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SIMULATION STUDY OF INTERMITTENT POSITIVE CONTROL IN A TERMINAL--ETC(U)
JAN 77 S ROSSITER, J WINDLE, R STRACK

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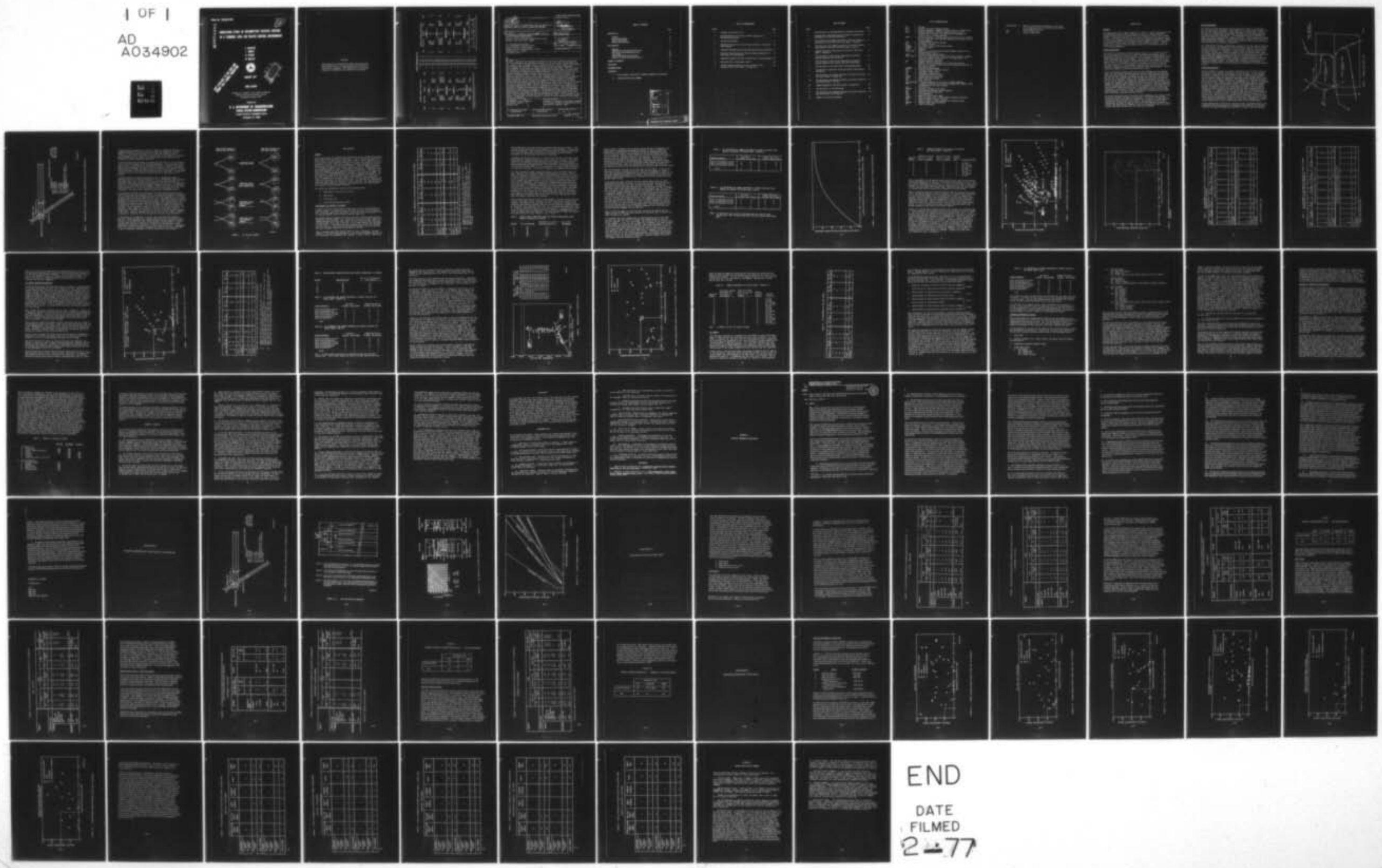

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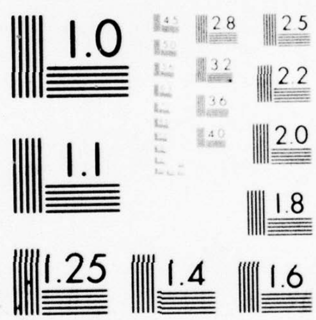

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Report No. FAA-RD-76-193

SIMULATION STUDY OF INTERMITTENT POSITIVE CONTROL IN A TERMINAL AREA AIR TRAFFIC CONTROL ENVIRONMENT

S. ROSSITER
J. WINDLE
R. STRACK
W. MULLEN

JANUARY 1977

FINAL REPORT

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Systems Research & Development Service
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NOTICE

METRIC CONVERSION FACTORS

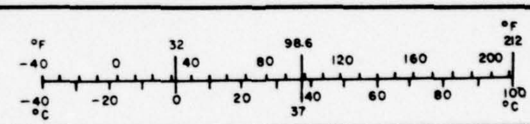
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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S. Rossiter, J. Windle, R. Strack, [redacted] W. Mullen

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16. Abstract
A dynamic simulation was conducted to provide an initial and limited investigation into the operational and procedural problems that may exist when intermittent positive control (IPC) is present within a terminal area air traffic control (ATC) system. The simulation was performed at the National Aviation Facilities Experimental Center (NAFEC) and utilized the digital simulation facility (DSF). The test environment simulated a single Discrete Address Beacon System (DABS) sensor site and used the IPC algorithm provided by the MITRE Corporation. The results indicated that the algorithm tested at NAFEC adversely interacted with the present ATC system in a number of operational areas. Rather than remaining passive until required, IPC generated controller alerts and, at times, commands when controllers were following normal procedures and aircraft pairs were well outside ATC separation standards. These unnecessary alerts occurred most frequently between arrivals in the final approach area and between arrivals and departures in those areas where routes crossed. The arrival encounters usually involved high closure rates, and, in general, all encounters demonstrated that a lack of knowledge of ATC intent and a sensitivity to controller technique precipitated the premature IPC activity. Data indicated that significant reductions in the number of IPC messages generated could be achieved by reductions in IPC threshold parameters. Modifications to control procedures could produce similar reductions, but were not considered acceptable because of the tendency toward increased workload and reduced operations rates. As an appendix to this report, a comparative analysis between an airborne collision avoidance system (ACAS) and IPC is provided.

17. Key Words
Intermittent Positive Control
Air Traffic Control
Terminal Area

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LIST OF ABBREVIATIONS

A/C	=	Aircraft
ACAS	=	Airborne Collision Avoidance System
AF	=	Software Parameter; immediate altitude limit for Command Test
AFIFR	=	Software Parameter; altitude separation within which a flashing PWI is forced for an IFR aircraft regardless of vertical time of closest approach
AFPWI	=	Software parameter; altitude separation within which a flashing PWI is forced for a VFR aircraft regardless of vertical time or closest approach
ARTS	=	Automated Radar Terminal Systems
ATC	=	Air Traffic Control
ATCRBS	=	Air Traffic Control Radar Beacon System
CALERTS	=	Controller alerts
CMDS	=	Commands
Controlled	=	Refers to an aircraft being provided positive control by an authorized ATC facility
DABS	=	Discrete Address Beacon System
Data Block	=	That data displayed with an aircraft radar, beacon, or digital target providing identity (code or call sign) speed, and altitude if Mode C available
DSF	=	Digital Simulation Facility
F	=	Symbolic character displayed in aircraft data block to indicate to controller that pilot is receiving flashing PWI on IPC cockpit display
FORTRAN	=	Software Coding Language
FPWI	=	Flashing proximity warning indicator
IFR	=	Instrument flight rules
ILS	=	Instrument landing system
IPC	=	Intermittent positive control
IPCSEL	=	Command Selection Subroutine
KIAS	=	Knots indicated airspeed
LTR	=	Limit turn rate
Miss Distance	=	Projected distance at the time of closest approach
Mode C	=	Altitude information from aircraft equipped with ATCRBS or DABS transponder and encoding altimeter
nmi	=	Nautical mile
POSCOM	=	A control variable in IPC logic
PPI	=	Plan position indicator (radar display)
PWI	=	Proximity warning indicator
RNAV	=	Area navigation
Scan	=	Nominal 4-second radar sweep
Sigma V	=	Xerox processor used to drive digital simulation facility
TAU	=	Ratio of range to rate of closure
TH	=	Time to point of closest approach in horizontal plane
TRACON	=	Terminal Radar Control Facility
TV	=	Time to coaltitude

Uncontrolled	=	Refers to an aircraft operating on a VFR flight or no flight plan with no communication with the controlling ATC facility
VFR	=	Visual flight rules
VSL	=	Vertical speed limit

INTRODUCTION

PURPOSE.

The primary objective of these tests was to conduct a limited investigation into the operational and procedural problems that may exist when Intermittent Positive Control (IPC) is present within a terminal air traffic control (ATC) system. A secondary objective was to conduct an additional and special series of tests at the request of the Office of Systems Engineering Management (OSEM) of the Systems Research and Development Service (SRDS) to provide a comparative evaluation of IPC and ACAS (airborne collision avoidance system). A letter report on the results of this secondary objective was forwarded to SRDS and is included as appendix A.

SYSTEM DESCRIPTION.

IPC, which is currently in the developmental stage, is a collision avoidance service provided to aircraft by a totally automated ground-based system. To receive IPC service, an aircraft must carry a Discrete Address Beacon System (DABS) transponder and an IPC display. The transponder, in addition to its usual beacon function, receives digital messages from the ground and presents them on the pilot IPC display. IPC software monitors the location, altitude, and velocity of all aircraft throughout a contiguous airspace via the surveillance capability. A ground-based computer processes the data and continuously provides proximity warning information and, when necessary, conflict resolution commands to aircraft receiving IPC service.

Pilots receiving IPC service receive any of the following four IPC message types: (1) the "steady" proximity warning indicator (PWI) message tells the pilot that another aircraft is nearby, but not in a hazardous situation with his own; (2) the "flashing" PWI (FPWI) message tells the pilot that another aircraft is in potential conflict with his own and requires his attention; (3) the "Don't" (negative) command is a message which informs the pilot that he must not maneuver in some specified direction; and (4) the "Do" (positive) command is a message which commands the pilot to perform a specified maneuver. All four messages provide the pilot with an indication of the location of the nearby aircraft which has given rise to that message to aid in pilot visual acquisition. In addition to these four messages to pilots, the IPC system issues messages to the air traffic controller of a controlled aircraft whenever his aircraft encounters another aircraft.

The service provided by the IPC system varies depending on the control status of the two aircraft involved in an encounter. An aircraft flying under instrument flight rules (IFR) is controlled by a controller or uncontrolled (flying under visual flight rules (VFR)). The operation of IPC is then conveniently described in terms of the action taken when both aircraft in a conflict are uncontrolled (VFR-VFR), when one is controlled and one is uncontrolled (IFR-VFR), and when both are controlled (IFR-IFR).

SYSTEM ENVIRONMENT.

The testing utilized the Digital Simulation Facility (DSF) at the National Aviation Facilities Experimental Center (NAFEC) in a stand-alone configuration. The test environment simulated a single DABS sensor site serving a terminal ATC facility. Testing was accomplished utilizing the IPC algorithm provided by MITRE Corporation (reference 1). The algorithm was coded in FORTRAN by MITRE and inserted into the DSF's Sigma V processor. Numerous logic and coding changes were made by NAFEC to the algorithm as part of the testbed verification. These changes were reported by letter report dated May 1975, salient abstracts from that report are included as appendix B.

The simulated ATC facility configuration consisted of six ATC control positions; one local control, one departure control, two arrival control, and two "ghost" (enroute feeder) control positions. Typical traffic flows for the simulation are shown in figure 1. In addition to the in-house controllers, five field controllers who had been detailed to NAFEC for area navigation (RNAV) simulation studies participated in the IPC study for the major portion of these tests. These controllers were representatives from the following Terminal Radar Approach Control (TRACON) facilities: Houston, Atlanta, Minneapolis, New York, and Bradley Approach Control. They provided a valuable source of controller opinion on the IPC concept. The controllers' opinions and assessment of controller acceptability of the IPC function are presented in the DATA ANALYSIS section.

SYSTEM MODIFICATIONS.

Initial attempts to conduct an orderly, expeditious flow of traffic with the IPC function fully operable continually met with failure. It was virtually impossible to land any aircraft because of the high number of IPC commands occurring on and about the final approach course. Some "desensitization" of IPC was required within the immediate instrument landing system (ILS) turn-on area in order to eliminate unnecessary IPC commands if a reasonable operation was to be achieved. Figure 2 shows the desensitized area used for the remainder of the tests. This desensitization deleted IPC encounters between landing aircraft and aircraft on the airport surface, and between pairs of arrival aircraft on adjacent parallel or converging ILS courses. Only encounters between controlled aircraft pairs within the zone were eliminated from IPC processing. If a controlled aircraft outside the zone or an uncontrolled aircraft were in conflict with an aircraft inside the zone, the IPC alarm was not deleted. An effort was made to minimize the size of the zone so as to retain as much IPC protection as possible while attempting to delete as many false alerts and unnecessary commands as practicable. The zone was tailored to the specific terminal area tested and is not to be considered as a general solution applicable to every airspace and airport/route configuration.

Another modification, which was of significant value in reducing alerts, was a change in IPC vertical separation thresholds from 1,000 feet to 750 feet. Since the ATC system considers as acceptable, at least in the low-altitude

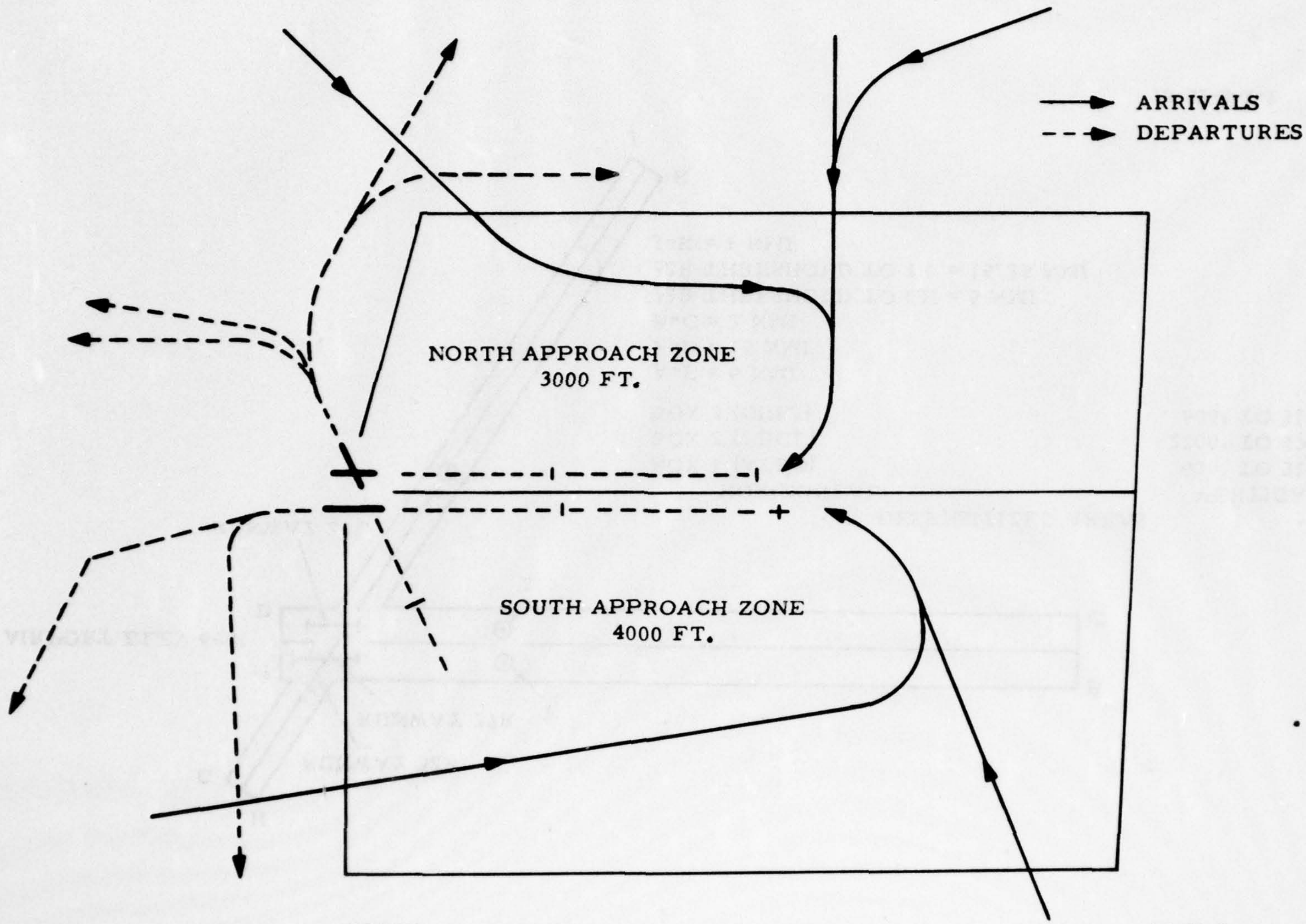

FIGURE 1. TERMINAL AREA TRAFFIC FLOW

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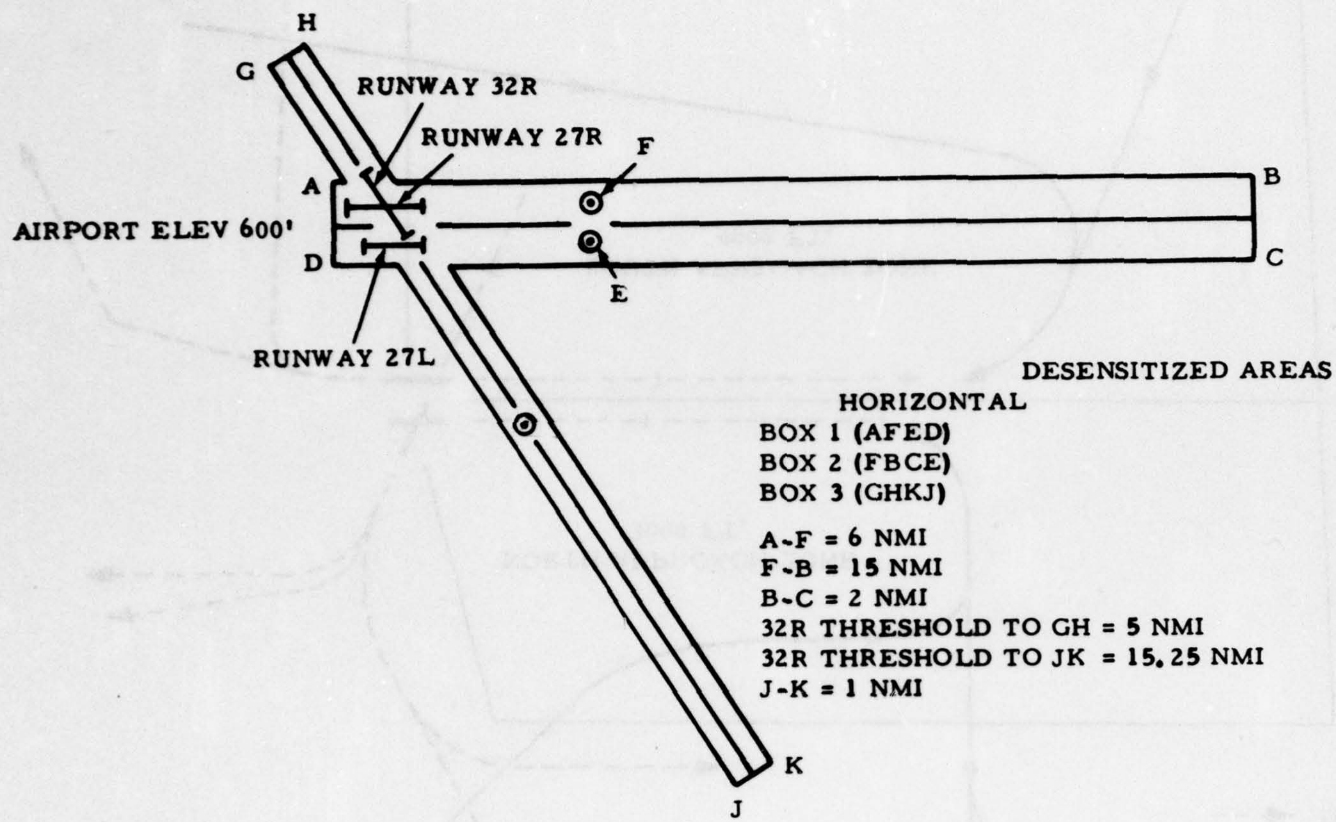

DESENSITIZED AREAS

HORIZONTAL	VERTICAL
BOX 1 (AFED)	600' TO 3100'
BOX 2 (FBCE)	2200' TO 4700'
BOX 3 (GHKJ)	600' TO 3100'

A-F = 6 NMI
F-B = 15 NMI
B-C = 2 NMI
32R THRESHOLD TO GH = 5 NMI
32R THRESHOLD TO JK = 15.25 NMI
J-K = 1 NMI

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FIGURE 2. DESENSITIZED IPC AREA USED IN NAFEC SIMULATION FOR CONTROLLED OPERATIONS

stratum, vertical separation criteria of 1,000 feet between IFR aircraft, it seemed meaningless to alert the controller when this separation existed. However, it was observed that many of the remaining controller alerts occurred outside the ATC separation envelope when no real hazard was involved. The algorithm currently being used in ongoing tests uses 770 feet as the minimum IPC vertical separation threshold.

In the IPC logic given to NAFEC, no attempt had been made to test the relative time of aircraft horizontal and vertical convergence. It was possible for an aircraft pair to be diverging in one dimension while converging in the other. Under such circumstances, no alarm should be required. Logic was developed at NAFEC, reported to SRDS, and added to the IPC algorithm. An analysis of eight test runs in which this logic was applied resulted in reductions in unnecessary controller alerts on the average of 55 percent and in some runs, up to 75 percent.

Further analysis of interim data indicated that a considerable number of controller alerts were being generated for only a one-scan (4-second) duration. This would seem to be a logical reaction in a densely populated aircraft environment where most aircraft are maneuvering. The effect on the controller, however, is a distracting radar display of flashing data blocks. To preclude this condition, the IPC logic was changed to require that the controller alert condition persist for two out of three scans before displaying it to the controller. The result was a significant reduction in one-scan alerts.

All controlled aircraft in the system had full data blocks displayed on the controller plan position indicator (PPI). Uncontrolled aircraft were displayed with a limited data block showing only mode C altitude information. During an encounter that involved an uncontrolled aircraft, the identification of a DABS-equipped aircraft was forced into the data block. When the controller alert was displayed, the aircraft's data block was blinked, and a steady velocity vector 60 seconds in length was displayed from the target position along the track determined by the IPC tracker. When the threshold for FPWI was reached, the character "F" was displayed flashing in the third line of the data block, left justified. When commands were generated, the "F" was deleted. Positive commands were displayed left justified on the third line and negative commands on the right. Negative commands were prefixed with an "N." Figure 3 depicts representative sequences of events between two aircraft during encounters.

At this point, it is important to mention that along with the foregoing algorithm changes and additions, several coding deficiencies and errors were detected. It is emphasized that testbed verification was conducted to assure that the algorithm was acceptable for operational testing; however, traffic scenarios were primarily single-pair encounters and the detection of many deficiencies required the presence of a large number of aircraft. Considerable effort and time were expended in analyzing and improving the basic algorithm so that a reasonable assessment of IPC/ATC interaction could be made.

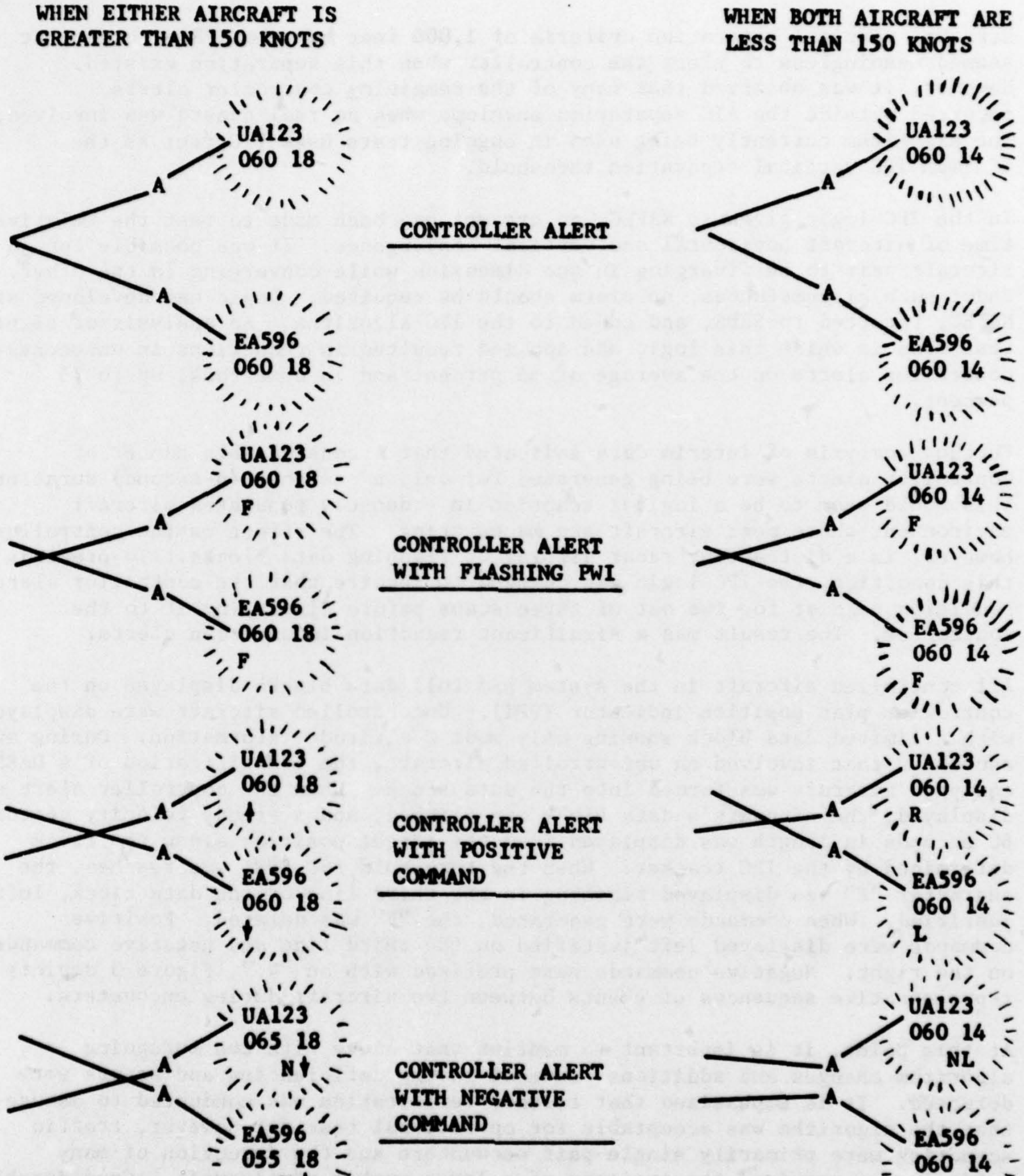

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FIGURE 3. IPC PPI DATA DISPLAY

DATA ANALYSIS

GENERAL.

In all test series, the terminal area encompassed an area of 30-nautical-miles (nmi) radius from the center of the airport. All IPC encounters, where one or both aircraft were within this region, were counted. Mode C capability for all aircraft as well as perfect surveillance accuracy was assumed in all tests. Simulation runs were 1 hour and 15 minutes, providing 15 minutes for traffic buildup with the last hour for data collection. Field and NAFEC controllers were randomly assigned to the critical control positions. IPC message rates are presented herein in terms of the number and duration of controller alerts, FPWIs and commands that were generated during the data hour. The results are based on the IPC algorithm defined in reference 1 and modified by NAFEC. The IPC parameters AF and AFIFR referred to in this reference are defined in the IPC logic as follows: AF is the vertical range threshold for a controller alert or command to be declared; AFIFR is the vertical range threshold for an FPWI to be declared to a controlled aircraft. All references to standard ATC separation mean 1,000 feet vertical or 3 nmi horizontal. No consideration was given to variable types of separation used between heavy and light aircraft as a result of wake turbulence avoidance.

The results are presented by series in the following order:

1. High-density all-arrival IFR series,

2. IFR series,

3. VFR series, and

4. Controlled/uncontrolled series.

HIGH-DENSITY ALL-ARRIVAL IFR SERIES.

A total of six test runs was made of high-density IFR arrival operations to parallel runways. No departure operations were included. With no requirement to provide spacing for departures, interarrival spacing was based solely on ensuring adequate arrival runway occupancy separation.

The traffic samples contained 135 arrival aircraft of which 25 percent were ATCRBS and 75 percent DABS. Four variations of the basic traffic sample with randomly generated aircraft start times, aircraft identification, and start fixes were used in the first four runs. Two of these samples were then used in runs 5 and 6. An average of 92 arrival operations per hour was obtained over the six runs. The controlled/controlled encounter logic was used with threshold parameter values for AF and AFIFR of 750 feet.

Table 1 presents IPC hourly message rates for runs 1 through 6. In runs 1 through 4, controllers were instructed to use standard procedures and did not alter techniques to accommodate IPC. However, in runs 5 and 6, controllers

TABLE 1. IPC ENCOUNTERS IN THE HIGH-DENSITY ALL-ARRIVAL IFR SERIES

Test Run	No. of CALERTS	No. of Scans	No. of A/C FPWIs	No. of A/C Scans	No. of A/C Cmds	No. of A/C Scans
1	5	19	4	10	0	0
2	6	21	6	16	0	0
3	19	63	23	51	7	12
4	19	75	24	64	8	28
Totals	49	178	57	141	15	40
Average	12.3	3.6	14.3	2.5	3.8	2.7
5*	6	25	6	8	2	4
6*	8	17	6	12	0	0
Totals	14	42	12	20	2	4
Average	7	3.0	6	1.7	1	2

*During these runs controllers were instructed to use the following techniques:

a. Stagger turn-ons of aircraft from north and south of the ILS course,
b. Ensure ILS intercept heading not greater than 30°,
c. Ensure that aircraft are at ILS intercept altitude (3,000 vs. 4,000) at least 4 nmi laterally from centerline between ILS courses, and
d. Ensure that aircraft are at 170 KIAS or less, when 6 nmi laterally from ILS course.

were instructed to use those control techniques indicated below table 1. The altered ATC procedures were not considered to be major changes to standard ATC control procedures. Their purpose was to reduce aircraft closure rates close-in to the ILS courses and to obviate the IPC tracker overshoot problem experienced in the horizontal and vertical dimensions.

Looking across the table for run 1, it can be seen that five controller alerts were generated, which persisted for a total duration of 19 scans. The column headed "No. of CALERTS" actually indicates total number of IPC encounters, since a controller alert by design persists throughout the whole encounter for controlled/controlled aircraft pairs. The fourth and fifth columns show that four aircraft received FPWI for a total duration of 10 scans (average duration 2.5 scans per aircraft). In the five encounters, no commands were generated.

For runs 1 through 4, table 1 shows an average of 12.3 controller alerts per hour. However, this average is somewhat nonrepresentative because of the marked variability in controller alert rates between runs 1 and 2, and 3 and 4. A detailed analysis and discussions with NAFEC and field controllers participating in these runs revealed that the difference in encounter rates from one run to another was primarily due to the difference in controller teams and their control techniques. Field controllers representing a cross-section of facilities utilized techniques considered by them to be standard, day-to-day control methods. In order to substantiate test team observations concerning the effect of control techniques, an additional two runs, 5 and 6, were made. As can be seen in table 1, IPC encounter message rates in runs 5 and 6 are comparable to runs 1 and 2, but are substantially less than that obtained in runs 3 and 4. It is noted that the control procedures used in runs 1 and 2 were comparable to those in runs 5 and 6, and, in fact, were the basis from which the special procedures were derived.

Table 2 shows hourly arrival rates, average number of control instructions per aircraft controlled (vector, altitude, and speed instructions issued by controller), and number of IPC encounters for runs 1 through 6. Average hourly operation rates dropped from 95 to 88 aircraft and controller workload increased by 29 percent, when comparing runs 3 and 4 to the special procedure runs 5 and 6. Although inconclusive because of the small sample of runs involved, it does point out that the use of special control procedures to accommodate IPC can result in higher controller workload. This same tendency of lower IPC activity and higher workload is also evident in runs 1 and 2.

TABLE 2. AVERAGE HOURLY OPERATIONS RATES AND CONTROL INSTRUCTIONS, HIGH-DENSITY ALL-ARRIVAL IFR SERIES

Run No.	No. of Arrivals	Average No. of Instructions per Aircraft	No. of IPC Encounters
1	93	7.2	5
2	93	7.4	6
3	95	5.4	19
4	95	4.8	19
5	89	6.3	6
6	87	6.9	8

Tables 3 (runs 1 through 4) and 3a (runs 5 and 6) present a breakdown of the total number of encounters and command encounters by control position and whether one or both aircraft were located outside the densensitized zone. As can be seen in table 3, the encounters are evenly distributed among the control positions. However, this is not the case for runs 5 and 6 in table 3a, where all but one north/south encounter was eliminated. When both of the aircraft pairs are under the control of one controller, the majority of encounters are outside the desensitized zone, indicating that normal single-stream sequencing close-in to the ILS should produce minimum IPC encounters in the critical ILS zone. When two controllers are involved, the majority of encounters occur with one of the aircraft on or within 0.6 nmi of the ILS course.

Most IPC encounters occurred 10 to 15 nmi east of the runways. This area is where most aircraft are being vectored to the ILS final approach. Figure 4 shows the percentage distribution of the location of encounters relative to the centerline between the parallel ILS courses. Fifty percent of the total IPC encounter scans occurred within 4 nmi of either side of the centerline and 90 percent within 12 nmi.

In the 6 hours of runs, there was only one occasion (four scans) in which simultaneous encounters occurred. In this case, one pair was under the South Controller and the other pair under the North Controller. One multiple encounter occurred involving three aircraft. One aircraft, located 5 nmi east and 3 nmi north of the runway heading east on the downwind leg, was in conflict with an aircraft 9 nmi east and 2 nmi north on intercept to 27R. Because of the increased command threshold from 45 to 75 seconds for a multiple encounter, a command was issued to a third aircraft already established on the 27R ILS course about 13 nmi east of the runway. All three aircraft received vertical maneuver commands even though all aircraft were separated from each other by more than ATC separation standards. Six of the command encounters in table 3 occurred when one of the aircraft was within a lateral distance of 3 nmi of the ILS course. As shown in table 3, three command encounters occurred when one of the aircraft was in the desensitized zone. With the exception of two encounters involving five scans of negative commands, all of the rest were vertical positive commands of short duration.

Table 4 lists the number of scans that the controller was alerted and the number of scans of FPWI that were displayed to the pilot prior to each of the eight IPC-generated commands.

It is evident that most commands were of short duration; five of the eight persisted for only two scans (8 seconds), the minimum number of scans for positive commands. In five of the eight, the controller was not alerted prior to the command. In fact, in each of these five encounters, the pilot received an FPWI before the controller was alerted. This occurred because of the two-out-of-three rule which required that the alert status exist for two-out-of-three consecutive scans before displaying the alert to the controller; no such rule applied to FPWI. Short alert times prior to commands occurred for the most part when one or both aircraft were turning. Controllers vectoring aircraft close-in to the ILS courses momentarily set up situations which looked dangerous to IPC, but because the controller continued turning the aircraft, the command situation dissipated quickly.

TABLE 3. IPC ENCOUNTERS AND COMMAND ENCOUNTERS BY CONTROL POSITION, HIGH-DENSITY ALL-ARRIVAL IFR SERIES (RUNS 1 THROUGH 4)

Control Position	Encounters		Command Encounters	
	In Zone	Out of Zone	In Zone	Out of Zone
North Arrival/North Arrival	1	16	0	2
North Arrival/South Arrival	12	5	2	0
South Arrival/South Arrival	2	13	1	2
Total	15	34	3	4

TABLE 3a. IPC ENCOUNTERS AND COMMAND ENCOUNTERS BY CONTROL POSITION, HIGH-DENSITY ALL-ARRIVAL IFR SERIES (RUNS 5 AND 6)

Control Position	Encounters		Command Encounters	
	In Zone	Out of Zone	In Zone	Out of Zone
North Arrival/North Arrival	0	5	0	0
North Arrival/South Arrival	1	0	0	0
South Arrival/South Arrival	1	7	0	1
Totals	2	12	0	1

NOTE: "In Zone" means one aircraft in desensitized zone and the other outside zone. "Out of Zone" means both aircraft outside desensitized zone.

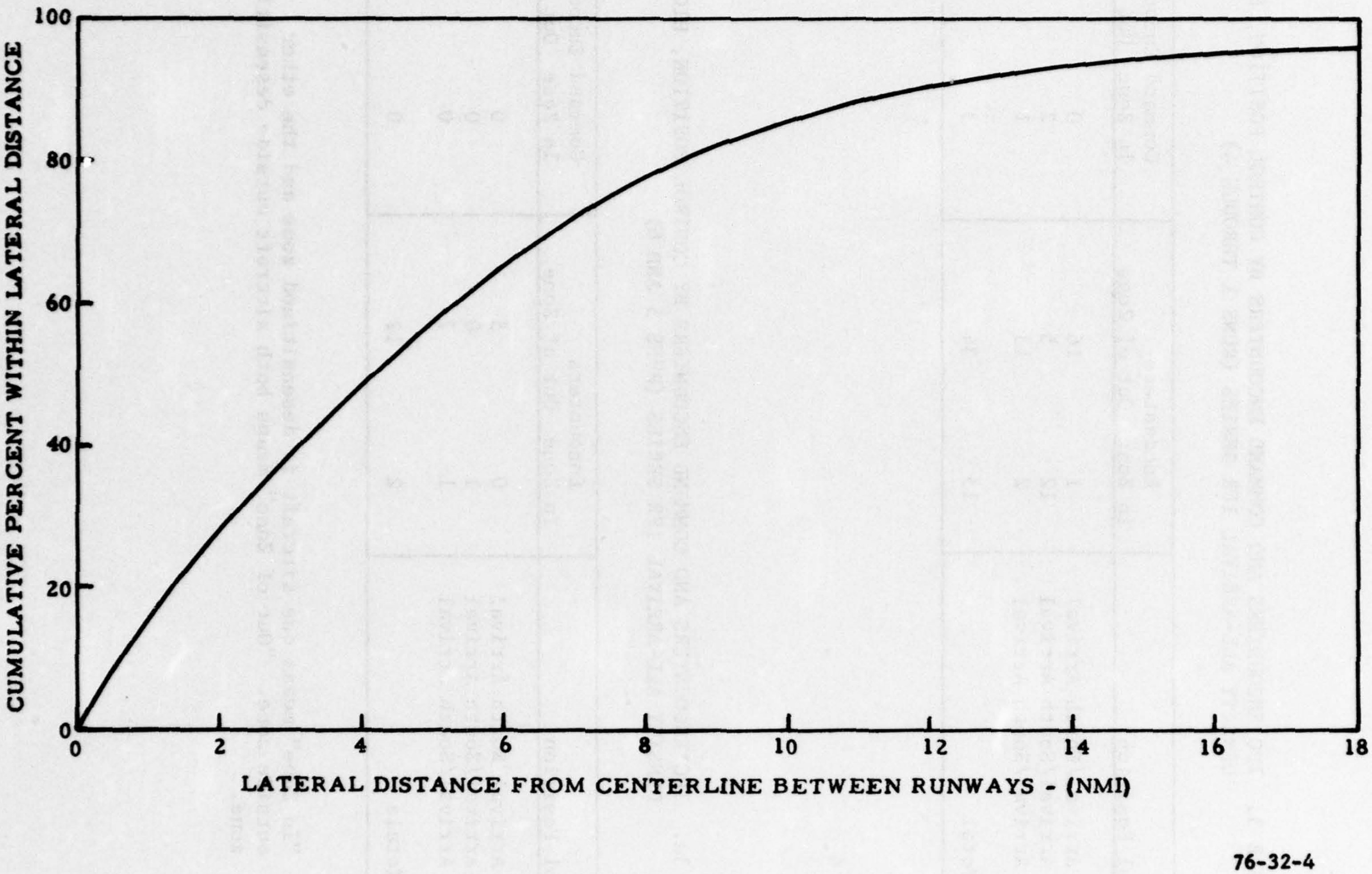

FIGURE 4. CUMULATIVE PERCENT OF AIRCRAFT SCANS IN WHICH A CONTROLLER ALERT EXISTED

TABLE 4. COMMAND ENCOUNTERS--HIGH-DENSITY ALL-ARRIVAL IFR SERIES (RUNS 1 THROUGH 6)

Encounter Number	Controller Alerted This No. of Scans Prior to Command	Pilot Rec'd FPWI This No. of Scans Prior to Command	Command Duration Scan	Aircraft Profile
1	0	1	2	Turning
2	0	1	1	Not Turning
3	3	4	2	Not Turning
4	0	1	7	Turning
5	6	3	2	Not Turning
6	0	1	2	Turning
7	3	4	3	Not Turning
8	0	1	2	Turning

There is no doubt that the special ground rules in runs 5 and 6 were effective in reducing message rates; however, the relative effectiveness of each of the four control techniques is not known. All that can be concluded is that careful avoidance of track geometries that tend to produce high vertical or horizontal closure rates can reduce IPC message rates. However, these restraints appear to interact with ATC and would not be acceptable to the ATC system.

Figure 5 shows the separation between aircraft pairs that existed during each scan of the IPC encounters in runs 1 through 6. Also indicated in this figure is the type of IPC message, i.e., controller alert, FPWI, or command that existed. Over 95 percent of all IPC encounters occurred when aircraft were separated by more than normal ATC separation criteria of 3 nmi horizontal or 1,000 feet in altitude. Alerts and FPWI even occurred when aircraft were separated by more than 5 nmi and some of these aircraft never approached any closer. It is to be noted that no heavy aircraft requiring greater than standard separation were used in the traffic samples.

Figure 6 is a scatter plot showing projected miss distance and estimated time to closest approach (TH) for each scan of the IPC encounters in runs 1 through 6. The data points are uniformly distributed between 0 and 1 nmi. If the projected miss distance used by the IPC algorithm as a threshold for declaring a controlled/controlled encounter were decreased from 1 nmi to 0.5 nmi, the impact on message rates would be as shown in table 5. Original data from table 1 are repeated for ease of reference. Controller alerts decreased by 33 percent and commands by 41 percent by using a projected miss distance of 0.5 nmi. In addition to reducing to a 0.5-nmi miss distance, the TH time thresholds were reduced from 75 to 60 seconds for controller alert, 60 to 45 seconds for FPWI and 45 to 32 seconds for commands. Table 6 shows that further reductions would result in an overall decrease of 71 percent in controller alerts and 87 percent in commands. Original data from table 1 are repeated for ease of reference.

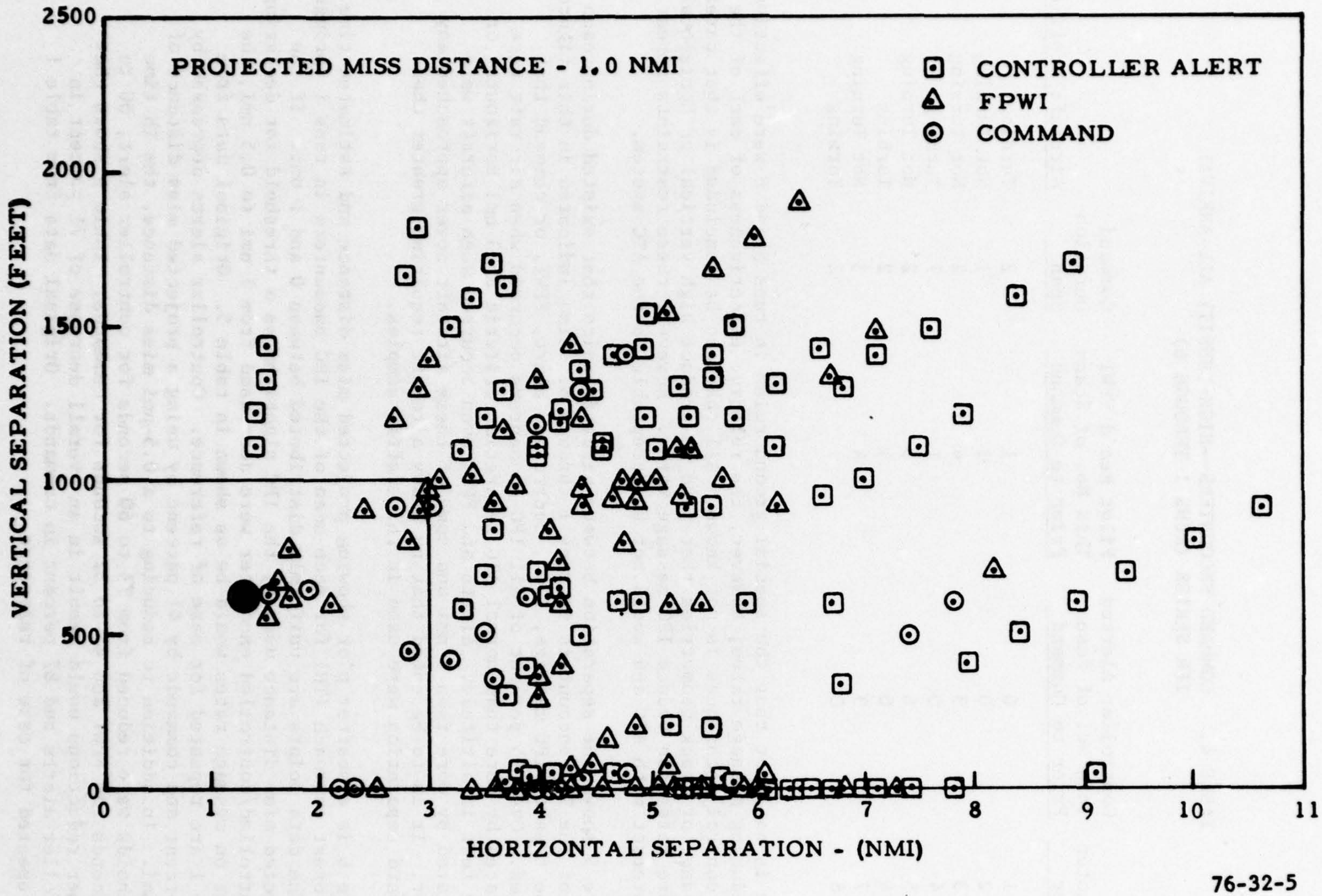

FIGURE 5. SEPARATION BETWEEN AIRCRAFT FOR EACH SCAN OF IPC ENCOUNTERS

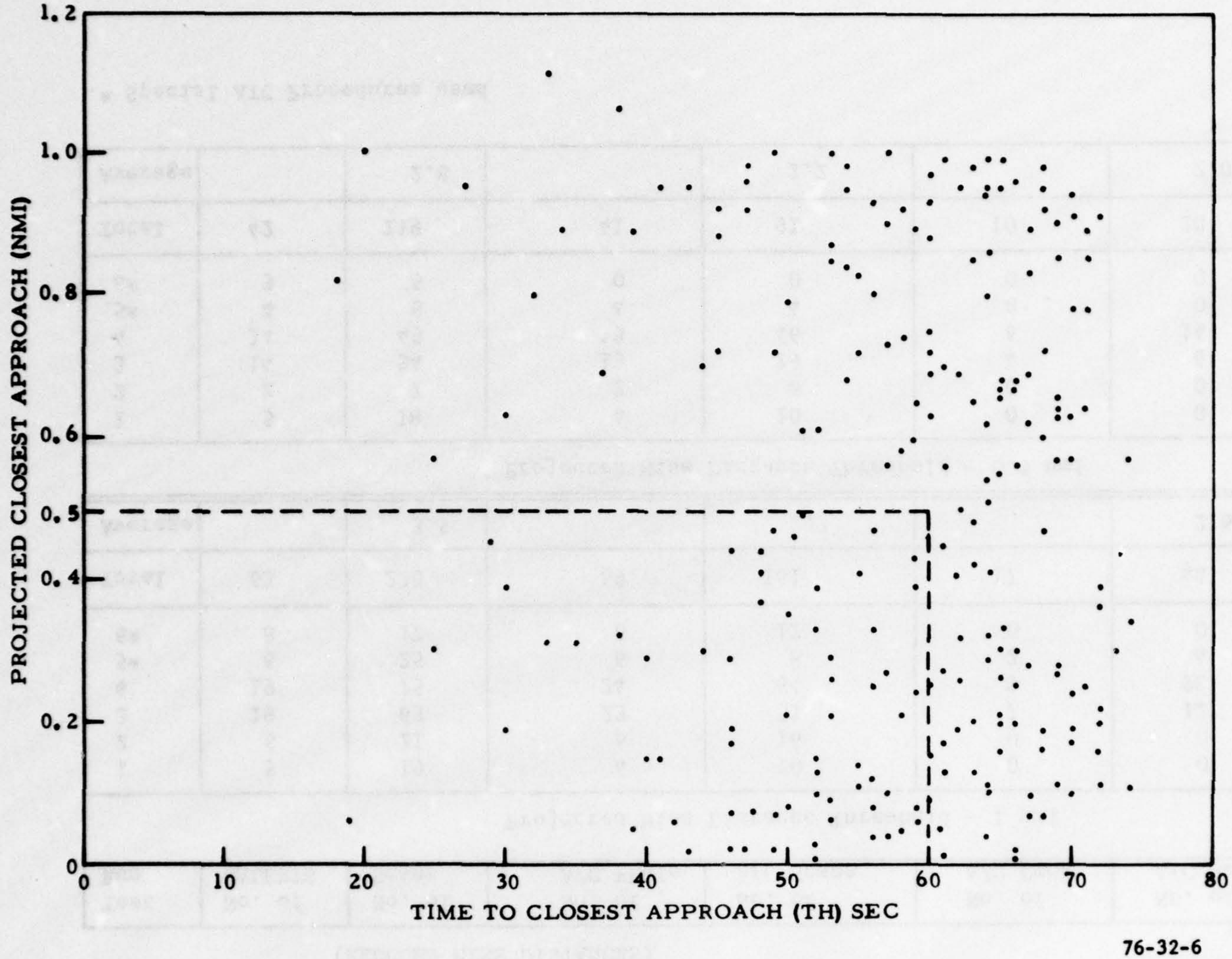

FIGURE 6. PROJECTED MISS DISTANCE AND TIME OF CLOSEST APPROACH FOR EACH SCAN OF IPC ENCOUNTERS

TABLE 5. IPC ENCOUNTERS IN IFR ARRIVAL OPERATIONS TO PARALLEL RUNWAYS (REDUCED MISS DISTANCES)

Test Run	No. of CALERTS	No. of Scans	No. of A/C FPWIs	No. of A/C Scans	No. of A/C Cmds	No. of A/C Scans
Projected Miss Distance Threshold = 1 nmi						
1	5	19	4	10	0	0
2	6	21	6	16	0	0
3	19	63	23	51	7	12
4	19	75	24	64	8	28
5*	6	25	6	8	2	4
6*	8	17	6	12	0	0
Total	63	220	69	161	17	44
Average		3.5		2.3		2.6
Projected Miss Distance Threshold = 0.5 nmi						
1	5	18	4	10	0	0
2	2	7	2	6	0	0
3	14	34	13	25	4	6
4	14	49	18	46	6	14
5*	4	6	4	4	0	0
6*	3	5	0	0	0	0
Total	42	119	41	91	10	20
Average		2.8		2.2		2.0

* Special ATC Procedures used

TABLE 6. IPC ENCOUNTERS IN IFR ARRIVAL OPERATIONS TO PARALLEL RUNWAYS (REDUCED MISS DISTANCE AND TIME THRESHOLDS)

Test Run	No. of CALERTS	No. of Scans	No. of A/C FPWIs	No. of A/C Scans	No. of A/C Cmds	No. of A/C Scans
Projected Miss Distance Threshold = 1 nmi						
1	5	19	4	10	0	0
2	6	21	6	16	0	0
3	19	63	23	51	7	12
4	19	75	24	64	8	28
5*	6	25	6	8	2	4
6*	8	17	6	12	0	0
Total	63	220	69	161	17	44
Average		3.5		2.3		2.6
Projected Miss Distance Threshold = 0.5 nmi CA = 60 sec FPWI = 45 sec CMD = 32 sec						
1	3	5	0	0	0	0
2	1	2	0	0	0	0
3	5	9	2	4	0	0
4	8	25	4	10	2	4
5*	1	1	2	2	0	0
6*	0	0	0	0	0	0
Total	18	42	8	16	2	4
Average		2.3		2.0		2.0

* Special ATC Procedures Used.

Figure 7 is a plot of the separation that existed during each scan of those IPC encounters remaining after using the reduced projected miss distance of 0.5 nmi and the reduced time thresholds. It can be seen that about 80 percent of the encounters still occur outside ATC separation criteria. In table 6, the number of command encounters has been reduced to only one encounter (two aircraft commands).

IFR SERIES (ARRIVALS/DEPARTURES).

A total of six runs was made using IFR control procedures in a medium-density ATC terminal environment in which three runways were used. High-performance arrival aircraft were vectored for an ILS approach to runway 27R, lower performance arrival aircraft to 32R, and departure aircraft, regardless of performance category, departed on runway 27L or 32R dependent upon direction of flight after takeoff. Traffic load consisted of 104 aircraft with 25-percent ATCRBS and 75-percent DABS equipped, with one-half of the aircraft scheduled departures and the other half arrivals. Controllers were randomly assigned to the three critical operating positions; two arrival controllers and one departure controller. A different random variation of the basic traffic sample was used for each of runs 7 through 10. Two of these samples were then used for runs 11 and 12. An average of 82 operations per hour was obtained over the six runs.

Table 7 shows IPC hourly encounter rates for runs 7 through 12. During runs 7 through 10, controllers were instructed to control traffic using normal ATC operating procedures. Two runs (11 and 12) were conducted where the controllers were instructed to follow the five special control procedures listed in table 7. The table indicates that these special procedures significantly reduced the number of encounters and commands.

Table 8 shows no significant change in airport operations rate as a result of introducing the special procedures. These results were influenced by the use of the medium-density traffic sample which did not saturate the area with aircraft. Although not as pronounced as that exhibited in the all-arrival IFR series, there was a tendency (about 15 percent) for the control efforts per aircraft to increase in the special procedure runs.

Tables 9 (runs 7 through 10) and 9a (runs 11 and 12) present a breakdown of the number of encounters and command encounters per control position, and whether in or out of the desensitized zone about the ILS course.

When both aircraft were under the control of one arrival controller, the majority of encounters were outside the desensitized zone. When two arrival controllers were involved, the majority of encounters occurred when one of the aircraft was inside the zone. These results agreed with those observed in the high-density all-arrival IFR series.

Ninety-five percent of all encounters occurred within 15 nmi of the airport, and 75 percent, within 10 nmi. In the 6 hours, there were no occasions where simultaneous alerts were being displayed to the controller. One multiple encounter involving three aircraft outside the desensitized zone, all under

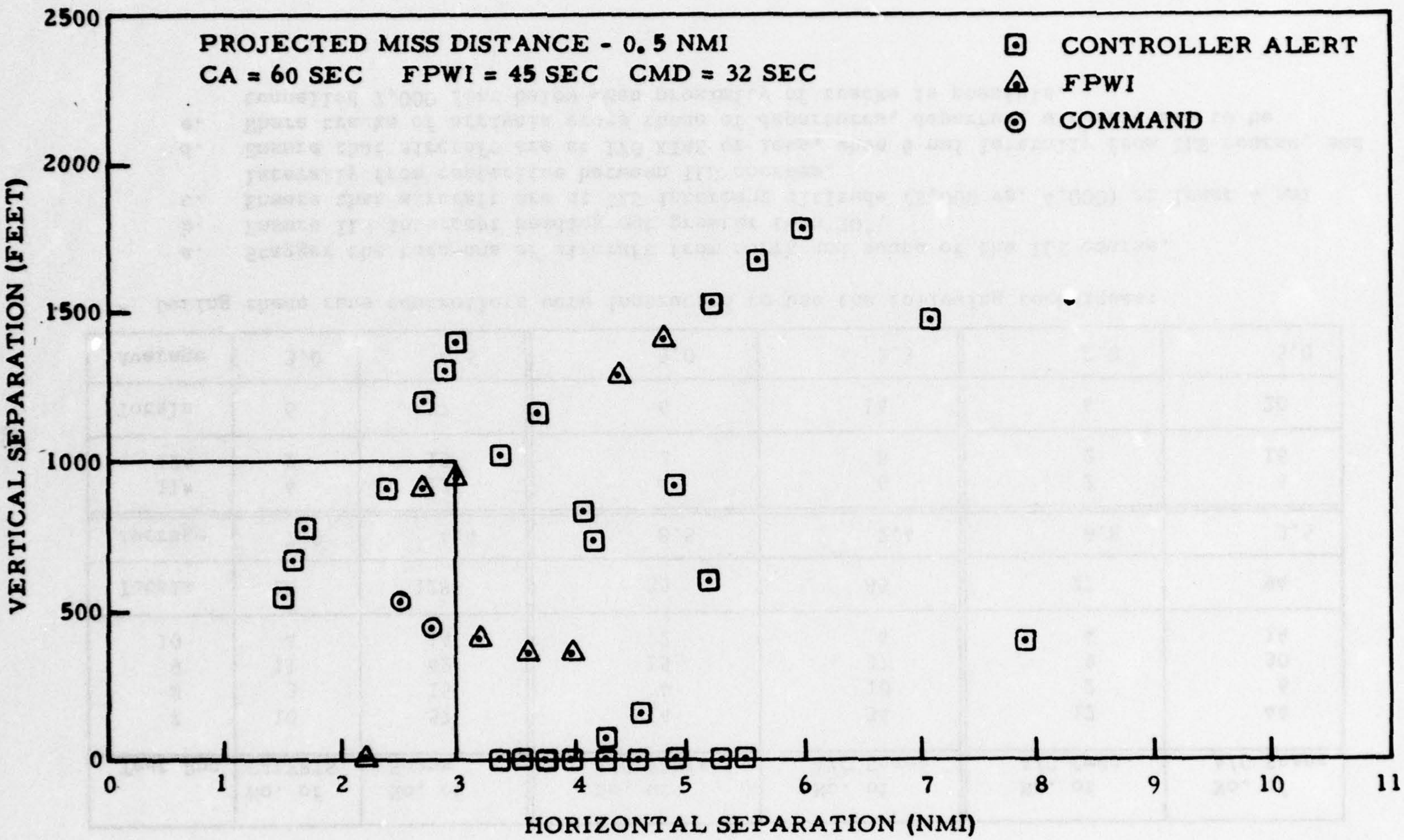

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FIGURE 7. SEPARATION BETWEEN AIRCRAFT FOR EACH SCAN OF IPC ENCOUNTERS

TABLE 7. IPC ENCOUNTERS IN THE IFR SERIES (ARRIVAL/DEPARTURE)

Test Run	No. of CALERTS	No. of Scans	No. of A/C FPWIs	No. of A/C Scans	No. of A/C Cmds	No. of A/C Scans
7	10	57	14	34	12	44
8	3	15	4	10	2	6
9	11	42	15	37	9	30
10	4	14	2	4	4	14
Totals	28	128	35	85	27	94
Average	7.0	4.4	8.8	2.4	6.8	3.5
11*	4	12	4	6	2	4
12*	2	15	2	8	2	16
Totals	6	27	6	14	4	20
Average	3.0	4.5	3.0	2.3	2.0	5.0

* During these runs controllers were instructed to use the following techniques:

a. Stagger the turn-ons of aircraft from north and south of the ILS course,
b. Ensure ILS intercept heading not greater than 30°,
c. Ensure that aircraft are at ILS intercept altitude (3,000 vs. 4,000) at least 4 nmi laterally from centerline between ILS courses,
d. Ensure that aircraft are at 170 KIAS or less, when 6 nmi laterally from ILS course, and
e. Where tracks of arrivals cross those of departures, departure aircraft are to be tunnelled 2,000 feet below when proximity of tracks is possible.

TABLE 8. AVERAGE HOURLY OPERATIONS RATES AND CONTROL INSTRUCTIONS, IFR SERIES

Run No.	Operations Rate	Avg. No. of Instructions Per Aircraft
7	84	3.4
8	81	3.3
9	83	3.9
10	79	3.4
11	83	4.1
12	81	4.0

TABLE 9. IPC ENCOUNTERS AND COMMAND ENCOUNTERS BY CONTROL POSITION--IFR SERIES (RUNS 7 THROUGH 10)

	Encounters		Command Encounters	
Control Position	In Zone	Out of Zone	In Zone	Out of Zone
North Arrival/North Arrival	1	1	1	1
North Arrival/Departure	0	5	0	3
North Arrival/South Arrival	6	1	1	0
South Arrival/South Arrival	0	7	1	2
South Arrival/Departure	0	3	0	1
Departure/Departure	0	4	0	3
Total	7	21	3	10

TABLE 9a. IPC ENCOUNTERS AND COMMAND ENCOUNTERS BY CONTROL POSITION--IFR SERIES (RUNS 11 AND 12)

	Encounters		Command Encounters	
Control Position	In Zone	Out of Zone	In Zone	Out of Zone
North Arrival/North Arrival	0	1	0	0
North Arrival/Departure	0	1	0	0
North Arrival/South Arrival	1	1	1	0
South Arrival/South Arrival	0	1	0	0
South Arrival/Departure	0	1	0	1
Departure/Departure	0	0	0	0
Total	1	5	1	1

Note: "In Zone" means one aircraft in desensitized zone and the other, outside zone. "Out of Zone" means both aircraft outside desensitized zone.

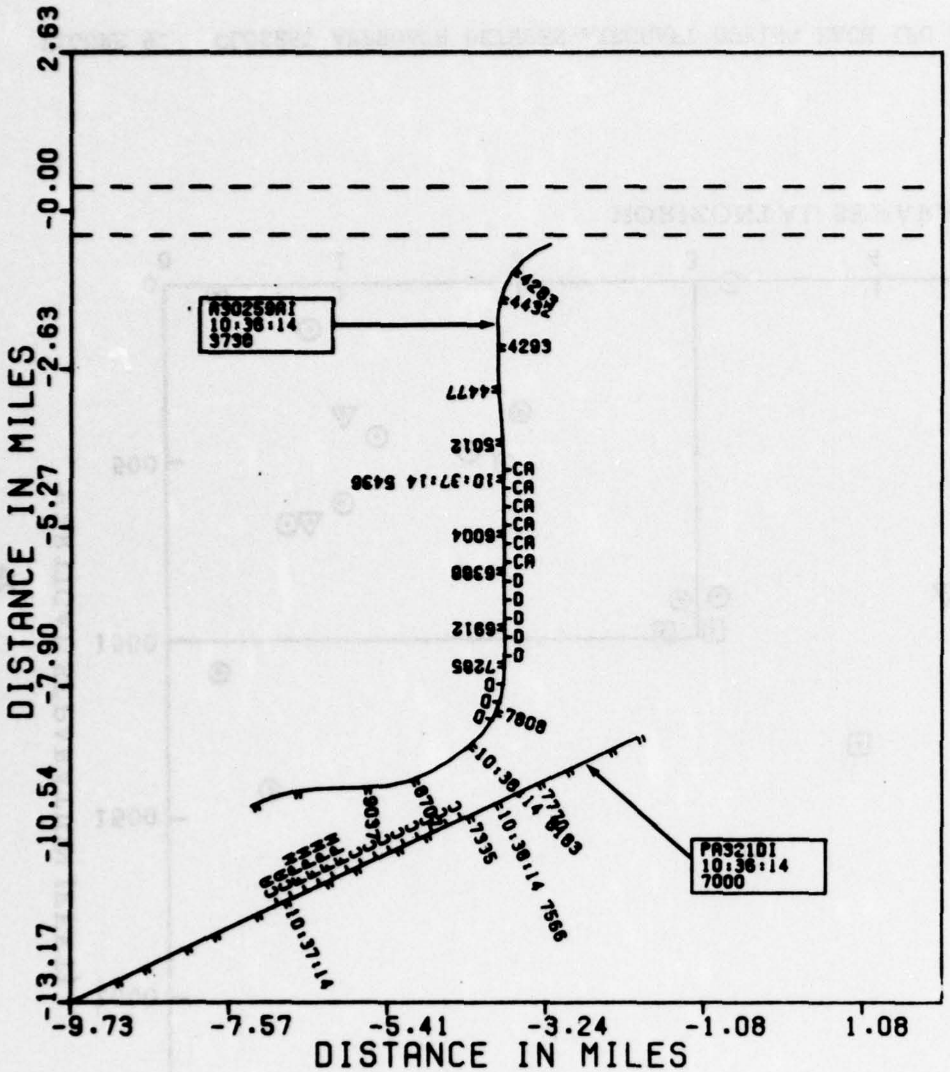
the jurisdiction of the South Controller, resulted in vertical positive commands to the three aircraft. The command only lasted two scans, and the closest any pair approached each other was 3.2 nmi horizontally and 717 feet vertically.

Fifty-three percent of the command encounters involved departures. Departure-versus-departure encounters were overtake situations; arrival-versus-departure were cases where IPC interfered with the controller's intent to pass the departure over the arrival. An example of such interference is illustrated in the encounter in figure 8.

As depicted in figure 8, aircraft A30259 is a departure aircraft and is not IPC-equipped. With a high rate of climb, it is apparent that adequate vertical separation would have been attained, but the climb command to PA321, an arrival with IPC equipment, places the aircraft in a climb-chase situation. Each aircraft at this time is under the jurisdiction of a different controller. The arrival controller did not countermand IPC. Whether or not he is coordinating with the departure controller is not known. The departure controller does not voice-link the descend command to his IPC-unequipped aircraft, since his plan was to have it pass above the arrival. When it occurs to him that the arrival is being commanded out of the normal procedural situation, i.e., to maintain 7,000 feet throughout this area, he finally gives a horizontal maneuver to correct the situation. This encounter typifies those situations where controller acceptance of IPC would be marginal. The controllers commented that the controller alert feature, even though in many cases premature, could be tolerated, but intrusion by IPC commands into ATC strategy prematurely could be very disruptive.

Looking at this encounter from another point of view and assuming that the controller was not in command of the situation, resolving the conflict in the vertical dimension was inappropriate, since in this case the possibility existed that the unequipped aircraft did not receive his command. In general, it can be said that the prime method of separating aircraft by a terminal radar controller is the radar vector or horizontal maneuver command. For this reason, IPC commands in the vertical dimension would, in most cases, be less disruptive in the arrival area. In the departure area, however, the need to pass under and above the arrival aircraft in many cases means that the departure controller utilizes altitude separation many more times. In addition, constraints imposed by the runway and required separation at that point give the departure controller a more uniform stream of traffic. In this situation, it is reasonable to assume that, all other things being equal, i.e., no adjacent restricted areas of control, a horizontal maneuver might be more acceptable to the controller.

Figure 9 shows the separation that existed between aircraft at the point of closest approach for each IPC encounter in runs 7 through 12. The type of message is also indicated in the figure. Nine of the 12 encounters that resulted in ATC violation involved a departure aircraft either being released too early behind a previous departure or a departure failing to pass above an arrival because IPC issued an interfering vertical command. As can be seen, the preponderance of IPC encounters occurred when aircraft pairs were separated by more than ATC separation criteria.



RUN 12 ENCOUNTER 2
PA321DI - 199 KTS
A30259AI - 265 KTS

TIME	IPC	RNG	DZ	RDOT	ZDOT	TH	TV	MIS
10:37:14	CA	7.7	1564	-398	2868	69	35	0.14
10:37:18	CA	7.3	1346	-401	2854	64	28	0.14
10:37:22	FPW	6.8	1176	-404	2758	60	26	0.15
10:37:26	FPW	6.4	996	-407	2742	55	22	0.16
10:37:30	FPW	5.9	807	-409	2770	51	17	0.18
10:37:34	FPW	5.4	612	-411	2818	46	13	0.19
10:37:38	C	5.0	413	-412	2870	42	9	0.19
10:37:42	C	4.5	258	-413	2701	38	6	0.20
10:37:46	C	4.1	88	-414	2653	33	2	0.20
10:37:50	C	3.6	94	-414	2678	29	-2	0.20
10:37:54	C	3.1	239	-414	2521	25	-6	0.20
10:37:58	C	2.7	357	-414	2290	20	-9	0.22
10:38:2	C	2.2	413	-415	1837	15	-13	0.29
10:38:6	C	1.7	472	-413	1545	10	-18	0.62

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FIGURE 8. ENCOUNTER PLOT IN HORIZONITAL PLANE

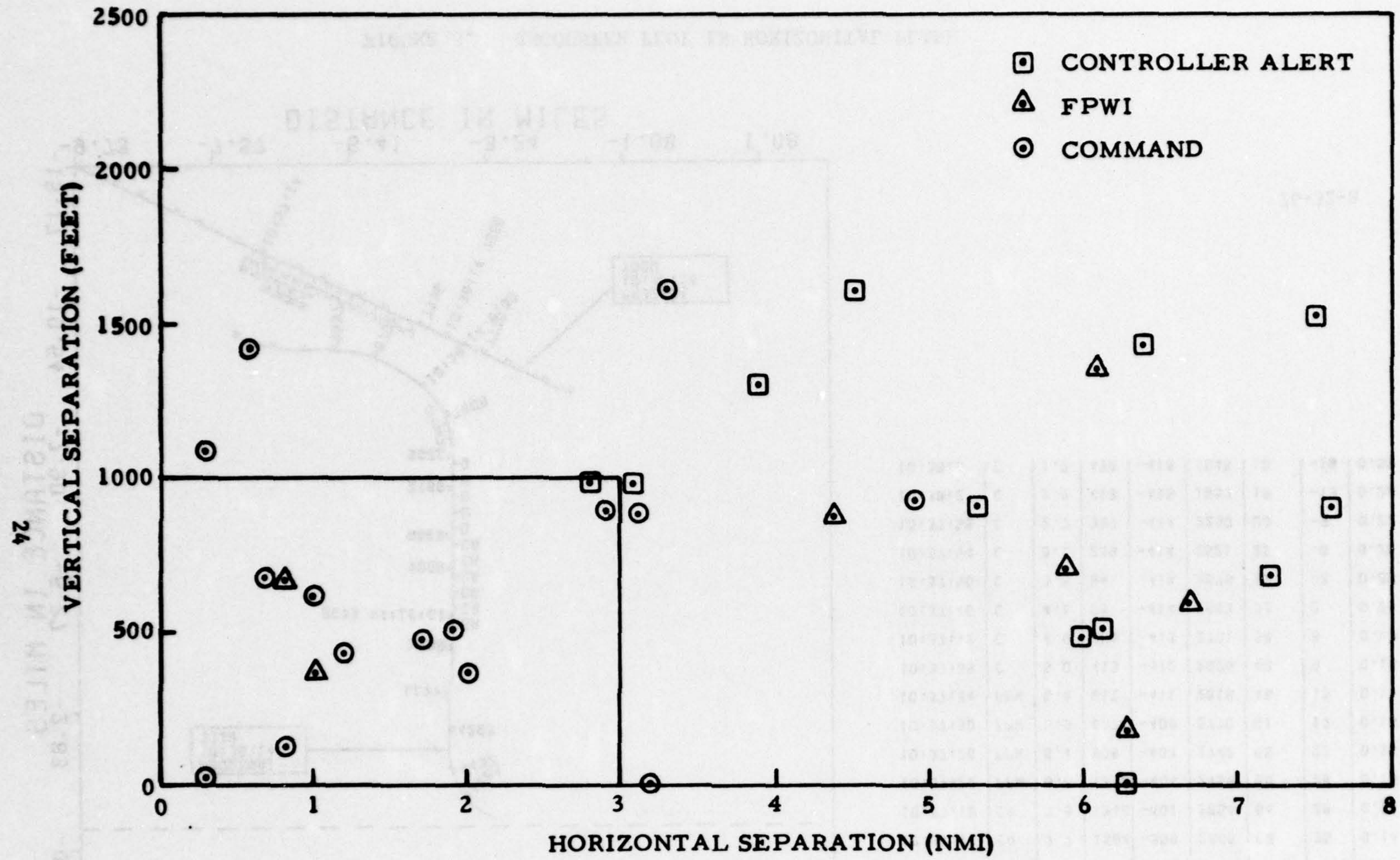

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FIGURE 9. CLOSEST APPROACH BETWEEN AIRCRAFT DURING EACH IPC ENCOUNTER - IFR SERIES- (RUNS 7 THROUGH 12)

Table 10 shows the number of scans that the controller was alerted and the number of scans of FPWI that was displayed to the pilot prior to each of the IPC-generated commands. In 9 of the 15 command encounters, the controller was alerted only one or no scans prior to the command. The majority occurred when aircraft were turning.

TABLE 10. COMMAND ENCOUNTERS--IFR SERIES (RUNS 7 THROUGH 12)

Encounter Number	Controller Alerted This Number of Scans Prior to IPC Command	Pilot Rec'd FPWI This No. of Scans Prior to IPC Command	Command Duration (Scans)	Aircraft Profile
1	0	1	6	Turning
2	1	2	2	Turning
3	9	4	5	Not Turning
4	3	2	5	Not Turning
5	1	-	2	Turning
6	3	3	2	Turning
7	3	2	3	Turning
8	0	1	5	Not Turning
9	1	2	2	Turning
10	0	1	4	Not Turning
11	1	-	3	Turning
12	4	2	4	Not Turning
13	1	-	3	Not Turning
14	1	2	2	Turning
15	6	4	8	Not Turning

Note: - = ATCRBS Aircraft, No Cockpit Display

VFR SERIES.

Four runs were conducted in a terminal area environment in which the meteorological conditions were such that VFR separation could be applied. For these tests, to simulate the "see and follow" or visual-approach type of separation, the controllers were permitted to use, where possible, a minimum separation of 1 nmi horizontal or 500 feet vertical. The controlled/controlled IPC logic was used with AF and AFIFR parameters set to 450 feet. Traffic samples contained 150 flights of which 40 percent were ATCRBS and 60 percent were DABS, with one-half of the flights scheduled arrivals and the other half departures.

Traffic flows to and from the airport and runway utilization were the same as in the IFR series. Operations rates averaged 103 aircraft per hour, about 25 percent higher than that obtained in the IFR series. IPC encounter data are presented in table 11. In comparing the first four runs of tables 7 and 11, there is a 50-percent increase in the number of controller alerts generated

TABLE 11. IPC ENCOUNTERS IN THE VFR SERIES

Run No.	No. of CALERTS	No. of Scans	No. of A/C FPWIs	No. of A/C Scans	No. of A/C Cmds.	No. of A/C Scans
13	11	48	18	40	8	28
14	18	75	16	34	11	57
15	5	20	2	6	0	0
16	8	60	14	40	8	32
Total	42	203	50	120	27	117
Average	10.5	4.8	12.5	2.4	6.8	4.3

and a 59-percent increase in total duration in the VFR series versus the IFR series. Average number of aircraft commands and average duration of encounter are comparable for both series.

In the VFR series, controllers were confronted for the first time with two unrelated IPC encounters at the same time. No such events were observed in any of the IFR test runs. Four occasions of simultaneous encounters occurred during the VFR test runs and involved the following controllers:

1.	Departure vs Departure aircraft--Vertical positive commands North Arrival vs. South Arrival--Vertical positive commands	2 scans
2.	North Arrival vs. Departure--Vertical positive commands North Arrival vs. South Arrival--Controller Alert	1 scan
3.	North Arrival vs. North Arrival--Vertical positive commands North Arrival vs. South Arrival--FPWI	1 scan
4.	North Arrival vs. North Arrival--Vertical positive commands North Arrival vs. North Arrival--Controller Alert and FPWI	4 scans

Only encounters 2, 3, and 4 were displayed on the same controller display. Those controllers who held the north arrival position during these encounters might have had difficulty in quickly establishing priority of action. Actually, in these three cases, IPC established its own priority by generating controller alert and commands to one pair while issuing controller alert and FPWI to the other pair. However, when two unrelated simultaneous alerts are displayed a method of indicating priority of action to the controller would be beneficial. This could be a time-keyed indicator displayed on the controller alert vector lines.

The range from the airport at which the encounters occur was somewhat further in this series than was the case in the IFR series. Only 71 percent fell within 15 nmi of the airport; whereas, the IFR series showed 95 percent. The two major differences between the series were the increased density of traffic and the reduced separation criteria in the VFR series. Table 12 shows the distribution of encounters and commands by control position and whether one or both aircraft were outside the desensitized zone. As can be seen, the majority of encounters (62 percent) occurred in the arrival-versus-arrival operation, 24 percent between an arrival and a departure, and 14 percent between successive departures. A similar distribution of events by control position had been experienced in the IFR series. As was true in both the all-arrival and IFR series and was also true in the VFR series, when two arrival controllers were involved in an encounter, one of the aircraft was invariably inside the desensitized zone. However, when only one controller was involved, both aircraft were outside the zone.

TABLE 12. IPC ENCOUNTERS AND COMMAND ENCOUNTERS BY CONTROL POSITION--VFR SERIES (RUNS 13-16)

Control Position	Encounters In Zone	Encounters Out of Zone	Command Encounters In Zone	Command Encounters Out of Zone
North Arrival/North Arrival	1	5	0	2
North Arrival/Departure	0	7	0	3
North Arrival/South Arrival	12	2	3	0
South Arrival/South Arrival	1	5	1	0
South Arrival/Departure	1	2	0	1
Departure/Departure	1	5	0	3
Total	16	26	4	9

One multiple encounter occurred involving three aircraft, all under the north controller. It lasted for three scans, and vertical commands were generated to each aircraft. One pair approached 0.4 nmi, and the other pair 1.8 nmi, all at the same altitude and 10 nmi north of the ILS course.

In a VFR type of environment, where visual acquisition of one aircraft by another is the rule rather than the exception, there is less definitive control and consequently it can be expected to generate greater IPC activity. No requirements for altitude separation between opposite-side approaches and closer spacing of aircraft contribute to increasing alarm rates.

CONTROLLED/UNCONTROLLED SERIES.

This series represents a medium-density terminal area environment with an airport operations rate of 82 controlled aircraft and 84 uncontrolled aircraft transiting the area during the hour. For the uncontrolled aircraft, no communication existed between pilot and controller; however, the aircraft's target was displayed on the controller's PPI with a limited data block.

The construction of the uncontrolled sample in this series was based on information available in reference 2. Flight plans for each of the uncontrolled aircraft were randomly generated based on each of the following factors:

1. Start time,

2. Aircraft category; e.g., single engine, twin engine, high performance, low performance,

3. Transponder equipment--ATCRBS or DABS,

4. Flight plan class:
   a. Overflight-
      (1) ingress fix,
      (2) egress fix,
      (3) cruise altitude,

b. Outbound flight-
   (1) departure airport,
   (2) egress fix,
   (3) cruise altitude--climb profile based on aircraft category,

c. Inbound flight-
   (1) ingress fix,
   (2) arrival airport,
   (3) cruise altitude--descent profile based on aircraft category,

d. Local flights-
   (1) touch and go's
      (a) airport,
      (b) duration,
   (2) round robins,
      (a) airport,
      (b) route,
      (c) altitude,
      (d) duration,
   (3) local itinerant--from airport within local area to airport within local area
      (a) departure airport,
      (b) arrival airport,
      (c) cruise altitude.

The start time of each flight was randomly selected. Transponder mix for the uncontrolled flights was established as 75-percent ATCRBS and 25-percent DABS versus 25-percent ATCRBS and 75-percent DABS for controlled flight. Probabilities for random assignment of the flight plan factors were based on reference 2.

The tests were directed toward investigation of the controlled versus uncontrolled encounters and the attendant interaction with ATC. IPC logic for controlled/uncontrolled encounters contained in the algorithm defined in reference 1 has undergone considerable revision in threshold values and command selection since these tests were conducted. Hence, results presented herein are not representative of what might be expected from current ongoing algorithm tests. The amount of IPC activity resulting from uncontrolled intruder aircraft is dependent upon the uncontrolled traffic model used. Because of these factors, the presentation of numbers of encounters does not imply a representation of any particular real-world environment. Rather, they are used to focus attention on which aircraft receive commands and the location in the terminal area where one might expect problems to result from controlled/uncontrolled encounters.

In four runs there was a total of 24 encounters between controlled and uncontrolled aircraft. Fourteen of these encounters resulted in IPC commands. One was a multiple aircraft encounter involving two controlled and one uncontrolled aircraft, all of which received commands. In 8 of the 14, only the IFR aircraft received the command, because the uncontrolled was an ATCRBS aircraft unable to receive a command. Of those encounters in which the IFR was ATCRBS (three cases) and the controller elected not to relay the displayed command, only one encounter violated ATC separation criteria. In those cases where the IFR was DABS equipped, all encounters were safely resolved.

In 4 of the 14 command encounters, only the uncontrolled aircraft received the command. In three of these cases, the projected miss distance remained greater than 1 nmi; hence, neither a controller alert nor a command was generated to the IFR aircraft. In the remaining case, TH did not decrease below IFR command thresholds. It should be noted that in an environment such as this, the fact that nothing is displayed to the controller when the command is issued, only to an uncontrolled aircraft (because controller alert thresholds are not violated) could be dangerous. Within the current system, the controller is advised to call traffic to controlled aircraft, time permitting. Assume he calls traffic to an unequipped controlled aircraft, and the pilot requests to be provided separation. The controller will be aware that the uncontrolled is DABS equipped; however, he will have no knowledge of what maneuver the algorithm will issue. The maneuver he issues the controlled aircraft may possibly aggravate the situation. If he makes the assumption that IPC will provide the necessary separation, he has no way of knowing if the uncontrolled aircraft will, in fact, take the command. For several reasons, one being that the uncontrolled aircraft has the wrong aircraft in sight, the uncontrolled aircraft might not respond to the command. In the best circumstances, the controller will have unnecessarily moved a controlled aircraft. In the worst circumstance, he may have compounded the encounter. There would appear to be two alternatives to improve the situation;

1. Provide the controller with all data sent to an uncontrolled aircraft, and

2. Provide the controller with the command that has been acknowledged by the uncontrolled aircraft.

The first alternative gives the controller more information to assess the situation. The second alternative provides the controller with the information that the uncontrolled aircraft is at least aware of the situation, but still provides no clue as to compliance.

Occasionally, due to the short separation distances involved in uncontrolled/controlled encounters, it is difficult on a typical terminal PPI display to determine if the commanded uncontrolled aircraft will resolve the conflict. This situation is aggravated further by tracker lag which lags behind actual aircraft maneuver. Dependent upon aircraft speed and turn rate, this tracker lag could be up to 45° in error.

Those of the 14 command encounters which occurred outside 5 nmi laterally of the final approach course did not seriously disrupt ATC. However, controllers indicated that uncontrolled aircraft intruding with controlled aircraft that were near or already established on final approach seriously affected their orderly flow. The one multiple encounter occurred when an uncontrolled DABS aircraft overflying the airport at an improper altitude triggered a multiple aircraft encounter involving an ATCRBS departure flight and a DABS arrival flight on final approach to 27R. The arrival responded to a left-turn command directing the aircraft across the other parallel course, 27L. This was a dangerous situation and clearly indicated that a more extensive definition of a desensitized zone must be established than that used in these tests. The desensitized zone used deleted IPC messages to IFR pairs within the zone. In this particular encounter, an IFR aircraft on final approach to 27L might not have been protected from the aircraft on 27R taking the left-turn maneuver.

RESULTS OF CONTROLLER QUESTIONNAIRE.

During the course of the dynamic testing, questionnaires were administered to the participating controllers. In addition to NAFEC controllers, responses and critiques were obtained from field controllers who participated in the simulation and represented moderate- to high-density field facilities; i.e., New York, Atlanta, Houston, Minneapolis, and Bradley Field. As mentioned in the introduction to this report, the algorithm as delivered to NAFEC had several serious deficiencies. Considerable effort was expended and frustration encountered in trying to bring the algorithm to an acceptable level for further testing. The controllers were privy to all these trials. In general, controllers felt that they already had the most effective collision avoidance system in the ATC system and that IPC would not improve orderliness or increase capacity. They could appreciate that a properly designed separation monitor such as IPC could provide an additional safety against blunders; however, if that system gave alarms prematurely and in fact took over command in normal authorized situations, the effect could result in less orderliness, more stress, and more workload in recovering from the situation.

Occasionally, a command to an aircraft on final approach resulted in a missed approach which interfered with a smooth, orderly operation. Participating controllers felt that the display of a 60-second vector projection from each of the encounter pairs and a flashing data block were effective, provided the range between the pair was not so great as to be difficult to detect the reason for the alert. The command in the third line of the data block was easily interpreted except when clutter produced an overlapping of symbology. This deficiency is somewhat attributable to the limitation of the DSF facility, where automatic offset is not a feature, but should be considered in an ARTS facility also.

The automatic offset must have provision for an unrestricted view of the third data line. On one occasion the leader line from the data block to the aircraft symbol directly overlayed the symbolic arrow used for the IPC descent command. Quick interpretation would be critical in instances where the voice link of commands by the controller to unequipped controlled aircraft is the only means of providing collision avoidance information to these aircraft. The concept of human voice link is questionable, however, since, if the controller does not respond to the controller alert by providing a verbal command or if a pilot blunder creates a need for immediate command, it is doubtful that the controller could respond quickly enough. Consideration could be given to a more mechanical method of command transmission in these circumstances, possibly voice synthesization. However, this in itself could introduce a host of other problems such as frequency preemption and the relay of unnecessary commands.

Table 13 presents a summary of responses in two key areas: (1) the effect of IPC on the ATC system components, and (2) IPC acceptability by the controllers. It is noted that in the questionnaire there were two additional categories of "greatly decreased" and "greatly increased" for each of these factors. However, no controllers ever responded in these extreme categories. Controllers felt that the control procedures, traffic samples, and terminal area were realistic for evaluating the IPC concept. As already mentioned, participating controllers represented moderate- to high-density facilities and were not unduly concerned with traffic densities, aircraft performance characteristics, or PPI display features. Those indicating a decrease in orderliness were mostly concerned with those commands issued to aircraft on final approach. As indicated in the table, 70 percent of the controllers felt that IPC did not materially affect traffic handling capactity. This was borne out by the objective data which indicated for the most part that controllers could maintain high operations rates with IPC operating in the system. There was a mixed reaction to IPC's effect on safety, probably due to controllers varied opinion as to how "safe" should be defined. Sixty percent of the controllers felt that workload increased as a result of IPC. Objective measures such as number of instructions per aircraft appeared to support an increase in workload when controllers attempted to reduce IPC message rate. Forty percent of controllers indicated no change in workload. These controllers felt that alerts occurred when aircraft were well separated and consequently did not interfere with their operations. Almost one-half of the controllers felt that situations developed which were stressful, particularly commands to aircraft on final approach. The majority of controllers indicated no change in applied separation.

TABLE 13. SUMMARY OF CONTROLLER OPINION

		Decrease	No Change	Increase
1.	IPC Effect on:			
	a. Orderliness	50%	50%	
	b. Traffic handling capacity	30%	70%	
	c. Safety	25%	35%	40%
	d. Workload		40%	60%
	e. Stress		55%	45%
	f. Separation used by controller		63%	37%
2.	IPC Acceptability			
	a. Strongly oppose	21%		
	b. Oppose	32%		
	c. Indifferent	26%		
	d. Favor its use	21%		
	e. Strongly favor	0%		

Controllers indicated that the controller alert had some value in alerting them to potential problems developing, such as a fast departure overtaking a slow departure. Controllers unanimously felt that IPC should not issue commands to aircraft under their control, since IPC has no knowledge of controller's intent. Based on the objective data and observation of the simulation, commands often occurred at large aircraft separation when controllers were safely vectoring aircraft to an ILS approach.

Fifty-three percent of the controllers opposed or strongly opposed the use of IPC; not necessarily the IPC concept, but the IPC algorithm as tested. Controller opposition was based on the IPC false alarm rates and lack of knowledge of controller intent. In addition, a number of controllers felt that the IPC required too strict adherence to procedures in order to eliminate unwanted alerts, which was not always possible in a high traffic density situation. Those favoring the IPC favored the controller alert rather than the command feature.

SUMMARY OF RESULTS

The following results address the key elements outlined in the NAFEC product plan; i.e., interaction with ATC, parameter values, tailoring of system for specific environments, display of IPC data, and controller procedures. These results are based on an analysis of test data, controller questionnaires, and test team observation.

1. IPC was designed to be an intermittent collision avoidance system, to provide a backup to the ATC system and protect against blunders. The algorithm tested at NAFEC produced an unacceptable number of unnecessary controller alerts and pilot commands. Alerts and commands were generated when controllers were following normal procedures and aircraft pairs were well outside ATC separation standards. These unnecessary alerts and commands occurred most frequently between opposite-side ILS arrivals and between arrivals and departures.

2. In the final approach area, in which up to 50 percent of IPC activity occurred, normal controller procedures routinely create situations involving high closure rates that appear dangerous to IPC, which lacks knowledge of ATC intent, and is overly sensitive to such controller techniques as turning an arrival aircraft in ahead of another and occasional high-speed, large-angle turn-on to the ILS course.

3. On the one hand, IPC alerted the controller prematurely in cases where aircraft were widely separated and there was no need for an alert. On the other hand, IPC did not always provide sufficient warning time to controllers in command encounters, particularly if aircraft were turning at the time of command. In the majority of cases, the controller received no more than one scan (4 seconds) and in some cases no notice prior to command.

4. Eighty percent of encounters involving opposite-side arrivals were situations where one of the aircraft was already established on the ILS course. The present IPC logic would generate commands to the aircraft on approach as well as the intruder. It is evident that special consideration should be given to the aircraft on approach by adjusting thresholds so that the intruder is commanded first and the aircraft on approach receives a command only as a last resort.

5. ATC/IPC interaction can be reduced in the terminal area by a reduction of algorithm thresholds. Reductions on the order of 71 percent in controller alerts and 88 percent in commands were obtained in the all-arrival IFR operations to parallel runways by reducing both projected miss distance threshold from 1 nmi to 0.5 nmi and controller alert, FPWI, and command thresholds from 75 seconds, 60 seconds, and 45 seconds to 60 seconds, 45 seconds, and 32 seconds, respectively. No attempt was made to evaluate the safety implications of reduced thresholds.

6. IPC positive vertical maneuver commands between departure and arrival aircraft pairs occasionally are due to the IPC tracker's failure to sense an abrupt vertical deceleration as the departing aircraft levels off below the arrival aircraft. The use of positive commands is unnecessary and disruptive. If the tracker lag problem cannot be alleviated, then negative commands or a vertical speed limit command would minimize ATC/IPC interaction in these cases.

7. In the IPC algorithm tested, the factors affecting the choice of the resolution plane were the existing vertical separation and the horizontal speeds of the aircraft. It was clear from test results that resolution planes should not be determined merely by using these criteria, but should recognize the particulars of the ATC environment, namely arrival or departure. Generally, arrival controllers separate aircraft by issuing vectors or horizontal commands. For this reason, IPC commands in the vertical plane did not seriously disrupt established horizontal flow patterns. In the departure area, however, the need to pass under and over arrival routes required that the departure controller utilize altitude separation many times. For that interaction which occasionally occurs between successive departure aircraft (overtake), the use of horizontal commands more closely approximates what the controller would do. Because of this, IPC vertical commands interfered more often with the departure controller's instructions.

8. Throughout the tests, there were only three multiple encounters, each involving three aircraft. There were also only five cases of simultaneous alerts, four under the VFR separation conditions, one under the IFR separation conditions. When two unrelated alerts are displayed simultaneously on the same display, a method of indicating priority of action would be beneficial to the controller. This could be a time-keyed indicator displayed on the controller alert vector indicating the pair requiring his immediate attention.

9. In the all-arrival IFR series, arrival/departure IFR series, and VFR series, the run-to-run variation in the IPC message rate was considerable. In each series, the run with the highest number of IPC events was consistently 3.7 times that obtained in the run with the lowest number of events. This variability was attributable to the different controller teams and their control

techniques. One desirable attribute of a collision avoidance system should be insensitivity to the differing capabilities and techniques that invariably exist in the controller population.

10. Special test runs showed that significant reductions in IPC message rates can be achieved by controllers employing such control techniques as shallow localizer intercept angles, staggered turn-ons, minimum approach speed, and establishing ILS approach altitude at 4 nmi laterally of ILS course. However, controller workload in terms of number of instructions per aircraft increased (29 percent), and hourly operations rates decreased (95 to 88) in the all-arrival IFR series. In the arrival/departure IFR series, because of the moderate traffic load, the use of these special procedures did not change operation rates, but the tendency toward increased instructions per aircraft (15 percent) did exist. In addition, these modifications tend to restrict the controller's freedom of movement in the expeditious handling of traffic. This is particularly true where visual separation is employed and IPC may derogate the intent of the system.

11. The algorithm does not adequately handle the special circumstances of controlled VFR in which minimum ATC separation criteria are employed; i.e., 1 nmi or 500 feet. In a visual approach mode, consideration should be given to discretely adapting a range-only criteria for issuing commands since, in all cases, minimum separation is only applied when visual acquisition is achieved by the succeeding aircraft. Such special IPC logic could be initiated by controller keyboard entries.

12. The efficacy of the FPWI to controlled aircraft is questionable, since the pilot would most likely not respond on his own without contacting the controller. However, FPWI displayed on the controller's scope does provide some index about those encounters requiring immediate attention. Additionally, the high incidence of PWI's, which by definition indicate no immediate hazard, may prompt further interaction. Pilots unable to visually acquire an intruder might overload communications channels by requesting further information on traffic.

13. Current changes being made to uncontrolled/controlled encounter logic to assure that the uncontrolled aircraft receives a command prior to the controlled aircraft assumes that the uncontrolled aircraft is DABS equipped. However, if in the initial implementation period a high proportion of the uncontrolled aircraft are unequipped, then the controlled aircraft will receive a command. When a controlled aircraft is in an encounter with an uncontrolled aircraft, it is important to the controller that the equipment status, i.e., ATCRBS or DABS, of the uncontrolled aircraft be immediately evident, since this will influence his choice of action for the controlled aircraft. It was felt that the displayed symbol, a box □, for uncontrolled ATCRBS, and a diamond ◊ for uncontrolled DABS, did not adequately distinguish these circumstances in close proximity conflicts.

14. In an uncontrolled/controlled encounter in which an IPC command is issued to an equipped uncontrolled aircraft, nothing is displayed to the controller in the present IPC logic when controller alert thresholds are not violated.

The possibility exists for the controller to aggravate rather than help the situation. For example, the controller having no knowledge of an IPC command being issued to the uncontrolled aircraft might maneuver the controlled aircraft in a manner that negates the IPC command to the uncontrolled aircraft. It is felt that commands being sent to uncontrolled aircraft should be forced onto the controller's display.

15. Due to the short separation distances involved, particularly in uncontrolled/controlled encounters, it is difficult on a typical terminal PPI display to determine if the commanded uncontrolled aircraft will resolve the conflict. This situation is aggravated further by the IPC tracker which lags behind actual aircraft maneuver.

16. Although the chance of data block overlap was a problem in the DSF, the automatic offset feature in an ARTS facility would tend to minimize this problem. The offset feature should, however, be refined to ensure the data block's being positioned in a totally clear area during that time when IPC commands are displayed to prevent any masking of displayed commands. This is particularly critical when voice link of commands by the controller to controlled aircraft not equipped with IPC displays, is the only means of providing collision avoidance information to these aircraft.

17. It was impossible to determine what level of controller alerts might be acceptable to controllers because of the many unnecessary alarms. Participating controllers felt that a properly tuned IPC could provide additional safety against blunders. However, because the IPC, with current thresholds, alarmed prematurely and, in fact, issued commands in normal routine situations, about half the controllers felt the result was less orderliness, more stress, and increased workload; the other half indicated no change in these areas. The effect of IPC interacting with the controller in those instances where he is following routine control procedures is for him to delay his response to and occasionally ignore controller alerts. Fifty-three percent of controllers opposed the use of IPC, not necessarily the IPC concept, but the IPC algorithm as tested. Controller opposition was based on the high false alarm rate and IPC's lack of knowledge of controller intent. Those favoring the IPC favored the controller alert rather than the command feature. In addition, field controllers voiced concern over how IPC will cope with possible mode C altitude error in the choice of vertical maneuver commands. The combined effect of altitude errors for an aircraft pair could result in IPC issuing commands which precipitate conflicts rather than resolve them.

CONCLUSION

It is concluded that this first dynamic test of IPC operating in an ATC terminal environment indicates that from an operational point of view, IPC adversely interacts with the present ATC system. Rather than remaining passive until needed, the IPC, with current thresholds, frequently interrupts the ATC system. Interruption does not automatically mean disruption, but raises the question of authority which will adversely affect the degree of acceptance by the controllers. Controllers invariably determine the most appropriate command to issue. If this should conflict with the command being displayed in the cockpit, the pilot could become confused. Additionally, the concept of using the controller as a communication link between IPC and unequipped aircraft will undoubtedly require a determination of responsibility, particularly in those cases involving controlled and uncontrolled unequipped aircraft. Quick-turning aircraft can generate IPC messages with little or no prior warning to the controller. He may react by blindly transmitting the command. If resolution is not achieved, a question of legal implications arises in an airspace where two systems are exercising control.

RECOMMENDATIONS

The foregoing test results clearly indicate that several areas warrant further investigation to determine if adverse interaction between ATC and IPC can be reduced to a more acceptable level. It is therefore recommended that tests be specifically designed to explore:

1. Reduction of time and miss distance thresholds. To what limits can thresholds be reduced to eliminate false alerts and commands while still providing adequate time for safe escape?

2. IPC desensitization. Define the essential characteristics of those encounters on and about the final approach course so that logic may be developed to provide protection for aircraft while eliminating intolerable alarm rates.

3. Multiaircraft logic. Develop logic which will provide for a look-ahead feature for determining effectiveness of the planned IPC maneuver to avoid secondary encounters; i.e., improve pair-wise logic.

4. Command selection. Develop logic which considers the attributes of the terminal environment, i.e., arrivals or departures, in determining an initial plane of resolution.

5. Controller display. Extensive tests are required to determine what new techniques may be required to provide for the most meaningful display of IPC data to the controller. Several items of interest would be:

a. When two alerts occur simultaneously, provide a priority-of-action indicator to the controller.

b. Determine what is the most effective means for identifying the IPC equipment status of uncontrolled aircraft.

c. Resolve the question of which ATC automated function will have exclusive use of the flashing data block as an attention feature, e.g., metering and spacing data, handoff, conflict alert, IPC, etc.

d. Determine the most effective means of displaying command information; e.g., data block and/or tabular list.

6. Controlled VFR. Develop logic to accommodate the special separation standards used in controlled VFR. Determine feasibility of implementing logic by controller keyboard entry or transponder code output.

7. Uncontrolled/controlled encounters. Revise logic so that when an uncontrolled aircraft, in an encounter with a controlled aircraft, receives a command prior to IFR thresholds being violated, the command would be forced onto the controller's display.

8. Voice link to ATCRBS. Conduct a study on the impact on workload and the efficacy of the controller performing the data link function between IPC and the pilot of an unequipped aircraft.

9. Tracker performance. Investigate the possibility of reducing tracker lag by improving turn and climb/descent/level-off detection. The tracker should be more responsive to aircraft performance characteristics of speed, turn rate, and vertical velocities.

10. Area adaption. Investigate the possibility of including controller intent in the IPC algorithm by the use of area adaptation tables tailored to each location. The tables could be particularly useful in an RNAV environment where IPC could monitor deviations from predetermined tracks rather than relying on threshold violations based on course prediction.

11. Controller interface. Establish an advisory group of field facility air traffic controllers to participate directly in developmental efforts and in a comprehensive study to delineate the controller's responsibility when IPC becomes functional.

REFERENCES

1. Federal Aviation Administration, Intermittent Positive Control Computer Algorithms for Test Bed Experiments, FAA-EM-74-2, 1975.

2. McCosker, W. Robert and Mulry, Leo J., Three-Dimensional, Visual Flight Rules, General Aviation Airport Study, Final Report, Federal Aviation Administration, April 1974.

APPENDIX A

IPC/ACAS COMPARATIVE EVALUATION

DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

DATE:

IN REPLY REFER TO:

NATIONAL AVIATION FACILITIES
EXPERIMENTAL CENTER
ATLANTIC CITY, NEW JERSEY 08405

SUBJECT: Letter Report, NA-76-9-LR, IPC/ACAS Comparative Evaluation under Activity 034-242-010, PAA 03-260

FROM: Director, ANA-1

TO: ARD-1

This report covers the test results of the Intermittent Positive Control (IPC)/Airborne Collision Avoidance System (ACAS) Comparative Evaluation under Subprogram 034-242, Intermittent Positive Control Simulation. The NAFEC Program Manager is Anthony Spingola. The authors of this report are Sidney Rossiter, project manager; Robert Strack, test director; and James Windle, operations research analyst.

The purpose of this test was to make a comparative evaluation of IPC simulation results and ACAS simulation results, both of which employed the Chicago high-density terminal environment. NAFEC was requested by OSEM/SRDS to conduct a special series of tests which was not included in the original product plan. The ATC/ACAS-Phase II dynamic simulation [1] was conducted at NAFEC in 1972.

The air traffic (ATC) laboratory of the digital simulation facility (DSF) was configured to duplicate the environment simulated during the ATC/ACAS - Phase II tests. The IPC algorithm (FAA-EM-74-2, Rev. 1) was resident in the Sigma V computer of the DSF. During the course of IPC/ATC interaction tests, analysis of DSF simulation data revealed several deficiencies in the algorithm, the principal ones being the excessive number of false alerts and one-scan duration alerts. Modifications to the algorithm were made at NAFEC and inserted into the algorithm prior to starting the IPC/ACAS tests. These changes were subsequently reported by letter to SRDS and are outlined as follows:

1. Modified the algorithm so as not to declare the IPC encounter if aircraft were predicted to be converging laterally, but diverging in altitude. Similarly, if aircraft were predicted to be converging in altitude, but diverging laterally, an IPC encounter would not be declared.

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1 G. Jolitz, Air Traffic Control/Collision Avoidance System Interface Simulation - Phase II, FAA-RD-73-140.

2. Required the controller alert condition to exist for two out of three consecutive scans prior to being displayed to the controller.

3. Established desensitized zones that encompassed the three ILS courses. This desensitization deleted IPC interaction between landing aircraft and aircraft on the airport surface, and between pairs of arrival aircraft on adjacent parallel or converging ILS courses. Only controlled aircraft within the zone were filtered. If a controlled aircraft outside the zone were in conflict with an aircraft inside the zone the IPC alarm was not filtered. The dimensions of the zones, shown in Figure 1, Enclosure 1, were based on an analysis of IPC encounter data from preliminary test runs.

The ATC/ACAS tests also used desensitized areas. These areas, shown in Figure 2, Enclosure 1, had boundary lines parallel to the ILS course within which ACAS changed from full system to landing/departure mode. Each of these boundaries was used separately as a test parameter. It can be seen in Figure 3, Enclosure 1, that when going from full system to landing/departure mode zone 2 is eliminated.

It can also be seen from Figure 3 that in the vertical dimension ACAS issues an alarm when intruders are within an altitude separation of ±3300 feet from an equipped aircraft. IPC uses a vertical "time to collision" (TAU) threshold. IPC eliminates from conflict consideration level or vertically separating aircraft whose altitude separation is greater than 750 feet under IFR procedures and 450 feet under VFR procedures. Original FAA EM-74-2 (Rev. 1) parameter values of 1000 feet were incompatible with ATC separation criteria. NAFEC reduced the parameters to values more in line with IFR and VFR operations. In the horizontal dimension ACAS uses a TAU criterion in zone 2 which generates an alarm if the intruder is within 40 seconds to 1.8 nmi separation from the equipped aircraft and a TAU criterion in zone 1 which generates a command for aircraft within 25 seconds of each other. IPC uses a TAU criterion and a horizontal projected miss distance (1 nmi) threshold. If both vertical and horizontal TAU thresholds were violated but aircraft were projected to miss by more than 1 nmi, IPC would not generate a controller alert, flashing proximity warning indicator (FPWI), or command.

3

Assume for the moment that two aircraft satisfy the vertical conflict criteria for both ACAS and IPC and the 1-nmi projected horizontal miss distance required by IPC. Figure 4 then shows the combination of closing speed and aircraft separation at which ACAS and IPC horizontal thresholds are violated. The curves for IPC assume 200-knot aircraft speeds. For example, an aircraft pair closing at a speed of 350 knots would initiate an IPC controller alert when separated by 7.4 nmi, an FPWI at 5.9 nmi, and IPC command at 4.5 nmi. ACAS TAU II would be penetrated at a separation of 5.7 nmi resulting in an advisory or command depending on whether the aircraft's flight profile would be changed by the message and TAU I penetrated at a distance of 2.4 nmi resulting in a positive command.

The ATC/ACAS study presented simulation results comparing the Inner Switchpoint Boundary (I-SPB), the Middle Switchpoint Boundary (M-SPB), and the Outer Switchpoint Boundary (O-SPB). This report presents the same type of data as used in the ACAS study, i.e., relative number and duration of messages generated. However, to determine the full significance of such messages one must also take into account the type and effect of the message. For example, ACAS vertical speed limit commands could be less disruptive than IPC positive vertical commands in that they permit an aircraft to approximate its original profile and might obviate the need for a positive vertical command. On the other hand, IPC positive vertical commands tend to be less disruptive than ACAS limit turns since they do not interfere with the intended direction of flight in those areas where the controller is establishing a sequence of traffic by vectoring techniques.

The following summary of results is based on the analyses of data presented in Enclosure 2, ACAS/IPC Comparative Data, and Enclosure 3, Detailed Breakdown of IPC Alarms. Although data for ACAS I-SPB, M-SPB, and O-SPB are presented in the enclosures, comparisons are only made with the ACAS O-SPB and IPC.

1. The results of the baseline simulation runs in the IPC, i.e., runs in which no aircraft were equipped with IPC, were comparable to the baseline runs in ACAS in terms of runway operations rate.

2. As increasing proportions of aircraft equipped with ACAS or IPC were introduced into the ATC system there was no significant change in operations rates in either the ACAS series or IPC series.

4

3. In all of the comparative tests there was no significant difference in operations rate between ACAS runs and IPC runs.

4. IPC required a desensitization zone about the final approach course as did ACAS.

5. Throughout the test series IPC consistently issued less commands per hour than ACAS (O-SPB).

6. Generally, IPC commands were of shorter duration than ACAS commands.

7. In most instances, IPC generated controller alerts unnecessarily, some of which transitioned to command status even though ATC separation criteria were not being violated. The data indicated that these unnecessary alarms are directly attributable to the IPC threshold values.

8. Most of the commands issued by ACAS were to reduce vertical speed while almost all IPC commands were positive climb/descend commands. In all tests, only 6 scans of negative vertical commands in 3 encounters were generated by IPC.

9. A significant number of IPC alerts and commands occurred when one of the aircraft pair was located within the desensitized zone, i.e., 0.6 nmi laterally of the ILS course on approach to the runway, and the other aircraft was being vectored to the other parallel ILS course. ACAS eliminated these types of encounters to a great extent by utilizing an outer switchpoint boundary which switched the ACAS from full to a desensitized mode at a distance 4.4 nmi laterally of the ILS course.

10. A scan-by-scan comparison of what ACAS would have generated during each scan of IPC conflict showed that ACAS would not have alarmed in many instances where IPC controller alert and FPWI existed. This was because of either the combination of large separation and closing speed triggered CALERT or FPWI IPC thresholds prior to ACAS TAU II thresholds or one or both aircraft was in the ACAS landing/departure mode.

5

11. A large number of advisories (70.82 per hour for ACAS; 253.74 per hour for IPC) were issued. For IPC, the overwhelming majority were steady PWI's indicating no immediate hazard. Without even considering any impact on data link channels which would be a function of time distribution of the message, it would appear at least that the possibility of increasing communications channels workload exists. Pilots unable to visually acquire an intruder would most likely request information from the controllers. In a controlled environment, the use of a nonhazardous warning is questionable.

12. As evidenced by the large run-to-run variation in the number of messages (sometimes a factor of 2 from one run to another), both ACAS and IPC are sensitive to controller technique. Normal ATC aircraft sequencing procedures for approach vary with traffic load, aircraft types, and weather conditions. Such control techniques as cutting one aircraft in front of another on final approach and aircraft approaching the ILS from opposite sides at large intercept angles result in high closure rates between aircraft. ACAS and IPC are sensitive to closure rates resulting from techniques normally used to expedite traffic.

13. Controllers participating in the original ACAS study indicated that they consciously attempted to accommodate ACAS to some extent by turning arrivals to shallow intercept angles and avoided cutting aircraft in ahead of other inbound aircraft (a technique known as shooting the gap). Controllers used standard control procedures and did not alter technique to accommodate IPC. Rates of closure in excess of 350 knots between aircraft approaching from opposite sides were not uncommon in the IPC runs. Had IPC controllers altered their procedures similarly to those of ACAS controllers, alarm rates for IPC runs would no doubt have decreased. Although it is apparent that modifications to control procedures can reduce alarm rates, the acceptance of a system predicated on such changes is highly questionable.

14. During an evolutionary implementation period when part of the aircraft population will be ATCRBS equipped without DABS/IPC data link capability, IPC can still provide protection to these aircraft.

Controllers can relay, by voice communication with aircraft, commands being displayed on the CRT. ACAS does not as yet provide a similar capability to unequipped aircraft.

15. It appears that some portion of ACAS avoidance maneuvers could be beneficial to IPC in minimizing the effect of interaction with ATC. Instances of IPC vertical commands occurred wherein the IPC vertical tracker failed to sense an abrupt aircraft vertical deceleration. This tracker lag was particularly true of departures leveling off at 1000 feet below arrival aircraft, and arrivals leveling off to approach altitude at 3 nmi laterally of the ILS course and alarming with aircraft on the ILS course. It appears that if the ACAS vertical speed limit command could be included in the IPC command repertoire the need for IPC positive vertical commands would have been reduced.

The comparative analysis of ACAS and IPC message rates made in this report were based on ACAS using the original ANTC 117 logic and the IPC logic defined in FAA EM-74-2 (Rev. 1). The threat evaluation logic and avoidance maneuvers of both systems are different and no comparative analysis was made of the level of protection provided conflicting aircraft by each system. This report recognizes that both system concepts are currently in the developmental stage and further refinements could significantly affect the results contained herein. At the stage of development at which each system was tested, both systems interact unacceptably with the ATC system in that they interfered with ATC normal operating procedures, particularly in the area where aircraft are maneuvering to the final approach area. The results presented herein should be considered in light of the following:

1. The ACAS study investigated alternate desensitization zones extending from 1.1 nmi to 4.4 nmi laterally of the ILS course. Because of time limitations, no such extensive analysis could be made for IPC during these preliminary tests. Rather, a desensitization zone was used which was of minimum area and eliminated undesirable alarms on the ILS. The question of how and where to desensitize IPC needs to be thoroughly investigated.

2. An important difference between the ACAS and IPC which has a direct bearing on the nature of ATC interaction is the manner by which the controller is informed of the existence of a

conflict. The ACAS provides no alert or information to the controller until the pilot advises him of ACAS commands. On the other hand, IPC alerts the controller prior to a command being issued and provides him with enough information to evaluate the situation. However, very often the IPC alerts him prematurely in circumstances when aircraft are well outside ATC separation criteria. Further study is required to determine how far thresholds might be reduced to eliminate false alarms and still provide adequate warning and safe escape time.

3. It appears that vertical commands, particularly in the approach areas, are less disruptive to the controller than limit turn commands since they do permit traffic to continue in intended direction. For the most part, sequencing and spacing aircraft in the terminal area is accomplished by vectoring aircraft in the horizontal plane. Limit turn commands are more apt to interfere with this process than are vertical commands. Moreover, if the vertical speed limit restrictions in ACAS can effectively be used in IPC to obviate the need for climb/dive commands, the effect on the ATC system would be even further reduced.

A forthcoming Letter Report, NA-76-14-LR, will present further analysis of data dealing specifically with IPC/ATC interaction.

ROBERT L. FAITH

3 Enclosures

cc:
ANA-64
ANA-523
ARD-54
ARD-210 (D. Hopson)

ENCLOSURE 1

ACAS/IPC DESENSITIZED ZONES AND TAU THRESHOLDS

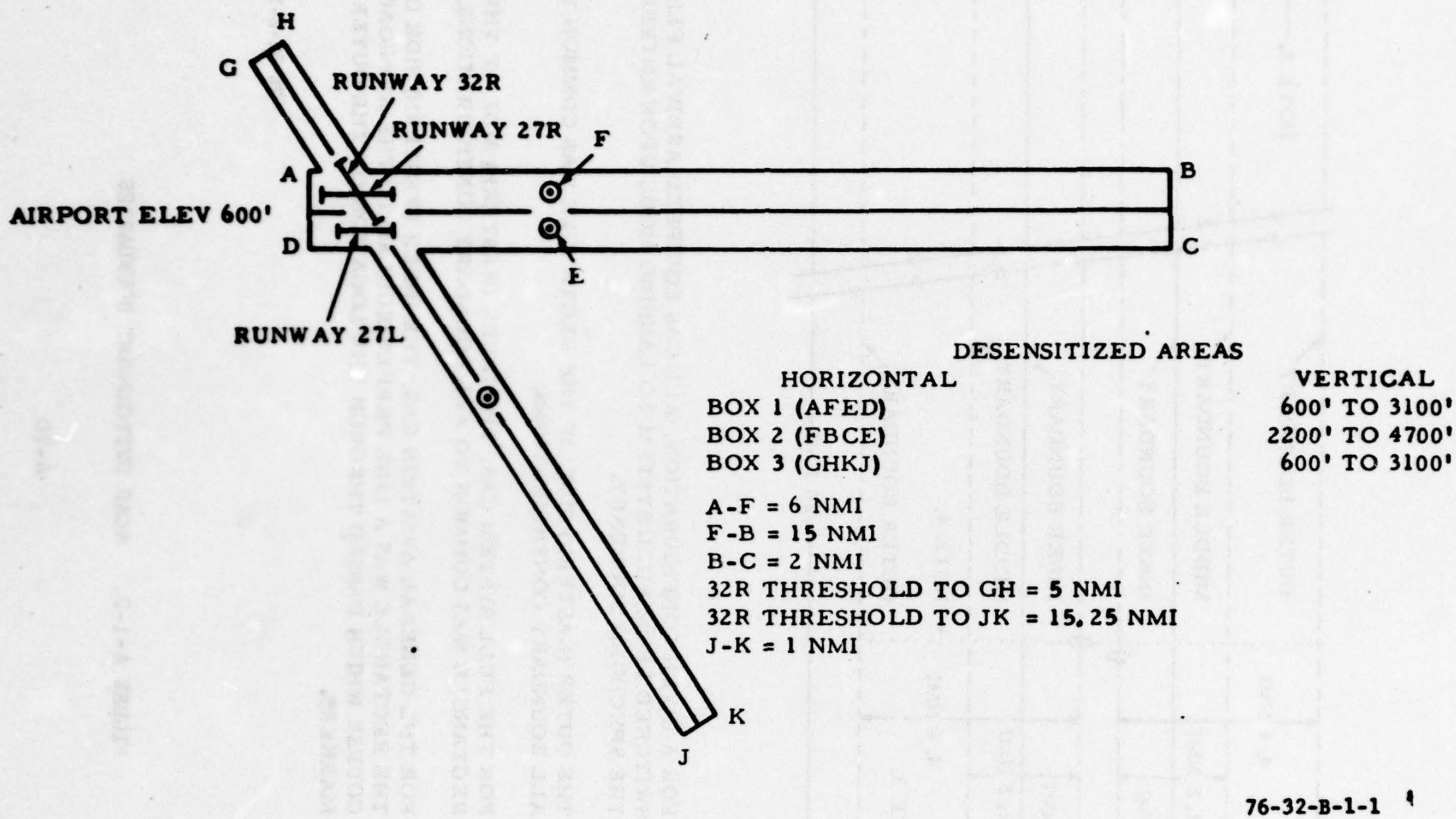
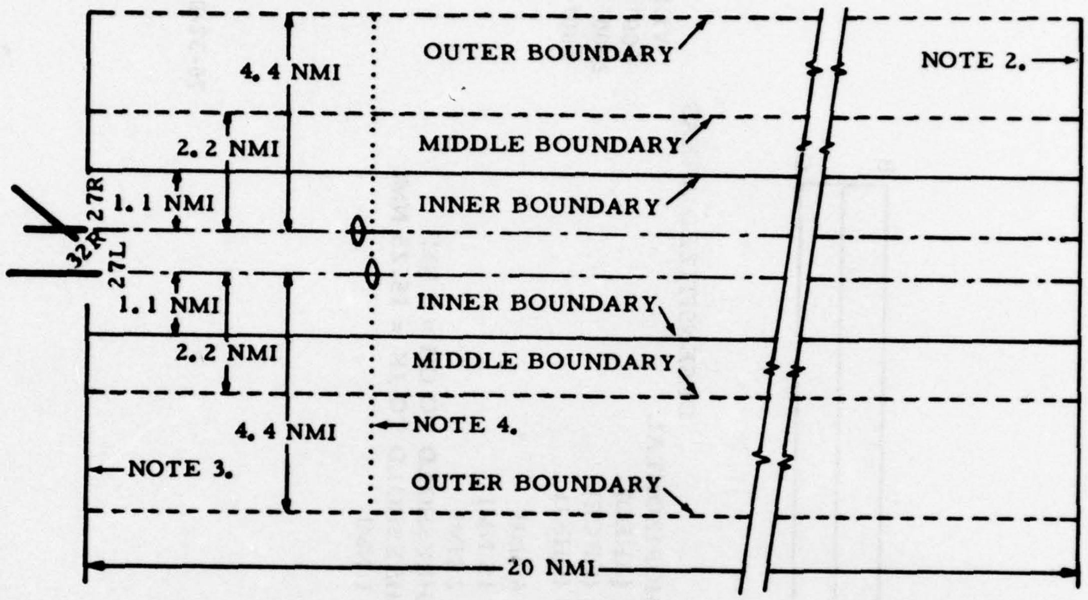


FIGURE A-1-1. DESENSITIZED IPC AREA USED IN NAFEC SIMULATION FOR CONTROLLED OPERATIONS



NOTE 1. FOR A GIVEN CONFIGURATION, ALL CAS EQUIPPED ARRIVAL FLIGHTS SWITCHED FROM FULL SYSTEM TO LANDING MODE UPON ENTERING THE SPECIFIED BOUNDARY.

NOTE 2. THE OUTER (EASTERN) SIDE OF THE RECTANGLE WAS COMMON TO ALL BOUNDARY CONFIGURATIONS.

NOTE 3. FOR THE FULL SYSTEM CAS, THE INNER (WESTERN) SIDE OF THE RECTANGLE WAS COMMON TO ALL BOUNDARY CONFIGURATIONS.

NOTE 4. FOR THE GENERAL AVIATION CAS, THE INNER (WESTERN) SIDE OF THE RECTANGLE WAS A LINE PERPENDICULAR TO THE APPROACH COURSE WHICH PASSED THROUGH THE LOCATION OF THE OUTER MARKERS.

76-32-B-1-2

FIGURE A-1-2. ACAS SWITCHPOINT BOUNDARIES

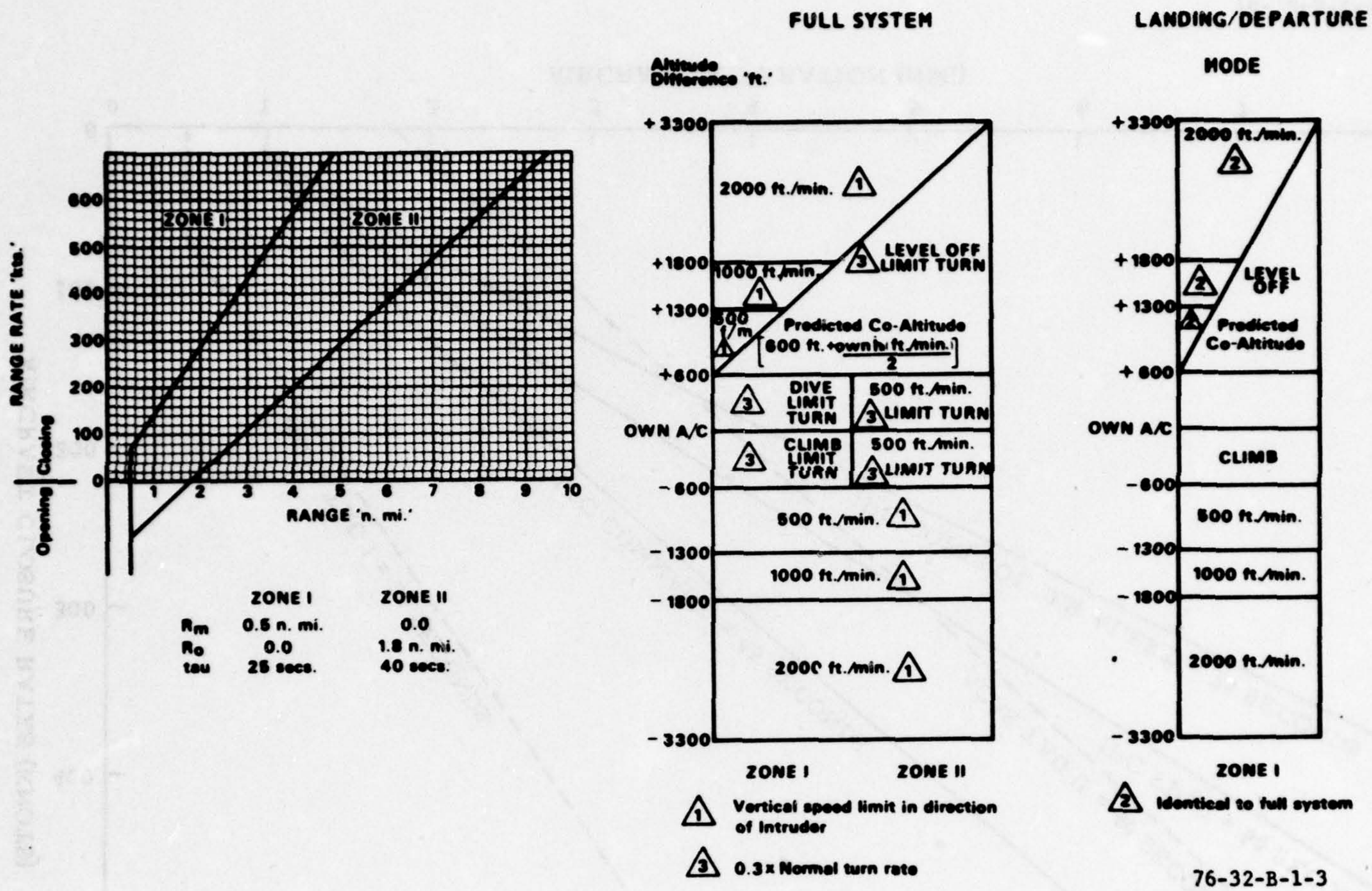


FIGURE A-1-3. THE COMMERCIAL CAS THREAT EVALUATION PARAMETERS AND RESPONSE

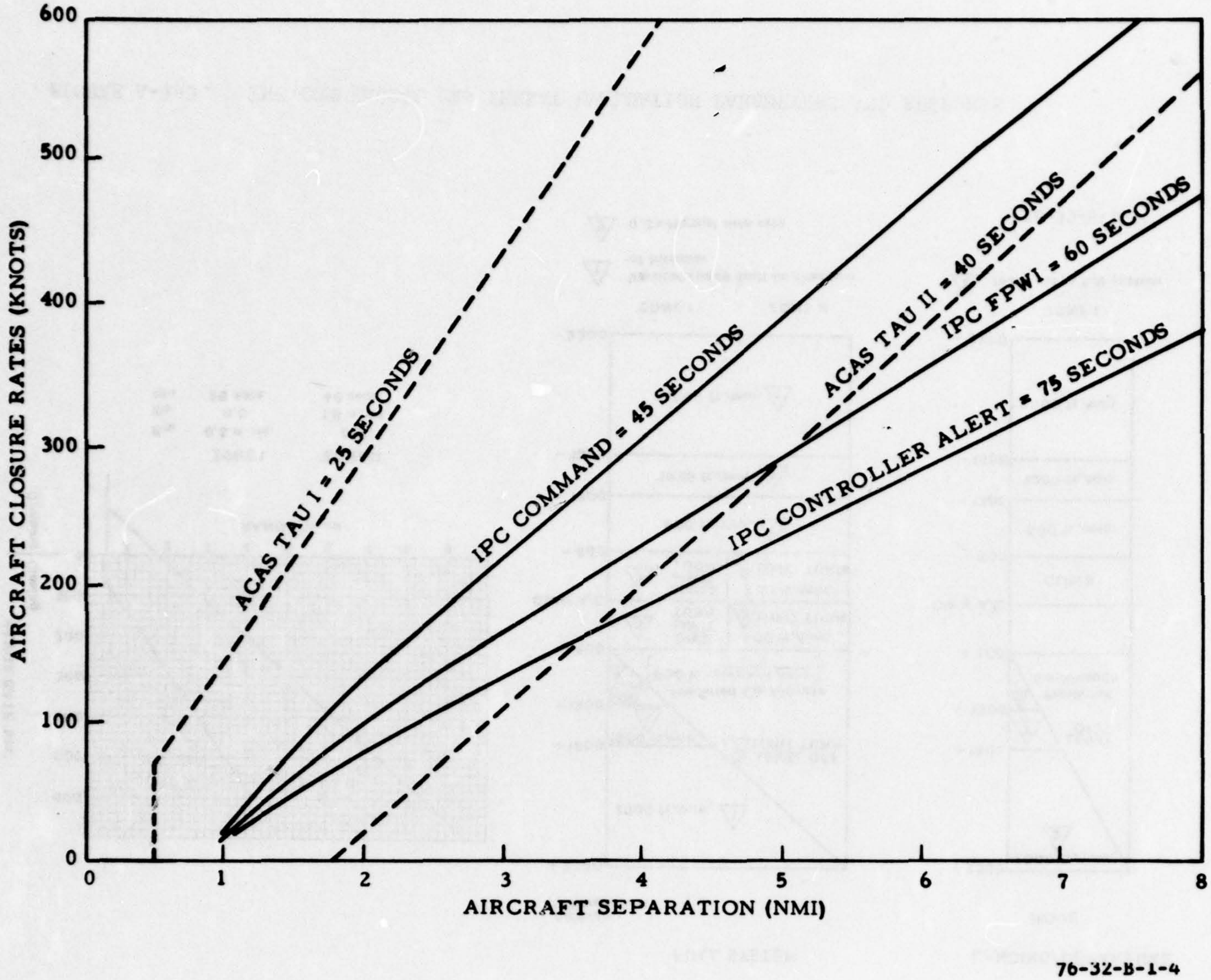


FIGURE A-1-4. IPC/ACAS COMPARATIVE HORIZONTAL THRESHOLDS

ENCLOSURE 2

ANALYSIS OF IPC/ACAS TEST DATA

For this simulation the terminal area extended to 30 nmi radius from the center of the airport. All IPC encounters where one or both aircraft were within this region were counted. The alarm rates for ACAS and IPC have been summarized into average hourly number and duration commands, advisories, and controller alerts. Controller alerts are germaine to IPC only, since ACAS did not have this capability. Commands for ACAS included effective events, i.e., those climb, descend, level-off, limit turn rate, and vertical speed limit (VSL) messages that affected a flight profile. For example, a turning aircraft receiving a limit turn rate command reduced its turn rate to one-third of the normal turn rate. Commands for IPC included climb, descend, turn right, turn left, and negative commands. Advisory messages for ACAS are those limit turn rate and VSL instructions that did not affect an aircraft's profile. For example, a limit turn rate instruction to an aircraft in straight line flight did not affect its profile. These advisories did not interact with the controller since he was unaware of their existence. Comparable advisories for IPC were steady proximity warning messages (PWI) which advised the pilot of non-hazardous nearby traffic and flashing proximity warning messages (FPWI) which advised the pilot that a conflict was imminent. ACAS/IPC comparative results were categorized into the same four series of runs that were used in Reference 1:

1. VFR series
2. IFR series
3. High-density arrival series
4. General aviation series

VFR Series

Six simulation runs were conducted in this series. Three of these utilized traffic samples in which 65 percent of the flights were DABS equipped and 35 percent were ATCRBS equipped. These runs will subsequently be referred to as the high mix series. The other three runs used traffic samples with a mix of 32 percent DABS flights and 68 percent ATCRBS. These runs will be referred to as the low mix series. With the exception of the type of collision avoidance equipment used in the IPC traffic samples, aircraft characteristics and the terminal operational environment were identical to that used in the 65 percent

Reference 1, G. Jolitz, Air Traffic Control/Collision Avoidance System Interface Simulation - Phase II, FAA-RD-73-140.

equipped - 35 percent unequipped high mix series and 32 percent equipped - 68 percent unequipped low mix series reported in the ACAS study.

A cloud ceiling of 5,000 feet was assumed to exist. If either of an arrival pair was above 4,000 feet MSL, IFR separation was required. When both aircraft of a pair were at or below 4,000 feet, VFR control procedures were used. Controllers were instructed to provide a minimum of 500-feet vertical or 1-nmi horizontal separation. Altitude separation was not required between aircraft approaching the parallel ILS courses from opposite sides. The controlled/controlled encounter logic was used with IPC algorithm threshold values of AF=AFIFR=750 feet applicable when either or both aircraft were above 4,000 feet MSL and AF=AFIFR=450 feet at or below 4,000 feet MSL. AF is a parameter defined in FAA-EM-74-2, Rev. 1, as the vertical immediate range for a controller alert or command to be declared. AFIFR is the vertical immediate range for a flashing PWI to be declared to a controlled aircraft.

Tables 1 and 2 present a comparison of ACAS/IPC message rates averaged over three 1-hour data runs using perfect surveillance accuracy. The ACAS outer switchpoint boundary (O-SPB) has been selected for the purpose of this discussion; however, the I-SPB or M-SPB could have been used. It can be seen from Table 1 that in the high mix series ACAS (O-SPB) issued commands to an average of 10.7 aircraft per hour whereas IPC issued commands to 8 aircraft. ACAS command duration averaged 13.8 seconds. IPC commands lasted from 8 to 24 seconds with an average of 12.7 seconds. IPC alerted the controller an average of 11.7 times per hour. Alerts lasted from 4 to 40 seconds with an average duration of 18.9 seconds. Controller alerts by design persisted throughout the entire encounter. ACAS issued an average of 64.7 advisories while IPC averaged 208 PWI and 15 FPWI advisories per hour.

Table 2 presents results for the low mix series. ACAS (O-SPB) issued commands to an average of 2.3 aircraft per hour versus 4.6 IPC commands. ACAS command duration averaged 14 seconds. IPC commands lasted from 8 to 16 seconds with an average duration of 11.4 seconds. IPC alerted the controller an average of 8.3 times

TABLE 1 IPC/ACAS AVERAGE HOURLY NUMBER AND DURATION OF MESSAGES

VFR SERIES - HIGH MIX

MESSAGE		ACAS						IPC	
		I-SPB		M-SPB		O-SPB		WITH DESENSITIZED ZONE	
		NO.	AVG DUR SEC	NO.	AVG DUR SEC	NO.	AVG DUR SEC	NO.	AVG DUR SEC
CONTROLLER ALERT								11.7	18.9
COMMANDS	CLIMB	0	0	0	0	0	0	4.0	12.7
	DESCEND	0	0	0	0	0	0	4.0	12.7
	LEVEL OFF	0.3	3.0	0.7	3.0	0.7	3.0	-	-
	LIMIT TURN	11.3	14.8	5.0	14.1	3.0	16.3	-	-
	VSL	10.0	16.5	8.0	15.8	7.0	13.7	-	-
	TOTAL	21.6	15.4	13.7	14.5	10.7	13.8	8.0	12.7
ADVISORIES	LIMIT TURN	8.7	27.2	6.7	17.9	5.3	21.8	208 (PWI)	
	VSL	69.3	25.9	68.7	32.8	59.3	30.9	15 (FPWI)	
	TOTAL	78.0	26.0	75.3	31.5	64.7	30.2	223	

TABLE 2 IPC/ACAS AVERAGE HOURLY NUMBER AND DURATION OF MESSAGES

VFR SERIES - LOW MIX

MESSAGE		ACAS						IPC	
		I-SPB		M-SPB		O-SPB		WITH DESENSITIZED ZONE	
		NO.	AVG DUR SEC	NO.	AVG DUR SEC	NO.	AVG DUR SEC	NO.	AVG DUR SEC
CONTROLLER ALERT								8.3	15.7
COMMANDS	CLIMB	0	0	0.7	11.5	0	0	2.3	11.4
	DESCEND	0	0	0.3	15.0	0	0	2.3	11.4
	LEVEL OFF	0	0	0.3	6.0	0	0	-	-
	LIMIT TURN	3.3	16.0	4.3	7.7	0.7	21.0	-	-
	VSL	3.3	14.0	2.3	13.3	1.7	11.2	-	-
	TOTAL	6.7	15.0	8.0	9.9	2.3	14.0	4.6	11.4
ADVISORIES	LIMIT TURN	6.0	18.9	4.0	17.2	1.7	4.2	101.3(PWI)	
	VSL	29.7	27.9	35.0	19.6	17.3	28.5	3.3(FPWI)	
	TOTAL	35.7	26.4	39.0	19.3	19.0	26.4	104.7	

per hour. Alerts lasted from 4 seconds to 40 seconds with an average duration of 15.7 seconds. ACAS issued an average of 19 advisories while IPC averaged 101.3 PWI and 3.3 FPWI advisories per hour.

At first look, the foregoing results indicate that in terms of absolute numbers of aircraft receiving commands and duration of commands, IPC and ACAS (O-SPB) are somewhat comparable. ACAS encounter data, however, do not include any encounters which involved equipped versus unequipped flights or unequipped versus unequipped flights. Unfortunately, no ACAS event count data were available from Reference 1 for the VFR series with all aircraft ACAS equipped. IPC encounter data do include DABS versus ATCRBS (unequipped) and ATCRBS versus ATCRBS encounters. Hence, IPC comparative counts in Tables 1 and 2 are inflated as a result of providing collision protection to all aircraft whereas unequipped aircraft in the ACAS simulation were not protected, nor were equipped aircraft protected against unequipped. If one were to delete from the IPC data in Tables 1 and 2 all encounters in which one or both aircraft were ATCRBS equipped, the results would be as shown in Table 3.

ACAS (O-SPB) data from Tables 1 and 2 have been included in Table 3 for ease of reference. Table 3 for the high mix series shows that ACAS (O-SPB) issued 10.7 commands per hour versus 4.6 commands for IPC. For the low mix series ACAS issued 2.3 commands per hour versus an average of 0.7 commands for IPC. These results with ATCRBS encounters deleted indicate that IPC issued 6.1 (high mix) and 1.6 (low mix) fewer commands than does ACAS. Even after deleting all encounters involving an ATCRBS aircraft, the traffic advisories for IPC, 150 in the high mix and 40 in the low mix series, remain high relative to an average of 64.7 and 19 for the ACAS high and low mix respectively.

Reference 1 indicates no significant effect on operations rate of introducing ACAS into the terminal area. Similar results were obtained with IPC. Table 4 shows average operations rates for ACAS (O-SPB) and IPC for traffic samples with equipment mixes ranging from 0 to 100 percent equipped.

TABLE 3 IPC/ACAS AVERAGE HOURLY NUMBER AND DURATION OF MESSAGES WITH ATCRBS ENCOUNTERS DELETED

VFR SERIES

MESSAGE	IPC WITH ATCRBS ENCOUNTERS DELETED				MESSAGE	ACAS O-SPB			
	HIGH MIX		LOW MIX			HIGH MIX		LOW MIX	
	NO.	AVG DUR SEC	NO.	AVG DUR SEC		NO.	AVG DUR SEC	NO.	AVG DUR SEC
CONTROLLER ALERT	5.3	18.0	0.7	20.0					
COMMANDS					LEVEL OFF	0.7	3.0	0	0
CLIMB	2.3	14.9	0.3	8.0	LIMIT TURN	3.0	16.3	0.7	21.0
DESCEND	2.3	14.9	0.3	8.0	VSL	7.0	13.7	1.7	11.2
TOTAL	4.6	14.9	0.7	8.0	TOTAL	10.7	13.8	2.3	14.0
ADVISORIES									
PWI	142.7		38.7		LIMIT TURN	5.3	21.8	1.7	4.2
FPWI	7.3		1.3		VSL	59.3	30.9	17.3	28.5
TOTAL	150.0		40.0		TOTAL	64.7	30.2	19.0	26.4

TABLE 4

HOURLY OPERATIONS RATE - VFR PROCEDURES

	0%	Low Mix	High Mix	100%
ACAS (O-SPB)	147.3	147.3	146.3	147.3
IPC	149.3	152.3	154.7	149.0

Although Table 4 indicates a consistently higher operations rate for IPC versus ACAS for all mixes, no statistical significance can be placed on such differences since they are well within underlying run-to-run test variability.

IFR Series

Three runs were made with parallel runway operations using IFR control procedures. Table 5 shows comparative message rates for ACAS and IPC. The IPC issued commands to an average of 3.3 aircraft per hour while ACAS (O-SPB) issued commands to 6.3 aircraft per hour. IPC commands lasted from 4 seconds to 32 seconds with an average duration of 12 seconds. ACAS command duration averaged 18 seconds. IPC generated 9 controller alerts. Alerts lasted from 4 seconds to 40 seconds with an average duration of 17.4 seconds. ACAS issued an average of 69.7 advisories while IPC averaged 189.3 PWI and 8.7 FPWI per hour. These runs were made with the high mix sample, i.e., 65 percent DABS, 35 percent ATCRBS. Reference 1 did not contain any data for the IFR series in which all aircraft were ACAS equipped. ACAS data in Table 5 do not include either ACAS equipped versus unequipped, or unequipped versus unequipped encounter pairs. IPC message rates, however, do include DABS versus ATCRBS and ATCRBS versus ATCRBS pairs.

TABLE 5 IPC/ACAS AVERAGE HOURLY NUMBER AND DURATION OF MESSAGES

IFR - HIGH MIX

MESSAGE		ACAS						IPC	
		I-SPB		M-SPB		O-SPB		WITH DESENSITIZED ZONE	
		NO.	AVG DUR SEC	NO.	AVG DUR SEC	NO.	AVG DUR SEC	NO.	AVG DUR SEC
CONTROLLER ALERT								9.0	17.4
COMMANDS	CLIMB	0	0	0.3	3.0	0	0	1.3	14.0
	DON'T CLIMB	-	-	-	-	-	-	0.3	4.0
	DESCEND	0	0	0.3	3.0	0	0	1.3	14.0
	DON'T DESCEND	-	-	-	-	-	-	0.3	4.0
	LEVEL OFF	0.3	6.0	0	0	0	0	-	-
	LIMIT TURN	2.3	18.6	3.7	18.6	1.3	24.3	-	-
	VSL	7.3	13.5	3.0	10.6	5.0	16.5	-	-
	TOTAL	10.0	14.4	7.3	13.9	6.3	18.1	3.3	12.0
ADVISORIES	LIMIT TURN	5.0	26.9	3.3	22.4	5.3	18.9	189.3(PWI)	
	VSL	63.0	29.1	71.0	28.3	64.3	29.2	8.7(FPWI)	
	TOTAL	68.0	29.0	74.3	28.1	69.7	28.4	198.0	

For comparison purposes, again it seemed equitable to compare ACAS with IPC after deleting all of those IPC encounters where one or both of the pairs was ATCRBS. Table 6 presents message rates after deleting all encounters which involved an ATCRBS-equipped aircraft. ACAS (O-SPB) data from Table 5 have been included in Table 6 for ease of reference. It can be seen in Table 6 that ACAS (O-SPB) issued 6.3 commands per hour as opposed to an average 1.4 commands issued by IPC. This decrease for IPC is somewhat comparable to the 6.1 fewer commands issued by IPC in the VFR high mix series. The IPC average of 126.7 advisories remains high relative to the 69.7 advisories issued by ACAS. IPC operation rates averaged 151 aircraft per hour versus 145.3 average operations in the ACAS (O-SPB) runs. No statistical significance can be placed on such a difference.

High Density Arrival - VFR Procedures

Three runs were made with arrival operations only to parallel runways using VFR control procedures. With no requirement to provide spacing for departures, inter-arrival spacing was based solely on ensuring adequate runway occupancy separation. The intent was to saturate the arrival controller with a very high volume of traffic in order to provide a rigorous test for ATC interface with ACAS and IPC.

Table 7 presents message rate data for ACAS (O-SPB) based on two 1-hour data runs and IPC based on three 1-hour data runs. All flights were 100 percent equipped. It can be seen that ACAS (O-SPB) issued commands to an average of 40 aircraft whereas IPC generated 8.3 commands. This indicates 31.7 fewer aircraft receiving commands for IPC. ACAS commands averaged 16.1 seconds. IPC commands lasted from 8 to 32 seconds with an average duration of 13.6 seconds. IPC alerted the controller 17 times per hour. Alerts lasted from 4 to 44 seconds with an average duration of 15.2 seconds. ACAS (O-SPB) generated 144.5 advisories per hour versus 300 PWI and 20 FPWI advisories for IPC.

Table 8 on page 6 shows hourly operations rates for the ACAS (O-SPB) and IPC for runs made with none of the aircraft equipped and runs where all aircraft were equipped.

TABLE 6 AVERAGE HOURLY NUMBER AND DURATION OF MESSAGES WITH ATCRBS ENCOUNTERS DELETED

IFR SERIES - HIGH MIX

MESSAGE	IPC WITH ATCRBS ENCOUNTERS DELETED		MESSAGE	ACAS O-SPB	
	NO.	AVG DUR SEC		NO.	AVG DUR SEC
CONTROLLER ALERT	3.7	16			
COMMANDS					
CLIMB	0.7	10	LIMIT TURN	1.3	24.3
DESCEND	0.7	10	VSL	5.0	16.5
TOTAL	1.4	10	TOTAL	6.3	18.1
ADVISORIES					
PWI	123.3		LIMIT TURN	5.3	18.9
FPWI	3.3		VSL	64.3	29.2
TOTAL	126.7		TOTAL	69.7	28.4

TABLE 7 IPC/ACAS AVERAGE HOURLY NUMBER AND DURATION OF MESSAGES

HIGH DENSITY ARRIVAL SERIES

MESSAGE		ACAS						IPC	
		I-SPB		M-SPB		O-SPB		WITH DESENSITIZED ZONE	
		NO.	AVG DUR SEC	NO.	AVG DUR SEC	NO.	AVG DUR SEC	NO.	AVG DUR SEC
CONTROLLER ALERT								17.0	15.2
COMMANDS	CLIMB	.7	12.5			2.5	10.8	4.0	14.6
	DON'T CLIMB	-	-			-	-	0.3 *	8.0
	DESCEND	0	0			2.5	8.4	4.3	14.0
	DON'T DESCEND	-	-			-	-	0.3 *	8.0
	LEVEL OFF	0	0			0	0	-	-
	LIMIT TURN	49.0	17.7			15.5	11.8	-	-
	VSL	28.0	17.7			19.5	21.1	-	-
	TOTAL	77.7	17.7			40.0	16.1	8.3	13.6
ADVISORIES	LIMIT TURN	28.0	35.5			19.5	42.4	300 (PWI)	
	VSL	226.7	31.6			125.0	44.1	20 (PPWI)	
	TOTAL	254.7	32.0			144.5	43.8	320	

* Positive to negative transition command

TABLE 8

HOURLY ARRIVAL OPERATIONS RATE - VFR PROCEDURES

	Equipment Mix	
	0%	100%
ACAS (O-SPB)	105	105
IPC	102	101

There is no impact on operations rate of introducing ACAS or IPC into the system. Moreover, there is no significant difference in operations rate between ACAS and IPC runs.

General Aviation Series

Two IPC runs were conducted in which 40 percent were low performance, general-aviation-type aircraft. These general aviation flights were operating on VFR flight plans; however, they were under approach control jurisdiction prior to entering the terminal area. The remaining 60 percent of the aircraft were commercial flights operating on IFR flight plans. All aircraft were DABS equipped. Controllers were instructed to provide 500 feet vertical or 1 nmi horizontal separation between VFR/VFR and VFR/IFR pairs, and 1,000 feet vertical or 3 nmi horizontal separation between IFR/IFR pairs. IPC treated all conflicts as controlled versus controlled with thresholds of AF=AFIFR=450 feet for VFR/VFR and VFR/IFR pairs, and AF=AFIFR=750 feet for IFR/IFR pairs. A comparison of the command rates presented in Table 9 shows that ACAS (O-SPB) issued commands to an average of 29.1 aircraft per hour as opposed to an average of 14 commands for IPC. ACAS commands averaged 16 seconds in duration. IPC commands lasted 8 to 32 seconds with an average duration of 13.7 seconds. IPC generated an average of

TABLE 9 IPC/ACAS AVERAGE HOURLY NUMBER AND DURATION OF MESSAGES

GENERAL AVIATION SERIES

MESSAGE		ACAS						IPC (100% DABS)	
		100% I-SPB		HIGH MIX I- SPB		100% O-SPB		WITH DESENSITIZED ZONE	
		NO.	AVG DUR SEC	NO.	AVG DUR SEC	NO.	AVG DUR SEC	NO.	AVG DUR SEC
CONTROLLER ALERT								15.5	24.0
COMMANDS	CLIMB	5.0	9.5	1.7	10.0	2.0	13.0	7.0	12.9
	DON'T CLIMB	-	-	-	-	-	-	0.5 *	12.0
	DESCEND	4.3	11.0	1.0	12.0	2.0	14.8	7.0	12.9
	DON'T DESCEND	-	-	-	-	-	-	0.5 *	12.0
	LEVEL OFF	2.3	4.3	0	0	0.7	4.5	-	-
	LIMIT TURN	21.3	16.3	8.0	16.0	3.7	11.8	-	-
	VSL	43.9	17.7	18.7	22.1	20.7	17.7	-	-
	TOTAL	76.8	16.0	29.4	19.4	29.1	16.0	14.0	13.7
ADVISORIES	LIMIT TURN	15.0	29.4	6.7	30.8	7.6	22.7	396.0(PWI)	
	VSL	201.4	39.7	89.2	41.6	132.3	43.5	27.0(FPWI)	
	TOTAL	216.4	39.0	95.9	40.9	139.9	42.4	423.0	

* Positive to negative transition command

15.5 controller alerts. IPC alerts lasted from 4 to 64 seconds with an average duration of 24 seconds. ACAS (O-SPB) issued an average of 139.9 advisories while IPC issued 423 advisories per run. The substantially higher number of PWI's generated by IPC in the general aviation series relative to the VFR and IFR series is primarily attributable to slower speeds and resulting longer time in the system of the general aviation aircraft. As shown in Table 10, there was no impact on operations rates of introducing either ACAS or IPC into the ATC system. There is also no significant difference in the operations rates obtained with ACAS or IPC.

TABLE 10

HOURLY OPERATIONS RATE - GENERAL AVIATION SERIES

	Equipment Mix		
	0%	High Mix	100%
ACAS (O-SPB)	133	130 (I-SPB)	133
IPC	133	133	130

ENCLOSURE 3

DETAILED BREAKDOWN OF IPC DATA

Detailed Breakdown of IPC Data

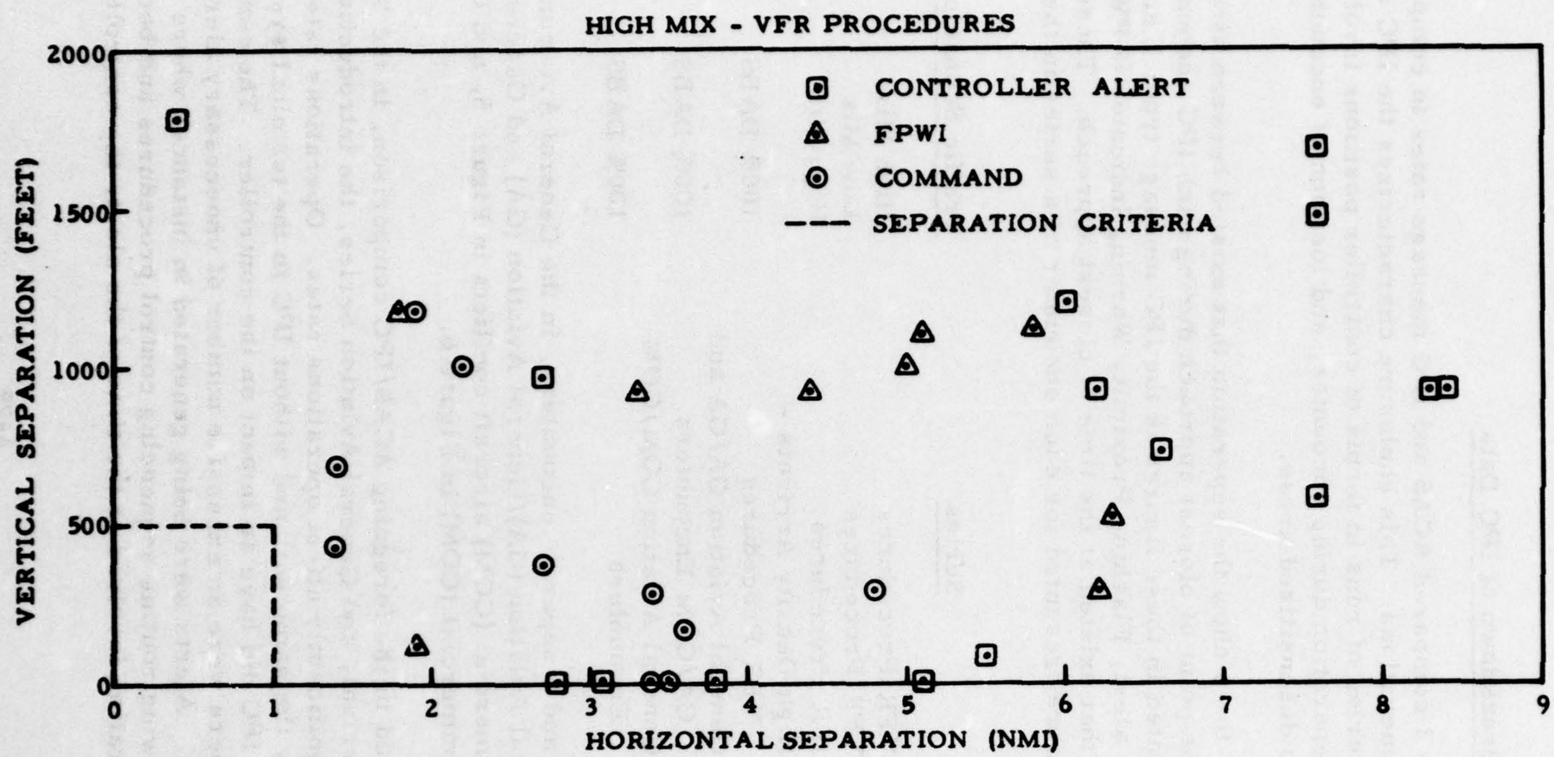
Enclosure 2 compared ACAS and IPC message rates in comparable terminal operations. This enclosure characterizes the IPC messages for each series of runs in terms of controller positions involved, aircraft separation during encounter, and location of encounter relative to desensitized areas.

Figures 1 to 6 show the separation that existed between aircraft pairs at the point of closest approach during each IPC encounter. Also indicated in these figures is the IPC message type, i.e., controller alert, Flashing Proximity Warning Indicator (FPWI) or command that existed at the time of closest approach. These separation data are presented for each encounter of a series in the following order.

Figure	Series	Traffic Scenario
1	VFR Procedures	High Mix
2	VFR Procedures	Low Mix
3	IFR Procedures	High Mix
4	High Density Arrivals - VFR Procedures	100% DABS
5	General Aviation GA/GA and GA/COM Encounters	100% DABS
6	General Aviation COM/COM Encounters	100% DABS

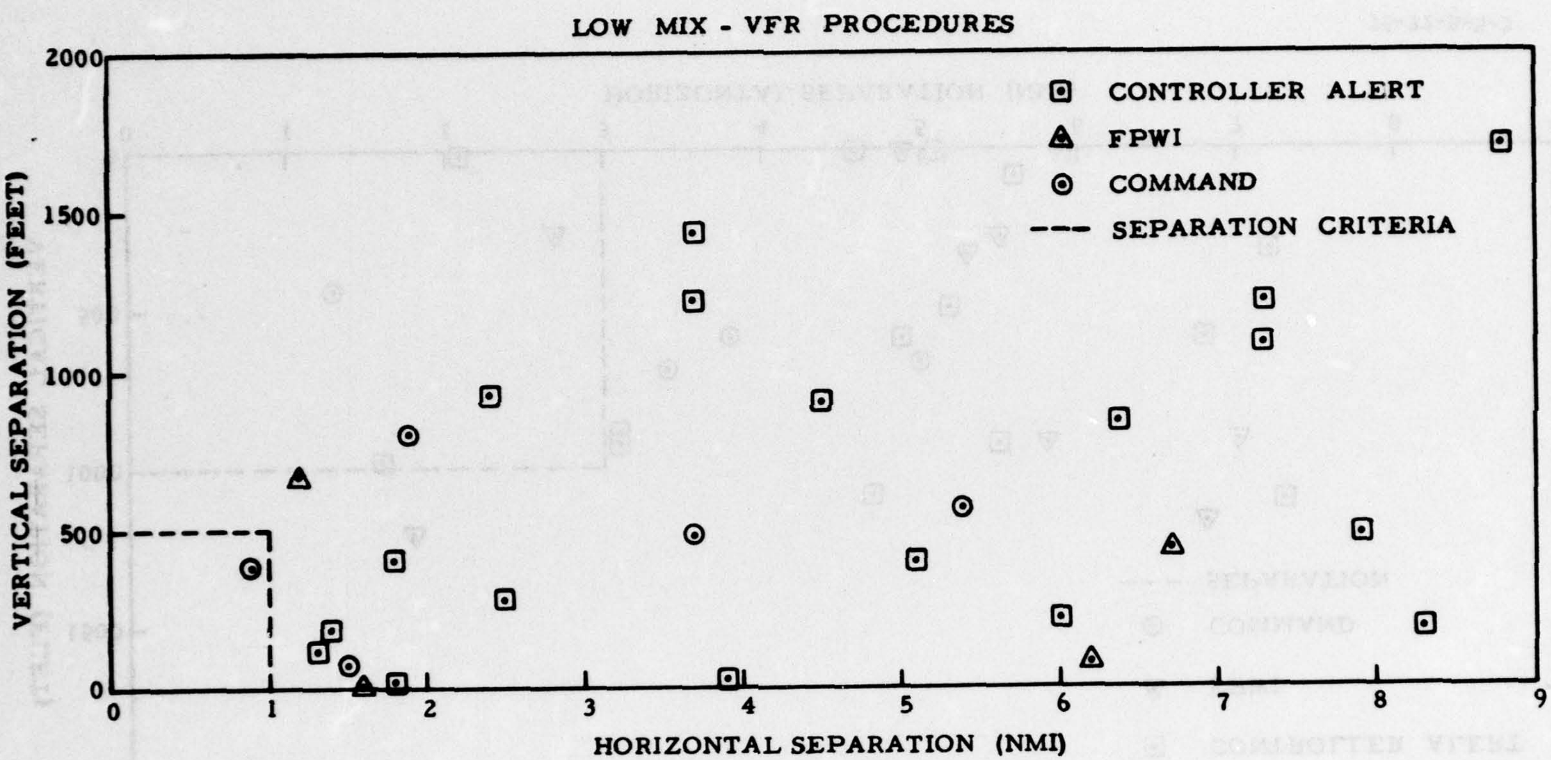
Figures 5 and 6 separate encounters, in the General Aviation Series, into General Aviation (GA)/General Aviation (GA) and General Aviation (GA)/Commercial (COM) aircraft conflicts in Figure 5, and Commercial (COM)/Commercial (COM) in Figure 6.

As indicated in the foregoing ACAS/IPC comparison, in the VFR, High Density Arrival, and General Aviation Series, the introduction of IPC did not significantly affect operations rates. Operations rates were essentially the same with and without IPC in the terminal system. However, IPC did have an impact on the controller. The controllers felt that there were an excessive number of unnecessary alerts and commands. Alerts were being generated in instances where controllers were following routine sequencing control procedures and because of the wide separation involved at the time of the alert, the controller saw no



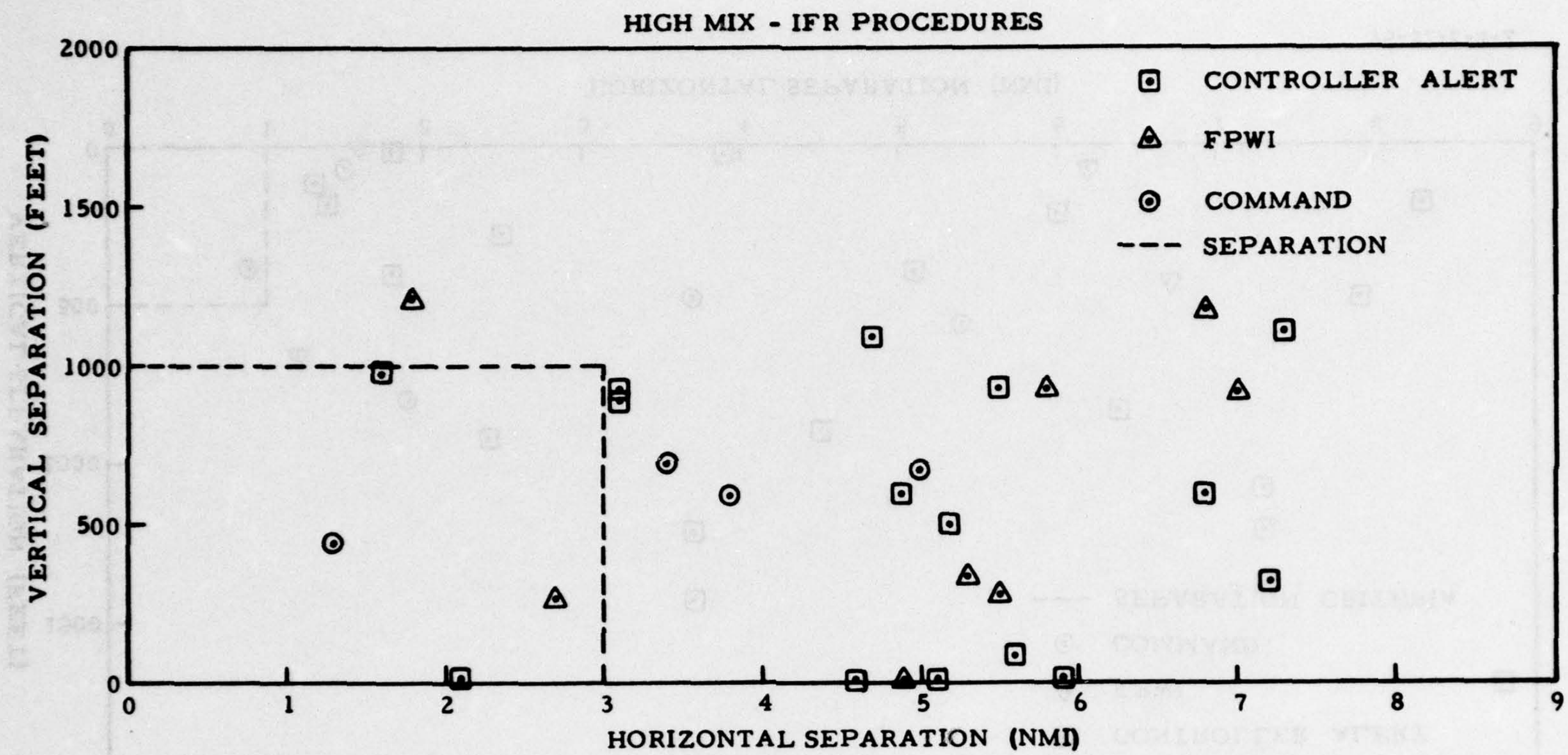
76-32-B-3-1

FIGURE A-3-1. CLOSEST APPROACH BETWEEN AIRCRAFT SURING EACH IPC ENCOUNTER



76-32-B-3-2

FIGURE A-3-2. CLOSEST APPROACH BETWEEN AIRCRAFT DURING EACH IPC ENCOUNTER



76-32-B-3-3

FIGURE A-3-3. CLOSEST APPROACH BETWEEN AIRCRAFT DURING EACH IPC ENCOUNTER

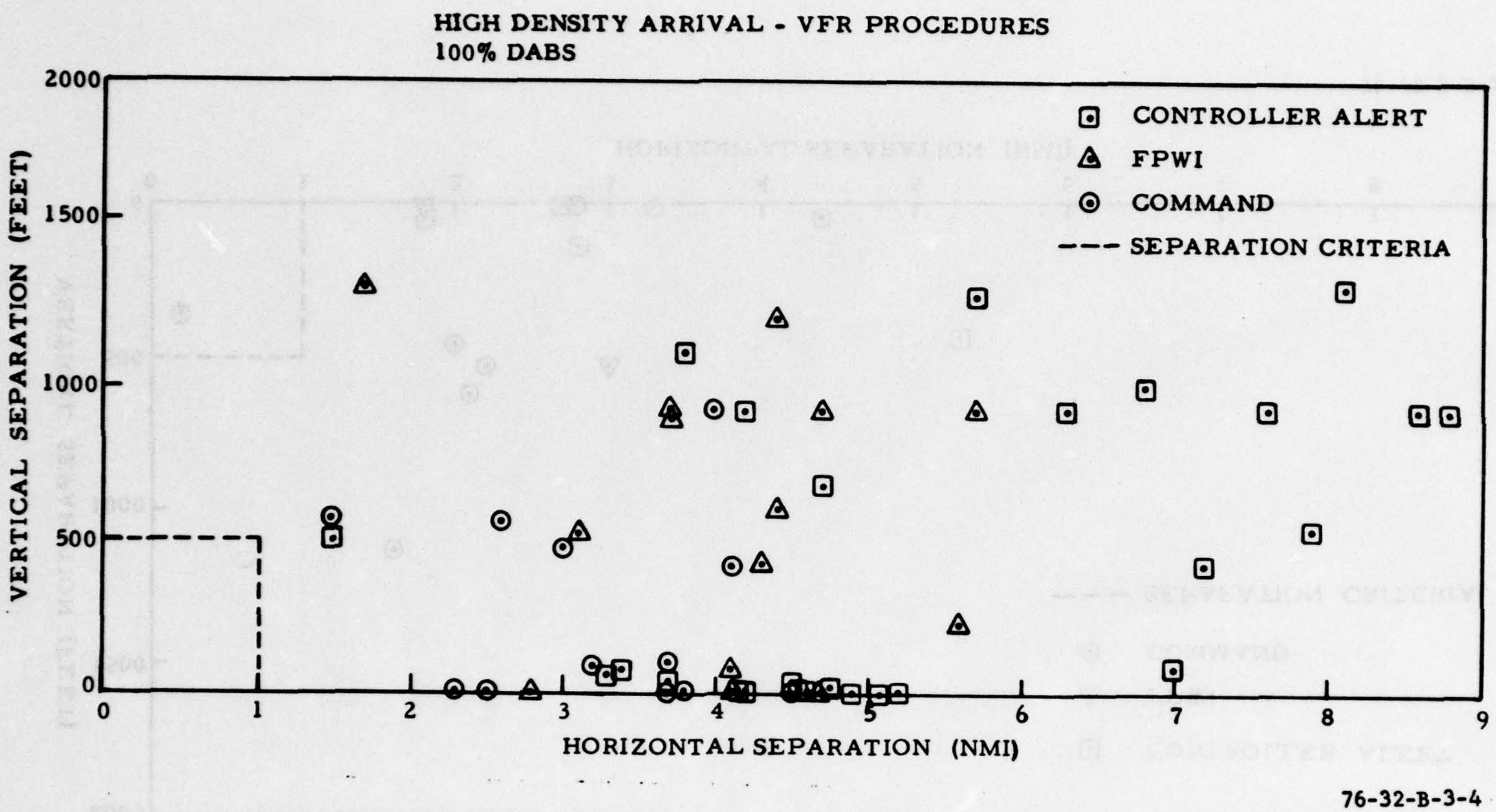


FIGURE A-3-4. CLOSEST APPROACH BETWEEN AIRCRAFT DURING EACH IPC ENCOUNTER

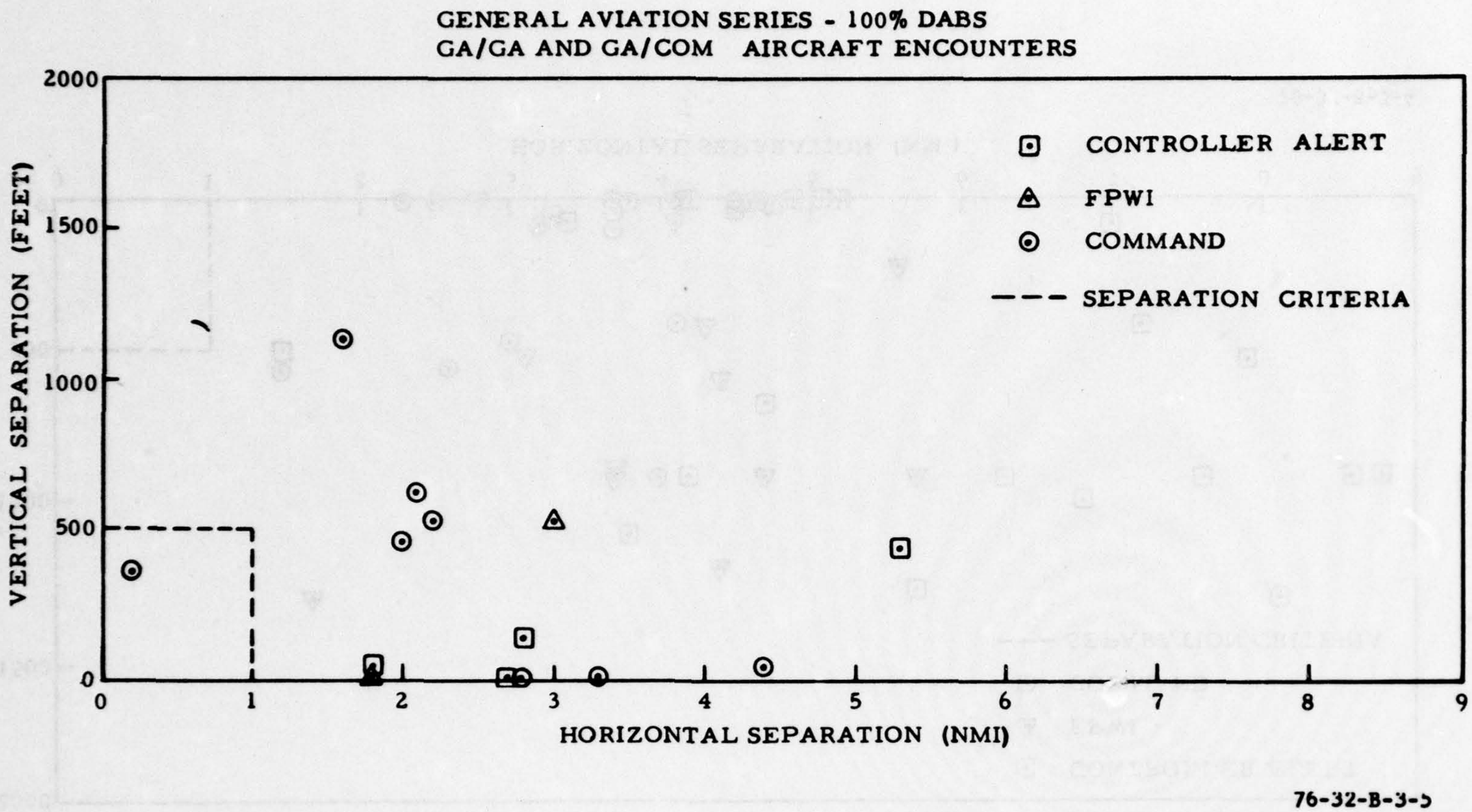


FIGURE A-3-5. CLOSEST APPROACH BETWEEN AIRCRAFT DURING EACH IPC ENCOUNTER

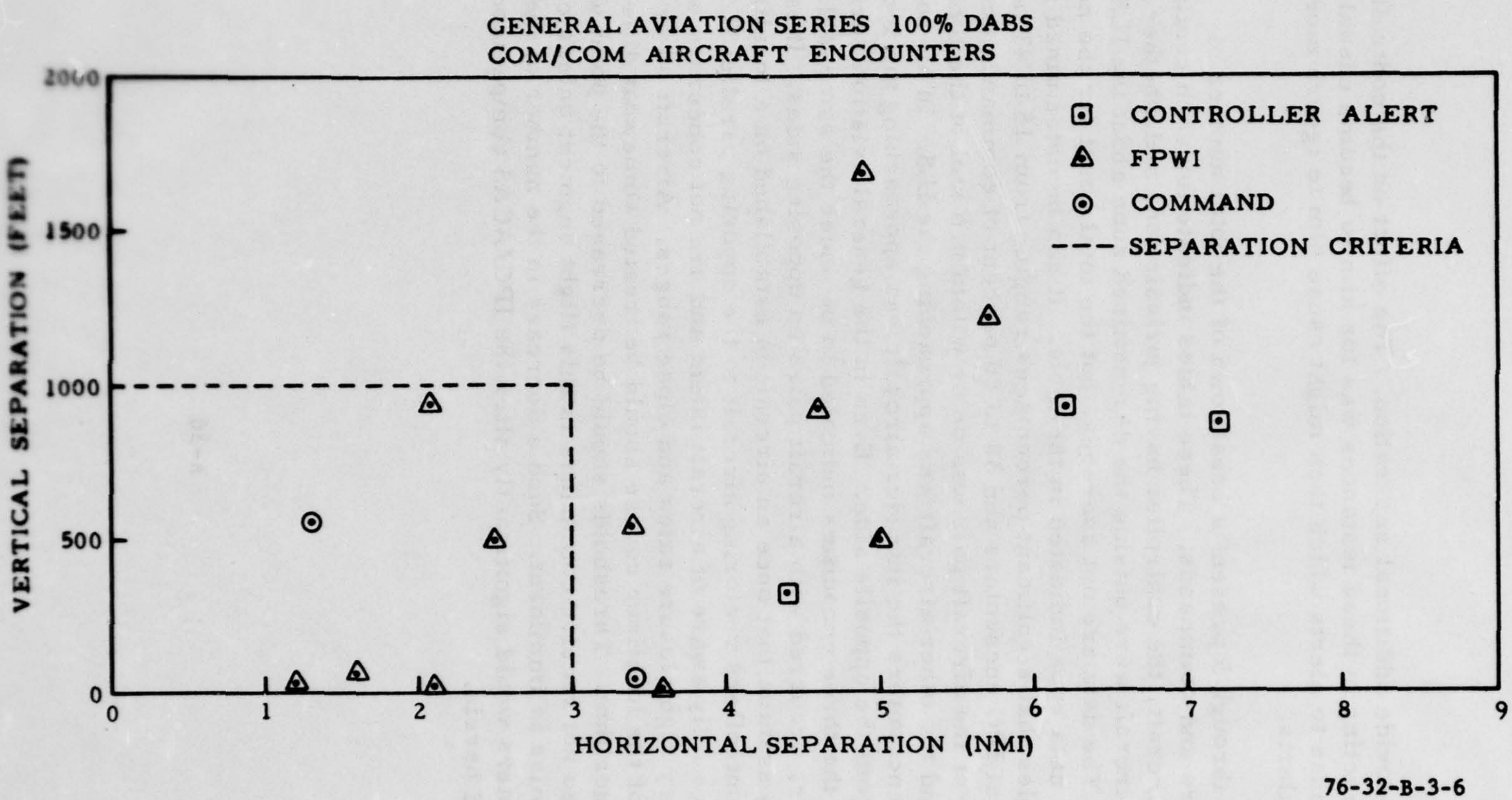


FIGURE A-3-6. CLOSEST APPROACH BETWEEN AIRCRAFT DURING EACH IPC ENCOUNTER

need to provide additional separation. The effect on the controller of IPC interacting in these instances was for him to become casual in his response to alerts which then might cause him to ignore more serious alerts.

Tables 1 through 5 present a breakdown of the total number of encounters and commands. These tables indicate for each conflicting pair of aircraft, the controller having jurisdiction, and whether one or both aircraft were outside the desensitized zone about the ILS course. The data are not averages, but the total count for the number of hourly data runs indicated in the table. It can be determined from these tables that significant percentages ranging from 15 to 43 percent of the total IPC encounters and 38 to 50 percent of commands occurred when one of the aircraft pair was on or within 0.6 nmi of the localizer course and the other aircraft was approaching the ILS. In all but two of these encounters the intruder aircraft was approaching the localizer course from the opposite side. Even in the general aviation series, Table 5, the three encounters indicated to be under the same-side controller, occurred with aircraft pairs on opposing sides. It is logical to assume that once an aircraft is established on a localizer course controllers vectoring aircraft to the opposing parallel ILS course are fully aware of aircraft intent and are not concerned with momentary high closure rates and close ranges. Aircraft on or within 0.6 nmi of the localizer course should be treated somewhat differently by the algorithm. Thresholds should be decreased to the point where aircraft do not receive commands in this flight segment unless collision or near miss is imminent. Such a decrease in the number of these types of encounters would significantly alter the IPC/ACAS comparisons presented herein.

TABLE 1 TOTAL NUMBER OF EVENTS OVER THREE 1-HOUR RUNS

HIGH MIX - VFR SERIES

	OPPOSITE SIDES ARRIVAL VS ARRIVAL	SAME SIDE ARRIVAL VS ARRIVAL	ARRIVAL VS DEPARTURE	DEPARTURE VS DEPARTURE	TOTALS	PERCENT OF TOTAL
ENCOUNTERS						
ONE AIRCRAFT INSIDE ONE AIRCRAFT OUTSIDE	14	1	0	0	15	43
BOTH AIRCRAFT OUTSIDE	3	9	8	0	20	57
TOTAL ENCOUNTERS	17	10	8	0	35	100
COMMANDS						
ONE AIRCRAFT INSIDE ONE AIRCRAFT OUTSIDE	5	0	0	0	5	42
BOTH AIRCRAFT OUTSIDE	0	3	4	0	7	58
TOTAL COMMANDS	5	3	4	0	12	100

TABLE 2 TOTAL NUMBER OF EVENTS OVER THREE 1-HOUR RUNS

LOW MIX - VFR SERIES

	CONTROLLER POSITION					
	OPPOSITE SIDES ARRIVAL VS ARRIVAL	SAME SIDE ARRIVAL VS ARRIVAL	ARRIVAL VS DEPARTURE	DEPARTURE VS DEPARTURE	TOTALS	PERCENT OF TOTAL
ENCOUNTERS						
ONE AIRCRAFT INSIDE, ONE AIRCRAFT OUTSIDE	9	0	0	0	9	33
BOTH AIRCRAFT OUTSIDE	7	4	6	1	18	67
TOTAL ENCOUNTERS	16	4	6	1	27	100
COMMANDS						
ONE AIRCRAFT INSIDE ONE AIRCRAFT OUTSIDE	3	0	0	0	3	43
BOTH AIRCRAFT OUTSIDE	0	0	4	0	4	57
TOTAL COMMANDS	3	0	4	0	7	100

TABLE 3 TOTAL NUMBER OF EVENTS OVER THREE 1- HOUR RUNS

HIGH MIX - IFR SERIES

	OPPOSITE SIDES ARRIVAL VS ARRIVAL	SAME SIDE ARRIVAL VS ARRIVAL	ARRIVAL VS DEPARTURE	DEPARTURE VS DEPARTURE	TOTALS	PERCENT OF TOTAL
ENCOUNTERS						
ONE AIRCRAFT INSIDE / ONE AIRCRAFT OUTSIDE	4	0	0	0	4	15
BOTH AIRCRAFT OUTSIDE	6	12	5	0	23	85
TOTAL ENCOUNTERS	10	12	5	0	27	100
COMMANDS						
ONE AIRCRAFT INSIDE / ONE AIRCRAFT OUTSIDE	2	0	0	0	2	40
BOTH AIRCRAFT OUTSIDE	0	0	3	0	3	60
TOTAL COMMANDS	2	0	3	0	5	100

TABLE 4 TOTAL NUMBER OF EVENTS OVER THREE 1-HOUR RUNS

HIGH DENSITY ARRIVAL - 100% DABS

	OPPOSITE SIDES ARRIVAL VS ARRIVAL	SAME SIDE ARRIVAL VS ARRIVAL	ARRIVAL VS DEPARTURE	DEPARTURE VS DEPARTURE	TOTALS	PERCENT OF TOTAL
ENCOUNTERS						
ONE AIRCRAFT INSIDE, ONE AIRCRAFT OUTSIDE	14	1	-	-	15	29
BOTH AIRCRAFT OUTSIDE	10	27	-	-	37	71
TOTAL ENCOUNTERS	24	28	-	-	52	100
COMMANDS						
ONE AIRCRAFT INSIDE, ONE AIRCRAFT OUTSIDE	5	0	-	-	5	38
BOTH AIRCRAFT OUTSIDE	3	5	-	-	8	62
TOTAL COMMANDS	8	5	-	-	13	100

TABLE 5 TOTAL NUMBER OF EVENTS OVER TWO 1-HOUR RUNS

GENERAL AVIATION - 100% DABS

	OPPOSITE SIDES ARRIVAL VS ARRIVAL	SAME SIDE ARRIVAL VS ARRIVAL	ARRIVAL VS DEPARTURE	DEPARTURE VS DEPARTURE	TOTALS	PERCENT OF TOTAL
ENCOUNTERS						
ONE AIRCRAFT INSIDE ONE AIRCRAFT OUTSIDE	9	3	0	0	12	39
BOTH AIRCRAFT OUTSIDE	4	8	7	0	19	61
TOTAL ENCOUNTERS	13	11	7	0	31	100
COMMANDS						
ONE AIRCRAFT INSIDE ONE AIRCRAFT OUTSIDE	5	2	0	0	7	50
BOTH AIRCRAFT OUTSIDE	0	3	4	0	7	50
TOTAL COMMANDS	5	5	4	0	14	100

APPENDIX B

TESTBED VERIFICATION SUMMARY

Prior to operational testing, testbed verification was conducted. The following are the major results of this initial phase.

1. Slot-Rule Logic. Added code to IPCSEL to adjust slots after horizontal and vertical commands. Added code to IPCSEL to check the horizontal dimension if the vertical dimension is taken prior to calling the slot-rule logic. Also, added code to IPCSEL to prevent slot-rule logic from issuing incompatible commands.

2. Master Resolution Logic. Code was added to set POSCOM = 0 when negative commands are issued. Code was also added to test if uncontrolled aircraft in IFR/VFR pair is ATCRBS. This prevents premature setting of PIFR=1.

3. Changed three parameters, AF, AFIFR, and AFPWI, from a value of 1,000 feet to a value of 970 feet.

4. The IPC algorithm, as coded in the DSF/IPC testbed, appeared to perform in accordance with the concepts and/or specifications outlined in FAA EM-74-2 (reference 1). Analysis of the data indicated that further refinement of the algorithm was required before it was suitable for full-scale IPC/ATC interaction evaluation.

5. Horizontal Tracker. The horizontal tracker lags the actual heading of the aircraft during turns. The magnitude of lag is dependent upon the variables of turn rate and velocity. Comparison of numerous flight profiles confirmed that lag varies (approximately) in direct proportion with turn rate and inversely with velocity, i.e., the worst cases are created by slowly moving aircraft with a high rate of turn, and conversely, a high-speed aircraft with a slow turn rate can more easily be tracked. A heading error of 45° is common for aircraft flying at or below 120 knots which are turning at rates greater than 5° per second. Thus, late detection of IPC events occurs each time the event is initiated during a horizontal maneuver. Also, because of the nature of the turn detection logic, an overshoot almost always occurs approximately 24 to 28 seconds into the turn. Furthermore, as pointed out in MITRE Memorandum D43-M3545, this same tracker lag prolongs the duration of the command condition once horizontal resolution is attempted. If the turn detection threshold could be made more sensitive to the velocity of the aircraft, the severity of the above problems could be reduced. Changes of this nature would increase the likelihood of false turn detection; however, this detrimental effect would be balanced (to some degree) by the benefits of better tracker performance during turns.

6. Vertical Tracker. The vertical tracker lags aircraft performance proportional to the vertical velocity of the aircraft. (Acceleration rates were not varied to determine their effect.) This lag tends to cause late detection of IPC events. When vertical resolution is attempted, this same lag may cause the positive command to persist for 12 to 20 seconds after separation is effected.

7. Positive Vertical Commands. If two aircraft with high (opposite) vertical velocities conflict, a positive vertical command may result when the aircraft are still separated by 3,000 or 4,000 feet. There is, in these cases, ample time for each of the aircraft to level and miss each other by more than 1,000 feet. The addition of logic to test such a condition against a suitable threshold would result in a more operationally acceptable IPC system.

8. Negative Commands. If an uncontrolled ATCRBS-equipped aircraft is in close proximity to a DABS-equipped aircraft, issuance of a negative command is somewhat meaningless. The uncontrolled ATCRBS aircraft cannot receive the PWI warning (flashing or steady) nor can it receive the negative command. The DABS-equipped aircraft will receive both the PWI warning and the command; however, that will not prevent the uncontrolled ATCRBS aircraft from maneuvering toward the DABS-equipped aircraft. Often when aircraft are in close proximity this leaves insufficient time for resolution based upon a positive command. This condition is particularly sensitive to tracker lag.

9. Multiaircraft Logic. The existing multiaircraft logic is inherently pair-wise logic. Frequently, in multiaircraft conflicts, this is not advantageous. In many cases, a far simpler resolution could effect the desired separation if the conflict were considered as a multicondition rather than two or more pair-wise conditions. In addition to causing fewer commands to be issued, this would have the additional benefit of creating fewer secondary conflicts.