registers. Information stored in these registers can be read out under control of the ground interrogator.

An upward compatible control field will be added to the TCAS air-air formats to permit the information in these registers to be read by TCAS.

Air-air data for TCAS could include threat aircraft speed, heading and altitude intent. This information could be used by TCAS in evaluating threats and selecting resolution advisories.

# TCAS AIR-AIR INFORMATION

- CURRENT MODE S TRANSPONDERS CAN PROVIDE AIRBORNE DATA ON REQUEST TO THE GROUND
  - 250, FIFTY-SIX BIT REGISTERS
- SAME CAPABILITY TO BE PROVIDED FOR THE TCAS AIR-AIR LINK
- AIR-AIR DATA COULD INCLUDE
  - SPEED
  - HEADING
  - INTENT

## ADS-MODE S BENEFITS

The figure summarizes the ADS-Mode S benefits presented in this overview.

ADS-Mode S is a systems approach that supports ADS and provides a number of surveillance and data link capabilities.

Since Mode S is an internationally accepted operational system on the beacon frequencies, there are no spectrum problems.

The system will be owned and operated by the FAA.

The concept provides useful benefits to existing beacon surveillance applications.

Perhaps the most significant benefit is that a single avionics set provides both ADS and beacon radar capability. This provides compatibility with existing beacon installations as well as operation in regions using ADS as the surveillance technique. This interoperability permits a smooth transition to ADS and is unique to ADS-Mode S among the techniques that have been proposed to implement ADS.

## ADS-MODE S BENEFITS

- SYSTEM APPROACH TO ADS THAT PROVIDES A NUMBER OF SURVEILLANCE AND DATA LINK CAPABILITIES
- NO FREQUENCY SPECTRUM PROBLEMS
- OWNED AND OPERATED BY THE FAA
- PROVIDES ENHANCEMENTS TO EXISTING BEACON SURVEILLANCE APPLICATIONS
- SINGLE AVIONICS SET PROVIDES BEACON RADAR AND ADS CAPABILITY
  - COMPATIBLE WITH EXISTING BEACON SYSTEMS
  - PROVIDES FOR SMOOTH TRANSITION TO ADS

# OUTLINE

- OVERVIEW
- FUNDAMENTAL QUESTIONS
- OTHER ADS APPLICATIONS
- IMPLEMENTATION ISSUES
- SUMMARY
- SUPPORTING STUDIES

## FUNDAMENTAL QUESTIONS

The development of the ADS-Mode S concept raised three fundamental questions concerning the feasibility of the concept:

1. Can a long Mode S squitter support ADS? That is, does it have sufficient capacity to transfer the required ADS data and does it provide acceptable usage of the 1090 MHz reply channel?

2. Will the normal transponder reply power level support adequate operational range? Recall that the concept requires coverage to 100 NM in the en route area.

3. Can ADS-Mode S provide surveillance in high traffic densities?

# FUNDAMENTAL QUESTIONS

- CAN A LONG MODE S SQUITTER SUPPORT ADS?
  - SUFFICIENT MESSAGE CAPACITY
  - ACCEPTABLE MODE S 1090 MHZ CHANNEL USAGE
- WILL IT PROVIDE ADEQUATE RANGE?
- CAN IT OPERATE IN HIGH TRAFFIC DENSITIES?

# MESSAGE CAPACITY

## Airborne Format

An example of ADS-Mode S message formats is shown in the figure. (Details are provided in the ADS Squitter Formats Supporting Study).

The airborne position format contains a 3-bit message type field, a one-bit time field, 19 bits each for latitude and longitude and 12 bits of barometric altitude.

A one-bit time field is sufficient since GPS units will be required to perform a position fix each second on a GPS second mark. Units that cannot support this timing will be required to extrapolate to the next GPS second mark. Since the squitter is transmitted twice per second, the only ambiguity in the time of measurement is whether the measurement was made on the second just preceding the squitter, or in the previous second due to processing delays. A bit that specifies an even or odd GPS second is sufficient to resolve the ambiguity.

Latitude and longitude are provided to a resolution of 10 feet with an ambiguity of about 1000 NM.

Altitude is provided as encoded in the Mode S reply, and provides a nominal resolution of 25 feet.

## Surface Format

Latitude-longitude for the surface format replaces the two most significant bits of the airborne format with two additional least significant bits and thus provides a resolution of 2.5 feet and an ambiguity of 250 NM.

In place of altitude, the surface format provides information on heading and movement.

## Identification Format

Provision of the aircraft ID (e.g., AA 123) seems necessary in support of TCAS and CDTI operations. Since it rarely changes in flight, it is provided in a separate format once every 5 seconds. Note that the position format and the identification formats both contain the aircraft 24-bit address so there is no problem in associating the position with the ID.

# FUNDAMENTAL QUESTIONS

## MESSAGE CAPACITY

**ADS-MODE S** (112 BITS)

| CONTROL | MODE S ADDRESS | ADS MESSAGE - 56 BITS | PARITY |
|---|---|---|---|

AIRBORNE POSITION FORMAT (0.5 SEC UPDATE)

| TYPE | TIME | LAT - LONG | BARO ALT | SPARE |
|---|---|---|---|---|

SURFACE POSITION FORMAT (0.5 SEC UPDATE)

| TYPE | TIME | LAT - LONG | HDG - MOVEMENT |
|---|---|---|---|

IDENTIFICATION FORMAT ( 5 SEC UPDATE)

| TYPE | N/A | ICAO AIRCRAFT I.D. |
|---|---|---|

## SQUITTER IMPACT ON CHANNEL OCCUPANCY

If the additional squitter length were to present a problem, it would do so in a high density environment. The figure shows a worst case reply rate scenario for a single Mode S transponder on a per second basis.

Ground stations are assumed to interrogate the transponder at a total aggregate rate of 100 Air Traffic Control Radar Beacon System (ATCRBS) interrogations per second, leading to a reply channel occupancy of 2000 microseconds. Mode S activity adds an additional 992 microseconds as shown.

The addition of two 112-bit squitters per second adds 240 microseconds to the channel occupancy. The additional squitter for ID once per 5 seconds adds an average of 24 microseconds per second. The total increase in squitter occupancy of 264 microseconds per second increases the total channel occupancy for a transponder from 0.299% to 0.326%. This is considered to be a tolerable increase in channel occupancy.

Since the use of the ADS-Mode S squitter will make it possible for TCAS and ATC surveillance systems to operate in a passive mode, it is equally appropriate to conclude that the use of the longer squitter has the effect of reducing the occupancy of the reply channel.

# SQUITTER IMPACT ON CHANNEL OCCUPANCY

## (REPLIES PER TRANSPONDER PER SECOND)

| | | |
|---|---|---|
| **ATCRBS** | | **OCCUPANCY (μ SEC)** |
| • GROUND | 100 | 2000 |
| **MODE S** | | |
| • GROUND | 1 SHORT | 64 |
| | 4 LONG | 480 |
| • SQUITTER | 1 SHORT | 64 |
| • ALL-CALL | 1 SHORT | 64 |
| • TCAS | 5 SHORT | 320 |
| | | 2992 μSEC |

CHANNEL OCCUPANCY (CURRENT SQUITTER) 0.299%
CHANNEL OCCUPANCY (ADS SQUITTERS) 0.326%
(ADDITIONAL 264 μSEC)

## ADS OPERATIONAL RANGE

The design baseline for squitter reception range was based on TCAS experience.

Range improvements relative to TCAS are easily accomplished through the use of improved antenna gain through vertical aperture and the use of horizontal sector beams. A second technique for enhanced range performance was the use of a receiver with a reduced noise figure. (Antenna characteristics and a link budget for ADS-Mode S receivers are presented in the ADS-Mode S Operating Range Supporting Study).

These improvements produce a conservative ADS squitter operating range of 50 NM using an omni-directional antenna and 100 NM using a 6-sector antenna.

The resulting range is comparable to the performance of the VHF data link.

# FUNDAMENTAL QUESTIONS

## ADS OPERATIONAL RANGE

- TCAS EXPERIENCE IS DESIGN BASELINE FOR SQUITTER RANGE
- RANGE IMPROVEMENTS ARE RELATIVELY EASY
  - ANTENNA GAIN VIA VERTICAL APERTURE
  - ANTENNA GAIN VIA HORIZONTAL SECTOR BEAMS
  - REDUCED NOISE FIGURE
- IMPROVEMENTS PRODUCE CONSERVATIVE ADS SQUITTER RANGE OF
  - 50 NM USING OMNI-DIRECTIONAL ANTENNA
  - 100 NM USING 6-SECTOR ANTENNA
- RANGE IS COMPARABLE TO VHF DATA LINK

## ADS-MODE S OPERATING DENSITY

In order to estimate the operating density for ADS-Mode S, an analysis was conducted which assumed that the probability of an update at least once every 5 seconds should be greater than or equal to 99.5%. This performance is representative of the current surveillance system. (Details of this analysis are presented in the ADS-Mode S Operating Density Supporting Study).

### Case 1 - Current Highest Density

The first case analyzed is based on the worst case interference scenario used earlier, except that an additional load of 20 ATCRBS replies per second has been added for TCAS operation, and the number of Mode S replies per second has been increased to 14 to account for the ADS squitters.

Note that this is an extreme worst case since it represents the highest ATCRBS transponder reply rates observed in the development of Mode S and TCAS, and includes an anticipated worst case for Mode S. Note also that approximately 75% of the ATCRBS replies elicited from the ground are due to military interrogators. This component of the interference scenario is expected to decrease as military activity is reduced.

Another worst case assumption is that every reply generated is received at a signal strength high enough to perturb the detection of the desired squitter. The Mode S reply uses pulse position modulation and is robust to interfering signals that are lower in power than the desired signal. Therefore, interference caused by replies from distant aircraft would be unlikely to interfere with the reception of a squitter from a nearby aircraft.

Even with these worst case assumptions, ADS-Mode S provides operation into the moderate densities shown in the table. Capacity values are given within a radius of 150 NM or 250 NM for the omni and 6-sector case respectively, because these are the maximum ranges from which interfering replies can be received. This performance is adequate for the majority of second buy sites.

### Case 2 - Current Medium Density

This case is more representative of the what would be observed in all but the highest density environments. The resulting operational density is appropriate for virtually all of the second buy sites.

### Case 3 - All Mode S High Activity Environment

This case indicates the performance that would be achieved in an environment where ATCRBS fruit has been eliminated. The performance is compatible with the highest traffic density environments.

# FUNDAMENTAL QUESTIONS

## ADS/MODE S OPERATING DENSITY

### 5 SECOND UPDATE, RELIABILITY ≥ 99.5%

| CASE | REPLIES/AIRCRAFT/SEC | | MAXIMUM AIRCRAFT IN RADIUS R | |
|---|---|---|---|---|
| | ATCRBS | MODE S | OMNI ANTENNA R = 150 NM | 6-SECTOR ANTENNA R = 250 NM |
| 1 * | 120 | 14 | 85 | 215 |
| 2 | 60 | 14 | 140 | 350 |
| 3 ** | 0 | 14 | 280 | 700 |

* CURRENT HIGH DENSITY
** ALL MODE S WITH NOMINAL DATA LINK ACTIVITY

## ADS-MODE S PERFORMANCE SUMMARY

The proposed squitter has the required message capacity and can operate on the 1090 MHz channel with negligible impact.

ADS-Mode S can easily achieve the required operating ranges of 100 NM en route and 50 NM in the terminal area.

Moderate traffic densities can be supported in high ATCRBS interference environments and the concept can operate into the highest traffic densities if ATCRBS fruit is reduced. As indicated earlier, reduction of ATCRBS fruit levels will involve coordination with military users. Note that military adoption of the ADS-Mode S concept would lead to a substantial decrease in ATCRBS fruit.

# ADS-MODE S PERFORMANCE SUMMARY

SQUITTER

- HAS THE MESSAGE CAPACITY
- CAUSES NEGLIGIBLE 1090 MHZ IMPACT

RANGE

- ACHIEVES REQUIRED OPERATING RANGES

TRAFFIC DENSITY

- SUPPORTS MODERATE TRAFFIC DENSITIES IN HIGH ATCRBS INTERFERENCE ENVIRONMENTS
- CAN SUPPORT HIGH TRAFFIC DENSITIES IF ATCRBS FRUIT IS REDUCED

# OUTLINE

- OVERVIEW
- FUNDAMENTAL QUESTIONS
- OTHER ADS APPLICATIONS
  - PRECISION RUNWAY MONITOR
  - CDTI
  - SMALL TERMINAL SENSOR
  - GAP FILLER
- IMPLEMENTATION ISSUES
- SUMMARY
- SUPPORTING STUDIES

## PRECISION RUNWAY MONITOR

ADS-Mode S (using differential GPS) provides high accuracy and a once per second position update rate. Analysis indicates that a 20 NM operating range (adequate for PRM operations) can be supported. Horn antennas may be required in high interference environments.

ADS-Mode S can provide a low cost alternative to the E-scan radar. It is more accurate than the E-scan at ranges greater than 2 NM.

As for surface surveillance, the performance of ADS-Mode S in multipath must be measured to fully characterize the use of this concept for PRM.

# PRECISION RUNWAY MONITOR

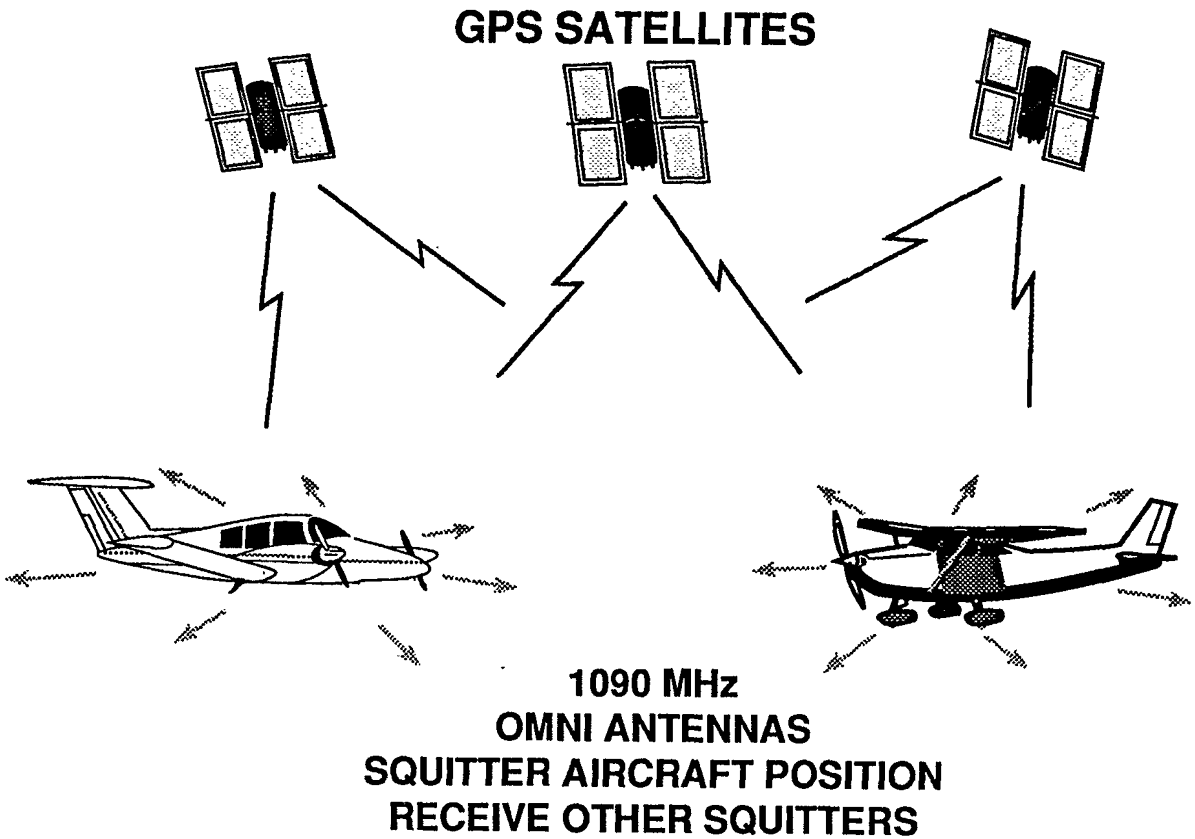
- ADS-MODE S WITH DIFFERENTIAL GPS
  - HIGH ACCURACY
  - FAST UPDATE RATE
- 20 NM OPERATING RANGE
- AN ALTERNATIVE TO THE E-SCAN RADAR
  - MORE ACCURATE THAN E-SCAN AT RANGES GREATER THAN 2 NM
- ISSUE: PERFORMANCE IN MULTIPATH ENVIRONMENT

## COCKPIT DISPLAY OF TRAFFIC INFORMATION (CDTI)

CDTI operation is similar to TCAS in that squitters are received air-to-air.

A range of 14 NM can be supported for CDTI using receivers equivalent to those in TCAS. In low interference environments, this range can be extended to 40 NM through the use of low-noise receivers.

# ADS-MODE S
# COCKPIT DISPLAY OF TRAFFIC INFORMATION (CDTI)




RANGE: 14 NM WITH CURRENT TCAS 2 EQUIPMENT
40 NM WITH LOW-NOISE RECEIVERS

## ADDITIONAL ADS-MODE S APPLICATIONS

ADS-Mode S can directly provide a low cost approach for the small terminal sensor. This sensor is intended for use in low traffic terminals that would not qualify for conventional ground beacon equipment due to its high cost.

Another natural application of ADS-Mode S is in the role of a gap filler for en route coverage. This can be of use in providing a fill in for low altitude coverage or for the monitoring of airways in remote areas.

# ADDITIONAL ADS-MODE S APPLICATIONS

- SMALL TERMINAL SENSOR
  - SURVEILLANCE SERVICE FOR LOW-TRAFFIC TERMINALS
- GAP FILLER FOR EN ROUTE COVERAGE
  - FILL IN FOR LOW ALTITUDE COVERAGE
  - AIRWAY MONITORING IN REMOTE AREAS

# OUTLINE

- OVERVIEW
- FUNDAMENTAL QUESTIONS
- OTHER ADS APPLICATIONS
- IMPLEMENTATION ISSUES
- SUMMARY
- SUPPORTING STUDIES

## REQUIRED STANDARDS ACTIVITY

Mode S and TCAS are operational systems. Thus Minimum Operational Performance Standards (MOPS) have been published by the RTCA, and Standards and Recommended Practices (SARPs) issued by ICAO.

The standards for Mode S will have to be modified to define the new squitter format.

In order to benefit from ADS-Mode S, TCAS standards will have to be modified to require the TCAS equipment to receive the new long squitter in addition to the current short squitter. Additional changes will be required to define the manner in which TCAS will use the ADS data for passive surveillance. Any use of ADS data for miss distance filtering will also lead to a change in the standards.

The standards for ADS are currently in development. These standards currently address only the particular needs of ADS over the ocean. These standards will have to be modified to add the requirements for ADS-Mode S.

# REQUIRED STANDARDS ACTIVITY

MODE S MOPS AND SARPS

- MODIFICATION TO DEFINE NEW SQUITTER FORMAT

TCAS MOPS AND SARPS

- MODIFICATION TO RECEIVE LONG SQUITTER AND TO UTILIZE ADS DATA FOR SURVEILLANCE

ADS MOPS AND SARPS (CURRENTLY IN DEVELOPMENT)

- STANDARDIZATION OF THE FORMATS FOR ADS AND DIFFERENTIAL GPS CORRECTION

## AVIONICS MODIFICATIONS

Since the 56-bit squitter is retained, TCAS can continue to operate without modification. In order to take advantage of ADS-Mode S data, TCAS can be modified to accept a long squitter in addition to the short squitter.. This modification will require a software and/or hardware modification depending on the TCAS manufacturer.

Modifications to existing data link transponders for use with ADS-Mode S include the transmission of the long squitter. This is a software change for all transponder manufacturers.

# AVIONICS MODIFICATIONS

<u>TCAS MODS</u>

- ACCEPT LONG OR SHORT MODE S SQUITTER (OPTIONAL)
- SOFTWARE AND/OR HARDWARE CHANGE DEPENDING ON TCAS MANUFACTURER

<u>MODE S TRANSPONDER MODS</u>

- TRANSMIT LONG SQUITTER
- SOFTWARE CHANGE TO DATA LINK TRANSPONDER FOR ALL MANUFACTURERS

## SPECIFICATIONS REQUIRED FOR ADS-MODE S GROUND EQUIPMENT

ADS-Mode S utilizes a modular concept in the definition of its ground equipment. Specifications will be required for the procurement of the following equipment:

### 1090 MHz Receiving Stations

A single receiver is specified for all applications. This receiver is similar to equivalent components for a TCAS unit so the technology is well understood by industry.

### 1030 MHz Transmitter

One or more transmitters will be specified for various applications. This is a higher powered version of the transmitter used for TCAS.

### Antennas

Several antennas are required to support the different applications as shown in the table. The-5 foot open array and TCAS antenna technology are relevant to the requirements of these antennas.

### Processor

This device houses a multisensor tracker that combines the output of the ADS-Mode S receivers with those of conventional beacon equipment in order to suppress duplicate reports and provide a correlated, seamless surveillance stream to ATC users.

### Communications Equipment

This is off-the-shelf communications equipment as needed to tie together the various elements of the ADS-Mode S ground equipment.

# SPECIFICATIONS REQUIRED FOR ADS-MODE S GROUND EQUIPMENT

1090 MHZ RECEIVING STATIONS

- SINGLE RECEIVER FOR ALL APPLICATIONS

1030 MHZ TRANSMITTER

- ONE OR MORE TYPES DEPENDING ON APPLICATIONS

ANTENNAS

- OMNI
- 6 SECTOR
- SURFACE
- PRM

PROCESSOR

- MULTISENSOR TRACKER

COMMUNICATIONS EQUIPMENT

- GROUND TRANSFER OF ADS DATA

# OUTLINE

- OVERVIEW
- FUNDAMENTAL QUESTIONS
- OTHER ADS APPLICATIONS
- IMPLEMENTATION ISSUES
- SUMMARY
- SUPPORTING STUDIES

## SUMMARY

ADS-Mode S has the capability to provide a natural transition from a beacon surveillance environment to a GPS-based surveillance environment.

Mode S can support the transfer of ADS data with only minor modifications to existing equipment.

Existing standards for Mode S and TCAS require only minor modifications to support the ADS-Mode S concept.

The resulting system will use existing frequency allocations and will be located on existing FAA real estate. It will be a system owned and operated by the FAA.

In addition to ADS, the concept enhances the operation of other beacon-based activities.

## SUMMARY

- ADS-MODE S PROVIDES A NATURAL TRANSITION TO GPS-BASED SURVEILLANCE
- MODE S CAN TRANFER ADS DATA WITH MINOR MODIFICATIONS
- ONLY MINOR CHANGES ARE NEEDED TO EXISTING STANDARDS
- USES EXISTING FREQUENCY ALLOCATION, AND EXISTING FAA REAL ESTATE
- SYSTEM OWNED AND OPERATED BY THE FAA
- OTHER BEACON-BASED SURVEILLANCE ACTIVITIES CAN BE ENHANCED

# OUTLINE

- OVERVIEW
- FUNDAMENTAL QUESTIONS
- OTHER ADS APPLICATIONS
- IMPLEMENTATION ISSUES
- SUMMARY
- SUPPORTING STUDIES

# SUPPORTING STUDIES

- ADS SQUITTER FORMATS
- ADS-MODE S OPERATING RANGE
- ADS-MODE S OPERATING DENSITY

# ADS-MODE S MESSAGE STRUCTURE

| TYPE | FIGURE OF MERIT | |
|---|---|---|
| AIRBORNE POSITION | DGPS | 5 M |
| | WADGPS* | 10 M |
| | GPS | 100 M |
| SURFACE POSITION | DGPS | 5 M |
| | GPS | 100 M |
| AIRCRAFT ID | | |

*WIDE AREA DIFFERENTIAL GPS

# AIRBORNE POSITION MESSAGE

## SQUITTERED TWICE PER SECOND

| VALUE | SIGNIFICANCE |
|---|---|
| 2 | DGPS |
| 3 | WADGPS |
| 4 | GPS |

| BITS | FIELD | LSB | RANGE |
|---|---|---|---|
| 3 | TYPE/FOM | | |
| 1 | TIME (GPS) | 1 SEC | 0 OR 1 SEC |
| 19 | LATITUDE | 10 FT | 0 TO 15 DEG |
| 19 | LONGITUDE | 10 FT | 0 TO 18 DEG |
| 12 | ALTITUDE | 25FT | -1 TO 56 KFT |
| | | 100FT | 56 TO 127 KFT |
| 2 | SPARE | | |
| 56 | TOTAL | | |

# SURFACE POSITION MESSAGE

## SQUITTERED TWICE PER SECOND

| VALUE | SIGNIFICANCE |
|---|---|
| 5 | DGPS |
| 6 | GPS |

| BITS | FIELD | LSB | RANGE |
|---|---|---|---|
| 3 | TYPE/FOM | | |
| 1 | TIME (GPS) | 1 SEC | 0 OR 1 SEC |
| 19 | LATITUDE | 2.5 FT | 0 TO 3.75 DEG |
| 19 | LONGITUDE | 2.5 FT | 0 TO 4.5 DEG |
| 8 | TRUE HEADING | 1.4 DEG | 0 TO 360 DEG |
| 6 | MOVEMENT | | |
| 56 | TOTAL | | |

| VALUE | SIGNIFICANCE | |
|---|---|---|
| 0 | NOT MOVING | |
| 1 TO 59 | VELOCITY | 1 TO 59 KTS |
| 60 | VELOCITY | ≥ 60 KTS |
| 61 | DECELERATION-BRAKING | |
| 62 | ACCELERATION - TAKE OFF | |
| 63 | BACKING UP | |

# AIRCRAFT ID MESSAGE

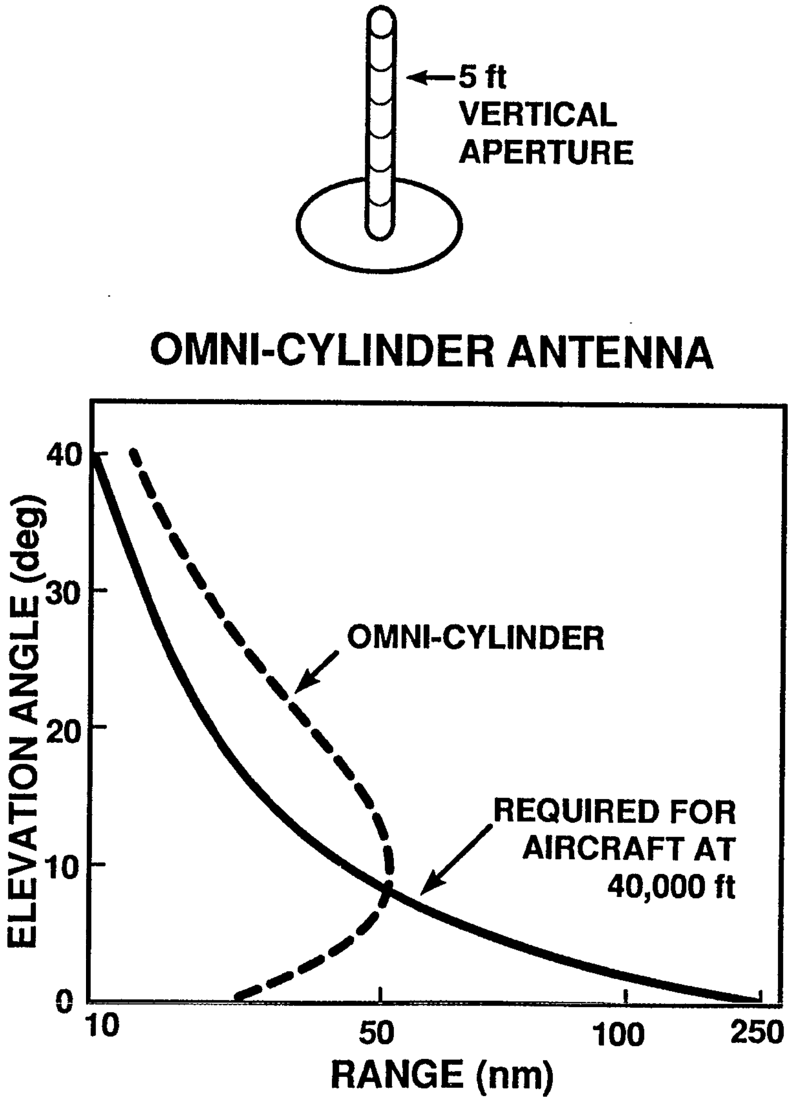
## SQUITTERED TWICE PER 10 SECONDS

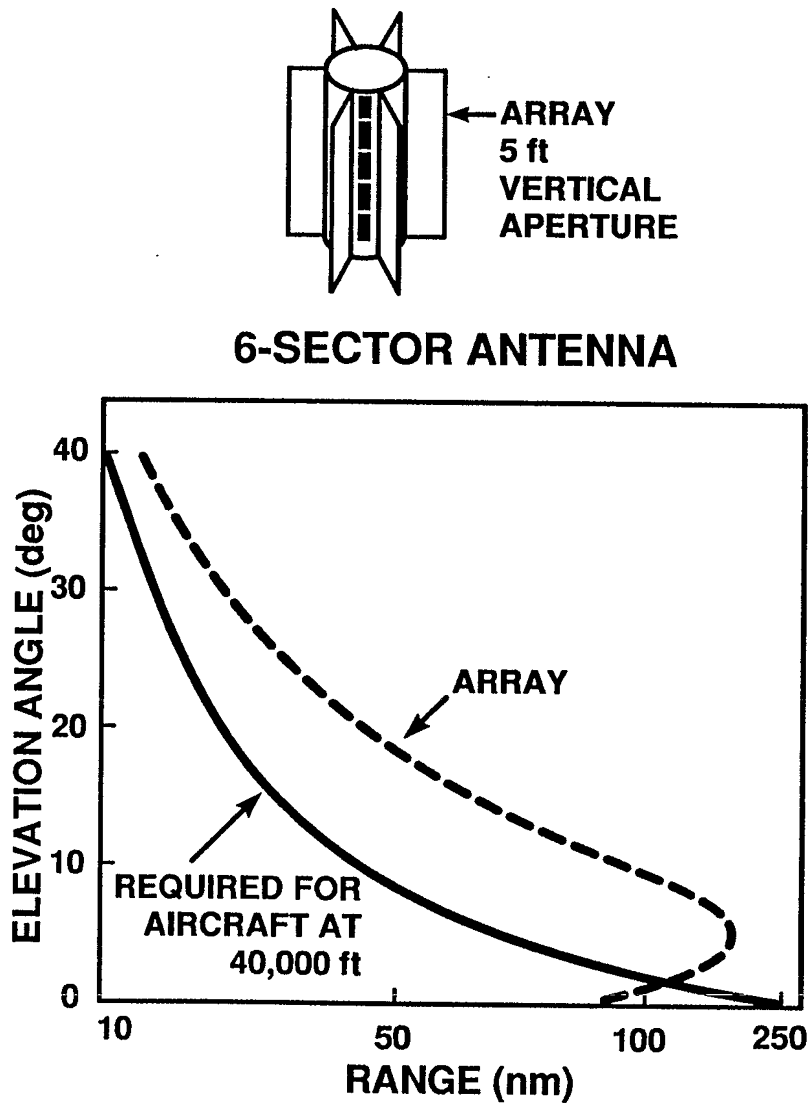
| BITS | FIELD | RANGE |
|---|---|---|
| 3 | TYPE/FOM | EQUAL TO 1 |
| 5 | NOT USED | |
| | AIRCRAFT ID | |
| 6 | CHARACTER NO 1 | A/N |
| 6 | CHARACTER NO 2 | A/N |
| 6 | CHARACTER NO 3 | A/N |
| 6 | CHARACTER NO 4 | A/N |
| 6 | CHARACTER NO 5 | A/N |
| 6 | CHARACTER NO 6 | A/N |
| 6 | CHARACTER NO 7 | A/N |
| 6 | CHARACTER NO 8 | A/N |
| 56 | TOTAL | |

# SUPPORTING STUDIES

- ADS SQUITTER FORMATS
- ADS-MODE S OPERATING RANGE
- ADS-MODE S OPERATING DENSITY

# ADS-MODE S AIR SURVEILLANCE RANGE ESTIMATES



# LINK BUDGET FOR ADS-MODE S RECEPTION

| | TCAS (10 NM) | 5 FT OMNI LNA (50 NM) | 6 ELEMENT LNA (100 NM) | UNITS |
|---|---|---|---|---|
| TRANSPONDER POWER, 250 WATTS INTO ANTENNA | 54 | 54 | 54 | DBM |
| TRANSPONDER ANTENNA GAIN (HORIZONTAL DIRECTION) | 0 | 0 | 0 | DB |
| FREE SPACE PATH LOSS | -118.5 | -132.5 | -138.5 | DB |
| RECEIVING ANTENNA GAIN (5 FOOT VERTICAL APERTURE) | 0 | 4 | 7 | DB |
| RECEIVING CABLE LOSS | -3 | -2 | -2 | DB |
| RECEIVED POWER AT REFERENCE PORT | -67.5 | -76.5 | -79.5 | DBM |
| MINIMUM POWER REQUIRED FOR DETECTION | -77 | -88.5 | -88.5 | DBM |
| NOMINAL POWER MARGIN | 9.5 | 12 | 9 | DB |

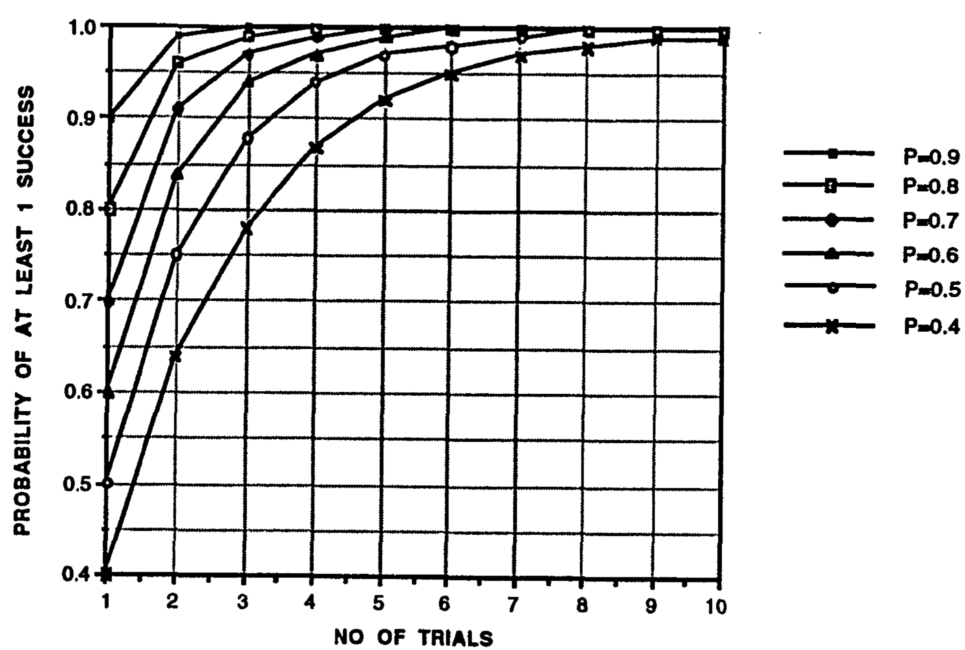
# SUPPORTING STUDIES

- ADS SQUITTER FORMATS
- ADS-MODE S OPERATING RANGE
- ADS-MODE S OPERATING DENSITY

# INTERFERENCE ANALYSIS CONSIDERATIONS

- MODE S SQUITTER CAN BE CORRECTLY RECEIVED IF:
  - OVERLAID BY NO MORE THAN ONE ATCRBS REPLY
  - NOT OVERLAID BY A MODE S REPLY
- REPORT PROBABILITY PER 5-SEC UPDATE MUST BE EQUIVALENT TO CURRENT OPERATION
  - GREATER THAN 99.5%
- MULTIPLE SQUITTERS AVAILABLE PER UPDATE
  - TWO SQUITTERS PER SECOND
  - UPDATE RATE OF 5 SECONDS

# EFFECT OF MULTIPLE SQUITTERS



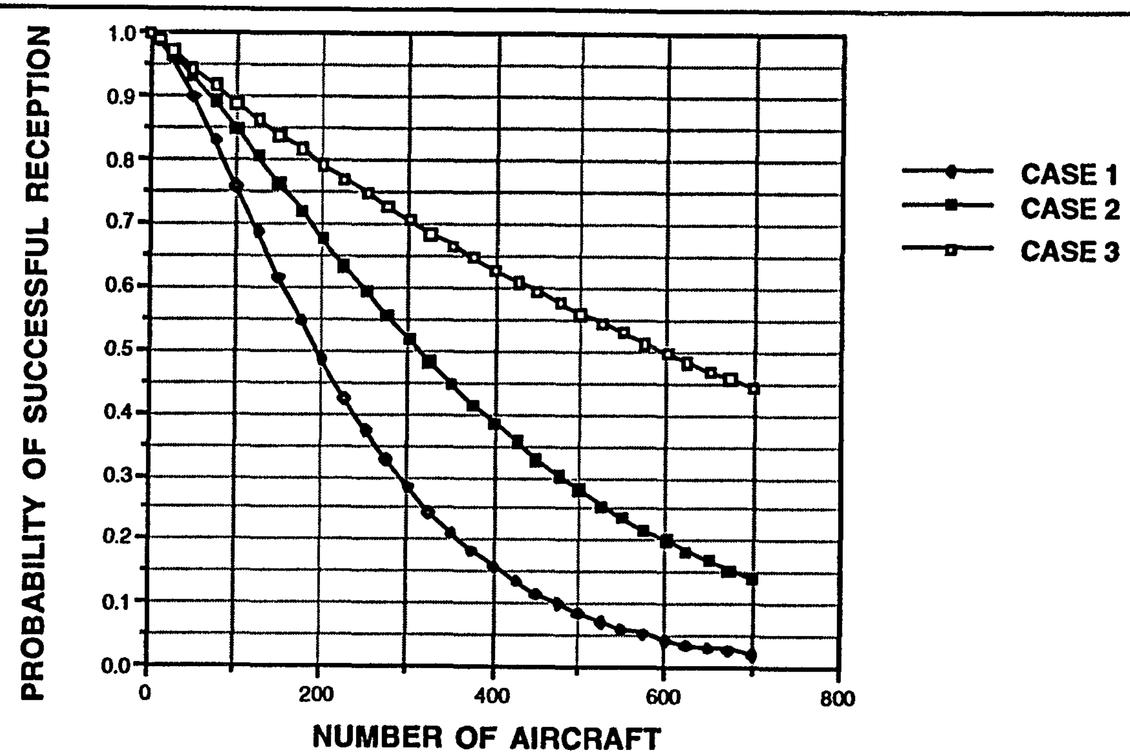
# INTERFERENCE CASES

REPLIES PER SECOND PER AIRCRAFT

| CASE | ATCRBS | MODE S SHORT | MODE S LONG |
|---|---|---|---|
| 1 | 120 | 8 | 6 |
| 2 | 60 | 8 | 6 |
| 3 | 0 | 8 | 6 |
| 4 | 0 | 8 | 11 |

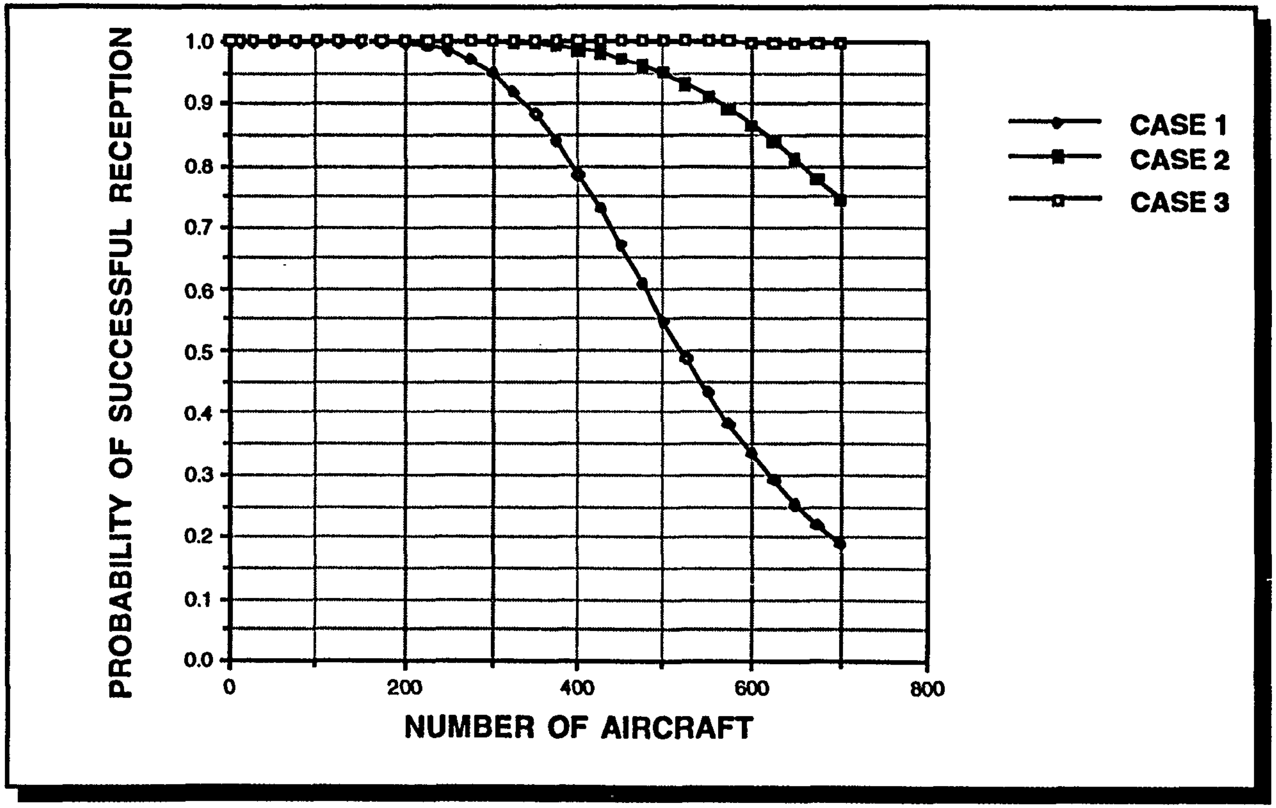
# DETECTION PROBABILITY EACH HALF SECOND

## (6-SECTOR ANTENNA)



# DETECTION PROBABILITY OVER 5 SEC

## (6-SECTOR ANTENNA)



# ADS-MODE S OPERATING DENSITY

## 5 SECOND UPDATE, RELIABILITY ≥ 99.5%

| REPLIES/AIRCRAFT/SEC | | MAXIMUM AIRCRAFT | |
|---|---|---|---|
| ATCRBS | MODE S | OMNI | SIX SECTOR |
| 120 | 14 | 85 | 215 |
| 60 | 14 | 140 | 350 |
| 0 | 14 | 280 | 700 |
| 0 | 19 | 195 | 485 |

# OPERATING RANGE AND DENSITY SUMMARY

<u>RANGE</u>

- ADS-MODE S ANTENNA AND RECEIVER ACHIEVE DESIRED OPERATING RANGE

<u>TRAFFIC DENSITY</u>

- ATCRBS FRUIT IS THE DOMINANT FACTOR THAT DETERMINES CAPACITY AT MAX RANGE
- FAA COMPONENT OF ATCRBS FRUIT WILL BE ELIMINATED WHEN ADS-MODE S IS IMPLEMENTED
- MAJORITY OF ATCRBS FRUIT IS GENERATED BY THE MILITARY
  - COORDINATION REQUIRED TO REDUCE MILITARY ATCRBS INTERFERENCE FOR HIGH DENSITY AIRSPACE