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REPORT OF THE FAA TASK FORCE ON AIRCRAFT SEPARATION ASSURANCE. --ETC(U)
JAN 79 N A BLAKE , E KOENKE , L PAGE
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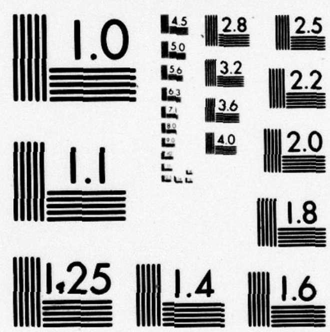

MICROCOPY RESOLUTION TEST CHART

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15. Supplementary Notes

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16. Abstract

A task force has developed FAA Engineering and Development consensus on the integrated aircraft separation assurance system for the National Airspace System. This report details a study of system errors, mid-airs, and near mid-airs to define the problem. The system element requirements are defined to provide two levels of backup to the ATC system: a separation violation warning and a final fail safe collision advisory and resolution function.

The current FAA ASA development programs are discussed and the changes are detailed which are required to transition to an integrated ASA system. This report consists of three volumes. Volume I is the Executive Summary with an overview of the work performed by the Task Force. Volume II is the detailed main concept description delineating the required systems and interfaces. Volume III includes appendices, referred to in the main report, which define in detail the specific interfaces and designs required for system integration.

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I. INTRODUCTION

In July 1977, the Associate Administrator for Engineering and Development established a task force to develop a technical plan within the Federal Aviation Administration's (FAA) Engineering and Development (AED) for an integrated aircraft separation assurance system for the National Airspace System. The task force consists of Neal A. Blake (AEM-2), Chairman, Edmund J. Koenke (AEM-20), Leland F. Page (ARD-100), and Martin T. Pozesky (ARD-200). This report presents the results of the task force, which include the following:

- development of a summary of midair collision, near midair collision, system error and altitude deviation data;
- establishment of the functional requirements for the aircraft separation assurance system;
- definition of the capabilities and performance of Conflict Alert, Conflict Resolution, Automatic Traffic Advisory and Resolution Service (ATARS), Beacon Collision Avoidance System (BCAS), and Automated Terminal Service (ATS) in meeting the requirements;
- definition of the integrated aircraft separation assurance system;
- determination of the detailed role of each of the system elements listed above;
- definition of the interfaces and interactions among the system elements;
- definition of the design features needed in each of the individual systems to achieve compatibility and allow the individual systems to perform their respective roles properly; and
- identification of needed future activities and management's decisions relating to implementation and use of the system.

The task force concluded that the individual Aircraft Separation Assurance (ASA) elements should be combined into an integrated aircraft separation assurance system. The report addresses each of the areas listed above.

II. SUMMARY OF THE AIRCRAFT SEPARATION ASSURANCE PROBLEM

Four measures of system performance--midair collisions, near midair collisions, altitude deviations, and system errors--were examined in order to establish the requirements for the aircraft separation assurance program. These requirements were then used as the basis for evaluating the effectiveness of the technical systems under development, and as the basis for defining the integrated aircraft separation assurance system which is made up of these elements. While the study addressed primarily the contributions that technology might offer in reducing the problem, the task force realized that procedural and training improvements were also being pursued and that AED was supporting these activities as well.

In examining the measures of the ASA problem, the task force concluded that the overall problem was made up of two clearly distinct problem areas. The midair collision problem on the one hand appears to be primarily, although not entirely, one of collisions between small general aviation aircraft operating under Visual Flight Rules (VFR) see-and-be-seen outside of the Air Traffic Control (ATC) system. The second and potentially far more serious problem relates to midair and near midair encounters between controlled aircraft and between controlled and uncontrolled aircraft, due to pilot deviation and system error situations involving aircraft under air traffic control. Although there have been no Instrument Flight Rules (IFR) collisions involving large air carrier aircraft in recent years*, the potential for such collisions is very real. The risk of such collisions is judged to be directly related to the number of near midair collisions occurring within the system. An analysis by the FAA's Air Traffic Service indicates that only 4.7% of the system errors resulted in near midair collisions, and only .8% of these were classified as critical.

A. Midair Collisions

Figure ES-1 presents a summary of the midair collisions reported to the National Transportation Safety Board (NTSB) for the period covering calendar year 1964 through calendar year 1978. Approximately two-thirds of the collisions and two-fifths of the fatalities occurred in the vicinity of an airport (within 5 nm and 3,000' of the field). Of these, all except one collision occurred in the landing pattern airspace. As one might expect, more airport vicinity accidents (81%) occurred at non-tower airports than at those with towers. However, the number of occurrences at airports with towers is significant.

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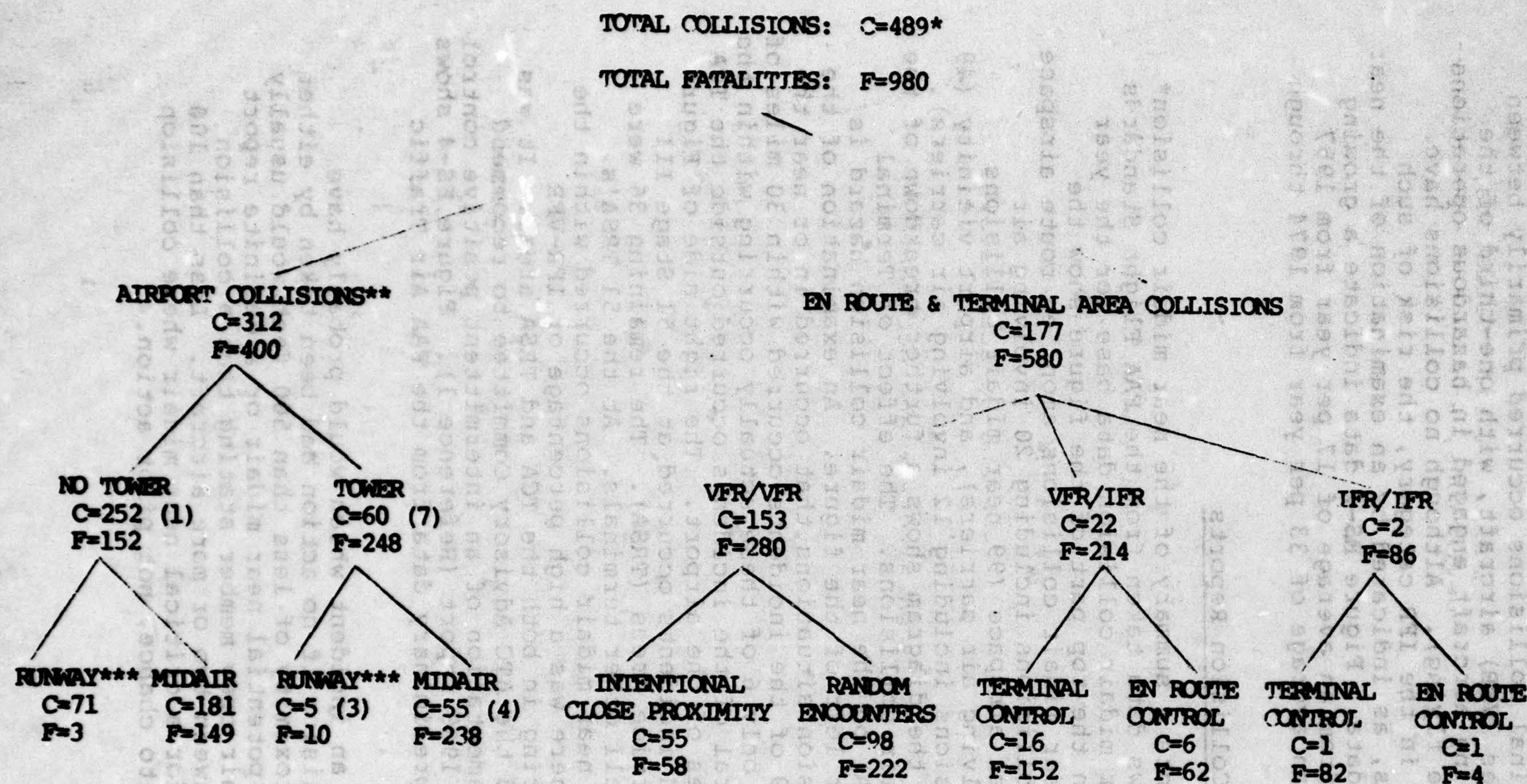
*The San Diego collision involved an air carrier aircraft on an IFR flight plan operating under a visual approach clearance in the airport traffic area and a general aviation aircraft conducting instrument training activities as a VFR Aircraft.



*Includes only preliminary numbers for 1978 (as of 6/15/79 NTSB closeouts).
**Within 5 miles of airport below 3,000 feet.
***One aircraft on the ground.
( ) Number of IFR-IFR and IFR-VFR Collisions at airports.

FIGURE ES-1
MIDAIR COLLISIONS BY AIRSPACE REGION/SERVICE
JANUARY 1964 - DECEMBER 1978

En route and terminal collisions occurred primarily between Visual Flight Rules (VFR) aircraft, with one-third of the collisions involving aircraft engaged in hazardous operations (intentional close flying). Although no collisions have occurred recently in the IFR category, the risk of such collisions remains, as indicated by an examination of the near midair collision data. Figure ES-2 data indicate a growing trend of midairs from an average of 17 per year from 1957 through 1964, to an average of 33 per year from 1974 through 1978.

B. Near Mid-Air Collision Reports

Figure ES-3 presents a summary of the near midair collision* situation and shows data taken from the FAA Flight Standards Service (AFS) near midair collision data base for the year 1975. The data in the top part of the figure show the distribution of near midair collisions among en route airspace (79 near midair collisions including 20 involving air carriers), terminal airspace (99 near midair collisions including 36 involving air carriers), and airport vicinity (49 near midair collisions including 12 involving air carriers). The lower part of the diagram shows a further breakdown of the terminal near midair collisions. The effect of Terminal Control Areas (TCA) on the near midair collision hazard is shown at the lower left of the figure. An examination of the near midair collision situations that occurred in or near the TCAs shows that 29 of the incidents occurred within 30 miles of TCA airports with only 6 of these actually occurring within the TCA itself. Several of the incidents occurred outside the TCA but within 30 miles of the airport. The right side of Figure ES-3 shows that 34 incidents occurred at the 51 Stage III Terminal Radar Service Areas (TRSA). The remaining 36 were distributed over all other terminals. At the 51 TRSA's, two-thirds of the near midair collisions occurred within the TRSA airspace. There was a high percentage of IFR-VFR interaction occurring in both the TCA and TRSA areas. It was this fact that led the ATC Advisory Committee to recommend strongly the implementation of an intermittent positive control function in their 1969 report (Reference 1). Figure ES-4 shows a summary of the preliminary data from the FAA Air Traffic

*A near midair is an incident which would probably have resulted in a collision if no action had been taken by either pilot. Closest proximity of less than 500 feet would usually be required for a potential near midair or a definite report received from an air crew member stating that a collision hazard existed between two or more aircraft. Less than 100 feet is required for a critical near midair where collision avoidance was due to chance, not pilot action.

NUMBER OF ACCIDENTS BY SEGMENTS OF AVIATION INVOLVED

	ACCIDENTS		NUMBER					
YR.	TOTAL	FATAL	FATALITIES	AC/AC	AC/GA	AC/MIL	GA/MIL	GA/GA
57	15	6	19 a/	0	0	1	4	10
58	16	12	86	0	0	2	2	12
59	13	10	20	0	0	0	3	10
60	26	10	152 b/	1	4	0	2	19
61	20	10	22	0	0	0	0	20
62	19	9	27	0	0	0	5	14
63	13	3	6	0	0	0	2	11
64	15	7	12	0	0	0	2	13
65	27	14	30	1	0	0	2	24
66	27	11	33	0	1	0	1	25
67	26	20	157	0	2	1	3	20
68	37	23	69	0	3	0	1	33 c/
69	28	12	122	0	3	0	2	23 c/
70	37	21	55	0	0	0	5	32 c/
71	32	20	96	0	3	1	1	27
72	25	13	41	0	1	0	0	24 c/
73	24	12	29	0	0	0	0	24
74	34	19	48	0	0	0	2	32
75	29	13	47	0	0	0	1	28
76	31	24	64	0	0	0	1	30
77	34	17	41	0	0	0	0	34
78P	34	24	191 d/	0	1	0	0	33
TOTAL	562	310	1,367	2	18	5	39	498

a/Includes 3 persons on ground
b/Includes 6 persons on ground
c/Includes 1 U. S. GA vs. foreign aircraft
d/Includes 7 persons on ground (1978 data preliminary only)

AC: Air Carrier
GA: General Aviation
MIL: Military

Source: NTSB Briefs of Accidents Involving Midair Collisions, January 1978.

FIGURE ES-2
MIDAIR COLLISIONS BY SEGMENT
JANUARY 1957 - DECEMBER 1978

1975 FAA FLIGHT STANDARDS' NEAR MIDAIR COLLISION REPORTS

TOTAL REPORTS
227 (68)

En Route	Terminal	Airport
79 (20)	within 30 nmi of a terminal, excluding airport 99* (36)	Altitude below 3,000 feet and 5 nmi of an airport 49 (12)

Terminal 99* (36):

TCA (within 30 nmi)	Other Terminal Areas	TRSA (within 30 nmi)
29 (18)	36 (11)	34 (7)

	BOTH INSIDE TCA BOUNDARY	AT TCA BOUNDARY	BOTH OUTSIDE TCA BOUNDARY	BOTH INSIDE TRSA BOUNDARY	AT TRSA BOUNDARY	BOTH OUTSIDE TRSA BOUNDARY
	6 (4)	4 (1)	19 (13)	24 (4)	2 (2)	8 (1)
IFR/IFR	3 (3)	0	3 (2)	1 (0)	0	1 (0)
IFR/VFR	A 3 (1)	B 4 (1)	14 (11)	C 16 (4)	D 2 (2)	4 (1)
VFR/VFR	0	0	2 (0)	7 (0)	0	3 (0)

*98 of 99 terminal reports occurred within existing surveillance coverage
( ) air carrier involved
A - One report involved a VFR aircraft not in contact with ATC
B - Three reports involved VFR aircraft not in contact with ATC, traffic advisories in two of these
C - Two reports occurred with both aircraft participating in TRSA
D - One report occurred with both aircraft participating in TRSA

FIGURE ES-3

FAA AIR TRAFFIC SERVICE PRELIMINARY VALIDATED NEAR MIDAIR COLLISION REPORTS
(July 1976 through November 1978)

TOTAL REPORTS
1,267 (202)

En Route
394 (69)

Terminal
(within 30 nmi except airport area)
493

Airport
(within 5 nmi and 3000 ft.)
380

	TCA & Periphery* 83		Other Terminal Area 272 (34)	TRSA & Periphery* 138	
IFR/IFR**	20	0	24	15	2
IFR/VFA	0	1	28	1	4
IFR/UNK	20	28	160	78	18
VFA/VFA	0	1	7	1	2
VFA/UNK	7	4	20	2	2
UNK/UNK	1	1	33	10	3

*TCA or TRSA Periphery excludes the Airport Traffic Area and includes airspace within 2,000 feet and 5 nmi of the TRSA or TCA boundaries.
**IFR listings include VFR Stage III separation service.
VFA is VFR with traffic advisories.

Of the 206 TCA and TRSA encounters with at least one aircraft in communication: 72 incidents occurred after traffic call to one aircraft; 6 incidents after traffic call to both aircraft.

FIGURE ES-4

Service validated near midair data, which correlates the Flight Standards and Department of Defense reports with follow-up interviews of the individuals reporting (Reference 3). This data, covering the period from July 1, 1976, through November 1978, shows an overall reporting rate of more than twice the rate in 1975, although the percentages of occurrence in various airspace are about the same. The data shows a serious problem still exists with uncontrolled aircraft in controlled airspace.

C. Altitude Deviations

Figure ES-5 presents data on an operational problem that persists in spite of airborne altitude alert equipment and pilot recurrent training, and which may well persist even with implementation of the data link system to transmit clearances to the cockpit. Of the 13,327 reports in NASA's Aviation Safety Reporting System data base, 1,002 indicated altitude deviations (Reference 4). Deviations are defined as excursions beyond 300 feet from the flight altitude or overshoots or undershoots of an assigned altitude by at least this amount. This analysis of the altitude deviation problem uses information in the data base as of 7/15/79 to determine deviations as a function of airspace, ATC function and flight plan type.

Figure ES-6 presents a summary of the enabling and associated factors related to altitude deviations (analyzed as of 1/15/77). Of the 65 reports available, 46 had sufficient detail for detailed analysis. Sixteen of the remaining 19 reports represented cases reported by controllers who noted an overshoot, but did not know the reason for it. Eight of these involved military aircraft. The most significant causes of altitude deviation included failure to monitor other flight instruments when flying by reference to a flight director or on an autopilot, misunderstood or delayed clearances, and inattention due to visual searching for air traffic or to correcting abnormal conditions in the aircraft. These reasons coupled with improper subsystem operation account for the majority of the problems that arose in the cases studied.

Figure ES-7 summarizes the factors contributing to the altitude deviation problem. An analysis of the altitude deviations indicated that 75% of the cases involved human factor problems or human error. There were 10 cases of misunderstood clearances including 3 cases where the read-back was incorrect and the error was not detected by the controller. Ten cases showed traffic distraction and high cockpit workload, where inattention during periods of high climb or descent rates caused deviations. The primary causes cited for high workload were searching for traffic called by the controller and diversion of attention on correcting fault conditions presented to the pilot through

ALTITUDE DEVIATIONS REPORTED TO NASA AVIATION SAFETY REPORTING SYSTEM

Reports in ASRS data base on July 16, 1979	13,327
Reports coded as containing an altitude deviation	1,002

Primary problem codes assigned to altitude deviation reports:

Flight crew problem	754
Air Traffic Controller problem	173
Other problem	75
	1,002

Airspace in which altitude deviations occurred:

On airways	345
Terminal control area	248
Positive control airspace	220
Other controlled airspace	110
Airport traffic area/control zone	90
Terminal radar service	23
	1,036*

ATC agency controlling flights**:

Center	449
Approach control	325
Departure control	214
Local control	64
	1,052*

Flight plans in altitude deviation reports:

Instrument flight rules	962
All other entries	52
	1,014*

*Totals do not equal 1,002 because of multiple aircraft involved in some occurrences.

**ATC facility involvement is estimated indirectly; this information is not recorded directly in ASRS data base 1.

Source: NASA's Aviation Safety Reporting System; represents three years of data.

FIGURE ES-5

ALTITUDE DEVIATIONS: ENABLING AND ASSOCIATED FACTORS

OCCURRENCES IN DATA BANK* AS OF 1/15/77	65
INSUFFICIENT DATA TO PERMIT ANALYSIS OF FACTORS	19
REPORTS ANALYZED IN DETAIL	46

FACTOR CATEGORY	ENABLING FACTOR	ASSOCIATED FACTOR
MAN		
COGNITION, DECISION MAKING	1	4
MONITORING BEHAVIOR	4	4
SUBSYSTEM OPERATION	5	1
FLIGHT CONTROL	1	1
COMMUNICATIONS:		
MISUNDERSTOOD CLEARANCE	9	1
OTHER COMMUNICATION PROBLEMS	4	1
DISTRACTION, HIGH WORKLOAD	10	6
SOFTWARE		
OPERATING PROCEDURES, CHECKLISTS	0	5
NAVIGATION INFORMATION, CHARTS	2	0
SIMILAR IDENTIFIERS OR TRIP NUMBERS	2	0
HARDWARE		
ALTITUDE ALERT SYSTEM DESIGN	1	3
AUTOPILOT MALFUNCTION	4	0
OTHER AIRCRAFT SUBSYSTEM PROBLEM	1	1
RADAR NOT AVAILABLE OR OUT OF SERVICE	0	2
ENVIRONMENT		
TURBULENCE, UPDRAFTS	2	0
HIGH COCKPIT NOISE LEVELS	0	2
COCKPIT/INSTRUMENT LIGHTING LEVELS	0	2

*Of these reports, 16 were controller descriptions of altitude assignment deviations who had not been made aware of any reason for occurrence. Eight involved military aircraft.

Source: NASA's Aviation Safety Reporting System; represents 17 months of data.

FIGURE ES-6

ALTITUDE DEVIATIONS: ANALYSIS OF ENABLING AND ASSOCIATED FACTORS

	NUMBER OF CASES
o **75% INVOLVED HUMAN FACTORS OR HUMAN ERROR**	34
o **MISUNDERSTOOD CLEARANCES** 3 Cases where readback was incorrect and ATC acknowledged	10
o **TRAFFIC DISTRACTION AND HIGH COCKPIT WORKLOAD** Inattention during periods when high climb/descent rates are used	10
o **ERRORS IN COGNITION, DECISION MAKING, MONITORING, SYSTEM OPERATIONS AND FLIGHT CONTROL**	11
o **AIRPLANE, SOFTWARE, OR ENVIRONMENT** "Insidious" failure of altitude capture-hold function (4) Failure to monitor flight instruments when on autopilot Absence of altering system (pilot dependence on warning system) (1)	12

Source: NASA's Aviation Safety Reporting System; represents 17 months of data.

FIGURE ES-7

cockpit indicators. Failure to monitor flight instruments continuously resulted in 4 cases of deviation resulting from failure of an autopilot altitude hold function. There was also a case where the pilot had become so dependent on an altitude alerting system that he caused an altitude deviation when he flew an aircraft which did not have an altitude alerting system.

D. System Errors

Figure ES-8 presents the number of system errors* that occurred since 1970. This area is an indicator of the how well the air traffic control system is performing. The data for this figure are taken from the Systems Effectiveness Information System (SEIS) data base (Reference 2). The bottom portion of the figure shows implementation dates for the Automated Radar Terminal System (ARTS) III, radar data processing function in the en route centers, the immunity program, and conflict alert in the centers. Conflict alert along with improvements in air traffic control training leveled the growth in system errors in late 1975 and 1976 in the en route centers.

Figure ES-9 presents a list of the primary causes of the system errors that have been occurring. Over 50% fall in 3 areas: judgment, inattention, and communications. A fourth general area which occurs in conjunction with some of the other areas listed is coordination. Controller coordination errors are not listed in the SEIS data base as a direct or contributing cause. Each system error is given a cause by the review board, but in addition 37% of the system errors in 1976 were cited as having a coordination error also involved. Coordination errors include, for example, failure to coordinate an action with the next controller before hand-off or use of another controller's airspace without coordination. Judgment includes the ability to predict conflicts between converging aircraft at different speeds, over or under estimating climb performance of an aircraft, and the ability to project the performance of aircraft (e.g., high-speed military), particularly in the terminal airspace. It is significant that hardware failures have not played a large role in causing system errors.

E. Summary

Figure ES-10 summarizes the problem. An annual midair collision rate which has grown from 17 per year to 32 per year with an approximate average of 60-80 fatalities. In 1976 there were 31 midair collisions with 23 of these resulting in 63 fatalities.

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*A system error is an operational error which results in less than the appropriate separation minima being provided to aircraft receiving air traffic service (including minimum authorized longitudinal, lateral or vertical spacing between aircraft, between aircraft and terrain or obstacles, or between aircraft and airspace to be protected).

SYSTEM ERRORS

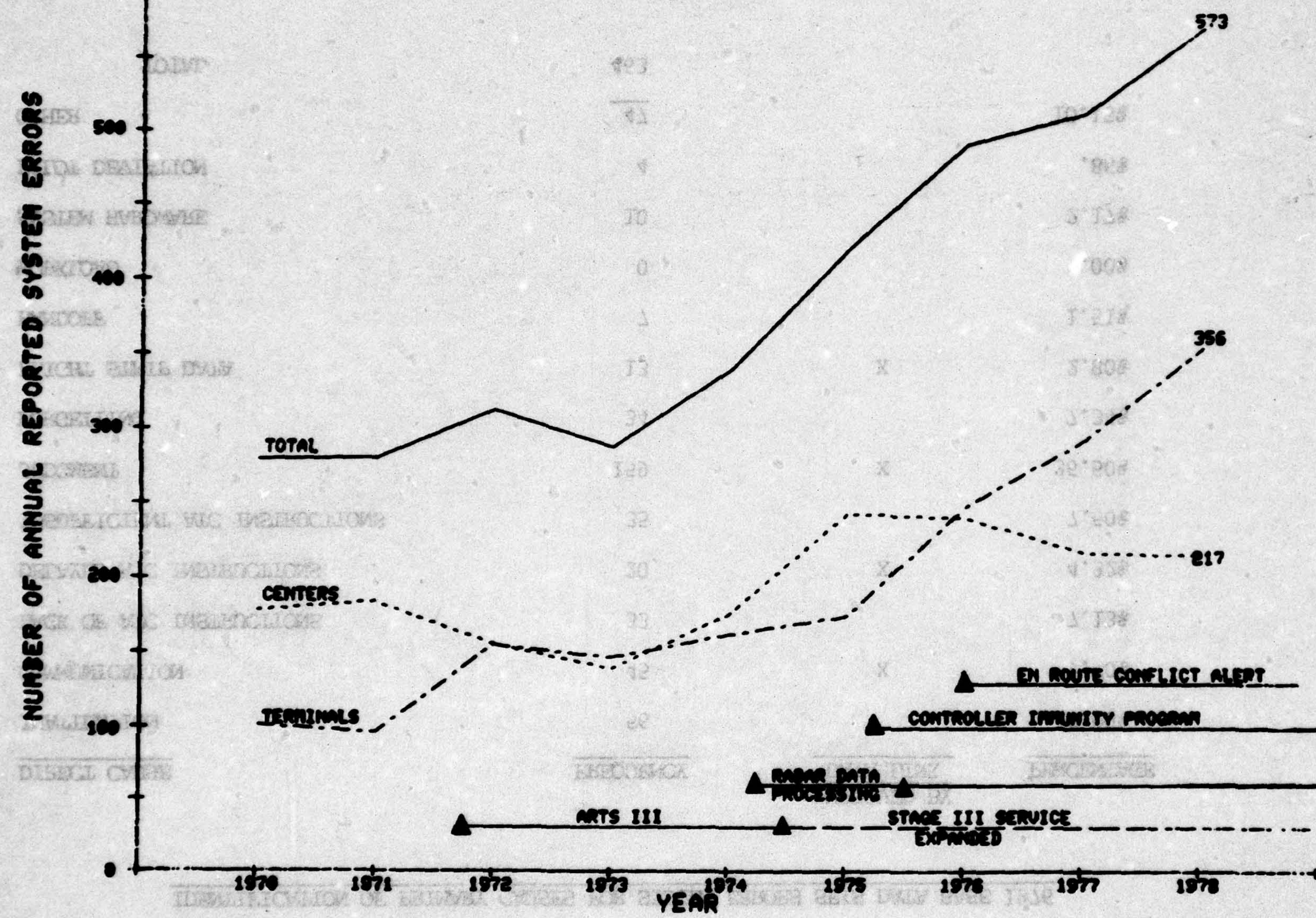

FIGURE ES-8

IDENTIFICATION OF PRIMARY CAUSES FOR SYSTEM ERRORS SEIS DATA BASE 1976

DIRECT CAUSE	FREQUENCY	IMPROVED BY DATA LINK	PERCENTAGE
INATTENTION	56		12.08%
COMMUNICATION	45	X	9.70%
LACK OF ATC INSTRUCTIONS	33		7.13%
DELAYED ATC INSTRUCTIONS	20	X	4.32%
INSUFFICIENT ATC INSTRUCTIONS	35		7.50%
JUDGMENT	159	X	36.50%
FORGETTING	34		7.34%
FLIGHT STRIP DATA	13	X	2.80%
HANDOFF	7		1.51%
WORKLOAD	0		.00%
SYSTEM HARDWARE	10		2.17%
PILOT DEVIATION	4		.86%
OTHER	47		10.15%
TOTAL	463		

FIGURE ES-9

SUMMARY OF THE PROBLEM

- ANNUAL MAC RATE - 30 TO 35 WITH 60 TO 80 FATALITIES (NTSB)

- ANNUAL NMAC REPORT RATE - 524 (FAA TRAFFIC SERVICE)

- ANNUAL SYSTEM ERROR REPORT RATE - 521 (FAA SEIS DATA BASE)
  (Current Rate about 1.5 Per Day)

- ANNUAL ALTITUDE DEVIATION REPORT RATE - 213 (NASA ASRS)

FIGURE ES-10

SUMMARY OF THE PROBLEM
(con't)

- o THE MAJOR PROBLEM TO BE SOLVED INVOLVES REDUCING THE NUMBER OF NMAC'S AND SE'S
  - TCA'S HAVE BEEN EFFECTIVE IN REDUCING THE PROBLEM WITHIN THE TCA AIRSPACE
  - STAGE III EXPANDED RADAR SERVICE AREAS STILL HAVE SIGNIFICANT NMAC REPORTS
  - VFR/IFR INTERACTIONS STILL OCCUR IN SIGNIFICANT NUMBERS AT BOTH TCA AND TRSA'S.
  - MIDAIR COLLISIONS OCCUR LARGELY BETWEEN UNCONTROLLED AIRCRAFT OPERATING IN LOW DENSITY AIRSPACE REGIONS
  - ALTHOUGH THERE HAVE BEEN NO IFR COLLISIONS RECENTLY, THE CONTINUALLY INCREASING NUMBER OF NMAC AND SE SITUATIONS INDICATES THE SERIOUSNESS OF THE THREAT IN THIS AREA.

FIGURE ES-11

The annual near midair collision rate taken from the Flight Standards Service data base is 227 (for 1975) and from Air Traffic Service is 524 (for 1976 through 1978). The number of system errors occurring during 1977 was 521 (only 5% of which contributed to a near midair). The current rate is approximately 1.5 per day and is increasing. Altitude deviations, in addition to other deviations, occurred at the rate of one every other day. The altitude deviation data analyzed were taken from the Aviation Safety Reporting System Data Base for a 47-month period, which indicated a total of 13,327 deviations, with 23 deviations that resulted either in near midair collisions or in separation minima violations. The preceding data make it clear that the major problem to be solved relates to reducing the number of near midair collisions. Most system errors are not safety problems. The biggest cause of safety problems is non-compliance (by pilots and controllers) with regulations and procedures or adhering to assigned clearances.

Terminal control areas have significantly reduced the midair and near midair collision problem where implemented. The problem still remains in other airspace. Stage III radar service terminal areas (TRSA) still experience a number of near midair collision reports. Interactions between IFR and VFR aircraft still occur at both TCA and TRSA facilities, though most midair collisions actually involve uncontrolled aircraft operating in low density airspace. Although there have been no IFR collisions recently, the number of near midair collisions indicate the seriousness of such a threat.

III. ASA SYSTEM REQUIREMENTS

The primary requirement of the automatic Aircraft Separation Assurance (ASA) system is to reduce aircraft collision risk measured by potential for near midair collisions and midair collisions, particularly to controlled aircraft participating in the air traffic control system. In meeting this requirement, the ASA system should provide at least two levels of backup to the controller and pilot in the performance of his aircraft separation assurance function. The first level of backup is to provide a supplement to the see and avoid system in terms of warnings of impending violations of separation minima. The second level of backup includes provision of a final fail-safe collision detection and resolution function to detect and correct for human errors. In addition to IFR, the ASA system should provide final fail-safe collision detection and avoidance services to equipped users operating under visual conditions or visual flight rules.

In support of the general requirements stated above, the ASA system must also meet the following essential requirements:

- Operation of the automatic ASA system must be fully integrated with and compatible with the air traffic control system.

- It must offer protection in most airspace, including airspace not covered by primary or secondary radar systems.

- Each of the elements making up the ASA system must interface with each other and with the air traffic control system, and operate in a compatible and mutually supporting mode.

- The ASA system must not generate excess unwanted alerts(an alarm occurring when no separation violation has occurred).

- The ASA system must not miss alerts or fail to provide warnings on potentially dangerous threats.

- It must offer flexibility in the choice of pilot maneuvers during conflict resolution in cases where pilots see the threat aircraft.

- The logic must be capable of handling encounters involving multiple aircraft (representative of existing and expected multi-aircraft encounters).

- System operation must be judged acceptable by both pilots and controllers.

- The partial service for equipped users must be available to the first user who purchases the appropriate equipment (i.e., not requiring the equipping of a majority of the aviation fleet before a significant level of protection is achieved).

IV. CURRENT DEVELOPMENT PROGRAMS

The approach taken by the team after defining the integrated aircraft separation assurance system requirements (as above) continued with an examination of the current ASA development programs. This defined which requirements could be met by each of these programs, what the effectiveness of each element would be in resolving the problems, what the potential role of each would be in an integrated system, and what problems still remained to be resolved. In addition, the team conducted the necessary analysis, simulation, and design activities to resolve the problem areas and to refine an integrated system meeting the requirements stated above. The remaining parts of this section summarize the team's review and findings relating to each of the current development programs, which include

Conflict Alert, Conflict Resolution, the Automatic Traffic Advisory and Resolution Service, the Beacon Collision Avoidance System, and the Automated Terminal Service system.

A. Conflict Alert

Conflict Alert is designed to warn controllers in the en route airspace of potential separation minima violations up to two minutes before they occur (except for highly accelerated encounters). Altitude clearances can be manually inserted into the computer by the controller, which serves to inhibit the generation of a number of false alarms. This system is currently implemented within radar coverage at all centers, excluding the terminal airspace. The system is also usable on primary radar targets with manual track initiation and insertion of altitude.

In the terminal area, Conflict Alert is designed to warn controllers of potential separation minima violations up to 40 seconds in advance. The logic currently uses 1.2-mile horizontal and 375-foot vertical separation minima criteria. The system is implemented in most of the ARTS III terminals, with implementation at the dual beacon sites in progress.

Although the system warns of most impending violations of separation minima, it does not provide a secondary backup to protect against equipment problems or human errors by the controller in generating and issuing resolution clearances, or by the pilot in executing a clearance which was generated as a result of the controller's action.

Conflict Alert is designed to tell the controller when a conflict situation occurs. The controller, however, can suppress the alert, and no second warning is given if the situation fails to resolve itself. In short, there is no effective backup in the case of human error.

One can conclude that in many cases conflict alert will be effective in its objective to warn the controller to take action to prevent a midair collision. In most cases, this will result in successful resolution. In some percentage of the cases, however, where human errors occur, an automatic backup system is needed. This need can be met by other elements of the ASA system, such as the Automatic Traffic Advisory and Resolution Service and Beacon Collision Avoidance System described in later sections.

B. Conflict Resolution

Conflict Resolution is defined as an advisory assistance to the en route controller in resolving a conflict situation. As currently envisioned, Conflict Resolution would offer the controller a family of acceptable solutions, leaving the selection of the actual resolution for any given conflict up to the controller. It is envisioned that the Conflict Resolution advisories would be given to the controller at the time that the original Conflict Alert is displayed.

The Conflict Alert and ATARS functions will be integrated in both enroute and terminal airspace. Where a Conflict Resolution advisory is present en route , its separation solution will be a subset of the ATARS advisories that will be given later if needed.

Coexistence of terminal Conflict Resolution and ATARS resolution in ARTS III terminals would be impractical due to timing incompatibilities between the two. Therefore, the ATARS resolution will be used in the event that the Conflict Alert is not effective.

Although Conflict Resolution should help reduce the human error problems, it will never eliminate them, and additional backup is required, as noted earlier in the section on Conflict Alert.

C. <u>DABS, DABS Data Link, and ATARS</u>

The Discrete Address Beacon System (DABS) can communicate with and transfer messages to individual aircraft. This is accomplished by the data link which permits unique control capabilities, both augmented manual and automatic, including the Automatic Traffic Advisory and Resolution Service. The problem of near midair collision situations arising out of misunderstood clearances or incorrect clearances issued by ATC was raised during the previous discussion on resolution situations detected by Conflict Alert. The use of ground-air-ground DABS data link to relay clearance information offers one possible way of reducing the number of occurrences where misunderstood or incorrect clearances have caused incidents. Since the DABS data link offers a method of improving the situation through the transmission and verification of clearances issued, it forms an integral part of the aircraft separation assurance system, as well as being a key element of one of our major system development programs. One use of the data link which is being examined is the relay of altitude clearance data to the pilot. As noted earlier, altitude clearance violations are occurring with regularity, and it is hoped that this use of the data link will be helpful in reducing human errors. It still does not totally protect against human errors which may occur in generating and carrying out the clearance. In examining altitude deviations, it appears that use of the data link for this purpose would be helpful in preventing approximately 20% of the cases that were examined in detail. These cases are the ones which are identified in the Aviation Safety Reporting System data base as misunderstood clearances. Data link would not be effective in preventing many of the other altitude deviation cases.

This, however, represents only one small use of the data link. The DABS data link forms an integral part of the Automatic Traffic Advisory and Resolution System (ATARS) in that all traffic advisory and suggested resolution maneuvers are transmitted via the link. The data link is a key element of the Beacon Collision Avoidance System, as all air-to-air and ground-to-air control messages use the link. The data link will also form the basis for much of the future control message automation functions. The link can serve a number of other functions including transmission of wind shear and other weather information to the cockpit.

ATARS is an automatic system providing traffic advisory and final fail-safe collision avoidance protection, which meets the requirements for a system to provide protection assistance against the impact of human error for the IFR system and increased traffic awareness and safety for the VFR pilot. The ATARS service is an outgrowth of the Intermittant Positive Control (IPC) concept defined by the ATC Advisory Committee. The IPC concept has gone through considerable evolution based on the results of analysis, simulation, and flight tests, as well as on user and controller reaction to the proposed services. This process has led to a restructuring of the original concept of bringing pilots under positive control when their aircraft are in a collision situation. This concept appeared to create significant problems in many areas. The IPC concept has been reworked and augmented with a new approach which provides traffic advisories to pilots, with several options available for the type of display used to present this information to the pilot. The concept also includes providing the pilot with suggested resolution maneuvers, which the pilot has the option of selecting if he chooses. In cases where the pilot has the other aircraft in sight, alternative maneuvers may be selected by the pilot; this change is supported by the flight test work conducted by Lincoln Laboratory. The results of the Lincoln experiment showed that general aviation pilots were generally satisfied with 1500-foot horizontal and 200-foot vertical miss distances. ATARS uses 0.5-mile (3000-foot) and 500-foot separation distances to provide 2000-foot horizontal and 300-foot vertical separation. These larger values are used to compensate for errors in the surveillance and tracking systems, and to accommodate for pilot response times. The

Lincoln results also showed that when the pilots were only given traffic advisory information and the resolution maneuver information was suppressed, half the time the pilots selected the same maneuver as the one provided by ATARS. The other half of the time an alternative maneuver was selected. The tasks also highlighted the fact that 30% of the time the pilots did not see the other aircraft, and were glad to have the resolution advisories. These cases were generally associated with encounters that were overtake or head-on situations. As a result of the tests and discussions with future users and operators, the IPC function has been replaced with the ATARS service which provides traffic advisories to the pilot on traffic in the pilot's vicinity which is not currently a collision threat, but which is close enough that, should either aircraft maneuver, a collision threat could be generated very quickly. Such information is helpful to the pilot in planning his future maneuvers. The system also provides resolution advisories when aircraft are on potential midair or near midair collision courses. These advisories indicate the direction and approximate altitude of the other aircraft. The system also provides resolution advisories, which, as noted previously, may be used by the pilot if he does not see the other aircraft. Alternatively, the pilot may select another safe maneuver if he has contact with the other aircraft. While these functions apply generally to all categories of flight, there are some differences. For the case of two VFR aircraft involved in a potential collision situation, the full set of services is provided directly to the pilot by a data link. In the case where two IFR aircraft are involved, it is necessary to integrate tightly the performance of ATARS with the Conflict Alert function previously described. Simulation studies have determined that it is feasible to integrate these services such that the resulting function alerts the controller in the same manner as the present Conflict Alert function, accompanied if desired with a family of acceptable resolution maneuvers. The integrated function in all cases leaves the controller adequate time (within the constraints imposed by the terminal Conflict Alert parameters) to resolve the conflict and only at the last moment (i.e., final fail-safe) selects the best solution from the family for direct transmission to the pilot.

D. Beacon Collision Avoidance System

An airborne collision avoidance system, by definition, is an aircraft based backup system which warns the pilot of potential collision situations and provides him with resolution advisories. While the FAA has evaluated a number of Proximity Warning Indicator (PWI) and airborne collision avoidance systems, two systems based on use of the Air Traffic Control

Radar Beacon System (ATCRBS) frequencies, signal formats, and existing transponders have been selected. The Full BCAS meets all the requirements set forth above, provides the maximum amount of additional protection to those users equipping, and requires no new International Civil Aviation Organization (ICAO) actions. The Active BCAS is similar but only provides protection limited to areas of medium and low aircraft densities, but is likely to be available much sooner due to its less complicated structure.

1. <u>Full Capability BCAS</u>

The design of a satisfactory BCAS poses a substantial engineering challenge in order to provide an independent airborne system that can operate in all ATCRBS garble and fruit environments, and also operate compatibly with the air traffic control system. The design of the system is greatly complicated by the requirement for operation in high density environments. This requires a fairly sophisticated system employing many operating modes (passive, active, etc.) which results in increased unit costs, limiting the number of users who can afford the system, hence limiting the protection provided by the system. The current Full BCAS design permits the use of horizontal and vertical maneuvers, which eliminates some of the constraints (such as limit turn and limit climb/descent rates) which characterized the earlier Airborne Collision Avoidance System (ACAS) type of system. Although it still does not totally eliminate interference with the ATC system, it does eliminate most of the undesired interference. Full BCAS does not provide logic which is totally compatible with operations in the airport traffic patterns. Complete traffic pattern compatibility appears to be technically difficult particularly at the smaller airports, where VFR aircraft separations tend to be smaller. However, those users requiring additional safety in high density areas, particularly during the implementation period for the DABS/ATARS system, may elect to equip with the Full capability BCAS system.

2. <u>Active BCAS</u>

In examining the possibilities for reducing the costs of the BCAS system, it seems possible to tailor the requirements for BCAS to those imposed by operations in low density airspace or outside of radar covered airspace, since the separation system backup requirement in high density areas appears to be met primarily by ATARS. Hence a simpler BCAS tailored to the requirements of these regions can be of benefit. The recommended system employs only the active portion of the full BCAS and certain degarbling enhancements for which the technology exists today.

Thus the logical mix of systems would employ ATARS for high density and Active BCAS for areas outside of high density, with Full capability BCAS available instead for those wishing additional levels of backup protection and more complete capability. Regardless of whether the user equips with the full BCAS or with the simpler version of BCAS, the BCAS system will be interfaced with the ATARS and the ATC system to permit exchanges of information between these systems, and also to inhibit the use of the BCAS resolution commands in those portions of the airspace in which the ATARS system has been implemented. We believe that the current design of BCAS provides the necessary interface to achieve compatibility with the ATC system.

E. Automated Terminal Service

The Automated Terminal Service system (ATS) is defined as a low cost automatic system providing computer generated voice traffic and conflict advisory, and traffic pattern management services. It was designed initially as a low cost substitute for manned control towers for installation at airports as they met tower establishment criteria. Since it provides an aircraft separation assurance capability, and it uses low cost ATCRBS, or in a later phase DABS, avionics, it potentially can have the greatest effect on reducing the midair collision problem for general aviation airports.

However, the cost of these systems may preclude their implementation at many general aviation airports, and a procedural version or self-announce type of system also exists which may have substantial benefits in reducing the collision risk, particularly at the lower density general aviation airports. In this type system pilots announce their positions as they progress through the traffic pattern. Although an advisory circular has been disseminated recommending this procedure, all announcements are currently made on a single frequency, which results in unsatisfactory operation in high density areas due to messages overlapping and garbling. Additional discrete VHF frequencies are needed to make the service effective in preventing midair collisions at uncontrolled general aviation airports.

Hence it seems possible that ATS implementation might include terminals beyond those qualifying for manned control towers under the present criteria, based on the improved safety provided by the system. It also seems clear, however, that the procedural or self-announce system offers the best possibility for improved safety at the majority of the general aviation airports.

A feasibility model of the ATS system has been tested at the National Aviation Facilities Experimental Center (NAFEC). Operational testing of this system is being initiated at the Tom's River, New Jersey, general aviation airport.

F. Integrated Aircraft Separation Assurance System

Once the examination of the ASA system elements was completed and their capabilities and shortcomings assessed, the team defined the potential system roles for each of these elements as well as the necessary changes to these elements. The table shown in Figure ES-12 was prepared at the conclusion of the work to provide a summary of the roles of the several system elements. Conflict Alert, possibly augmented by en route conflict resolution, is considered to be the primary function in reducing system errors which lead to near midair encounters. ATARS, when integrated with Conflict Alert, provides the primary automatic defense against near midair collisions, and hence becomes an automated extension of Conflict Alert in cases where human error occurred. ATARS also has a primary role in augmenting the see-and-be-seen flight regime. The role of BCAS as a part of an integrated aircraft separation assurance system is primarily in areas outside of ATARS and radar coverage including low density en route and oceanic airspace including low and medium density terminals. ATS or a procedural version of the ATS appears to be an effective solution for the terminal midair collisions currently occurring between general aviation aircraft.

AIRCRAFT SEPARATION ASSURANCE FUNCTIONAL ROLES

	EN ROUTE CA-CR	TERMINAL CA	ATARS	BCAS	ATS OR PROC. ATC
Midair Collisions - General Aviation			P	(B)	P
En Route Near Midair Collisions			P	P	
En Route System Errors	P		B		
Approach - Departure Near Midair Collisions			P	(B)	
Approach - Departure System Errors		P	B		
High Density Tower Near Midair Collisions			P		
High Density Tower System Errors		P	B[1]		
Low Density and Non Radar Areas				P (Enr)	P (Term)
Oceanic				P	

ATARS = Automated Traffic Advisory and Resolution Service
BCAS = Beacon Collision Avoidance System
ATS = Automated Terminal Service
CA = Conflict Alert
CR = Conflict Resolution
P = Primary
B = Backup
1 = "Smart" Logic May be required - Traffic Pattern Compatible

FIGURE ES-12

V. SYSTEM INTERFACE

A. Conflict Alert, and ATARS Interface

The ATC system roles discussed in earlier sections indicate clearly that the Conflict Alert logic must be integrated with the ATARS logic. This is true particularly for the terminal area systems, to assure that the controller is always given the maximum time for conflict resolution before the automatic ATARS system steps in to resolve the problem by giving commands to the pilots. In addition, this integration assures that there will always be compatible generation of advisories between the two systems and that the advisory finally selected by the ATARS functon will be one of the family of solutions offered earlier to the controller as part of the conflict resolution function. An interface to assist in this integration is described in Appendix D of this report.

B. ATARS-BCAS Interface

The ATARS-BCAS interface is described in Appendix C of this report. The logic of the BCAS avionics operates to suppress the BCAS resolution advisory whenever both the threat aircraft and the BCAS aircraft are within the ATARS service area and receiving ATARS service from the ground ATC system. The ATARS system is also advised of any proposed actions by the BCAS equipped aircraft relating to aircraft not under ATC surveillance. This information is entered into the ATARS conflict table and used as a constraint in issuing further commands to the BCAS equipped aircraft should that aircraft become involved in a conflict with aircraft receiving ATARS advisories.

C. ATS-ATC Coordination

Whenever surveillance information from an ATS system is available in another ATC facility, the interface described under ATARS-BCAS Interface provides the required coordination. If the surveillance information interface is not implemented, then ATS coordinates hand-offs with the ATC system automatically either through the DABS air-to-air link or through the ground digital interface.

VI. SUMMARY OF ASA ELEMENT INTEGRATION

In addition to the interface changes noted above and described more fully in the appendices, the following changes are required to the ASA system elements.

A. ATARS Ground Computer Algorithms

Flow chart changes to implement the Conflict Alert Emulator described above have been developed. The new logic produces a consistent mechanism for generating all alerts for the controller and the pilot and ensures the compatibility of the resolution advisories given to the controller and the pilot.

A command evaluation module or matrix approach replaces the earlier rules for determining which advisories and commands to issue for horizontal conflict resolution. This method looks at all possible combinations of maneuvers and selects the one most appropriate for the conditions. This change allows an additional module to use a "domino logic" to check for further encounters as a result of the original command decision. Additional features of this matrix approach provide for simpler implementaton of terrain, obstacle and special use airspace avoidance warning logic.

Two parameter changes to ATARS resulted from the study of ATARS protection against altitude clearance violations. Simulation results have shown that these changes provide adequate protection while permitting aircraft to achieve normal ATC-assigned vertical separations.

The resolution strategy for ATARS is changed for conflicts that take place at a range greater than 50 nautical miles from the DABS sensor. For conflict at the longer ranges all resolution maneuvers may have to be vertical because of insufficient surveillance accuracy at that range. The look-ahead time for resolution advisories should be increased from 32 to 40 seconds beyond 50 nautical miles if both aircraft have speeds less than 150 knots.

Additions to the ATARS ground logic are required to implement the ATARS-BCAS interface. ATARS must contain geographical maps to implement two boundaries. The outer boundary is the limit of the ATARS service area. The inner boundary encloses airspace where BCAS resolution advisories are inhibited. ATARS must have logic to update status bits in the ATARS or BCAS avionics when an aircraft crosses one of these boundaries. ATARS must have the capability to receive data pertaining to aircraft in conflict on the downlink from the ATARS or BCAS avionics. This data is used to coordinate conflicts between ATARS and BCAS when one aircraft may be outside surveillance coverage.

A conceptual approach for a change to the ATARS multi-site design has been developed. This approach provides for coordination between neighboring ATARS sites using either coordination through ground communications or coordination through-the-transponder. This approach has been made compatible with the ATARS-BCAS interface. An approach to converting the high level logic of ATARS from an epoch-oriented to a sector-oriented logic has also been developed. This modification can reduce the cost of the ground lines for site-to-site communication by permitting the transmission of coordination data to take place over a longer period of time.

B. <u>ATARS or ATARS-BCAS Display</u>

The ATARS display, or the ATARS-BCAS display in a BCAS aircraft that is used to present either BCAS or ATARS advisories, must include a Conflict Indicator Register (CIR) and logic to update it, based upon inputs from ATARS, another BCAS or own aircraft's BCAS logic. The CIR contains information pertaining to other aircraft in conflict with own aircraft that is necessary for coordination between BCAS and ATARS. The CIR must have a lockout capability that prevents two different requests for operation on the CIR from being honored simultaneously. The CIR is described in detail in Appendix C.

C. <u>DABS Transponder</u>

Every DABS transponder which is to be used with an ATARS or a combined ATARS-BCAS display must have the capability to transmit 112-bit messages in the DABS Comm-B format, as well as receive messages in the 112-bit Comm-A format. This is required for the CIR ATARS-BCAS interface communications as detailed in Appendix C.

D. <u>DABS Sensor</u>

Minor changes to the DABS sensor are required so that multiple messages downlinking CIR information can be received while the aircraft is still within the antenna beam. DABS must be able to recognize a few new message codes. No changes in the fundamental capability of the sensor are required.

E. Proposed DABS National Standard

The ATARS-BCAS interface and the ATARS multi-site design logics using communications through-the-transponder require that four bits in the DABS surveillance interrogation and five bits in the DABS surveillance reply formats be assigned for use by these logics. The spare bits are presently available but the wording of the proposed DABS National Standard must be changed to permit their use for this purpose.

F. BCAS Logic

Detailed flow charts have been developed describing the BCAS logic required to support the ATARS/BCAS interface. BCAS must have the provision to terminate routine, active surveillance interrogations when commanded from the ground. BCAS must have the capability to make repeated interrogations of another aircraft in quick succession in order to read the CIR information from that aircraft. The BCAS multi-aircraft logic must be compatible with ATARS, and the active logic must be a subset of the full capability logic.

G. Terminal Conflict Alert

The ARTS software should be modified when ATARS with a Conflict Alert Emulator is implemented at the DABS site serving that ARTS facility. There are three options for implementing a changeover from ARTS Conflict Alert software to the DABS Conflict Alert Emulator. One method is to allow simultaneous operation and display of the Conflict Alert and the Emulator for comparative purposes. Another would use simulataneous operation but display only one at a time. The third would have the Conflict Alert in the ARTS shut off before operating the Conflict Alert Emulator. The first of the three options is recommended to provide for a smooth operational transition, and to allow side by side comparison to show complete and faithful reproduction of alerts. The details of the Emulator are presented in Appendix D.

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GLOSSARY

ACAS	Airborne Collision Avoidance System
AED	FAA Engineering and Development
AEM	FAA Office of Systems Engineering Management
AFS	FAA Flight Standards Service
ARD	FAA Systems Research and Development Service
ARTS	Automated Radar Terminal System
ASA	Aircraft Separation Assurance
ASRS	NASA Aircraft Safety Reporting System
ATARS	Automatic Traffic Asvisory and Resolution System
ATC	Air Traffic Control
ATCRBS	Air Traffic Control Radar Beacon System
ATS	Automated Terminal Service
BCAS	Beacon Collision Avoidance System
CIR	Conflict Indicator Register
Comm A/B	DABS message "Communication A or B" formats
DABS	Discrete Address Beacon System
ERS	Expanded Range Service for TRSA Stage III areas
FAA	Federal Aviation Administration
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
IMC	Instrument Meteorological Conditions
IPC	Intermittent Positive Control
MAC	Mid Air Collision
NAFEC	National Aviation Facilities Experimental Center

GLOSSARY (cont')

NASA	National Aeronautics and Space Administration
NMAC	Near Mid Air Collision
NTSB	National Transportation Safety Board
PWI	Proximity Warning Indicator
SE	System Error
SEIS	System Effectiveness Information Systems
SVFR	Special Visual Flight Rules
TCA	Terminal Control Area
TRSA	Terminal Radar Service Area
VFA	Visual Flight Rules with Radar Advisories
VFR	Visual Flight Rules
VHF	Very High Frequency
VMC	Visual Meteorological Conditions
UNK	Unknown