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FAA TECHNICAL CENTER LETTER REPORT

PILOT UTILIZATION OF

AUTOMATIC TRAFFIC AND RESOLUTION ADVISORIES

by

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NOTICE

The Automatic Traffic Advisory and Resoltion Service (ATARS) was a concept that envisioned ground-based Discrete Address Beacon System (DABS) sensors equipped to provide a collision avoidance service. In October 1981, the Federal Aviation Administration discontinued development work on the ATARS concept, as being redundant with decisions to implement a ground-independent collision avoidance system, TCAS.

This report documents data derived from the ATARS development program and describes technical characteristics of such a collision avoidance service. The purpose of the report is technical documentation. No implementation or further development of ATARS is anticipated.

ABSTRACT

This report presents the results of a large scale systematic field experiment conducted at the Federal Aviation Administration Technical Center to evaluate the utility, and the human factors aspects of an automatic advisory service. The automatic advisory service is composed of two services; 1. a Traffic Advisory Service (TAS) which displays a continually updated, course-up traffic map of the airspace around the subject aircraft, and 2. a Resolution Advisory Service (RAS) which suggests conflict avoidance maneuvers calculated on the basis of ground radar surveillance information.

Analyses of pilot opinion data examines the pilots' assessments of the information content of the display, and their acceptance of the automatic advisory service. Objective data, taken by on-board observers and by ground-based surveillance equipment, is used to analyze pilot reaction to advisories, separation results, and visual acquisition performance.

EXECUTIVE SUMMARY

This report presents the results of a large scale systematic field experiment conducted at the Federal Aviation Administration Technical Center to evaluate the utility, and the human factors aspects of an automatic advisory service. The automatic advisory service is composed of two services; 1. a Traffic Advisory Service (TAS) which displays a continually updated, course-up traffic map of the airspace around the subject aircraft, and 2. a Resolution Advisory Service (RAS) which suggests conflict avoidance maneuvers calculated on the basis of ground radar surveillance information.

The flight test program involved 12 subject pilots flying 72 flights (6 flights each), in a total of 424 near miss encounters. Physical (flight) data were taken by on-board observers, and by ground-based magnetic tape recorders. Subjective data concerning pilot opinion and perception were collected with post-flight and post-encounter debriefings. The analysis of these data is divided into the following five categories:

- o Dependence of Data on Test Conditions
- o Pilot Utility Assessment of the Advisory Service
- o Pilot Acceptance of the Advisory Service
- o Use of the Advisory Service
- o Characteristics of the Training Program

In subjective measures of opinion and objective measures of performance, the advisory service was found to have a high degree of pilot acceptance, and it was found to aid the pilot in managing midair encounters. There was a distinct preference shown for the TAS over the RAS. Analysis of data on the Closest Point of Approach (CPA) showed that, for encounters with CPA less than 1000 feet, the average achieved minimum slant range increased by 22.9 percent when pilots complied completely with the resolution advisories over when they did not.

The results of the analysis lead to the following conclusions:

- o Horizontal and vertical maneuvers in response to an automatic advisory service are effective in increasing aircraft separation.
- o Supplementary information, over and above the basic position and relative motion information, is unwanted by pilots, and interferes with their comprehension of traffic situations. Conflict resolution advisories are seen as less important than this basic information.
- o Certain characteristics of pilot interaction with an automatic advisory service, (such as the ability to maximize achieved separation), are established by the very first flight experience with the service, while other characteristics (such as satisfaction with the

service and time to visual acquisition) take four flight experiences to mature.

- o Self-study with a comprehensive training manual is an effective method for training pilots in the use of an automatic advisory service.

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Mr. Gerald Skelton, ACT-230, helped get the test program underway by seeking out suitable aircraft to rent, coordinating rental agreements, supporting the testing as an observer and spotter in the intruder aircraft.

Mr. Richard Popper, Columbia University, supported the development of the human factors analysis by helping prepare and present the pilot training program, and by supporting development of the test plan and the analysis of the data and development of results.

TABLE OF CONTENTS

Abstract i

Executive Summary ii

Acknowledgements v

Introduction 1

Background 4

System Overview 7

Flight Test Program Objectives 13

Test Structure 15

Introduction 15

Flight Path Geometries 17

Selection of Flight Patterns 17

Encounter Arrangement (Conflict Geometries) 18

Scheduling 20

Pilot Selection 23

Training 24

Flight Activities 25

Test Flight 25

Communications 28

Air Traffic Control (ATC) 28

Factors Outside of Strict Control 29

Summary 30

Test Execution and Data Collection 33

Introduction 33

Airborne Instrumentation 36

Biographical Data 42

Ground School Training 43
Flight Data Collection 46
Test Flights 46
Flight Summary 48
Manual Data Forms 48
Preflight Exam 49
Flight Log 49
Encounter Log 50
Encounter Debriefing 50
Flight Debriefing 51
System Data Extraction 51
Data Processing 53
Manual Data Quantification 53
System Data Extraction Tapes 53
Data Base Construction 56
Data Base Structure 56
Biographical File 57
Ground School Exam File 57
Flight Data File 57
Text File 57
Summary 58
Data Reduction and Analysis 59
Introduction 59
Dependence of Data on Test Conditions 61
Pilot Utility Assessment of the Advisory Service 64
Introduction 64
Ranking of Pilots' Ratings of Displayed Data 66

Variability of the Ratings 68

Stability of Displayed Data Rankings with Flight Number 72

Information Level 74

Summary 78

Pilot Acceptance of the Advisory Service 80

Introduction 80

Flight Debriefing 82

Encounter Debriefing 84

Combined Index of Pilot Satisfaction 88

Encounter Type and Satisfaction 90

Summary 97

Use of the Advisory Service 99

Introduction 99

Visual Acquisition 102

Pilot Response 108

Closest Point of Approach (CPA) 110

Distribution of CPA Data 122

Pilot Behavior as a Function of System Estimates of Risk 127

Summary 131

Characteristics of the Training Program 135

Results 138

Introduction 138

Dependence of Data on Test Conditions 140

Pilot Utility Assessment of the Advisory Service 140

Pilot Acceptance of the Advisory Service 141

Use of the Advisory Service 142

Characteristics of the Training Program 142

Conclusions 144

Recommendations 145

References 146

LIST OF TABLES

TABLE		PAGE
1	Advisory Thresholds	11
2	Latin Square for Scheduling	22
3	Summary of Flight Conditions	32
4	Cockpit Display Specifications	39
5	Ground Training Test Scores	45
6	Rankings of Advisory Service Displayed Data	66
7	Sources of Variability in Displayed Data Ratings	69
8	Rankings of Displayed Data by Flight Number	72
9	Frequency of Pilot Comments	76
10	Mean Global Ratings of the Service and the Display	82
11	Average Means for Global Ratings as a Function of Flight Number	83
12	Weighting of the Encounter-based Index of Satisfaction, S1	85
13	Meanings of the Sums of the Encounter Debriefing Questions	86
14	Summary Statistics for the Encounter-based Index of Satisfaction, S1	86
15	Summary Statistics for the Combined Index of Pilot Satisfaction, S2	88

16	Mean Scores of the Preflight Exam for each Flight Number	89
17	Response to Question 5 (Display Timing) as a Function of Encounter Type	91
18	Response to Question 6 (Advisory Timing) as a Function of Encounter Type	91
19	Response to Question 7 (Usefulness of the Service) as a Function of Encounter Type	92
20	Response to Question 15 (Service vs. ATC) as a Function of Encounter Type	92
21	Weighting of the Per-encounter Index of Satisfaction,S3	93
22	Meanings of the Values of the Per-encounter Index of Satisfaction, S3	94
23	Mean Time (in Seconds) to Visual Acquisition	102
24	Number of Cases without Visual Acquisition	106
25	Frequency of Responses to the RAS as a Function of Intruder Position	116
26	Frequency of Compliance/Noncompliance with the RAS as a Function of Intruder Position	117
27	Sources of Variability in Slant Range CPA's Below 1000 Feet	119
28	CPA Slant Range as a Function of Compliance with the RAS (aCPA's below 1000 Feet)	120
29	Statistics on Distribution of CPA Data	122
30	Definitions of "Risk" Categories	127
31	Percentages of Maneuvers as a Function of "Risk" Level and Encounter Type	128
32	Definition of "Outcome" Categories	130
33	"Outcome" as a Function of "Risk"	130

LIST OF ILLUSTRATIONS

FIGURE		PAGE
1	Hardware Engineering Design Block Diagram	8
2	Software Engineering Design Block Diagram	10
3	Data Collection Block Diagram	34
4	Subject Aircraft Cockpit with Display	37
5	Subject Aircraft	38
6	Ratings of Displayed Data	71
7	Pilot Opinion on Information Level	75
8	Per-Encounter Index of Satisfaction S3, as a Function of Encounter Type	95
9	Time to Visual Acquisition, Head-on	103
10	Time to Visual Acquisition, Lateral Encounter	104
11	Time to Visual Acquisition, Tail-chase	105
12	Mean of Minimum Achieved Separation as a Function of Compliance with the RAS	112
13	Horizontal and Vertical Separation at CPA for Encounters with CPA within 1000 Feet	114
14	Horizontal and Vertical Separation at CPA for Compliance versus Noncompliance	118
15	Mean Preflight Exam Score versus Flight Number	137

LISI OE ΔEEENDICES

A. Flisht Patterns A1

B. Data Collection Forms B1

INTRODUCTION

This report presents the results of a large scale systematic field experiment conducted at the Federal Aviation Administration Technical Center to evaluate the utility, and human factors aspects of an automatic advisory service. The automatic advisory service is composed of two services. The first, called Traffic Advisory Service (TAS), consists of displayed symbology depicting the actual location of nearby traffic. The second is a Resolution Advisory Service (RAS) which suggests possible avoidance maneuvers. The purpose of the advisory service is to increase safety by providing the pilot with detailed information on nearby aircraft.

See-and-avoid has been the primary means of avoiding midair collisions for pilots flying under Visual Flight Rules (VFR) and Instrument Flight Rules (IFR) in Visual Meteorological Conditions (VMC). Once an aircraft is visually acquired, the pilot makes a threat assessment. At present, the information used in making a threat assessment (such as velocity, heading, and altitude of an aircraft) is determined by visual observation supplemented by data obtained from ATC advisories.

One of the goals of the TAS is to provide enough information on both proximate and potentially threatening aircraft so that a pilot can visually acquire the aircraft, make an accurate threat assessment and avoid increasing danger and

the necessity for extreme maneuvers. At present, air traffic controllers support see-and-avoid operations by providing advisories to the pilot on a work-permitting basis. The automatic advisory service is designed to provide high quality advisories as a fulltime service for all equipped aircraft within the coverage area.

The report is divided into the following sections:

- o Background
- o System overview
- o Flight Test Program Objectives
- o Test Structure
- o Test Execution and Data Collection
- o Data Reduction and Analysis
- o Results
- o Conclusions
- o Recommendations

The first section presents a brief history of studies involved in the development of various collision avoidance systems.

The "System Overview" provides an explanation of the engineering design of both the hardware and software system structures.

The third, "Flight Test Program Objectives," describes the objectives of this study.

The "Test Structure" section is divided into six subsections and a summary describing the various aspects of the flight test program. Reasons for flight pattern selection and procedures for pilot selection and training are presented as well as a discussion of the test plan structure.

The fifth section, "Test Execution and Data Collection," describes the execution of the flight test program and how the data was gathered, processed, and entered into a comprehensive data base for analysis. Topics covered are activities before, during, and after a test flight.

The sixth section, "Data Reduction and Analysis," is divided into five subsections and a summary. The dependence of test results on either test design characteristics (e.g. flight pattern type) or other factors not strictly controllable is examined. Pilots' evaluations of the displayed information and comments regarding the information level are examined. Evidence of pilot satisfaction and acceptance are also examined in detail. Visual acquisition data and point of closest approach information are examined to identify pilot behavior. The training program is assessed in the subsection "Characteristics of the Training Program."

The last three sections, "Results, Conclusions and Recommendations," summarize the findings of this study.

BACKGROUND

The requirement for the development of a discrete address beacon system was identified in the 1969 Department of Transportation (DOT) Air Traffic Control (ATC) Advisory Committee Study (Reference 1). The study recommended modifications to the present Air Traffic Control Radar Beacon System (ATCRBS) which would improve the surveillance accuracy and the reliability of the system. Specifically, a discrete address mode data link function (Mode S) was proposed which would support a system which automatically transmitted traffic advisories to the pilot. This ground based system, called Intermittent Positive Control (IPC), would operate in the multi-computer Mode S ground equipment. The IPC algorithm would process raw surveillance data supplied by the radar site and send individual messages to each aircraft equipped with a Mode S transponder and related display equipment. The pilot would receive the traffic advisories on a display installed in the aircraft instrument panel.

Both the computer algorithms and the cockpit displays for this service have undergone a steady evolution since the 1969 DOT study. A single-site algorithm was published in 1975 (Reference 2). A multi-site algorithm, called IPC Change 2, was published in September 1976 (Reference 3) and subsequently tested at the Federal Aviation Administration Technical Center and at sites in Clementon and Elwood, New

Jersey. Flight tests of the single-site algorithm were conducted at the Mode S experimental facility at Hanscom Air Force Base, Massachusetts from October 1974 to February 1977 by Lincoln Laboratory (Reference 4). A second study which came out of this testing examined the effects of the IPC display on visual acquisition (Reference 5). Lincoln Laboratory was concerned with the design of a traffic advisory service that complemented the ground-based resolution service while maintaining compatibility with other applications being developed for the Mode S data link. They developed the message formats that provided the pilot with the information that he requires while attempting to minimize the workload involved. There were 103 flights completed in this test series. The results of this testing of the original IPC algorithms demonstrated the usefulness of the traffic advisory portion of the IPC as an aid to visual acquisition of traffic; however, it was also found that in many cases the pilot was unable to make a threat assessment based on the limited amount of information provided by the IPC display. Clock position and relative altitude information alone did not permit effective determination of the direction in which it was safe to turn. The present advisory service algorithm (the Automatic Traffic Advisory and Resolution Service, ATARS) is based on the results of the Lincoln Laboratory tests, knowledge gained from operation of IPC Change 2, and simulation studies of single-site IPC done by the Technical Center

(e.g. Reference 6) and the MITRE Corporation.

In October 1981 the Federal Aviation Administration discontinued work on the ATARS concept, deeming it redundant with decisions to implement a ground-independent collision avoidance system, the Traffic Alert and Collision Avoidance System (TCAS).

SYSTEM OVERVIEW

The automatic advisory service used in this test program utilizes the Mode S ground system to communicate with airborne display instrumentation. The relationship between the system components is presented in terms of two system-level block diagrams; one showing the hardware configuration and one showing the software configuration.

The hardware design for the automatic advisory service is shown in Figure 1. The three main blocks are "Intruder Aircraft," "Subject Aircraft," and "Mode S Sensor." The intruder aircraft is supplied with an ATCRBS transponder which replies to Mode S sensor interrogations. The subject aircraft also responds to the Mode S interrogations and receives data link messages through the Mode S transponder. Any advisory, whether TAS or RAS, is given priority for use by the display. The Mode S ground system includes a surveillance function, the advisory service computer function and a data link function. The surveillance function gathers altitude, position, aircraft identification number, and aircraft equipage information which the advisory service function processes to identify potential conflicts. The Mode S data link function then transmits the TAS and RAS messages developed by the advisory service function to the subject aircraft via the surveillance function.

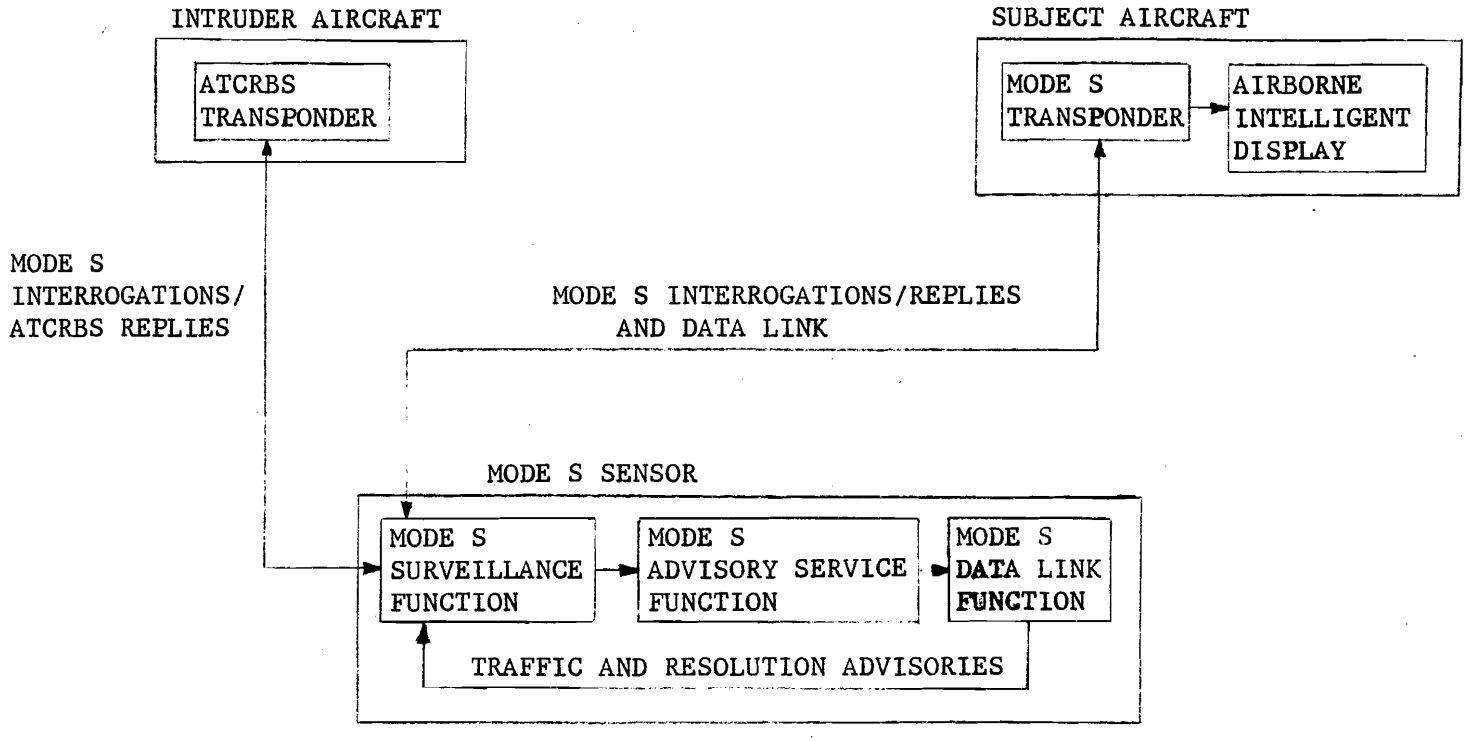


FIGURE 1 - HARDWARE ENGINEERING DESIGN

BLOCK DIAGRAM

The software block diagram (Figure 2) shows the data flow through the advisory service function. Surveillance information is processed by the "Sector Processing" module where aircraft velocity and position information (which comprise the "state vector") is smoothed. This track data is then turned over to the "Aircraft Update" module where the prediction time for each state vector within a current sector is updated to a common time. The aircraft under advisory service coverage are ordered by x coordinate, and aircraft with both low altitude and low speed are entered in the "X-List" with all other aircraft entered in the "EX-List." The next step in the process is the "Coarse Screen" where each aircraft is assigned a three-dimensional window. If other aircraft are detected inside this window, they become potential pairs. This list is then examined by the conflict detection algorithm which classifies traffic into two categories; Proximate and Threatening. These classifications are made on the basis of velocities, current separation, closing rates and a projected miss distance calculated from current trajectories. (Table 1 shows the advisory threshold criteria for these classifications, and for the issuance of conflict resolution advisories.) The type of service required (TAS or RAS) is then determined. If a resolution is required, the "Master Resolution" module determines which type of resolution message is appropriate. Positive advisories are those that advise the pilot to maneuver in a specific direction (e.g. turn left).

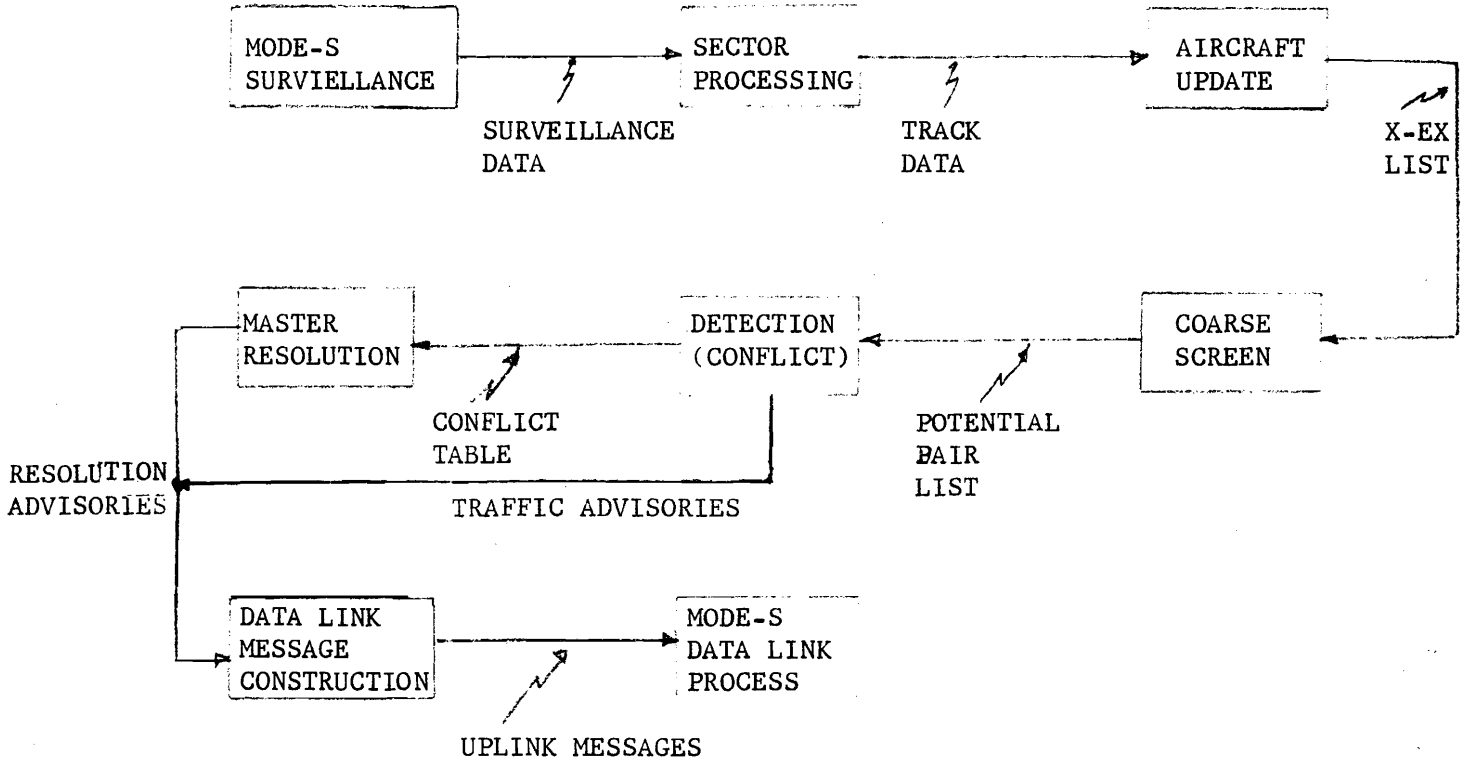


FIGURE 2 - SOFTWARE ENGINEERING DESIGN BLOCK DIAGRAM

	PROJECTED MISS DISTANCE (N. Mi)	ALTITUDE SEPARATION (FEET)	RANGE (N. Mi.)	TIME UNTIL CLOSEST POINT OF VERTICAL APPROACH (SEC)	TIME UNTIL CLOSEST POINT OF HORIZONTAL APPROACH (SEC)
PROXIMATE					
if	–	<2000	<2	–	–
or if	–	<2000	<(V1+V2)X30	–	–
THREATENING					
if	<1	<900	<1.2	–	–
or if	<1	–	<1.2	<50	–
or if	<1	–	–	<50	<50
or if	<1	<900	–	–	<50
RESOLUTION ADVISORY IS ISSUED					
if	<1	<750	<0.75	–	–
or if	<1	–	<0.75	<25	–
or if	<1	–	–	<25	<25
or if	<1	<750	–	–	<25
ADVISORY IS: NEGATIVE					
if	>0.5	–	–	–	–
or if	–	>375	–	–	–
POSITIVE					
if	<0.5	<375	–	–	–

ADVISORY THRESHOLDS

TABLE 1

Negative advisories are those that advise the pilot not to maneuver in a specific direction (e.g. do not climb). If a traffic advisory alone is required, the "Master Resolution" module is bypassed. Both the RAS and TAS are then processed by the "Data Link Message Construction" module which prepares the formats and message strings for the "Mode S Data Link Function." More specific details of the message formats can be found in References 7 & 8.

FLIGHT TEST PROGRAM OBJECTIVES

The objective of this flight test program was to determine the characteristics of pilot interaction with an automatic traffic and resolution advisory service. The characteristics were divided into the following areas for analysis:

- o Pilot Utility Assessment of the Advisory Service
- o Pilot Acceptance of the Advisory Service
- o Use of the Advisory Service
- o Characteristics of the Training Program

In the first area, "Pilot Utility Assessment of the Advisory Service," the flight test program examines the usefulness of the service as reflected in the pilots' ratings of the displayed data.

The second area, "Pilot Acceptance of the Advisory Service," considers the pilot's assessment of the credibility and accuracy of the TAS and RAS. Some of the questions addressed are: Do pilots like the system?; Are pilots satisfied with the system?

Under the third category, "Use of the Advisory Service," the flight test program explored the extent to which subject pilots used information obtained from the display when managing encounters. Questions such as, "Did the subject pilots use the RAS to make these avoidance maneuvers or did they use the traffic advisory service to assess their own maneuvers?" are examined in detail.

Finally, "Characteristics of the Training Program" addresses questions regarding the amount and type of training that the pilots need before they can use the system effectively.

TEST STRUCTURE

INTRODUCTION.

This section covers the test plan structure and is divided into the following seven main sections:

- o Flight Path Geometries
- o Scheduling
- o Pilot Selection
- o Training
- o Flight Activities
- o Factors Outside of Strict Control
- o Summary

The first section examines the six flight patterns used in the test program, how they were selected, and the reason for the encounter arrangements.

Scheduling of pattern type and pilot sequencing are explained in the section, "Scheduling." The ordering of flight patterns, equal distribution of time of day and distributed learning aspects were accomplished by means of a latin square design.

There were several restrictions in the subject pilot selection process that had to be strictly observed. The determination of these restrictions and the selection process are examined in the section entitled "Pilot Selection."

The fourth section discusses the three types of training the pilots received: a Pilot's Manual (Reference 9), ground school and one familiarization flight in the subject aircraft.

The section "Flight Activities" examines the procedures of the test flight, the subject pilot's experience and the responsibilities of the observer and test safety pilot.

Certain conditions hampered some tests and sometimes caused a flight to be cancelled or aborted. "Factors Outside of Strict Control," explains what these conditions were relative to the flight tests.

FLIGHT PATH GEOMETRIES.

This section is divided into two subsections:

- o Selection of Flight Patterns
- o Encounter Arrangement (Conflict Geometries)

SELECTION OF FLIGHT PATTERNS. A total of six flight patterns were developed; each path using the same four navigational points (see Flight Patterns, Appendix A). The selection of the flight path geometries was limited by certain practical considerations such as sensor coverage areas, navigational workload, the need to avoid the Philadelphia terminal control area, New York Center airspace, and the McGuire AFB control area. The encounter arrangements were designed to maintain an even distribution of encounter types (head-on, tail-chase,and lateral) over all six flights. The goal in selecting the flight paths was to establish a series of flights for the pilot that were:

- o Consistent with normal and expected flight operations.
- o Confined to the 60 nautical mile (nm) coverage area of the Clementon, New Jersey Mode S sensor.
- o Easily observed and controlled from the Technical Center.
- o Easily managed by Center test pilots so that the required encounters could be set up and executed successfully.

ENCOUNTER ARRANGEMENT (CONFLICT GEOMETRIES). The conflict geometries were selected so that they exercised the full range of the advisory service display capabilities. During the design stages of the flight test program several decisions were made in order to optimize the variety of questions that could be answered and the reliability of the answers to these questions.

One of the issues concerned the number of aircraft that would be used during the flight tests. Analysis of the nature of the aircraft conflict led to the restriction that only those conflicts that involve just two aircraft would be considered. Two aircraft encounters are not the only types that arise, and particularly in heavily trafficked terminal areas, maneuvers designed to reduce the accident potential of one conflict may create a domino effect with respect to other traffic. However, in order to reduce the number of design variables in the test, maintain safety, and to increase the statistical reliability of the results, the planned encounters were limited to two aircraft encounters.

The second aspect of the aircraft conflict is that the intruder vector may contain a vertical as well as a lateral component. Therefore conflicts may arise because the intruding aircraft descends toward the subject aircraft, or climbs up into the subject aircraft. Because examination of operations during vertical flight encounters was not the subject of this test, such vertical component conflicts were

ruled out as systematic variations in the design. Although encounters during turns and altitude changes did occasionally occur, generally, the intruder flew straight and level into and through the encounter.

This left conflicts between aircraft at stable altitude differences which were partitioned into three general classes depending upon the lateral position of the intruder. These conflicts were called "head-on" when the intruder aircraft was closing with the subject aircraft within plus or minus 45 degrees of the subject aircraft ground track heading. Encounters were considered as "lateral encounters" if the intruder aircraft was approaching 90 degrees, plus or minus 45 degrees relative to the subject aircraft heading. Finally "tail-chase" encounters were those in which the intruder was approaching the target aircraft within 45 degrees of the reciprocal of the subject aircraft heading. This partitioning of encounter types while arbitrary, is a reasonable compromise to reduce the number of test variables and increase the statistical reliability of the test results.

The subject aircraft was a twin-engine Beech Baron (BE-55) flown at a speed of 120 knots. The intruder aircraft was a Cessna 210 flown at 165 knots.

SCHEDULING.

Six different patterns were used in the test series. Each pattern was flown equally often by each pilot and the sequence of the patterns was distributed so that each type followed another equally often. This was accomplished by use of a latin square design.

The criteria used to schedule the flights were as follows:

- o The order in which the flight patterns were flown was different for each of the six pilot pairs. This was desirable because the patterns may not be the same in difficulty (e.g., navigational workload). Furthermore, because of the course geometry certain patterns contain encounters that are particularly difficult to resolve. In order to distribute the effects of flight experience evenly over the six patterns (thereby avoiding any biased weighting of one) each pattern occurred in each position equally often. To avoid carry-over effects each pattern was preceded by each other pattern equally often.
- o In order to avoid the possibly unequal effects of time of day (morning and afternoon) upon the results, each pattern was flown an equal number of times in the morning and afternoon. In addition, each pilot flew an equal number of morning and afternoom flights.
- o In order to take advantage of distributed learning, subject pilots experienced a waiting period between

flights.

The first and second criteria were satisfied using a latin square (Table 2) to assure that no two sequences were identical. For example, for pattern sequence 5, pilot E flew pattern D in the morning for his third flight, and pilot G flew pattern D in the afternoon for his third flight. The third criterion was accomplished by stipulating that:

- o No pilot could fly more than one flight per day.
- o No pilot could fly more than two flights per week.

TABLE 2 - LATIN SQUARE FOR SCHEDULING

PATTERN SEQUENCES

		1	2	3	4	5	6
	PILOTS --	F/D	B/K	A/I	C/L	E/G	H/J
	1	F a/b	D a/b	E a/b	C a/b	A a/b	B a/b
	2	A b/a	B b/a	D b/a	F b/a	C b/a	E b/a
FLIGHT NUMBER	3	E a/b	C a/b	A a/b	B a/b	D a/b	F a/b
	4	C b/a	E b/a	B b/a	A b/a	F b/a	D b/a
	5	B a/b	A a/b	F a/b	D a/b	E a/b	C a/b
	6	D b/a	F b/a	C b/a	E b/a	B b/a	A b/a

KEY:

Letters A - F: Designate the pattern types used (see Appendix A for pattern diagrams).

Letters a & b: Designate the time of day that the flight took place (morning and afternoon, respectively).

PILOT SELECTION.

The flight test program required the participation of 12 government employees, multi-engine rated pilots with at least 6 hours of flight time in the previous 3 months and a minimum of 200 hours of total flight time. Prospective subject pilots were notified by letter, Center newspaper and public address system, of a meeting which would brief them on the program and its requirements. At the close of the meeting all interested pilots submitted applications for participation in the flight test program. The applications contained the pilot's aircraft ratings and flight hours, which were used to determine who was qualified. Out of those who qualified, twelve were chosen at random and letters of selection were sent to those twelve pilots.

Those selected were assigned identification letters which were to be used throughout the test series, and each pilot was asked to fill out a biographical background questionnaire which became part of the data base. All references to a particular pilot were made by identification letter, never by name.

TRAINING.

The prime concern in the pilot orientation was the requirements necessary for the pilot to understand the advisory service well enough to use the information effectively. Each pilot received a Pilot's Manual for self-study one week prior to ground school. Exams were given at the beginning and at the end of the ground school. The first was to see how much the pilots learned from the self-study material and the second was to see if the ground school enhanced the pilot's understanding of the material. A familiarization flight in the subject aircraft was also provided as a training or preparatory aid before any flight testing began.

The first step during the ground school session was the administration of a test covering the advisory service. This test grade became part of a permanent data file of the training program for each pilot. The ground school training began after the first test was completed and graded. The entire system was reviewed with special emphasis placed on the areas identified as trouble spots from the first exam. After the ground school session was complete, the pilots took a second exam, similar to the one they had taken at the beginning of the session. Grades between the pilot test/re-test scores were compared and averaged. Pilots were then paired to the extent possible so that each of the 6 flight sequences would be flown by two pilots with similar

scores.

FLIGHT ACTIVITIES.

This section is divided into the following subsections:

- o Test Flight
- o Communications
- o Air Traffic Control (ATC)

TEST FLIGHT. Before each test flight the safety pilot, ATC coordinator, observers, and subject pilot discussed the flight, procedures, altitudes, communications and flight test requirements. The subject pilot did not participate in those briefings in which the encounters were planned and discussed, since that part was to be acted upon by the subject pilot when the situation occurred. In order to keep the scope of these tests within reasonable bounds, certain parameters of the planned encounters were held constant throughout the test series. These fixed aspects of the encounters were clearly communicated to the subject and safety pilots during briefings to ensure their understanding of the flight test parameter constraints:

- o The subject pilot considered both aircraft to be operating under VFR conditions (visibility 4 nm, ceiling more than 3000 feet).
- o The intruder aircraft was equipped with an altitude encoding altimeter and transponder. Aircraft without altitude encoding equipment were not processed by

the ground-based advisory service equipment. The intruder was not equipped with the advisory service capability.

- o No ATC involvement was staged. The subject pilot did not receive or ask for traffic advisories. However, traffic advisories on aircraft other than the two test aircraft were uplinked by ATC in the event that they were not Mode C equipped.
- o The safety pilot, who was the Pilot-In-Command (PIC), was responsible for ensuring adequate separation throughout the test series. The safety pilot supported the subject pilot during the test flight by handling the communications. No help was given to the subject pilot during the flight with respect to bringing his attention to the display or pointing out aircraft for visual acquisition. The intruder did not respond to the conflicts, only the subject aircraft initiated maneuvers, if the subject pilot deemed it necessary. The intruder aircraft was considered blind to the presence of the subject aircraft throughout all phases of the encounters.

Encounters were designed so that this last constraint did not produce any unreasonable demand on the subject or safety pilots. The velocity differences between the subject aircraft were small so that modest maneuvers of the subject aircraft were effective. Although the display contains a number of features selectable by the pilot, all flights were

flown under the following conditions (Reference 9 gives a detailed explanation of these features):

- o Display: Displayed range set on auto-adjust
- o Proximate Mode: Option 5 (full symbology for threats and non-threats except that when a threat exists simultaneously with a proximate aircraft, the proximate aircraft will not display the altitude and velocity vector).
- o Proximate Priority: No information other than the advisories were transmitted to the display.
- o Information Level: All flights were flown with the full advisory service.

Before a test flight the observers would complete a flight log with information about the weather, airport conditions, aircraft status, and time of day. The subject pilot completed a preflight exam prior to the day's flight briefing. During the flight, the observer completed the encounter log recording the physical data before, during, and after an encounter. Immediately following each encounter the observer asked the subject pilot questions concerning the encounter just completed and recorded the answers on the encounter debriefing form. After the flight, the subject pilot completed the flight debriefing which was concerned with the entire flight experience.

COMMUNICATIONS. During all flights a site control point called Mode S Control was located at the Technical Center radar site. All communications, air-to-ground and ground-to-ground, went through Mode S Control. Occasionally a vector was given to the two test aircraft from Mode S Control to aid interception of the subject aircraft. Since the subject pilot was not to know from where the intruder aircraft was coming, a coded form of communications between the intruder aircraft and subject aircraft was necessary. This was accomplished by having the intruder ask for position reports from the subject aircraft when visual acquisition was lost. Advisories from ATC were given to the subject only when requested by the safety pilot.

AIR TRAFFIC CONTROL. The ATC coordinator provided updated information concerning the airspace used by the Technical Center. ATC was aware of the requirements during the flight test and was provided with the following information:

- o Transponder codes of both aircraft involved in the flight test.
- o Altitude of each aircraft during the flight test.
- o Intended route of flight (see Flight Patterns, Appendix A).
- o Time flight was expected to begin.

FACTORS OUTSIDE OF STRICT CONTROL.

A flight would not be attempted if the visibility was less than 4 nautical miles, the ceiling (cloud layer) was less than 3000 feet, or the wind velocity was greater than 35 knots at flight test altitude. Hardware failures (in such equipment as the radar sensor or airborne instrumentation), software malfunctions, or aircraft maintainence problems caused delays and/or cancellations. Unplanned encounters were welcome since they provided additional data for analysis and the opportunity to compensate for missed encounters.

SUMMARY.

This section described the test plan structure and was divided into the following six sections:

- o Flight Path Geometries
- o Scheduling
- o Pilot Selection
- o Training
- o Flight Activities
- o Factors Outside of Strict Control

There were six flight patterns (A-F) used in the test series. The order in which the pilots flew the six patterns was determined by using a latin square design.

Following a series of announcements and a briefing on the flight test program, applications were received from potential subject pilots. The applicants were then screened for qualifications such as multi-engine rating, current medical certificate, and 200 hours of flight time with at least 6 in the past 3 months. A total of 12 pilots were chosen to participate in the test program. After notification of acceptance into the program, the pilots were given a self-study Pilot's Manual to familiarize themselves with the advisory service system. These manuals were given to the subject pilots one week prior to the ground school training session. At the beginning of the training session an exam was administered to test the knowledge gained from the self-study Pilot's Manual. The subsequent instruction

covered the training manual contents and answered any questions the pilots had concerning the advisory service. At the conclusion of the course a similar exam to the first was given to the subject pilots, this time with the purpose of identifying any increase in knowledge of the service that occurred as a result of the training session.

Radar sites at the Technical Center and at Clementon, New Jersey were used in the flight test program. The Technical Center was the headquarters for communications between the aircraft and the Clementon radar site. The flight coordinator briefed the Air Traffic Control watch supervisor about the altitudes, flight patterns, and aircraft numbers of the day's flight. The subject pilot, safety pilot and observers participated in a preflight briefing. The observer completed a flight log while the subject filled in a preflight exam. During each encounter the observer completed an encounter log with physical data regarding the encounter. The observers queried the subject pilots about the advisory service subsequent to each encounter, thereby providing answers to the encounter debriefing form. At the completion of a test flight the subject pilot completed a flight debriefing form which asked for an evaluation of the advisory service. The safety pilot was the Pilot-In-Command (PIC) and was responsible for assuring safety during the flight. The safety pilot handled the communications because the intruder pilot needed frequently updated position information from the subject aircraft, in order to plan his

approaches. If the visibility was less than 4 nautical miles, ceiling was less than 3000 feet, or high winds existed at flight level, cancellations would occur. If these thresholds were violated after a flight began, the flight was aborted. Other factors which caused delays, postponements or cancellations were malfunctions due to aircraft maintainence problems, equipment failures, or software problems.

A summary of the flight test conditions is presented in Table 3.

TABLE 3 - SUMMARY OF FLIGHT CONDITIONS

		TYPE	SPEED	SERVICE
AIRCRAFT	SUBJECT	Beech 55	120	Equipped
	INTRUDER	Cessna 210	165	Unequipped
WEATHER	Vis.>4 nm.	Ceiling>3000 ft.	Wind at 3000 ft.<35 kts.	
ENCOUNTERS	Straight & Level	One Intruder		

TEST EXECUTION AND DATA COLLECTION

INTRODUCTION.

Test execution and data collection are described in the following six sections:

- o Airborne Instrumentation
- o Biographical Data
- o Ground School Training
- o Flight Data Collection
- o Data Processing
- o Data Base Construction

All the data collection activities are illustrated in Figure 3. The test data were obtained by means of exams, questionnaires, log forms, and magnetic tapes. These data were entered into a comprehensive data base for analysis.

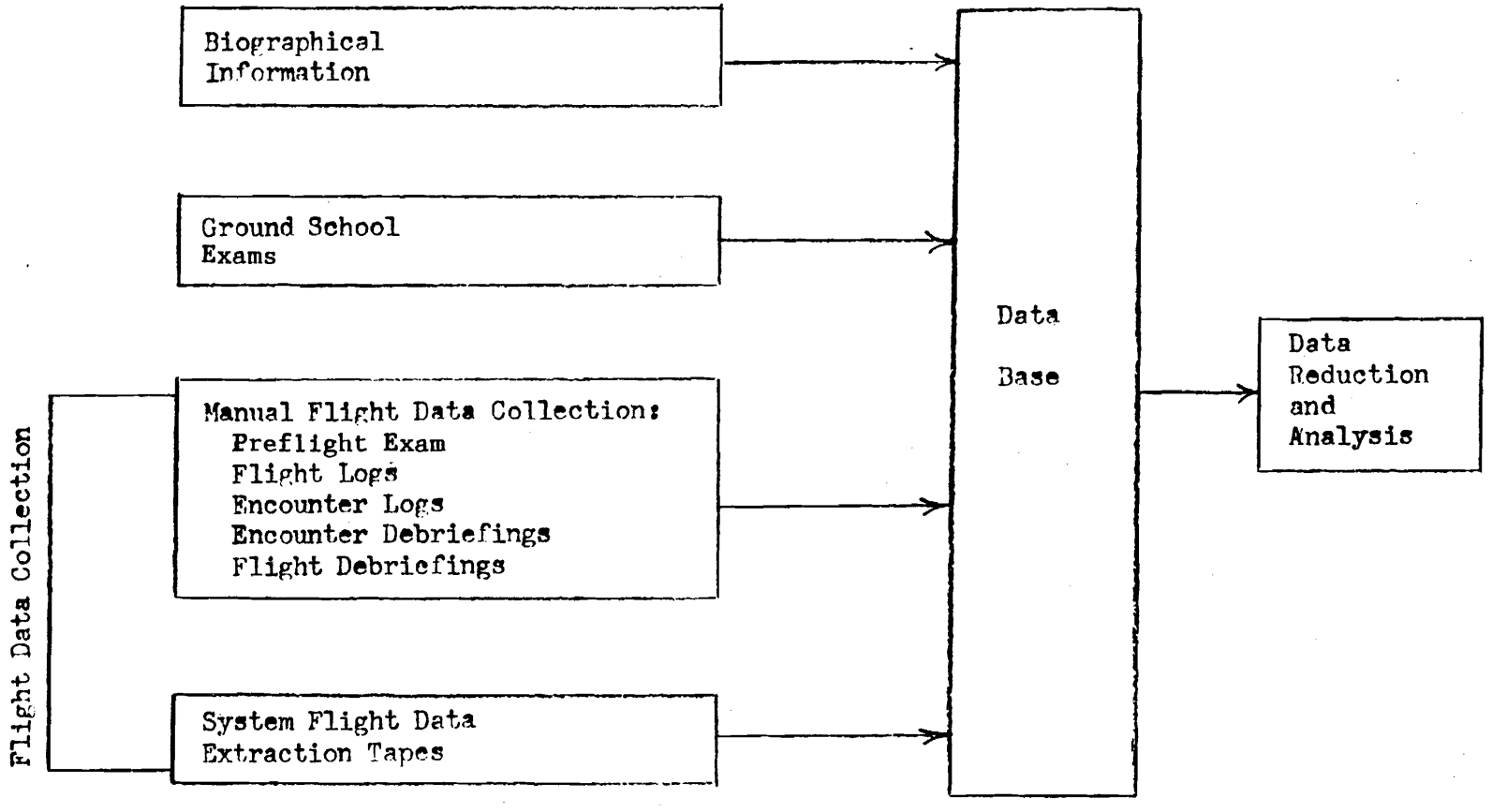
The airborne instrumentation section explains the screen position relative to the pilot's eyesight and how the images displayed on the screen are perceived. The human factors aspects of the display are described in detail.

The biographical data consist of the aviation experience and certification levels of the subject pilots.

The ground school training served as a formal class for the subject pilots subsequent to individual study of the Pilot's Manual.

DATA COLLECTION BLOCK DIAGRAM

FIGURE 3



The flight data collection section describes the test flights and the data collected during the flights. There were two categories of flight data: written (manual) flight data, and system extraction data. Before each flight the subject pilot completed a preflight exam, while the observer filled out the initial portions of the flight log. During the flight the observer completed the flight log and two other forms, the encounter log, and the encounter debriefing. The encounter log was completed during each encounter, and the encounter debriefing was the observer's transcription of the subject pilot's responses to debriefing questions asked immediately after the encounter. A flight debriefing was completed by the subject pilot after the flight was finished.

Magnetic data extraction tapes were collected at the Mode S site for each flight. These tapes contained surveillance information, time, aircraft identification numbers, and the automatic advisory service data.

The data processing section describes the procedure of reducing all the obtained data to a format that facilitated entry into the data base.

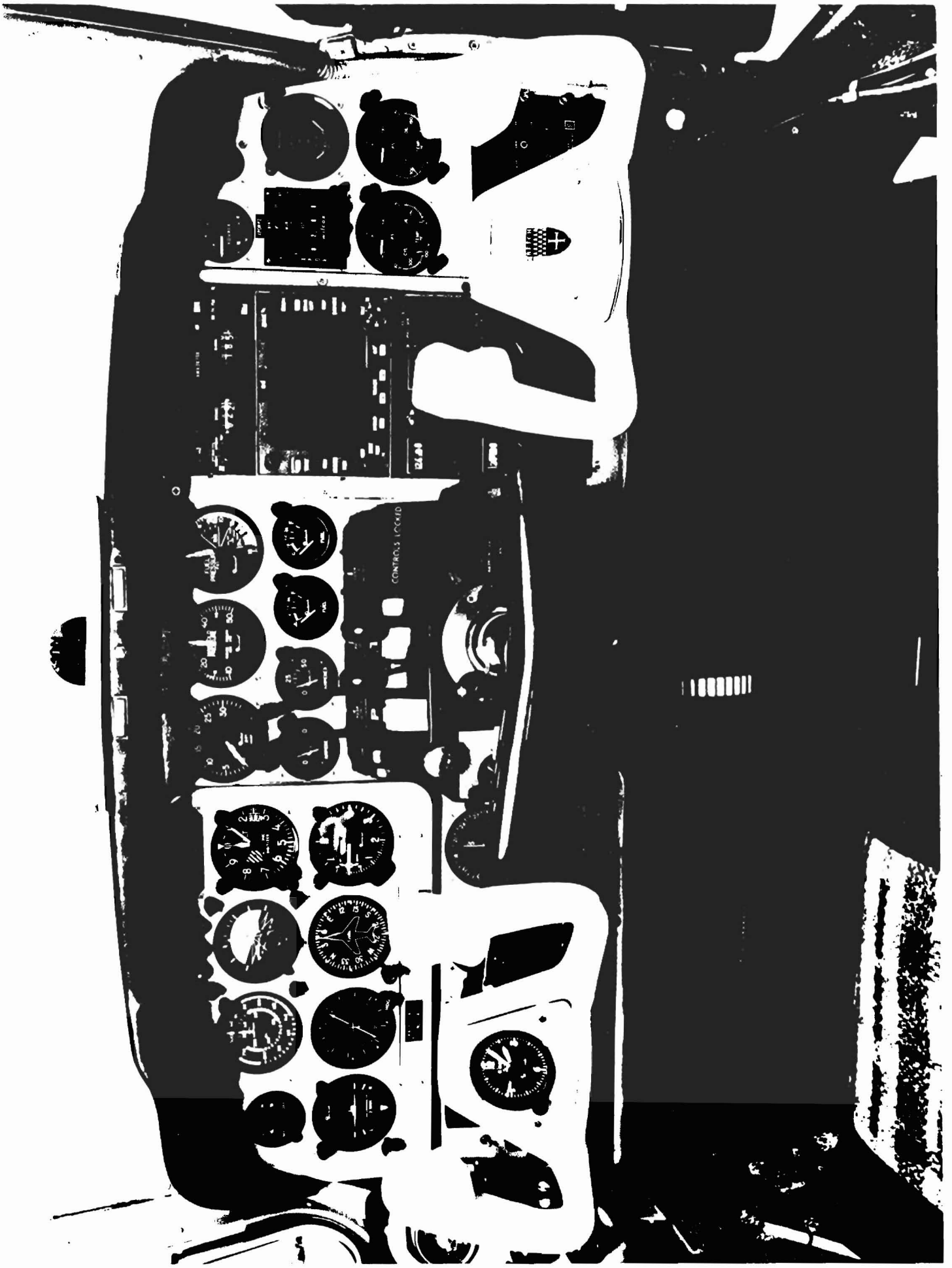
The data base construction section describes the data base structure and the process of data entry and validation.

Finally, the entire data collection procedure is summarized.

AIRBORNE INSTRUMENTATION.

A Bendix weather radar color display was adapted to display the TAS and RAS information. A detailed explanation of the display design is found in Reference 8 by Lincoln Laboratory. The display was installed in the right instrument panel (Figure 4) of a BE-55 Beech Baron (Figure 5). The Mode S transponder, display, power supply and logic units were installed in the rear seat area of the BE-55. The screen of the display was located approximately 45 degrees from the pilot's line of sight in the horizontal plane and approximately 10 degrees down in the vertical plane. Although some peripheral information from the display may be available to the pilot while scanning other instruments, bringing the display into the optimal visual zone (30 degree cone, see Reference 10) required the pilot to turn his head. Insofar as the display is not a primary flight instrument, this limitation is not critical. However, notice that because of its location, there may be occasions when auditory signals would help alert the pilot to upcoming traffic information.

The display itself subtends a visual angle of approximately 7 degrees (maximum) which is typical for this kind of aircraft (see Table 4).



SUBJECT AIRCRAFT COCKPIT WITH DISPLAY - FIGURE 4

SUBJECT AIRCRAFT - FIGURE 5

TABLE 4 - COCKPIT DISPLAY SPECIFICATIONS

Aircraft Type	Yoke to Screen	Eye to Screen	Eye to Panel	Size & Type	Tilt	Screen Location	Crew Size VFR	Crew Size IFR
Test A/C Beech 55	20"	28"	22"	5 sq in Bendix	No	Right Panel	1	2
Boeing 727	20"	38"	32"	"	Yes	Center Console	3	3
Cessna 402	16"	29"	24"	"	Yes	Right Panel	1	2
Convair 580	21"	34"	36"	"	Yes	Right Panel	2	2

Since the fovea, the region of the eye with highest visual acuity, subtends an angle of approximately 2 degrees (Reference 11) eye movements are necessary in order to bring regions of the display into foveal vision. These movements will necessarily be saccadic (Reference 12). Approximately four saccades can be executed per second and it takes approximately 0.1 to 0.2 seconds exposure to establish maximal acuity (Reference 13). Given an update rate of 4.7 seconds on the display, there will be adequate time between updates for information extraction and integration. The threshold of acuity is approximately 1/60 of a degree for the normal observer (Reference 14). This is the visual angle subtended by an object of 0.05 inches at a distance of 15 feet. Obviously, the graphical symbology and alpha-numerics of the display are well above threshold. In terms of contrast sensitivity, the modulation transfer function estimates of square wave spatial frequencies at levels that approximate the display show a maximum between 2 and 10 cycles/degree (Reference 15). This is close to the stroke-width values of the display, and consequently suggests that the display, if not optimal, is quite adequate.

The above description of the human factors characteristics of the display allows only a coarse evaluation of its human engineering properties. In particular, the nature of the dynamic interaction of the display with the pilots scan of flight instruments and visual scene cannot be adequately

assessed from the available information. For example, it has been shown (Reference 16) that pilots do not read all instruments in equal detail. This becomes evident when oculographic data are examined which show different distributions of glance times for different instruments during simulated flight. It is important to know at what level of detail the display is read. Much of the detailed information on the traffic symbol is probably ignored by the pilot whose main interest is focused on monitoring the developing encounter at a higher cognitive and perceptual level and checking for the presence of the resolution advisory, or formulating his own.

BIOGRAPHICAL DATA.

Confidential biographical data were obtained from each subject pilot. The biographical profile of a typical subject pilot is presented here.

Each selected subject pilot was given a background information questionnaire to complete. The supplied information was examined for completeness. If any item was found incomplete, the form was returned to the pilot for clarification.

The information solicited by the biographical data form includes the following:

- o Aviation certification history
- o Different aircraft experience
- o Pilot-in-Command hours
- o Simulator experience

Throughout the test program pilots were identified by code letters only, thereby guaranteeing confidentiality of the information.

The 12 pilots that were chosen for the test reflect a broad range of age, education, and experience. Their ages ranged from 30 to 60 with an average age of 37.4 years. The level of education spanned from high school graduation to two year post-baccalaureate degrees with a mean of 4.1 years post high school. The number of years since receipt of first pilot's license ranged from 5 to 39 with an average of 12.5

years from original licensure. The total number of hours flown ranged from 300 to 11,800 with an average of 2016.6 hours per pilot. Of these hours, 20 to 5,500 were in multi-engine aircraft.

GROUND SCHOOL TRAINING.

The training of the subject pilots consisted of two parts: self-study by the pilot of the Pilot's Manual, and a ground school training session.

One week before the scheduled ground school, each subject pilot was given a copy of a 32-page Pilot's Manual for self-study. The pilots' knowledge of the automatic advisory service was tested by examinations, given at the beginning and at the end of the ground school training session which ran from 8:30 AM to 11:50 AM on October 17, 1980.

During the ground school, the advisory service was explained and the test flight program was discussed. The pilots were especially instructed not to discuss their opinions of the service with one another. The pilots were not told how to use the automatic advisory service information, but were told to use the information they deemed appropriate during test flight encounters.

The ground school exam scores were used to pair the subject pilots so that two pilots with similar scores would be scheduled to fly the same sequence of six flight patterns,

alternating the order of morning/afternoon flights. Table 5 shows the average test scores for the pilot pairs. Two of the six pairs of pilots were not grouped according to score because of late changes or replacement. Pilot pair C-L differed in their scores by 5 points because Pilot L was a replacement for a pilot who dropped out of the test series. Pilot pair A-I were "leftovers" from the original pairing process.

TABLE 5 - GROUND TRAINING TEST SCORES

Pilot Pairs	Test Scores
C - L	11.5 - 16.5
B - K	12.0 - 12.0
D - F	12.5 - 13.5
A - I	14.0 - 19.0
E - G	16.0 - 15.0
H - J	17.5 - 17.5

FLIGHT DATA COLLECTION.

The successful execution of flight tests depended upon the weather and the test equipment. A total of 72 flights (12 pilots flying 6 flights each) was successfully concluded from November 14, 1980 to May 13, 1981. During these flights a total of 424 encounters were achieved. The collected data were contained in written forms and system data extraction tapes. In this section the test execution will be summarized. The forms which were used to gather manual data will be described.

TEST FLIGHTS. The major factors which could prevent a scheduled test flight from being carried out were weather and equipment conditions. Therefore, shortly before each flight a final confirmation was obtained on the visual meteorological conditions and the operational status of various equipment components. After these items were determined to be satisfactory, the subject pilot, safety pilot, and observers were briefed on the flight pattern, altitude, and flight procedures. The subject pilot was given a preflight exam, and the observer started to complete the flight log. The pilots and observers then boarded the aircraft, and the flight coordinator took his position at the communications site (called Mode S Control), where he handled communications between the aircraft and the Mode S sensor. The aircraft taxied, reported ATC assigned aircraft identification numbers, and the flight began. As soon as the

subject aircraft reached a straight and level course, the observer completed the flight log. During each encounter in the flight, the observer completed an encounter log. After each encounter, the subject pilot was asked a series of questions concerning the conflict situation just completed, and the answers were recorded on the encounter debriefing form. After the flight was finished, the subject pilot completed a flight debriefing form.

FLIGHT SUMMARY. The test sequence consisted of 77 scheduled flights. Five of these flights encountered problems with either equipment malfunctions or weather changes which resulted in a decision to abort the flight. The 72 successful test flights occurred from November 18, 1980 to May 13, 1981, half of the flights being in the mornings and the other half in the afternoons. Each flight had at least two encounters. Sixty-one (82 percent) of the flights had five to seven encounters. A total of 424 encounters were achieved. Among them, 327 were planned encounters which involved only the subject aircraft and the predesignated intruder aircraft flying the planned encounter geometries. There were 32 multiple aircraft encounters which involved non-project aircraft. The remaining 65 encounters were unplanned encounters involving either non-project aircraft, or the predesignated intruder flying on unplanned encounter geometries. The distribution of all encounter types was as follows:

94 (22%) - Head-on encounters

181 (43%) - Lateral Encounters

149 (35%) - Tail-chase encounters

MANUAL DATA FORMS. Five forms were used to collect manual flight data (Data Collection Forms, Appendix B). These were the preflight exam, flight log, encounter log, encounter debriefing, and flight debriefing. The data from these separate forms were linked by the subject pilot code letter

and the number of the pilot's flight (1 - 6).

Preflight Exam. The preflight exam, consisting of nine questions concerning the automatic advisory service display, was given to the subject pilot during the preflight briefing in order to test his recollection of the display symbology.

Flight Log. The flight log was completed by the observer to describe the test conditions of the flight, including:

- o The identification codes of the safety pilot, intruder pilot, and observers
- o The types of aircraft used
- o The weather conditions
- o The departure time
- o The time when the aircraft first reached a straight and level course.

These data were either provided to the observer by the appropriate technical personnel (e.g. in the case of weather information), or were obtained by him directly from instrumentation on-board the subject aircraft. The information contained in the flight log made it possible to subsequently categorize the data base by such features as pilot, flight number, and visibility.

Encounter Log. The observer completed the encounter log to describe the conditions and events of each encounter. This log contained the following information:

- o Flight log
- o Turbulence at the beginning of the encounter
- o Type of encounter (i.e. head-on, lateral encounter, or tail-chase)
- o Type of advisories received from the automatic advisory service
- o Evasive action taken by the subject pilot in response to the conflict situation and the advisories
- o Observer's ratings of various aspects of the conflict management by the subject pilot such as altitude and course maintainance, instrument and external scans, maneuver coordination, airspeed control, fuel management and workload.

Encounter Debriefing. Immediately after each encounter the observer asked the subject pilot a series of questions, and completed an encounter debriefing. The twelve questions asked concerned the pilot's opinions about the automatic advisory service for the encounter. The answers were collected on-board the aircraft while the subject pilot's impressions of the encounter were still fresh.

Flight Debriefing. At the end of the flight when the subject pilot could reflect on his overall experience, he completed a flight debriefing form. This form contained twenty-five questions in different response formats. The data thus collected was comprised of:

- The ratings of the utility of the general aspects and individual components of the automatic advisory service display
- The evaluation of the relative merits of the advisory services (TAS and RAS)
- The description of the attitude toward and the utilization of the automatic advisory service
- The evaluation of the overall system quality of the service

SYSTEM DATA EXTRACTION. Magnetic tapes were used to record system data at the Mode S sensor. The extracted data contained:

- Time and scan number
- Surveillance reports
- Tracked aircraft positions and velocities
- Traffic and resolution advisory messages sent to the subject aircraft.

For most of the flights, coverage was provided by the Mode S sensor at Clementon, New Jersey. In order to reduce the system load, the regular 60 nautical mile radius coverage

area was reduced to a wedge extending from the 90 degree azimuth to the 210 degree azimuth. This wedge-shaped area did not include the traffic in and around the Philadelphia terminal control area (TCA). There were a few instances when some system problems hampered the operation of the Clementon site. In these cases, the Technical Center site was used to cover the test flights.

DATA PROCESSING.

Before being entered in the data base, the biographical data, ground school exam results and manual flight data were all quantified. The system data tapes were processed to extract the aircraft conflict information and the surveillance reports of all the involved aircraft from which the closest point of approach (CPA) was calculated for each encounter. Finally, the flight data and system extracted data were correlated so that all the system data pertaining to test encounters were collected.

MANUAL DATA QUANTIFICATION. The data obtained manually in the biographical questionnaire, ground school exam and the flight manual data forms were quantified and entered into the data base. Most of the data required very little preparation. For example, the temperature, wind velocity, and rating scales could be entered directly into the data base. The multiple-choice questions and yes or no questions produced results which could also be readily stored. However, the answers to an "open-ended" question had to be classified into 21 basic categories before they could be entered into the data base.

SYSTEM DATA EXTRACTION TAPES. The system data extraction tapes contained the surveillance reports of all aircraft in the Mode S sensor coverage area as well as the automatic

advisory service data of those aircraft in potential conflict. To determine the identity of the aircraft involved in the encounters, a correlating process was performed. This was done by examining two sources of corroborating information:

- o Plots of aircraft positions and the automatic advisories from the data tapes.
- o Listings of possible intruder aircraft from the data tapes.

For most of the flights a ground observer sitting in front of the plan position indicator (PPI) screen at the Mode S site monitored the flight and recorded significant events in progress, such as the identification of the aircraft in conflict, the encounter time and scan numbers, the automatic advisory contents and the system data extraction tape numbers.

The plots of known aircraft positions and listings of relative range and bearing of the intruder were all prepared from the system data tapes. These visual representations were then compared with the manual data of the observer's logs. Usually this simple process of correlation was sufficient to identify the intruder aircraft which was involved in a single encounter. However, during an encounter a non-project aircraft might be in the immediate area, and cause an unplanned or multiple encounter. For the unplanned and multiple encounters an exhaustive search for all

aircraft was accomplished by comparing plots and printouts of all relevant tracks.

After all of the aircraft involved in an encounter were discovered and verified by these correlation efforts, actual CPA and predicted CPA data were calculated. The actual CPA is the minimum distance between the subject and intruder aircraft during the encounter. The predicted CPA is the minimum miss distance which was projected by the automatic advisory service tracker function during an encounter.

DATA BASE CONSTRUCTION.

In this section the data base structure is described. The data were entered and validated in the data base and software was developed to allow retrieval of the data for data reduction and analysis.

DATA BASE STRUCTURE. The data base is comprised of four distinct files: biographical file, ground school exam file, flight data file, and text file. These files were all linked by subject pilot code numbers. The data of the flight data file and the text file were chronologically ordered. The basic record of the flight data file was the information for an individual encounter which was derived from the following six sources:

- o Form 1 Preflight exam
- o Form 2 Flight log
- o Form 3 Flight debriefing
- o Form 4 Encounter log
- o Form 5 Encounter debriefing
- o Form 6 System extraction data tapes

All the encounters of a single flight have the same data in the first three forms. The data format of each file is briefly described as follows.

Biographical File. The biographical file contained the background data for all 12 subject pilots. The data for each pilot were coded in a single 80-column card.

Ground School Exam File. The ground school exam file contained the scores of each of the two exams taken by each of the 12 subject pilots. One score is missing because one pilot missed the second exam.

Flight Data File. The flight data file contained the data for all 424 flight encounters. Each encounter had six forms. The first five forms of the manual flight data were coded in a fixed length data block containing twenty-four 72-column lines. The system data for each encounter had variable length and contained the CPA information (predicted CPA, and actual vertical CPA), followed by a block of surveillance and automatic advisory service data during the entire encounter.

Text File. The text file contained all the pilot comments made at the end of each flight. These comments were classified into 21 distinct statements, and the statement numbers were used to code the comments in the data base.

After the data were entered, the data base was validated.

SUMMARY

The test execution and data collection provided a comprehensive data base. The entire data collection effort is summarized in Figure 3. The biographical information, ground school exams, and manual flight data were coded and entered into the data base. The system flight data extraction tapes were processed to produce flight path plots and position listings, from which the aircraft involved in the encounter were identified and confirmed by correlation with the manual flight data, then the relevant system data were extracted and entered in the data base. Before any analysis was performed, the data base was subjected to a thorough validation.

DATA REDUCTION AND ANALYSIS

INTRODUCTION.

The data analysis is divided into five major sections.

- o Dependence of Data on Test Conditions
- o Pilot Utility Assessment of the Advisory Service
- o Pilot Acceptance of the Advisory Service
- o Use of the Advisory Service
- o Characteristics of the Training Program

The first section addresses whether or not the data are significantly affected by either the test design parameters, or those factors outside of strict control.

The second section examines the pilots' ratings of the utility of the displayed information, and their comments regarding the information level of the system. Particular attention is devoted to ranking of the ratings, and the effect of the number of experiences with the automatic advisory service in stabilizing those rankings.

The third section examines evidence of pilot satisfaction and acceptance based upon responses contained in the post-flight debriefing and the encounter debriefing. Overall ratings of the advisory service and of the display, along with indices of satisfaction constructed from post-encounter questions, are used to determine the level of satisfaction and the ways in which that level is influenced by increasing

experience with the system, and by the different types of encounters which occur.

In the fourth section pilot behavior and performance are discussed. Data on visual acquisition are examined with respect to encounter type and the level of experience with the service. Pilot maneuvers are examined with respect to the different levels of compliance with the Resolution Advisory Service (RAS), predicted risk, encounter type, level of experience, and the performance in maximizing the separation between aircraft.

The last section provides an analysis of the methods used to train the pilots in the use of the system. Exams are used to assess the relative effects of a self-study manual, a ground school training session, and knowledge gained from actual flight experience with the system.

DEPENDENCE OF DATA ON TEST CONDITIONS.

Within the data analysis section, pilot's global ratings of the display and of the service are used to determine levels of pilot satisfaction with the automatic advisory service. In addition, a combined index of pilot satisfaction is constructed using a weighted sum of responses to encounter debriefing questions and the two global ratings. In using information from these data to form conclusions, it is important to determine the degree to which the data are influenced by the test conditions.

The test conditions considered were the factors built into the design of the test program (the individual flight patterns, the sequences in which the flight patterns were flown, and the distribution of morning/afternoon flights), and those that were outside of strict control (cloud ceiling, range of visibility, and type of cloud cover). The two global ratings, the combined index of pilot satisfaction, and five questions from the flight debriefing (question numbers 3, 20, 21, 23, and 24) were tested against these conditions using trend analysis, analyses of variance, t-tests, and contingency tables.

There were three possible dependencies seen in the analysis; 1. the global rating of the display showed a significant degree of variation with flight pattern sequence, 2. there was a slight tendency for the pilots to express greater confidence in the resolution advisories (question 23 of the

flight debriefing) when the cloud ceiling was lower, and 3. both the global ratings and the combined index of satisfaction showed a tendency to increase as the sky became more overcast. The latter two tendencies were apparent upon inspection of the data, but were not statistically significant below the 10 percent level. On the other hand, the variation in global display rating resulting from pattern sequence, while statistically significant ($F= 4.65$; $P< 0.05$), is more likely to reflect differences between the pilot pairs flying the different pattern sequences than differences in the flight pattern sequences themselves. This apparent dependency was, therefore, discounted as a random event.

This general lack of significant dependencies indicates that the counter-balancing design (latin square) used was successful in eliminating systematic data dependencies, and the meteorological limitations imposed on the flights were sufficient to avoid major random dependencies.

In addition, all of the encounters were subject to the following three constraints:

1. No vertical rate or maneuvering encounters were flown.
2. No planned multiple aircraft encounters were flown (32 unplanned multiples occured).
3. The intruder aircraft were not equipped with the automatic advisory service.

The test results may have been different had these constraints not been in effect.

PILOT UTILITY ASSESSMENT OF THE ADVISORY SERVICE.

INTRODUCTION. In the course of the post-flight debriefings, the subject pilots rated the utility of 11 distinct features of the display. All ratings were made on a ten-point scale, ranging from the lowest rating of 0 to the highest value of 9. Pilots' ratings of the displayed data were examined to determine what information was used by them to manage midair encounters during the flight test program. The analysis is divided into the following four subsections.

- o Ranking of Pilots' Ratings of Displayed Data
- o Variability of the Ratings
- o Stability of Displayed Data Rankings with Flight Number
- o Information Level

In the first subsection the displayed data are ranked in order of their average rating by the pilots. This ranking provides an assessment of the relative worth of the various information components of the display.

In the second subsection an analysis of variance is performed to determine the major sources of variability in the pilots' ratings. The factors "Pilot," "Flight Number," "Displayed Data," and the two-factor interactions between these are examined.

In the third subsection the displayed data ratings are ranked for every flight number in order to determine how much experience is necessary to stabilize pilot opinion of

the relative value of displayed data.

In the last subsection the answers to two different questions, soliciting essentially the same information, are used to determine whether the level of displayed information was insufficient or superfluous. Also, pilots' responses to the "open-ended" question asking for comments and suggestions are examined to determine which specific features of the display they did or did not like.

RANKING OF PILOTS' RATINGS OF DISPLAYED DATA. Questions 6 through 16 on the post-flight debriefing asked the pilots to "Rate (0-9) each component of the traffic advisory service in terms of how useful it is to you in managing an encounter situation?" It was explained to the pilots that 9 was the highest rating and 0 was the lowest. Table 6 shows the means of the ratings for each of the displayed data over all 72 test flights, with the displayed data listed in the order of their mean rated preference.

TABLE 6 - RANKING OF ADVISORY SERVICE DISPLAYED DATA

DISPLAYED DATA	NUMBER OF DATA POINTS	MISSING DATA	MEAN RATING
Relative Altitude	72	0	8.5
Basic Traffic Position("+" Symbol)	72	0	7.5
Relative Motion Line	72	0	7.1
Range Ring	72	0	7.0
Point of Closest Approach	72	0	6.9
Resolution Command	72	0	6.8
Vertical Speed	64	8	6.4
Traffic Course Track	72	0	6.4
Out-of-Range Traffic ("Δ" Symbol)	43	29	5.8
Turn Status	70	2	5.3
Own Aircraft Course Track	72	0	5.1

It is apparent from these ratings that the most popular displayed data are those that give basic information regarding the position and relative motion of the intruder. The rating of Vertical Speed information may have been different if vertical rate encounters had been part of the test, however, all encounters flown were essentially in the horizontal plane. The rating of the Out-of-Range Traffic data was omitted from most of the statistical analyses described below because of its large number of missing values. The pilots often omitted rating this feature because it rarely occurred.

VARIABILITY OF THE RATINGS. The raw ratings of the remaining 10 displayed data (after the omission of Out-of-Range Traffic data) were put through a repeated-measures analysis of variance. Since only 10 of the 720 possible scores were missing, the usual strictures regarding imbalance in repeated-measures designs may be waived. Because the score sample involves ratings of 10 displayed data, made by 12 pilots, over 6 flights per pilot, the primary sources of variability examined are "Displayed Data," "Flight Number," and "Pilot." Variances resulting from either of the first two factors are systematic, due to the designs of the automatic advisory service and the flight test program, while variance resulting from "Pilot" is random due to the random nature of subject pilot selection. It is found that these three primary factors and their two-factor interactions account for 75 percent of the variability in the ratings, the remaining 25 percent being attributable to residual error resulting from unidentified sources. As the layout of the analysis is moderately complex, it is convenient to present the results in a summary table. Table 7 gives the values of mean-squared error resulting from each factor, the F-ratio describing the significance of each factor, and the P-value describing the probability of the result occurring by chance. Since variance resulting from the interaction of a systematic factor and a random factor is itself random, the sources of variance involving the factor "Pilot" are all considered random.

TABLE 2 - SOURCES OF VARIABILITY IN DISPLAYED DATA RATINGS

SOURCE OF VARIANCE	DF	MN SQ	F RATIO	P-VALUE	SIGNIFICANT
DISPLAYED DATA (S)	9	70.62	6.86	<0.0001	YES
FLIGHT NUMBER (S)	5	3.36	0.91	0.50	NO
PILOT (R)	11	64.69	33.35	<0.0001	YES
DATA*FLIGHT (S)	45	1.97	1.01	0.45	NO
PILOT*DATA (R)	99	10.30	5.31	<0.0001	YES
PILOT*FLIGHT (R)	55	3.71	1.91	<0.0002	YES
RESIDUAL ERROR (R)	485	1.94	----	----	---

DF= Degrees of freedom F= F distribution P= Probability
(S) - Systematic (R) - Random

The estimated mean-square for "Pilot" is high, as would be expected from a truly random sample. The mean-squared error for "Pilot*Data" is large indicating a significant degree of variation among the pilots in the rating order of their preferences for the individual displayed data, which in turn contributes to the estimated mean-square of the factor "Displayed Data." When tested against "Pilot*Data," however, the variability unique to "Displayed Data" is highly reliable statistically (F= 6.86; DF= 9,99; P<0.0001). This high variability attributable to "Displayed Data" indicates that pilots are making wide ranging and variable discriminations in their assessments of the value of the automatic advisory service. Aside from the random variance components for "Pilot," "Pilot*Flight," and "Pilot*Data,"

(all of which are significant), the main effect of "Displayed Data" is the only systematic variation in these data.

The absence of any main effect of "Flight Number," or of the interaction "Data*Flight," is more interesting. The failure of "Displayed Data" to interact with "Flight Number" indicates that the preference profiles are consistent across "Flight Number." There is no evidence of any consistent tendency for data that were initially rated highly to decrease in rating dramatically, or for initially unpopular data to advance greatly in rating as experience increases. Figure 6 presents the mean ratings for the data, averaged over successive blocks of two flights, and shows that no displayed data gained or lost more than one rating point.

The lack of interaction between "Displayed Data" and "Flight Number" also shows that an observed absence of any trend in the combined means of all 11 displayed data ratings is believable. The combined means of all 11 ratings for the six flight numbers are, in order: 6.4, 6.6, 6.5, 7.0, 6.5, and 6.6.

KEY

Flight Numbers 1 & 2

Flight Numbers 3 & 4

Flight Numbers 5 & 6

a. Own Aircraft Course Track
b. Turn Status
c. Point of Closest Approach
d. Range Ring
e. Relative Motion Line
f. Resolution Command
g. Traffic Course Track
h. Vertical Speed
i. Basic Traffic Symbol (+)
j. Relative Altitude

(BLOCKS OF TWO FLIGHT NUMBERS)

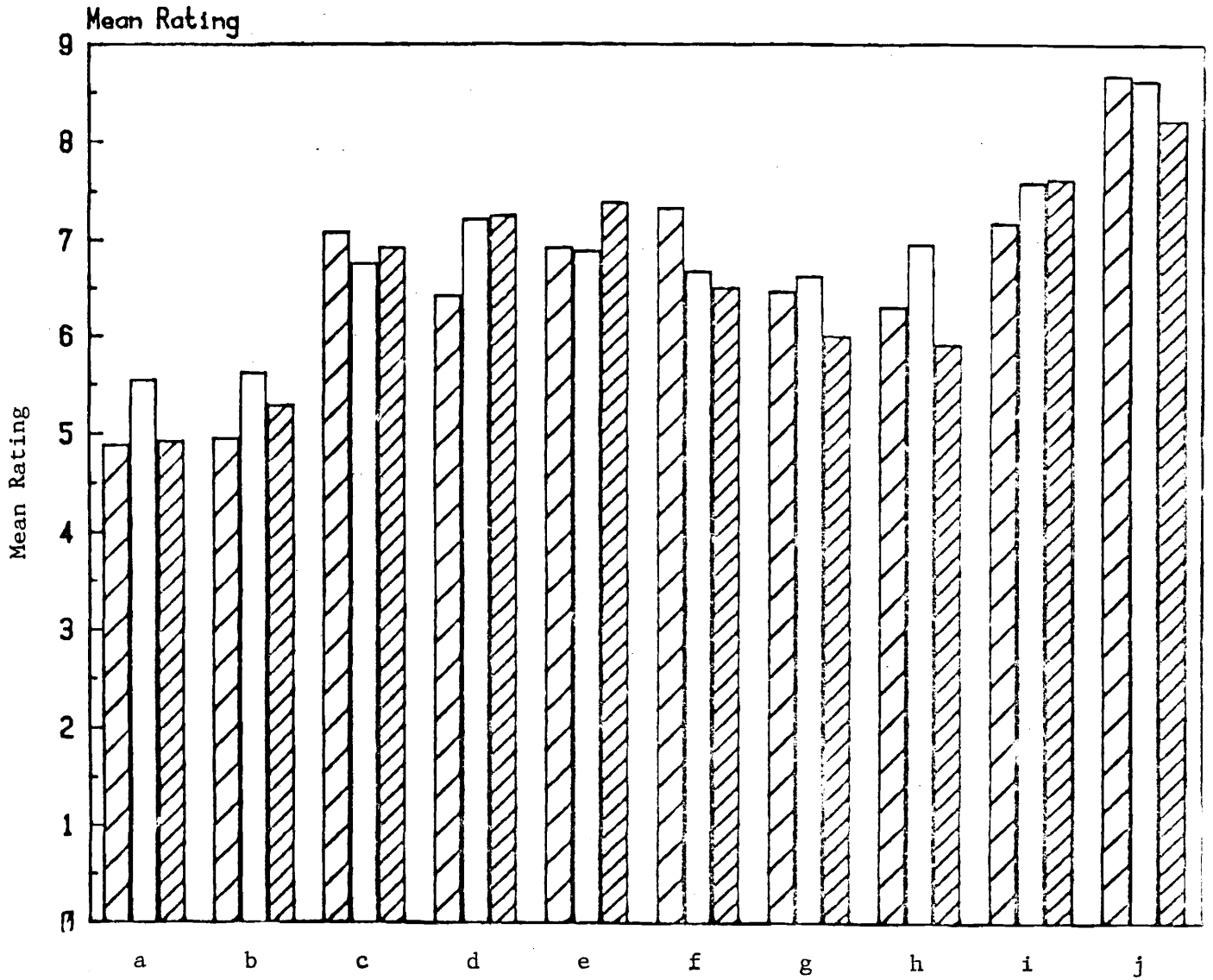


FIGURE 6 - RATINGS OF DISPLAYED DATA

STABILITY OF DISPLAYED DATA RANKINGS WITH FLIGHT NUMBER. The stability of the rating profiles was examined by converting the mean ratings for each flight number to ranks. Table 8 exhibits the rankings for the six flight numbers.

TABLE 8 - RANKING OF DISPLAYED DATA BY FLIGHT NUMBER

	FLIGHT NUMBER						
DISPLAYED DATA	1	2	3	4	5	6	SUM
Relative Altitude	10	10	10	10	10	10	60
Basic Traffic Position	5.5*	9	9	9	9	9	50.5
Relative Motion Line	8	5.5	4	7	8	8	40.5
Range Ring	3	5.5	8	8	7	7	38.5
Resolution Command	9	8	6	4	5	5	37
Point of Closest Approach	7	7	3	6	6	6	35
Traffic Course Track	5.5	4	7	3	4	4	27.5
Vertical Speed	4	3	5	5	3	3	23
Turn Status	1	2	1	2	2	2	10
Own Aircraft Course Track	2	1	2	1	1	1	8

* The value 5.5 indicates a tie.

A glance across the top rows of Table 8 shows that the displayed data that pilots consistently found most useful pertain to basic information regarding the location and relative motion of the intruder. An interesting characteristic of these data is the decline in the relative ranking of the RAS feature, "Resolution Command," which started out as one of the most highly ranked data and

steadily fell to fifth place in the rankings. Most of the other displayed data rankings were relatively stable.

To investigate the stability of the rankings, the Kendall coefficient of concordance, "W" (Reference 17), was computed. For the six flight numbers, that coefficient equals 0.82. The most straightforward way to interpret this descriptive statistic is to convert it into an average of rank-order correlations among flight numbers. There are 15 possible pairings among the flight numbers: 1 with 2 through 6; 2 with 3 through 6, and so on. The result above implies that the mean rank-order correlation for all 15 pairings would be 0.78, indicating a fair amount of stability across all of the flight numbers.

As mentioned before, no trend is seen in the magnitude of the combined means of all 11 ratings for each flight number, but there is an obvious effect of time upon the stability of the rankings. The columns of Table 8 that correspond to the first three flight numbers exhibit fluctations, whereas by flight number four, the rankings are virtually "set in concrete." For the first three flight numbers as a unit, the concordance coefficient W is 0.79, implying an average correlation of 0.68 for the three possible pairings. For the last three, W is 0.98, and the average correlation among flight numbers 4 through 6 is 0.97. This stability suggests that four flights with the advisory service are sufficient to stabilize pilots' attitudes toward the various displayed

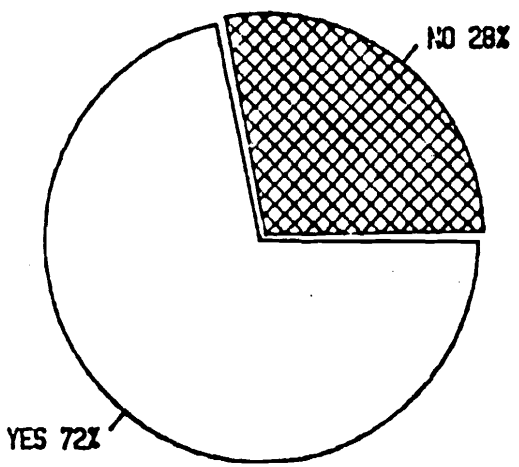
data.

INFORMATION LEVEL. One of the most striking results of the post-flight debriefing was the lop-sided majority of responses to a particular question which was, in effect, asked twice. When pilots were asked "Would any additional traffic advisory information be useful to you in deciding what or what not to do?" 86 percent of the responses were NO. There was an apparent, but not statistically significant, tendency for negative answers to become less prevalent as the pilots gained experience with the system. When the question was put in the form: "Was there unnecessary information displayed?" the overall response was constant at 72 percent YES (see Figure 7) without specification as to the unnecessary elements. The bottom rows of Table 8 provide some guidance as to what information is seen by the subject pilots as unneeded.

In order to determine what features the pilots specifically did not like, the frequencies of the responses to question 27 of the flight debriefing ("Can you suggest any mods or improvements in the display?") were examined. The subject pilots answered this question in text form, and the comments were extracted and classified into 21 distinct statements. The frequencies of the comments are given in Table 9.

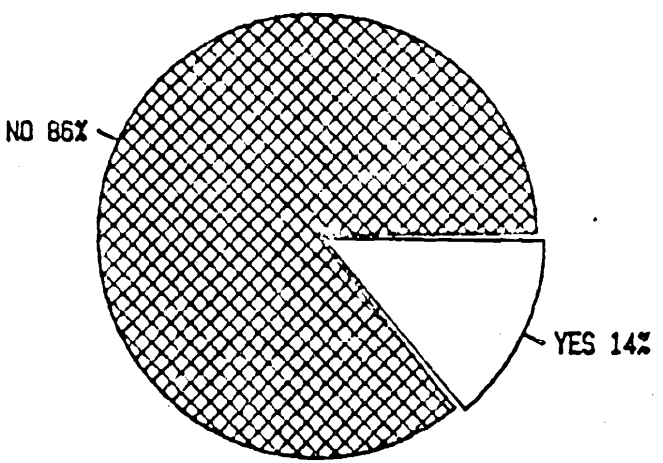
QUESTION 5:

WAS THERE UNNECESSARY INFORMATION DISPLAYED?



QUESTION 4:

WOULD ANY ADDITIONAL TRAFFIC ADVISORY INFORMATION BE USEFUL TO YOU IN DECIDING WHAT OR WHAT NOT TO DO?



PILOT OPINION ON INFORMATION LEVEL

FIGURE 7

TABLE 9 - FREQUENCY OF PILOT COMMENTS

	COMMENTS	Number of Flights Comment Was Made	Number of Pilots Who Made Comment
01	REMOVE THE TIC MARKS	3	2
02	REDUCE THE INTRUDER SYMBOL TO THE BASIC "+"	21	10
03	SOMETIMES THERE IS TOO MUCH CLUTTER	16	10
04	MOVE THE SCREEN CLOSER TO THE PILOT	8	5
05	ENLARGE THE SCREEN	4	2
06	MAKE THE SCREEN SUNLIGHT READABLE	10	7
07	THE THREAT SHOULD BE RED	5	2
08	THERE SHOULD BE AN AUDIO SIGNAL TO ALERT THE PILOT OF A PROX	12	6
09	THE "X" AT THE END OF THE POINT OF CLOSEST APPROACH SHOULD BE A DIFFERENT SYMBOL	2	2
10	I RECIEVED A LATE ADVISORY THIS FLIGHT	1	1
11	THERE IS TOO MUCH INFORMATION IN TOO SMALL OF AN AREA	2	2
12	THE "+" "-" TO DENOTE VERTICAL DIRECTION WAS GOOD	2	2
13	THE ADVISORY AREA SHOULD BE INCREASED	3	3
14	THERE WAS A LOT OF OVERLAPPING	4	3
15	THE OUT-OF-RANGE SYMBOL NEEDS TO BE USED MORE OFTEN	1	1
16	A TIME FILTER ON TAIL CHASES WOULD HELP ALOT	1	1
17	I RECIEVED A BAD COMMAND THIS FLIGHT	4	3
18	I WOULD LIKE TO SEE ATARS OPERATE IN A BUSY AREA	2	2
19	THERE SHOULD BE A COUNT DOWN TO TIME OF CLOSEST APPROACH	4	3
20	THE THREAT SHOULD BE FLASHING	2	1
21	NO COMMENTS	16	10

Some of the figures in the column "Number of Flights Comment was Made" may seem artificially high due to individual pilots repeating a single comment on a number of flights, therefore a second column "Number of Pilots who Made Comment" was included.

Looking at the comments that were made by more than three pilots narrows down the list to five major items (comment numbers 02, 03, 04, 06, and 08). Most of the pilots (83 percent) made negative comments concerning the information regarding control and equipage of the intruder aircraft which augmented the basic traffic symbol (a "+") and the "clutter" associated with the encounters that were close enough for the symbols to overlap. Additionally, 50 percent of the pilots indicated that there should be an audible signal of some kind to alert the pilot of a proximate advisory.

Other comments were directed toward problems in reading the display in direct sunlight and the position of the display. Comment number 17, "I received a bad command...," was examined separately. It was found that in 3 of the 4 cases, the resolution advisory provided to the pilot was safe and appropriate, but the subject pilot was not satisfied. The fourth comment was in response to a bad command caused by a three aircraft encounter. Since the RAS used in these tests was not designed to handle multiple aircraft encounters, this was a limitation and not a failure of the RAS logic. No

statistically significant impact on results by these 4 cases was observed.

SUMMARY. In the course of the post-flight debriefings, the subject pilots rated the utility of 11 kinds of displayed data. All ratings were made on a ten-point scale, ranging from the lowest rating of 0 to the highest value of 9. Pilots' ratings of the displayed data were examined to determine what information they found useful in managing midair encounters during the flight test program. The analysis was divided into four main subsections.

- o Rankings of Pilots' Ratings of Displayed Data
- o Variability of the Ratings
- o Stability of Displayed Data Rankings with Flight Number
- o Information Level

The first three subsections examined the rankings, variability, and time-stability of the ratings. The general results are that the subject pilots showed the most appreciation for the basic elements of the TAS which give information about the position and relative motion of the intruder. The RAS was initially one of the most highly ranked features but declined steadily to fifth place in the post-hoc rankings by the fifth flight experience, indicating a distinct preference for the TAS features over the RAS. Differences between the displayed data and those between the individual pilots themselves were the major sources of

variability in the ratings. The preference profiles for the displayed data were basically independent of the level of experience with the advisory service. Although the rankings showed some change through time, they were virtually fixed by the fourth flight experience. This provides some evidence that four flight experiences with the service is sufficient to stabilize pilots' working attitudes toward displayed information.

Using two different question formats, the pilots were asked about the level of displayed information. The overwhelming majority of responses indicated that too much information was displayed and that no crucial information was lacking. Had multiple or vertical encounters been included in the test scenarios, the pilots may have needed and wanted more of the displayed information.

Pilots, responding to an "open-ended" question asking for suggestions and comments, expressed a desire for a reduction of the traffic symbol to its basic form (a "+") and for a reduction in the amount of clutter. Additionally, 50 percent of the pilots indicated that there should be an audible signal of some kind to alert the pilot of a proximate advisory.

PILOT ACCEPTANCE OF THE ADVISORY SERVICE.

INTRODUCTION. The post-flight debriefings and the debriefings that took place in the cockpit subsequent to each encounter contain information that bears on the central issue of how highly the pilots regarded the service. The analyses of these data on satisfaction and acceptance are divided into the following subsections.

- o Flight Debriefing
- o Encounter Debriefing
- o Combined Index of Pilot Satisfaction
- o Encounter Type and Satisfaction

In the first subsection, global ratings of the display (e.g. size, legibility, and color; called R1) and of the automatic advisory service (TAS and RAS) as a whole (R2) contained on the flight debriefing are examined to determine the level of satisfaction expressed after each flight. Differences between these two global ratings and their dependence on the number of flights with the advisory service are examined.

In the second subsection, responses to four questions from the encounter debriefing are added for each encounter in a particular flight and averaged over all of the encounters in that flight to create an index of satisfaction (S1) that is based on encounter debriefings. The characteristics of this index are examined with respect to level of response and the way in which that level changes with the number of experiences.

In the third subsection a combined index of pilot satisfaction (S2) is formed from both the global ratings R1 and R2, and the encounter-based satisfaction index S1. The S2 index is analyzed as a function of level of experience with the advisory service, and is also compared with the preflight exam scores to identify to what degree any change is attributable to increasing familiarity with the system.

In the fourth subsection, responses to the four questions that were used to construct S1 are averaged over individual encounters to construct a per-encounter index of satisfaction (S3). This S3 index is examined as a function of encounter type (Head-on (HO), Lateral encounter (LE), and Tail-chase (TC)) to determine whether or not the position of the intruder relative to the subject aircraft influences the pilot's satisfaction with the advisory service.

FLIGHT DEBRIEFING. The post-flight debriefings asked for ratings of the display (question 25) and of the advisory service as a whole (question 26). Over the 72 test flights both global ratings, (called R1 and R2 respectively), ranged from a minimum of 3 to a maximum of 9. The average ratings for both were quite high: the grand mean for R1 was 7.06, with a standard error of 0.17, and for R2 these statistics were 7.72 and 0.14. For ease of presentation, the time-course of these global ratings is given in Table 10 broken down by blocks of two successive flight numbers. Each of these means is based on 24 observations, hence they are somewhat more stable than the means for individual flights.

TABLE 10 - MEAN GLOBAL RATINGS OF THE SERVICE AND THE DISPLAY

BLOCKS OF TWO SUCCESSIVE FLIGHT NUMBERS

	FIRST	MIDDLE	LAST	ALL 6
DISPLAY (R1)	6.67	7.08	7.42	7.06
SERVICE (R2)	7.29	7.83	8.04	7.72

All of the above means are satisfactorily high and the tendency of both sets of means to increase is statistically reliable. A repeated-measures analysis of variance of these data yielded a residual mean-square for error of 0.52, on 55 DF. The difference between the grand mean for R1 and that for R2, though slight in magnitude, was highly significant statistically ($F= 9.6$; $DF= 1,11$; $P= 0.01$). The uptrend for both ratings across the six flights was also statistically

significant (F= 2.91; DF= 5,55; P= 0.02). The interaction between type of rating and flight number did not approach statistical significance (F < 1), indicating that the growth curves as a function of flight number were essentially parallel for the two ratings. The observed trend in means averaged over both ratings was monotonic as shown in Table 11, indicating that satisfaction with both aspects of the system increased constantly.

TABLE 11 - AVERAGE MEANS FOR GLOBAL RATINGS AS A FUNCTION OF FLIGHT NUMBER

	1	2	3	4	5	6
(R1+R2)/2	6.75	7.21	7.33	7.58	7.71	7.75

ENCOUNTER DEBRIEFING. Data obtained from the debriefing that occurred after every encounter contain additional information bearing upon pilot satisfaction. In constructing an encounter-based index of satisfaction, (called S1), the following four questions were seen as most relevant.

Question 5	Did the display light up in time?
Question 6	Did the threat advisory occur too early or too late?
Question 7	Did you find [the TAS and RAS] useful in avoiding traffic?
Question 15	Would you rather have the [TAS and RAS] advisories or traffic controller advisories? Both?

These four questions were chosen on the basis of their content validity. In particular, an answer to any of them that denoted disfavor toward the service would point to some genuine problem. The possible answers "No, the display was tardy in appearing," or "No, the service was no help at all," provide ample opportunity to ventilate dissatisfaction with the system.

The S1 index was constructed using a weighted sum of responses to the four questions. Table 12 shows the weighting used.

TABLE 12 - WEIGHTING OF THE ENCOUNTER-BASED INDEX OF SATISFACTION, S1

QUESTION NUMBER	RESPONSE WEIGHTING	
	SATISFACTORY= 2	UNSATISFACTORY= -1
5	Yes= 2	No= -1
6	OK= 2	Late/Early= -1
7	Yes= 2	No= -1
15	The service or Both= 2	ATC alone= -1

For each encounter, these values were summed across the four questions. The sum was then averaged over the encounters that occurred during the flight, and that average was stored in each flight record as variable S1.

Before presenting summary data on S1, it might be well to exhibit concretely what the discrete values of its constituent sums represent. Table 13 shows the meanings of the total "score" for an encounter (disregarding the rare missing value).

TABLE 13 - MEANINGS OF THE SUMS OF THE ENCOUNTER DEBRIEFING QUESTIONS

SCORE	MEANING
8	All four satisfactory, no unsatisfactory
5	Three satisfactory, one unsatisfactory
2	Two satisfactory, two unsatisfactory
-1	One satisfactory, three unsatisfactory
-4	All four unsatisfactory

Table 14 presents summary statistics for S1.

TABLE 14 - SUMMARY STATISTICS FOR THE ENCOUNTER-BASED INDEX OF SATISFACTION, S1

FLIGHT	N	MIN	MAX	MEAN	STD ERR
1	12	1.7	8	5.55	0.58
2	12	3.2	8	6.06	0.45
3	12	2.8	8	6.11	0.47
4	12	5.6	8	7.32	0.24
5	12	5.8	8	7.32	0.24
6	12	5.3	8	7.08	0.26

Table 14 exhibits characteristics that are common to these data and the mean global ratings in Table 10 (R1 and R2). As before, there is an uptrend across flight numbers, which flattens out around the fourth flight. This provides more evidence that four flights is sufficient to stabilize pilot opinion of the advisory service.

A glance at the maxima and minima reveals another common characteristic: the improvement over time stems primarily from the elimination of unfavorable reactions. On the first flight, the individual who is least enamored of the advisory service emits an average of just over two unsatisfactory responses per encounter (score of +1.7). By the fourth flight no pilot averages as much as one unsatisfactory response per encounter (all scores exceed 5). Thus the general uptrend seen consists primarily of the truncation of the lower tail of the distribution of responses, as dissatisfactions are eliminated. On all flight numbers, the maximal observed score is the highest attainable, and the distributions per flight number tend to concentrate at the high end in the latter stages of the flight test program.

COMBINED INDEX OF PILOT SATISFACTION. A combined index of pilot satisfaction (called S2) was formed from a scaled sum of the global rating of the display R1, the global rating of the advisory service R2, and the satisfaction index based on the encounter debriefing S1. The R2 index, owing to its smaller variability and the nature of its content, received a weight of 2. The S2 index has been scaled to a ceiling of 100. Table 15 exhibits the descriptive statistics for this index.

TABLE 15 - SUMMARY STATISTICS FOR THE COMBINED INDEX OF PILOT SATISFACTION, S2

FLIGHT	N	MIN	MAX	MEAN	STD ERR
1	12	33	98	75.1	5.2
2	12	47	99	79.5	4.1
3	12	65	99	81.5	2.7
4	12	69	100	86.8	2.6
5	12	76	99	87.2	2.0
6	12	66	100	87.5	2.9

As before, a consistent and statistically reliable uptrend is seen ($F= 4.42$; $DF= 5,55$; $P= 0.002$), which reaches an asymptote of around 87 percent at the fourth flight number, implying that pilot opinion has stabilized by the fourth flight experience with the advisory service.

The results from the preflight exam show a similar uptrend which can be attributed to increasing familiarization with

the advisory service. Table 16 shows means for each flight number with a maximum attainable score of 18.

TABLE 16 - MEAN SCORES OF PREFLIGHT EXAM FOR EACH FLIGHT NUMBER

FLIGHT NUMBER					
1	2	3	4	5	6
15.7	15.8	16.7	17.1	17.2	17.1

Obviously, no great interpretive weight can be placed upon a trend such as this which, although statistically reliable ($F= 2.54$; $DF= 5,54$; $P< 0.05$), shows such a limited dynamic range. The upper limit, about 17 (again, reached by flight number 4), reflects less than one error per flight in the nine aspects of the advisory sevice which the exam explores. The slight progress seen in these mean scores probably stems solely from the elimination of the few pilot errors that were seen initially. The Pearson product-moment correlation between the exam scores and S2 is 0.58 which implies that about one-third (0.58 squared) of the variation in satisfaction is associated with increasing familiarity with the advisory service, insofar as that familiarity is reflected in the scores of the preflight exam.

ENCOUNTER TYPE AND SATISFACTION. Of the 424 recorded encounters, 94 were classified as Head-on (HO), 181 as Lateral (LE), and 149 as Tail-chase (TC). The responses to the encounter debriefing form are now examined as a function of encounter type. The discussion focuses on the four questions which were the constituents of the encounter-based index of satisfaction S1.

Question 5	Did the display light up in time?
Question 6	Did the threat advisory occur too early or too late?
Question 7	Did you find [the TAS and RAS] useful in avoiding traffic?
Question 15	Would you rather have the [TAS and RAS] advisories or traffic controller advisories? Both?

Tables 17 - 20 show the responses to these questions broken down into the three encounter types. The column "TOTAL" shows the number of encounters in that encounter type for which the question was answered. The numbers in the two columns for the responses to the question are percentages of that total number. Thus, the entries in the first row of Table 17 signify that answers to Question 5 of the encounter debriefing were recorded on a total of 89 HO encounters. Of these 89 answers 13.5 percent (i.e. 12) were NO, and the remaining 86.5 percent were YES. Data in the second and third rows have the same structure for LE and TC encounters.

TABLE 17 - RESPONSE TO QUESTION 5 (DISPLAY TIMING) AS A FUNCTION OF ENCOUNTER TYPE

	RESPONSE (% OF TOTAL)		
TYPE	NO	YES	TOTAL
HO	13.5	86.5	89
LE	6.6	93.4	169
TC	3.5	96.5	149

(CHI-SQUARE= 8.54; DF= 2; P< 0.02)

TABLE 18 - RESPONSE TO QUESTION 6 (ADVISORY TIMING) AS A FUNCTION OF ENCOUNTER TYPE

	RESPONSE (% OF TOTAL)		
TYPE	EARLY/LATE	OK	TOTAL
HO	23.6	76.4	89
LE	14.6	85.4	151
TC	11.3	88.7	133

(CHI-SQUARE= 6.34; DF= 2; P< 0.05)

TABLE 19 - RESPONSE TO QUESTION 7 (USEFULNESS OF THE SERVICE) AS A FUNCTION OF ENCOUNTER TYPE

	RESPONSE (% OF TOTAL)		
TYPE	NO	YES	TOTAL
HO	11.4	88.6	88
LE	9.6	90.4	167
TC	1.4	98.6	139

(CHI-SQUARE= 10.73; DF=2; P< 0.005)

TABLE 20 - RESPONSE TO QUESTION 15 (SERVICE VS. AIC) AS A FUNCTION OF ENCOUNTER TYPE

TYPE	AIC	SERVICE OR BOTH	TOTAL
HO	17.4	82.6	86
LE	7.5	92.5	159
TC	1.4	98.6	139

(CHI-SQUARE= 19.5; DF= 2; P< 0.0001)

The Pearson Chi-squared statistic that accompanies each table tests for the existence of a statistical relationship between encounter type (HO, LE, or TC) and the distribution of responses to the question. Responses to all four questions are significantly related to encounter type. The nature of the relationship is evident from inspection of the tables. The frequency of responses to each question which are unfavorable to the advisory service is never great, but

that frequency is invariably less for LE than for HO encounters, and still less for TC than for LE. In terms of favorable response, the encounter types are consistently ranked in the order tail-chase first, lateral second, and head-on third.

Since the ranking of encounter type in each of the four questions was so consistent, it was decided to combine the four questions into a single index (called S3) which would reflect satisfaction on a per-encounter basis. The S3 index was constructed using a weighted average of the responses to the four questions. Table 21 shows the weightings for the possible responses.

TABLE 21 - WEIGHTING OF THE PER-ENCOUNTER INDEX OF SATISFACTION, S3

QUESTION NUMBER	RESPONSE WEIGHTING	
	SATISFACTORY= 3	UNSATISFACTORY= -1
5	Yes= 3	No= -1
6	OK= 3	Late/Early= -1
7	Yes= 3	No= -1
15	The service or Both= 3	ATC alone= -1

These rescorings were averaged over all recorded answers to the four questions in every encounter. The resulting averages were multiplied by 4, and rounded, to scale all derived scores to range from -4 to 12. The obtained scores are interpreted in Table 22.

TABLE 22 - MEANINGS OF THE VALUES OF THE PER-ENCOUNTER INDEX OF SATISFACTION, S3

VALUE	MEANING
12	No unsatisfactory responses out of three or four questions
8	One unsatisfactory response out of four questions
7	One unsatisfactory response out of three questions
4	Two unsatisfactory responses out of four questions
1	Two unsatisfactory responses out of three questions
0	Three unsatisfactory responses out of four questions
-4	Four unsatisfactory responses out of four questions

The distribution of S3 was extremely skewed. The prevalence of the maximum possible score, 12, ranged from 70 percent in HO encounters to 89 percent in TC. Figure 8 presents an overview of these data. The caption "All OK" in the bar chart denotes an absence of unsatisfactory answers (i.e. the value of S3 is 12). All scores less than 12 have been grouped into the category "GRIPES." The approval score of the pilots concerning the advisory service is seen to be strongly dependent upon encounter type. The mean score of S3 for HO encounters was 9.5, rising to 10.5 for LE, and peaking at 11.4 for TC encounters. A conventional analysis of variance to test for differences among these means would be inappropriate, in the light of the extreme skewness of the data. A Kruskal-Wallis one-way analysis of variance, based on ranks, yielded an approximate Chi-squared statistic of 7.9, with 2 DF.

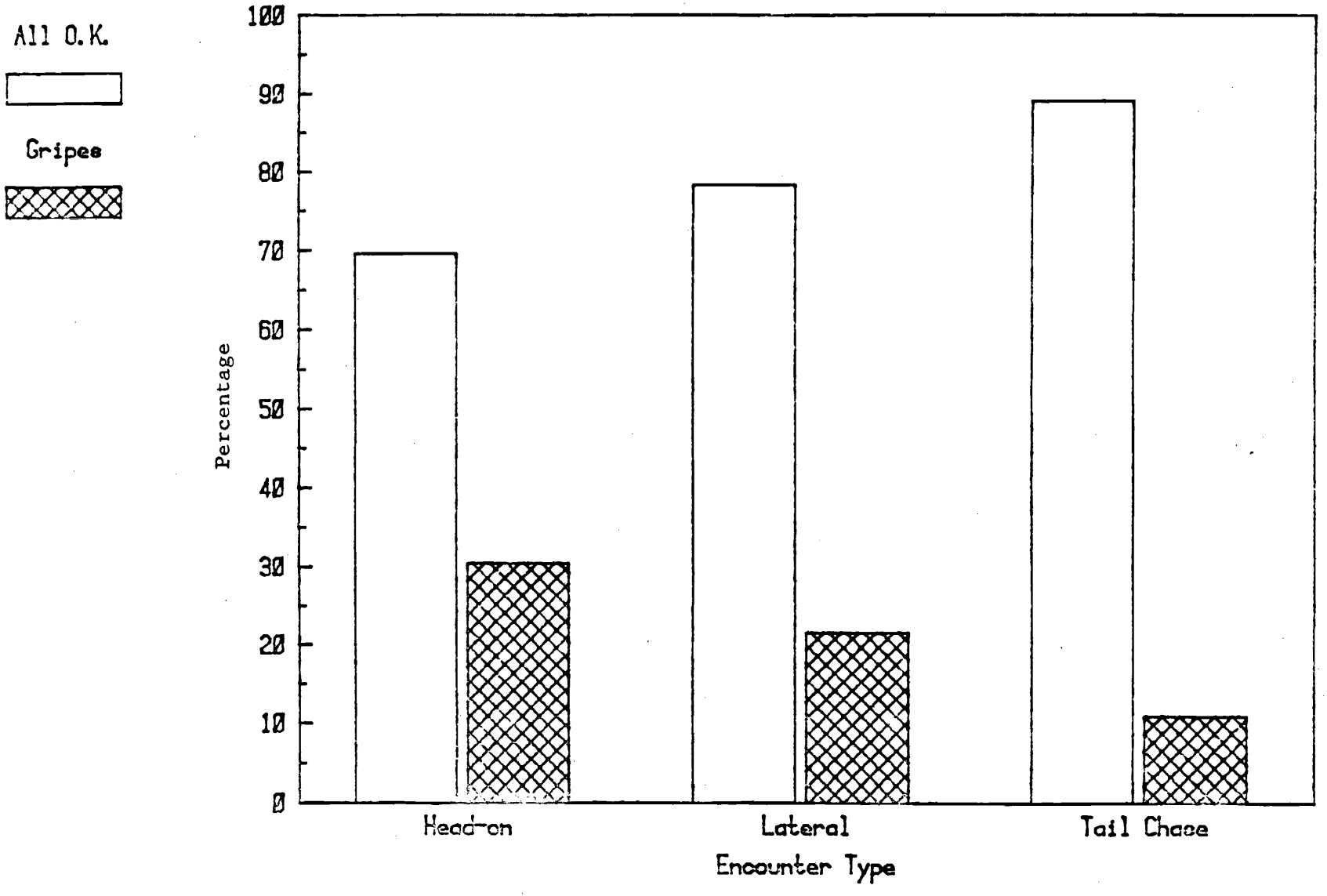


FIGURE 8 - PER-ENCOUNTER INDEX OF SATISFACTION, S3
AS A FUNCTION OF ENCOUNTER TYPE

The probability of a statistic this large arising by chance is less than 0.02.

From the strong dependence of satisfaction upon encounter type, it can be concluded that the advisory service is viewed by the pilot as being of most use when the intruder is unseen, as in the case of overtaking traffic.

SUMMARY. The post-flight debriefings and the debriefings that took place in the cockpit subsequent to each encounter contain information that bears on the central issue of how the pilots regarded the service. The analyses of these data on satisfaction and acceptance were divided into the following subsections.

- o Flight Debriefing
- o Encounter Debriefing
- o Combined Index of Pilot Satisfaction
- o Encounter Type and Satisfaction

In the first subsection, global ratings of the display (called R1) and of the advisory service as a whole (R2), were examined to determine the level of satisfaction expressed after each flight. In the second subsection, responses to four questions from the encounter debriefing were added for each encounter in a particular flight, and averaged over all of the encounters in that flight to create a per-flight index of satisfaction (S1) based upon encounter debriefings. Thirdly, a combined index of pilot satisfaction (S2) was formed from both the global ratings R1 and R2 and the encounter-based index of satisfaction S1.

There was a significant preference shown in the global ratings for the service as a whole over the display. Both the pilot's ratings and the constructed indices were quite high throughout all of the flights, but there was a marked uptrend which flattened out around the fourth flight. Correlating the combined index of pilot satisfaction with

the data from the preflight exam indicates that approximately one-third of the increase in pilot satisfaction is a result of increasing familiarity with the system.

In the fourth subsection, responses to the four encounter debriefing questions that were used to construct the per-flight index of satisfaction S1 were averaged over individual encounters to construct a per-encounter index of satisfaction (S3). When this S3 index was examined as a function of encounter type (Head-on (HO), Lateral encounter (LE), Tail-chase (TC)), it was seen that satisfaction is highest for the TC, lower for LE, and lowest for HO indicating that pilots regard the advisory service most highly when the intruder is least likely to be visible, and that they value the advisory service least when the intruder is most likely to be in sight.

USE OF THE ADVISORY SERVICE.

INTRODUCTION. Utilization of the automatic advisory service can be examined by looking at how well the advisories aid in visual acquisition, whether or not pilots follow the RAS, and whether or not compliance with the RAS increases the separation between aircraft. These analyses are divided into the following subsections.

- o Visual Acquisition
- o Pilot Response
- o Closest Point of Approach (CPA)
- o Distribution of CPA Data
- o Pilot Behavior as a Function of System Estimates of Risk

In the first subsection the time between the pilot's receipt of a first advisory and his achievement of visual contact is taken as an index of time to visual acquisition. This index is examined as a function of both the number of experiences with the advisory service and the encounter type. Additional analysis of visual acquisition in the tail-chase situation is presented because the advisory service (TAS and RAS) may have special value in situations where the intruder is unseen.

The second subsection examines statistics concerning maneuvers made by the subject pilots. The question of whether pilots differ in their propensities to maneuver is addressed and the frequency of maneuvers with respect to the

number of experiences with the advisory service is examined.

The data extraction tapes from the Mode S ground system were processed to obtain data on the closest point of approach (CPA) which is the minimum three-dimensional separation between the subject aircraft and the intruder during an encounter. In the third subsection the actual and system-predicted closest point of approach (aCPA and pCPA) are examined with respect to four defined pilot reactions to the RAS. For those encounters with aCPA's less than 1000 feet the individual horizontal and vertical components of the CPA are plotted with respect to each class of pilot reaction.

In the fourth subsection an examination of the aCPA data distribution shows a great degree of variability, positive skewness, and tail-heaviness (kurtosis) which renders it unsuitable for analysis by standard parametric methods. Though a variety of transformations fail to completely stabilize and normalize the variance, the transformation 10log(aCPA/pCPA) is chosen as a continuous estimator of performance. This performance estimator is examined as a function of maneuver type, number of experiences with the advisory service, latency (time to pilot's awareness of an advisory), and intensity of maneuver.

In the last subsection, pCPA's are categorically partitioned into classes of the system's estimate of risk, and the pilots' propensity to maneuver is examined with respect to

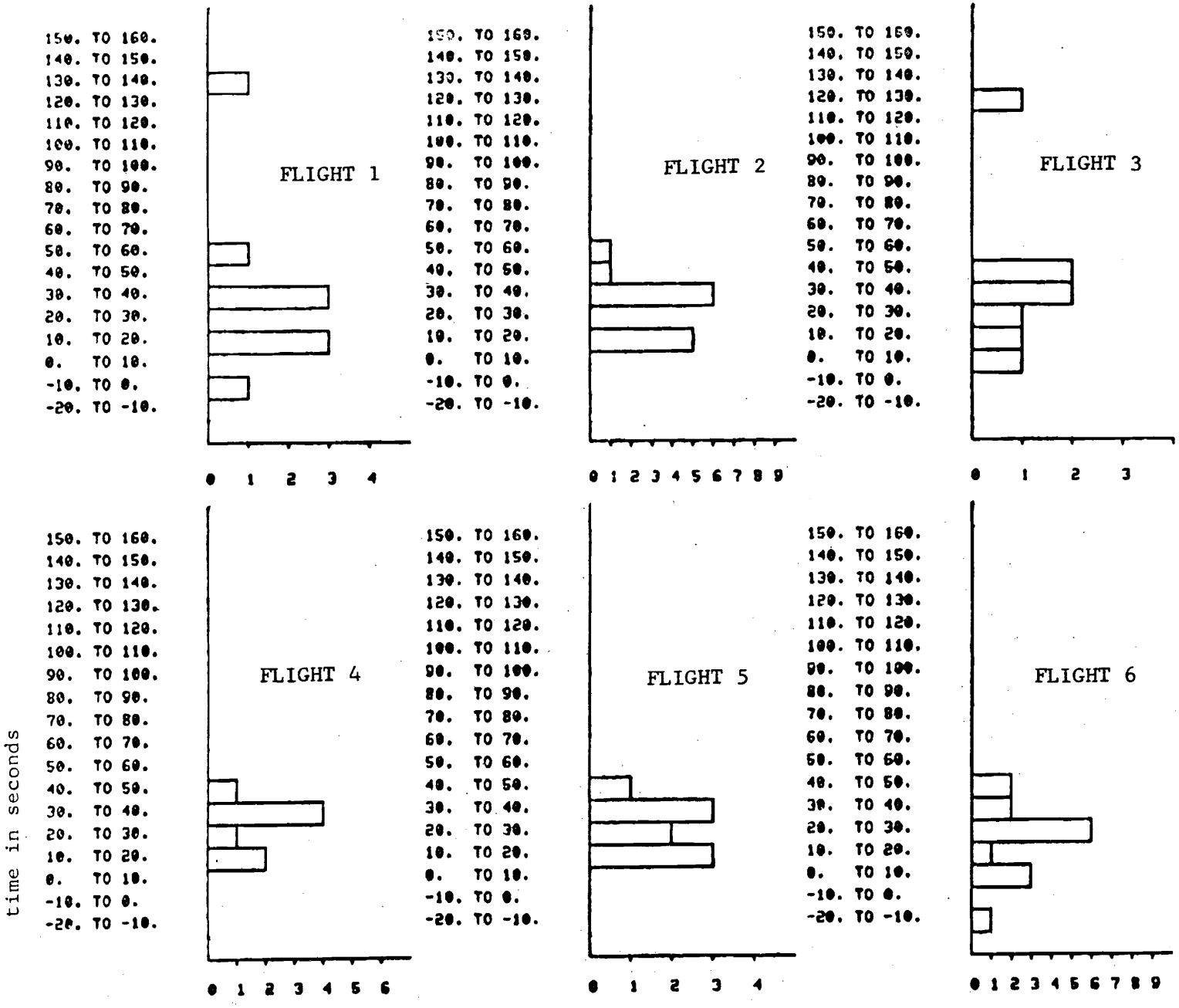
this categorical risk estimate and with respect to encounter type. Also, an analysis is presented of factors affecting outcome (defined as good if the aCPA exceeds the pCPA by 10 percent or more). The factors risk, maneuver, encounter type and their two-factor interactions are investigated to determine which most significantly influence a pilot's performance in achieving safe separation.

VISUAL ACQUISITION. One way to tell how well the pilots learn to use the display to help find traffic is to measure how soon after the first advisory they acquire visual contact and how this changes as they gain experience with the system. Table 23 shows the average time in seconds to visual acquisition for each flight number for head-on, lateral, and tail-chase encounters.

TABLE 23 - MEAN TIME (IN SECONDS) TO VISUAL ACQUISITION

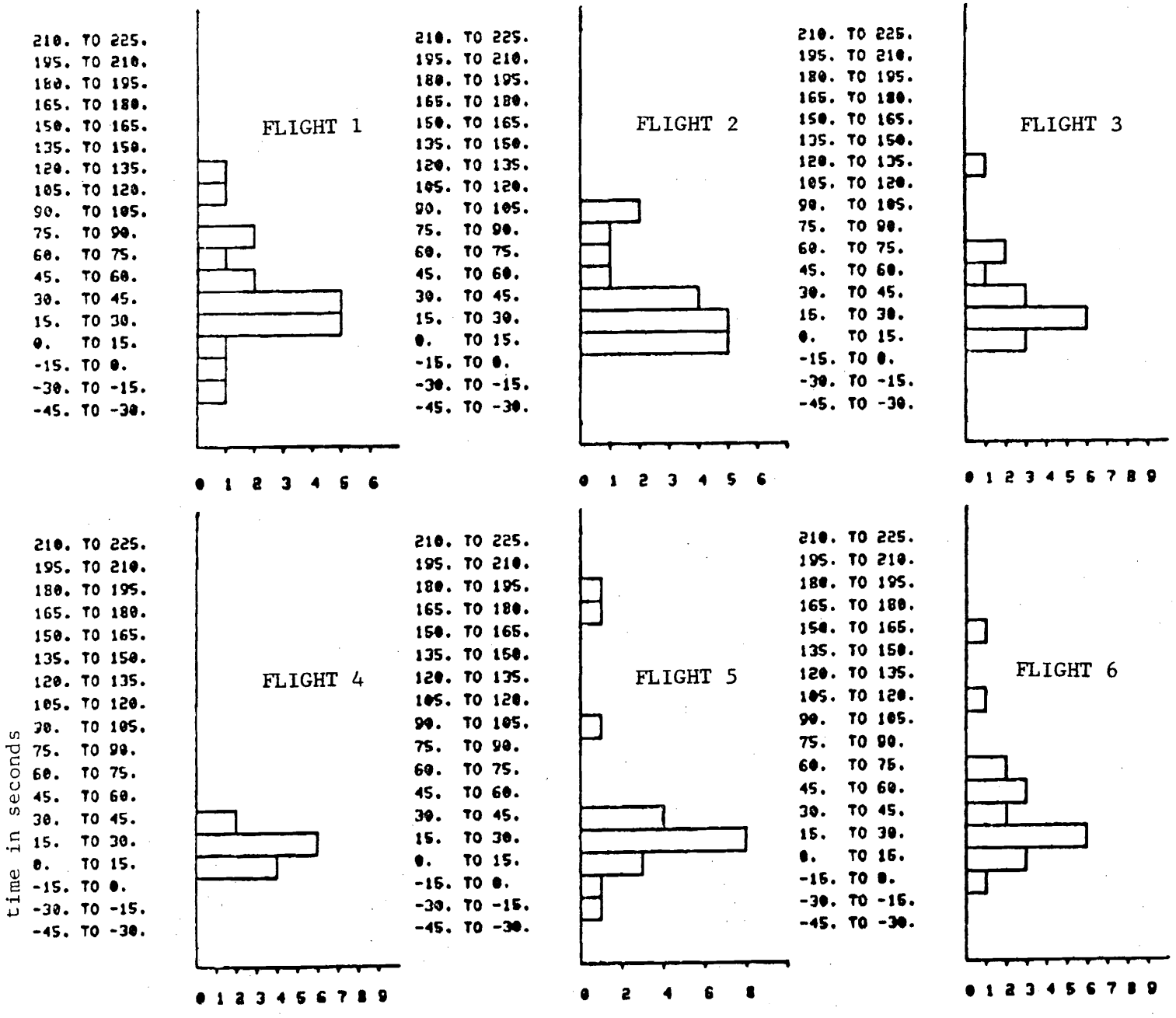
	FLIGHT NUMBER					
ENC. TYPE	1	2	3	4	5	6
Head-on (HO)	42	29	40	28	27	25
Lateral (LE)	46	33	34	20	36	43
Tail-chase (TC)	144	99	105	86	88	88

The expected learning curve pattern is seen in each case. The means (except for LE in flight number four) established their final levels by the fourth flight. Figures 9, 10, and 11 show the frequency distributions for each flight number per encounter type. Though the data for the last two flights in the LE category show an increase in the average time to visual acquisition, the frequency distribution in Figure 10 shows that the most common values were clustered around the 15 - 30 second range with two isolated cases each at the upper end of the scales which weight the averages upward.



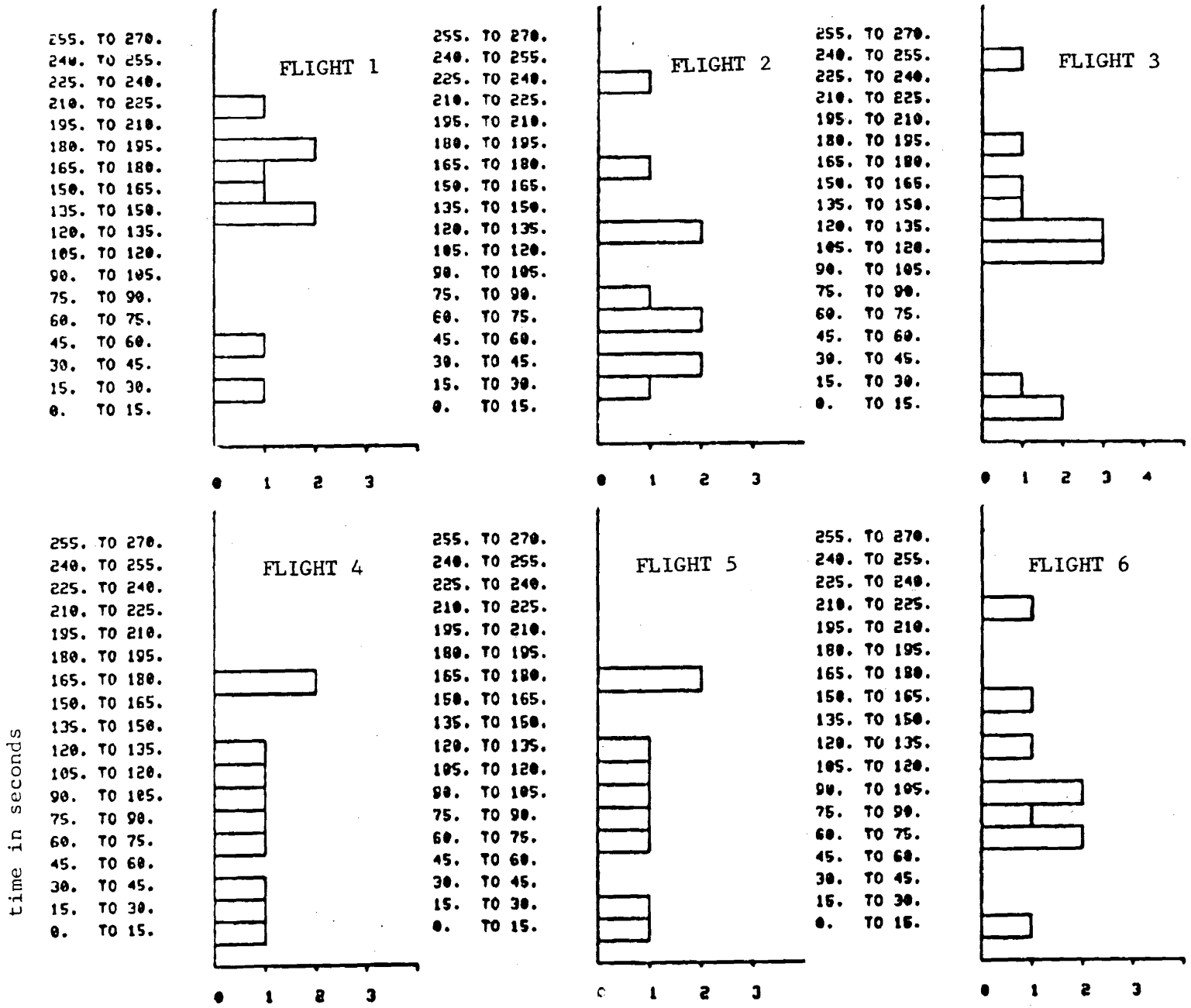
TIME TO VISUAL ACQUISITION, HEAD-ON

FIGURE 9



TIME TO VISUAL ACQUISITION, LATERAL ENCOUNTER

FIGURE 10



TIME TO VISUAL ACQUISITION, TAIL-CHASE

FIGURE 11

In addition it can be seen that flight number four in the LE category contains fewer data points than the other flight numbers for this encounter type (this appears to be a random occurrence). Visual acquisition was not achieved in all encounters; Table 24 shows the number of encounters per encounter type and flight number for which visual acquisition data does not exist.

TABLE 24 - NUMBER OF CASES WITHOUT VISUAL ACQUISITION

	FLIGHT NUMBER					
	1	2	3	4	5	6
Head-on	4/13	4/17	6/14	6/14	8/17	4/19
Lateral	8/28	11/30	16/32	15/27	18/37	7/25
Tail-chase	16/25	12/22	14/27	13/30	12/21	15/24

Entries are a/b where a is the number of cases without visual acquisition, and b is the total number of encounters in each encounter type and flight number.

The observed improvement in any measure of performance in visual acquisition (e.g. time to visual acquisition), by itself, cannot be construed as being caused by the presence of the advisory service since there are too few data on encounters without the service. For example, it could be that the subjects became more adept at spotting the intruder, or they spent more time looking outside of the cockpit. In particular, the examination of visual acquisition data for head-on and lateral encounters, although interesting, provides no conclusive information on the utility of the display. The data on tail-chase

encounters, however, are of special significance.

Since an aircraft coming up from behind is well outside of a pilot's field of vision, visual acquisition seldom occurs without the prompt of a traffic advisory. A detailed examination shows that visual acquisition occurs in 18 of the 45 tail-chase encounters that occurred in the last two flight numbers. Additionally, visual acquisition occurred in 11 cases before closest point of approach while the intruder was behind the subject. The range at which visual acquisition occurred varied from 640 feet to over 10,000 feet with 11 instances of visual acquisition at a range of over 2000 feet. These data strongly suggest that the advisory service did help the pilot to visually acquire intruding traffic in tail-chase encounters where the likelihood of visual acquisition without a traffic advisory is small.

PILOT RESPONSE. A prominent concern is to what extent the subject pilot maneuvers at any time during an encounter, and how this is influenced by the advisory service. Of the 424 encounters, 54 percent did not generate a maneuver as recorded by the observer. This suggests that visual acquisition generated confidence that the miss distance would exceed the pilot's maneuver threshold. An important first question is whether the pilots differ among themselves in terms of their propensity to maneuver. The answer is that there are marked significant differences among the pilots. The observed fraction of encounters on which an individual pilot maneuvered ranged from a minimum of 25 percent to a maximum of 75 percent. An eleven degree of freedom chi-squared test yielded a chi-square of 36.9, indicating a probability of 0.0001 that this amount of variation would randomly occur in a homogeneous pilot sample.

The tendency to maneuver can also be examined as a function of flight number, (i.e. the experience level of the pilots). The flight numbers are not homogeneous with respect to maneuvers. The observed tendency is for the prevalence of maneuvers to diminish through time. A five degree of freedom chi-squared test yielded 16.8 indicating a probability of 0.005 that the observed degree of decrease would randomly occur if the tendency to maneuver were independent of flight number.

The trend of decreasing propensity to maneuver is more

easily seen by combining the six flight numbers into three blocks of two flights each. Of the 135 encounters that occurred on the first two flight numbers, 58 percent resulted in maneuvers. This percentage dropped to 46 percent of 144 encounters in the second two flights, and to 35 percent of the 145 encounters that occurred in the last two flights.

A plausible interpretation of this decrease in propensity to maneuver, based on a multitude of studies of the psychology of novel experience, (References 18 & 19), suggests that during adaptation to this new system, the pilots were overly sensitive to display information, and tended to respond more frequently early in their experience.

CLOSEST POINT OF APPROACH (CPA). The purpose of the CPA analysis is to examine how the advisory service was used by the pilots in managing encounters. Input for the analysis is surveillance data which was recorded by the Mode S ground system and processed to compute the CPA's of the subject aircraft and the intruder aircraft for each encounter. Two kinds of CPA were extracted; the achieved CPA (aCPA) and the predicted CPA (pCPA). The aCPA is the actual minimum three-dimensional separation of the aircraft in conflict as determined from Mode S reports. The pCPA is the minimum value of the predicted three-dimensional miss distance during the encounter.

To examine the effect of compliance or non-compliance with the RAS on the aCPA, the data were partitioned into the following five mutually excusive and exhaustive categories:

1. Followed RAS. This is the case if each and every maneuver made by the pilot corresponds completely with each and every positive resolution advisory issued. If only negative advisories are issued, the pilot's lack of any maneuver is construed as complete compliance, as is "positivization" of the negative advisory (e.g. turning left in response to a "no right").

2. Differed from RAS. This is the case if the pilot maneuvers, but his maneuvers neither contradict nor completely follow the RAS.

3. Did Not Maneuver. This is the case if the pilot made no maneuver when positive advisories were issued.

4. Contradicted RAS. This is the case if any or all of the pilot's maneuvers contradicted any or all of the resolution advisories (e.g. a left turn when a "no left" or a "right" is issued).

5. No RAS. This is the case if no resolution advisory information was issued to the subject aircraft. This has no relevance to the ways in which pilots respond to resolution advisories, but is included here for the sake of completeness.

Figure 12 shows the average achieved minimum separation for each of the five cases of pilot reaction to advisories. Three values are given for each case: the average three-dimensional slant range, and its horizontal and vertical components at the aCPA. Notice that when pilots complied completely with the displayed resolution advisories, the average achieved minimum slant range was greater than 2000 feet and the minimum vertical separation was well over 400 feet. For cases of pilots not maneuvering or contradicting the resolution advisories, the average separations are consistently smaller with an average achieved minimum vertical separation of 318 feet for the latter case. The last columns illustrate that resolution advisories were indeed consistently issued when small separations were imminent.

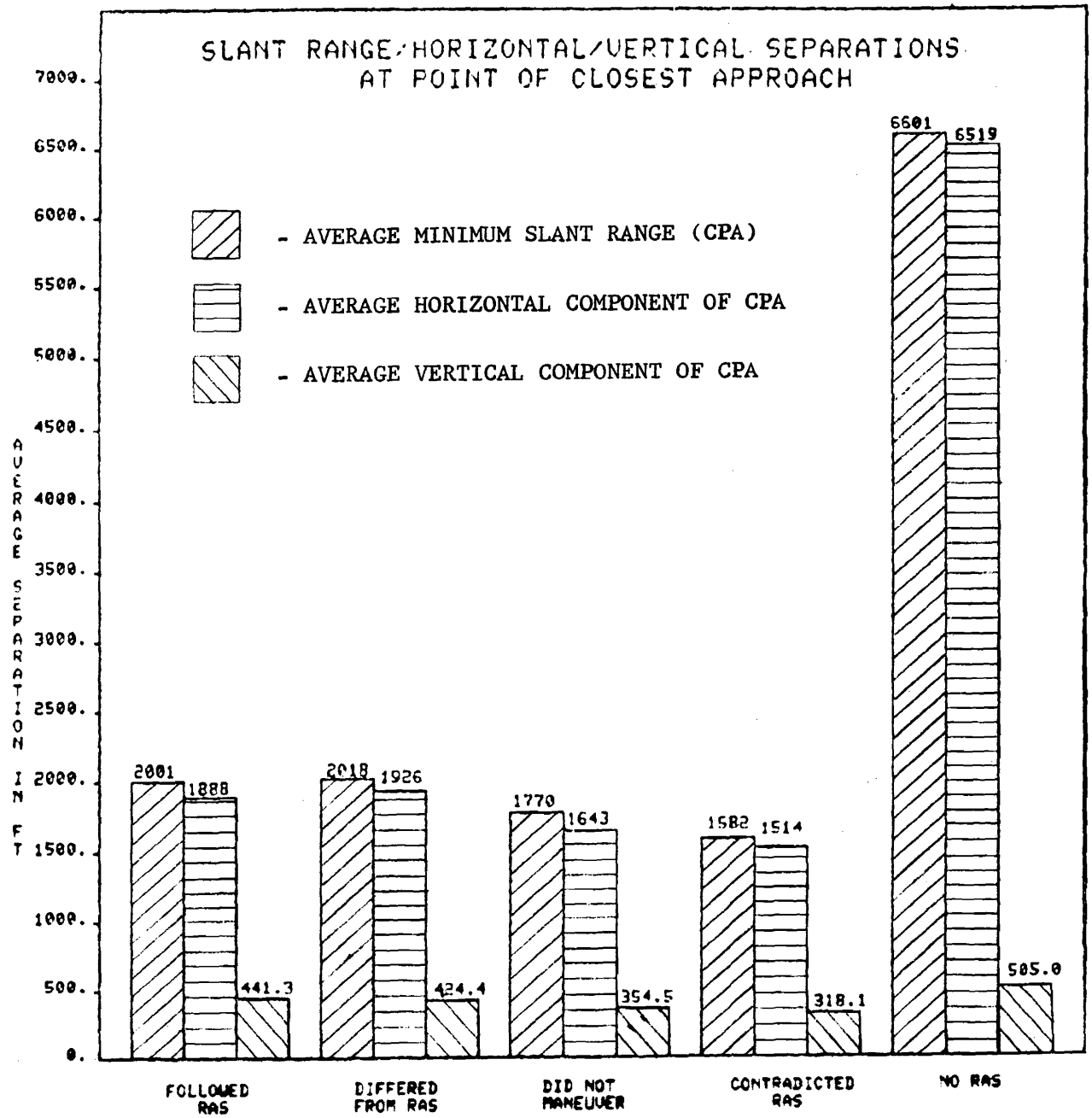


FIGURE 12 - MEAN OF MINIMUM ACHIEVED SEPARATION AS A FUNCTION OF COMPLIANCE WITH THE RAS

The encounters which had an aCPA of less than 1000 feet were subjected to an additional analysis. Figure 13 shows the vertical and horizontal separations for each case of pilot reaction to issued resolution advisories. In all those encounters during which the pilot complied completely with the RAS, the achieved vertical separation was at least 300 feet. In the remaining encounters, the achieved vertical separation was frequently less than 300 feet and in one case the aircraft were co-altitude.

There is a difference in the average absolute vertical separation between those cases when the intruder was above the subject aircraft (458 feet) and those cases when he was below (331 feet). A t-test between the cases above and those below shows that this difference is statistically significant ($P < 0.0001$). There was no such statistical difference in the mean minimum horizontal separations.

An examination into the reasons for this difference resulted in the non-experimentally verified but plausible hypothesis that the observed difference is attributable to one or more of the following factors:

1. When maneuvering for collision avoidance it is likely that aircraft descent rates exceed climb rates; hence achieved vertical separation at CPA is likely to be greater for maneuvers involving descents.

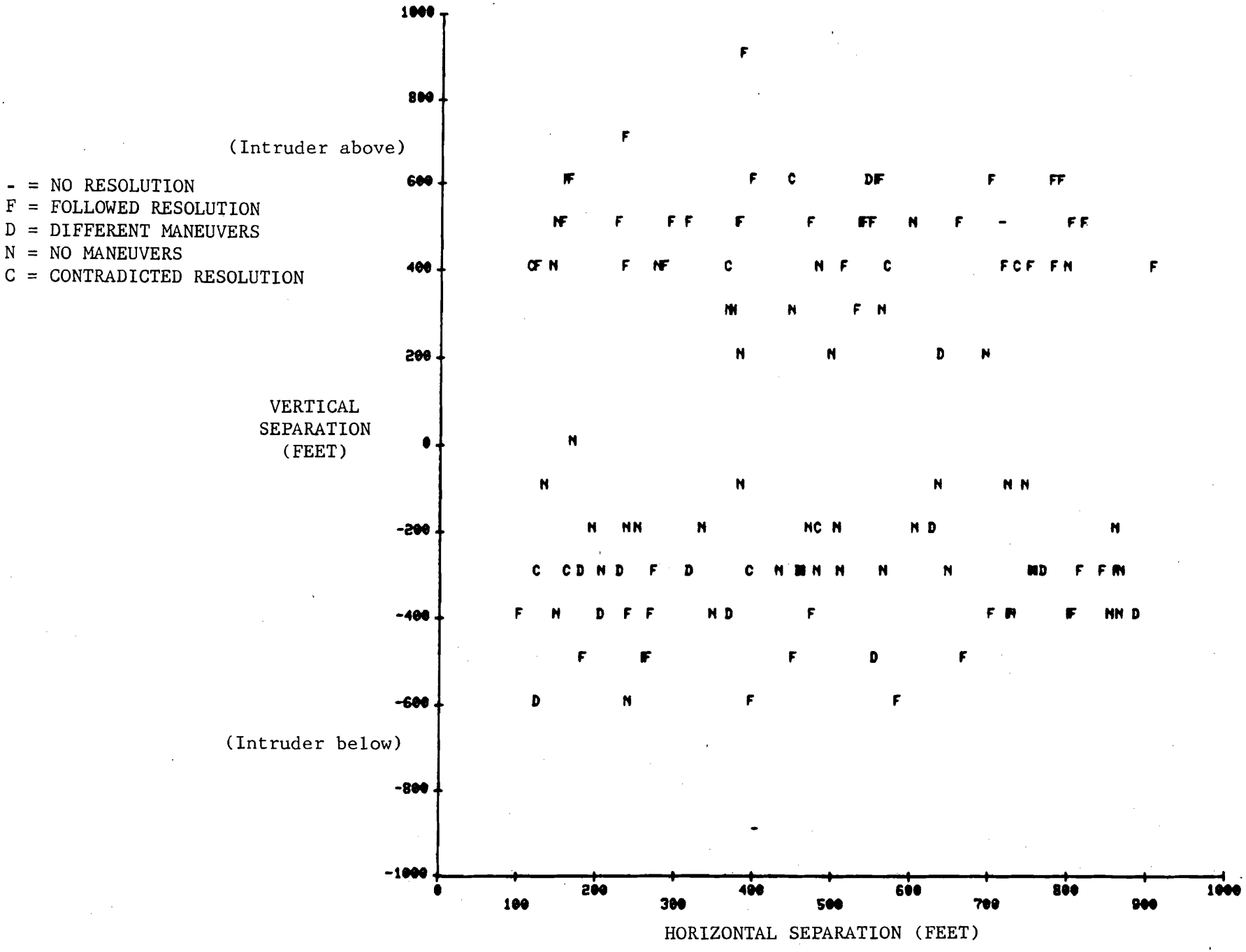


FIGURE 13 - HORIZONTAL AND VERTICAL SEPARATION AT CPA FOR ENCOUNTERS WITH CPA WITHIN 1000 FEET

2. In encounters where vertical separation is small and visual contact is achieved, it is difficult for the pilot to accurately judge the magnitude and direction of the vertical separation. It has been observed (by FAA Technical Center test pilots experienced in collision avoidance system testing) that for a given absolute vertical separation the intruder from above appears to have less vertical separation and hence appears to be more threatening than the intruder from below. Pilots are therefore more likely to maneuver and increase separation for intruder aircraft that are above.

3. Aircraft are more visible when they are above versus below the horizon. The increase in achieved vertical CPA separation when the intruder aircraft are above may be a manifestation of the tendency for pilots to maneuver more frequently when they perceive a threatening encounter and have visual contact as compared to when they do not have visual contact.

4. A small but nevertheless potential factor may be caused by the intruder pilots. These pilots were instructed to maintain a given altitude throughout the encounter. For safety reasons, prior to visual contact the intruder pilots tended to carefully monitor the altimeter and to ensure that any deviations from assigned altitude were on the side of increased vertical separation. Once visual contact was established, however, there was no longer the need to maintain this positive safety factor and vertical separation

distances may have tended to slightly decrease. The fact that the intruder pilots established visual contact more frequently when the subject aircraft was above may contribute to the observed differences.

To investigate the effects of the difference in vertical position the pilots' reactions to the advisories were broken down by vertical position of the intruder. Table 25 shows the frequency of responses in each category.

TABLE 25 - FREQUENCY OF RESPONSES TO THE RAS AS A FUNCTION OF INTRUDER POSITION

	NO RAS	FOLLOWED RAS	DIFFERED FROM RAS	DID NOT MANUVER	CONTRADICTED RAS
ABOVE	1	33	2	13	5
BELOW	1	19	11	30	4
TOTAL	2	52	13	44	9

It can be seen that the pilots complied completely with the resolution advisories most often when the intruder was above them, and they made no maneuver most often when the intruder was below. Indeed, most of the pilots' responses fall into the "Followed RAS" category or the "Did Not Maneuver" category. The other three categories have too few occurences to warrant separate statistical analyses. Therefore, to proceed with an analysis of the effects of pilots' compliance and the vertical position of the intruder, the categories "Differed From RAS" and "Contradicted RAS" have

been combined with the "No Maneuver" category into one category called "Noncompliance." The two "No RAS" observations have been dropped from the following analysis as they have no bearing on compliance with the advisories. Table 26 shows the frequency of responses as a function of intruder position, and Figure 14 shows the horizontal and vertical separations for these two new categories. The greater vertical separation achieved by pilots when they complied versus when they did not is clearly illustrated by Figure 14 where the non-complied cases are seen to cluster closer to the zero separation axis and the complied cases farther away.

TABLE 26 - FREQUENCY OF COMPLIANCE/NONCOMPLIANCE WITH THE RAS AS A FUNCTION OF INTRUDER POSITION

	COMPLIED	NONCOMPLIED
ABOVE	33	20
BELOW	19	45
TOTAL	52	66

Table 27 presents the results of an analysis of variance using slant range as the dependent variable and compliance and vertical position as the suspected sources of variation.

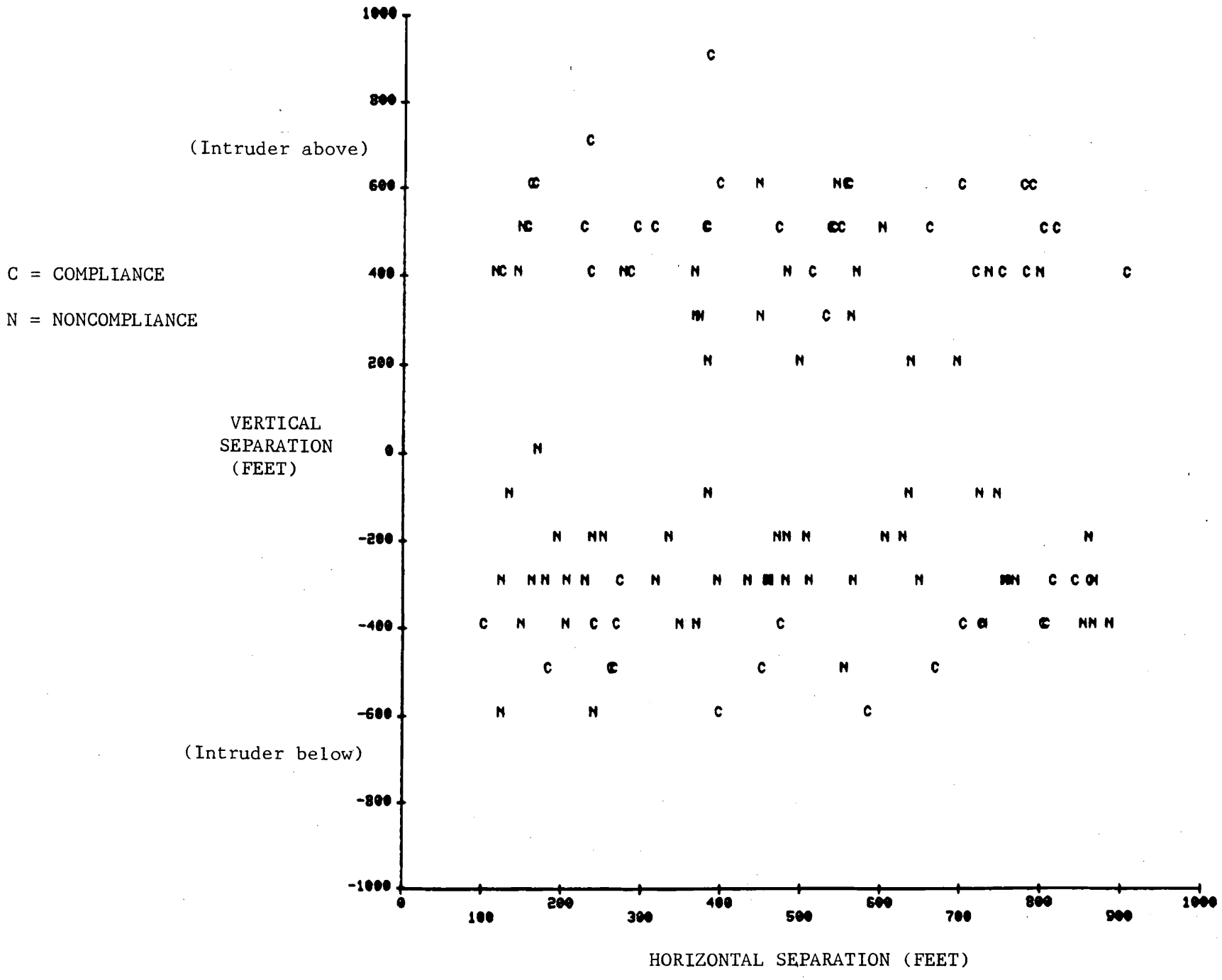


FIGURE 14 - HORIZONTAL AND VERTICAL SEPARATION FOR COMPLIANCE VERSUS NONCOMPLIANCE

TABLE 22 - SOURCES OF VARIABILITY IN SLANT RANGE

CPA'S BELOW 1000 FEET

SOURCE OF VARIATION	DF	MN SQ	F-RATIO	P-VALUE	SIGNIFICANT
VERTICAL POSITION	1	11894	0.346	0.56	NO
COMPLIANCE	1	419142	12.181	0.001	YES
POSITION*COMPLIANCE	1	3045	0.089	0.77	NO
RESIDUAL	114	34395	---	---	---

The failure of "Vertical Position" to reach significance indicates that whether the intruder was above or below did not contribute significantly to the three-dimensional slant range. Therefore, the best estimate available for slant range is the grand mean of the total sample, 640 feet. Assuming the pilots demonstrate a random sample of behaviors from some larger population, one can be confident that there is a 95% probability that the larger population mean will be within the interval 606 feet to 673 feet. This range applies only in the situation of forced encounters, with an automatic advisory service present, and aCPA of less than 1000 feet.

The failure of the interaction of vertical position and compliance category to reach statistical significance indicates that differences in mean slant range between the compliance categories are not dependent upon vertical position of the intruder.

The only factor found to significantly affect the separation

was that of the pilot's compliance with the RAS. Table 28 shows the mean slant range separation, the estimates of the standard error of the means, and the 95% confidence interval of the population mean for slant separation as a function of compliance category.

TABLE 28 - CPA SLANT RANGE AS A FUNCTION OF COMPLIANCE WITH THE RAS (aCPA'S BELOW 1000 FEET)

	N	MEAN	STD ERR	95% CONFIDENCE INTERVAL
COMPLIANCE	52	714.8	23.99	666.6 to 762.9
NONCOMPLIANCE	66	581.5	23.70	534.2 to 628.9
DIFFERENCE	14	133.3	34.16	66.4 to 200.3
TOTAL	118	640.2	16.96	606.7 to 673.8

The difference in means represents a 22.9 percent improvement in separation when pilots complied completely with the RAS over when they did not. These analyses of the data for slant range less than 1000 feet indicate that when a pilot complies with the resolution advisory service he maintains a larger CPA than when he fails to comply. This suggests that a Resolution Advisory Service can contribute to airspace safety.

In discussing pilots' "performance," it should be mentioned what or how the pilots were instructed to perform. The pilot's manual, given to the pilots one week prior to the ground school training session, states the following:

"So far no mention has been made of what you, the

pilot, should do. The purpose of [the automatic advisory service] is two-fold: to issue traffic advisories and resolution advisories to you automatically. You--the pilot--are free to choose whether and how to make use of these advisories."

In addition, the pilots were told before each flight that they were to do whatever they felt was necessary to maintain safe separation. In this context performance measures do not indicate the pilot's "success" in achieving a stated goal so much as they reflect the pilot's actual use of the automatic advisory service. The only mention made of the system-predicted closest point of approach (pCPA) was that it was represented as an "X" at the end of the relative motion line, and that it marked the range and relative bearing of the intruder at the predicted point of closest approach. The interpretation and use of pCPA was up to the individual pilot.

DISTRIBUTION OF CPA DATA. The preceding subsection dealt with performance as it relates to the automatic advisory service, focusing specifically on the differences in aCPA as a function of the level of compliance with the RAS. In this subsection, the level of experience with the automatic advisory service, as well as other factors that are independent of the advisory service, are examined to determine their effects upon aCPA, and aCPA relative to pCPA.

The initial approach to the CPA data consisted of an examination of the properties of the statistics, the construction of indices representing performance adequacy, and comparisons of these statistics with design and action variables.

The pCPA was recorded in 342 cases, and the aCPA were recorded in 345 cases (341 in common). The vertical component of the aCPA (aCPvA) has been converted to absolute values and is based on 345 observations. Table 29 shows the descriptive statistics of these data.

TABLE 29 - STATISTICS ON DISTRIBUTION OF CPA DATA

VARIABLE	MEAN	MDN	MIN	MAX	S.D.	SKEW	KURT
aCPA	2414	1424	163	11759	2527	2.0	3.5
pCPA	1228	588	6	11634	1784	3.5	13.6
aCPvA (abs)	411	400	0	1600	177	1.4	6.2

All values (except skew and kurtosis) are in feet.

The most striking feature of these data is their high variability. The actual and predicted CPA both have coefficients of variation in excess of one hundred. Notice that all of the distributions are positively skewed and the tail-heaviness (kurtosis) ranges from marked in the case of aCPA to extreme in the case of pCPA. Coefficients of kurtosis shown here are larger than the Gaussian norm kurtosis of three. The distributional properties of these data render them unsuitable for analysis by standard parametric methods. There are two ways around this: 1. transformations that stabilize and normalize variance, 2. analyses based on categories or rank statistics.

A variety of transformations were applied to the data. The square root of aCPvA yields values that approximate a normal distribution. The log(aCPA) and log(pCPA) are much less assymetric than their arguments, but still tail-heavy. Although these transformations still do not completely stabilize variance, 10log(aCPA/pCPA) was chosen as a continuous estimator of performance, P1.

From the preceding analyses of pilot opinion and visual acquisition, it might be expected that P1 would show an increasing trend with experience, however, various one-way analyses of variance failed to show any relation between P1 and flight number. The absence of any effect of flight number on P1 is borne out by parametric as well as non-parametric analyses of variance.

Similarly, no relation was found to exist between P1 and the presence or absence of any maneuver. However, when specific contrasts were examined between presence or absence of turns or altitude change, performance was significantly influenced by these specific maneuvers. Since the arithmetic mean of logarithmic values is equal to the logarithm of the geometric mean of the actual values, a second performance index, P2, was defined as the geometric mean of the ratio (aCPA/pCPA) in order to examine groups of data for encounters in the specific classes of maneuvers. Of those intrusions that lack any lateral course change, P2 is equal to 2, whereas on those encounters in which course change occurred P2 is equal to 3. This difference is statistically (and practically) significant at the 0.001 level in a Wilcoxon two-sample test. This result confirms any pilot's intuition that turns are an effective avoidance maneuver.

The same kind of result was also generated, as might be expected, by altitude changes, however, since altitude differences constitute a relatively small portion of the three-dimensional separation between aircraft, it is more meaningful to examine the aCPvA alone, rather than with regard to the pCPA. On those encounters in which the pilot either climbed or descended, the mean absolute vertical separation, called P3, exceeded 500 feet. When such altitude changes are not present, P3 is less than 400 feet. The mean gain in separation is about 150 feet. The probability of such differences in means occurring by chance is virtually

nil.

The preceding analyses are based upon the presence or absence of turning and climb/dive maneuvers. One may then ask whether, within the class of maneuvers themselves, there is any positve relation between intensity of maneuver and effectiveness. The answer to this question is flatly no. Total degrees of course change or angle of steepest bank, though themselves highly correlated, are unrelated to performance effectiveness. The same holds true for altitude changes whether signed or unsigned.

Insofar as pilot response intensity is unrelated to performance effectiveness, the possible relations between response latency and objective performance were examined. The overall mean time to visually acquire the intruder aircraft was 54 seconds. These data range from 30 seconds prior to the first advisory to 4 minutes after the advisory. The mean time to note the display was seven seconds with a standard deviation of 15 seconds. These times ranged from instantaneous to two and a half minutes. Correlations of these latencies with the three CPA performance indices are all of trivial magnitude.

The failure of latency and intensity variables to predict objective performance measures is not unusual in research endeavors of this kind. Indeed, it would be surprising to find such relations. Attempts at psychological interpretations of such simple observables fail to recognize

that their variability is intrinsic and not constrained by the contexts in which they occur.

Measurement methods used in laboratory experiments such as reaction time or latency measures, response amplitude, or error measure are often useful to help in the design of display devices and systems, but it is almost certainly the case that such measures, because of their susceptibility to perturbation, are useless in the field assessment of such devices.

PILOT BEHAVIOR AS A FUNCTION OF SYSTEM ESTIMATES OF RISK. In this subsection categorical partitions of CPA data are employed to examine pilot behavior as a function of "risk." As mentioned earlier, pilots were not given specific instructions on how to react to the predicted CPA indicator in their management of an encounter, but regardless of how individual pilots did use it, the pCPA does have value in determining the relative potential danger of encounters after the fact. Table 30 associates with ranges of pCPA values, risk categories numbered 1 through 4, where 4 indicates the closest range of system-predicted miss distance.

TABLE 30 - DEFINITIONS OF "RISK" CATEGORIES

CATEGORY	pCPA RANGE (FEET)	FREQUENCY OF OCCURENCE
1	>2500	35
2	951 to 2500	79
3	421 to 950	114
4	< or = 420	114

The first hypothesis to be tested by these data is that the propensity to maneuver would be greater in situations of higher risk. Using as the dependent variable the presence or absence of a maneuver of any type, Table 31 displays the percentages of maneuvers in each risk category broken down by encounter type (before determining the estimated percentage, the value 0.5 was added to each cell to account

for bias).

TABLE 31 - PERCENTAGES OF MANEUVERS AS A FUNCTION OF "RISK" LEVEL AND ENCOUNTER TYPE

RISK CATEGORY	ENC. TYPE	MANEUVER (% OF TOTAL) YES	NO	TOTAL
1	HO	90	10	4
	LE	69	31	20
	TC	62	38	11
2	HO	66	34	21
	LE	60	40	38
	TC	17	83	20
3	HO	52	48	27
	LE	54	46	48
	TC	44	56	39
4	HO	71	29	28
	LE	46	54	37
	TC	37	63	49

Analysis of these data shows that the only significant factor of the two which influenced the propensity to maneuver was type of encounter which yielded a chi-squared statistic of 12.51 on two degrees of freedom. This indicates a probability of less than 0.002 that the observed degree of correlation between encounter type and propensity to maneuver would occur randomly. Table 31 shows that the encounter types were ranked in the order HO-LE-TC, with respect to the frequency of maneuver. Notice that this ordering is the reverse of that found earlier for pilot satisfaction. The pilots tended to maneuver least in

tail-chase encounters, which is the condition in which they expressed the highest regard for the utility of the advisory service. This tendency may be influenced by the pilot's perception of the collision threat and the time available to react. In a tail-chase the pilot has ample time to evaluate the traffic situation and to avoid unnecessary maneuvering. This is especially true in tail-chase encounters where the pilot, prompted by the display, is able to establish visual contact. By contrast, in the HO encounter the pilot, aware of his inability to accurately assess the encounter situation in the limited time available, attempts to maintain a safety factor by maneuvering more frequently.

Contrary to the hypothesis, but statistically borderline, it is noted that greater risk does not induce increased maneuvering tendencies. Indeed, the greatest tendency to maneuver arises when the predicted point of closest approach exceeds 2500 feet.

The ratio of actual to predicted CPA was partitioned into categories reflecting an encounter's outcome. Table 32 shows the definition of the two categories of outcome, called "good," and "poor."

TABLE 32 - DEFINITION OF "OUTCOME" CATEGORIES

CATEGORY	aCPA/pCPA	FREQUENCY OF OCCURENCE
Good	1.1 or more	279
Poor	<1.1	62

The effects of the defined risk catesories, the presence or absence of maneuvers, and the type of encounter upon outcome were examined. Presence of maneuver and type of encounter were at most of borderline importance. In a major analysis that incorporated all three of these independent factors, there is a slight indication of an interaction between the influence of risk and maneuver affecting outcome, however, it is the risk factor that has the most dramatic influence on outcome. This influence is seen most clearly in Table 33 relating risk to outcome.

TABLE 33 - "OUTCOME" AS A FUNCTION OF "RISK"

		OUTCOME		
RISK	aCPA RANGE (FEET)	GOOD	POOR	TOTAL
		aCPA/pCPA≥1.1	aCPA/pCPA<1.1	
1	>2500	49%	51%	35
2	951 to 2500	68%	32%	79
3	421 to 950	89%	11%	114
4	< or = 420	93%	7%	113
TOTAL		82%	18%	341

In Table 33 it is seen that outcomes that are nominally unsatisfactory (in the sense that the actual point of

closest approach does not markedly exceed the prediction and may even be less), tend to be most heavily concentrated where they will do the least harm. Failure of the pilot to better the prediction does little to endanger an encounter that does not really materialize. But as the risk increases the value of the advisory service to aid the pilot in increasing separation results in quantitative advantage to the flight.

SUMMARY. To examine the ways in which the pilots use the automatic advisory service it is useful to look at their observed performance. Performance was examined in this section by looking at how well the advisories aided in visual acquisition, whether or not pilots followed the RAS, and whether or not compliance with the RAS increased the separation between aircraft. These analyses were divided into the following subsections.

- o Visual Acquisition
- o Pilot Response
- o Closest Point of Approach (CPA)
- o Distribution of CPA Data
- o Pilot Behavior as a Function of System Estimates of Risk

In the first subsection the time between the pilot's receipt of a first advisory and his achievement of visual contact was taken as an index of time to visual acquisition. It was seen that pilots were achieving visual contact sooner as

their experience with the advisory service increased. This improvement, combined with the fact that in the later flights visual contact was often achieved early on in tail-chase encounters when the intruder was still behind the subject aircraft, strongly suggests that the automatic advisory service aids the pilot in achieving visual contact.

The second subsection examined statistics concerning maneuvers made by the subject pilot. It was noted that the pilots differed greatly in their propensity to maneuver, and that the general tendency to maneuver diminished with the number of flight experiences. Whether this decrease is due to oversensitivity to displayed information in the early flights or an increase in confidence resulting from experience with the advisory service or with the flight test program itself is indeterminate.

The data extraction tapes from the Mode S ground system were processed to obtain data on the closest point of approach (CPA) which is the minimum three-dimensional separation between the subject aircraft and the intruder during an encounter. In the third subsection the actual and system-predicted closest point of approach (aCPA and pCPA) were examined with respect to four defined pilot reactions to the RAS (1. complied completely with the RAS, 2. complied partially with the RAS or maneuvered differently, 3. ignored the RAS, 4. contradicted the RAS). It was seen that the smallest average aCPA's were achieved when the pilots

ignored or contradicted the RAS. For those encounters with aCPA's less than 1000 feet the individual horizontal and vertical separations were plotted. It was seen that the subject pilots complied with the RAS more often when the intruder was above the subject aircraft than when he was below and that separations were significantly higher when pilots complied completely with the RAS than when they did not.

In the fourth subsection an examination of the aCPA data distribution showed a great degree of variability, positive skewness, and tail-heaviness (kurtosis) which rendered it unsuitable for analysis by standard parametric methods. Though a variety of transformations failed to completely stabilize and normalize the variance, the transformation 10log(aCPA/pCPA) was chosen as a continuous estimator of performance. The only factor that was found to have a significant effect upon this estimator was the presence or absence of specific maneuvers which altered the course or altitude of the subject aircraft. Both horizontal and vertical maneuvers were found to significantly increase the geometric mean of the ratio of actual to predicted CPA. Other factors examined which failed to improve performance are experience with the advisory service (flight number), latency (time to pilot's awareness of an advisory), and intensity of maneuvers.

In the last subsection, pCPA's were catesorically

partitioned into classes of the system's estimate of risk. The propensity to maneuver was found to have no relationship to the pCPA but a strong relationship exists between propensity to maneuver and encounter type; pilots maneuver most often in head-on (HO) situations, less often in lateral encounters (LE), and least often in the tail-chase (TC) encounters. This ordering is the reverse of that found earlier for pilot satisfaction, and may be influenced by the time available to react which is necessarily shorter in the HO situation. Finally, an analysis of factors affecting outcome (defined as 'good' if the aCPA exceeds the pCPA by 10 percent) determined that of risk, maneuver, encounter type and their two-factor interactions, risk is most significant in determining outcome, with the highest percentage of good outcomes occurring in the higher risk encounters.

CHARACTERISTICS OF THE TRAINING PROGRAM.

A ground school exam (Appendix B) was administered to the subject pilots before and after the ground school training session. The exam scores were used for three purposes: 1. to match pilots in the replicated latin square of the experimental design, 2. to obtain an objective index of the subject pilots' comprehension of the advisory service prior to the first flight, and 3. to assess the value of the training session. Although a half day of ground school was conducted for the subject pilots, the results of the two exams did not show a significant difference (means of 72.5 percent on the first and 75.0 percent on the second). The performance on the first ground school exam indicates that the training manual provided the pilots with a useful body of information.

An additional exam was completed by the subject pilots prior to each flight (preflight exam, Appendix B). This permitted determining if any improvement in apparent knowledge of the system occurred as a result of flight experience, and to estimate the relative value of the ground school with actual flight experience. The preflight exam data were complete except for one missing value for pilot K (flight number 2). This pilot also received an unusually low score on the first and third exam administrations. Omitting this subject gives a range of exam scores between 10 and 18 (out of a possible 18), with a large proportion of scores between 16 and 18.

Analysis of variance indicates that the average scores differed between flights (probability of this being a random result equals 0.04). The significance of this difference increases slightly if the anomalous subject K is omitted. However, a rank order correlation of the means for the six flight numbers with a perfect monotonic uptrend fails to reach significance (P = 0.05), with or without pilot K. It might therefore be concluded that there was no preflight test improvement as experience increased. However, an examination of the exam score versus flight number curve (Figure 15) shows that the failure of the rank correlation to reach significance is attributable to the small reversal of means (17.7 to 17.08) between flights five and six. A "learning curve" of just this kind, is the most commonly noted trend for psycholosical test scores and performance measures of this type (Reference 20).

The homogeneity of the pilot sample can be assessed with the intraclass correlation coefficient. With or without pilot K this coefficient is approximately 0.50. A between-subject correlation of 0.50 indicates a fair amount of homogeneity, especially in view of the narrow dynamic range of the exam scores. Since the F-ratio is statistically reliable, this correlation coefficient is also reliable.

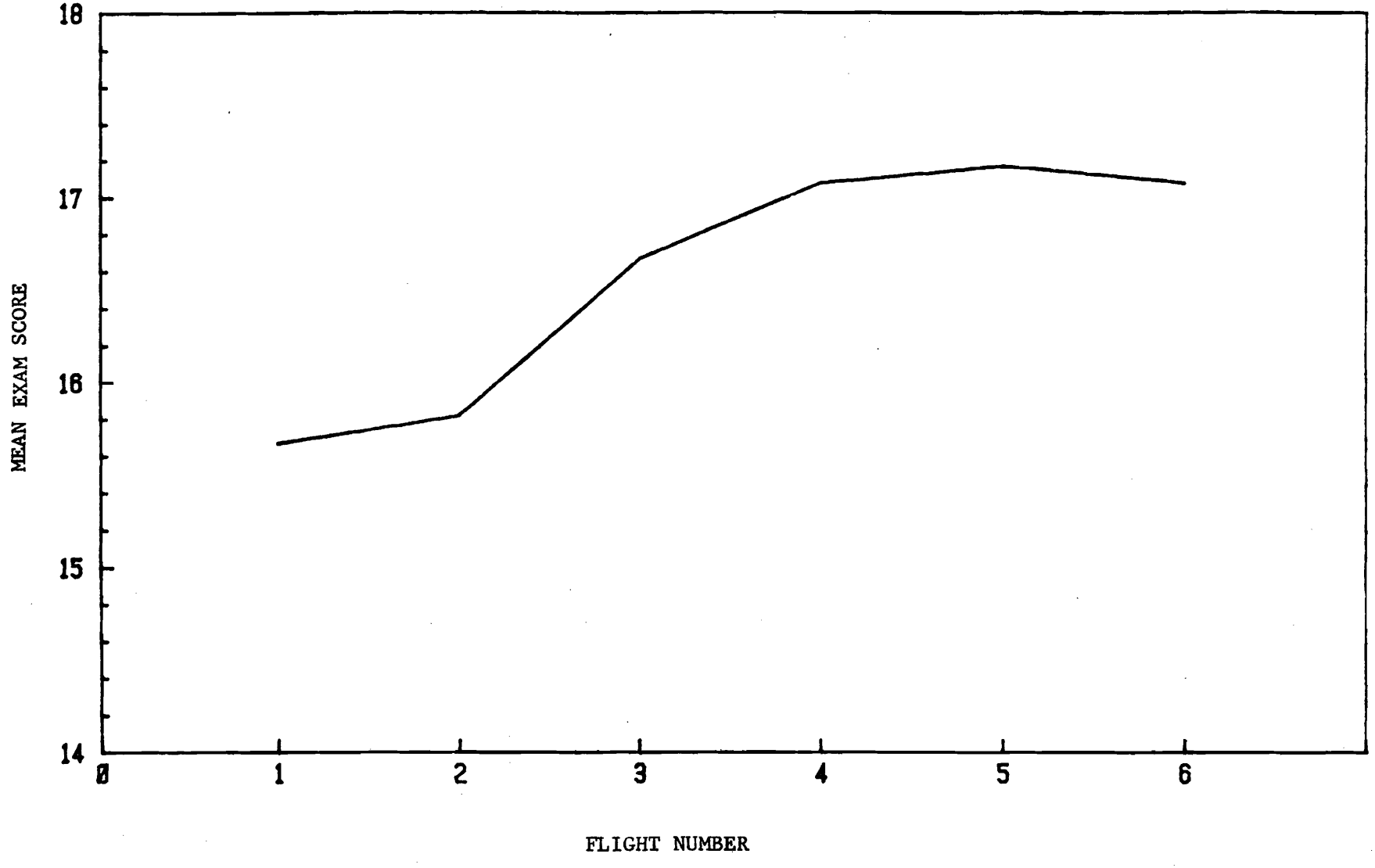


FIGURE 15 - MEAN EXAM SCORE VERSUS FLIGHT NUMBER

RESULTS

INTRODUCTION.

This report described a flight test program involving 12 subject pilots, flying 72 flights (6 flights each), with a total of 424 midair encounters, using an automatic advisory service. The automatic advisory service was composed of two services; 1. a Traffic Advisory Service (TAS) which displayed a continually updated, course-up traffic map of the airspace around the subject aircraft, and 2. a Resolution Advisory Service (RAS) which suggested conflict avoidance maneuvers calculated on the basis of ground radar surveillance information. Physical data were taken by on-board observers, and by ground-based magnetic tape recorders. Subjective data concerning pilot opinion and perception were collected with post-flight debriefings and post-encounter debriefings. All of the encounters were subject to the following three constraints:

1. No vertical rate or maneuvering encounters were flown.
2. No planned multiple aircraft encounters were flown (32 unplanned multiples occured).
3. The intruder aircraft were not equipped with the automatic advisory service.

The test results may have been different had these constraints not been in effect.

This section summarizes the major findings of the data analysis, and is divided into the following five sections.

- o Dependence of Data on Test Conditions
- o Pilot Utility Assessment of the Advisory Service
- o Pilot Acceptance of the Advisory Service
- o Use of the Advisory Service
- o Characteristics of the Training Program

DEPENDENCE OF DATA ON TEST CONDITIONS.

- The counter-balancing design (latin square) used in the flight test program was successful in eliminating any major systematic data dependencies, and the meteorological limitations imposed on the flights were sufficient to avoid the major random dependencies (page 62).

PILOT UTILITY ASSESSMENT OF THE ADVISORY SERVICE.

- The subject pilots showed most appreciation for those elements of the TAS which gave basic information regarding the location and relative motion of the intruder (page 66).

- There was a distinct preference shown in the pilots' ratings for the TAS features over the RAS. The RAS was initially one of the most highly rated features, but declined steadily to fifth place in the post-hoc ranking of the pilots' ratings, by the fourth flight (page 72).

- The stability of the ranking of pilots' ratings of the displayed data indicates that four flight experiences with the service are sufficient to stabilize pilots' working attitudes toward displayed information (page 73).

- The subject pilots felt that no crucial information was lacking in the displayed data, and, in general, too much information was displayed (page 74).

- The subject pilots explicitly expressed a desire for the basic traffic symbol alone, and for a general reduction in the level of displayed information (page 77).

- Fifty percent of the subject pilots indicated that there should be an audible signal to alert the pilot of a proximate advisory (page 77).

PILOT ACCEPTANCE OF THE ADVISORY SERVICE.

- The subject pilots showed a high regard for the automatic advisory service and the display in every measure of pilot satisfaction. The expressed satisfaction with the system, although uniformly high for all flight numbers, leveled out and reached its essential maximum on the fourth flight (pages 82, 86, 88).

- The subject pilots showed a significant preference for the automatic advisory service (TAS and RAS) as a whole, over the display (e.g. size, legibility, and color) (page 82).

- Approximately one-third of the increase in pilot satisfaction with experience may be associated with increasing familiarity with the system (page 89).

- The subject pilots regarded the automatic advisory service most highly when the intruder was least likely to be visible (page 94).

USE OF THE ADVISORY SERVICE.

- An observed decrease in the time to visual acquisition of traffic suggests that the automatic advisory service aids the pilots in achieving visual contact with the intruder aircraft (page 107).

- Minimum separations were significantly larger when pilots complied completely with the RAS than when they did not (pages 111, 120).

- The subject pilots complied completely with the RAS more often when the intruder was above the subject aircraft than when he was below (page 116).

- There was no significant improvement in achieved separations as experience with the automatic advisory service increased (page 123).

- Both horizontal and vertical maneuvers were found to significantly increase separations between aircraft (page 124).

- The subject pilots maneuvered most often in head-on encounters, less often in lateral encounters, and least often in tail-chase encounters (page 128).

CHARACTERISTICS OF THE TRAINING PROGRAM.

- The subject pilots gained most of their knowledge of the automatic advisory service through self-study with a

Pilot's Manual. A classroom training session did little to increase knowledge of the system over and above that already gained from the manual (page 135).

- The subject pilots gained additional knowledge of the system throughout the flight test program as a result of actual flight experiences, but their increase in performance on the preflight exam leveled out at its maximum by the fourth flight (page 135).

CONCLUSIONS

- Horizontal and vertical maneuvers in response to an automatic advisory service are effective in increasing aircraft separation.

- Supplementary information, over and above the basic position and relative motion information, is unwanted by pilots, and interferes with their comprehension of traffic situations. Conflict resolution advisories are seen as less important than this basic traffic advisory information.

- Certain characteristics of pilot interaction with an automatic advisory service, (such as the ability to maximize achieved separation), are effective from the very first flight experience with the service, while other characteristics, (such as satisfaction with the service, and decrease in time to visual acquisition), take four flight experiences to mature.

- Self-study with a comprehensive training manual is an effective method for training pilots in the use of an automatic advisory service.

RECOMMENDAIIONS

- The level of displayed information should be kept to a minimum for the sake of clarity in communicating to the pilot only the location and predicted relative motion of intruding aircraft.

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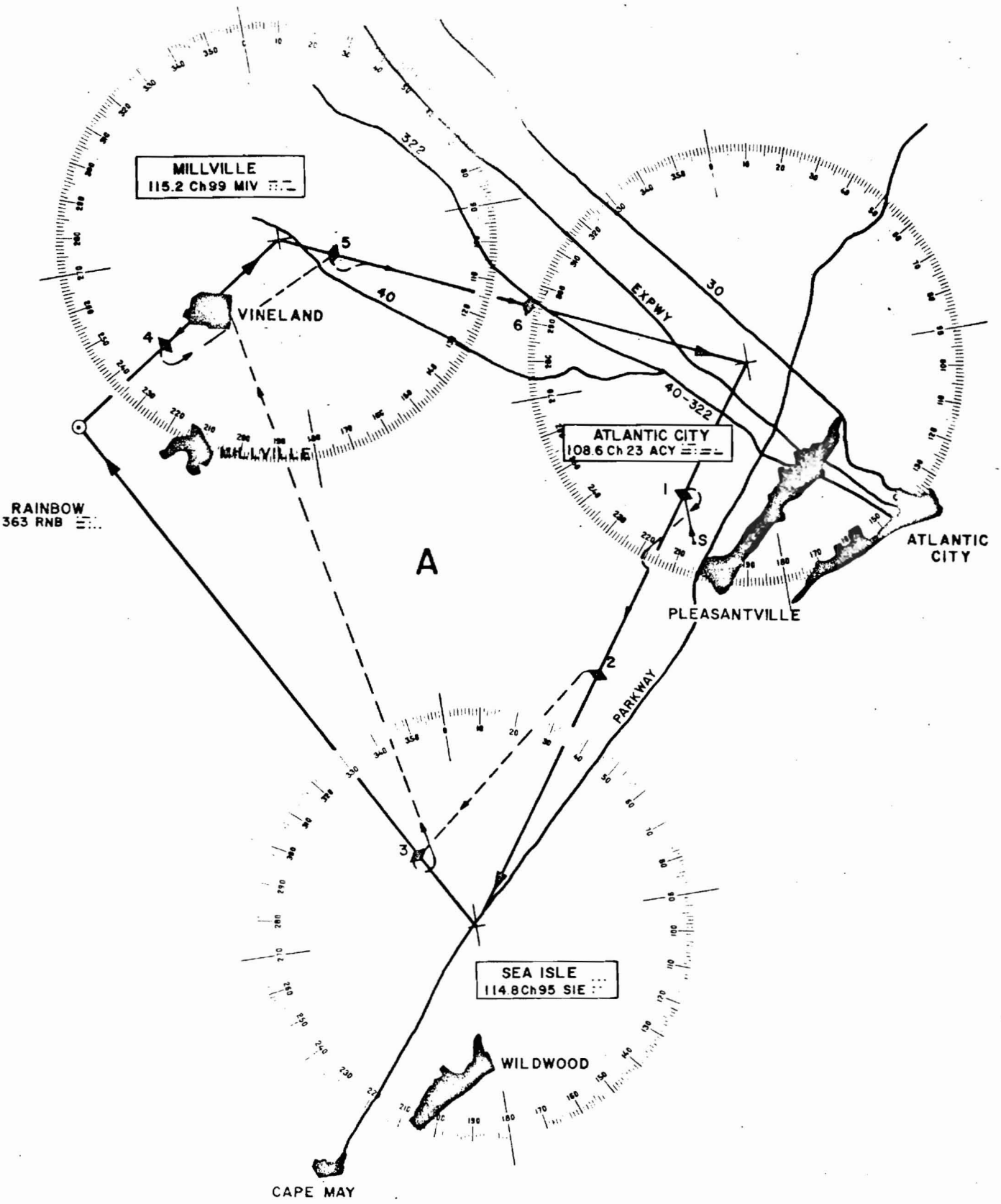
FLIGHT PATTERNS

APPENDIX A

This appendix contains a copy of each of the six flight patterns (patterns A - F). The solid line represents the planned path for the subject aircraft and the dashed line represents the planned path for the intruder. All six paths use the same four navigational points; Atlantic City Airport (ACY), Millville Airport (MIV), Rainbow NDB*(RNB), and the Sea Isle VOR**(SIE).

*Non-directional Radio Beacon

**VHF (Very High Frequency) Omni-directional Range Station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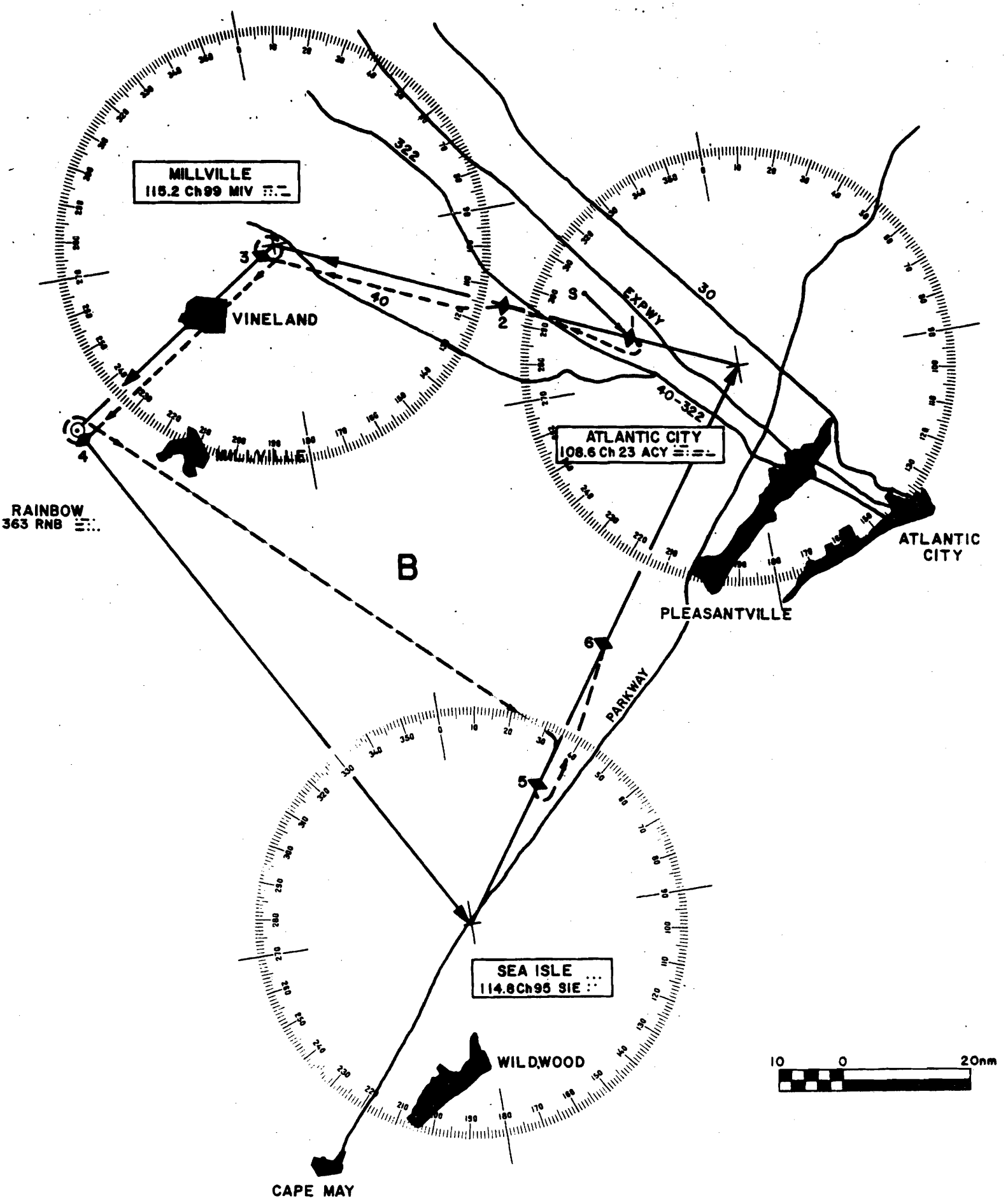
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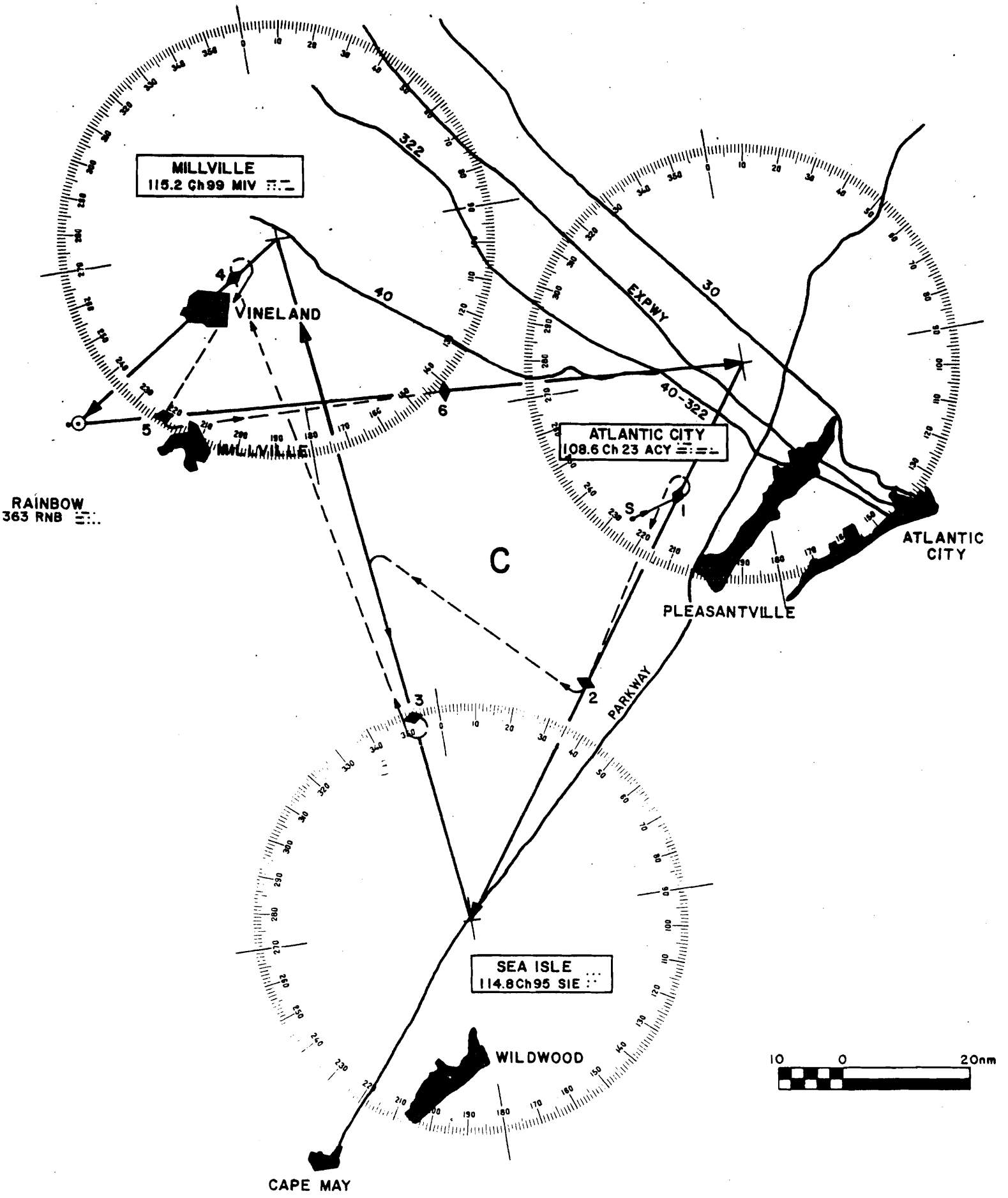
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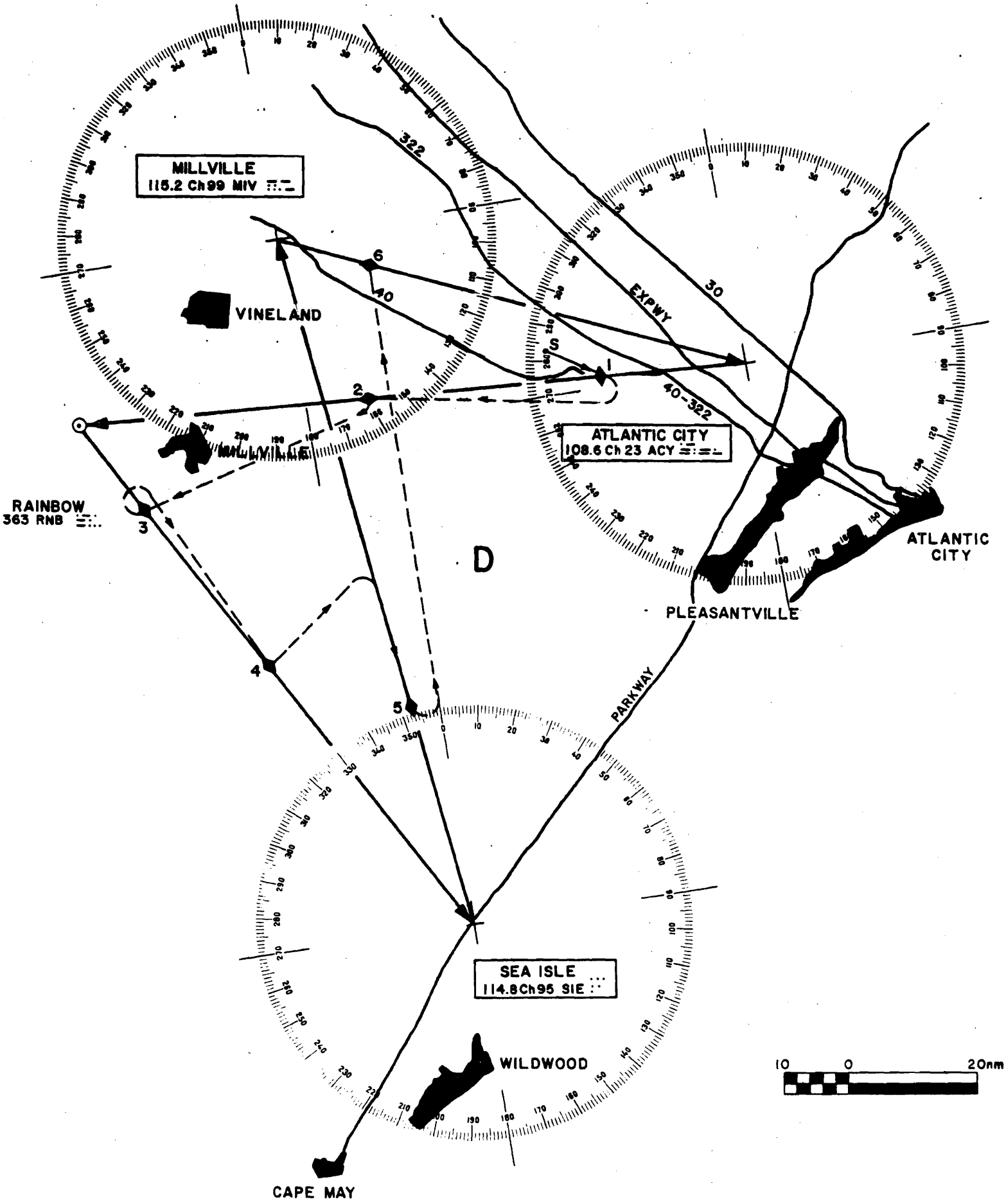
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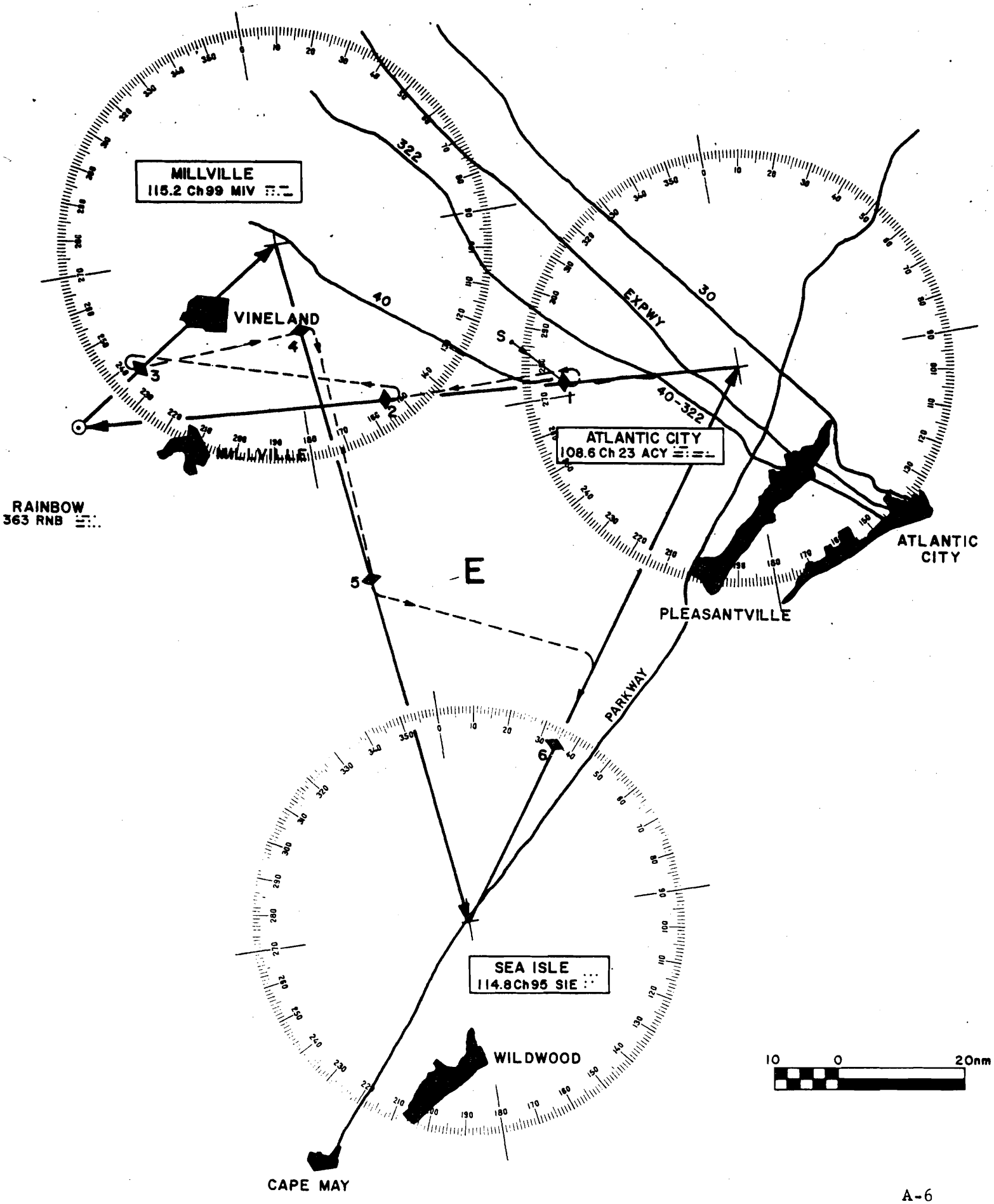
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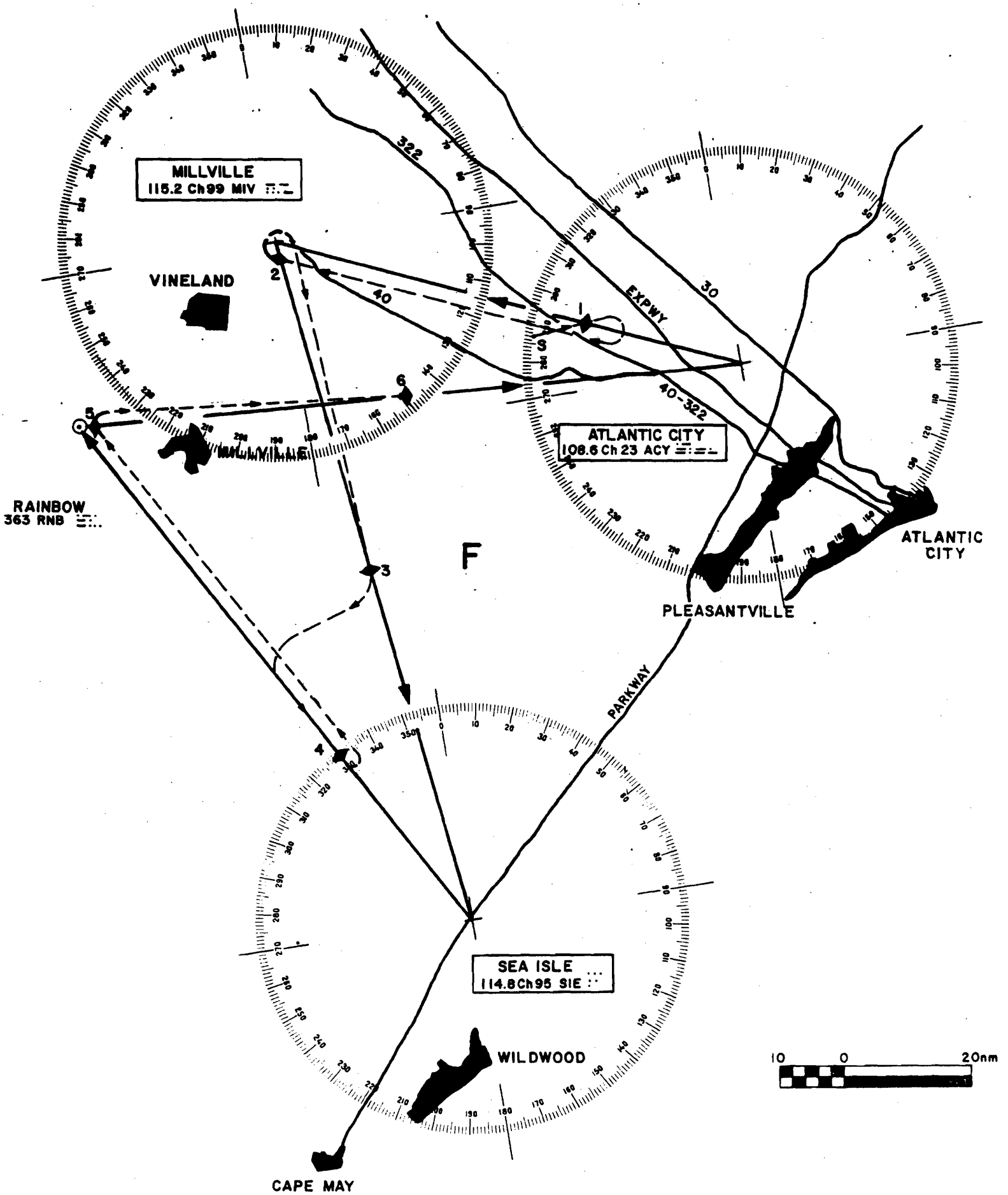
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DATA COLLECTION FORMS

APPENDIX B

This appendix contains the blank forms that the pilot, observers, and the flight coordinator completed throughout the flight test series.

	Page
Form 1 - Preflight Exam	B-2
Form 2 - Flight Log	B-4
Form 3 - Flight Debriefing	B-5
Form 4 - Encounter Log	B-8
Form 5 - Encounter Debriefing	B-10
Ground School Exam	B-11

PRE FLIGHT BRIEFING FOR SUBJECT PILOT

PILOT ID: MISSION NUMBER: DATE:

1. WHAT DOES THIS NUMBER REPRESENT?

2. WHAT COLOR IS THIS SYMBOL?

3. WHAT DOES THIS LINE REPRESENT?

4. WHAT DOES THE LENGTH OF THE ARROW REPRESENT?

5. WHAT DOES THE CIRCLE REPRESENT?

6. WHAT COLOR ARE THESE SYMBOLS?

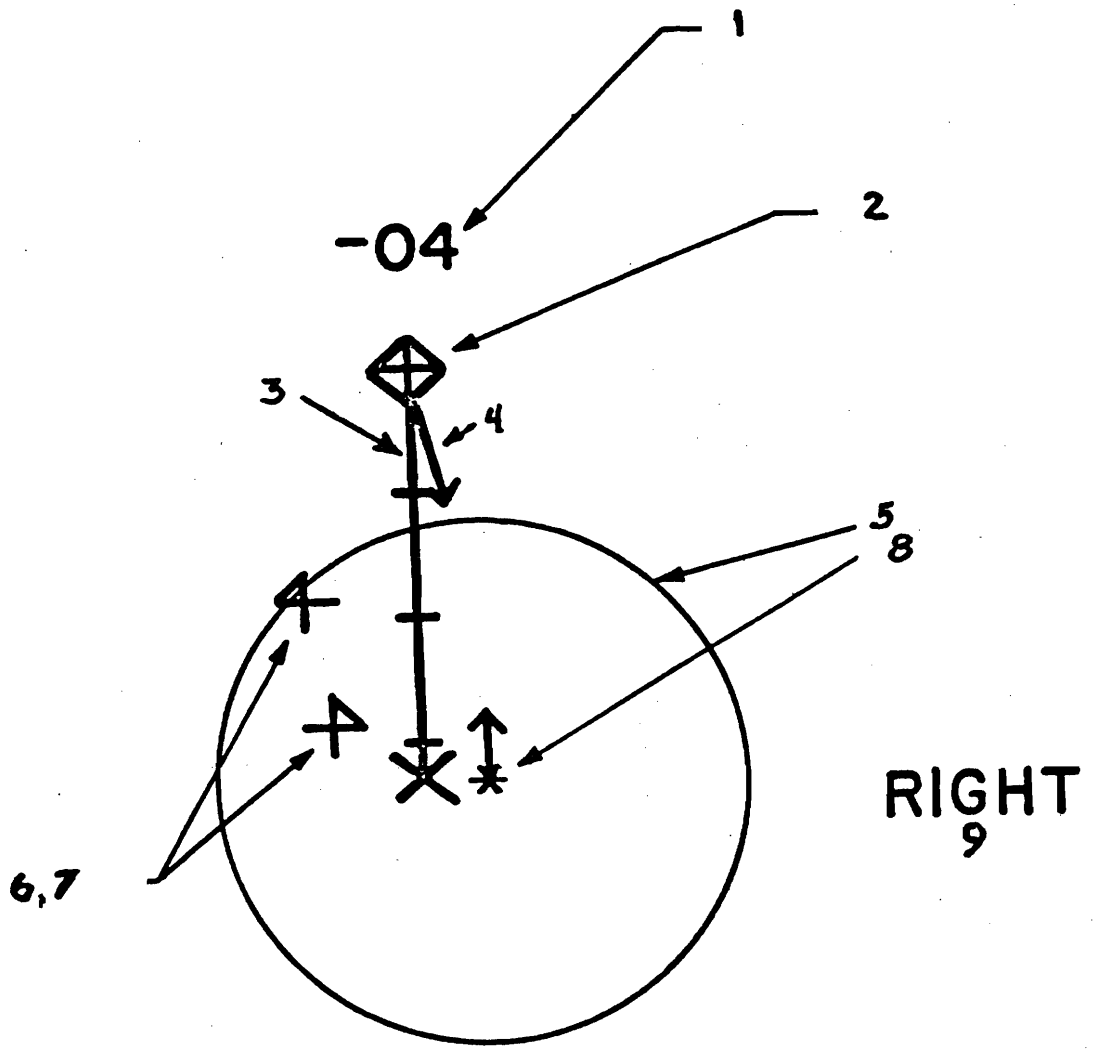
7. WHAT DO THESE SYMBOLS REPRESENT?

8. WHAT DOES THIS SYMBOL REPRESENT?

9. WHAT COLOR IS THIS ADVISORY?

FORM 1 - PREFLIGHT EXAM

(page 1 of 2)



FORM 1 - PREFLIGHT EXAM

(page 2 of 2)

OBSERVER'S LOG

[1] DATE: [2] TIME (LOCAL):

[3] TEST PILOT ID: [4] PILOT MISSION #:

[5] SAFETY PILOT ID:

[6] OBSERVER ID: [7] FLIGHT ID (A to F):

[8] TEST AIRCRAFT ID: [9] INTRUDER AIRCRAFT ID:

[10] PRE-FLIGHT CHECK OK (Y/N): IF NO, SPECIFY PROBLEM:

[11] WEATHER: SKY(0-9): [12] CEILING: [13] VISIBILITY:

[14] OBSTRUCTIONS TO VIS: [15] TEMP:

[16] DEW POINT: [17] WIND DIR:

[18] VELOCITY: [19] ALTIMETER:

[20] PREDICTED WINDS ALOFT (AT 3000 FT):

[21] DEPARTURE TIME:

[22] ABORT (Y/N)? (DESCRIBE IN "NOTES" BELOW):

[23] AUDIO RECORD START (Y/N):

[24] STOP WATCH START:

[25] ELAPSED TIME STRAIGHT & LEVEL:

[26] ALTITUDE STRAIGHT & LEVEL:

[27] DME FROM ACY AT S & L:

PRE-FLIGHT NOTES:

FORM 2 - MISSION LOG

(page 1 of 1)

DEBRIEFING FORM

[1] Test Pilot ID: [2] Pilot Mission #:

[3] What did you think of the colors used to code the ATARS information?

[4] Would any additional traffic advisory information be useful to you in deciding what or what not to do?

[5] Was there unnecessary information displayed?

Rate (0-9) each component of the traffic advisory service in terms of how useful it is to you in managing an encounter situation?

[6] basic traffic symbol + _____

[7] relative altitude _____

[8] out-of-range traffic symbol (Δ) _____

[9] vertical speed _____

[10] traffic course track _____

[11] own aircraft course track _____

[12] relative motion line _____

[13] range ring _____

[14] point of closest approach _____

[15] turn status _____

[16] resolution command _____

ATARS provides traffic advisories and resolution advisories. How would you evaluate the relative contribution of these two services in maximizing your safety? For example 50-50, 2 to 1, 1 to 10, or what?

[17] Traffic Advisory:Resolution Advisory :

FORM 3 - MISSION DEBRIEFING

(page 1 of 3)

[18] Did the information in the traffic advisory prompt you to take avoidance maneuvers prior to receiving a resolution advisory?

Never _____

Sometimes _____

Often _____

Always _____

[19] How confident were you of the advisability of these maneuvers?

Not at all _____

Somewhat _____

Very _____

[20] In a threat situation, did the traffic advisory service aid you in visual acquisition of the traffic?

Never _____

Sometimes _____

Often _____

Always _____

[21] Once you had visually acquired traffic, did you:

forget about the screen. _____

continue to consult the traffic and resolution advisories _____

ignore further traffic advisories, but respond to resolution advisories _____

continue to consult traffic advisories, but ignore resolution advisories _____

[22] How adequate was the traffic advisory service in preparing you for the resolution advisory?

not useful at all _____

somewhat useful _____

very useful _____

[23] How confident are you that the resolution commands maximize the miss distance.

not at all confident _____

somewhat confident _____

very confident _____

[24] If you never see the traffic how do you feel about following the resolution advisories?

not at all confident _____

somewhat confident _____

very confident _____

[25] Please rate (0-9) how you feel about all aspects of the display format together (size, legibility, color, etc.) _____

[26] On the whole, please rate (0-9) how you feel about ATARS service. _____

[27] Can you suggest any mods or improvements in the display or service?

(1) INTRUSION NUMBER:

(2) TEST PILOT ID:

(3) PILOT MISSION NUMBER:

(4) FLIGHT LEG (1 2 3 4)

(5) ALTITUDE MAINTENANCE:

(6) COURSE MAINTENANCE:

(7) TURBULENCE? HOW MUCH?

(8) WORK LOAD BEFORE INTRUSION

(9) TIME OF FIRST ADVISORY:

(10) TIME PILOT NOTES ADVISORY:

(11) STAGE PILOT NOTES ADVISORY(P TH R)

(12) TIME OF VISUAL ACQUISITION:

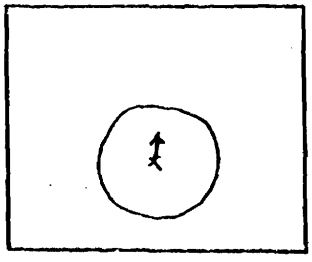
(13) IF ONE WAS IT PLANNED?

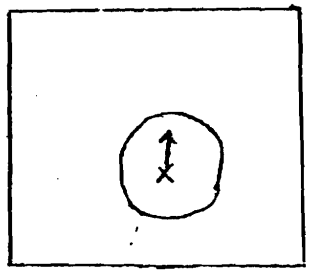
(14) ADVISORY TYPE(P TH RES)

(15) INTRUSION TYPE(HO PU TC)

(16) IF MORE THAN ONE, DRAW SYMBOLOGY: WAS THE MOST CRITICAL PLANNED?

(17) TRACK INTRUSION:





(18)

	PROX	THREAT	RES AD
OCCURS (time)			
MANEUVER(Y/N)			

(19)

	ON SCREEN RES	MANEUVER TAKEN
TYPE MANEUVER (CLI,DES,RIGHT,LEFT)		
RATE (BANK OR FT/MIN)		
COURSE CHANGE (FEET--DEGEES)		

(20) DOES PILOT HEAR THREAT?

(21) TYPE COMMAND RECEIVED:

(22) DOES PILOT HEAR CLEAR?

(23) TIME BACK ON COURSE:

(24) CRITICAL EVENTS?(E.G.OTHER TRAFFIC)

(25) ADVISORY TIMMING---TO SOON_____ABOUT RIGHT_____TO LATE____

(26) RESOLUTION: CORRECT_____NOT CORRECT_____DONT KNOW_____

FORM 4 - INTRUSION LOG

(page 1 of 2)

RESPONSE CHECK LIST:

(ALL RATING SCALES 0-9)

[30]_____ALTITUDE DURING INTRUSION (RANGE IN FT.)

[31]_____COURSE DURING INTRUSION (0 - 9)

[32]_____MAINTAIN INSTRUMENT SCAN (Y/N)

[33]_____MAINTAIN EXTERNAL SCAN (Y/N)

[34]_____MANEUVER COORDINATION (0 - 9)

[35]_____AIRSPEED CONTROL (0 - 9)

[36]_____FUEL MANAGEMENT (OK / NG) LAST INTRUSION ONLY

[37]_____PROP SYNC (OK / NG)

[38]_____WORKLOAD RATING (0 - 9)

[1] Intrusion Number:

[2] Test Pilot ID: [3] Pilot Mission #:

[4] Where did the intruder come from (clock position)?

[5] Did the display light up in time?

[6] Did the threat advisory occur too early or too late?

[7] Did you find ATARS useful in avoiding the traffic?

[8] Did you maneuver before you received an advisory?

If yes, why?

[9] Did you find the resolution advisory or the display the most helpful?

[10] What did you think of the resolution advisory?

[11] Was the intruder going faster or slower than you?

[12] Was the intruder ATARS equipped?

[13] Was he above/below you or at same altitude?

[14] How would you rate the workload of the intrusion (0-9)?

[15] Would you rather have ATARS advisories or traffic controller advisories? Both?

FORM 5 - ENCOUNTER DEBRIEFING

(page 1 of 1)

ATARS Orientation Test Format

1. Which of the following might occur several minutes before point of closest approach?

   1) Proximate advisory

   2) Traffic threat advisory

   3) Resolution advisory

   4) Both 1 and 2

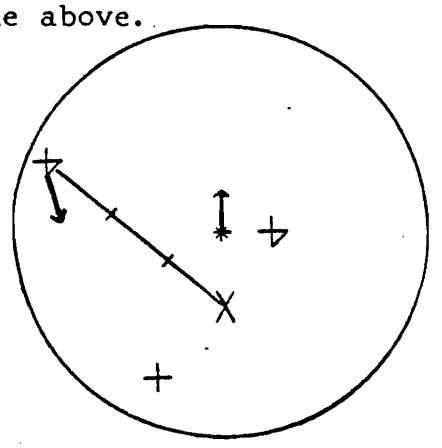
2. If you choose to ignore a resolution advisory, and decide to maneuver at your own discretion:

   1) Your ATARS display will automatically shutdown leaving you to rely on manual resolution of traffic conflicts.

   2) You will have violated FAA regulations.

   3) The probability of in-flight conflict decreases.

   4) None of the above.



3. Upon evaluating the traffic situation depicted above which aircraft is(are) the <u>most</u> critical threat(s)?

   1) The aircraft at 3 o'clock.

   2) The aircraft at 3 o'clock and 10 o'clock.

   3) The aircraft at 7 o'clock.

   4) The aircraft at 10 o'clock.

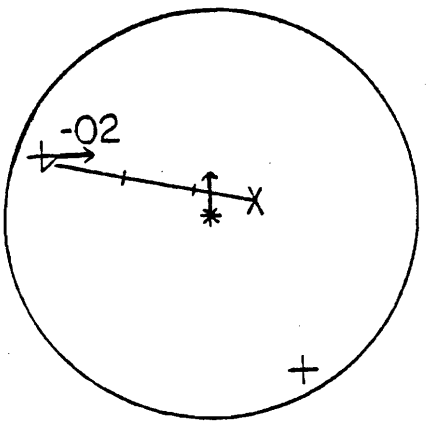
4. Which of the following is false?

1) The threatening aircraft is 200 feet below you.

2) The threatening aircraft is climbing.

3) The most threatening intruder is located at 10 o'clock.

4) The large "X" represents the point of closest approach.



5. Which of the following is false?

1) Proximate aircraft are displayed because they set limits on possible maneuvers to avoid or resolve a conflict.

2) Proximate aircraft are displayed because they can at any time, become a threat.

3) Proximate aircraft are never displayed when a critical threat appears.

4) Proximate aircraft advisories occur with any altitude separation of less than 2000 feet and range less than 2 nautical miles.

6. The symbol means:

1) The aircraft is ATARS equipped.

2) The aircraft is controlled by ATC.

3) The aircraft is a threat.

4) None of the above.

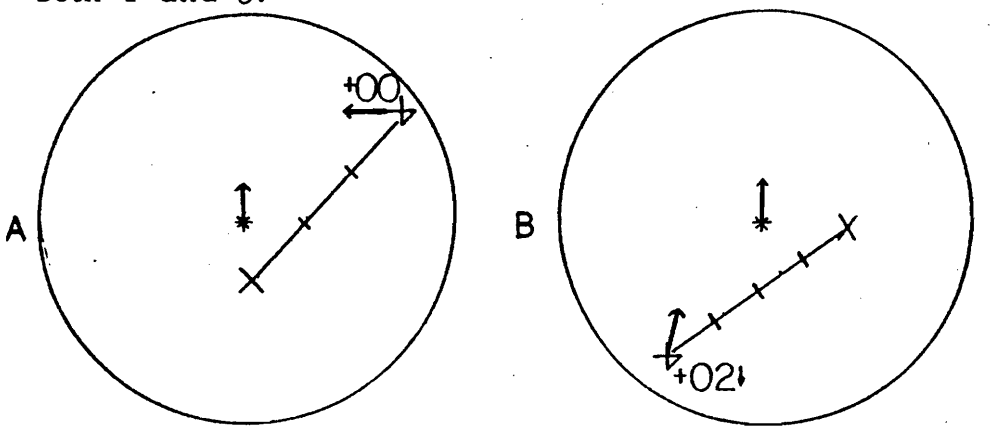
7. If your screen is clear (no traffic), the ATARS display will alert you to the presence of a threat by:

   1) Displaying the relevant symbols on your screen.

   2) Emiting a 'beep-beep' every 4.7 seconds.

   3) Emitting a synthesized voice warning 'threat'.

   4) Both 1 and 3.



8. Upon evaluating the two separate situations above, one can conclude that:

   1) In situation B the threatening aircraft will pass behind you.

   2) In situation A the threatening aircraft will pass in front of you.

   3) In both situations the altitude of the threatening aircraft is identical to yours.

   4) In both situations the estimated point of closest approach will occur in 30 seconds.

Given a threatening aircraft at 12 o'clock with the following properties:

- o velocity is less than yours.
- o aircraft is 200 feet above you and descending.
- o range is 2 nm.
- o aircraft is turning.

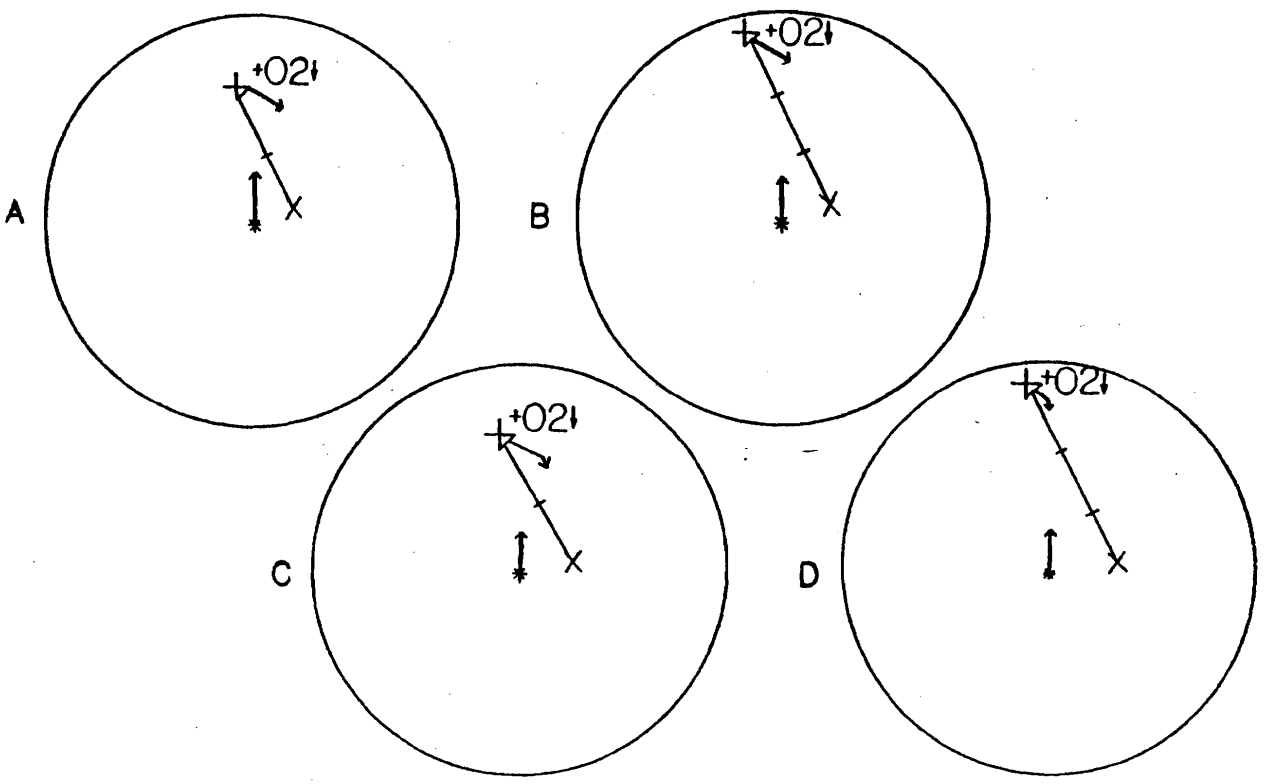
9. Which figure will appear on your ATARS display?

1) Figure a

2) Figure b

3) Figure c

4) Figure d



10. All simultaneous threats will:

1) be represented by green target symbols.

2) be supplied with relative motion lines.

3) cause a resolution advisory to be displayed.

4) be represented by a red "".

11. A resolution advisory will:

    1) occur several minutes before the time of closest approach.

    2) compel the pilot to take the recommended evasive action.

    3) typically occur at most 30-40 seconds before the time of closest approach.

    4) never occur when you really need it.

12. A yellow circle centered on the asterisk representing your own aircraft:

    1) defines a range of 4 nautical miles.

    2) defines a range within which an intruder will be identified as threatening.

    3) defines a range of 2 nautical miles.

    4) defines the advisory picture area.

13. Proximate aircraft which fall outside of the advisory picture area:

    1) cannot be displayed by ATARS.

    2) will be represented by an "X" at the appropriate bearing and at the edge of the picture area.

    3) will be represented by a green triangle which will always appear at the lower left of the picture area.

    4) will be represented by a green triangle at the appropriate bearing and at the edge of the picture area.

14. Which symbol within the advisory picture area provides a graphic display of <u>threatening</u> traffic?

    1) a green "+"

    2) a yellow asterisk

    3) a red "+"

    4) a red "+"

15. When a red '+02' symbol appears next to a traffic symbol:

1) a threatening aircraft is located 200 feet below you.

2) a proximate aircraft is located 200 feet below you.

3) a threatening aircraft is located 20 feet above you.

4) a threatening aircraft is located 200 feet above you.

16. An up (↑) or down (↓) arrow is displayed next to the altitude information to tell you:

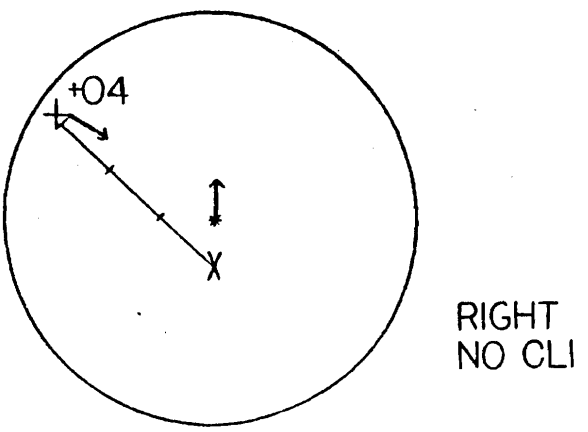
1) whether your separation from the aircraft is increasing or decreasing.

2) the direction of vertical movement of a threatening aircraft.

3) the predicted point of closest approach.

4) the direction of vertical movement of proximate or threatening aircraft.

For questions 17, 18, and 19, refer to the Figure below.



17. The symbol which depicts the present position of your plane is:

1) "+"

2) "+04 "

3) "*"

4) "+"

18. The predicted point of closest approach of the threat is represented by:

1) *

2) Right
NO CLI

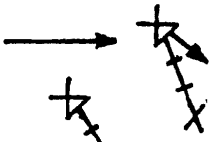
3) 'X'

4)

19. The symbol that depicts a threatening aircraft, its relative motion, course, and point of closest approach is:

1)

2) +04

3) 

4)

20. Fast moving threats have:

1) short course arrows.

2) relative motion lines angled close to their course arrows.

3) relative motion lines angled far away from their course arrows.

4) blinking threat symbols.