FAA-RD-76-22

Project Report
ATC-57

IPC Design Validation and Flight Testing – Interim Results

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16 March 1976

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Prepared for the Federal Aviation Administration,
Washington, D.C. 20591

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Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FAA-RD-76-22		

4. Title and Subtitle	5. Report Date
IPC Design Validation and Flight Testing – Interim Results	16 March 1976
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
J.W. Andrews and J.C. Koegler	ATC-57
9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
Massachusetts Institute of Technology Lincoln Laboratory P.O. Box 73 Lexington, Massachusetts 02173	11. Contract or Grant No. DOT-FA72-WAI-261
12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
Department of Transportation Federal Aviation Administration Systems Research and Development Service Washington, D.C. 20591	Interim Test Report February – October 1975
	14. Sponsoring Agency Code

15. Supplementary Notes

The work reported in this document was performed at Lincoln Laboratory, a center for research operated by Massachusetts Institute of Technology under Air Force Contract F19628-76-C-0002.

16. Abstract

Intermittent Positive Control, an automated aircraft collision avoidance system requiring the participation of the aircraft pilots involved, is being evaluated in a series of live flight tests. This document provides an interim summary of the results obtained in these flight tests. Results are given for IPC algorithm design evaluation flights (34) and for pilot interaction evaluation flights (14) flown from Hanscom Field, Bedford, Massachusetts between February and October, 1975.

17. Key Words	18. Distribution Statement
Intermittent Positive Control (IPC) Discrete Address Beacon System (DABS) Flight Test IPC Algorithms Collision Avoidance Systems	Document is available to the public through the National Technical Information Service, Springfield, Virginia 22151.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	
Unclassified	Unclassified	108	

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1.0 OVERVIEW

1.1 Background

M.I.T. Lincoln Laboratory is conducting evaluation flight tests of the Intermittent Positive Control (IPC) aircraft collision avoidance concept. General aviation aircraft are flown in a series of conflict situations which permit the measurement of conflict resolution parameters and the collection of pilot reaction data. The flight testing, as presented in the IPC flight test plan [1], is midway through the originally outlined program. This interim report provides a summary of the progress made in these IPC flight tests. The period covered by this report is February to October, 1975, inclusive.

1.2 Summary of Objectives

Design validation and pilot evaluation, as summarized in Table 1-1, are the two basic objectives of the IPC flight tests. Design validation of the IPC concept will assess how well the IPC collision avoidance maneuvers provide separation between aircraft when the system operates with cooperative pilots and aircraft in a live environment. The evaluation by subject pilots provides the system developers with the insight necessary to insure a design compatible with the needs of pilots involved in live conflict situations.

Table 1-1.
FLIGHT TEST OBJECTIVES

Design Validation

- Evaluate and improve, if necessary, IPC logic
- Validate the results of computer simulation
- Demonstrate IPC - DABS compatibility

Pilot Interaction Evaluation

- Evaluate total system effectiveness
- Characterize threat perception at time of IPC alarms
- Evaluate Suitability of baseline pilot response rules

The flight tests are designed to identify IPC problems in the area of detection and resolution of conflict situations. The identified problems are analyzed and technical notes prepared summarizing the problem and possible solutions. Solutions are subjected to analytical and simulation studies to determine the best implementation scheme. The solutions are incorporated into the flight test algorithm, validated, and flown for subject pilot evaluation.

1.3 Status of Tests

The validation of the basic IPC computer algorithms [2] is essentially complete. A total of 34 validation flights (Table 1-2) have been flown by the test pilots. Some resolution problems were identified and logic revisions made. Validation testing of proposed solutions will continue in parallel, on an as needed basis, with subject pilot testing. Subject pilot testing is well under way with 14 missions completed. The remaining 11 missions of the total of 59 flown, were flown to demonstrate IPC to visitors from the aviation community.

Table 1-2.
FLIGHT TEST MISSIONS
(February - October 1975)

Validation	34
Demonstration	11
Subject Pilot	14
Total	59

During the 59 missions conducted there were 647 planned encounters flown (Table 1-3). The planned encounters are near-miss intercepts scheduled between the two test aircraft. During the conduct of these missions one or both of the test aircraft encountered itinerant aircraft proceeding through the test area resulting in a command to the test aircraft. There were 73 of these unplanned encounters recorded.

Table 1-3.
ENCOUNTER CLASSIFICATION
(February - October 1975)

Type of Encounter	Planned Encounters	Unplanned Encounters	Total
DABS/DABS			
VFR/VFR	288	-	288
VFR/IFR	159	-	159
IFR/IFR	26	-	26
ATCRBS/DABS			
VFR/VFR	83	56	139
VFR/IFR	72	17	89
IFR/IFR	19	-	19
	647	73	720

A list of 120 pilot subjects who participated in earlier proximity warning experiments for the D.O.T. Transportation System Center in Cambridge, Massachusetts was obtained. Questionnaires were prepared and distributed to the pilots on this list and a subject pilot file compiled. The subject pilot file contains completed questionnaires from approximately one hundred pilots. A summary of this file is presented in Table 1-4.

Table 1-4.
SUBJECT PILOT FILE

Total Pilot Sample

	min	max	mean	std. dev.
Pilot age	23	58	41	9
Years as active pilot	1	39	13	9
Total hours flown	24	25,000	2277	4555

Pilot Ratings:

Type	No.
Student	2
Private	38
Commercial	55
Instrument	55
Instructor (CFI)	16
Instructor (CFII)	9
ATR	13

Pilot Training:

Type	No.
Military	27
Civilian	89
Airline	9

Pilot Experience:

Type	No.
Business	37
Pleasure	89
Military	5
Commercial	18

1.4 Summary of Principal Findings

Validation Results

The Validation results are reported in Section 2. Two generic categories of encounters have been identified during flight testing. They are designated, for this report, as nominal and non-nominal conflict situations. The nominal involve two DABS-IPC equipped aircraft with neither aircraft having accelerated motion and both pilots responsive to the IPC system (Sections 2.3 and 2.4). Non-nominal include all other conflict situations. For example, situations involving: at least one maneuvering aircraft; a DABS-IPC and an ATCRBS aircraft; a non-responsive pilot; or more than two aircraft.

The IPC algorithm performed well in the resolution of nominal VFR/VFR and IFR/VFR encounters, ensuring acceptable horizontal or vertical separation when commands were followed promptly. However, the algorithm had only limited success in its attempts to avoid issuing commands to the IFR aircraft in nominal IFR/VFR encounters.

For a large class of non-nominal encounters, IPC was found to provide adequate separation between two aircraft in conflict. But, for certain especially difficult encounter situations, the resolution obtained in flight testing was unsatisfactory. Although it is evident that no collision avoidance system can completely eliminate the mid-air collision hazard, the capability of IPC to resolve conflicts can and should be extended to cover those situations likely to arise from prudent pilots flying according to established flight rules (Section 2.5).

Subject Pilot Results

The preliminary observations of subject pilots are reviewed in Section 3. The automated traffic advisory service provided by the ordinary proximity warning of IPC is a greatly appreciated aid to general aviation pilots flying in so-called "see and avoid" uncontrolled airspace. In fact, pilots have suggested that a single innocuous tone to alert them to the presence of an ordinary proximity warning on the IPC display would be helpful. It has also been suggested that the three light PWI configuration at each of the twelve clock positions be changed to two lights at each position to provide more useful relative altitude information. Pilots generally are interested in knowing whether traffic is above or below them, not simply whether the traffic is within 500 feet of coaltitude.

There is generally insufficient time during the flashing PWI sequence for the pilot to assess near miss situations and resolve them successfully prior to the receipt of IPC commands. This suggests that the function of the flashing PWI be reviewed. Either more warning is required or more assistance should be given to help the pilot decide what to do. One method to provide assistance would be to advise the pilot what command would most likely result if the situation continues to deteriorate (Section 3.3).

Pilots willingly follow commands when they cannot acquire their traffic visually. However, many pilots state that commands are unnecessary and refuse to follow them or respond in a minimal fashion when their traffic is in sight. This suggests that a more effective pilot interface may be needed (Section 3.4).

The present implementation of the acknowledgment feature has led to many late or missing acknowledgments, and the resulting backup commands were frequently too late, inconsistent or counterproductive (Section 3.5).

1.5 Recommendations

The results to date indicate that IPC is a viable system concept, and that the proposed algorithms are generally effective. There are several areas, however, which require special engineering attention, as indicated in Table 1-5. Some of these studies are currently underway by the MITRE Corporation and the M.I.T. Lincoln Laboratory. For a complete description of these and other problems, see the referenced section and appendices.

Table 1-5.
IPC ENGINEERING RECOMMENDATIONS

Problem Area	Recommendations	References
Aircraft turning during the conflict detection process can occasionally cause late or ineffective commands.	- Turn sensing based on tracker. - Improved data adaptation of tracker. - Improved tracker performance. - More use of negative commands.	A.6 A.8 A.10
A DABS-IPC aircraft can be commanded to maneuver in front of an ATCRBS or noncomplying DABS-IPC aircraft, resulting in prolonged hazards.	- A possible remedy is to make use of the vertical dimension.	A.7
Command selection in some cases may be delayed until very near the time of closest approach.	- Avoid giving ineffective commands. - Attempt to give earlier commands.	A.3
Vertical chase situations can occur between vertically maneuvering ATCRBS and DABS-IPC aircraft.	- Avoid using vertical commands if a chase can result.	A.1
Anomolous low elevation surveillance can cause resolution failures (e.g. pop-up targets and diffraction from vertical obstacles).	- Although judicious siting of the DABS antenna is required some adaptation of the IPC system to accommodate the anticipated coverage boundary effects will be necessary.	A.9
Following IPC commands which are contrary to normal pilot resolution can cause pilot concern, especially when the traffic is lost visually.	- Acquired pilot confidence in IPC resolution appears to be one answer to this compatibility question. - Additional protocol to provide communication of pilot intent/constraints prior to commands.	3.3
Positive commands may be generated when aircraft are at long ranges and have large projected miss distances.	- A miss distance test implemented to prevent unnecessary commands.	A.2

Table 1-5. (con't)

Problem Area	Recommendations	References
Pilots generally fail to WILCO commands within a short time of command receipt.	- Eliminate the WILCO if possible. - Refine the definition and application of the WILCO function, otherwise.	3.5
The flashing PWI sequence is too short to allow pilots to assess a situation and take evasive action on their own.	- Provide instruction to pilots not to attempt to maneuver during flashing PWI unless absolutely required.	3.4

2.0 RESULTS OF VALIDATION TESTING

The emphasis in validation testing has been upon the determination of the capability of the IPC system to resolve conflicts in a real environment. Because validation encounters typically involve test pilots in each aircraft flying in a pre-planned manner, analysis of pilot interaction issues is limited. However, basic questions concerning surveillance, IPC tracking, and IPC resolution strategy have been fruitfully explored within this limitation. This section presents an analysis of the results of validation tests. The IPC configuration under test is described in Reference 2.

2.1 Evaluation Criteria

Following each validation flight, each IPC encounter was examined and the following questions asked:

a) Was the achieved separation adequate?

b) Were the commands needed? (Were positive rather than negative commands needed? Were commands in both maneuver planes needed rather than just one?)

c) Were the command directions and the sequence of commands reasonable? Was the timing of commands and PWI reasonable?

d) Would the resolution be successful for reasonable variations in the initial geometry, the response delays, or the maneuver rates?

e) Did IPC complement see-and-avoid capability or did it nullify see-and-avoid capability (e.g. by turning aircraft in a way that caused visual contact to be lost)?

f) After responding to commands could aircraft then return to course without receiving a second sequence of commands? If aircraft return to course immediately, how would the success in resolving the second encounter compare to the success in resolving the first?

g) Did IPC perform in accordance with the stated system objectives and system descriptions?

When cases were discovered in which IPC performed in an unexpected or inadequate manner, such behavior was recorded in the IPC mission data summaries. When sufficient data existed to characterize a particular problem, an IPC performance note was prepared which contained a description of the problem, an assessment of its significance, and an indication of possible remedies. Such notes are incorporated into this report as Appendix A.

2.2 Evaluation Techniques

2.2.1 Classification of IPC Encounters

Table 2-1 provides a list of encounter attributes shown to be important by the IPC flight tests. In testing, the desired values of some encounter attributes are chosen during mission planning and the intercept then controlled to achieve these values. However, certain variables are less susceptible to control and are not planned, although their effects upon IPC performance are examined. Test safety implications of all unplanned variables are constantly reviewed.

Table 2-1.
IPC ENCOUNTER VARIABLES

Planned:		Unplanned:
Flight rules	(IFR, VFR)	Subject pilot compliance
Equipment	(DABS, ATCRBS)	Itinerant ATCRBS traffic
Speeds		Wind
Crossing Angle		Visibility
Miss Distance		Surveillance anomalies
Approach Type	(straight & level, turning, climbing, descending)	
Interceptor compliance		

Test results have shown that encounters with certain attributes are inherently more difficult to resolve than others. For this reason it is convenient to divide encounters into two groups: nominal and non-nominal as defined in Table 2-2.

Table 2-2.
CLASSIFICATION OF ENCOUNTERS

Nominal Encounters	Non-Nominal Encounters
No initial acceleration	Acceleration during conflict development
and	or
Both IPC equipped	One aircraft ATCRBS
and	or
Both complying	One aircraft non-complying DABS
and	or
Only two aircraft involved	Multiple aircraft involved
and	or
Normal surveillance quality	Degraded surveillance quality

Since several algorithm changes which will impact IPC performance in non-nominal encounters are being tested at present, no conclusions will be reported concerning IPC performance in such cases. However, the test results which have motivated algorithm refinements are discussed in later sections.

2.2.2 Measure of Separation

The IPC algorithm is designed to resolve conflicts in either the horizontal or vertical planes. In the analysis of test results it is useful to have a single separation measure which takes both horizontal and vertical separation into account. Slant range closest approach is not a wholly satisfactory measure since vertical and horizontal components of separation are not equally significant (e.g. an approach of 500 feet vertically is more acceptable than an approach of 500 feet horizontally). The simplest measure which takes this fact into account is an elliptical separation which multiplies the vertical component of separation by a fixed "stretch" factor, c, before calculating the magnitude of the separation vector. Thus if the horizontal separation is H and the vertical separation is V, an elliptical separation may be expressed as

$$(H^2 + (c\ V)^2)^{\frac{1}{2}}$$

In the analysis which follows, c = 4 will be used.* Thus a separation of 500 feet vertically and 0 feet horizontally produces an elliptical separation of 2000 feet (the same value achieved at a range of 2000 feet by coaltitude aircraft).

One technique for determining the beneficial effects of IPC commands which is useful in analyzing nominal encounters is to compare on an encounter-by-encounter basis the closest approach which would have been achieved in the absence of avoidance maneuvers to the closest approach which resulted from response to the IPC commands. In order to do this a time of closest approach, T, is calculated by rectilinear projection of the trajectories which existed for the scan on which the commands were <u>generated</u>. The elliptical separation which is projected to exist at time T will be called the <u>projected</u> elliptical closest point of approach. This is compared to the <u>actual</u> elliptical closest point of approach, i.e. the elliptical separation at the actual time of closest approach. Since for nominal encounters the aircraft in question are in straight flight, the projected closest approach should be fairly constant from scan to scan up to the point at which the aircraft begin to respond to IPC commands. (For those non-nominal encounters in which the aircraft are turning at the time commands are generated, the rectilinear projection of trajectories does not provide a good measure of the expected closest approach.)

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*The nominal algorithm thresholds for positive commands are 500 feet vertically and 3000 feet horizontally. Thus a 6:1 ratio of acceptable approach distance is implied. However, if we instead take the ratio of horizontal position error to altimetry error in order to compare the confidence intervals required to insure safety, the ratio would probably be significantly lower. The 4:1 ratio is chosen as a useful compromise for the purposes of analysis.

2.3 Results for Nominal VFR/VFR Encounters

Because of the preponderance of VFR traffic, VFR/VFR IPC encounters are expected to be the most common. The IPC algorithm utilizes the lowest tau thresholds for DABS/DABS VFR/VFR encounters (FPWI are issued for tau below 45 seconds and the command flag is set for tau below 32 seconds). These values are thought to be near the absolute minimum for effective avoidance and are set to these low values in order to minimize the rate of IPC intervention.

At the time of this writing some 40 nominal VFR/VFR encounters were available for analysis. Because the results of such encounters are highly repeatable it was not necessary to run many trials for each geometry in order to determine IPC performance for that geometry. (In pilot interaction testing when the variable reactions of subject pilots are included, this may no longer be the case.)

2.3.1 Closest Approach Analysis

In this section the closest approach statistics for nominal VFR/VFR encounters will be investigated to determine whether pilot compliance with commands ensures acceptable separation.

Figure 2-1 is a scatter diagram of the horizontal and vertical components of separation at the closest point of approach which would have resulted if the aircraft had continued in rectilinear flight from the time commands were generated. This figure represents the set of potentially hazardous values which IPC attempts to alter. Figure 2-2 presents a diagram of the actual values of the same approach parameters which resulted from IPC intervention. Note the general migration of points away from the origin. Except for the point identified by the arrow (symbol "A" at X = 1050, y = 380), the aircraft came no closer than about 2000 feet horizontally or 600 feet vertically.

It is instructive to examine the circumstances giving rise to this least satisfactory separation (arrow). Consider the encounter depicted in Figure 2-3, a horizontal plane plot for a typical nominal encounter with a planned track crossing angle of 135^{o}. (The crossing angle actually estimated at the time commands were generated was 137^{o}.) The planned horizontal miss distance was zero and the miss distance perceived by IPC tracking was 60 feet. The aircraft responded to commands within 8 seconds of the time they were received, and the horizontal closest approach was over 2900 feet. Note also that after commands were dropped both aircraft could return to course with no danger of a second close approach. This type of successful resolution is typical of the application of Command Selection Rule B (Reference 2, page 5-43) in nominal encounters.

Next, consider Figure 2-4, a horizontal plane plot of the encounter mentioned above which produced the least satisfactory separations. The geometry is very similar to that of Figure 2-3, but in this case the aircraft began to maneuver about 16 seconds (rather than 8 seconds) after receipt of

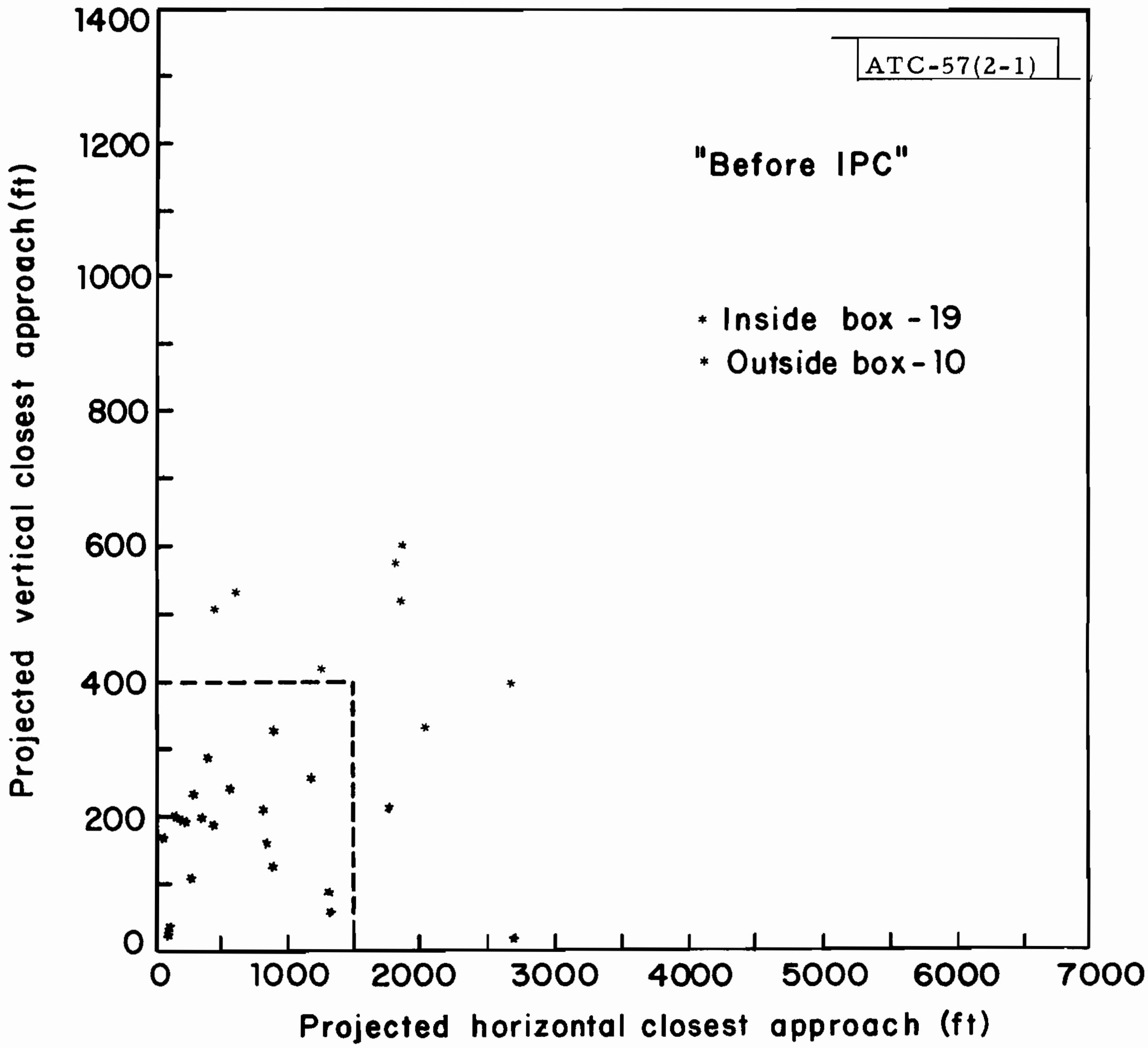


Fig. 2-1. Project closest approaches: nominal VFR/VFR encounters.

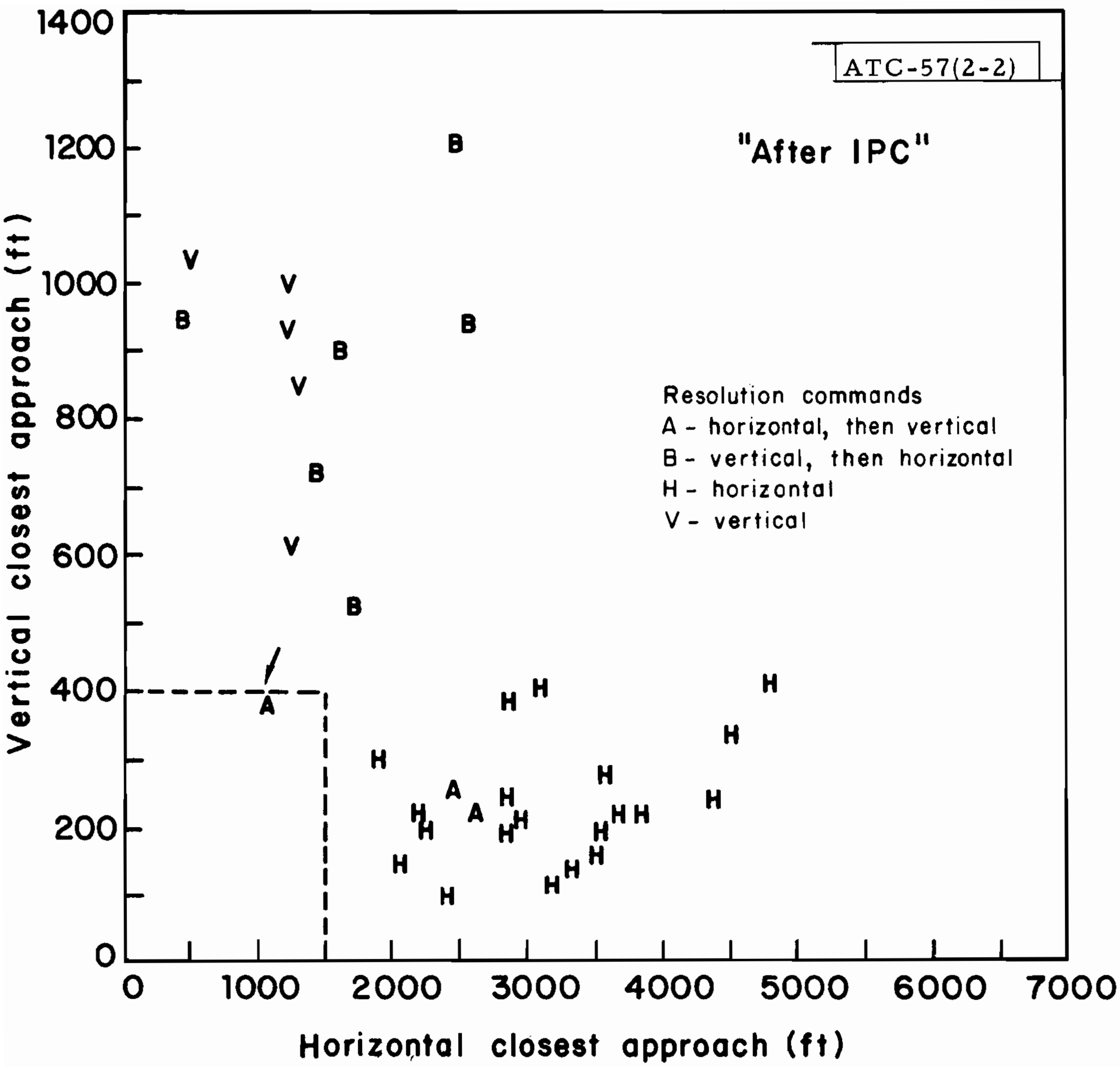
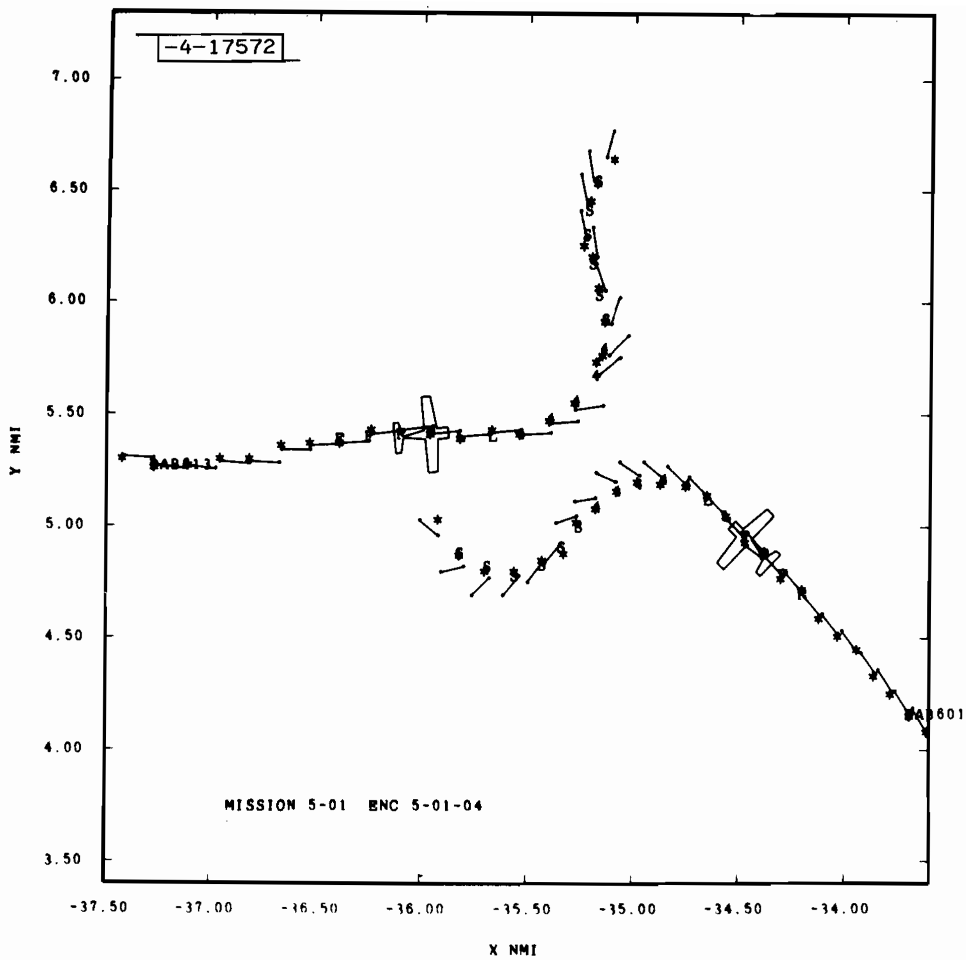


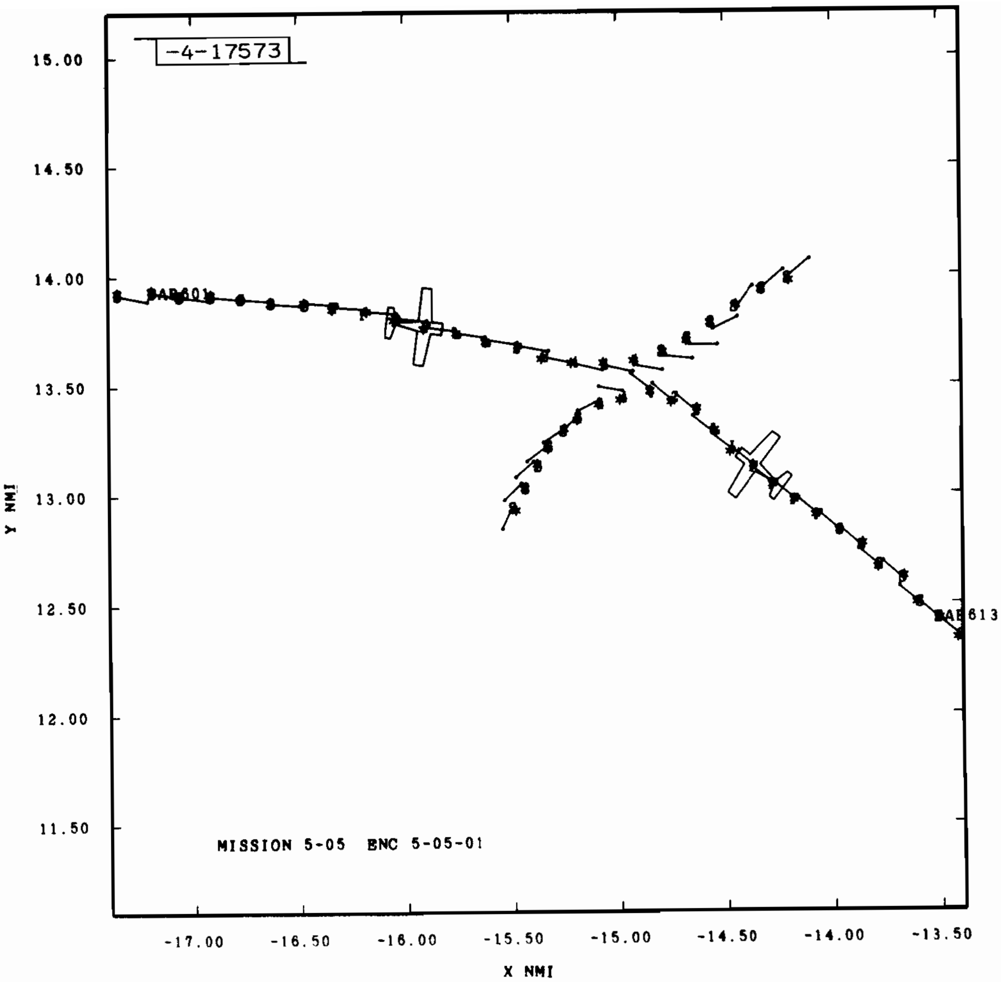
Fig. 2-2. Actual closest approaches: nominal VFR/VFR encounters.



AC1 TRACK = 1 ID = DAB601
AC2 TRACK = 2 ID = DAB613

SCAN	AC1	AC2	POS	TH	RANGE	MD	TV	RZ	VZ	VMD	DOT	TCMD
381			0	41.96	2.54	767.58	-1148.0	300.32	0.26	300.32	-526.26	32.
382	F	F	0	37.56	2.29	856.03	-1413.9	300.77	0.21	300.77	-474.11	32.
383	F	F	0	33.21	2.05	24.81	-97.1	347.29	3.58	347.29	-423.42	32.
384	F	F	-2	28.33	1.80	81.54	-101.4	362.52	3.58	362.52	-374.13	32.
385	F	F	1	23.95	1.57	69.78	-340.9	330.98	0.97	330.98	-324.15	32.
386	L	L	1	18.85	1.31	362.87	507.1	316.70	-0.62	296.71	-272.68	32.
387	L	L	4	13.49	1.06	272.75	-153.0	353.94	2.31	353.94	-221.76	32.
388	L	L	4	7.85	0.82	159.21	-107.1	380.55	3.55	380.55	-170.82	32.
389	L	L	4	1.78	0.59	559.12	-107.3	397.59	3.71	397.59	-121.03	32.
390	L	L	4	-4.89	0.43	1470.65	-125.1	407.09	3.25	407.09	-71,65	32.
391	L	L	4	-138.09	0.48	2929.22	416.0	364.75	-0.88	336.69	-1.00	32.
392	L	L	0	0.0	0.64	3227.78	0.0	379.12	0.0	379.12	69.12	32.
393	S	S	0	0.0	0.86	2734.22	0.0	343.43	0.0	343.43	135.97	32.
394	S	S	0	0.0	1.15	398.09	0.0	364.43	0.0	364.43	210.73	32.
395	S	S	0	0.0	1.37	264.01	0.0	380.81	0.0	380.81	280.65	32.
396	S	S	0	0.0	1.52	48.56	0.0	438.75	0.0	438.75	303.83	32.
397	S	S	0	0.0	1.73	137.42	0.0	478.65	0.0	478.65	339.34	32.
398	S	S	0	0.0	1.83	1855.13	0.0	503.09	0.0	503.09	281.19	32.

Fig. 2-3. Successful 135^{O} resolution; Rule B (encounter 5-01-04).



AC1 TRACK = 1 ID = DAB601
AC2 TRACK = 2 ID = DAB613

SCAN	AC1	AC2	POS	TH	RANGE	MD	TV	RZ	VZ	VMD	DOT	TCMD
142	S	S	0	42.44	2.72	650.16	-96.8	188.97	1.95	188.97	-601.69	32.
143	F	F	0	37.79	2.46	686.22	-96.6	198.42	2.05	198.42	-545.84	32.
144	F	F	0	32.94	2.19	780.42	-112.3	203.71	1.81	203.71	-490.06	32.
145	F	F	-2	28.35	1.93	619.11	-144.7	206.02	1.42	206.02	-433.69	32.
146	F	F	1	23.67	1.67	232.36	-204.5	206.38	1.01	206.38	-376.40	32.
147	L	L	1	18.69	1.40	209.56	-320.4	205.66	0.64	205.66	-317.77	32.
148	L	L	2	13.89	1.14	125.63	-579.9	204.46	0.35	204.46	-259.51	32.
149	L D	L C	2	8.58	0.88	386.39	-1388.4	203.17	0.15	203.17	-200.47	32.
150	L D	L C	4	2.55	0.63	426.47	-71.1	248.42	3.49	248.42	-142.38	32.
151	L D	L C	4	-6.30	0.38	251.81	-58.6	280.11	4.78	280.11	-85.46	32.
152	L D	L C	4	-35.04	0.16	616.02	-41.9	346.35	8.27	346.35	-27.14	32.
153	L D	L C	0	0.0	0.22	862.12	0.0	389.54	0.0	389.54	35.92	32.
154	S	S	0	0.0	0.48	832.45	0.0	460.64	0.0	460.64	94.22	32.
155	S	S	0	0.0	0.70	1293.14	0.0	504.36	0.0	504.36	140.76	32.
156	S	S	0	0.0	0.94	360.74	0.0	527.23	0.0	527.23	202.71	32.
157	S	S	0	0.0	1.17	1353.70	0.0	535.51	0.0	535.51	247.63	32.
158	S	S	0	0.0	1.43	581.83	0.0	534.84	0.0	534.84	312.77	32.

Fig. 2-4. Decreased separation due to response delay (encounter 5-01-01).

commands. The additional delay in the response reduced the closest approach by more than a factor of two. If the delay had been any greater this encounter might have been classified as non-nominal (due to non-compliance). One might expect that response delays of this magnitude would be critical when a tau threshold of 32 seconds is employed. Consider for instance a possible sequence of events for an encounter in which tau and time-to-collision are initially equivalent.*

Time Until Collision	Event
33 sec.	Command flag not set
29 sec.	Command flag set for first time
25 sec.	Commands generated
21 sec.	Commands transmitted and received
5 sec.	Response begins

Since commands are received only 21 seconds before collision, pilot response must be prompt. During validation missions test pilots were instructed to begin maneuvering approximately eight seconds after receiving commands. Subject pilot missions are being flown to determine the response delays to be expected from a general population of pilots.

Although Figures 2-1 and 2-2 show that IPC is beneficial on the average, they do not reveal whether the benefit was relatively uniform or whether there are particular encounters for which IPC was ineffective (e.g. were there any encounters for which IPC reduced the separation from 3000 to 2000 feet)? The elliptical separation concept described in Section 2.2.2 will now be employed to evaluate on an encounter-by-encounter basis, the increase in closest approach distance produced by IPC.

Figure 2-5 is a plot of actual versus projected elliptical closest approaches. Note that the points for which the projected and actual closest approaches are equal would lie along a line of slope 45°. The distance by which a point lies above this line is the apparent amount by which the IPC commands increased separation. The plotting symbols indicate the resolution planes (horizontal or vertical or combination) in which avoidance commands were issued. It can be seen that the effects of IPC commands were almost always beneficial, generally increasing the closest approach distance by more than 1000 feet.

*When the closing rate is fairly large, initial commands occur at ranges for which modified tau and time-to-collision are essentially equivalent. Normally, modified tau is less than the time remaining until collision, however, if acceleration is present, time-to-collision may actually be less than modified tau.

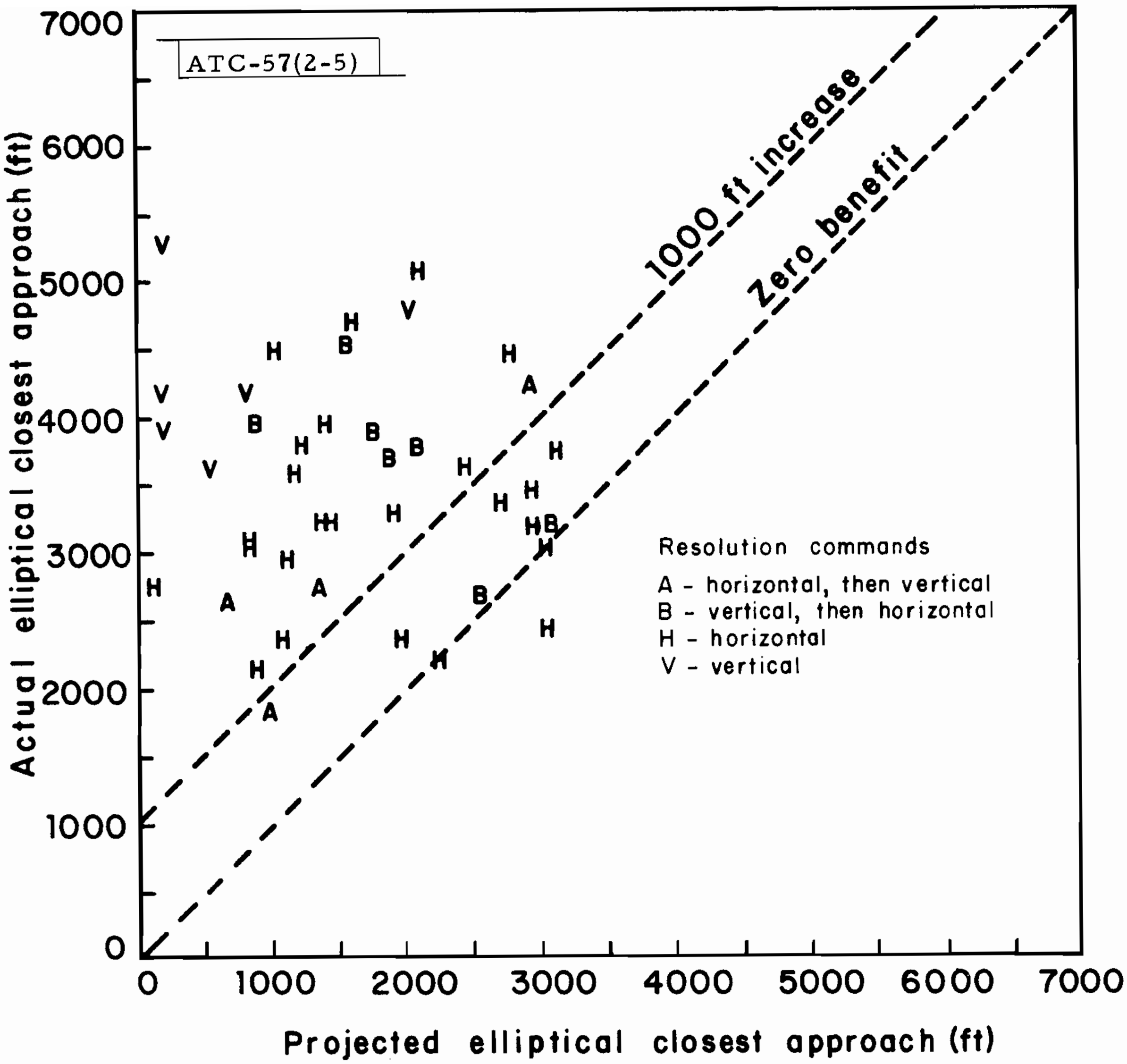


Fig. 2-5. Comparison of projected and actual closest approaches: nominal VFR/VFR encounters (elliptical measure with vertical stretch factor equal to 4.0).

2.3.2 PWI for Nominal VFR/VFR Encounters

During validation flights, the PWI logic functioned as intended and the two-mile minimum threshold for ordinary PWI alarms (instituted as a result of early flights) proved effective in preventing close approach without alarm. PWI bearing accuracy for nominal VFR/VFR encounters appeared to be within acceptable limits although PWI bearing lag was evident during turns. With test pilots flying the aircraft, no specific data could be collected on the pilots ability to use PWI since the test pilots knew the direction of traffic even before receiving PWI. Initial pilot reactions to PWI are commented upon in Section 3.3.

The duration of ordinary PWI alarms can be very long when the closing rate is low. For closing rates greater than 160 knots, ordinary PWI alarms are often never issued at all since the criteria for flashing PWI are satisfied first. This is because the ordinary PWI criteria are essentially a range test and the flashing PWI criteria are a tau (time-to-collision) test.

For encounters in which the aircraft are in level flight, flashing PWI's normally appear four scans before commands. However, in climbing/descending encounters, the normal duration is 1 scan. The reason for this is the fact that the altitude separation threshold for FPWI and command alarms are both equal to 1000 feet. When the aircraft trip the altitude separation guard rather than vertical tau guard, only the two-out-of-three logic prevents FPWI and commands from occurring simultaneously. For VFR aircraft, the vertical closure rate must exceed 1333 fpm in order for the FPWI flag to be set earlier than the command flag.* Thus for many climbing/descending encounters the flashing PWI feature does not provide the intended warning.

2.3.3 Duration of Commands for Nominal VFR/VFR Encounters

Positive commands generally remained in effect for 6 or 7 scans (see Figure 2-6). When horizontal commands were issued, they were almost always dropped as a result of the divergence test (see Section 2.3.5 below). For vertical commands issued in the climbing or descending tail chase encounters, the vertical positive commands were usually replaced by vertical negative commands as soon as VMD increased to 500 feet. However, if non-responding commands are issued (POSCMD=2) then the commands remain positive until the command flag is no longer set. This can result in positive commands persisting longer than necessary (discussed in more detail in Appendix A.4). A straightforward remedy has been suggested and will be evaluated at a later date.

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*Since TFPWI=45 sec., the tau and separation guards are violated simultaneously when VZ=1000 feet/45 sec (equivalent to 1333 fpm).

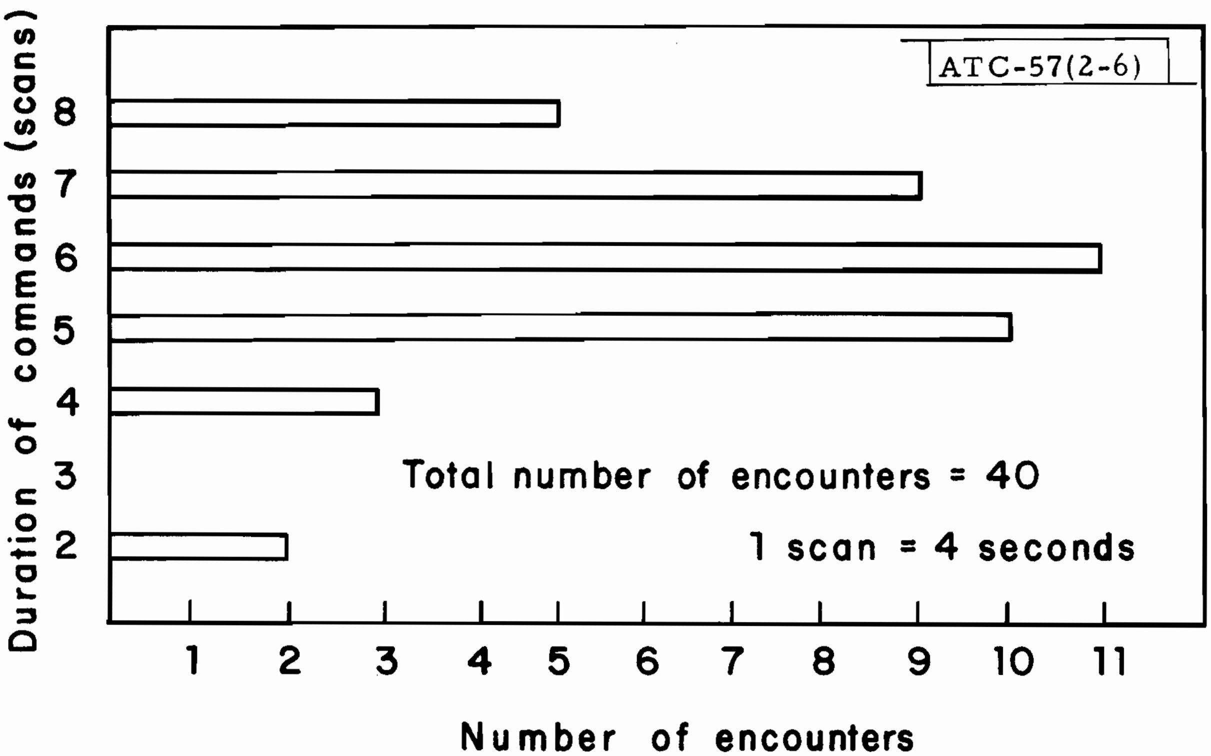

Fig. 2-6. Duration of positive commands: nominal VFR/VFR encounters.

2.3.4 Required Heading Change for Nominal VFR/VFR Encounters

For cases in which horizontal positive commands were issued, the aircraft were usually required to alter heading by 60-90 degrees before positive commands were dropped (see Figure 2-7). Since positive commands appear and disappear simultaneously for the two VFR aircraft, the aircraft that responds first usually turns through a larger angle. The aircraft were often turned further than was necessary to resolve the conflict.

2.3.5 Divergence Test

As a result of flight tests prior to the current algorithm configuration (LTAC-1), a divergence test was added to the logic which allowed commands to be dropped when the aircraft were diverging at a certain rate in the horizontal plane. In flight tests under LTAC-1 it was found that cases existed for which the divergence test dropped commands too soon or prevented commands from being issued when needed. The basic problem occurred when the aircraft were diverging horizontally at very low rates while continuing to close vertically. A proposal to remedy this problem by changing a test threshold has been approved for flight testing under future configurations (see Appendix A.5).

2.3.6 Separation as a Function of Crossing Angle

In order to examine the sensitivity of the achieved separation to encounter geometry a scatter plot of elliptical separation as a function of crossing angle was prepared (see Figure 2-8). Note that the achieved separation was insensitive to crossing angle.

2.3.7 Recovery Encounters

A recovery encounter is one which follows immediately after an initial encounter and which involves the same aircraft in a second set of commands. Because aircraft must maneuver in attempting to recover their original courses, the accelerations involved often make the recovery encounter more difficult to resolve than the initial encounter. Because the likelihood of recovery encounters and their geometry depend upon the way in which the initial encounter was resolved, the initial and recovery encounters cannot be considered as entirely separate events. In the test encounters of the missions included here, the performance of IPC with respect to recovery encounters often could not be determined because after the initial encounter, the test aircraft began immediately to set up for the next planned encounter and did not attempt to recover course. This issue is being addressed in subject pilot flight testing.

2.3.8 Nominal VFR/VFR Encounter Test Results (Validation Phase)

In general the IPC algorithm performed well for nominal VFR/VFR encounters, ensuring separations of more than 600 feet vertically or more than 2,000 feet horizontally. The only observed cases in which resolution was questionable were:

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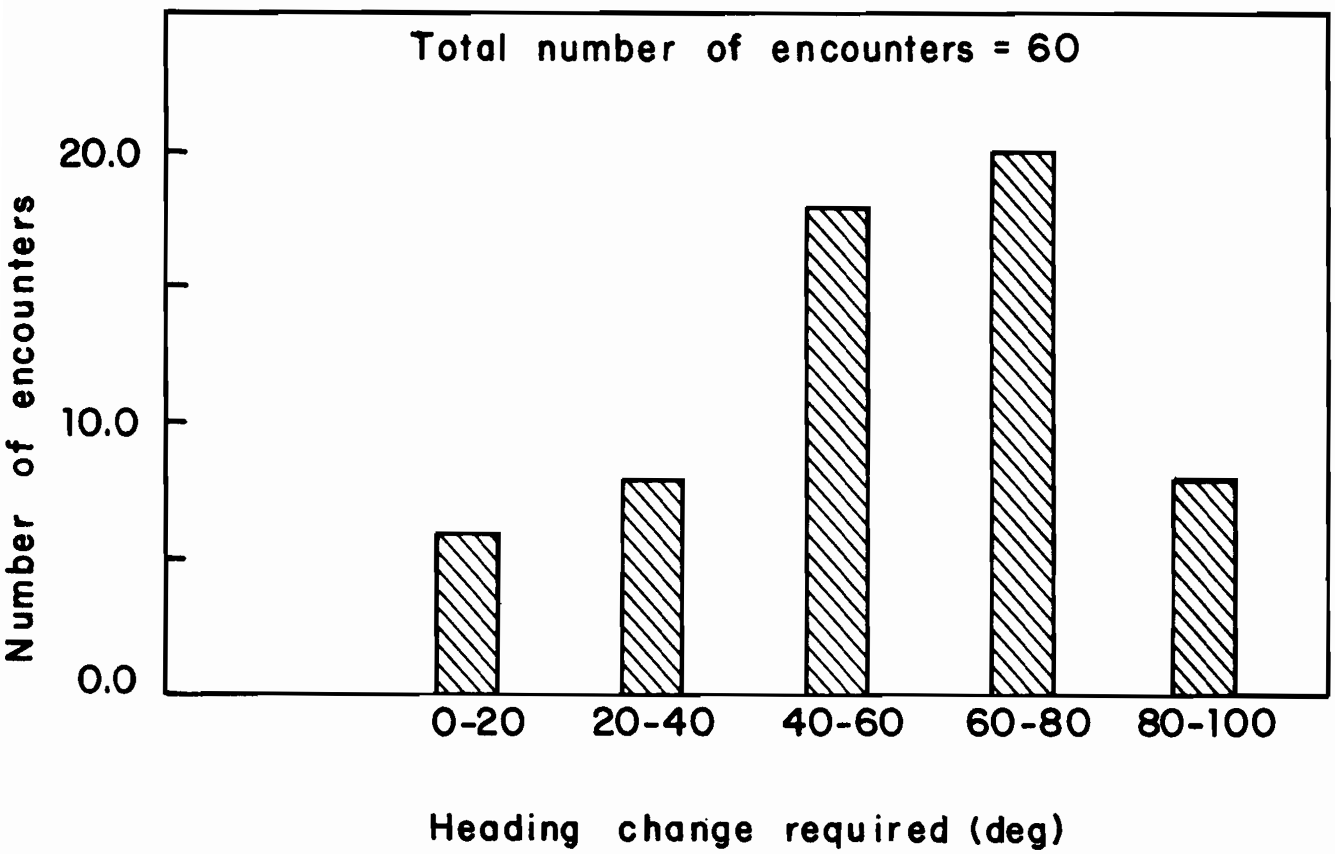

Fig. 2-7. Heading change required by horizontal IPC commands.

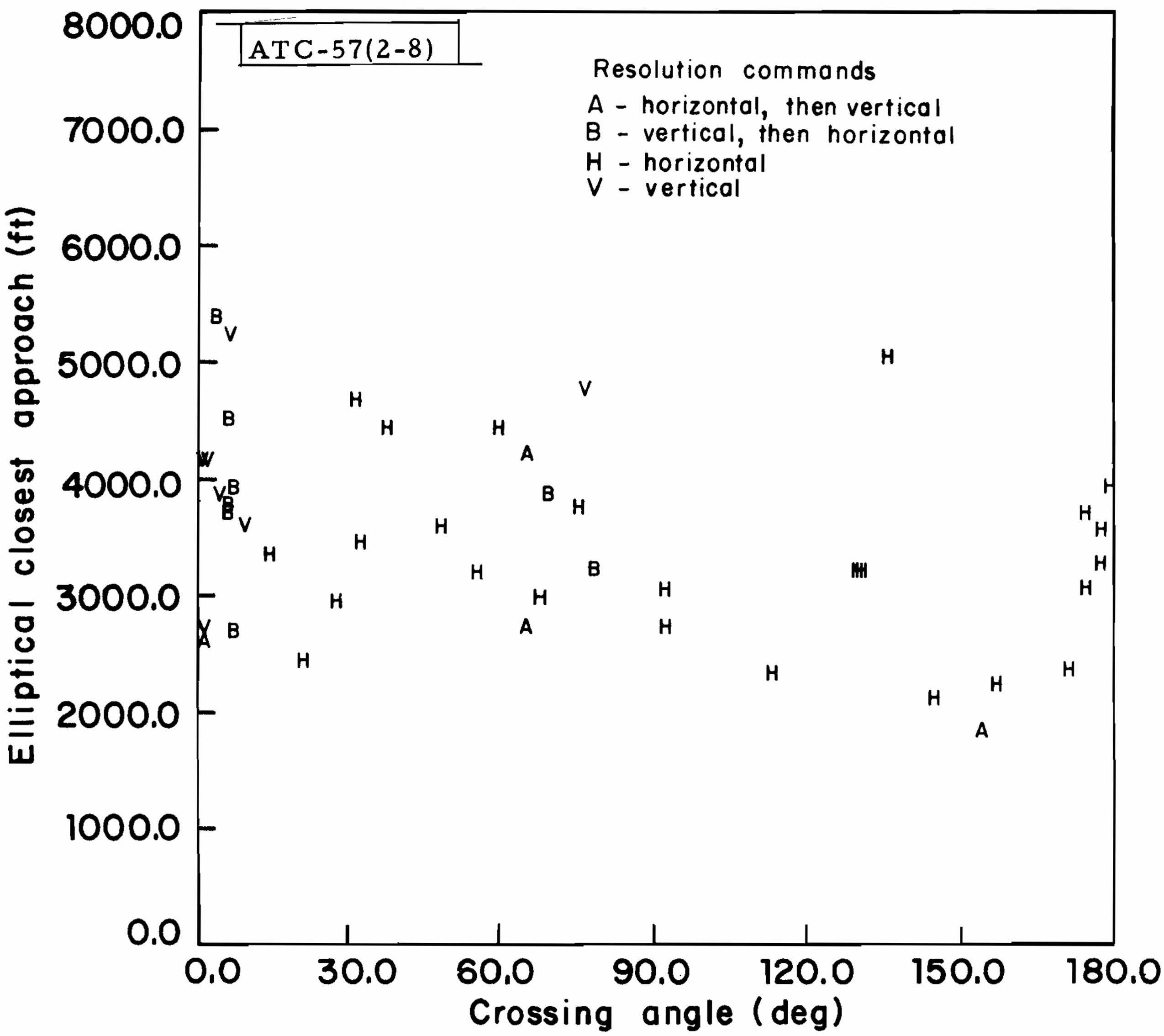

Fig. 2-8. Closest approach (elliptical) as a function of crossing angle: nominal VFR/VFR encounters.

a) Cases of substantial pilot delay in situations of high closing rate

b) Cases where commands were dropped too soon due to the divergence test

c) Cases where recovery encounters occurred which were more difficult to resolve than the initial (nominal) encounters.

It was also observed that with minor changes to the positive-negative transition logic, positive commands can sometimes be replaced by negative commands sooner than is currently possible.

2.4 Results for Nominal IFR/VFR Encounters

In this section flight test results for nominal IFR/VFR encounters under flight test configuration, LTAC-1 will be examined. At the time of this writing data for 44 nominal IFR/VFR encounters were available for analysis. The type of analysis presented differs from that conducted for VFR/VFR encounters.

The IFR/VFR logic employed under LTAC-1 differs from the VFR/VFR logic in the following ways:

a) Tau thresholds for the VFR and IFR aircraft are set separately. The intention is that the VFR aircraft receive the command first and maneuver to resolve the conflict, thus avoiding the need to issue a command to the IFR aircraft.

b) The thresholds for the VFR aircraft are considerably larger than the thresholds in the VFR/VFR case. Thresholds for the IFR aircraft are dependent upon whether the IFR aircraft is faster or slower than the VFR aircraft.

c) The miss distance threshold for issuing positive commands is 1.0 nmi rather than 0.5 nmi.

d) No test is made for acknowledgement from the IFR aircraft. If the VFR aircraft is determined to be non-responding, commands in both horizontal and vertical planes are immediately issued to both aircraft.

2.4.1 Achieved Separation

Figure 2-9 is a scatter plot of the horizontal and vertical separations at closest approach for the set of encounters in the nominal IFR/VFR data base. Note that in general, the achieved separations were greater than 6000 feet horizontally or 900 feet vertically. The principal exceptions (encounter 50909) occurred in a slow overtake tail-chase geometry. In this type of situation the horizontal alarm criteria are occasionally not violated until the aircraft are already at approximately 3000 feet separation. By comparison with the VFR/VFR data (Figure 2-2) it can be seen that the horizontal closest approach tended to be two or three times greater in the VFR/VFR cases.

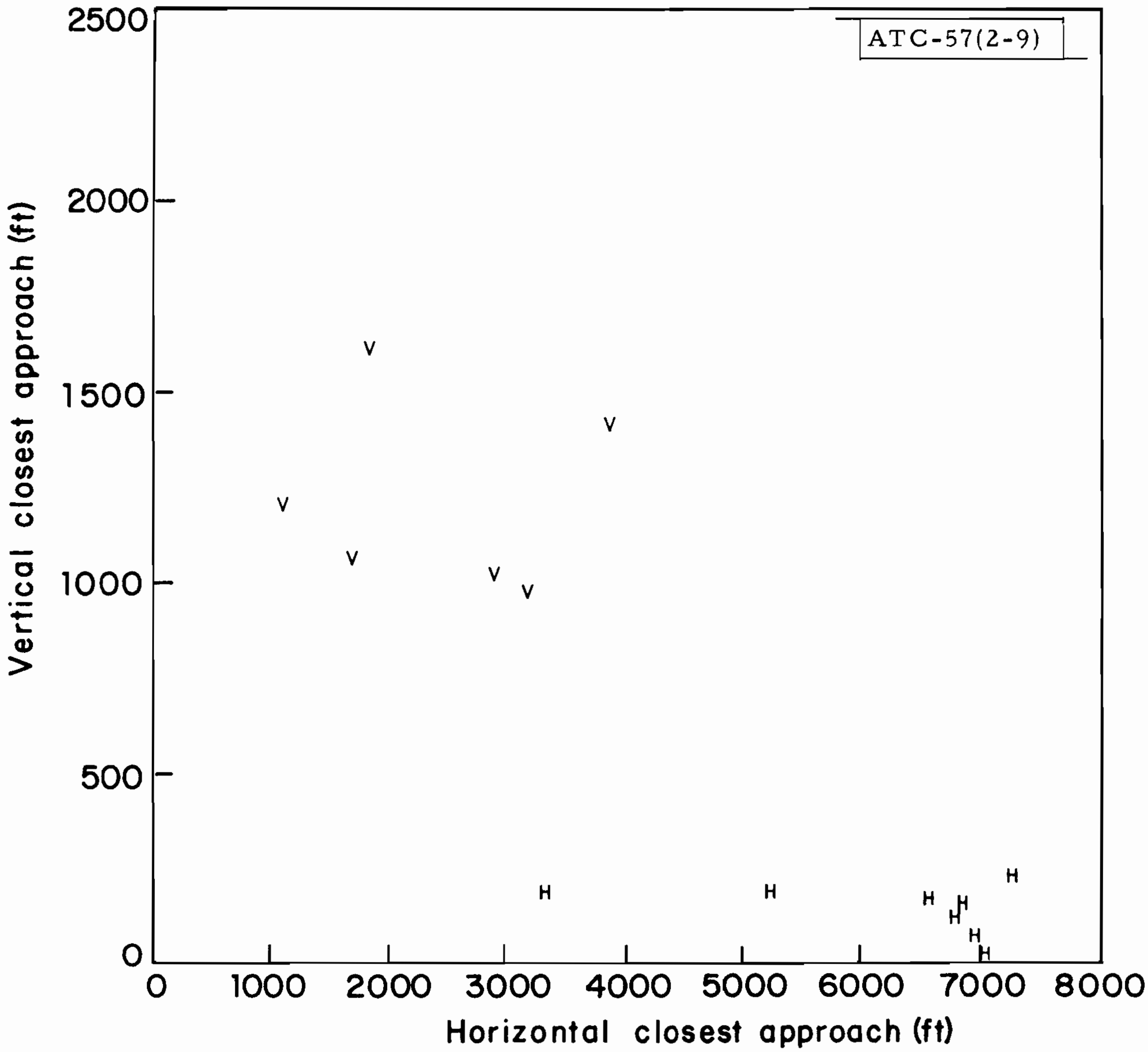

Fig. 2-9. Horizontal and vertical closest approach values: nominal IFR/VFR encounters.

2.4.2 Range of Commands for Nominal IFR/VFR Encounters

Figure 2-10 is a plot of the range at which the command to the VFR aircraft was transmitted as a function of crossing angle. Note that for crossing angles above 90 degrees the command often occurs at a range that precludes effective use of visual acquisition and evaluation. This data was collected with aircraft at ground speeds generally less than 150 knots. If higher speed aircraft were employed, the command ranges would increase even further. (Similar results can be obtained for ATCRBS/DABS encounters since these encounters employ a tau threshold of 64 seconds for the DABS aircraft). The implications of these results are important: in practice it has been found that the VFR pilot often never sees the IFR traffic which causes his command, or if he does see it he considers it to be too far away to allow him to evaluate the collision threat.

2.4.3 Commands to IFR Aircraft

The algorithm was generally unable to avoid issuing commands to IFR aircraft. Table 2-3 presents some statistics concerning command issuance. When the VFR aircraft was faster the tau command thresholds for the IFR aircraft was only 8 seconds less than the threshold for the VFR aircraft. It was impossible for the command to be transmitted and acted upon in this time period, much less for the aircraft to turn enough to affect the tracking estimate. Commands to the IFR were averted only once in 13 encounters. When the IFR was faster the tau thresholds differed by effectively 30 seconds (60 seconds versus 30 seconds). This allowed the IFR to escape commands 42% of the time.

The second column of Table 2-3 reflects the fact that tau does not necessarily decrease linearly with clock time, even for non-turning encounters. The 30 second tau difference when the IFR aircraft is faster was violated within 2 scans in 33% of the cases.

Table 2-3.

	No Command To IFR	Command To IFR Within 2 Scans
VFR Faster	$\frac{1}{13} = 8\%$	$\frac{11}{13} = 85\%$
IFR Faster	$\frac{5}{12} = 42\%$	$\frac{4}{12} = 33\%$

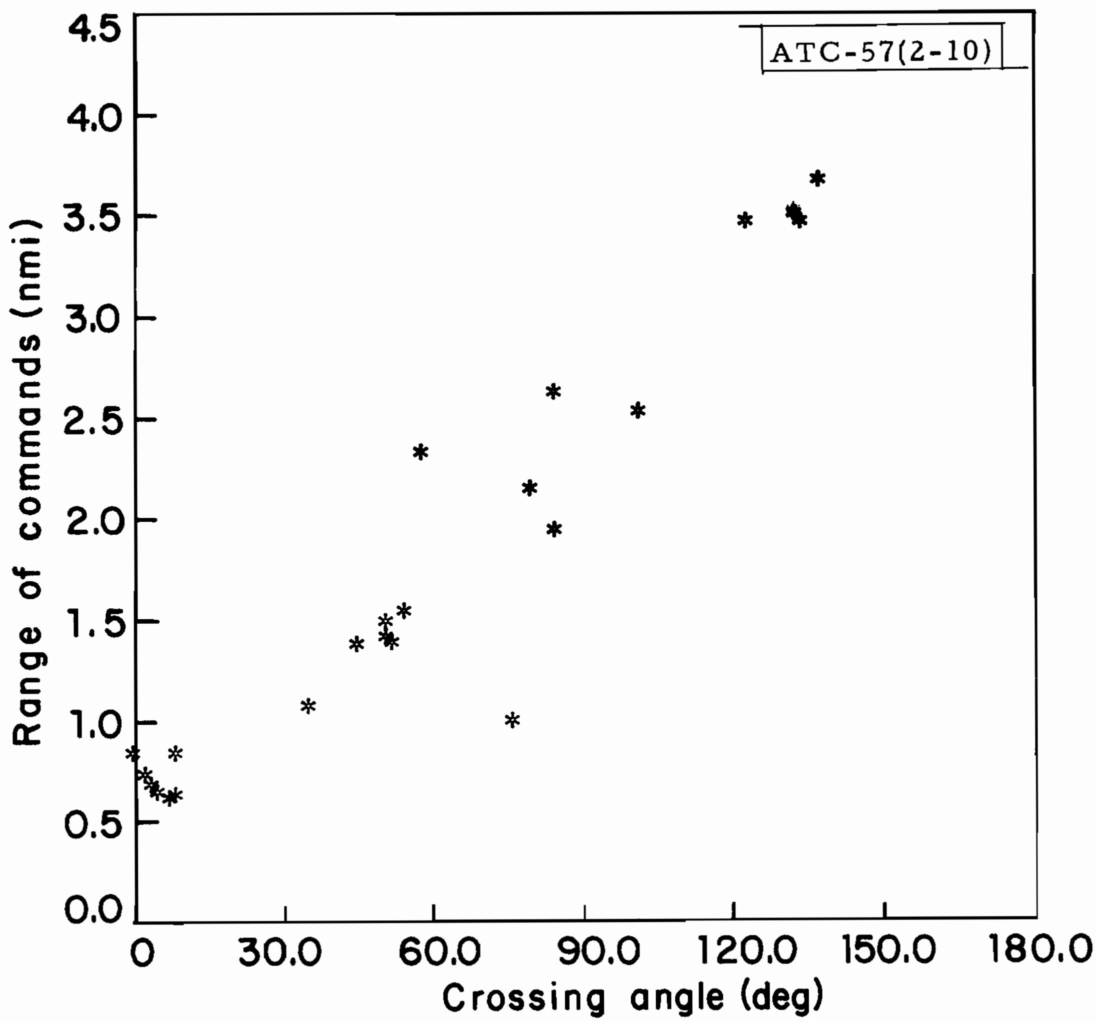

Fig. 2-10. Range of first IPC command as a function of crossing angle: nominal IFR/VFR encounters.

2.4.4 Maneuver Required of VFR Aircraft

Several cases have been observed in which the VFR aircraft was required to execute a very large heading change because the IFR aircraft was not commanded. If the VFR aircraft is slower and near the path crossing point at the time commands are issued, the IFR aircraft can continue to close no matter how far the VFR aircraft turns. This problem is discussed in more detail in Appendix A.7. The preference for vertical commands when a high speed aircraft is involved may prevent these ineffective turn commands from being issued. In that case however, the issuance of a climb/descend command to a slow VFR aircraft when no altitude rate restrictions are imposed on the faster IFR aircraft is questionable. No assurance can be given that resolution will be effective unless the IFR aircraft is instructed not to maneuver in a manner which nullifies the maneuver of the VFR aircraft.

In one encounter the IFR aircraft was climbing into the VFR aircraft and the VFR aircraft received a climb command. For many scans the horizontal tau value remained at a value too high to cause a command to the IFR aircraft but too low to allow dropping the command to the VFR aircraft. As a result the VFR was forced to climb several thousand feet without achieving increased separation from the IFR aircraft. Suggested algorithm modifications will make these kind of results very rare.

2.4.5 Nominal IFR/VFR Encounter Test Results (Validation Phase)

In general the IPC algorithm was successful in preventing close approaches between IFR and VFR aircraft under nominal conditions. Separations achieved tended to be greater than 900 feet vertically or 6000 feet horizontally. The algorithm was only partially successful in avoiding issuance of commands to the IFR aircraft. It was found that the maneuver of the VFR aircraft alone is sometimes ineffective or is easily nullified by a course change of the uncommanded IFR aircraft. The acceptability of the resolution to the VFR pilot must be evaluated in view of the fact that commands occur at very long ranges and the VFR aircraft is sometimes required to deviate very far from its desired course.

2.5 Non-nominal Encounters

As a group, non-nominal encounters are more difficult to resolve than nominal encounters and several related changes to the IPC algorithm have been proposed to extend the range of cases for which IPC is applicable. In this section the two major areas in which non-nominal encounters present collision avoidance difficulties, and remedial changes in the IPC logic, will be discussed

2.5.1 Non-complying Aircraft

An objective of the IPC design is to ensure effective resolution even though only one aircraft of a pair complies with commands. If this objective is achieved, it not only extends the range of cases for which encounters between two DABS/IPC equipped aircraft can be resolved, but allows encounters between a complying DABS/IPC aircraft and an ATCRBS aircraft to be resolved. Flight test results to date indicate that the above goal can usually be achieved providing that the non-complying aircraft does not maneuver in a way which nullifies the response of the complying aircraft. However, several specific cases have been identified in which the success of the current logic is questionable unless both aircraft comply with commands.

For instance, geometries have been observed in flight tests for which an effective turn command can be found for only one aircraft of the pair. Consider the geometry depicted in Figure 2-11 in which a slower aircraft is crossing the path of a faster aircraft. A command which turns the faster aircraft behind the slower is very effective, but a turn in either direction by the slower aircraft can create a more hazardous situation. Currently the IPC algorithm is structured to provide symmetry with respect to command type and maneuver plane, i.e. if a positive horizontal command is generated for one aircraft of the pair a positive horizontal command will also be generated for the other. For conflicts such as the one above this symmetry is disadvantageous. More effective resolution could be obtained by instructing the aircraft that is nearest path crossing to continue without turning or to maneuver to increase altitude separation. Further discussion and actual examples of this particular problem can be found in Appendix A.7.

Another observed problem produced by non-compliance is illustrated in Figure 2-12. Here an ATCRBS aircraft is descending into a DABS aircraft and a vertical command is issued. When the DABS aircraft responds, a vertical chase is established, and the ATCRBS aircraft continues to close to a near-miss situation. Even when a near-miss does not result, the DABS aircraft can be forced to descend (or climb) through a large distance before commands are dropped. Algorithm modifications which address this problem have been accepted for later flight testing.

It was noted before that an ATCRBS aircraft can maneuver in a way that cancels the effect of the maneuver of the DABS aircraft. The adverse consequences of this occurrence would be greatly reduced if the IPC algorithm were able to respond to a cancelling maneuver in one maneuver plane by issuing additional IPC commands in the other maneuver plane. However the current IPC logic allows the IPC commands to the DABS aircraft to become frozen while there are commands in only one direction. For this reason it appears that a "deterioration logic" may be required which would result in additional commands when initial commands are found to be ineffective.

2.5.2 Maneuvering Aircraft

A collision avoidance system must deal with special difficulties when resolving encounters in which one or both of the aircraft are accelerating during the conflict detection and command generation stages. The most obvious

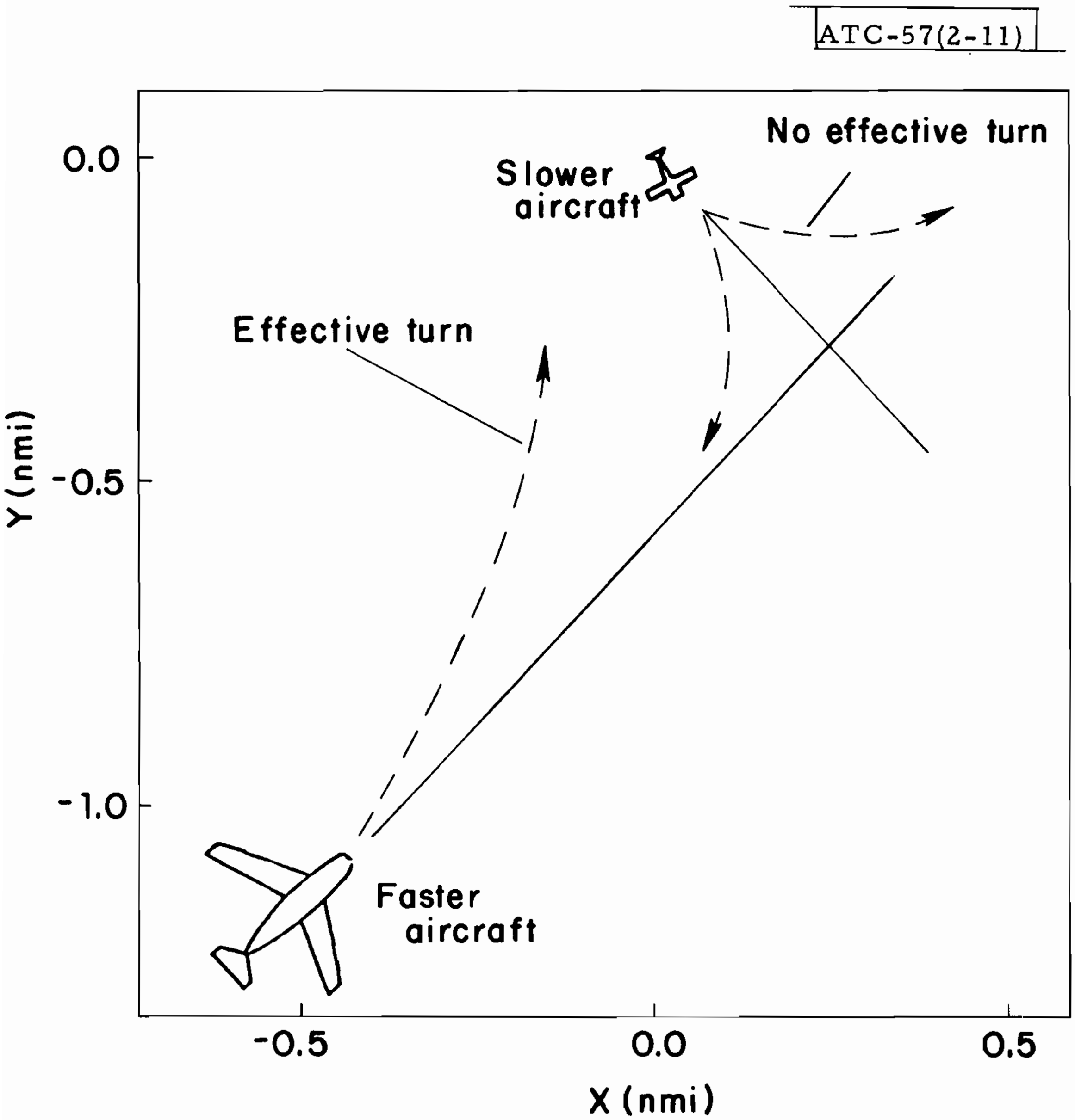

Fig. 2-11. Example of conflict for which horizontal command symmetry is ineffective.

problem is the development of tracker bias during turns. The current IPC tracker employs a turn detection and correction mechanism which greatly improves the ability of the tracker to estimate aircraft heading during turns. However bias still develops in the interval prior to turn detection and, in some cases in which the turn rate exceeds correctable limits. The resulting heading error can lead to detection of conflicts at a later time than is desired.

A problem can also arise in choosing the proper direction for commands. Consider that two aircraft which are separated in altitude by 200 feet and let the upper aircraft initiate a rapid descent just before IPC commands are generated. Command selection logic might issue a climb command to the aircraft perceived to be above. But due to tracker lag and normal response delays the "upper" aircraft may actually be below his traffic by the time he receives the command and begins acting upon it. Analogous cases involving horizontal maneuvers have been observed. The basic problem here is that the aircraft are maneuvering <u>from</u> a geometry in which one set of commands is appropriate <u>into</u> a geometry in which the opposite set of commands is appropriate. Further discussion and specific examples can be found in Appendix A.6.

Several methods for improving IPC capabilities with respect to maneuvering aircraft have been proposed and some are being tested. It is too early at this point to attempt to characterize IPC performance in this area, however it is believed that a satisfactory solution to the problems observed in flight tests must involve algorithm modifications in three areas:

a) <u>Tracking.</u> The tracker parameters must be adjusted to better reflect actual surveillance quality. The ability of the tracker to follow turns must be improved by taking aircraft speed and turn detection reliability into account. Further discussion of these points can be found in Appendix A.8.

b) <u>Use of turn detection in choosing strategy.</u> It should be noted that currently the turn detection logic is used only in the tracker in order to improve the estimation of the current aircraft heading. Many turning encounters cannot be resolved unless the IPC algorithm also utilizes turn information in choosing the resolution strategy. For instance, in cases where continuation of an existing turn would result in adequate separation it is better for IPC to issue commands which are consistent with the existing turn rather than to attempt to reverse the turn. In IPC flight tests, it has been observed that attempts to resolve encounters by reversing existing turns are often ineffective. One reason for this is the fact that the response delay is effectively doubled if the pilot requires 10 seconds to reverse his turn, and an additional 10 seconds just to turn back to the heading which existed when commands were received. It is also possible that the existing turn is necessary due to factors of which the IPC system is unaware (e.g., clouds, non-beacon aircraft, etc.). If the existing turn does not provide resolution, then vertical commands should be considered.

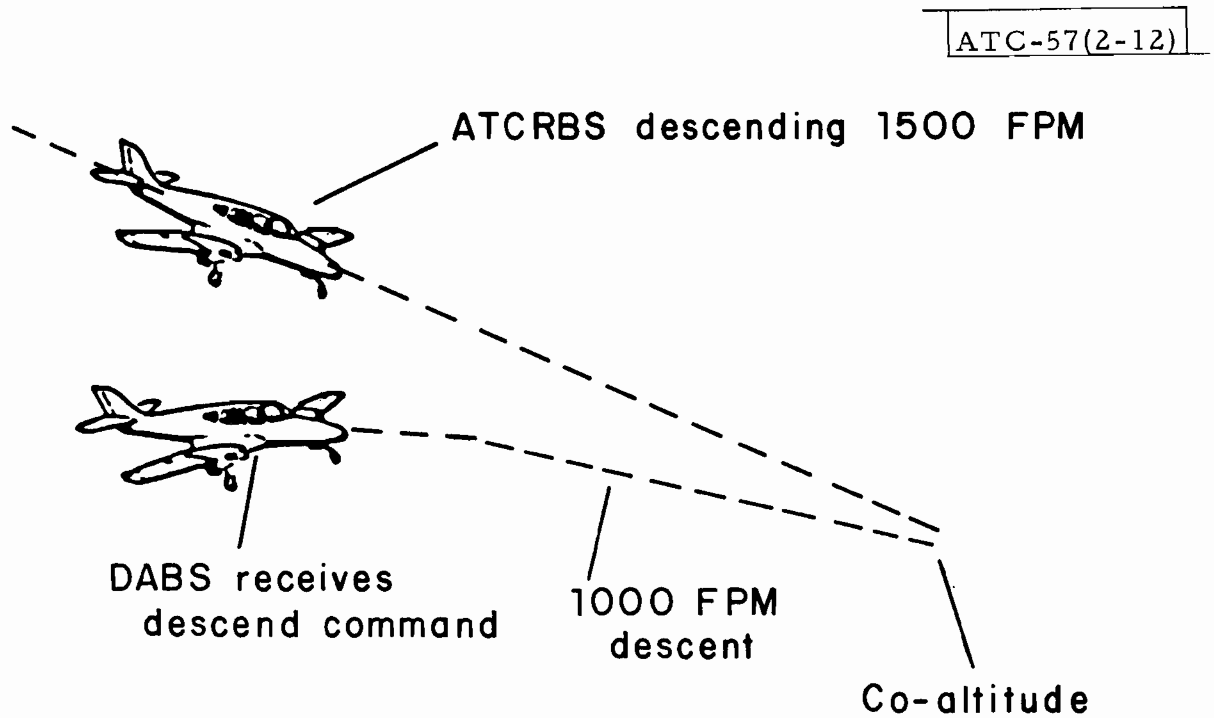

Fig. 2-12. 'Vertical chase' situation in which vertical commands to the IPC equipped aircraft are not effective (horizontal commands are required for resolution).

c) Alarm criteria. The critical IPC alarm variables such as tau and miss distance are calculated under an implicit assumption of rectilinear flight. When headings are changing, the calculated values can vary greatly from scan-to-scan. One cannot protect against this uncertainty merely by increasing the alarm thresholds since the thresholds then required would produce intolerably early alarms in many cases. However the IPC algorithm can be made to use alarm criteria which take potential or detected turns into account in a relatively efficient manner, i.e. which set an alarm flag only when a turn would be truly hazardous. The additional alarm thus generated may result in increased issuance of negative commands, but need not cause an increase in the number of positive commands (see Item d).

d) Prevention of adverse maneuvers. The IPC system is capable of preventing maneuvers which would create resolution problems. One manner in which this is done is the issuance of PWI warnings to the pilot in order to allow him to acquire his traffic visually. In many cases it can be assumed that PWI-aided visual acquisition will prevent maneuvers which increase the hazard. However, even with PWI, adverse maneuvers can still occur under the following conditions:

1) A pilot may initiate a maneuver before PWI alarms appear and continue the maneuver until receiving commands.

2) A pilot receiving a PWI from the six o'clock sector in which his view is obstructed by the airframe may view a turn as an acceptable option for a tail chase situation and turn in either direction.

3) A pilot may turn in order to rotate obstructing airframe and acquire the traffic indicated by the PWI.

4) A pilot may initiate a maneuver which he thinks will resolve the conflict and receive IPC commands which reverse his maneuver.

5) A pilot may fail to locate the traffic indicated by the PWI and maneuver anyway on the assumption that if the maneuver is not acceptable, the IPC system will issue further alarms. This reaction is sanctioned by the Pilots Guide to Intermittent Positive Control (Reference 3).

6) An ATCRBS aircraft may maneuver into a DABS aircraft.

Although it may be impossible to find a collision avoidance strategy which is always correct in case 6), the other cases can be attacked within the framework of IPC. One approach is to identify those geometries in which maneuvers can produce resolution failure and issue negative commands which instruct the pilot not to maneuver in specified directions. Such commands can prevent a pilot from inadvertently blundering into situations in which IPC offers insufficient protection. This concept is consistent with the published description of the negative command philosophy which states that the negative command is issued to the pilot when "his current trajectory is satisfactory but...a conflict would develop if he were to maneuver" (Reference 2). However, the algorithm in fact does not consider issuance of negative commands until a potentially hazardous closure rate has already been established.

It has also been observed that such negative commands are generally needed in situations in which their violation is certain to produce positive IPC commands. Under such conditions negative commands result in no real increase in the restrictions which IPC is imposing upon the pilot -- it is just a question of informing the pilot that he is restricted with negative commands rather than allowing him to be surprised by the restriction when he inadvertently precipitates positive commands.

In summary, it should be emphasized that, although tracker lag has been an object of concern for several years, it is <u>not</u> the only source of resolution problems for maneuvering aircraft. This can be demonstrated by re-simulating maneuvering encounters for which resolution was unsatisfactory but employing for simulation purposes essentially perfect track estimates. In most cases even perfect estimates can eliminate only one scan of alarm delay or a fraction of the total uncertainty in the future trajectory. Substantial improvements in resolution performance can be achieved only if the algorithm strategy is altered to prevent hazardous maneuvers from arising and to use turn detection information in choosing commands. Improved tracking may be a necessary condition for achieving the desired performance level, but it is not by itself sufficient.

3.0 SUBJECT PILOT EXPERIMENTS

The Subject Pilot Experiments are designed to assess the interaction of the human pilot with the IPC collision avoidance system while flying in a realistic environment. These investigations involve test pilots thoroughly familiar with the IPC system as well as pilot subjects whose experience varies from student pilot with twenty-four flight hours to airline captain with over twenty-five thousand flight hours. Appendix B provides a summary of subject pilot experience characteristics used as pilot selection criteria.

Fourteen subject pilot flights have been conducted. Although it is too early to quantify the results of these subject pilot tests, trends are developing which indicate some consistency in pilot reaction to certain IPC system features. These pilot reaction issues are summarized by the service provided, i.e., ordinary PWI, flashing PWI, and commands.

3.1 "See and Avoid" Environment

To properly assess the impact of proximity warning and IPC commands, an understanding of the current separation techniques employed in uncontrolled airspace is necessary. Pilots provide their own separation from other aircraft in uncontrolled airspace utilizing the "see and avoid" concept.

These pilots are obliged to spend much of their time scanning surrounding airspace to locate other aircraft. If there are passengers they are encouraged by the pilot to scan and to alert the pilot to other aircraft. When the pilot locates another aircraft, a judgement is performed as to whether the intruder aircraft is an immediate threat or is likely to become a threat to own aircraft. If the intruder is judged to be clearly diverging from own aircraft's path and constitutes no threat, the pilot is willing to break visual contact with this intruder aircraft. Any intruder which poses a threat to the pilot is kept in visual contact. The pilot proceeds on the initial course until ascertaining the actual flight path of the other aircraft. If the path of the intruder aircraft will take it too close (again an individual pilot judgement) to own aircraft, and the pilot of the intruder aircraft has not started an evasive maneuver (another judgement), the pilot responds with an evasive maneuver. This evasive maneuver tends to be a gradual one in which the pilot keeps the intruder aircraft in his view at all times. It is of prime importance to the pilot to keep the intruder in his view at all times as the pilot does not know whether the intruder pilot has seen own aircraft and does not know the intent of the intruder pilot. Once the aircraft are clear and are diverging the pilot is willing to break visual contact with the intruder aircraft. Pilots using the "see and avoid" technique tend to come fairly close to other aircraft before deciding to perform an evasive maneuver. Such close approaches are accepted because the closer the aircraft are, the more readily the pilot can determine the proper maneuver direction for increasing aircraft separation.

3.2 Ordinary PWI

Pilot reaction to the ordinary proximity warning portion of IPC has been very positive. This automated traffic advisory service is highly desired in the "see and avoid" uncontrolled general aviation environment.

Pilots very rarely locate traffic before the receipt of an ordinary PWI. The ability to locate the traffic once an ordinary PWI is issued varies widely due to atmospheric conditions, cockpit visibility, and individual pilot technique. The test pilots have trained themselves to locate traffic indicated by the ordinary PWI. It is very rare that they are unable to locate the aircraft indicated even when it is from an ATCRBS aircraft passing randomly through the test area. Many subject pilots have difficulty locating the indicated traffic. When the traffic is pointed out by the test pilot, even seasoned pilots have been surprised at how close it approaches their own aircraft without being sighted.

To fully utilize the automated traffic advisories the test pilots have developed a procedure of periodically scanning the IPC display to determine whether an ordinary PWI light is illuminated. This can be counterproductive as they reduce their time scanning outside the cockpit for aircraft which will not produce PWI indications (non-beacon equipped and non-Mode C). Subject pilots, who have not had time to adopt an IPC display scan procedure, are often slow to notice the ordinary PWI indication. In slow overtake situations some subject pilots have been unaware of an ordinary PWI for as long as thirty seconds. Some pilots, unaware of the nearby traffic, continued to close until startled by the rapid sequence of audio alarms, flashing PWI and commands. As a result they lacked awareness of the conflict situation and never saw the traffic.

When pilots locate traffic indicated by an ordinary PWI, they generally do not consider it a threat. However, they appreciate having their attention brought to the presence of another aircraft. They do not maneuver their aircraft to avoid an intruder since they usually do not have the ability, at this time, to judge whether a maneuver is needed or what its effect would be. Some pilots will elect to maneuver their aircraft to locate an intruder when a PWI persists and the intruder is behind them. This maneuver is normally a slight turn to the left to look behind to acquire the intruder.

Subject pilots generally check the IPC display before initiating a maneuver, as briefed. However, some pilots have elected to continue their maneuver in the direction of the indicated traffic while attempting to acquire the intruder. A sense of security seems to pervade these situations. When questioned, these pilots state that the system would indicate with commands that their maneuver was unacceptable so they proceeded until commands were generated. If an ordinary PWI is issued when a pilot has already started a maneuver, the subject pilots do not realize that they are closing on traffic until a flashing PWI alerts them. Some pilots do use the ordinary PWI to

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	Locate traffic before OPWI	Stop maneuver during OPWI	Aware of OPWI within 10-15 sec	Locate traffic during OPWI	Traffic considered a threat during OPWI	Maneuver to locate traffic with OPWI	Maneuver to avoid with OPWI
Often							
Sometimes		✓		✓		✓	
Rare	✓		✓		✓		✓

Fig. 3-1. Pilot usage of ordinary PWI (initial qualitative results).

inhibit an intended maneuver until they can locate the traffic. Once the traffic is located they proceed to initiate their intended maneuver. These maneuvers, in the direction of the traffic, with the pilot maintaining visual contact have not caused many commands to be generated. It appears that the alarm logic is compatible with pilot perception in these situations.

3.2.1 Ordinary PWI Suggestions

The test pilots have suggested that they be made aware of the initial presence of an ordinary PWI through the use of a single innocuous tone. This would allow them to check their IPC display only when a PWI was present.

The test pilots have also suggested that the intruder Mode-C altitude be provided in place of the three light configuration at each clock position to provide more accurate information on relative altitude/position. Another suggestion was to reduce the three light configuration at each clock position to two lights providing more useful relative altitude information. The center PWI light causes confusion as to the relative vertical position of the traffic. It indicates to the pilot that the traffic is within 500 feet of own altitude, but not whether it is above or below. The two light configuration would not only simplify the IPC display by eliminating twelve lights, but it would provide the specific information to indicate whether the traffic was above or below. The upper light could indicate that the traffic was above and within 1000 feet of own altitude while the lower light could indicate the traffic to be below and within 1000 feet.

3.3 Flashing PWI

The flashing proximity warning is intended to alert the pilot to the fact that his aircraft is on a direct or near collision course with another aircraft. The IPC concept states that there should generally be sufficient time during the flashing PWI period to assess the threat and determine the best course of action. The pilot is instructed to initiate a maneuver when the PWI commences to flash if the situation requires evasive action.

Subject pilot experience indicates that there is insufficient flashing PWI time to assess the situation prior to the receipt of IPC commands. For encounters with convergence angles greater than 90 degrees, the audio alarm accompanying the flashing PWI is the first indication of traffic which the IPC concept provides the pilot. For non-maneuvering aircraft on collision or near-miss courses, the flashing PWI will alarm for 3 or 4 scans (12-16 seconds). If one or both of the aircraft are maneuvering during the flashing PWI period, the flashing PWI may be illuminated for only one scan before commands are presented. This 4 to 16 second flashing PWI period has not been sufficient to allow pilots to locate, assess and initiate an evasive maneuver to clear an intruder before IPC issues commands.

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	Aware of FPWI within 5 sec	Locate traffic during FPWI	Traffic considered a threat during FPWI	Maneuver to locate or avoid during FPWI
Often	√			
Sometimes		√	√	
Rare				√

Fig. 3-2. Pilot usage of flashing PWI (initial qualitative results).

Tests were conducted using only the test pilots to investigate the compatibility between pilot selected evasive maneuvers and subsequent IPC commands. Compatibility problems were experienced between the resolution the pilot selected and executed and the one IPC eventually issued. On some encounters pilots started an evasive maneuver, when a PWI was present, to resolve a situation only to have that maneuver reversed a short time later by an IPC command. This caused a prolongation of the conflict, a reduction in the existing aircraft separation, and consternation on the part of the pilot. It is clear that simply increasing the duration of the flashing PWI period would not provide sufficient time to assess the threat and to determine the best course of action. The pilot has no way of knowing when or what maneuver the IPC system will issue.

3.3.1 Flashing PWI Suggestions

Flashing PWI will have a more consistently successful utilization if either (1) early warning is achieved to permit a greater chance of visual acquisition, or (2) advisories are provided for the maneuvers which should be avoided if the situation continues to deteriorate. Because of the ranges involved for FPWI, the former option will not be as successful as the latter. Command advisories may indeed take much of the guess work out of dealing with the system. It is imperative that pilots be instructed not to maneuver on the basis of FPWI without visual acquisition unless more information is made available.

3.4 IPC Commands

Subject pilots are instructed to follow all commands until they are discontinued. They are instructed to use a recommended angle of bank of 20 degrees for turning encounters and told they can provide an extra margin of safety by turning with a steeper bank angle. For vertical maneuvers, when flying low performance aircraft, they are instructed to make the best rate of climb and descend at a rate of at least 1000 feet per minute.

Subject pilot experience indicates that pilots have trouble locating the traffic before the command sequence occurs in conflict situations. In those situations where they have not located the traffic they normally follow the commands until they are dropped. The general response is 10-15 degrees of bank for horizontal maneuvers and approximately 500 feet per minute in commanded climbs and descents. When asked why they didn't use larger escape maneuver rates the response has been that they are trained to think quickly and act deliberately. The slow response to commands acts to prolong some conflicts but generally provides adequate separation.

When a pilot has the intruder in sight, his response to the IPC commands varies widely, depending on his experience and the particular conflict situation. For conflicts involving two aircraft in non-accelerated flight the

ATC-57(3-3)

	Locate traffic during commands	Agree with commands (traffic not sighted)	Agree with commands (traffic sighted)	Believe commands adequate	Believe commands early	Believe commands late	Follow commands	Believe commands on too long	Believe commands never issued when required	Believe commands necessary	Executed commands with less than recommended rates
Often		√		√	√			√			√
Sometimes	√		√				√			√	
Rare						√			√		

Fig. 3-3. Pilot usage of commands (initial qualitative results).

commands are generally classified as conservative by pilots. That is, the evasive maneuver that IPC is commanding comes prior to any maneuver that the pilot would initiate. Pilots have no quarrel with this fact per se. However, the IPC commands do not always correspond to the resolution the pilot would have normally taken. Lower flight time pilots appear to be more willing to follow all commands. Some higher time pilots either follow controversial commands with gradual maneuvers, breaking them off before the commands are dropped, or they ignore the commands altogether, with the statement that they are unnecessary for the particular situation. Another reason for not following the commands as briefed is that they may cause the pilot to lose sight of the intruder, which is undesirable in the "see and avoid" resolution.

Commands have been late and sometimes inadequate when one or both aircraft are in maneuvering flight at the time IPC commands are delivered. This appears to be due to tracker lag plus the inability to predict a maneuvering flight trajectory adequately (see Section 2.5.2).

3.4.1 IPC Command Suggestions

Pilots have suggested that the IPC concept have some way to allow the pilot who has the intruder in sight to resume command over the situation. A button in the cockpit could be pushed to indicate that the pilot has located the intruder and will provide the safe separation. IPC would then provide only proximity warning service for some period of time until the full service was restored. This concept has the advantage of effecting normal flight in a minimal way and allowing pilots the judgement to follow IPC or provide their own separation.

3.5 Pilot Acknowledgment

The pilot acknowledgment feature is the cause of many flight test problems. Subject pilots have generally been unable to successfully acknowledge commands. Some of the elements of this apparent pilot interface problem are detailed below.

a) Concept. The meaning and purpose of pilot acknowledgment are apparently in a fluid state and a consistent concept statement and test configuration have not yet been achieved. The meaning of pilot acknowledgment must be defined by clearly specifying the conditions under which the pilot is expected to acknowledge. The IPC reference document* states that "Each IPC 'do' or 'don't' message is acknowledged by the pilot activating a 'will comply' or 'won't comply' switch...". Since the inception of the flight test program other statements and documentation have substantially altered the above concept. First, the "won't comply" switch has been eliminated, thus

*Reference 2, paragraph 2.4, pg. 2-7.

allowing the pilot a single positive response option. Secondly, the "will comply" meaning has been eliminated ("in briefing pilots tell them they are expected to acknowledge every command and to comply with that command to the extent practicable.") Thus pilots acknowledge even when they cannot comply at all. These changes have resulted in the acknowledgment button losing most of its information content and becoming little more than a manual duplication of the DABS technical acknowledgment feature.

b) Test Realization. The flight test conditions, the encounters flown, and the cockpit hardware employed must be appropriate for the testing of the proposed concept. The concept changes mentioned above require corresponding hardware changes. For example, when the acknowledgment has a "will comply" connotation the aural alarm cannot be allowed to sound continuously until the button is pushed - if it does then pilots will push the button just to eliminate the noise. (In the most recent concept it is desired that the aural alarm sound until the button is pushed). Other factors concern the location of the button, its size, and the feedback which tells the pilot that he has properly pushed the button. Some pilots have objected to having to return their attention to the instrument panel in order to push the button. Others have stated that the button is too small and that it should provide a physical indication ("click") that it was properly pushed. There are plans to test a configuration in which an improved acknowledgment button is located on the control yoke.

c) Pilot Utilization. The pilot must be able to utilize the button according to the rules of (a). Prime considerations here are response delay, workload, and the physical difficulties of button-pushing. Under the suddenly increased workload of responding to collision avoidance commands pilots have frequently neglected to push the acknowledgment button even when they were complying. On the other hand, when the button-controlled aural alarm was used, pilots sometimes pushed the button automatically to silence the alarm and then began to think about collision avoidance. It remains to be demonstrated that the acknowledgment contains reliable information, without causing unnecessary response delays.

d) Algorithm Response. As currently configured the IPC algorithm makes radical changes in control strategy based upon the presence or absence of acknowledgment. For instance, if acknowledgments are received from two conflicting VFR aircraft the issuance of additional commands is suppressed for the remainder of the encounter. If a VFR aircraft is in conflict with an IFR aircraft and the VFR fails to acknowledge, additional commands are sent to the VFR and commands in both dimensions are issued to the IFR, regardless of whether or not the IFR command thresholds have been crossed. These algorithm responses can be justified only if the acknowledgment feature provides significant information on the likelihood of pilot compliance. However, the concept changes and questions of pilot utilization mentioned above appear to have greatly altered our understanding of the information content of the acknowledgment.

e) Benefits. The benefits of the pilot acknowledgment feature must be shown to outweigh the "annoyance factor" involved in its implementation. It has been observed that in many test encounters that the additional commands triggered by non-acknowledging aircraft were either not needed or were too late to affect the success of the resolution. More thought must be given to the type of problem acknowledgment is intended to solve and methods of eliminating unnecessarily severe algorithm responses. No simulation data addressing this issue has yet been presented to serve as a guide to flight testing.

4.0 FLIGHT TEST PLAN REVISIONS

The IPC flight test plan document [1] describes in detail the test bed and the operational methods being used in flight testing the IPC system. This Section summarizes the changes which have been made to the flight test plan.

IPC engineering coordination meetings are held monthly to review the progress of the flight test program and the simulation results achieved at MITRE and NAFEC. Revisions to the logic to correct problems identified by these programs are made to the baseline IPC algorithms in the form of change proposals.

4.1 Flight Test Algorithm Configuration

Two separate versions of the IPC algorithm have been created at the DABS Experimental Facility (DABSEF) to facilitate the flight test evaluation. Revisions to the logic which require no further validation flights by the test pilots are incorporated directly into the subject pilot testing configuration. Those logic revisions which require further validation flights are incorporated into a separate algorithm configuration. This configuration is subjected to further validation testing until all revisions have been validated. These revisions are then incorporated into the subject pilot configuration for evaluation.

4.2 Test Aircraft

A Bonanza F-33, with a maximum cruising speed of 170 knots, was substituted for the Cherokee-Six as the interceptor aircraft. The Cherokee-Six aircraft was found to be inadequate to meet the needs of the program. The margin of airspeed performance between the subject aircraft at normal cruise and the intereptor at maximum cruise was not sufficient to provide the desired intercept results.

4.2.1 Dual VHF Communications

The test aircraft are being modified so that each aircraft will be equipped with two independent VHF communication networks. The interceptor has already been modified and the two drone aircraft are expected to be modified by mid January 1976. This modification allows simultaneous transmission and reception on either VHF transceiver.

4.2.2 Aural Cockpit Alarm Logic

Modifications are being made to each of the test aircraft in an attempt to correct the difficulties pilots have experienced with the acknowledgement feature of the IPC system. A majority of subject pilot encounters involve a non-acknowledgment condition: the pilot, for some reason, fails to press the

WILCO button on the display within the allotted time. Three possible explanations have been suggested: (1) the pilot does not have enough time, (2) the button is too difficult to reach, or (3) the audible alarm does not remain on to remind the pilot. In order to ascertain the correct combination of the above explanations, it is necessary to experiment with some minor variations in the audio alarm protocol: setting a push button on the yoke in parallel with the YES button should reduce the time to a minimum and eliminate difficulties with not finding the button; providing an alarm during the acknowledgment sequence which does not terminate until the button is pressed will eliminate the third problem.

Implementation of a system with two alarm durations (one for FPWI, another for commands) is best achieved if the alarms sound different, since in that manner the pilot will know what is expected before the end of the shorter alarm. Further, if the alarm type for commands is to be software switchable for experimentation, it cannot be tied to the "Acknowledge Request" bit. Thus, two bits are needed to select the appropriate alarm and a third alternative alarm type is thereby available for experimentation. Reaction from subject pilots suggests that a pilot-selectable tone for OPWI would be desirable. Accordingly, Lincoln will implement a 2-bit generalized tone generator which will produce three different tone sequences as outlined in Table 4-1:

Table 4-1.
THREE TONE AUDIO ALARM

Tone No.	Type	Duration	Adjustment
1	Single tone	0.5 sec	Vol.*, Freq.
2	Two tones	.5 sec @ .5 sec	Vol., Freq.
3	FM (siren)	Until acknowledge button depressed	Vol., Freq., Rate Depth

The two bits which select the above tones are assigned to the testbed dependent display format in such a way that Tone No. 2 is obtained with the algorithm configuration used prior to the modification. The result is a completely downward compatible augmentation of the audible alarm protocol. It is proposed that the IPC events listed in the following table be used to trigger indicated alarms:

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*Vol, includes "off".

Table 4-2.
DECISION TABLE FOR USE OF
IPC AURAL ALARMS*

New Command Symbol?	FPWI For New Aircraft?	OPWI For New Aircraft?	Tone Generated
Yes	-	-	3
No	Yes	-	2
No	No	Yes	1

A discussion of the term "New Command Symbol" used in the decision table (Table 4-2.) follows. The flight-test configuration of the IPC display has no center cross. In the current IPC concept, a green arrow in one direction is always accompanied by a red cross in the opposite direction. Further, a transition from a positive command to the complementary negative command is accompanied by the deletion of a green arrow. On the other hand, when a non-complementary command appears, a new command symbol or symbols must be illuminated. Thus, the simplest way to check for new or non-complementary commands is to determine if any new command symbols are lit.

4.2.3 Airborne Intercept Control Display

A numeric display has been installed in each of the test aircraft to aid in controlling the intercepts. Four numeric windows provide the test pilot information on the relative position and heading of the other DABS test aircraft. This information is calculated in the ground computer and uplinked on the DABS data link on each four second scan of the DABS antenna. The information contains the horizontal range, relative bearing, magnetic heading and altitude of the other DABS test aircraft.

The horizontal range and altitude of the other aircraft which are uplinked on each scan are the same values utilized by the IPC algorithm. The magnetic heading which is uplinked to one aircraft is the value of gyro heading received on the downlink from the other aircraft via a special instrumentation package, Readout of Aircraft States (RAS). The RAS instrumentation package is described in the flight test plan [1].

4.3 Operational Procedures

IPC flight test operations are described in the IPC flight test plan [1]. This section includes those revisions to operational procedures which have been made since the publication of the flight test plan document.

*All conditions not represented in this table result in no aural alarm.

A total of four hours of IPC flight test operations are scheduled per week. The schedule is flexible allowing for various contingencies of validation and subject pilot operations. Currently two hours of validation and two hours of subject pilot data are being collected. The two hours of subject pilot data is separated into two one-hour periods allowing two subject pilots to evaluate the system per week. Fairly extensive revisions to the algorithm logic require the above amount of extended validation test time.

4.3.1 Subject Pilot Procedure

A comprehensive orientation briefing for prospective pilot subjects prior to an IPC evaluation flight is required. It is necessary to brief pilots on the IPC concept and the service it is intended to provide. A pilot guide handbook prepared by MITRE is provided to the pilots to augment this briefing. The pilot is also briefed on the type of information to be supplied to ground test personnel during the conduct of the evaluation flight. This information includes alerting the test personnel each time the pilot notices a PWI indication and each time an aircraft is sighted. PWI effectiveness results will be derived from this data. A brochure prepared by Lincoln is provided to subject pilots outlining the test objectives, the DABSEF test bed, and flight test procedures.

We have determined that an orientation flight prior to an IPC evaluation flight is not always required. In the future, orientation flights will be provided for only those pilots where it is deemed necessary to assure valid results from the evaluation flight. This decision will be based on the pilot history data provided by the pilot history questionnaire and on a personal interview with prospective subject pilots.

4.3.2 Dual VHF Communications Procedure

An operational requirement was recognized to modify the three test aircraft such that the pilot and copilot could independently communicate on separate VHF frequencies. Early flights with the test aircraft found the pilot and copilot switching the single selector switch back and forth to communicate effectively.

The interceptor aircraft has the requirement to continually monitor and transmit on the intercept frequency connecting the DABS control room with the test aircraft. The interceptor also has the need to monitor and transmit on the frequency assigned to the cognizant ATC facility to receive and acknowledge traffic advisories provided by the facility.

In the drone aircraft, the test pilot in the right seat has the need to monitor the intercept frequency and occasionally transmit to the interceptor any subject pilot course deviations. At the same time, the subject pilot, on the subject frequency, is providing the ground observer at DABSEF with a running commentary of reactions to the IPC system.

4.3.3 Airborne Intercept Control Procedure

The responsibility for coordinating the near-miss encounters between the two DABS aircraft is primarily an airborne function. The aircraft coordinate their RNAV position information via a VHF voice link which is monitored by ground personnel at DABSEF.

An airborne display in each of the test aircraft (Figure 4-1) provides location and course information of the other DABS aircraft. Each test pilot has a constant awareness of the location of the other test aircraft prior to any PWI indications.

The interceptor aircraft using the displayed horizontal range, altitude, relative bearing and magnetic heading of the drone aircraft can position itself to effect the desired encounter. Intercepts can thus be made against pilots who are not fully cooperative, e.g., not holding briefed course or altitude.

For flights involving subject pilots, the interceptor monitors the course deviations on the airborne display and adjusts the interceptor to make the desired intercept. This information is not provided to the subject pilot as it is not part of the IPC concept.

AIRBORNE INTERCEPT CONTROL

(RAS/ATC INTERFACE)

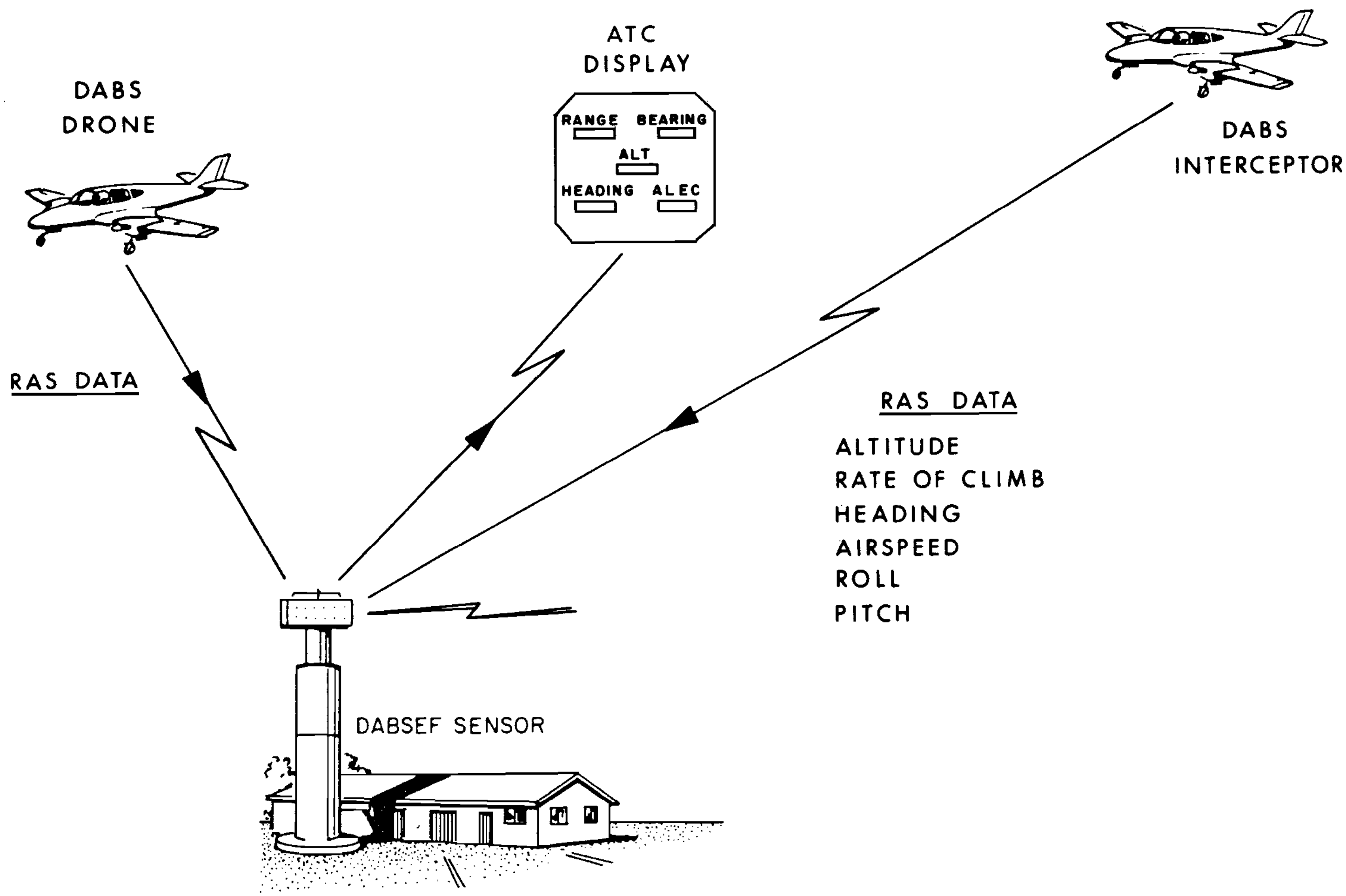

Fig. 4-1. Airborne intercept control.

APPENDICES A.1 - A.10

IPC PROBLEM AREAS

The following appendices document specific problems encountered in validation testing of Lincoln Test Algorithm Configuration 1 (LTAC-1)*. An attempt has been made to specify each problem in enough detail to allow proper evaluation of the seriousness of the problem and to allow the expertise of the system development engineers to be focused upon specific issues. In cases where the nature of the solution can be inferred from the nature of the problem, recommendations have been made concerning possible remedies. It is emphasized that this is only the first step in algorithm evaluation.

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*LTAC-1 refers to the configuration specified in Reference 2.

APPENDIX A.1

Subject: Inconsistent Pilot Acknowledgement Logic
Conditions: IFR/VFR or DABS/ATCRBS Encounter
Algorithm Section: Non-responding Logic
Original
Performance Note: L1

Several inconsistencies exist in the way in which the IPC algorithm of LTAC-1 responds to the presence or absence of pilot acknowledgement. In general, the algorithm attempts to treat non-acknowledgement as an indication that the initial set of commands is inadequate and additional commands must be added. Table A.1-1 provides a matrix depicting the conditions under which additional commands are issued. The following cases identified in Table A.1-1 should be noted.

a) Use of IFR acknowledgement. For Case A, in an IFR/VFR encounter, the VFR aircraft acknowledges but the IFR aircraft does not. Additional commands are not issued. Compare both Case B, in which in an IFR/IFR encounter additional commands are issued on the basis of the IFR acknowledgement status.

b) Use of DABS Acknowledgement in DABS/ATCRBS Encounter. Consider Case C, in which a VFR DABS encounters a VFR ATCRBS. The VFR DABS does not acknowledge and does not receive additional commands (in Case G an IFR DABS aircraft is in a similar situation). The reasoning behind this choice is that "in an ATCRBS/DABS encounter, if the DABS pilot is uncooperative with the first command, it seems futile to issue a second command". This is not true, however, for it has been found non-acknowledgement does not necessarily mean that the pilot is uncooperative. Consider three situations in which a pilot does not acknowledge in the required time period:

i. Avionics fails or pilot is totally uncooperative.
ii. Pilot is cooperative, but late in responding.
iii. Pilot cannot comply due to clouds, non-beacon traffic, terrain, aircraft capabilities, etc.

In situation (i) there is no benefit to issuing an additional command, but neither is there any cost since the command will not inconvenience the pilot who is ignoring the system. In situation (ii) the late acknowledgement implies that the pilot may be late in responding to the command, and additional commands may well be needed to ensure resolution. The benefits are potentially large and the cost of the additional maneuver is justified by the tardiness of the pilot's acknowledgement. In situation (iii) the cost is negligible

Table A.1-1

ISSUANCE OF NON-RESPONDING COMMANDS

		DABS VFR ACK	DABS VFR NACK	DABS IFR ACK	DABS IFR NACK
DABS VFR	ACK	0	1	0	Case A 0
	NACK	1	1	1	1
DABS IFR	ACK	0	1	0	Case B 1
	NACK	Case A 0	1	Case B 1	1
ATCRBS VFR		0	Case C 0	Case E 1	Case D 1
ATCRBS IFR		0	Case F 1	0	Case G 0

0 = Commands Not Issued
1 = Commands Issued

ACK = Aircraft Acknowledging
NACK = Aircraft Non-Acknowledging

and the potential benefit is tremendous: the additional command is the only way in which IPC can prevent a collision. Two of the flight test subject pilots have experienced encounters in which they would not comply with initial commands due to clouds but were willing to comply in another dimension.

Note also that Case E appears to be inconsistent with Case F. In Case F, the ATCRBS intruder is IFR and the DABS aircraft does receive an additional command when he fails to acknowledge.

c) IFR DABS vs VFR ATCRBS. In Case E, an acknowledging IFR aircraft in conflict with a VFR ATCRBS aircraft receives additional commands. In this situation, commands appear in both dimensions simultaneously. This case has been recognized as an error and a change proposal has been submitted to correct it. However the change proposed will result in an alteration in Case F, giving rise to the same questions advanced in Item b) above.

Other Criteria for Additional Commands

It has been noted that whenever an ATCRBS aircraft is involved, it may maneuver in a way that cancels the effect of the maneuver of a complying DABS aircraft. Thus backup commands may be required even though the DABS aircraft is responding. The most significant case discovered in this regard is the vertical chase condition which can result when an ATCRBS aircraft is climbing (or descending) into a DABS aircraft in a tail chase geometry. If the DABS aircraft responds, a vertical chase is established, and the ATCRBS aircraft can continue to close until collision without a backup command being issued to the DABS aircraft (see Figure 2-12 in Section 2.5.1). Similar situations can arise in the horizontal plane. A partial solution to the vertical chase problem is being tested. However the fact remains that the decision to issue, or not to issue, additional commands cannot be strictly a function of acknowledgement. There should be a "deterioration logic" which checks the actual projected separations and determines whether or not additional commands are required.

APPENDIX A.2

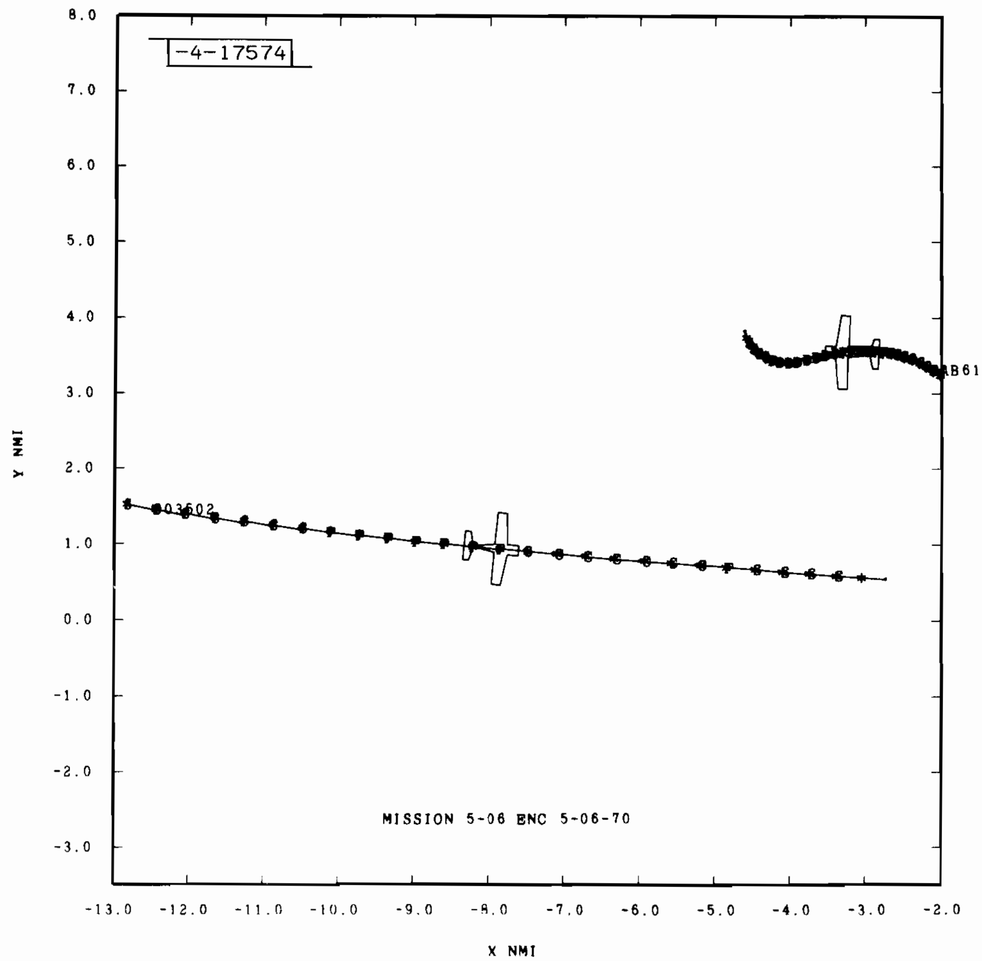
Subject: Positive Commands at Large Miss Distance
Conditions: High Speed Aircraft, Climbing or Descending
Algorithm Section: Horizontal/Vertical Selection Logic
Original
Performance Note: L2

Description:

Two aircraft may have a large horizontal miss distance but still have sufficient closing velocity to violate the tau criteria. If the altitude separation is greater than 500 feet, or one of the aircraft has a ground speed in excess of 150 knots, vertical commands are chosen. If the vertical miss distance is then found to be less than 500 feet, vertical positive commands are issued. If horizontal commands are selected, the criteria for positive horizontal commands is that the horizontal miss distance for VFR/VFR pair be less than 0.5 nmi, and for a VFR/IFR or IFR/IFR pair be less than 1.0 nmi. In the encounter shown in Figure A.2.1, the aircraft received positive vertical commands even though they were to pass no closer than 16,000 feet horizontally. If the horizontal dimension had been selected, the aircraft would have received negative commands. In this case, one aircraft had a ground speed of 286 knots and the other a ground speed of 88 knots. The larger the ground speeds, the larger is the possible miss distance at which commands may be generated.

Possible Remedies:

Two methods of avoiding this problem were suggested. The first was to avoid setting the command flag when miss distances are greater than a fixed threshold. The second method was to modify the decision logic which chooses the maneuver dimension (horizontal or vertical). If either command dimension results in issuance of a negative command, then that dimension would be selected. If both command dimensions result in negative commands the present logic would prevail. Both approaches have been incorporated into algorithm change proposals. Unless further flight test results prove otherwise, the problem is considered to be solved.



AC1 TRACK = 1 ID = DAB613
AC2 TRACK = 19 ID = 003502

SCAN	AC1	AC2	POS	TH	RANGE MD	TV	RZ	VZ	VMD	DOT	TCMD
138	S	S	0	71.46	6.5220019.28	52.8	3456.73	-65.43	0.0	-2100.45	64.
139	F	F	0	67.39	6.0819370.19	49.7	3172.98	-63.88	0.0	-1935.29	64.
140	F	F	-2	63.85	5.6618891.22	52.3	2976.09	-56.88	0.0	-1763.80	64.
141	F	F	1	60.16	5.2518284.22	54.8	2800.73	-51.08	0.0	-1603.46	64.
142	D	C	1	56.79	4.8517804.68	61.1	2674.77	-43.74	0.0	-1441.95	64.
143	D	C	1	53.81	4.4417387.41	63.7	2525.55	-39.65	0.0	-1267.33	64.
144	D	C	1	51.41	4.0516980.64	62.7	2365.81	-37.73	0.0	-1096.94	64.
145	D	C	1	50.00	3.6916639.99	58.8	2192.20	-37.30	0.0	-924.47	64.
146	D	C	1	50.50	3.3416370.41	53.4	2003.56	-37.50	0.0	-741.25	64.
147	D	C	1	54.91	3.0816275.16	52.7	1865.22	-35.42	0.0	-572.41	64.
148	D	C	0	71.77	2.8816414.79	48.2	1695.46	-35.17	0.0	-379.44	64.
149	F	F	0	129.76	2.8016685.13	41.8	1519.70	-36.35	0.0	-196.19	64.
150	S	S	0	0.0	2.8016957.73	0.0	1323.37	0.0	1323.37	78.80	64.
151	S	S	0	0.0	2.9016570.55	0.0	1120.85	0.0	1120.85	346.17	64.
152	S	S	0	0.0	3.0616169.99	0.0	968.77	0.0	968.77	512.32	64.
153	S	S	0	0.0	3.2915816.89	0.0	795.70	0.0	795.70	656.07	64.

Fig. A.2-1. A case of unnecessary positive commands (encounter 5-06-70).

APPENDIX A.3

Subject: Command Issuance Near Closest Approach
Conditions: Climbing or Descending
Algorithm Section: Tau/Range Tests
Original Performance Note: L3

Description:

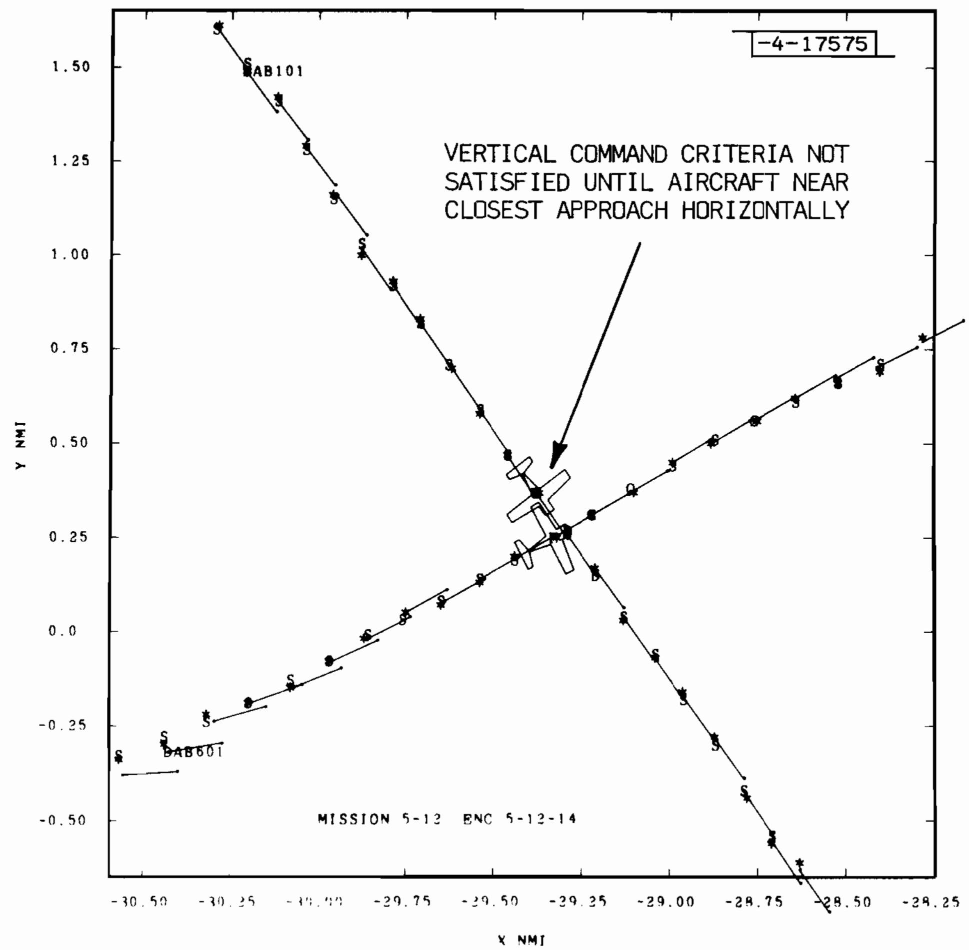
The vertical criteria for commands may first be satisfied when aircraft are near closest approach in the horizontal plane. In such cases the aircraft may be rapidly separating by the time positive commands arrive. Figure A.3-1 is a plot of such an encounter. Pilot reactions to this situation have been that the time of maximum concern had passed before IPC acted. According to individual perception, this means that either the IPC system was too late in acting or else it issued unnecessary commands. Either interpretation undermines pilot confidence and decreases pilot willingness to comply with future commands.

Possible Remedies:

One solution is to test before issuing commands to see whether or not the aircraft horizontal closing rate is expected to change sign and become favorable in the next few seconds. If so, IPC can just as well wait for this event rather than issuing an ineffective command.

Status:

This problem has been discussed at the IPC Engineering Coordination Meeting. No agreement was reached concerning the extent to which pilot confidence is affected by such encounters. This issue will be investigated further in subject pilot testing.



AC1 TRACK = 1 ID = DAB601
AC2 TRACK = 2 ID = DAB101

SCAN	AC1	AC2	POS	TH	RANGE	MD	TV	RZ	VZ	VMD	DOT	TCMD
1151	S	S	0	139.77	2.13	9488.09	113.9	-1788.45	15.70	1286.10	-107.40	32.
1152	S	S	0	57.43	2.01	4964.91	103.4	-1713.16	16.57	1183.01	-229.47	32.
1153	S	S	0	46.86	1.83	3967.38	114.1	-1670.80	14.65	1202.14	-230.55	32.
1154	S	S	0	39.08	1.67	3088.77	106.8	-1606.00	15.04	1124.66	-223.45	32.
1155	S	S	0	32.92	1.50	2375.56	91.7	-1523.94	16.62	992.14	-209.73	32.
1156	S	S	0	26.72	1.33	1794.54	76.9	-1430.17	18.61	834.64	-191.83	32.
1157	S	S	0	19.19	1.11	1280.71	64.8	-1329.09	20.53	672.23	-170.43	32.
1158	S	S	0	14.43	0.96	943.41	68.3	-1270.81	18.60	675.60	-147.53	32.
1159	S	S	0	8.55	0.78	713.11	65.0	-1197.26	18.42	607.82	-121.24	32.
1160	S	S	0	2.68	0.62	543.81	57.9	-1111.94	19.21	497.28	-95.49	32.
1161	S	S	0	-5.40	0.45	451.51	49.9	-1018.01	20.39	365.37	-68.84	32.
1162	S	S	-2	-19.85	0.27	403.29	53.3	-965.16	18.10	386.11	-41.29	32.
1163	F	F	1	-66.16	0.12	377.34	39.8	-848.93	21.32	166.83	-15.60	32.
1164	C	D	1	0.0	0.09	401.81	0.0	-779.73	0.0	779.73	8.99	32.
1165	C	D	0	0.0	0.23	447.87	0.0	-699.07	0.0	699.07	32.66	32.
1166	S	S	0	0.0	0.43	449.59	0.0	-655.93	0.0	655.93	64.54	32.
1167	S	S	0	0.0	0.61	448.00	0.0	-639.29	0.0	639.29	92.84	32.
1168	S	S	0	0.0	0.76	483.91	0.0	-685.41	0.0	685.41	116.06	32.
1169	S	S	0	0.0	0.94	467.58	0.0	-726.64	0.0	726.64	143.76	32.
1170	S	S	0	0.0	1.13	437.35	0.0	-759.31	0.0	759.31	175.52	32.
1171	S	S	0	0.0	1.30	423.78	0.0	-829.09	0.0	829.09	201.20	32.

Fig. A.3-1. A case of command issuance near closest approach (encounter 5-12-14).

APPENDIX A.4

Subject:	Failure to Delete Positive Commands
Conditions:	Non-acknowledgement and Positive to Negative Transition
Algorithm Section:	Negative/Positive Transition Logic
Original Performance Note:	L4

Description:

The portion of the IPC algorithm which changes positive commands to negative commands and vice-versa is asymmetric in its handling of horizontal and vertical commands. Figure A.4-1 is the logic flowchart for the negative/positive transition logic. Note that the first branch shown asks whether or not a horizontal command is present and if it is only the portion of the logic which is concerned with horizontal commands is exercised. During the flight tests, two types of problems have arisen due to this aspect of the logic:

a) When positive commands exist in both horizontal and vertical planes the transition logic will test only horizontal miss distance. Even when the aircraft are well separated vertically, positive commands may be continued due to a small horizontal miss distance. Figure A.4-2 is an example of such a case. At one point the aircraft were separated by 952 feet in altitude and had favorable altitude rates, yet positive commands were continued (in command issuance, a separation of greater than 500 feet with favorable altitude rates results in negative commands).

b) Cases have been observed in which a conflicting pair of aircraft receive a negative command in the horizontal plane and a positive command in the vertical plane. In such cases, the algorithm logic is in a state for which the answers to certain flowchart questions are undefined. This state arises in the following manner: Assume that both pilots acknowledge non-responding commands and POSCMD goes from 2 to 4. After a time (TSCMD) the positive/negative transition logic is exercised to see if positive commands are still required. However, the positive/negative transition logic will check only the horizontal dimension when horizontal commands are present. If the horizontal miss distance is greater than the positive command threshold, the positive horizontal command is replaced by a negative horizontal command, and the POSCMD returns to 0. The positive vertical command remains active. Thus the aircraft pair has POSCMD=0 with a negative command in the horizontal plane and a positive command in the vertical plane. Figure A.4-3 is an example of an encounter for which this occurred.

The need for positive commands may arise again, and the master resolution module will be entered. One branch test in the flowchart asks: "Does pair record contain a vertical or horizontal positive command? (POSCMD $\neq$ 0)". Note that for the state the algorithm is now in POSCMD = 0, but there is still a positive command present. The algorithm may also assume that non-responding commands can be generated even though positive commands already exist in both vertical and horizontal directions. The result of the branch test "Is positive command horizontal?" is not defined when positive commands exist in both horizontal and vertical. The resulting actions taken by the algorithm can depend upon the manner in which the branch logic was implemented.

Possible Remedies:

The positive/negative transition logic can be modified so that each time it is entered, each dimension with a positive command is checked for a possible transition. When a positive to negative transition occurs, all positive commands should be removed from the pair record.

Status:

A change proposal which implements the remedy suggested above has been accepted. Unless further flight test results prove otherwise, the problem is considered to be solved.

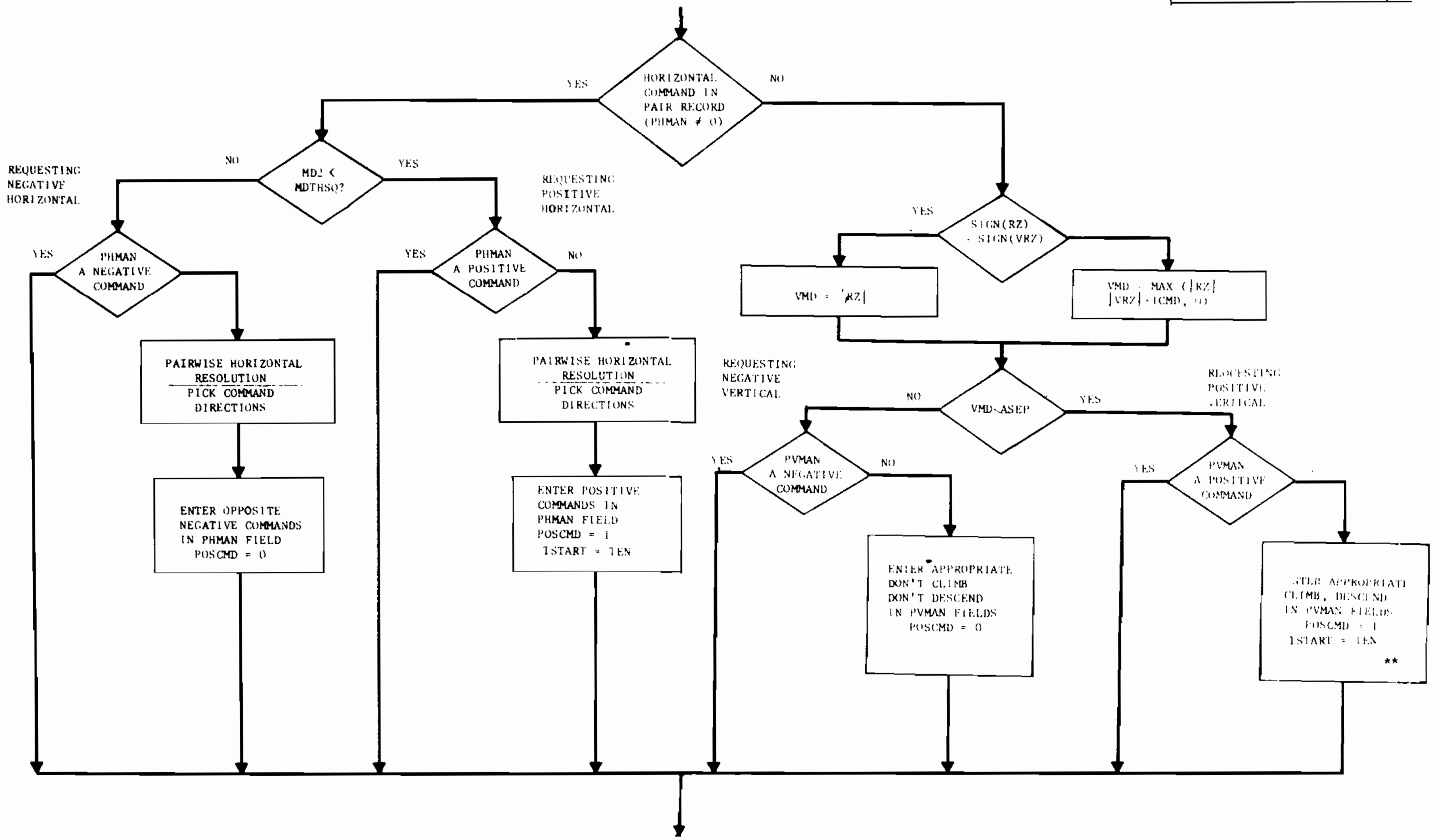
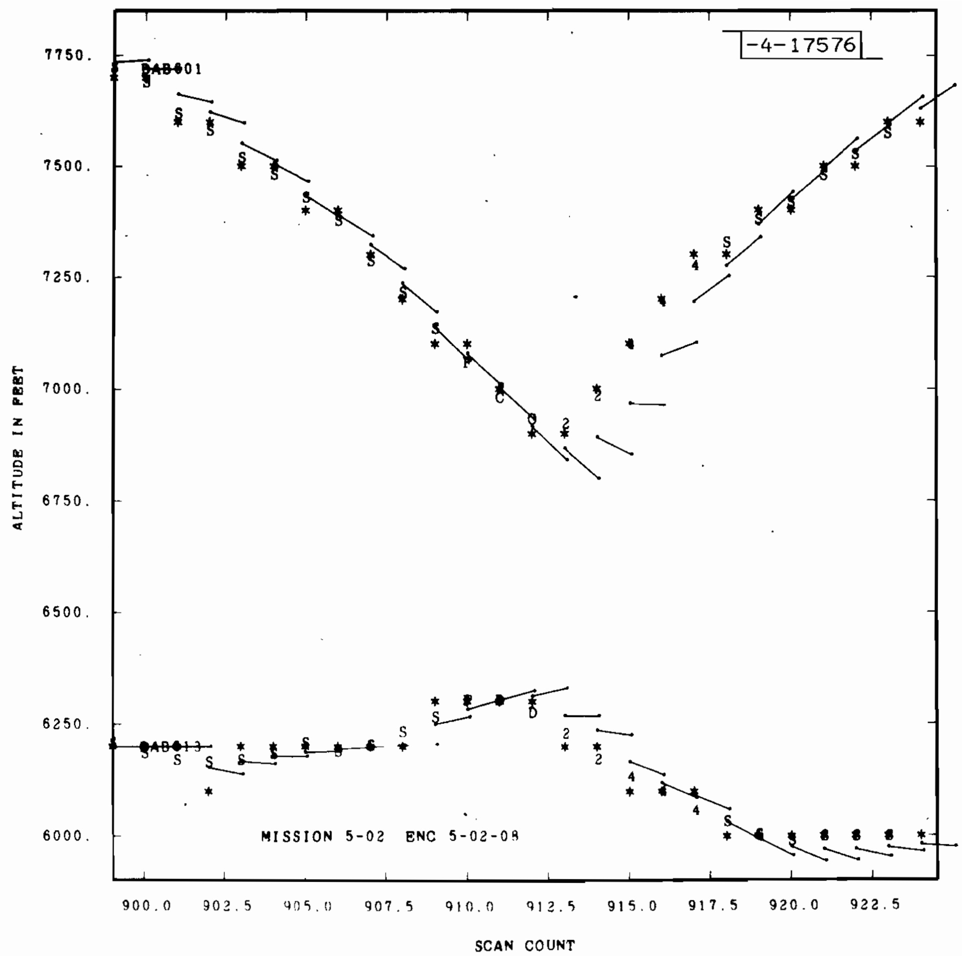


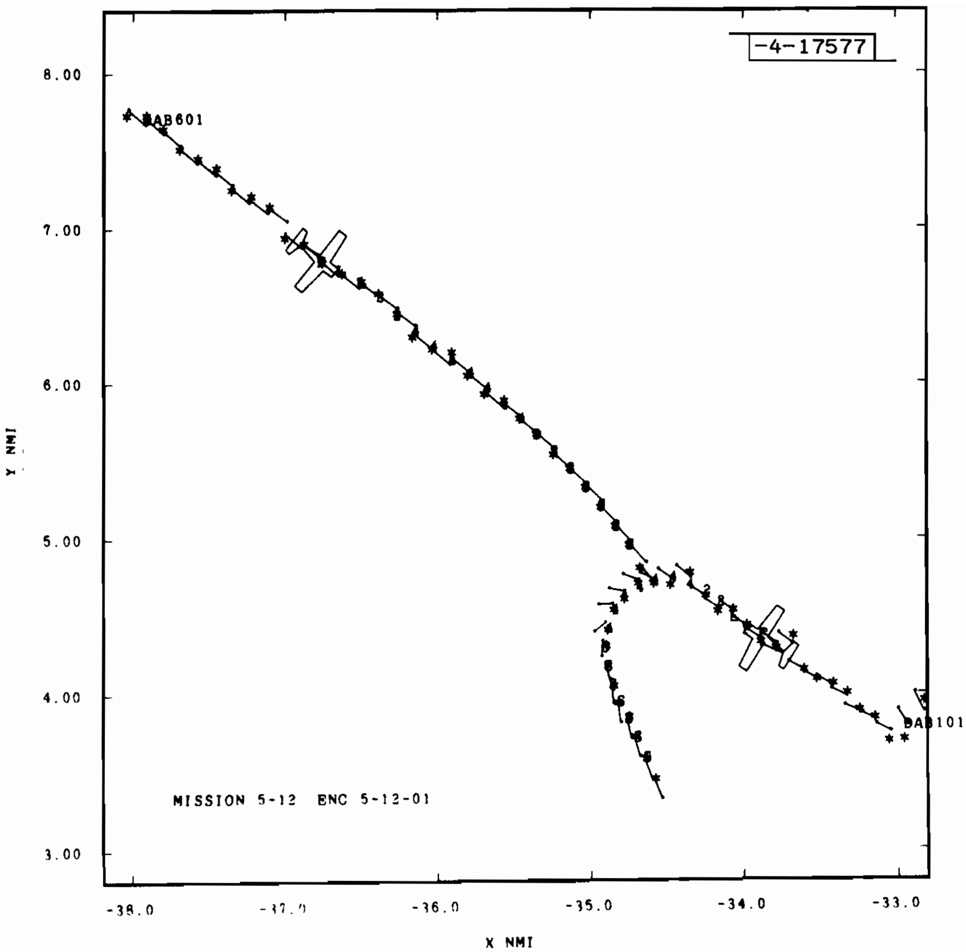
Fig. A.4-1. Negative/positive transition logic.



AC1 TRACK = 2 ID = DAB613.
AC2 TRACK = 3 ID = DAB601

SCAN	AC1	AC2	POS	TH	RANGE	MD	TV	RZ	VZ	VMD	DOT	TCMD
899	S	S	0	118.24	1.80	3479.51	-430.1	1552.35	3.61	1552.35	-89.90	32.
900	S	S	0	105.58	1.73	4012.92	-1264.6	1535.84	1.21	1535.84	-91.77	32.
901	S	S	0	97.40	1.66	4707.50	6317.3	1521.83	-0.24	1514.12	-91.03	32.
902	S	S	0	90.83	1.60	5086.27	320.5	1464.79	-4.57	1318.52	-88.92	32.
903	S	S	0	84.23	1.52	5286.39	553.2	1471.28	-2.66	1386.16	-86.27	32.
904	S	S	0	73.14	1.43	4892.93	164.8	1386.07	-8.41	1116.89	-86.12	32.
905	S	S	0	63.83	1.35	4592.56	129.2	1327.96	-10.28	999.03	-84.76	32.
906	S	S	0	53.86	1.25	4006.36	93.1	1246.44	-13.38	818.20	-83.81	32.
907	S	S	0	46.78	1.17	3533.99	91.2	1196.05	-13.12	776.26	-80.88	32.
908	S	S	0	38.25	1.07	2830.37	76.5	1123.28	-14.68	653.57	-78.13	32.
909	S	S	0	31.12	0.98	1862.24	60.9	1034.45	-16.98	491.06	-74.69	32.
910	S	S	-2	26.30	0.91	1256.86	38.8	889.07	-22.92	155.47	-69.00	32.
911	F	F	1	22.16	0.84	1005.28	35.0	798.34	-22.81	68.28	-62.18	32.
912	D	C	1	16.44	0.76	472.68	30.5	703.55	-23.05	0.0	-55.82	32.
913	D	C	2	8.75	0.68	10.06	25.8	605.83	-23.44	0.0	-49.71	32.
914	R D	L C	2	2.09	0.60	6.51	35.9	599.02	-16.69	64.84	-43.63	32.
915	R D	L C	4	-5.11	0.53	113.32	92.6	656.30	-7.09	429.43	-37.64	32.
916	R D	L C	4	-12.23	0.48	141.48	-128.2	800.50	6.24	800.50	-31.98	32.
917	R D	L C	4	-19.41	0.43	117.08	-59.4	952.91	16.05	952.91	-26.72	32.
918	R D	L C	0	-25.64	0.40	1065.32	-48.8	1102.15	22.59	1102.15	-20.99	32.
919	S	S	0	0.0	0.43	2569.47	0.0	1242.63	0.0	1242.63	6.19	32.
920	S	S	0	0.0	0.55	1774.48	0.0	1372.59	0.0	1372.59	79.91	32.
921	S	S	0	0.0	0.77	1643.39	0.0	1446.39	0.0	1446.39	155.47	32.
922	S	S	0	0.0	1.03	2.31	0.0	1525.53	0.0	1525.53	230.01	32.
923	S	S	0	0.0	1.25	1657.47	0.0	1564.33	0.0	1564.33	269.06	32.
924	S	S	0	0.0	1.45	3576.99	0.0	1622.27	0.0	1622.27	279.36	32.

Fig. A.4-2. A case of positive command continuance despite adequate separation (encounter 5-02-08).



AC1 TRACK = 1 ID = DAB101
AC2 TRACK = 2 ID = DAB601

SCAN	AC1	AC2	POS	TH	RANGE	MD	TV	RZ	VZ	VMD	DOT	TCMD
30			-2	61.47	4.03	1043.13	2009.2	-192.95	0.10	186.81	-931.47	64.
31	F	F	1	57.60	3.77	1428.89	-1177.5	-196.01	-0.17	196.01	-869.70	64.
32	F	L	1	5[illegible].13	3.50	1502.69	-699.9	-198.23	-0.28	198.23	-810.34	64.
33	L	L	2	48.56	3.23	1602.68	-655.0	-199.67	-0.30	199.67	-751.21	64.
34	L C	L D	2	45.97	3.01	2499.60	-735.9	-200.49	-0.27	200.49	-683.92	64.
35	L C	L D	4	40.99	2.72	2015.06	-930.3	-200.86	-0.22	200.86	-624.82	64.
36	L C	L D	4	34.22	2.40	616.47	-67.1	-247.33	-3.68	247.33	-571.45	64.
37	L C	L D	4	30.68	2.16	1489.24	-55.8	-279.80	-5.01	279.80	-509.72	64.
38	L C	L D	4	28.96	1.96	2896.33	-30.9	-360.14	-11.65	360.14	-441.12	64.
39	L C	L D	4	26.08	1.74	3444.14	-28.2	-457.30	-16.24	457.30	-373.93	64.
40	L C	L D	4	25.59	1.58	4345.98	-33.3	-512.63	-15.41	512.63	-307.85	64.
41	L C	L D	4	28.39	1.48	5577.03	-36.1	-586.87	-16.27	586.87	-240.19	64.
42	L C	L D	0	46.56	1.43	7237.43	-43.7	-628.46	-14.40	628.46	-135.51	64.
43	NR C	NR D	0	147.59	1.40	8197.83	-57.1	-646.74	-11.32	646.74	-40.82	64.
44	S	S	0	440.28	1.40	8417.76	-60.2	-696.20	-11.57	696.20	-13.48	64.
45	S	S	0	0.0	1.42	8623.11	0.0	-769.60	0.0	769.60	4.71	64.
46	S	S	0	0.0	1.41	8521.00	0.0	-813.39	0.0	813.39	15.10	64.
47	S	S	0	0.0	1.39	8346.05	0.0	-834.94	0.0	834.94	13.48	64.
48	S	S	0	0.0	1.38	8280.63	0.0	-841.45	0.0	841.45	11.71	64.
49	S	S	0	0.0	1.38	8300.08	0.0	-838.93	0.0	838.93	11.46	64.

Fig. A.4-3. A case of negative command in the horizontal plane and positive command in the vertical plane (encounter 5-12-01).

APPENDIX A.5

Subject: Divergence (DOT) Test Drops Command Too Soon
Conditions: Low Relative Velocity
Algorithm Section: Divergence Test
Original
Performance Note: L5

Description:

DOT is an algorithm variable defined as the product of range and range rate. The divergence test prevents the setting of the command flag when DOT exceeds a threshold DOTTH, initially set to 1.0 nmi-knot. This test was added when it was noted in early IPC flight testing that commands persisted for too long a period of time after aircraft were clearly separating. In most situations, the divergence test worked as intended, but cases were found in which commands were dropped too soon. Encounter 5-07-05 is one example.

Figures A.5-1 and A.5-2 are plots of encounter 5-07-05 in the horizontal and vertical dimensions. The encounter employed a climbing tail chase to generate vertical positive commands. Note that the commands were dropped after only two scans, even though the collision threat had not decreased significantly and aircraft had not acknowledged the commands. A follow-on conflict arose only three scans later as the situation changed slightly. Commands were dropped because of the divergence test in the conflict detection logic. On scan 293, the value of DOT was 2.24 nmi-kt. (range = .255 nmi; separation rate = 9 knots) and thus the 1.0 nmi-kt. threshold was exceeded. As mentioned above, the intention of the divergence logic is to quickly recognize when the conflict has been resolved in the horizontal plane. But separation rates such as were observed here (9 knots) could easily be due to tracking errors or transient course changes. If the altitude rate were sufficiently large, a command sequence such as observed in 5-07-05 could easily result in pilot confusion and lead to avoidance failure before commands could be re-established.

The divergence test works well under the following conditions:

a) The threshold (DOTTH) is large enough to accommodate tracking errors and course changes which may take place during the next few scans.

b) Aircraft have a large relative velocity so that DOT tends to increase rapidly after closest approach. (Thus a small positive value will be followed by larger positive values).

c) Aircraft are responding to horizontal commands, and thus DOT is a controlled parameter.

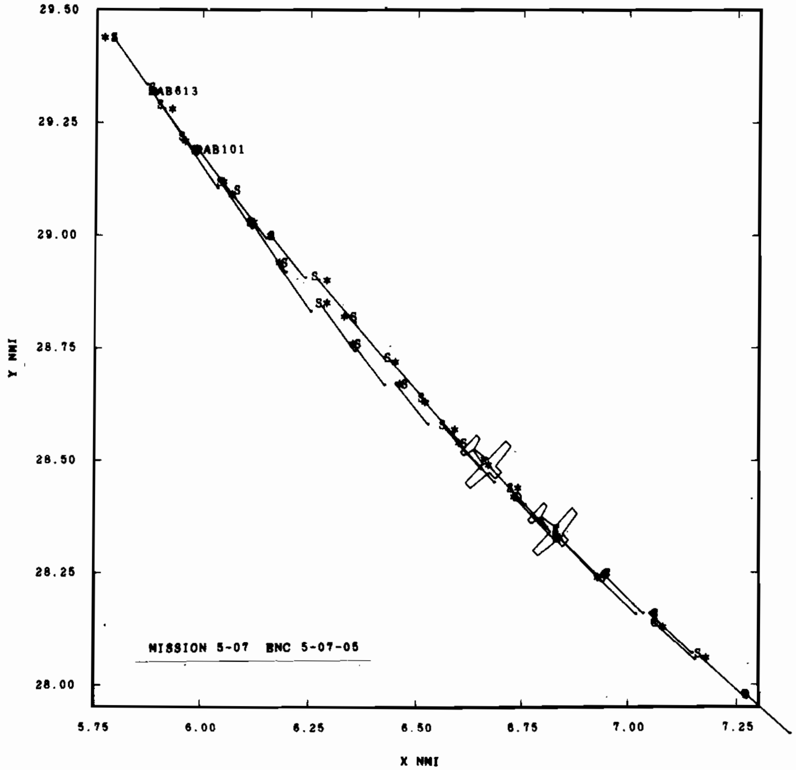
None of these conditions are met in encounters such as 5-07-05.

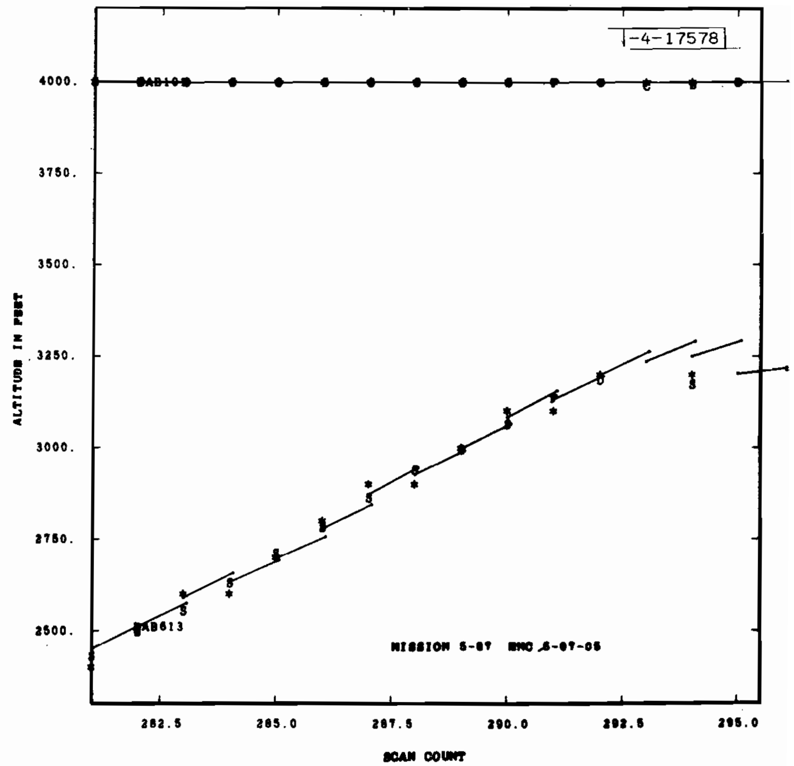
Possible Remedies:

The most obvious remedy is to increase the threshold DOTTH in order to require a greater divergence rate before dropping commands. It might also be desirable to consider other forms of the divergence test variable ("modified DOT")?

Status:

An algorithm change proposal which increases DOTTH from 1.0 to 10. kt-nmi has been accepted. Unless further testing proves otherwise, the problem is considered solved.





AC1 TRACK = 2 ID = DAB101
AC2 TRACK = 3 ID = DAB613

SCAN	AC1	AC2	POS	TH	RANGE	MD	TV	RZ	VZ	VMD	DOT	TCMD
281	S	S	0	-882.47	0.17	883.69	79.5	-1590.29	19.99	950.52	-1.13	32.
282	S	S	0	-937.37	0.20	95.65	92.4	-1550.11	16.78	1013.20	-1.00	32.
283	S	S	0	-963.13	0.17	615.13	92.6	-1489.36	16.09	974.38	-1.00	32.
284	S	S	0	-962.58	0.17	852.75	83.7	-1411.93	16.86	872.37	-1.00	32.
285	S	S	0	-949.74	0.17	920.90	92.2	-1368.71	14.85	893.67	-1.00	32.
286	S	S	0	-909.77	0.20	1167.23	86.4	-1303.64	15.08	821.09	-1.00	32.
287	S	S	0	-885.70	0.19	1112.52	74.1	-1221.85	16.49	694.25	-1.00	32.
288	S	S	0	-870.49	0.20	1102.74	61.6	-1128.46	18.32	542.18	-1.00	32.
289	S	S	0	0.0	0.21	1031.56	0.0	-1074.31	0.0	1074.31	1.20	32.
290	S	S	0	-842.17	0.20	943.11	59.6	-1002.58	16.83	463.96	-1.00	32.
291	S	S	-2	-871.58	0.20	769.69	51.1	-917.45	17.96	342.77	-1.00	32.
292	P	P	1	-873.96	0.22	267.99	54.4	-869.21	15.98	358.00	-1.00	32.
293	C	D	1	0.0	0.26	188.49	0.0	-801.39	0.0	801.39	2.24	32.
294	C	D	0	0.0	0.28	182.51	0.0	-764.84	0.0	764.84	3.15	32.
295	S	S	0	0.0	0.30	193.86	0.0	-750.31	0.0	750.31	4.09	32.

Fig. A.5-1. and Fig. A.5-2. A case in which commands are dropped too soon (encounter 5-07-05).

APPENDIX A.6

Subject:	Detrimental Turn Commands to Maneuvering Aircraft
Conditions:	Turning Aircraft
Algorithm Section:	Command Selection Logic, Tracking
Original Performance Note:	L6

Description:

In encounters involving turning aircraft, cases have been observed for which IPC commands served to vector aircraft into a collision situation rather than into a safe resolution. Such an event occurs when the aircraft are initially in a geometry which calls for turns in one direction and are maneuvering into a geometry which requires turns in the opposite direction. In such cases, the tracking lag combines with the heading changes occurring during the aircraft response time to make IPC commands invalid before they can be complied with.

Figures A.6-1 and A.6-2 present diagrams of the two types of observed cases in which the turn effect described above results in inappropriate IPC commands. Figure A.6-1 illustrates the case in which one aircraft maneuvers, and Figure A.6-2 the case in which both aircraft are maneuvering. In both cases, the encounter geometry is changing from a turn right/turn right geometry to a turn left/turn left geometry. When commands are generated, the right turns seem appropriate, but by the time the aircraft actually begin to respond the commands are inappropriate. The mirror image case exists in which left/left turn commands are involved.

Examples

Figure A.6-3 and A.6-4 are examples of test encounters in which a turn by one aircraft created the problem under discussion. In encounter 5-07-08 (Figure A.6-3), the aircraft ignored the turn commands. In encounter 6-27-04 (Figure A.6-4), the aircraft complied and were turned toward each other. Figure A.6-5 is an example of a test encounter (6-27-03) in which both aircraft were turning when commands were received. In this encounter the final resolution was aided by the fact that DAB101 did not comply with the command.

In Figure A.6-6, aircraft DAB601 began to turn right at a time when his IPC display was indicating an OPWI light at 12 o'clock (traffic was at 2 miles). The IPC command selection logic applied Rule C and issued a "don't turn right" command which was the best choice for the instantaneous geometry at the time of command generation. The aircraft ceased turning promptly, but the change in heading during the response time produced a final geometry in which the aircraft were flying essentially parallel and were forbidden to turn away from each other. If DAB552 had suddenly turned right (away from his negative command) a serious hazard would have quickly arisen. Note that if DAB601 had been allowed to continue his turn, he would have soon diverged from the path of the other aircraft.

Note that in two of these encounters the turns began before PWI lights were sent to the aircraft. Therefore pilot training in the use of PWI cannot be expected to prevent these types of maneuvers.

Heading Changes

Much attention has been given to the heading errors produced by tracker lag during turns, but in the current case an equally important consideration is the heading change which occurs between the time IPC commands are generated and the time the response to commands begins. Suppose for instance that an aircraft is turning at rate w when commands are generated. Commands are delivered 1 scan later, and the pilot stops turning m scans after receiving the commands. If T is the scan period, then the heading change which takes place is

$$\Delta(\text{heading}) = (m + 1)\, wT$$

Letting $w = 5^{\circ}/\text{sec}$, $m = 2$, and $T = 4$ sec, we find $\Delta(\text{heading}) = 60^{\circ}$. The combination of tracker lag and heading change during response delay can easily exceed 90°.

Possible Remedies:

No complete solution to the observed problem is evident, but there are several approaches which might be tried to reduce the sensitivity of IPC performance to turns. The steps which can be taken were discussed in Section 2.5.2 of the text. Briefly they are

1) Improve tracker turn detection
2) Use turn detection in choosing command direction
3) Use alarm criceria which can anticipate non-rectilinear flight
4) Use negative commands as preventive measures.

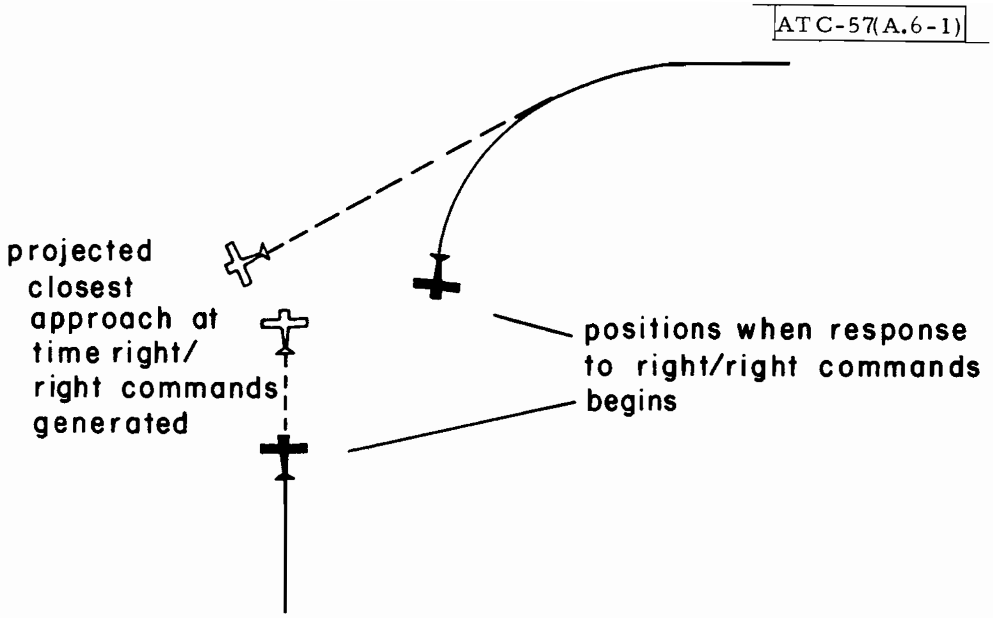


Fig. A.6-1. Detrimental turn commands (one aircraft maneuvering).

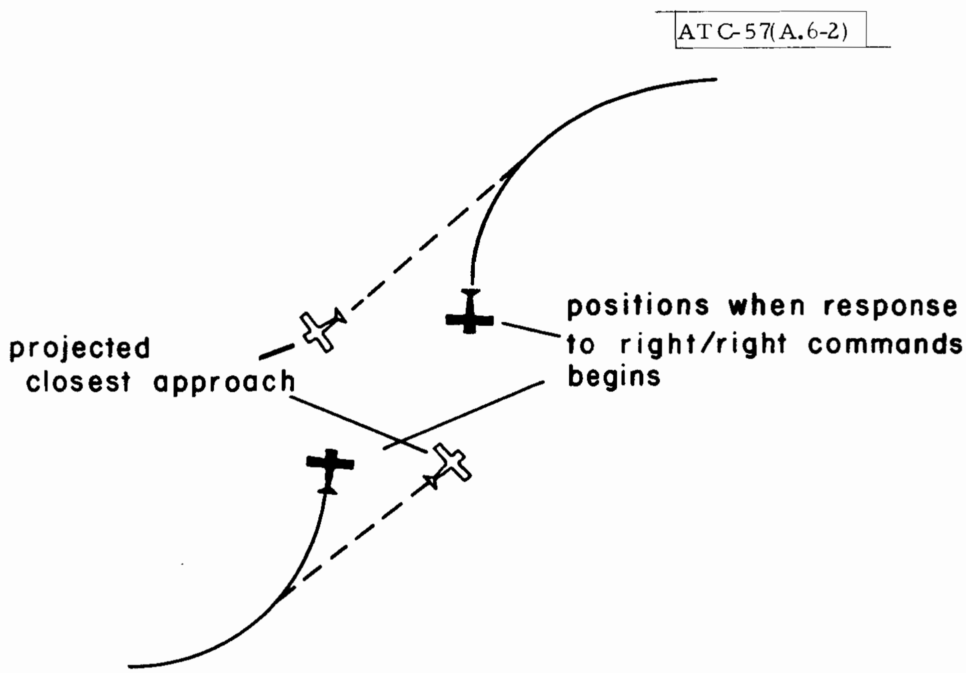
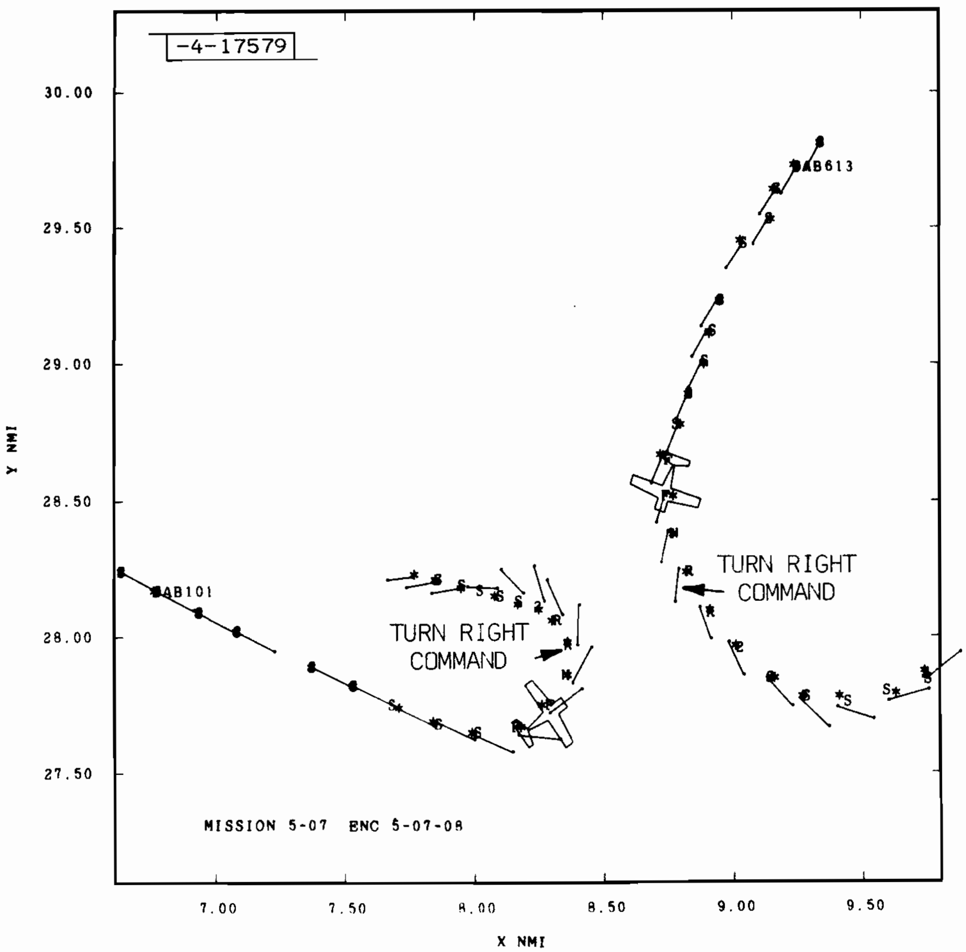


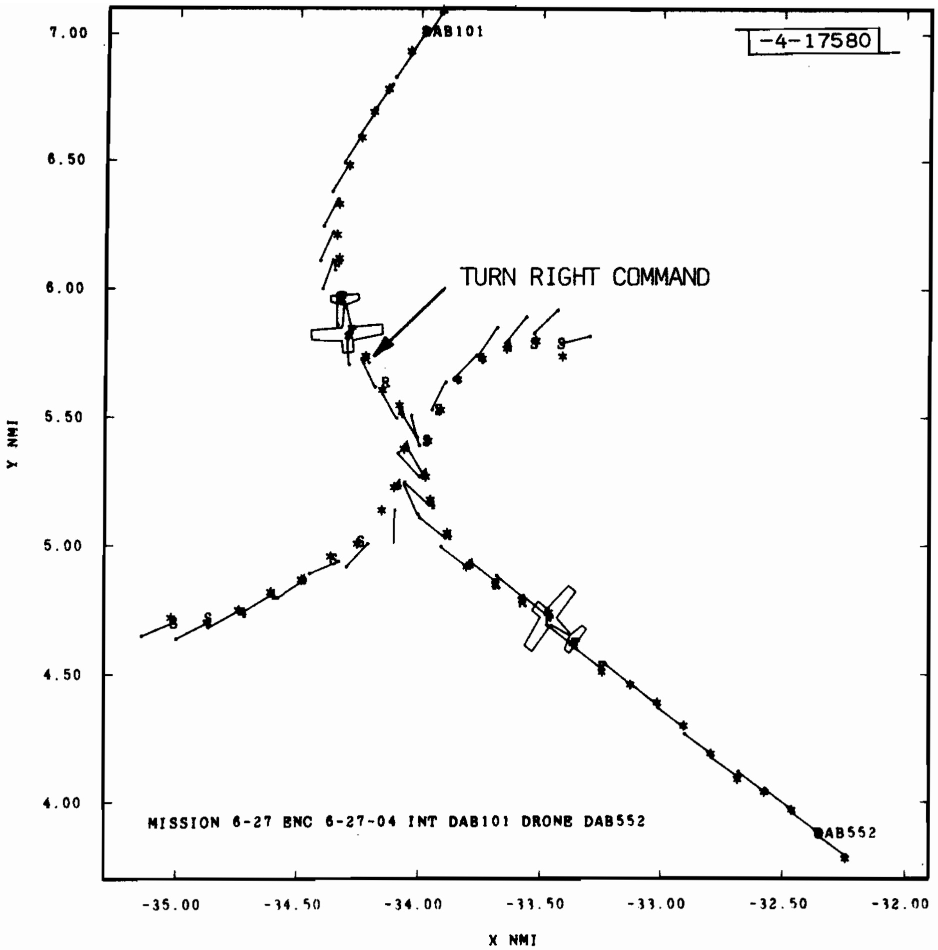
Fig. A.6-2. Detrimental turn commands (both aircraft maneuvering).



AC1 TRACK = 2 ID = DAB101
AC2 TRACK = 3 ID = DAB613

SCAN	AC1	AC2	POS	TH	RANGE	MD	TV	RZ	VZ	VMD	DOT	TCMD
345	S	S	0	44.19	2.07	6955.59	-383.5	89.84	0.23	89.84	-321.35	32.
346	S	S	0	41.15	1.89	6654.10	-145.2	95.62	0.66	95.62	-283.91	32.
347	S	S	0	38.58	1.73	6460.46	19.2	52.72	-2.75	0.0	-246.68	32.
348	S	S	0	35.75	1.56	6180.35	94.9	68.54	-0.72	45.42	-211.78	32.
349	F	F	-2	31.94	1.39	5723.40	-173.1	81.52	0.47	81.52	-180.51	32.
350	F	F	0	20.10	1.17	4359.41	-87.5	91.15	1.04	91.15	-184.62	32.
351	NL	NL	1	9.53	0.94	1019.98	22.6	51.18	-2.26	0.0	-211.42	32.
352	R	R	1	3.04	0.67	800.89	274.4	68.79	-0.25	60.76	-156.92	32.
353	R	R	2	-3.75	0.49	2286.12	-95.6	82.70	0.86	82.70	-74.38	32.
354	R D	R C	0	0.0	0.53	3047.80	0.0	46.25	0.0	46.25	42.24	32.
355	S	S	0	0.0	0.73	3687.35	0.0	20.05	0.0	20.05	97.97	32.
356	S	S	0	0.0	0.99	2794.83	0.0	49.51	0.0	49.51	209.31	32.
357	S	S	0	0.0	1.24	782.37	0.0	72.61	0.0	72.61	279.11	32.
358	S	S	0	0.0	1.44	2593.50	0.0	135.35	0.0	135.35	303.89	32.
359	S	S	0	0.0	1.72	4729.39	0.0	178.16	0.0	178.16	367.32	32.
360		S	0	0.0	1.94	7050.57	0.0	157.94	0.0	157.94	361.42	32.

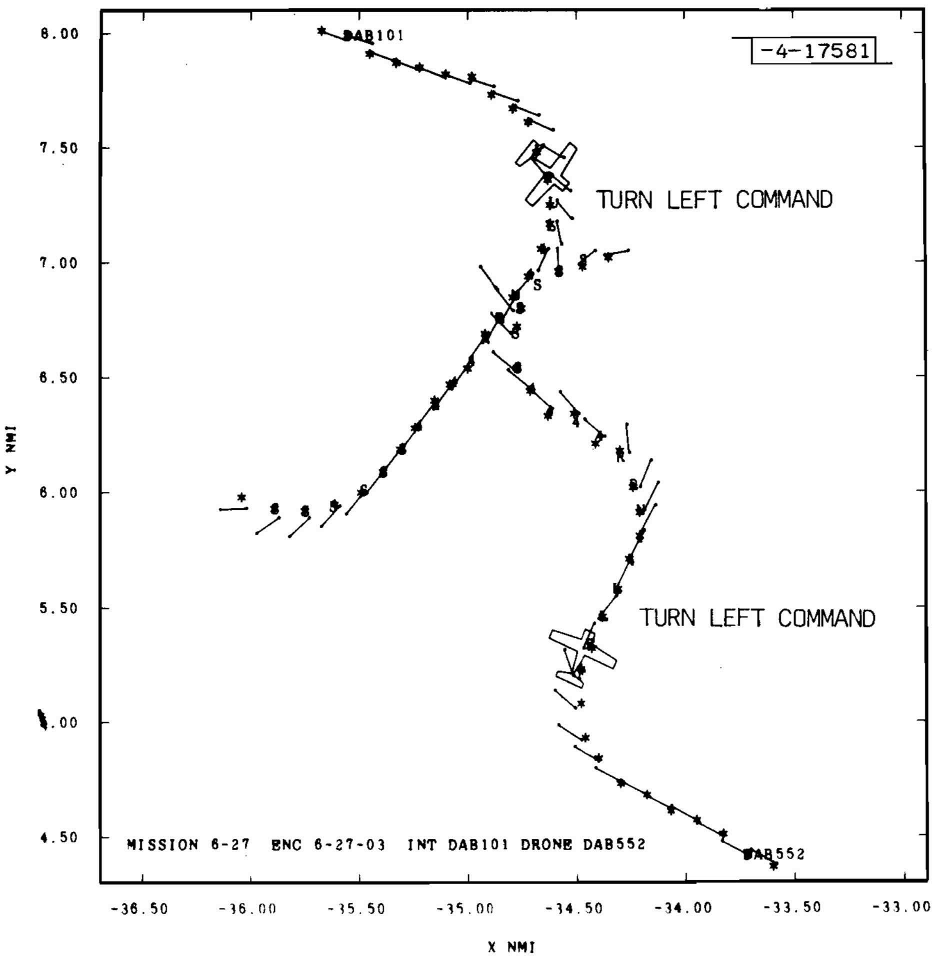
Fig. A.6-3. A case of detrimental turn commands (encounter 5-07-08).



AC1 TRACK = 1 ID = DAB552
AC2 TRACK = 3 ID = DAB101

SCAN	AC1	AC2	POS	TH	RANGE	MD	TV	RZ	VZ	VMD	DOT	TCMD
477	S	S	0	42.59	2.15	4174.04	-1171.5	-99.24	-0.08	99.24	-366.23	32.
478	F	F	0	36.97	1.95	3128.14	-1006.7	-99.78	-0.10	99.78	-339.98	32.
479	F	F	-2	26.77	1.68	1255.77	-1082.0	-100.10	-0.09	100.10	-340.74	32.
480	F	F	1	19.85	1.39	1105.09	-1323.7	-100.25	-0.08	100.25	-297.09	32.
481	R	R	1	14.02	1.15	602.23	-1791.7	-100.30	-0.06	100.30	-262.28	32.
482	R	R	4	8.65	0.89	955.16	-41.3	-146.68	-3.55	146.68	-204.10	32.
483	R	R	4	3.63	0.67	1347.28	-36.4	-179.18	-4.92	179.18	-146.58	32.
484	R	R	4	-6.16	0.40	762.36	-40.4	-199.62	-4.94	199.62	-86.83	32.
485	R	R	4	-34.81	0.13	167.88	-49.6	-210.74	-4.25	210.74	-29.66	32.
486	R		0	0.0	0.17	887.38	0.0	-215.02	0.0	215.02	16.85	32.
487	S	S	0	0.0	0.44	644.07	0.0	-215.18	0.0	215.18	81.09	32.
488	S	S	0	0.0	0.70	1137.46	0.0	-213.08	0.0	213.08	143.51	32.
489	S	S	0	0.0	0.99	1433.46	0.0	-210.07	0.0	210.07	231.53	32.
490	S	S	0	0.0	1.26	782.18	0.0	-207.01	0.0	207.01	305.20	32.
491	S	S	0	0.0	1.50	933.70	0.0	-204.36	0.0	204.36	369.09	32.
492	S	S	0	0.0	1.75	1170.48	0.0	-202.31	0.0	202.31	430.25	32.

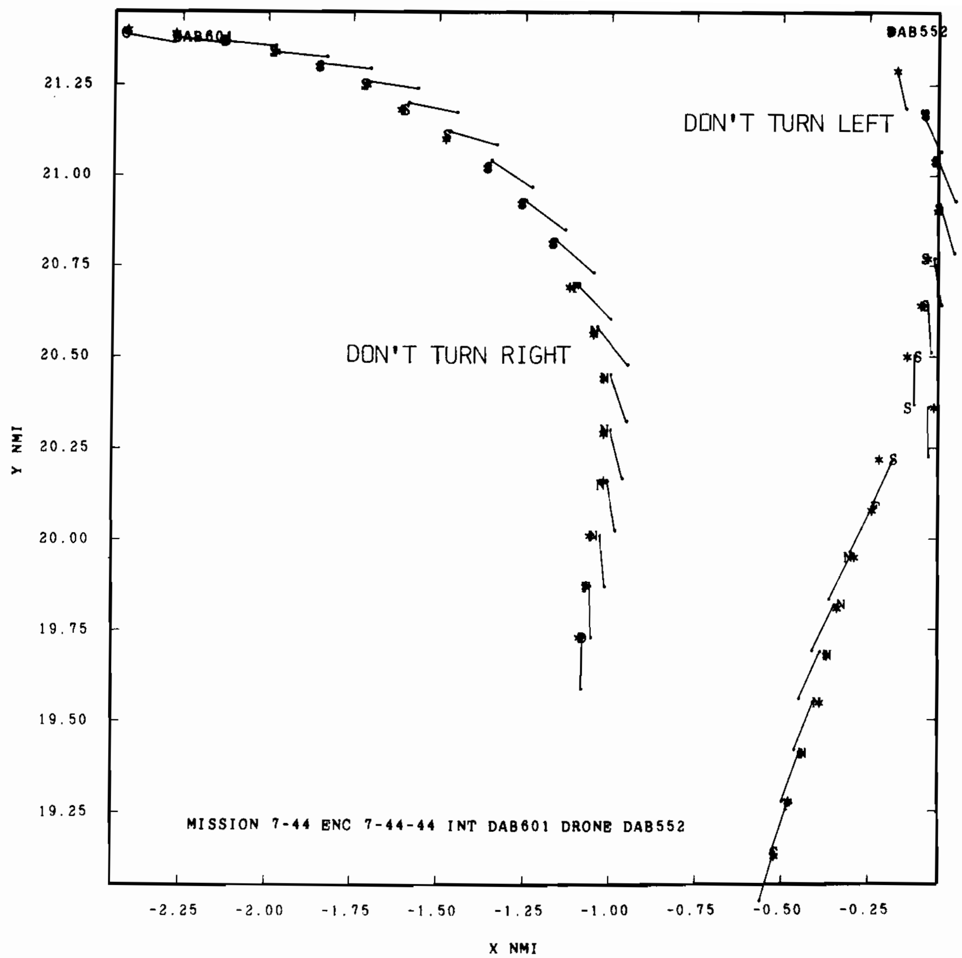
Fig. A.6-4. Another case of detrimental turn commands (encounter 6-27-04).



AC1 TRACK = 1 ID = DAB552
AC2 TRACK = 3 ID = DAB101

SCAN	AC1	AC2	POS	TH	RANGE	MD	TV	RZ	VZ	VMD	DOT	TCMD
343			0	71.95	2.57	12587.33	38.2	-134.04	3.51	0.0	-317.42	64.
344	F	F	-2	50.02	2.31	8068.40	26.3	-110.54	4.20	0.0	-364.38	64.
345	F	F	1	43.51	2.07	1428.44	24.3	-96.45	3.96	0.0	-333.24	64.
346	L	L	1	38.34	1.83	1857.67	27.4	-89.41	3.27	0.0	-289.08	64.
347	L	L	4	27.78	1.62	3383.09	36.0	-87.16	2.42	0.0	-305.05	64.
348	L	L	4	26.95	1.40	5832.49	54.1	-87.80	1.62	0.0	-225.12	64.
349	L	L	0	30.59	1.23	6388.06	93.7	-89.90	0.96	28.50	-144.46	64.
350	NL	NL	1	27.90	1.10	5877.06	-45.5	-138.88	-3.06	138.88	-118.90	64.
351	R	R	1	31.28	0.97	5513.79	-36.5	-173.96	-4.76	173.96	-76.13	64.
352	R	R	4	22.59	0.83	4646.52	-39.4	-196.48	-4.99	196.48	-66.54	64.
353	R	R	4	13.08	0.70	3592.12	-47.5	-209.06	-4.40	209.06	-60.42	64.
354	R	R	4	9.37	0.60	3512.67	-37.4	-260.90	-6.97	260.90	-27.12	64.
355	R	R	4	0.24	0.54	3207.34	-40.1	-294.35	-7.34	294.35	-14.30	64.
356	R	R	0	0.0	0.55	3290.59	0.0	-313.06	0.0	313.06	13.95	64.
357	S	S	0	0.0	0.63	3461.08	0.0	-321.24	0.0	321.24	42.21	64.
358	S	S	0	0.0	0.83	3794.82	0.0	-322.53	0.0	322.53	89.74	64.
359	S	S	0	0.0	1.05	4001.22	0.0	-320.01	0.0	320.01	135.88	64.
360	S	S	0	0.0	1.20	4016.89	0.0	-329.35	0.0	329.35	161.99	64.
361	S	S	0	0.0	1.56	3560.85	0.0	-315.43	0.0	315.43	259.47	64.
362	S	S	0	0.0	1.76	709.15	0.0	-309.27	0.0	309.27	345.24	64.

Fig. A.6-5. A case of detrimental turn commands involving commands to both aircraft (encounter 6-27-03).



AC1 TRACK = 1 ID = DAB601
AC2 TRACK = 3 ID = DAB552

SCAN	AC1	AC2	POS	TH	RANGE	MD	TV	RZ	VZ	VMD	DOT	TCMD
1718	S	S	0	60.21	1.96	7442.93	-35.7	186.12	5.22	186.12	-212.62	32.
1719	S	S	0	83.42	1.89	9163.31	9.8	120.61	-12.29	0.0	-139.37	32.
1720	S	S	0	80.68	1.81	9109.44	1.5	26.84	-17.76	0.0	-131.46	32.
1721	S	S	0	72.00	1.71	8626.49	-1.6	-27.82	-16.90	27.82	-128.96	32.
1722	S	S	0	63.26	1.59	8016.21	-5.8	-99.04	-17.19	99.04	-126.08	32.
1723	S	S	0	56.58	1.47	7362.89	-10.0	-183.18	-18.30	183.18	-117.60	32.
1724	S	S	0	51.08	1.34	6174.43	-14.0	-277.32	-19.80	277.32	-104.39	32.
1725	S	S	0	53.84	1.30	6083.09	-18.7	-330.59	-17.68	330.59	-92.08	32.
1726	S	S	-2	27.78	1.15	4692.79	-22.7	-401.32	-17.66	401.32	-129.46	32.
1727	F	F	0	25.57	1.05	4522.33	-24.8	-491.48	-19.82	491.48	-110.20	32.
1728	NR	NL	0	23.54	0.96	4318.87	-35.9	-492.06	-13.71	492.06	-91.52	32.
1729	NR	NL	0	26.76	0.90	3809.17	-56.5	-478.95	-8.48	478.95	-65.26	32.
1730	NR	NL	0	27.50	0.87	3567.20	-103.2	-460.81	-4.47	460.81	-55.51	32.
1731	NR	NL	0	31.12	0.85	3411.70	-266.5	-442.28	-1.66	442.28	-45.78	32.
1732	NR	NL	0	35.35	0.84	3167.56	5664.4	-426.28	0.08	423.87	-37.17	32.
1733	F	F	0	41.23	0.82	2885.19	-180.1	-460.32	-2.56	460.32	-29.69	32.

-4-17582

Fig. A.6-6. A case in which both aircraft are forbidden to turn away from each other (encounter 7-44-44).

APPENDIX A.7

Subject:	Turn Ahead of Non-Complying Aircraft
Conditions:	Horizontal Commands, Non-Compliance
Algorithm Section:	Command Selection Logic
Original Performance Note:	L7

When one aircraft of a conflicting pair cannot (or does not) comply with IPC commands, resolution is inherently more difficult than when both comply. Flight test results indicate that when a complying DABS aircraft is issued a turn command which turns it ahead of a non-complying DABS or ATCRBS aircraft, resolution is often unsatisfactory. This appendix divides the results of the turn-ahead maneuver into five cases (see Figure A.7-1 and A.7-2) which have been observed in flight tests. Each case is discussed separately and those cases for which resolution was unsatisfactory are identified.

Case 1. Resolution by Delay

In Case 1 (see Figure A.7-1) the complying aircraft is turned parallel to the path of the non-complying intruder well before crossing the intruder's path. The delay induced by the turn allows the intruder to pass ahead and the complying aircraft returns to course passing well behind the intruder. Although the required heading change required of the complying aircraft may be large, resolution is essentially successful.

If the turn ahead command were issued only when Case 1 resolution could be assured, then no further discussion would be necessary. However, variations in the relative speeds of the aircraft or the initial positions can produce results quite different from Case 1.

Case 2. Short Duration Command

In Case 2 (Figure A.7-2) the complying aircraft is near the path crossing point when commands are received. The command arrives too late to prevent path crossing. Because the speed advantage of the intruder is slight, commands are dropped shortly after path crossing and the complying aircraft can return to course without further difficulty. Figure A.7-3 is a plot of an actual IPC encounter in which Case 2 resolution resulted. Here IPC commands do not provide positive benefit and may be considered unnecessary. (Case 2 may be considered as a special case of the more general case discussed in Appendix A.4 of commands issued near closest approach.) Because Case 2 resolution preserves the existing miss distance, it does not appear to compromise safety, although pilots sometimes react unfavorably to such "resolution".

ATC-57(A.7-1)

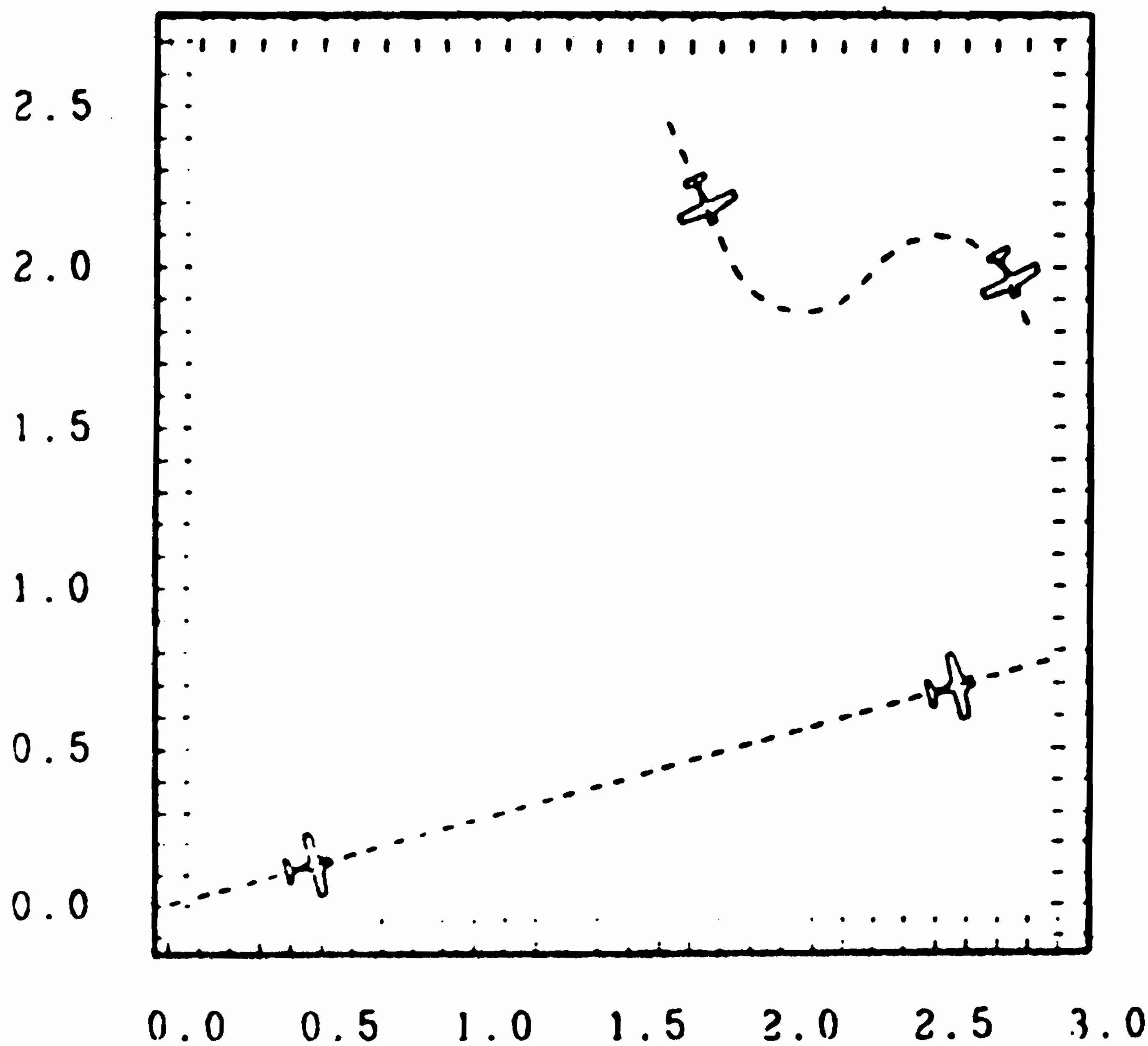
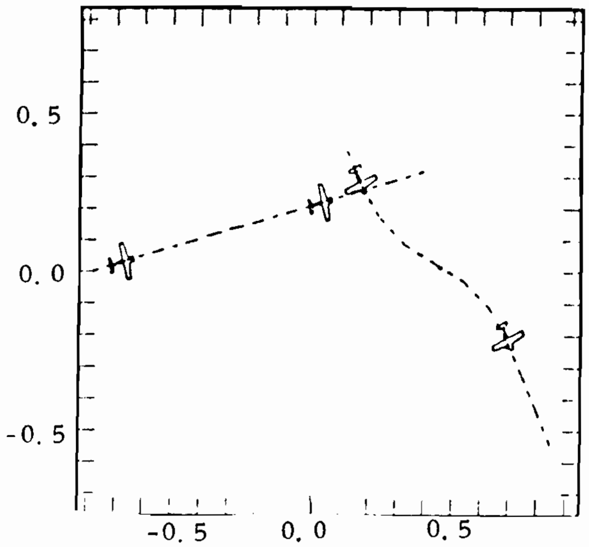
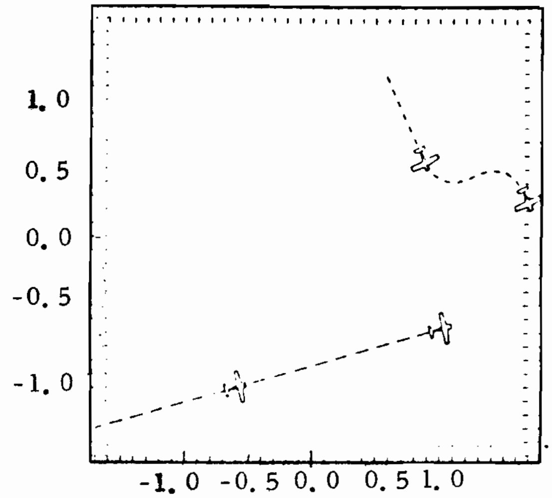


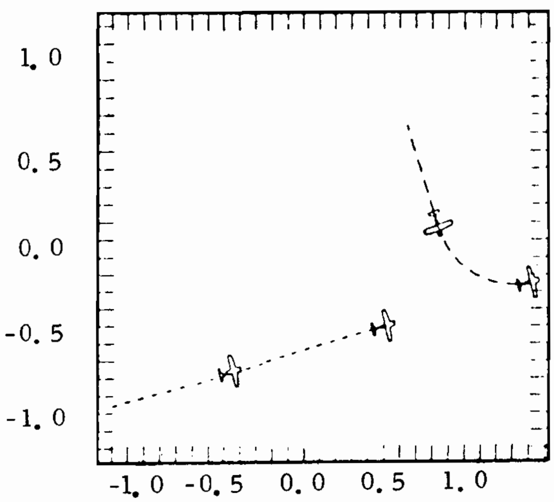
Fig. A.7-1. Turning delay allows faster intruder to pass ahead (Case 1).



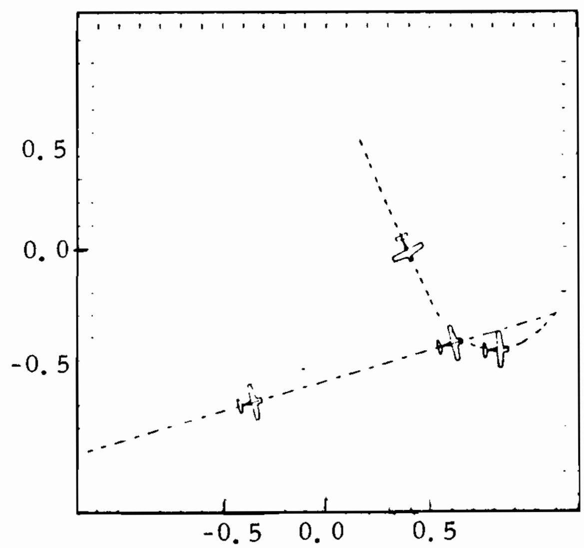
Late turn has little effect. (Case 2)



A second encounter occurs during recover. (Case 3)



A final tail chase geometry results. (Case 4)



More than one path crossing results. (Case 5)

Fig. A.7-2. Cases involving turning ahead of non-complying aircraft.

Case 3. Encounter During Recovery

Case 3 (Figure A.7-2) presents a situation similar to Case 1, but now the geometry and speed difference is such that when the complying aircraft attempts to recover his original heading he encounters the intruder for the second time. Furthermore, the second approach involves a maneuver and the success of IPC resolution is more questionable than for the initial non-turning encounter. Figure A.7-4 is a plot of an IPC encounter in which Case 3 resolution was obtained. Note that when commands were dropped the complying aircraft had an OPWI at the 6 o'clock. Thus, visual acquisition could not be expected to prevent a return-to-course maneuver.

Case 4. Transformation to Tail Chase

In Case 4 (Figure A.7-2) the complying aircraft turns away and commands are dropped leaving the pair in a tail chase geometry. As the intruder overtakes, a second sequence of commands are to be expected. Figure A.7-5 is an actual plot of a Case 4 resolution. The acceptability of this result must be examined with the following points in mind:

a. The pilot was maneuvered from a geometry in which he can see the intruder into a geometry in which he cannot see the overtaking intruder.

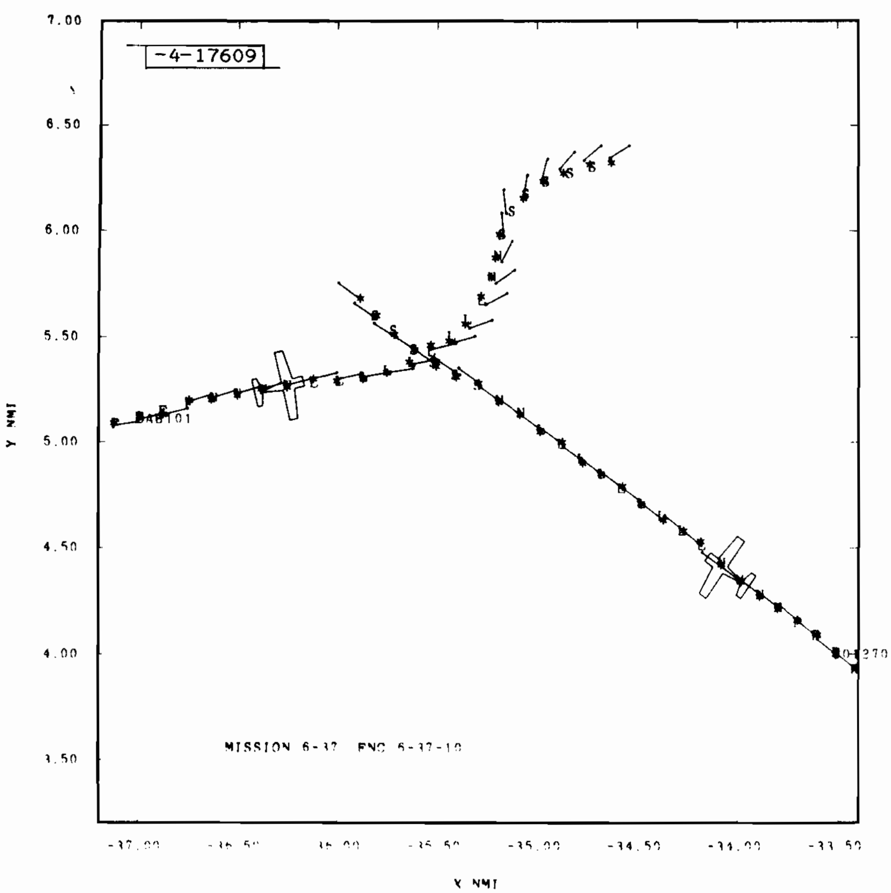
b. The second sequence of commands may reverse a return-to-course maneuver and result in the complying aircraft weaving ineffectively back and forth across the path of the intruder.

c. A course change by the overtaking intruder can readily nullify maneuvers of the DABS aircraft.

No final conclusions concerning the safety implications of Case 4 can be drawn from the current flight test results. However pilot reaction to Case 4 has been definitely negative both for the pilot who was turned and for IFR pilots who observed VFR aircraft being turned into their path.

Case 5. Second Path Crossing

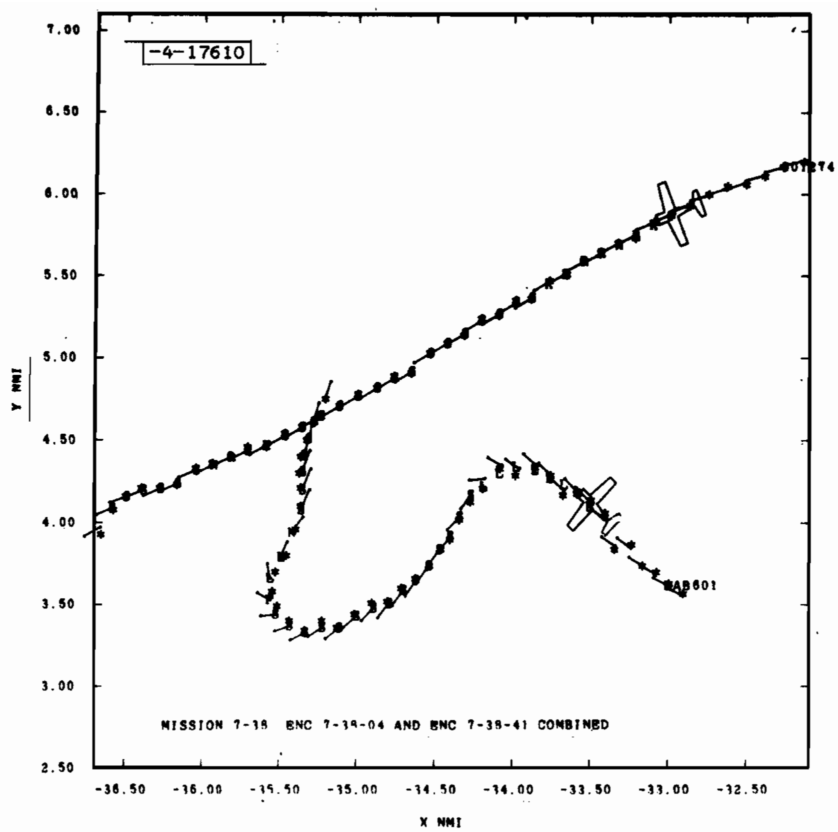
This case (see Figure A.7-2, Case 5) represents the least satisfactory result of all. Here, as in Case 2, commands are too late to prevent an initial path crossing. But unlike Case 2, the closure rate produced by the greater speed of the intruder causes commands to persist after crossing has occurred and the complying aircraft crosses the path of the intruder for a second time. Figure A.7-6 is a plot of an actual encounter for which case 5 results were obtained. Note that the horizontal separation at the first path crossing was adequate, but a collision could have occurred at the second path crossing if the aircraft had been co-altitude. Figure A.7-6 is a plot of a case in which



AC1 TRACK = 1 ID = DAB101
AC2 TRACK = 67 ID = 001270

SCAN	AC1	AC2	POS	TH	RANGE	MD	TV	RZ	VZ	VMD	DOT	TCMD
533	F	F	0	72.03	4.08	562.50	3145.4	-299.06	0.10	292.97	-818.06	64.
534	F	F	0	69.55	3.87	1066.95	6341.3	-299.29	0.05	296.27	-762.79	64.
535	F	F	0	66.09	3.66	2139.27	20528.9	-299.52	0.01	298.59	-713.86	64.
536	F	F	-2	62.00	3.44	2368.96	69.8	-253.31	3.63	20.89	-669.86	64.
537	F	F	0	57.85	3.22	3065.85	43.8	-220.86	5.05	0.0	-626.65	64.
538	NR	NR	0	53.70	3.00	3156.18	39.5	-200.47	5.08	0.0	-584.55	64.
539	NR	NR	0	49.61	2.78	3249.43	43.4	-189.50	4.36	0.0	-542.18	64.
540	NR	NR	0	45.28	2.56	3165.91	55.2	-185.11	3.35	0.0	-500.40	64.
541	NR	NR	1	40.49	2.34	2859.43	79.4	-184.92	2.33	35.88	-459.93	64.
542	L	L	1	35.42	2.10	2380.17	129.5	-186.98	1.44	94.60	-419.72	64.
543	L	L	1	30.80	1.88	2077.65	249.2	-189.96	0.76	141.17	-377.43	64.
544	L	L	1	26.22	1.65	2014.39	669.3	-193.00	0.29	174.54	-332.91	64.
545	L	L	1	21.71	1.42	1952.05	-24982.6	-195.63	-0.01	195.63	-287.39	64.
546	L	L	1	17.71	1.21	2046.08	-1191.5	-197.68	-0.17	197.68	-241.09	64.
547	L	L	1	14.61	1.03	2552.43	-877.7	-199.11	-0.23	199.11	-193.07	64.
548	L	L	1	11.46	0.87	2711.53	-882.2	-200.00	-0.23	200.00	-148.34	64.
549	L	L	1	8.49	0.73	2869.20	44.7	-154.08	3.45	0.0	-106.59	64.
550	L	L	0	9.36	0.66	3459.45	24.7	-121.68	4.92	0.0	-63.53	64.
551	NR	NR	0	17.89	0.64	3768.12	20.2	-101.19	5.00	0.0	-27.41	64.
552	NR	NR	0	0.0	0.66	3946.34	0.0	-90.02	0.0	90.02	16.70	64.
553	S	S	0	0.0	0.70	3569.04	0.0	-131.89	0.0	131.89	34.20	64.
554	S	S	0	0.0	0.80	3547.54	0.0	-99.92	0.0	99.92	49.32	64.
555	S	S	0	0.0	0.90	3528.17	0.0	-98.26	0.0	98.26	81.08	64.
556	S	S	0	0.0	1.01	3452.20	0.0	-94.29	0.0	94.29	106.49	64.
557	S	S	0	0.0	1.13	4354.85	0.0	-93.19	0.0	93.19	142.31	64.
558	S	S	0	0.0	1.27	4395.51	0.0	-93.57	0.0	93.57	180.26	64.

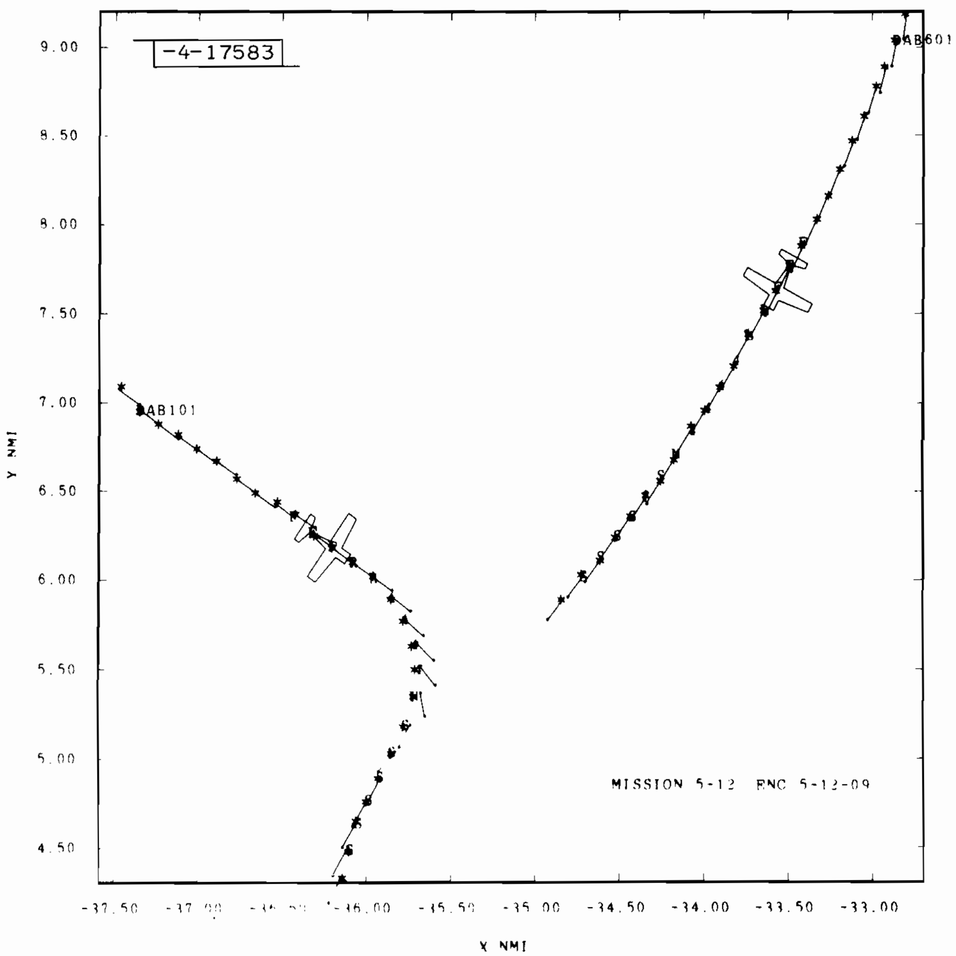
Fig. A.7-3. Case of late arrival of command: Case 2 (encounter 6-37-10).



AC1 TRACK = 1 ID = DAB601
AC2 TRACK = 66 ID = 001274

SCAN	AC1	AC2	POS	TH	RANGE	MD	TV	RZ	VZ	VMD	DOT	TCMD
582			-2	63.31	2.00	303.60	24.7	121.00	-4.90	0.0	-211.97	64.
583	P	P	1	51.79	1.83	154.70	20.4	100.49	-4.93	0.0	-213.28	64.
584	L	R	1	47.00	1.71	282.12	21.1	89.42	-4.24	0.0	-203.70	64.
585	L	R	1	44.45	1.61	349.42	26.1	85.06	-3.25	0.0	-188.21	64.
586	L	R	1	39.69	1.47	448.21	37.5	84.85	-2.26	0.0	-172.85	64.
587	L	R	1	36.36	1.36	683.74	61.9	86.90	-1.40	0.0	-156.23	64.
588	L	R	1	40.19	1.33	950.03	120.9	89.88	-0.74	42.29	-134.95	64.
589	L	R	1	39.96	1.24	1259.33	331.9	92.95	-0.28	75.02	-116.02	64.
590	L	R	0	89.56	1.27	930.30	-9886.1	95.61	0.01	95.61	-54.72	64.
591	S	S	0	0.0	1.27	7685.78	0.0	97.66	0.0	97.66	5.50	64.
592	S	S	0	0.0	1.34	7629.86	0.0	99.11	0.0	99.11	14.59	64.
593	S	S	0	0.0	1.38	6953.33	0.0	100.01	0.0	100.01	30.71	64.
594	S	S	0	0.0	1.41	6622.35	0.0	100.49	0.0	100.49	41.60	64.
595	S	S	0	0.0	1.42	6637.09	0.0	54.28	0.0	54.28	43.13	64.
596	S	S	0	0.0	1.45	6653.45	0.0	21.71	0.0	21.71	44.90	64.
597	S	S	0	0.0	1.45	6811.07	0.0	1.10	0.0	1.10	40.42	64.
598	S	S	0	0.0	1.42	7276.16	0.0	-10.23	0.0	10.23	28.66	64.
599	S	S	0	0.0	1.40	7805.86	0.0	-14.84	0.0	14.84	16.83	64.
600	S	S	0	0.0	1.39	8214.58	0.0	-15.15	0.0	15.15	7.91	64.
601	S	S	0	0.0	1.42	8312.51	0.0	-13.16	0.0	13.16	7.49	64.
602	S	S	0	786.92	1.35	7762.39	-13.5	-10.18	-0.75	10.18	-7.07	64.
603	S	S	0	377.09	1.33	6099.42	-24.7	-7.11	-0.29	7.11	-14.20	64.
604	S	S	0	145.27	1.22	2811.09	1366.9	-4.46	0.0	4.25	-30.41	64.
605	S	S	0	71.90	1.09	1735.36	-11.9	43.98	3.70	43.98	-46.65	64.
606	F	F	-2	26.58	0.93	1884.30	-15.1	78.08	5.16	78.08	-83.74	64.
606			1	26.58	0.93	1884.30	-15.1	78.08	5.16	78.08	-83.74	64.
607	L	R	1	15.37	0.79	3351.89	-19.2	99.56	5.19	99.56	-88.57	64.
608	L	R	0	22.99	0.69	4040.63	-24.9	111.11	4.46	111.11	-34.62	64.
609	NL	NL	0	0.0	0.66	3881.29	0.0	115.72	0.0	115.72	32.25	64.
610	S	S	0	0.0	0.72	3918.40	0.0	115.93	0.0	115.93	66.57	64.
611	S	S	0	0.0	0.81	3698.41	0.0	113.72	0.0	113.72	114.91	64.
612	S	S	0	0.0	0.93	3694.89	0.0	110.57	0.0	110.57	147.98	64.
613	S	S	0	0.0	1.07	3771.74	0.0	107.36	0.0	107.36	173.92	64.
614	S	S	0	0.0	1.23	3751.95	0.0	104.57	0.0	104.57	204.30	64
615	S	S	0	0.0	1.41	[illegible]	0.0	162.42	0.0	162.42	239.05	64.

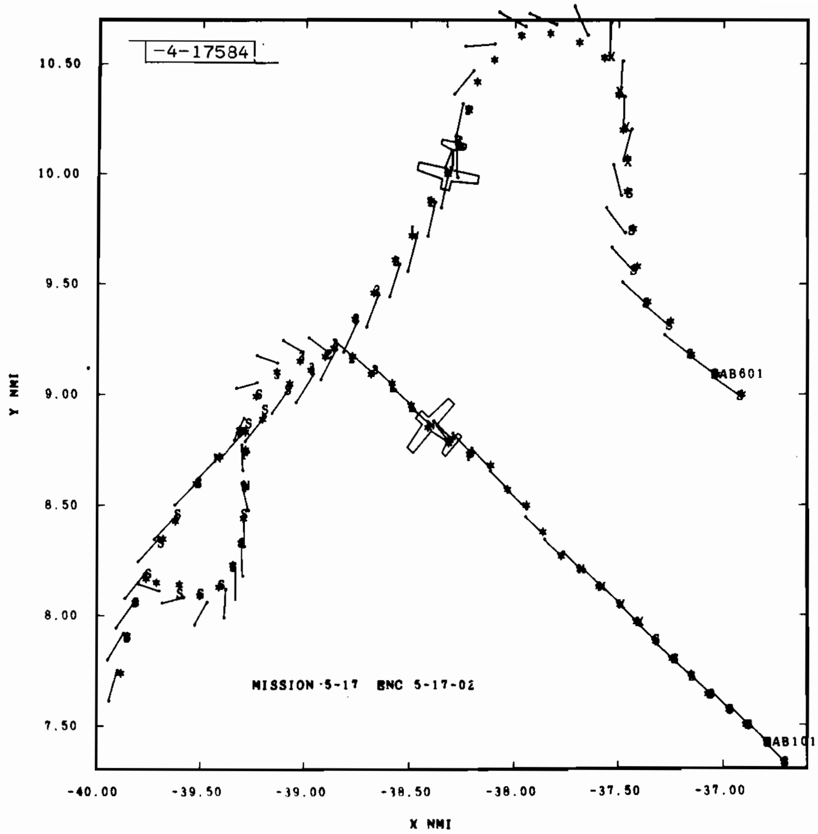
Fig. A.7-4. Case of encountering intruder a second time: Case 3 (encounters 7-38-04 and 7-38-41).



AC1 TRACK = 1 ID = DAB601
AC2 TRACK = 2 ID = DAB101

SCAN	AC1	AC2	POS	TH	RANGE	MD	TV	RZ	VZ	VMD	DOT	TCMD
575			0	72:35	3.58	2325.21	1897.3	-199.29	0.11	192.57	-621.34	64.
576	F	F	0	66.21	3.37	2102.47	3082.5	-199.39	0.06	195.25	-596.71	64.
577	F	F	-2	63.56	3.20	3030.88	5916.0	-199.53	0.03	197.37	-558.14	64.
578	F	F	1	60.02	3.01	3450.02	16411.1	-199.67	0.01	198.89	-520.35	64.
579	L	R	1	56.70	2.82	4123.14	100.0	-199.80	0.0	199.80	-481.60	64.
580	L	R	4	52.62	2.62	4525.65	-24950.7	-199.90	-0.01	199.90	-445.22	64.
581	L	R	4	48.57	2.43	4701.57	-19045.3	-199.96	-0.01	199.96	-409.32	64.
582	L	R	4	47.47	2.28	5277.89	-19563.2	-200.01	-0.01	200.01	-366.69	64.
583	L	R	4	48.36	2.16	5926.43	-23736.4	-200.03	-0.01	200.03	-320.79	64.
584	L	R	0	53.47	2.09	6849.39	-32181.9	-200.04	-0.01	200.04	-270.62	64.
585	NR	NL	0	90.47	2.02	8211.61	-49952.7	-200.04	0.0	200.04	-147.64	64.
586	S	S	0	409.28	2.02	5594.50	-96655.8	-200.03	0.0	200.03	-32.81	64.
587	S	S	0	0.0	2.07	12481.02	0.0	-200.02	0.0	200.02	4.07	64.
588	S	S	0	0.0	2.09	11996.81	0.0	-200.01	0.0	200.01	11.94	64.
589	S	S	0	0.0	2.10	10457.73	0.0	-200.00	0.0	200.00	23.64	64.
590	S	S	0	0.0	2.07	10586.39	0.0	-200.00	0.0	200.00	19.62	64.
591	S	S	0	0.0	2.08	11341.81	0.0	-200.00	0.0	200.00	22.63	64.

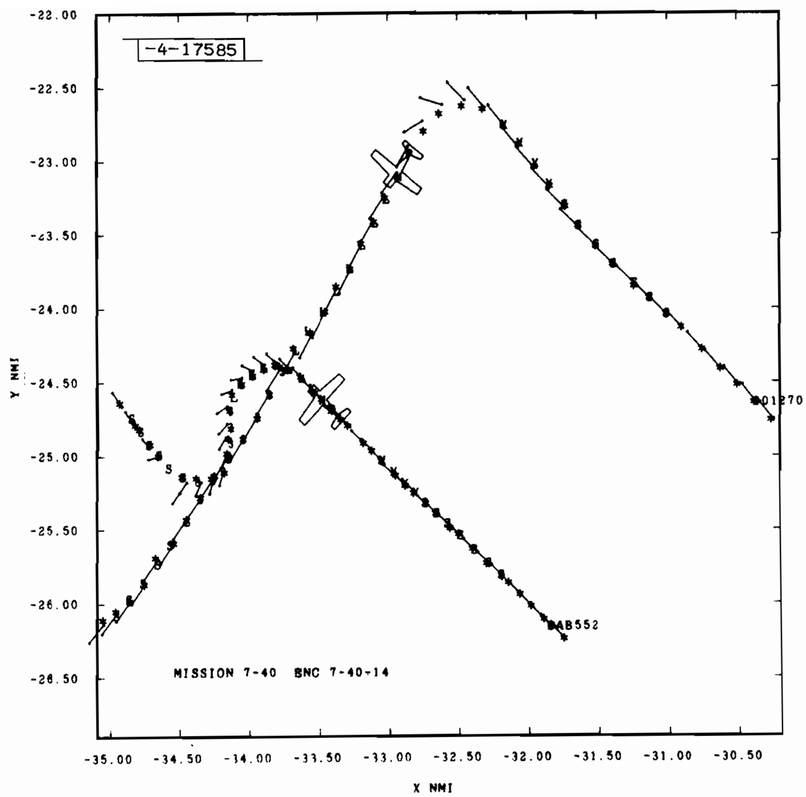
Fig. A.7-5. Case of complying aircraft being turned into a tail chase geometry: Case 4 (encounter 5-12-09).



AC1 TRACK = 1 ID = DAB101
AC2 TRACK = 2 ID = DAB601

SCAN	AC1	AC2	POS	TH'	RANGE	MD	TV	RZ	VZ	VMD	DOT	TCMD
168	S	S	0	0.0	1.64	9923.82	0.0	199.99	0.0	199.99	3.41	32.
169	S	S	0	0.0	1.67	9952.13	0.0	199.99	0.0	199.99	12.83	32.
170	S	S	0	0.0	1.69	9773.48	0.0	200.00	0.0	200.00	18.41	32.
171	S	S	0	0.0	1.71	9532.12	0.0	200.00	0.0	200.00	22.81	32.
172	S	S	0	0.0	1.76	8654.33	0.0	200.00	0.0	200.00	33.95	32.
173	S	S	0	0.0	1.80	7496.61	0.0	200.00	0.0	200.00	41.79	32.
174	S	S	0	0.0	1.86	4878.25	0.0	200.00	0.0	200.00	53.62	32.
175	S	S	0	0.0	1.94	455.41	0.0	200.00	0.0	200.00	70.85	32.
176	S	S	0	0.0	2.02	7819.10	0.0	200.01	0.0	200.01	114.13	32.
177	X	X	0	0.0	2.09	11301.59	0.0	200.01	0.0	200.01	121.17	32.
178	X	X	0	0.0	2.15	9960.33	0.0	200.00	0.0	200.00	145.59	32.
179	X	X	0	0.0	2.23	10022.34	0.0	246.40	0.0	246.40	157.86	32.
185	X	X	0	34.04	1.80	910.42	-229.7	313.07	1.36	313.07	-309.79	32.
186	F	F	-2	24.34	1.58	1949.23	-431.0	310.08	0.72	310.08	-322.58	32.
187	F	F	0	19.05	1.35	3069.69	-1133.0	307.03	0.27	307.03	-282.07	32.
188	NR	NR	1	14.96	1.14	2040.08	36235.8	304.37	-0.01	304.11	-232.89	32.
189	L	L	1	10.23	0.93	1877.61	1927.6	302.32	-0.16	297.31	-185.13	32.
190	L	L	2	3.43	0.68	1457.78	1407.6	300.89	-0.21	294.05	-134.72	32.
191	L D	L C	2	-2.50	0.51	1270.85	1406.0	299.99	-0.21	293.16	-94.34	32.
192	L D	L C	2	-16.05	0.31	969.87	1642.4	299.51	-0.18	293.68	-51.46	32.
193	L D	L C	3	-46.09	0.20	947.77	2146.6	299.32	-0.14	294.86	-21.76	32.
194	L D	L C	3	-1031.33	0.16	972.02	-104.3	345.72	3.32	345.72	-1.00	32.
195	L D	L C	0	0.0	0.17	976.49	0.0	378.39	0.0	378.39	9.34	32.
196	S	S	0	0.0	0.16	963.69	0.0	445.41	0.0	445.41	3.26	32.
197	S	S	-2	-220.20	0.11	145.15	-55.2	489.20	8.87	489.20	-4.73	32.
198	F	F	0	-1086.76	0.05	323.63	-49.3	560.67	11.37	560.67	-1.00	32.
199	NC	ND	0	0.0	0.16	575.63	0.0	604.52	0.0	604.52	16.51	32.
200	S	S	0	0.0	0.28	435.57	0.0	627.49	0.0	627.49	27.35	32.
201	S	S	0	0.0	0.35	147.85	0.0	635.79	0.0	635.79	35.03	32.
202	S	S	0	0.0	0.39	112.25	0.0	635.12	0.0	635.12	36.70	32.
203	S	S	0	0.0	0.39	19.70	0.0	629.66	0.0	629.66	31.04	32.
204	S	S	0	0.0	0.36	995.44	0.0	576.08	0.0	576.08	8.17	32.
205	S	S	0	0.0	0.33	1969.26	0.0	536.39	0.0	536.39	7.16	32.

Fig. A.7-6. Case of complying aircraft crossing path of intruder a second time: Case 5 (encounter 5-17-02).



AC1 TRACK = 2 ID = DAB552
AC2 TRACK = 65 ID = 001270

SCAN	AC1	AC2	POS	TH	RANGE	MD	TV	RZ	VZ	VMD	DOT	TCMD
300			0	0.0	2.13	12650.88	0.0	184.59	0.0	184.59	25.96	64.
301	S	S	0	0.0	2.14	12696.85	0.0	184.19	0.0	184.19	28.35	64.
302	S	S	0	0.0	2.15	12739.59	0.0	186.26	0.0	186.26	27.39	64.
303	S	S	0	0.0	2.14	12772.87	0.0	235.75	0.0	235.75	20.55	64.
304	S	S	0	0.0	2.14	12814.27	0.0	271.54	0.0	271.54	18.40	64.
305	S	S	0	0.0	2.17	12844.70	0.0	294.78	0.0	294.78	24.03	64.
306	S	S	0	0.0	2.19	12821.32	0.0	308.01	0.0	308.01	30.45	64.
307	S	S	0	0.0	2.24	12633.98	0.0	313.97	0.0	313.97	42.23	64.
308	X	X	0	0.0	2.28	12304.02	0.0	315.10	0.0	315.10	55.93	64.
309	X	X	0	0.0	2.34	11886.02	0.0	313.55	0.0	313.55	73.73	64.
310	X	X	0	0.0	2.40	11504.91	0.0	310.77	0.0	310.77	92.53	64.
315	X	X	-2	48.76	2.10	966.59	1327.0	300.20	-0.23	285.72	-301.36	64.
316	F	F	0	33.55	1.87	3087.74	1491.1	299.62	-0.20	286.76	-141.51	64.
317	NR	NR	1	27.49	1.63	1768.05	1889.5	299.37	-0.16	289.23	-302.47	64.
318	L	L	1	21.79	1.42	1951.96	2653.8	299.32	-0.11	292.11	-274.17	64.
319	L	L	1	16.06	1.19	2415.52	4159.2	299.40	-0.07	294.79	-232.79	64.
320	L	L	1	11.76	0.99	2719.50	7506.8	299.52	-0.04	296.97	-187.74	64.
321	L	L	1	8.07	0.83	3023.20	17774.2	299.66	-0.02	298.58	-140.32	64.
322	L	L	1	5.76	0.73	2990.55	100.0	299.78	0.0	299.65	-106.37	64.
323	L	L	1	2.98	0.64	3026.31	-49723.6	299.88	0.01	299.88	-74.15	64.
324	L	L	1	-0.03	0.59	2946.31	-31923.2	299.95	0.01	299.95	-43.97	64.
325	L	L	3	-6.32	0.53	2599.83	-30117.8	299.99	0.01	299.99	-34.41	64.
326	R	L	3	-14.67	0.46	1924.74	-33977.7	300.02	0.01	300.02	-29.97	64.
327	R	L	3	-29.32	0.37	1263.17	70.9	253.62	-3.58	24.81	-23.91	64.
328	R	L	3	-53.31	0.27	745.42	44.2	221.13	-5.01	0.0	-17.67	64.
329	R	L	3	-89.37	0.17	133.17	17.8	154.22	-8.66	0.0	-12.41	64.
330	R	L	3	-177.31	0.11	386.55	11.8	110.46	-9.36	0.0	-6.64	64.
331	R	L	3	-847.33	0.03	138.21	10.2	85.60	-8.39	0.0	-1.43	64.
332	R	L	0	0.0	0.09	421.43	0.0	120.84	0.0	120.84	4.28	64.
333	S	S	0	0.0	0.24	866.89	0.0	151.11	0.0	151.11	15.08	64.
334	S	S	0	0.0	0.33	920.30	0.0	152.19	0.0	152.19	23.09	64.
334			0	0.0	0.33	920.30	0.0	152.19	0.0	152.19	23.09	64
335	S	S	0	0.0	0.70	929.43	0.0	241.30	0.0	241.30	75.50	64.
336	S	S	0	0.0	[illegible]	949.93	0.0	281.99	0.0	281.99	166.78	64.
336			0	0.0	0.92	949.93	0.0	281.99	0.0	281.99	166.78	64.
337	S	S	0	0.0	1.14	1285.66	0.0	398.30	0.0	398.30	237.64	64.
337			0	0.0	1.14	1285.66	0.0	398.30	0.0	398.30	237.64	64.
338	S	S	0	0.0	1.30	576.57	0.0	614.48	0.0	614.48	256.38	64.

Fig. A.7-7. Case of ATCRBS aircraft 'receiving' effective command and DABS aircraft receiving ineffective command (encounter 7-40-14).

the turn command was reversed shortly before the second path crossing. This can result in the complying aircraft turning back and crossing the path of the overtaking intruder for a third time.

Case 5 resolution has been observed at least five times during IPC flight tests. It has occurred at crossing angles of 56 to 103 degrees and under VFR/VFR and IFR/VFR flight rules.

Possible Remedies:

One source of these problems lies in the fact that the algorithm is designed to always issue commands of the same type to each aircraft of a pair; i.e., both receive positive or both receive negative, both receive vertical or both receive horizontal. In the geometry depicted in Figure A.7-7 in which one aircraft is crossing the path of the other, any turn by the crossing aircraft (DAB552) is harmful. However a left turn by the other aircraft would be effective. In such situations, IPC should recognize the counterproductive nature of issuing turns to both aircraft. In this case, the crossing aircraft should either be told "go straight" or given a vertical command.

Another important point which has received discussion before (see Section 2.5.1 and Appendices A.1 and A.7) is that commands which are effective when both aircraft respond may be ineffective when only one responds. The current algorithm uses the same turn command direction choice logic for ATCRBS/DABS as is used for DABS/DABS encounters. In Figure A.7-7, the effective turn command is "issued" to the ATCRBS aircraft and the DABS aircraft receives the ineffective turn.

Whenever possible the IPC algorithm should issue commands which are effective even if only one aircraft responds. Certainly when it is known beforehand that one will not receive the command (ATCRBS vs DABS) or that the command to one will be delayed (IFR vs VFR), then the command which is most effective for the commanded aircraft should be chosen.

APPENDIX A.8

Subject:	Turn Detection Failure
Conditions:	High Rate Turn, Long Range
Algorithm Section:	Tracking
Original Performance Note:	L8

Description:

During the validation phase of IPC flight testing, pilots were instructed to turn with a bank angle of 25 degrees, thus producing a nominal turn rate of 5^{o}/second for a 100 knot airspeed. However, in several encounters pilots turned at higher rates and it was found that the IPC tracker was incapable of satisfactorily estimating the speed and heading during the turn. In encounter 6-21-17 (Figure A.8-1) the drone aircraft responded to the left turn command with a 9^{o}/second turn (approximately 30^{o} bank at airspeed 70 knots). Figure A.8-2 indicates that the groundspeed estimate dropped to 24 knots, one-third the actual value. The true decrease in airspeed from 110 knots to around 70 knots was due primarily to the fact that DAB101 was responding to a climb command as well as a turn command. Figure A.8-3 indicates that the heading estimate was in error by about 120^{o} for several scans. The turn detection logic failed to declare the turn until approximately eight scans after turn initiation. Similar tracker behavior was observed in Encounter 6-21-15 (see Figure A.8-4).

Although the tracking errors did not produce adverse results in the two examples employed here, one can show that the same maneuvers executed in other IPC encounters could lead to resolution failure. Some concern exists in regard to the use of subject pilots. The "Pilots Guide to Intermittent Positive Control" [3] asks pilots to use "deliberate and positive, but not violent, maneuvers" and to bank at "an angle no less than 20 degrees." The maneuvers depicted here seem to be consistent with these instructions and thus may be encountered during subject pilot flights.

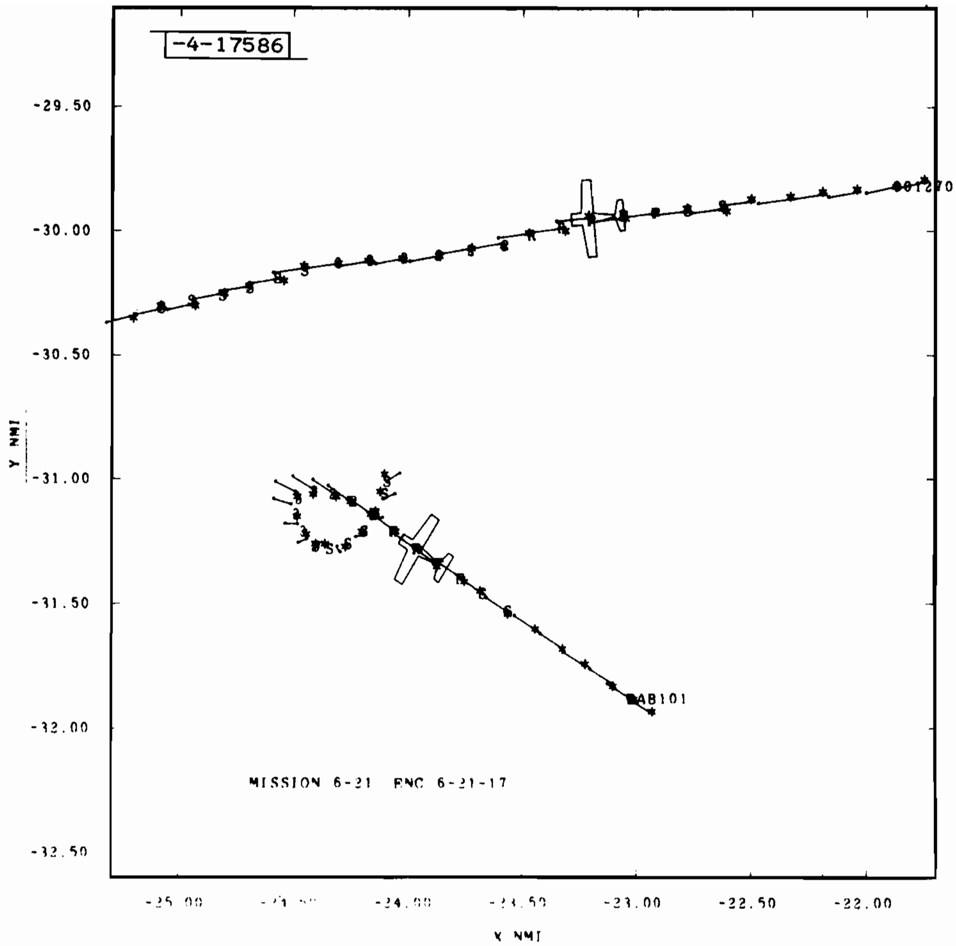
The source of this problem has been related to basic properties of the IPC tracking algorithms. The IPC tracking algorithm for the horizontal plane is basically a low-gain α-β tracker with a turn detection and correction mechanism. The low value of β (0.1) provides heavy smoothing and thus good velocity estimation when aircraft are flying straight. When turns occur, the tracker relies upon the turn detection mechanism to prevent excessive tracker lag. In the cases in question, turn detection failed to function properly and as a result large tracking errors accumulated. The principal reason for the turn detection failure is that the turn detection threshold, D2TH, is so large that turn detection is essentially inoperative during the first few scans of the turn. Thus the very firm α-β parameters employed in calculating the internal velocity estimates prevent the tracker from following the turn. When the aircraft heading is in error by more than 90° the straightforward α-β update tends to severely underestimate speed. In addition the cross-track deviation D2, used for turn detection begins to work in the wrong way, i.e., the faster the aircraft turns the smaller D2 becomes.

Possible Remedies:

The fact that the two-point estimation in Figure A.8-2 and A.8-3 provides credible estimates indicates that a properly adapted tracker should be capable of following turns such as these. In order to confirm that the problem lies in turn detection performance and was not inherent in the data quality or data rate, the same position reports were processed using a turn detection threshold better suited for the sensor data quality. The resulting tracks are shown in Figure A.8-5. By comparing to Figure A.8-1, note that with reduced thresholds the ability of the tracker to follow the turn was markedly improved. The following remedies would largely eliminate the observed problem:

a. The parameters used in calculating the turn detection threshold, D2TH, can be optimized for DABSEF quality data. A rough calculation indicates that for encounter 6-21-17 D2TH was too large by a factor of 25. The calculation of D2TH should assume azimuth errors of 0.04° and range errors of 30 feet.

b. Even when properly set, D2TH may assume large values for aircraft flying radially at long ranges. If the threshold D2TH is so large that the aircraft can turn through approximately 90° before crossing the threshold, then turn detection is not useful and the concept of a firmness table based only upon correlation success becomes questionable. Consideration should be given to a method for preventing the tracking from being overly firm in situations in which turn detection is ineffective.



AC1 TRACK = 1 ID = DAB101
AC2 TRACK = 67 ID = 001270

SCAN	AC1	AC2	POS	TH	RANGE	MD	TV	RZ	VZ	VMD	DOT	TCMD
835			0	80.31	1.97	134.47	56.9	-184.93	3.25	0.0	-160.37	64.
836	S	S	0	75.08	1.88	888.58	-182.3	-231.19	-1.27	231.19	-153.78	64.
837	S	S	0	70.01	1.78	1111.13	-75.8	-265.90	-3.51	265.90	-146.73	64.
838	F	F	0	65.71	1.69	580.36	-68.9	-289.41	-4.20	289.41	-139.20	64.
839	F	F	-2	63.29	1.61	771.77	-84.8	-297.46	-3.51	297.46	-129.79	64.
840	F	F	1	60.00	1.53	178.08	-85.9	-308.54	-3.59	308.54	-121.03	64.
841	F	R	1	54.26	1.42	753.32	-56.5	-359.16	-6.35	359.16	-114.25	64.
842	L	R	2	48.75	1.33	1003.79	-57.0	-392.04	-6.87	392.04	-107.51	64.
843	L C	R D	2	43.58	1.23	1276.18	-66.6	-410.82	-6.16	410.82	-100.50	64.
844	L C	R D	2	40.58	1.15	615.42	-85.6	-419.33	-4.90	419.33	-92.62	64.
845	L C	R D	3	39.36	1.09	127.58	-66.5	-467.49	-7.03	467.49	-83.29	64.
846	L C	R D	3	41.74	1.05	1117.85	-50.9	-544.39	-10.68	544.39	-72.14	64.
847	L C	R D	3	53.28	1.04	3664.25	-43.8	-640.02	-14.62	640.02	-56.06	64.
848	L C	R D	0	98.89	1.06	5856.05	-47.8	-699.84	-14.64	699.84	-32.11	64.
849	S	S	0	2388.95	1.09	6625.68	-76.0	-685.68	-9.02	685.68	-1.45	64.
849			0	2388.95	1.09	6625.68	-76.0	-685.68	-9.02	685.68	-1.45	64.
850	S	S	0	0.0	1.08	6472.08	0.0	-712.14	0.0	712.14	20.24	64.
851	S	S	0	0.0	1.12	6391.00	0.0	-724.45	0.0	724.45	51.55	64.
852	S	S	0	0.0	1.14	6498.09	0.0	-774.00	0.0	774.00	61.28	64.
853	S	S	0	0.0	1.17	6108.88	0.0	-804.36	0.0	804.36	97.15	64.
854	S	S	0	0.0	1.23	6045.87	0.0	-866.35	0.0	866.35	123.78	64.

Fig. A.8-1. Case 1 of inadequate tracker performance during a turn (encounter 6-21-17).

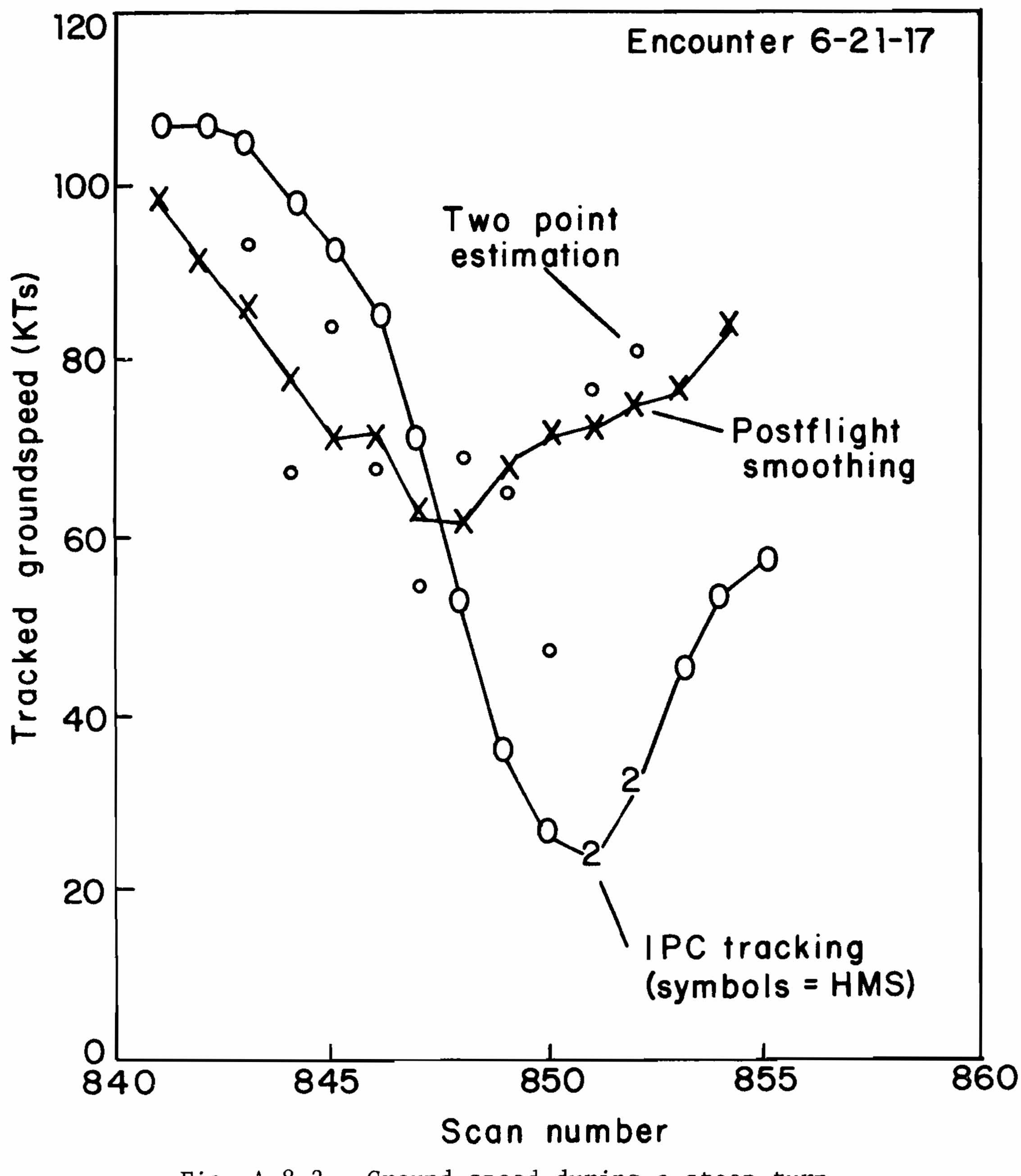


Fig. A.8-2. Ground speed during a steep turn.

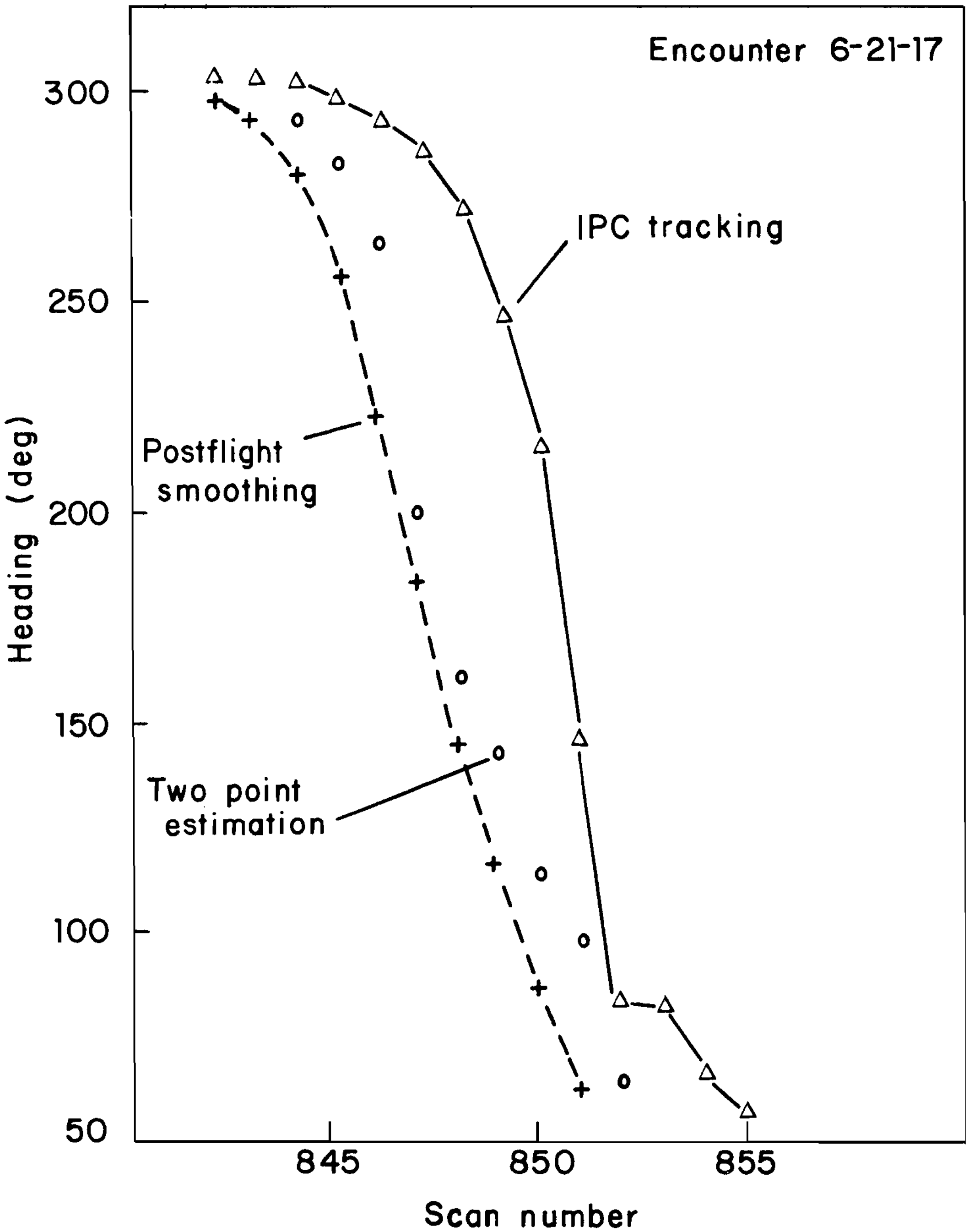
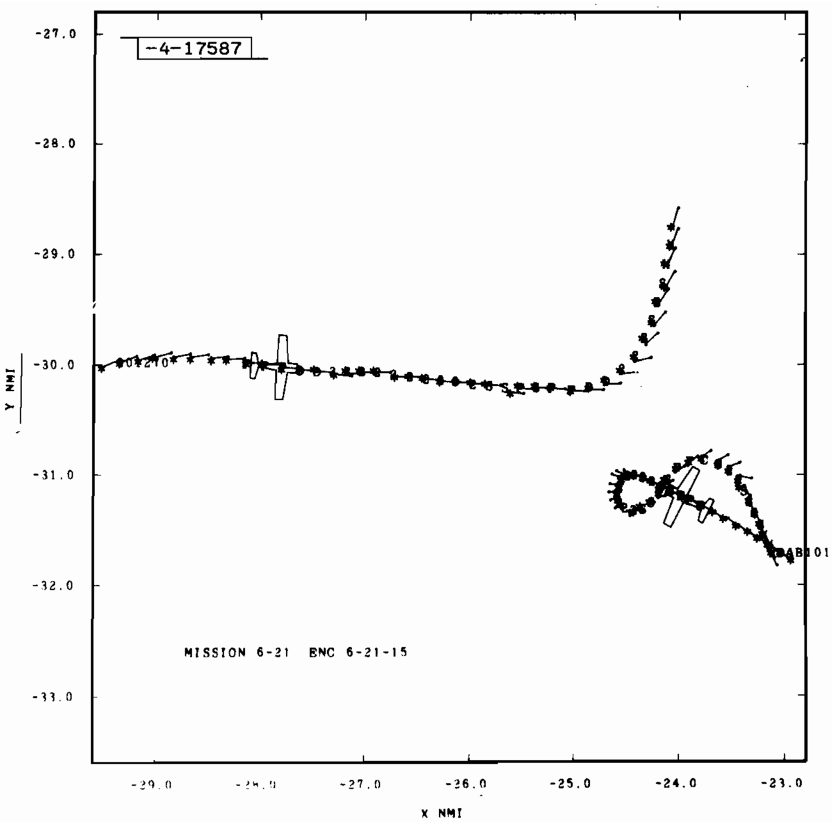


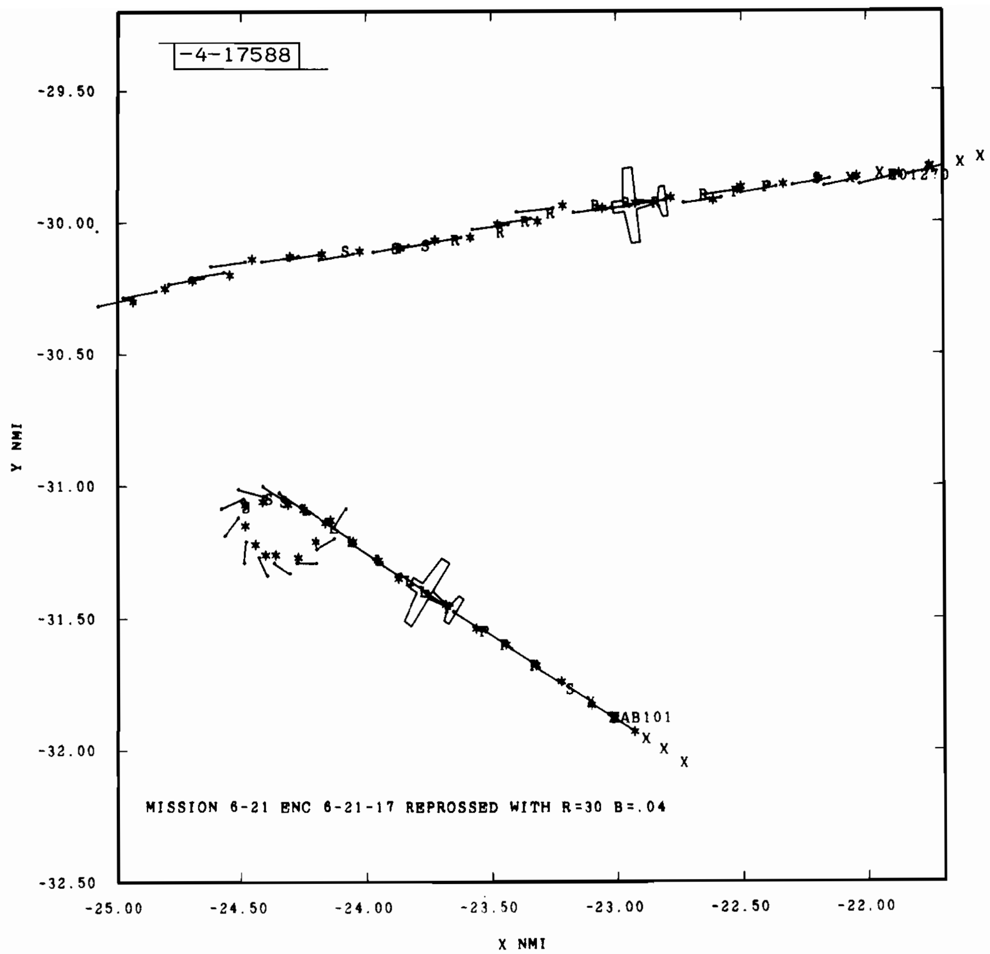
Fig. A.8-3. Headings during a steep turn.



AC1 TRACK = 1 ID = DAB101
AC2 TRACK = 67 ID = 001270

SCAN	AC1	AC2	POS	TH	RANGE	MD	TV	RZ	VZ	VMD	DOT	TCMD
604			0	70.50	4.85	2943.37	-33.1	-212.62	-6.41	212.62	-1185.04	64.
605	F	F	0	64.35	4.55	2191.32	-43.8	-220.82	-5.05	220.82	-1136.58	64.
606	F	F	-2	59.45	4.26	1645.91	-62.0	-222.21	-3.59	222.21	-1076.73	64.
607	F	F	1	56.00	4.00	1490.19	-96.1	-219.77	-2.29	219.77	-1003.49	64.
608	C	D	1	51.79	3.71	1292.78	-171.0	-215.61	-1.26	215.61	-932.02	64.
609	C	D	2	49.37	3.47	1472.42	-399.0	-211.13	-0.53	211.13	-852.11	64.
610	L C	L D	2	45.34	3.19	1305.99	-3408.6	-207.12	-0.06	207.12	-778.84	64.
611	L C	L D	2	44.28	2.98	1785.63	-71.0	-253.77	-3.57	253.77	-697.67	64.
612	L C	L D	2	42.81	2.77	2263.90	-41.1	-328.40	-7.98	328.40	-619.28	64.
613	L C	L D	2	42.17	2.58	3068.67	-40.6	-379.10	-9.33	379.10	-543.41	64.
614	L C	L D	2	39.96	2.36	3647.93	-37.1	-455.56	-12.27	455.56	-476.77	64.
615	L C	L D	2	41.56	2.23	5005.33	-41.7	-503.01	-12.07	503.01	-407.38	64.
616	L C	L D	2	44.44	2.11	6165.93	-41.8	-574.47	-13.75	574.47	-340.76	64.
617	L C	L D	2	47.97	2.00	7066.76	-48.7	-616.46	-12.67	616.46	-280.88	64.
618	L C	L D	2	54.46	1.92	7817.59	-52.6	-669.61	-12.74	669.61	-226.78	64.
619	L C	L D	0	79.72	1.91	8855.09	-62.8	-708.33	-11.27	708.33	-154.67	64.
620	S	S	0	90.68	1.85	7128.70	-83.4	-725.91	-8.71	725.91	-126.44	64.
621	S	S	-2	61.97	1.70	2820.72	-77.4	-779.33	-10.07	779.33	-152.10	64.
622	F	F	-1	75.12	1.66	2723.44	-86.8	-811.00	-9.35	811.00	-119.30	64.
623	S	S	0	64.97	1.53	462.08	-191.0	-779.93	-4.08	779.93	-115.18	64.
624	F	F	-2	56.65	1.42	1576.35	-1103.4	-751.80	-0.68	751.80	-110.68	64.
625	F	F	1	48.12	1.31	2615.19	76.8	-636.46	8.29	106.01	-105.66	64.
626	C	D	1	45.54	1.25	2708.23	71.8	-601.37	8.38	65.12	-97.47	64.
627	C	D	2	58.00	1.28	1745.54	80.7	-582.39	7.22	120.34	-81.38	64.
628	R C	L D	2	89.13	1.33	2006.65	58.2	-528.34	9.08	0.0	-57.91	64.
629	R C	L D	0	0.0	1.44	8587.66	0.0	-495.31	0.0	495.31	17.89	64.
630	S	S	0	0.0	1.59	7602.41	0.0	-478.25	0.0	478.25	181.22	64.
631	S	S	0	0.0	1.82	8243.78	0.0	-472.25	0.0	472.25	269.59	64.
632	S	S	0	0.0	2.10	7337.08	0.0	-473.02	0.0	473.02	392.45	64.
633	S	S	0	0.0	2.33	7097.36	0.0	-477.33	0.0	477.33	481.34	64.
634	X	X	0	0.0	2.60	6868.55	0.0	-482.90	0.0	482.90	578.52	64.
635	X	X	0	0.0	2.86	6572.89	0.0	-441.95	0.0	441.95	663.26	64.

Fig. A.8-4. Case 2 of inadequate tracker performance during a turn (encounter 6-21-15).



AC1 TRACK = 1 ID = DAB101
AC2 TRACK = 67 ID = 001270

SCAN	AC1	AC2	POS	TH	RANGE	MD	TV	RZ	VZ	VMD	DOT	TCMD
829	X	X	0	96.11	2.74	4369.48	1358.2	-300.00	0.22	284.98	-270.09	68.
830	X	X	0	96.42	2.61	4057.68	1583.7	-299.51	0.19	286.65	-242.58	68.
832	X	X	0	101.78	2.53	4715.43	2070.7	-299.32	0.14	289.49	-216.46	68.
833	X	X	0	94.85	2.47	3018.21	2985.6	-299.33	0.10	292.51	-220.06	68.
834	X	X	0	91.88	2.33	2473.17	70.6	-253.02	3.58	9.36	-200.66	68.
835	X	X	0	93.32	2.25	1764.93	44.7	-220.56	4.93	0.0	-184.06	68.
836	X	X	0	84.43	2.19	200.56	40.5	-200.18	4.95	0.0	-190.37	68.
837	X	X	0	80.73	2.05	279.63	44.6	-189.25	4.24	0.0	-173.29	68.
838	X	X	0	79.74	1.96	622.23	56.9	-184.92	3.25	0.0	-160.35	68.
839	S	S	0	71.12	1.90	436.04	-171.6	-231.19	-1.35	231.19	-166.21	68.
840	F	F	-2	66.48	1.76	844.58	-103.7	-273.83	-2.64	273.83	-150.00	68.
841	F	F	1	66.13	1.68	949.93	-91.7	-291.76	-3.18	291.76	-137.24	68.
842	F	R	1	60.64	1.64	365.08	-92.8	-288.04	-3.10	288.04	-139.36	68.
843	F	R	1	56.70	1.50	123.05	-86.5	-310.87	-3.60	310.87	-123.70	68.
844	L	R	1	54.34	1.42	1006.99	-57.5	-360.42	-6.27	360.42	-112.96	68.
845	L	R	1	46.71	1.35	706.21	-50.0	-380.24	-7.60	380.24	-116.23	68.
846	L	R	1	41.05	1.21	726.14	-61.4	-421.24	-6.86	421.24	-101.14	68.
847	L	R	1	41.04	1.14	564.95	-83.3	-426.43	-5.12	426.43	-90.26	68.
848	L	R	1	52.95	1.11	833.30	-60.5	-461.57	-7.63	461.57	-64.59	68.
849	L	R	0	289.19	1.04	6237.04	-47.3	-550.81	-11.64	550.81	-10.00	68.
850	S	S	0	-163.12	1.05	6250.57	-42.4	-645.54	-15.21	645.54	18.82	68.
851	S	S	0	-109.79	1.10	6521.91	-46.1	-700.27	-15.18	700.27	30.74	68.
852	S	S	0	-60.67	1.12	6440.86	-60.5	-689.40	-11.39	689.40	58.96	68.

Fig. A.8-5. Case of improved tracker performance during a turn (encounter 6-21-17).

APPENDIX A.9

Subject: Azimuth Error Near Obstacles
Conditions: Aircraft Near Obstacle Azimuth
Algorithm Section: None
Original
Performance Note: L9

Description:

An irregularity which has been observed to have dramatic impact upon IPC performance when it occurs is azimuth error due to diffraction around obstacles. Two major obstacles exist at DABSEF. The first, an antenna tower, is located at a 120° azimuth removed from the IPC flight test area. The second, the smokestack of the Hanscom Field power plant, is located between the DABSEF antenna and the IPC test area at an azimuth of 295.9° and at a range of about 1500 feet. Several IPC encounters have inadvertently occurred in the vicinity of the smokestack azimuth and resulted in resolution failure. Figure A.9-1 is an X-Y plot of such an encounter. As the encounter begins, aircraft DAB101 is observed to make a hard right turn. However discussion with the pilot and study of the downlinked roll angle confirm that in fact the aircraft was in straight flight during the period of the apparent turn. Figure A.9-2 and A.9-3 are plots of range and azimuth during the period in question. While the range measurements are consistent with a hypothesis of straight line flight, the azimuth data are not. Note also the apparent "S" turns of aircraft DAB601 as it approaches the conflict. Although roll angle data was not available for this aircraft it is apparent that these turns are also due to azimuth error. The severe impact of these azimuth errors upon IPC performance should be noted. Downlinked heading data indicates that DAB101 maintained a more or less constant heading of 110° up to the point at which it began to respond to commands. During this period the pilot observed a flashing PWI light which moved rapidly from one o'clock to nine o'clock. The pilot naturally assumed that the PWI motion was due to the relative motion of the other aircraft, since he knew that he was not turning. The pilot directed his attention to the nine o'clock sector instead of the one o'clock sector which contained the approaching threat. The right turn commands which were finally delivered were not correct - they turned the aircraft into each other.

The phenomena of azimuth error near obstacles has been subjected to both experimental and theoretical study at Lincoln Laboratory and is well understood for an obstacle such as the smokestack.

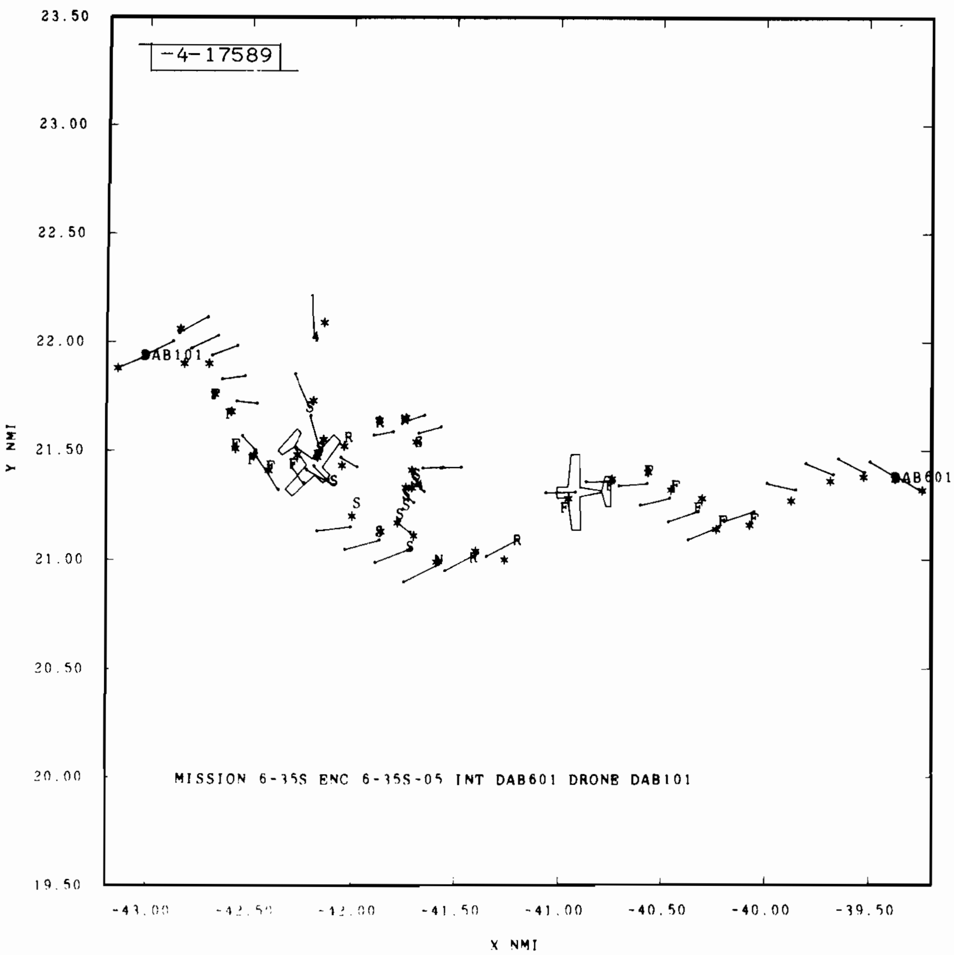
Figure A.9-4 is a plot of the theoretical azimuth error due to the Hanscom smokestack, compared with data from an experimental flight. Note that azimuth errors of up to 0.3 degrees are predicted for aircraft within 3° of the smokestack azimuth. These values are consistent with Figure A.9-3 which indicates errors of about 0.4 degrees at approximately 1 degree from smokestack azimuth. It can also be shown that the period of the apparent "S" turns of DAB601 as it approaches the conflict are the same as the period of the error curve of Figure A.9-4, which results in excellent correspondence between theory and experiment. A complete report of the cause and effects of diffraction in beacon systems can be found in Reference 4.

Possible Remedies:

It must be observed first of all that errors resulting from propagation anomalies of the above type are fundamental limitations of radar systems near the horizon or other obstacles to line of sight. Thus, although some correction for errors from known sources can be envisioned, it should be apparent that diffraction is basically a siting problem. Unfortunately, most terminal ASR's in the larger airports are sited in places which are completely unacceptable from the standpoint of blockage and multipath. Thus, the following recommendations need to be viewed as 'essential requirements':

a. DABS antennas must be sited so as to minimize the effects of diffracting obstacles. Elevation of the antenna may be the only effective solution.

b. IPC software must account for the fact that DABS coverage becomes anomalous near the horizon. Indiscriminate use of data in critical situations may be hazardous. (Use of ground diversity and special zone filters may be necessary.)



AC1 TRACK = 1 ID = DAB601
AC2 TRACK = 2 ID = DAB101

SCAN	AC1	AC2	POS	TH	RANGE	MD	TV	RZ	VZ	VMD	DOT	TCMD
696	S	S	0	44.11	2.91	4640.34	34.1	422.19	-12.37	26.22	-663.64	32.
697	F	F	0	43.71	2.66	7261.71	33.8	384.50	-11.37	20.79	-556.95	32.
698	F	F	0	39.77	2.42	6147.02	39.9	366.65	-9.19	72.70	-503.01	32.
699	F	F	0	39.76	2.24	757.61	54.0	361.79	-6.70	147.36	-429.37	32.
700	F	F	0	36.70	2.04	1717.56	82.8	364.65	-4.41	223.63	-378.25	32.
701	F	F	0	34.46	1.84	3858.83	54.0	324.84	-6.02	132.30	-325.25	32.
702	F	F	-2	27.30	1.57	3045.09	49.9	299.97	-6.01	107.55	-287.08	32.
703	F	F	1	19.16	1.27	1378.65	55.7	286.64	-5.15	121.99	-250.87	32.
704	R	R	1	12.18	0.94	2970.48	31.7	234.97	-7.40	0.0	-166.69	32.
705	R	R	0	10.86	0.75	4192.91	26.8	202.31	-7.55	0.0	-69.89	32.
706	NR	NR	0	0.0	0.68	4097.01	0.0	184.84	0.0	184.84	22.21	32.
707	S	S	0	0.0	0.54	3017.81	0.0	177.84	0.0	177.84	53.53	32.
708	S	S	0	0.0	0.39	1772.50	0.0	177.14	0.0	177.14	62.18	32.
709	S	S	0	0.0	0.52	1390.57	0.0	162.36	0.0	162.36	109.94	32.
710	S	S	0	0.0	0.35	50.04	0.0	179.34	0.0	179.34	70.78	32.
711	S	S	0	0.0	0.48	1846.03	0.0	134.32	0.0	134.32	69.40	32.
712	S	S	0	0.0	0.61	1721.32	0.0	106.91	0.0	106.91	99.99	32.

Fig. A.9-1. Resolution failure due to azimuth error near an obstacle (encounter 6-35S-05).

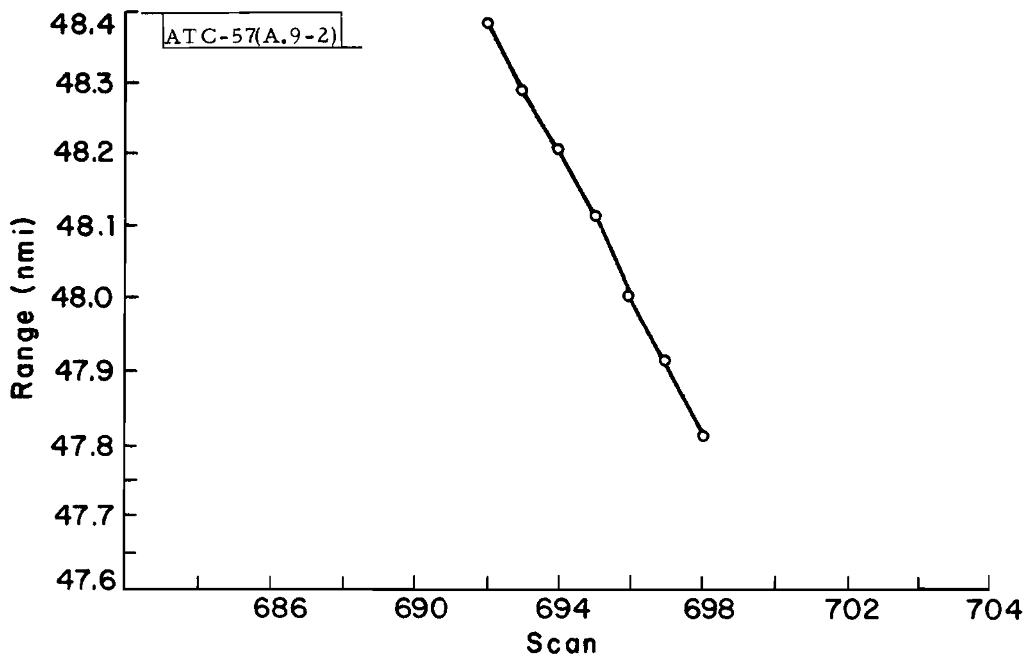


Fig. A.9-2. Range reports for encounter shown in Fig. A.9.1.

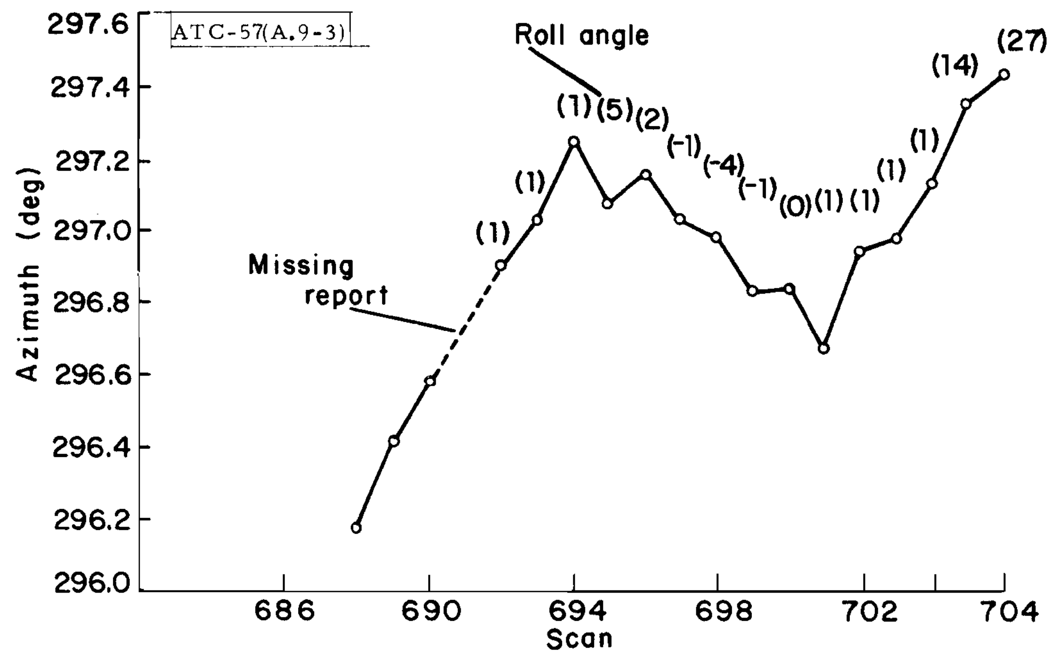


Fig. A.9-3. Azimuth reports and roll angle for encounter shown in Fig. A.9-1.

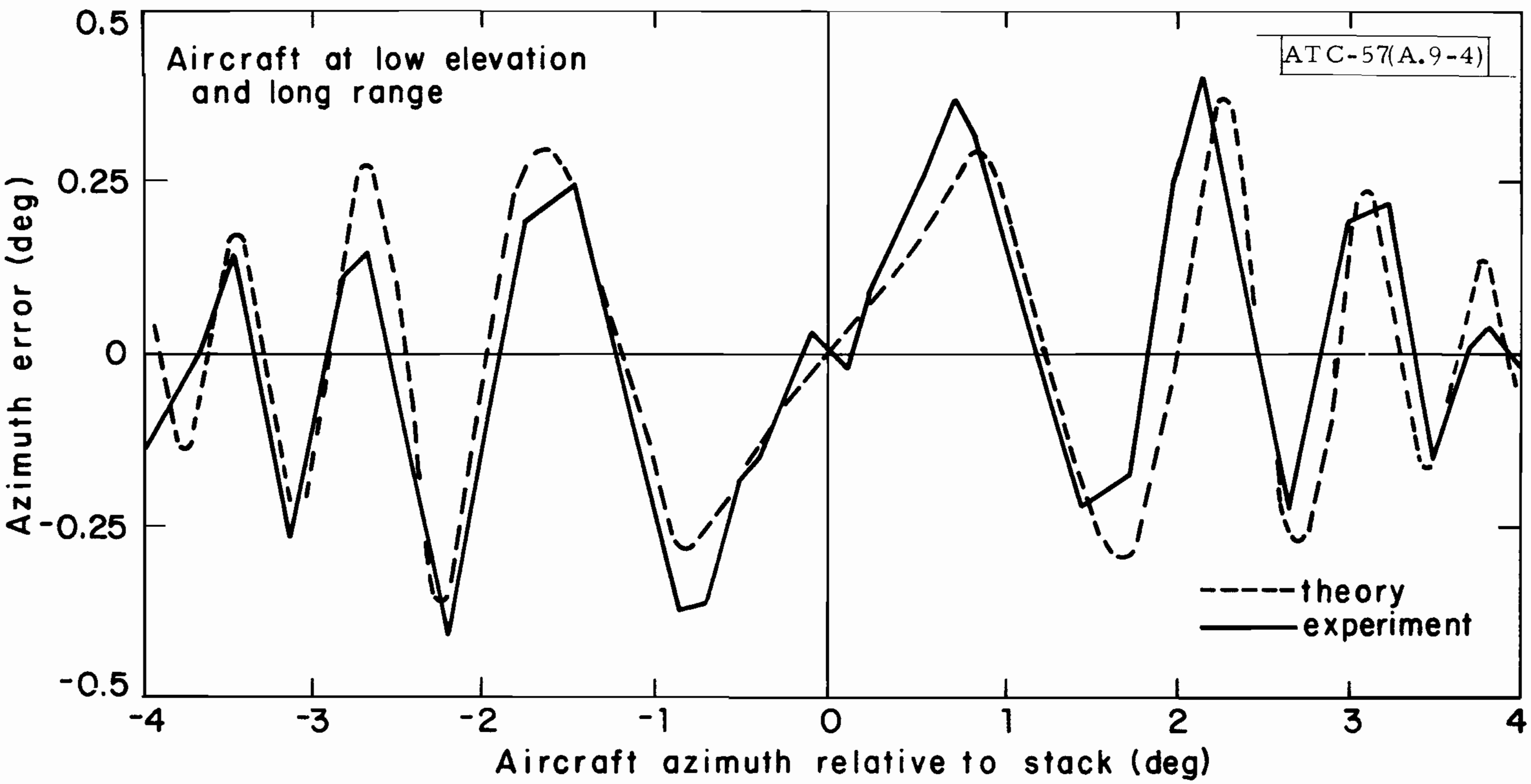


Fig. A.9-4. Monopulse azimuth error caused by Hanscom smokestack.

APPENDIX A.10

Subject: Wrong Commands From Rule A
Conditions: Issuance of Horizontal Commands Near Closest Approach
Algorithm Section: Command Direction Logic
Original Performance Note: L10

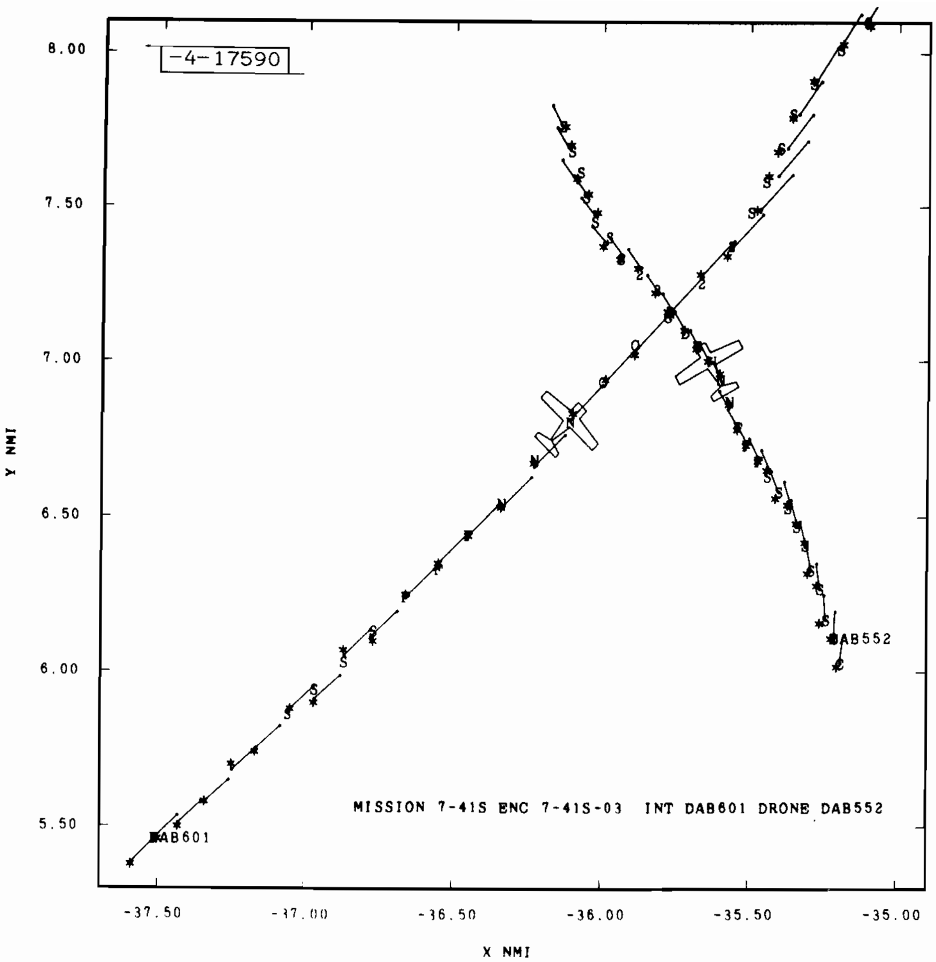
Background and Description:

The IPC command selection logic can apply command selection Rule A in such a way that commands are selected which turn aircraft into each other. Such an event was observed in encounter 7-41-03 (Figure A.10-1). The initial commands in this encounter were negative commands in the vertical dimension -however the aircraft were near the 500-foot altitude separation boundary and a 100-foot change in the reported altitude on one aircraft caused vertical positive commands to be issued. Three scans later the non-responding logic was entered and horizontal commands were computed. On this scan, the estimated separation between the aircraft was 120 feet (see Figure A.10-2) and each aircraft was less than 4 seconds form crossing the path of the other. The IPC commands tended to turn the aircraft back into each other after they had passed. The portion of the IPC logic which selected the commands is shown in Figure A.10-3. Because each aircraft was within a time TIMETX of crossing the path of the other, the algorithm applied Rule A which served to turn each away from the other's current position. By the time commands were delivered, the aircraft had crossed paths, and the commands were in the wrong direction.

Possible Solutions:

When the separation between converging aircraft is small compared to the turn radius, the application of Rule A is likely to be ineffective or counter-productive. When aircraft are within a few seconds of closest approach, response delays alone preclude effectiveness. When "last second" resolution is needed, the best policy is generally to maneuver to increase the miss distance (as opposed to maneuvering to decrease the closure rate). However at very small separations, IPC tracking cannot accurately determine the presence of the small existing miss distance, and IPC may maneuver the aircraft in a way that destroys this distance. A visual evaluation by the pilot is more likely to result in the correct reaction. The pilot can also better take into account the existing turn or climb configurations of the two aircraft. In fact, it can be argued that receipt of commands at such a time are likely to distract the pilot and reduce the chance for "last second" avoidance.

The algorithm could probably be improved by the addition of logic which suppresses the issuance of Rule A commands when aircraft are very near to closest approach horizontally. Alternatively, the logic could use Rule C when both converging aircraft are within TIMETX of track crossing.



AC1 TRACK = 2 ID = DAB552
AC2 TRACK = 3 ID = DAB601

SCAN	AC1	AC2	POS	TH	RANGE	MD	TV	RZ	VZ	VMD	DOT	TCMD
556	X		0	79.88	1.97	4619.45	-97.2	298.76	3.07	298.76	-166.03	32.
557	S	S	0	67.59	1.83	3431.40	-57.6	352.59	6.13	352.59	-167.54	32.
558	S	S	0	61.49	1.73	3525.22	-56.0	387.97	6.92	387.97	-161.92	32.
559	S	S	0	49.34	1.57	1754.77	-64.1	408.20	6.36	408.20	-162.74	32.
560	S	S	0	43.52	1.45	1918.20	-81.1	418.18	5.16	418.18	-154.62	32.
561	F	F	0	34.53	1.28	1025.48	-64.5	467.61	7.25	467.61	-146.72	32.
562	F	F	-2	26.90	1.12	567.02	-68.1	498.85	7.33	498.85	-135.38	32.
563	F	F	0	21.21	0.98	365.46	-81.7	515.52	6.31	515.52	-121.36	32.
564	NC	ND	0	15.66	0.84	463.40	-107.6	521.98	4.85	521.98	-105.37	32.
565	NC	ND	0	9.45	0.70	567.39	-155.2	522.26	3.37	522.26	-88.07	32.
566	NC	ND	1	-0.40	0.51	137.17	299.9	472.66	-1.58	422.22	-68.39	32.
567	D	C	1	-12.71	0.34	87.81	109.1	435.60	-3.99	307.88	-46.97	32.
568	D	C	1	-33.15	0.19	23.05	87.1	410.65	-4.72	259.69	-26.64	32.
569	D	C	2	-463.14	0.02	16.53	89.5	395.60	-4.42	254.10	-2.21	32.
570	R D	L C	2	0.0	0.15	11.95	0.0	434.73	0.0	434.73	22.73	32.
571	R D	L C	0	0.0	0.31	247.85	0.0	511.50	0.0	511.50	44.63	32.
572	S	S	0	0.0	0.48	99.16	0.0	612.27	0.0	612.27	70.97	32.
573	S	S	0	0.0	0.62	22.89	0.0	678.79	0.0	678.79	88.36	32.
574	S	S	0	0.0	0.68	101.98	0.0	717.09	0.0	717.09	88.52	32.
575	S	S	0	0.0	0.76	80.97	0.0	735.79	0.0	735.79	89.22	32.
576	S	S	0	0.0	0.87	91.32	0.0	739.84	0.0	739.84	93.91	32.
577	S	S	0	0.0	0.98	110.99	0.0	735.81	0.0	735.81	100.35	32.

Fig. A.10-1. Case illustrating wrong commands from Rule A (encounter 7-14-03).

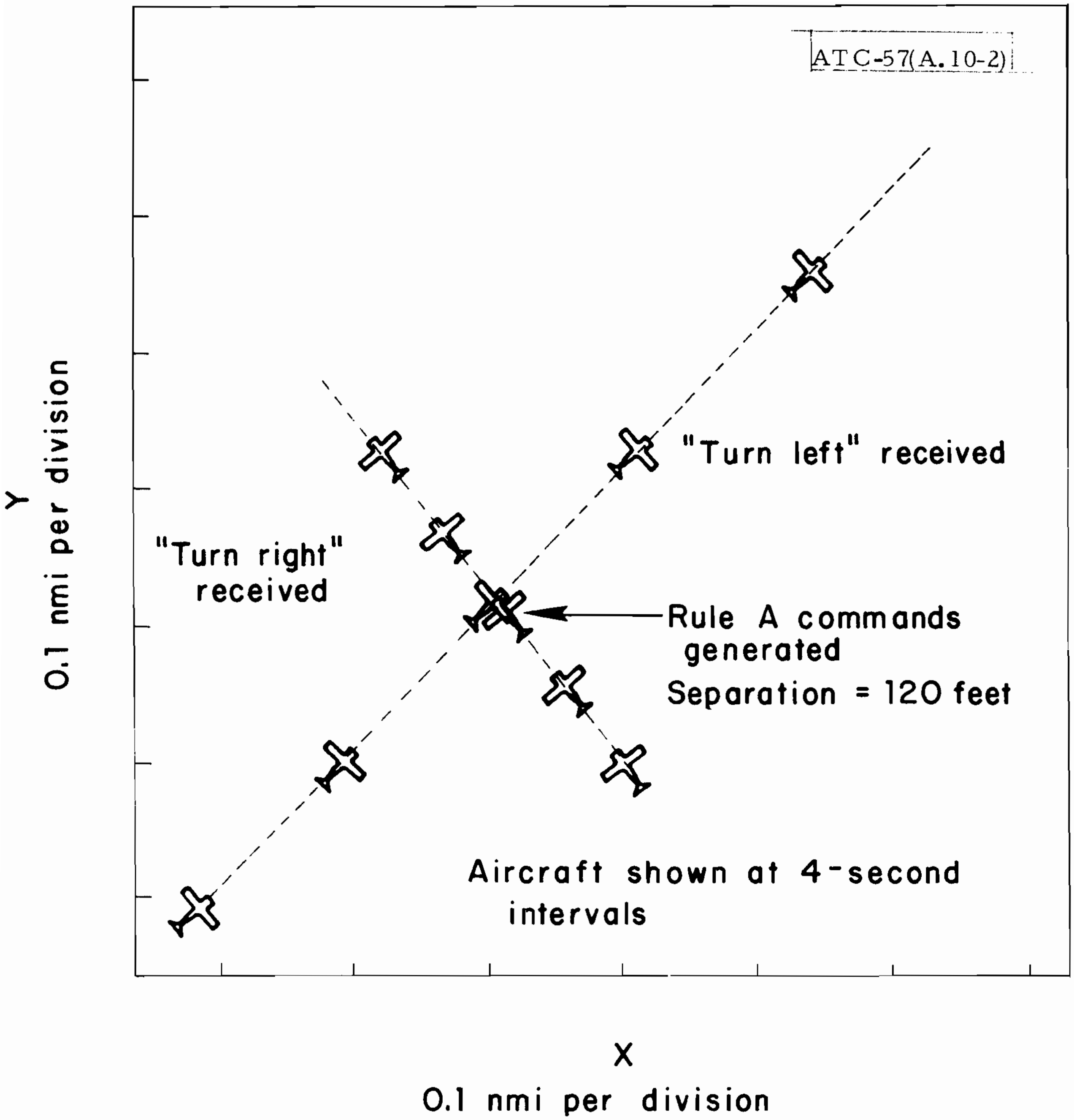


Fig. A.10-2. Expanded view of track crossing in encounter 7-14-03.

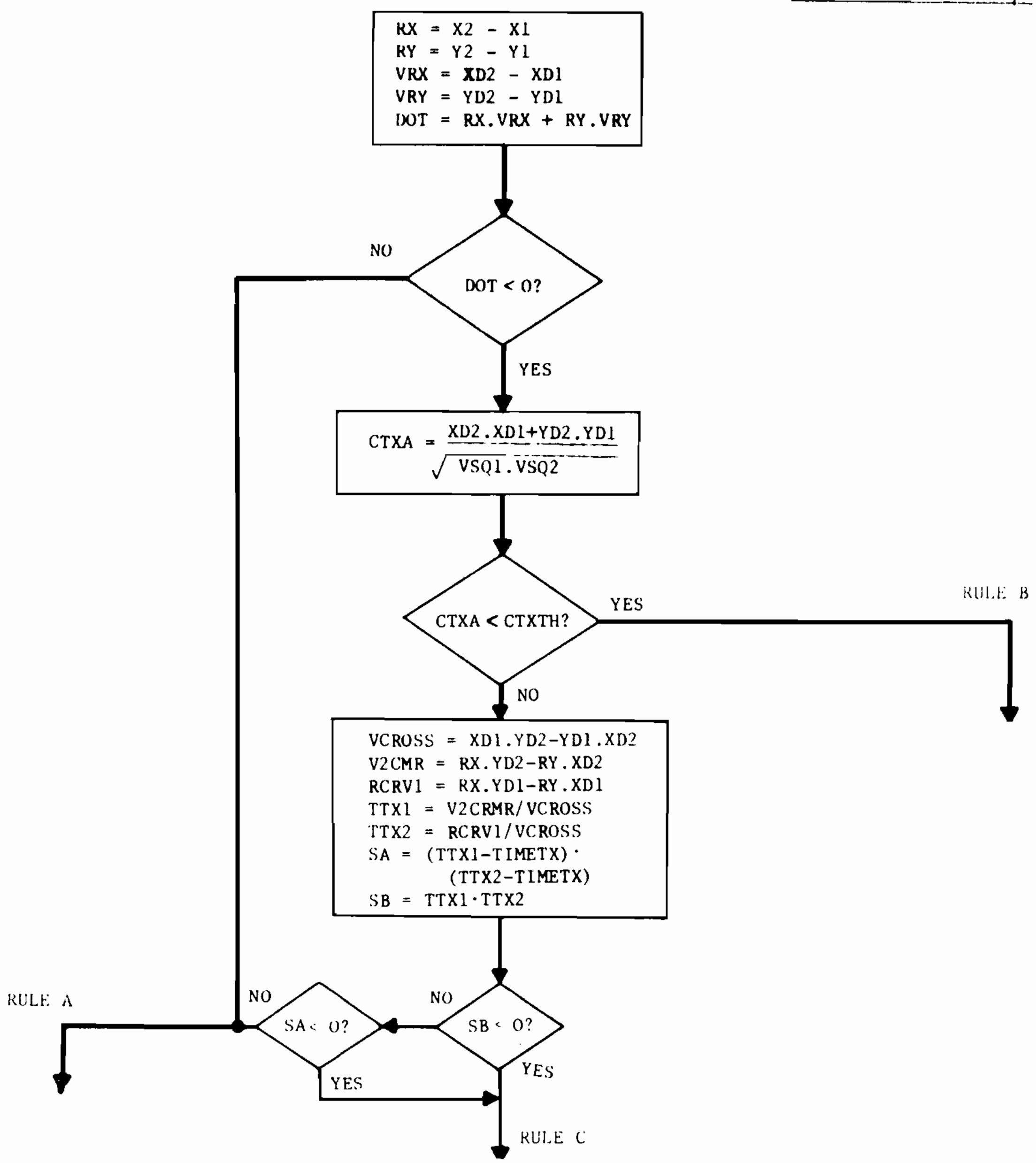


Fig. A.10-3. Command selection rule logic.

APPENDIX B

SUBJECT PILOT FILE SUMMARY

A Pilot History Questionnaire (Figure B-1) was distributed to 120 prospective pilot subjects who participated in earlier proximity warning experiments at the Transportation System Center, Cambridge, Massachusetts. A subject pilot data base has been compiled containing the completed questionnaires plus returns from other prospective pilot subjects. The summary results presented in the Appendix are compiled from 102 completed questionnaires.

A profile of an average subject pilot was derived from this sample of 102 prospective pilot subjects. The average subject is male, 41 years of age with 13 years as an active pilot, and has logged about 2000 hours in the air. He is civilian trained with a commercial and instrument rating and flies for pleasure and business.

The age of prospective subject pilots varies from a minimum of 23 to a maximum of 58 (Figure B-2) with sixty percent of the pilots over forty years of age. The number of active years these pilots have been flying varies from less than a year to over forty years (Figure B-3). The pilot flying less than a year is a student with 24 hours of flight time (Figure B-4) while the pilot with 40 years as an active pilot is an airline captain with over 25,000 flight hours.

ATC-57(B-1)

ID No. ___ ___ ___ (1 2 3)
Occ. ___ ___ ___ (4 5 6)
Do Not Write Here

PILOT HISTORY QUESTIONNAIRE

NAME ______________ ADDRESS ______________

CITY ______________ STATE ______________ DATE: MO. ___ ___ (7 8) YR. ___ ___ (9 10)

TELEPHONE NO. ______________ OCCUPATION ______________ AGE ___ ___ (11 12)

EXPERIENCE

NUMBER OF YEARS AS ACTIVE PILOT: ___ ___ ___ (13 14 15)

RATING: (PLACE CHECK IN THE BLOCK TO RIGHT IF YOUR ANSWER IS YES)

STUDENT ☐ 16 PRIVATE ☐ 17 COMMERCIAL ☐ 18

INSTRUMENT ☐ 19 INSTRUCTOR (CFI ☐ 20 , CFII ☐ 21) ATR ☐ 22

FLIGHT TRAINING:

MILITARY ☐ 23 CIVILIAN ☐ 24 AIRLINE ☐ 25

AIRCRAFT TYPE:

CESSNA ☐ 26 PIPER ☐ 27 BEECH ☐ 28 OTHER ☐ 29

ENGINE TYPES:

SINGLE ENGINE ☐ 30 MULTI-ENGINE ☐ 31

TIME IN HOURS:

SINGLE ENGINE ___ ___ ___ ___ (32 33 34 35) MULTI-ENGINE ___ ___ ___ ___ (36 37 38 39)

CURRENT PILOT EXPERIENCE:

BUSINESS ☐ 40 PLEASURE ☐ 41 MILITARY ☐ 42 COMMERCIAL ☐ 43

FLIGHT TIME:

TOTAL HOURS ___ ___ ___ ___ ___ (44 45 46 47 48) DUAL ___ ___ ___ ___ (49 50 51 52) SOLO ___ ___ ___ ___ (53 54 55 56)

X-COUNTRY ___ ___ ___ ___ (57 58 59 60) INSTRUMENT ___ ___ ___ ___ (61 62 63 64) NIGHT ___ ___ ___ ___ (65 66 67 68)

FLIGHT HOURS DURING LAST 60 DAYS ___ ___ ___ ___ (69 70 71 72)

TIME SINCE LAST X-COUNTRY FLIGHT (DAYS) ___ ___ ___ (73 74 75)

CURRENT FAA MEDICAL ☐ 76

OTHER PERTINENT INFORMATION: ______________

____

____

Fig. B-1. Pilot history questionnaire.

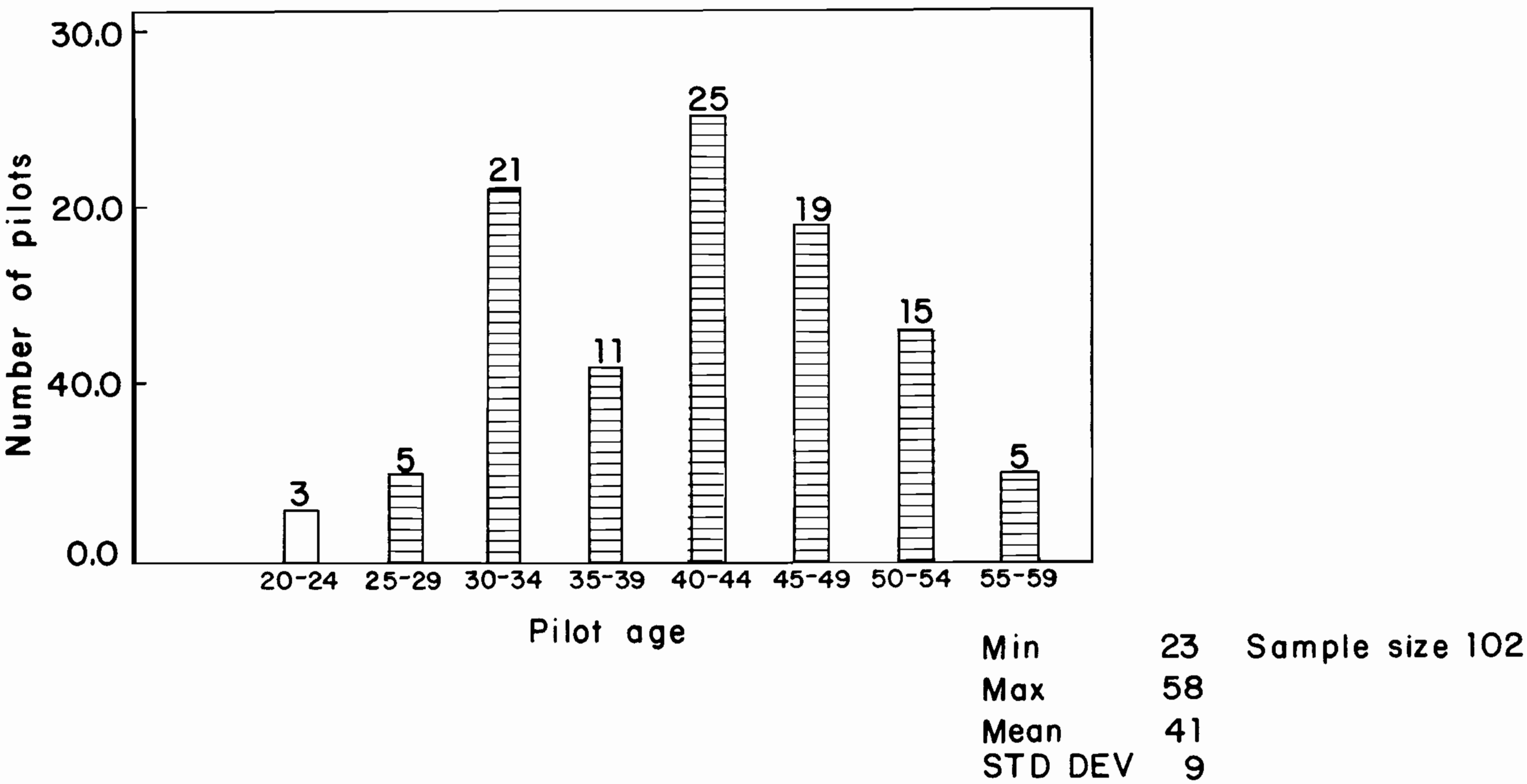
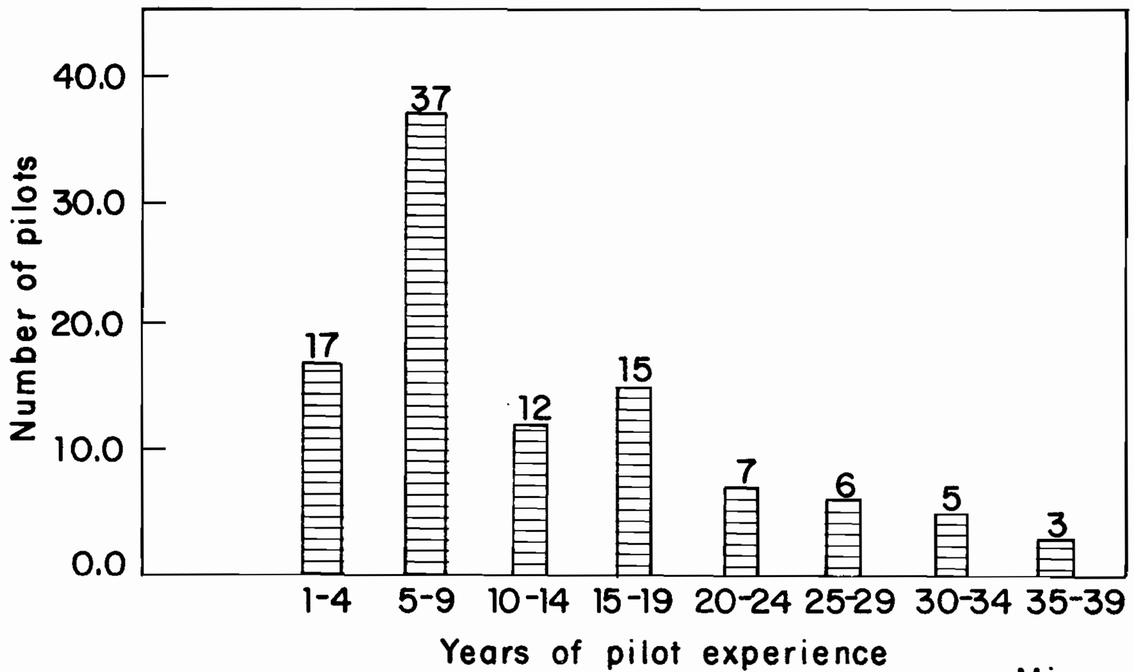


Fig. B-2. Subject pilot age.

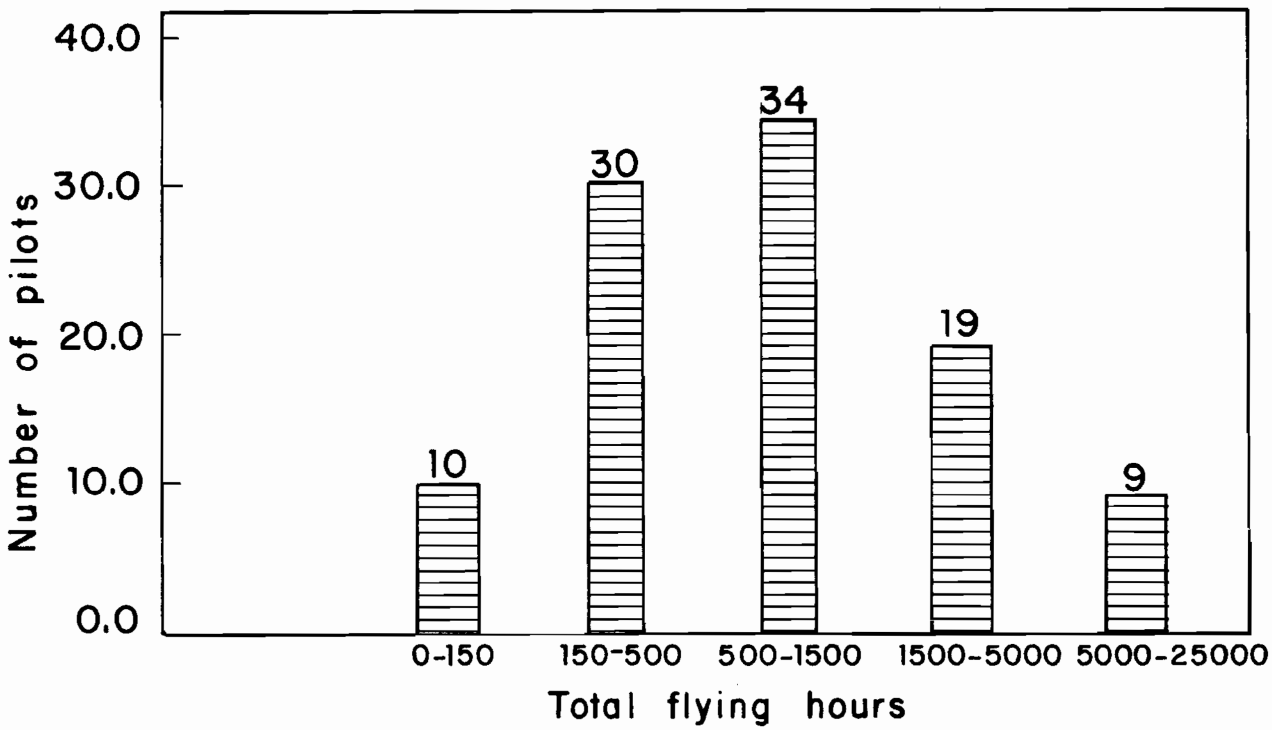
ATC-57(B-3)



Min	1
Max	39
Mean	13
STD DEV	9

Sample size 102

Fig. B-3. Subject pilot experience.



Min	24	Sample size 102
Max	25,000	
Mean	2277	
STD DEV	4555	

Fig. B-4. Subject pilot flying hours.

REFERENCES

[1] Plan For Flight Testing Intermittent Positive Control, Department of Transportation (June 1975), FAA-RD-74-210.

[2] Intermittent Positive Control Computer Algorithms for Test Bed Experiments, Department of Transportation (October 1973), Rev. 1, (April 1975), FAA-EM-74-2.

[3] A Pilot's Guide to Intermittent Positive Control, MITRE Document M75-61.

[4] Spiridon, A., "Impact of Obstacle Shadows on Monopulse Azimuth Estimate," Project Report ATC-50, Lincoln Laboratory, M.I.T. (17 July 1975), FAA-RD-75-91.