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AREA NAVIGATION HIGH ALTITUDE PAYOFF ANALYSIS
ENROUTE FAST TIME SIMULATION RESULTS

RICARDO CASSELL

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FINAL REPORT

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16. Abstract

A series of fast time simulations of high altitude route structures were conducted at Lincoln Laboratory, Massachusetts Institute of Technology, as a part of the FAA Area Navigation Engineering and Development Program Plan. This report presents the results of these simulations and supersedes the Preliminary Fast Time Simulation Results Report dated August, 1974. System/user payoff conclusions are presented based on the results of the simulations and observations by the author. While the limitations of fast time simulation resulting from the lack of controller intervention effects are recognized, the simulation techniques employed provide, as a minimum, a substantial basis for the identification of well marked trends and a sizeable data base upon which a reasonable degree of confidence can be placed.

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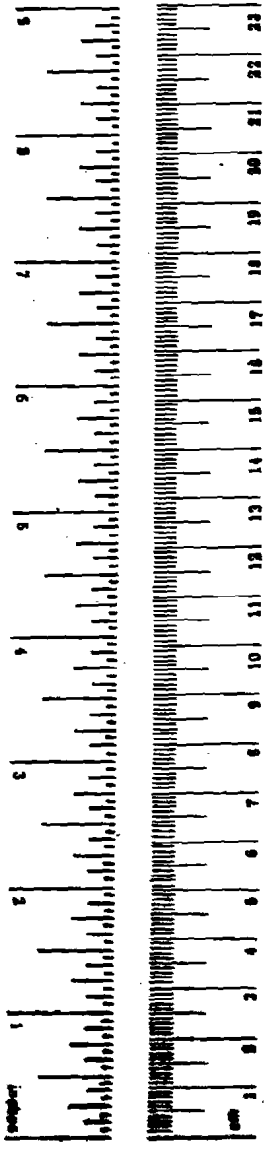
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

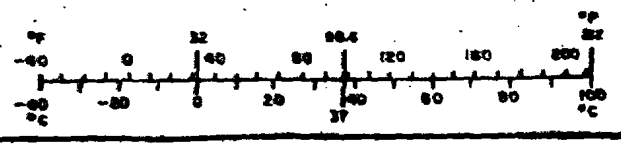
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2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

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



Approximate Conversions from Metric Measures

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



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EXECUTIVE SUMMARY

A series of fast time simulations of high altitude route structures was conducted at Lincoln Laboratory, Massachusetts Institute of Technology as part of the FAA Area Navigation Engineering and Development Program Plan (Ref. 1). This report presents the results of these simulations which were completed in July 1974 and supersedes the Preliminary Fast Time Simulation Results Report dated August 1974 (Ref. 2).

The fast time simulations were conducted in support of the high altitude RNAV route structure study (Ref. 3) conducted by the National Aviation Facilities Experimental Center (NAFEC) which was directed toward evaluation of the route design concepts set forth in the FAA/Industry RNAV Task Force Report, Application of Area Navigation in the National Airspace System (Ref. 4). In addition, information derived from the fast time simulations was used in part to provide quantitative data for user-system payoff analyses (Ref. 5) performed by Systems Control, Inc. The information presented in this report is supplemental to that provided in the NAFEC and Systems Control, Inc., reports (Refs. 3 and 5) and is of potential interest in further examination of the effects of the increased introduction of RNAV operations and routes in the high altitude enroute environment.

Conclusions are presented based on the results of the simulations and observations by the author. While the limitations of fast time simulation resulting from the lack of controller intervention effects are recognized, the simulation techniques employed provide, as a minimum, a substantial basis for the identification of well marked trends and a sizeable data base (which could only be made available through fast time simulation) upon which a reasonable degree of confidence can be placed.

The following major conclusions are based on the results of these simulations:

1 - A well designed charted RNAV high altitude route structure, based on design concepts similar to those used in the final NAFEC high altitude RNAV route design (Structure C) can be implemented to form an RNAV-VOR high altitude route network which will provide benefits to RNAV equipped users and the ATC system without unfavorable impact on non-RNAV operations. These benefits, available in a mixed RNAV-VOR environment, will increase as the percentage of RNAV system users increase.

   a. The requirements for controller intervention and the imposition of ATC restrictions will be reduced in a mixed RNAV-VOR charted high altitude route environment as a result of reductions in the number of potential conflicts as the percentage of RNAV system users increase.

b. High altitude RNAV charted routes, similar to those simulated, should provide a minimum average savings in flight miles (route miles times number of flights using the route) of approximately 1.8% compared to the Present High Altitude Structure. As savings of 1.8% in flight miles is estimated to yield a savings of approximately 570,000 gallons of jet fuel daily based on 1980 estimated fuel consumption rate.

c. Additional savings to the system user accrue as the result of increased availability of optimum cruise altitudes due to reductions in the number of potential overtake conflict situations. This reduction in potential overtake conflicts is the result of an increase in the number of available routes between departure and arrival airports provided in the RNAV-VOR network simulated.

d. As a result of the reduction in the average duration of potential conflicts, the duration of ATC imposed restrictions (primarily altitude restrictions) will be reduced as the percentage of RNAV system users increases.

e. Increased ATC system capacity is anticipated in a mixed RNAV-VOR charted high altitude environment due to reductions in the number of potential conflicts/ controller intervention actions. This reduction was found to be most pronounced in those ARTCC sectors which had high potential conflict counts in the simulation of the Present High Altitude Structure.

f. While intersection and diverge type potential conflicts are increased in most cases as the result of the introduction of RNAV routes and traffic in a predominantly VOR high altitude route system, this increase is offset by major reductions in all other types of potential conflicts. The increase in intersections found as the result of the complex RNAV-VOR intersecting routes would be reduced in the real world as VOR routes are re-aligned to be compatible with new RNAV routes or are deleted as RNAV routes are added as proposed by the RNAV Task Force.

g. The network of RNAV-VOR routes simulated represented a worst case situation in that neither the RNAV routes nor existing VOR routes were modified to provide compatibility between the two route systems. The RNAV routes were designed without regard to the location of existing VOR routes and were simply overlaid on the VOR structure with no attempt made to optimize the network formed. The optimization was beyond the scope of the NAFEC design work and the evaluation.

h. The potential for head-on conflicts is reduced through use of discrete climb and descent RNAV route segments which will reduce the requirement for radar vectoring and the imposition of climb and descent altitude restrictions during transition to and from cruise altitude.

i. As evident in the controller intervention tests, video map clutter, resulting from the requirement to provide both RNAV and VOR route information to the controller, presents a problem requiring resolution.

j. Based on the controller intervetion tests and the NAFEC simulation (Ref. 3) a savings in controller communications time and radio contacts result from the introduction of RNAV traffic.

2 - A total charted RNAV high altitude environment will provide, as a minimum, the same degree of advantages to both the system user and the ATC system as was found for the mixed RNAV-VOR environment. In addition, certain problems unique to a mixed RNAV-VOR environment would no longer exist or would be minimized in a total charted RNAV high altitude route structure environment.

a. The video map clutter associated with an RNAV-VOR mixed environment would not exist in a total RNAV environment.

b. The intersection conflict potential will be reduced as VOR routes which intersect with RNAV routes would be deleted. While some additional RNAV routes would be required, the overall result would be a reduction in the total number of intersecting routes.

c. The total number of potential conflicts would be reduced or, as a minimum, remain the same as those found for the mixed RNAV-VOR environment, since the RNAV-VOR route networks simulated represent a worst case situation due to the interaction of traffic on the two route systems which were not designed to be compatible.

3 - The introduction of charted RNAV routes in the high altitude environment offers the potential of accommodating increased traffic for the post-1982 period while minimizing the number of potential conflicts and controller workload associated with conflict prevention/resolution.

4 - The introduction of a pre-planned direct uncharted RNAV route system as proposed by the FAA-Industry RNAV Task Force would result in the highest number of potential conflicts of all systems simulated. Tests of the present high altitude structure and particularly the charted RNAV-VOR route networks

yielded lower potential conflict rates than the pre-planned direct route system. The potential reduction in flight miles inherent in a direct route system may be completely offset by an increase in the number of potential conflicts and controller workload.

Subsequent real time simulations, which will include controller participation in tests of selected high altitude sectors, are scheduled to be conducted at NAFEC in early 1976, and will provide a basis for calibration of the fast time simulation results.

BACKGROUND

In order to test the RNAV Task Force high altitude route structure design concepts, it was necessary to develop route structures which considered these concepts. Such structures were also necessary as a basis for analyses of the potential user/system payoffs resulting from the introduction of RNAV in the high altitude enroute environment. Both the evaluation of route design concepts and user/system payoff analyses further required that the route designs be simulated in some manner in order to derive quantitative data upon which necessary analysis and conclusions could be based.

It was first necessary to determine which airports and airport pairs (departure airport-arrival airport) should be considered for evaluation purposes. It was necessary that an adequate number of airport pairs be used to insure that the study was a realistic representation of a complex route structure and aircraft movement interactions in the high altitude environment. For this purpose, the data record tape of the 1969 peak day IFR traffic was used. Since some limitation had to be placed on the duration of simulations which were to be conducted, the busiest consecutive 5-hour period (2100 G. M. T. to 0159 G. M. T.) was selected from the peak day tape. A total of 175 airports within the contiguous United States were selected as exchanging the majority of high altitude traffic. An additional 11 airports outside the contiguous United States were also selected since traffic exchanges between them and the 175 airports within the contiguous United States was relatively high. Thus the total number of airports considered was 186 airports which formed 910 airport pairs (an airport pair is any two airports between which traffic was exchanged.) Further examination of the peak day tape showed that approximately 85% of the total high altitude traffic arriving or departing from all airports within the contiguous United States (excluding military flights such as those flying to/from military practice areas) were exchanged between 910 airport pairs formed by the 186 selected airports within the 5-hour period.

As a result of this analysis of the peak day tape, it was concluded that the 910 airport pairs formed by the selected 186 airports would be used as a basis for the high altitude simulations. The manner in which the data from the peak day tape was used in the preparation of traffic samples for simulation purposes is described in the Traffic Samples section of this report.

In order to provide necessary data in a timely manner to both the NAFEC RNAV route design concepts evaluation efforts and the payoff analyses conducted by Systems Control, Incorporated, fast time simulations appeared to provide the only reasonable approach by which the various traffic and route interactions could be examined. The concept of conducting a simulation of only limited "representative" high altitude areas in real time, using air traffic controllers to manage the traffic situations was considered and rejected as the

initial high altitude simulation activity. This was done for several reasons: (1) real time simulations are very costly and time consuming. It would have taken a number of years to perform the necessary real time simulations (assuming resources could be made available) required by the RNAV route structure concept analyses; (2) the selection of "representative" areas could not easily or reliably be determined for RNAV structures that were in a continuing development cycle; (3) manpower and equipment limitations at NAFEC for the conduct of real time simulations would have limited the number of air route traffic control center (ARTCC) sectors, geographic area, route structure complexity, and traffic density that could be simulated; (4) simulation of only smaller areas, such as five or six ARTCC sectors at one time, would run a high risk of missing critical traffic and route structure interactions that could be apparent only through simulation of much larger areas. For these reasons the simulation approach initially taken was to perform a series of fast time simulations. A limited number of controller intervention tests as described later in this report were performed in conjunction with the fast time simulation activities to provide preliminary data on the manner in which the controller test subjects interacted with selected traffic situations. The final phase of the high altitude simulation activities will be the conduct of real time simulations of selected ARTCC sectors which have been identified through the fast time simulations as meaningful candidates for further evaluation.

SIMULATION APPROACH

OBJECTIVES

The fast time simulations were conducted to assist the NAFEC RNAV high altitude route structure design concepts application activities (Ref. 3) and to provide data for the Systems Control, Incorporated user-system payoff analysis efforts (Ref. 5). In addition, the fast time simulations constitute one aspect of a total simulation program directed at determining the impact on both the ATC system and the system user resulting from the introduction of RNAV into the National Airspace System (Ref. 1 and 4).

The specific objectives of the fast time simulations discussed in this report were the following:

- Identify the impact of the introduction of three traffic density levels representative of pre-1977, 1977 to 1982, and post-1982 conditions when:
  - -- The present high altitude route structure is used
  - -- Selected airport pairs are served by high altitude RNAV routes
  - -- All high altitude traffic in the post-1982 time period fly via preplanned direct RNAV flight paths
- Identify the impact of various percentage mixes of RNAV and non-RNAV high altitude traffic sharing the airspace over the contiguous United States

As discussed in the previous section of this report, the limitations inherent in fast time simulations were recognized and it is acknowledged that achievement of the above objectives must be restricted to the identification of trends and specific results which provide a means for comparisons between the conditions tested. It is believed however, that the trends based on the data from these simulations are so well marked that valid conclusions can be formed and that the objectives have been satisfied to a major extent. Validation or qualification of these conclusions will be provided through a NAFEC real time simulation scheduled to start in February 1976 and the results will provide a basis for calibration of fast time simulation results.

TRAFFIC SAMPLES

The 1969 peak day IFR traffic data were used as a basis for the development of traffic samples for use in the fast time simulations. However, since the traffic exchanged between the 186 selected airports (Appendix A) constituted only approximately 85% of the total high altitude traffic during the selected busy 5-hour period, a system of supplementing the traffic so as to increase the total number of high altitude departures to a point as close as practical to 100% of the busy 5-hour period of the peak day was considered desireable. To accomplish this purpose, all of the selected airports within the contiguous United States

were considered candidates for the addition of supplemental high altitude departures. Analysis of the peak day tape provided the total number of high altitude departures from each of the 175 airports within the contiguous United States. Some of the high altitude departures flew to destination airports other than the selected 175 airports within the contiguous United States or the 11 selected airports outside, as did some of the arrivals at the selected airports originate as departures from other than these same selected airports. Therefore, supplemental high altitude traffic was added between a number of the 873 airport pairs formed by airports within the contiguous United States and the 37 additional airport pairs formed by inclusion of the 11 airports outside the contiguous United States.

Care was taken in the addition of departures at all airports to avoid swamping the destination airports with undue increases in arrivals. This was accomplished as an iterative process. First, the number of supplemental departures to be added at each airport was determined. Then destination airports were selected for the supplemental departures which result in increasing the number of flights between the airport pairs formed by departure-destination airports. No new airport pairs were formed in this process. Figures 1 through 4 show an example of how this was done for the Detroit-Metropolitan-Wayne County Airport (DTW). Figure 1 depicts the number of DTW high altitude departures to each of 29 airports during the selected 5-hour period. This accounted for 63 high altitude departures from DTW within the period and left 20 departures to be added since these flights were to other than selected airports. Figure 2 illustrates the airport pairs between which 20 supplemental DTW high altitude departures were distributed.

The next step after departures were added as required at each airport was to examine the resultant increase in arrivals at destination airports. Figure 3, using DTW again as an example, illustrates the high altitude traffic departing from other of the 186 selected airports within the busy 5-hour period destined for DTW prior to the addition of supplementary departures at any airport. As shown in Figure 3, there were 52 high altitude departures from a total of 23 airports destined for DTW. As high altitude departures were added at these 23 airports, DTW was selected as the destination of some of the added traffic. Figure 4 identifies the airport pairs between which 16 additional arrival flights to DTW were distributed.

The iterative process of supplementing the high altitude traffic then involved making adjustments in the original selection of destination airports for the added traffic to avoid unreasonable increases in arrivals at any of the selected airports. This involved more or less subjective decisions. As a general rule of thumb, these decisions were guided by an attempt to increase the number of arrivals by approximately the same percentage as departures for any given airport. As shown in the example of DTW in Figures 1 and 2, high altitude departures at DTW were increased by 20 flights to selected airports, or approximately 32%. Figures

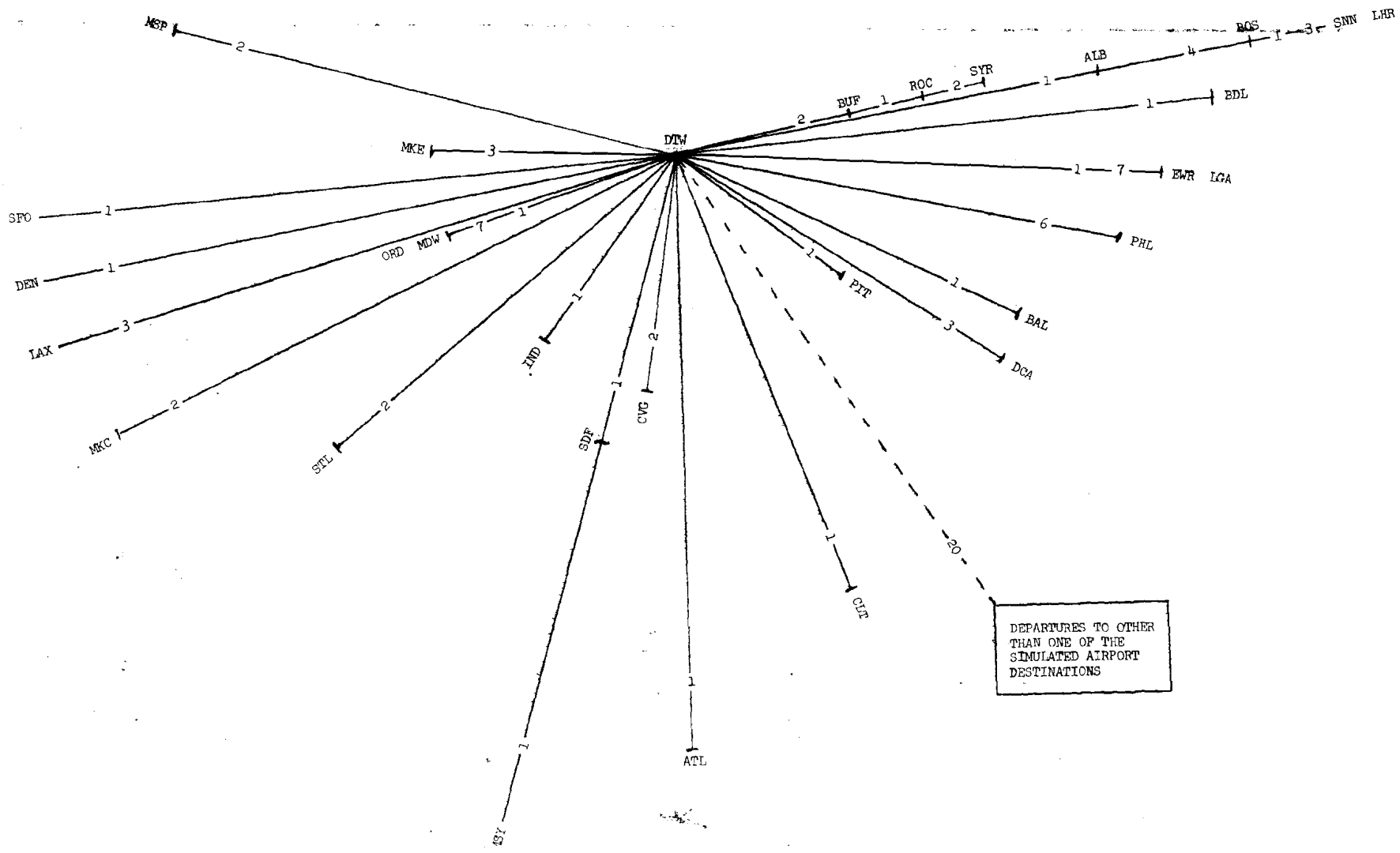

Figure 1 - 1969 Peak Day IFR High Altitude Traffic - DTW Departures During Selected 5-hour Period

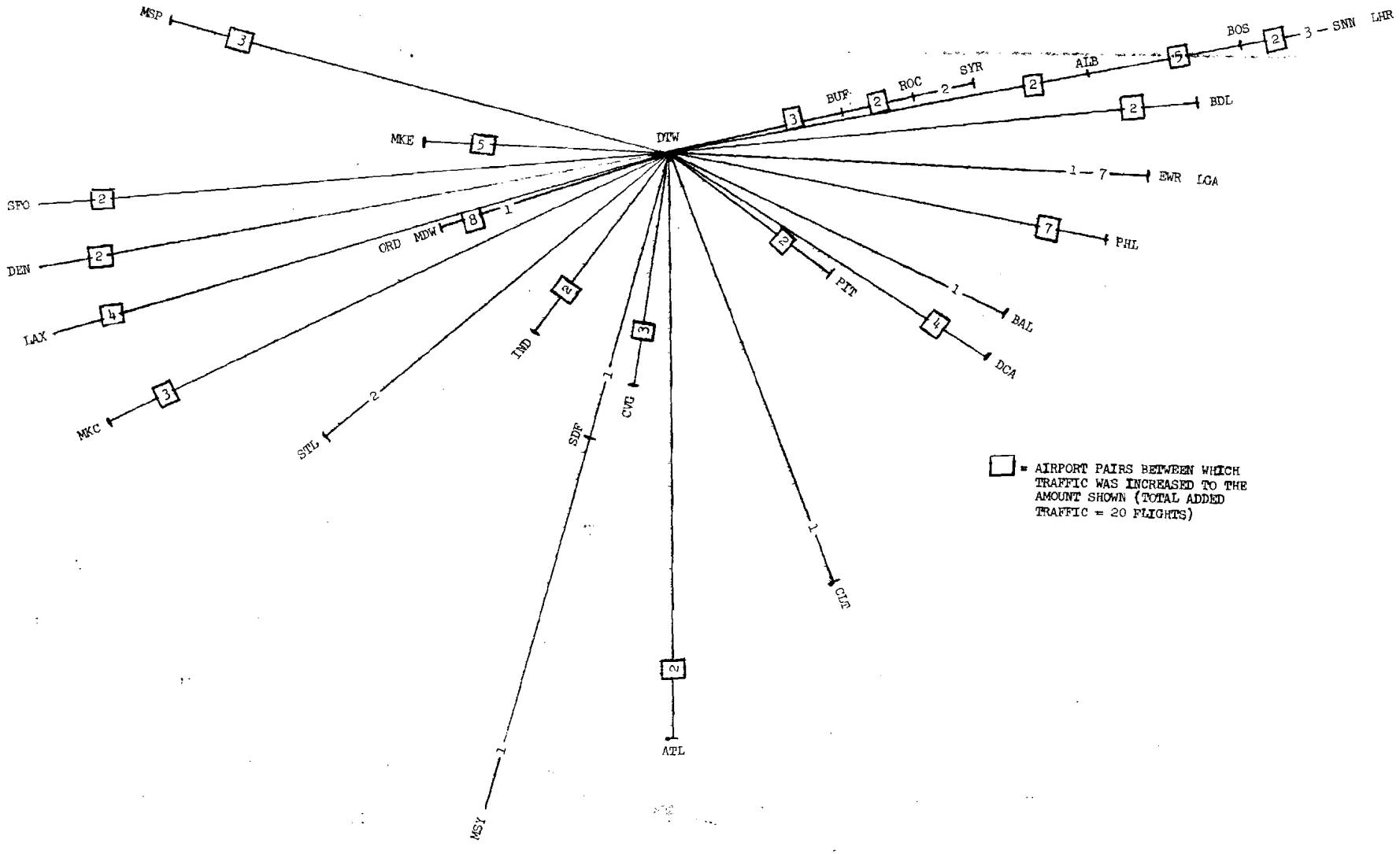

Figure 2 - Traffic Sample 1 (1972) - DTW Departures to Simulated Airports

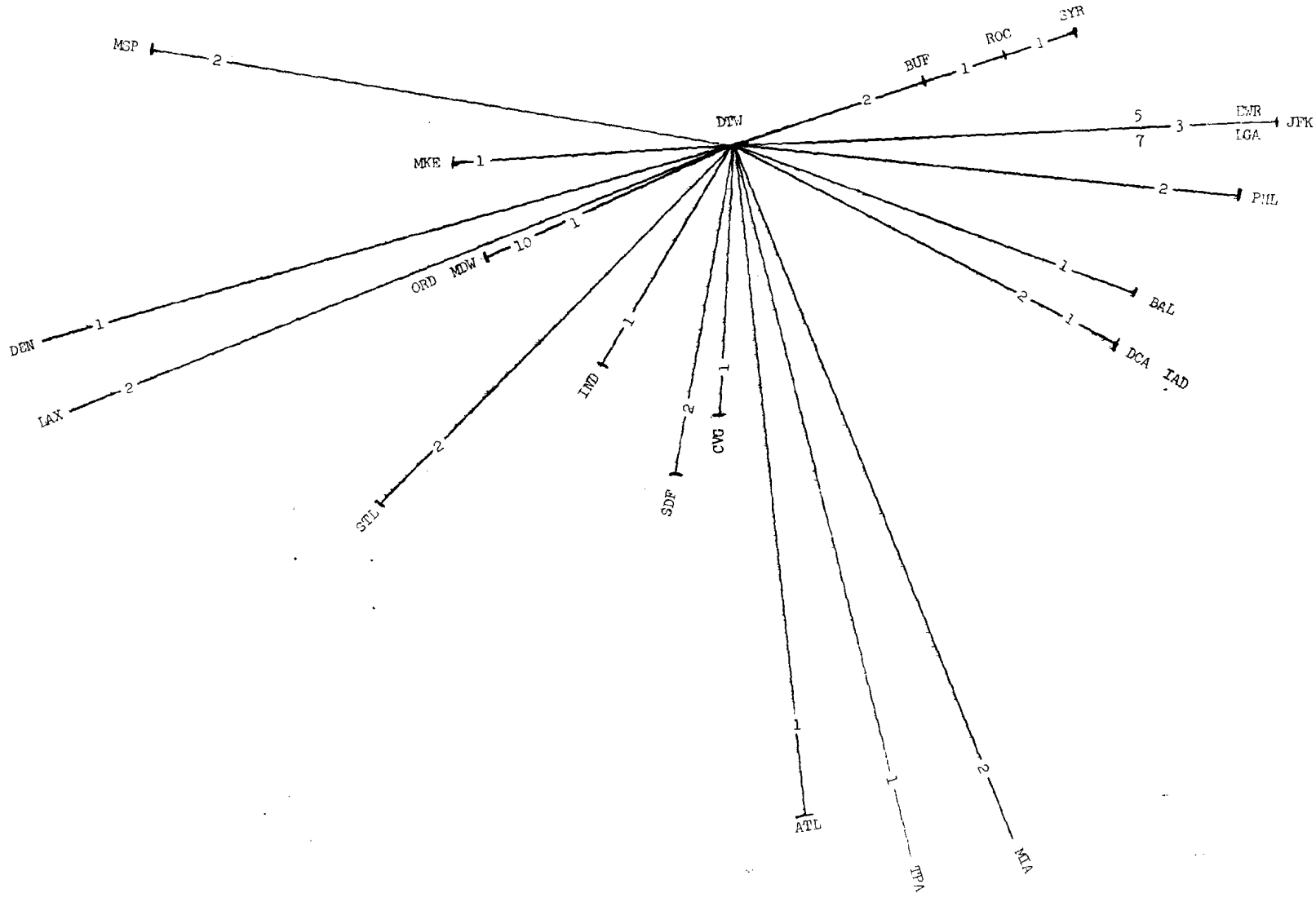

Figure 3 - 1969 Peak Day IFR High Altitude Traffic - DTW Arrivals from Simulated Airports During Selected 5-hour Period

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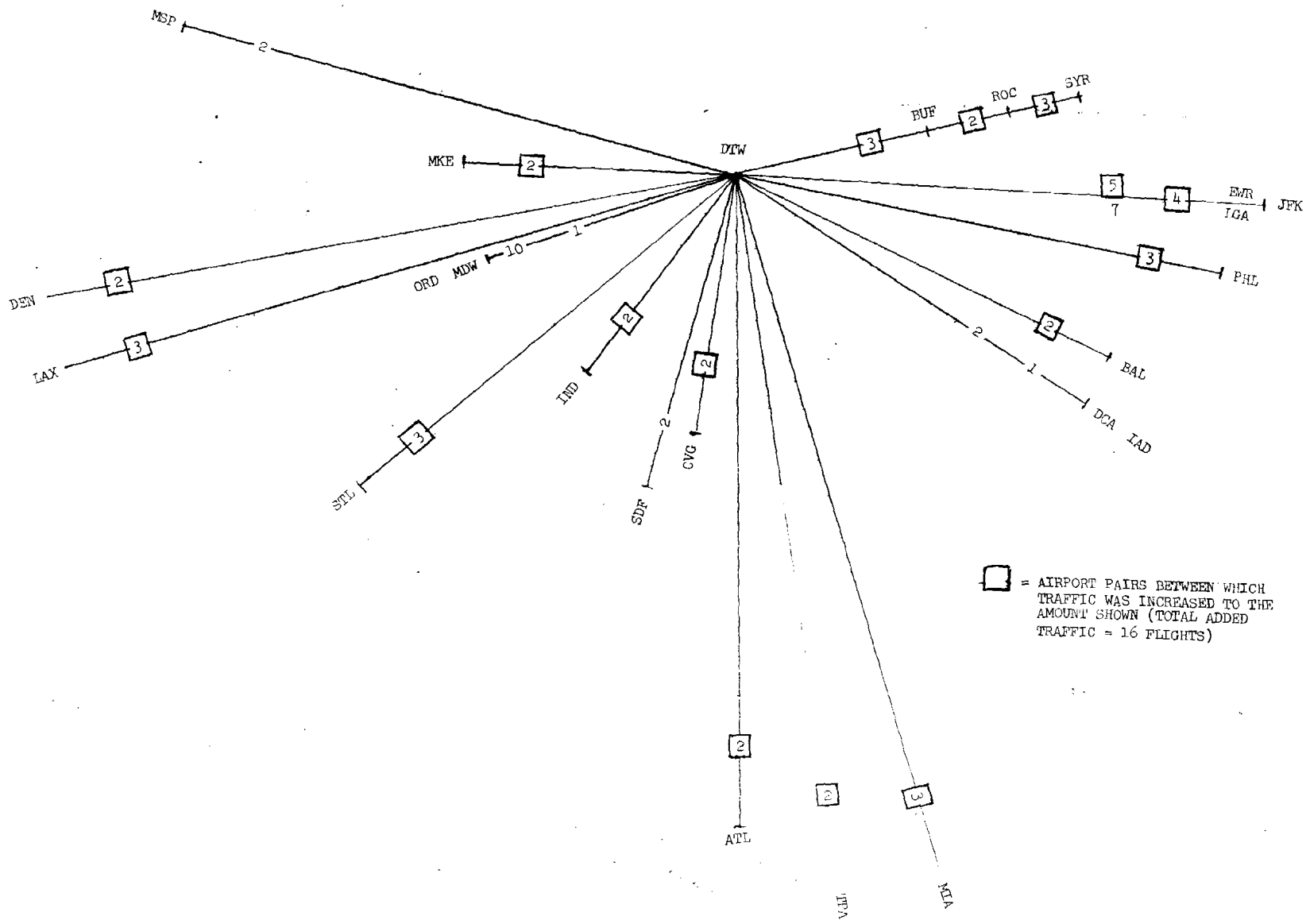

Figure 4 - Traffic Sample 1 (1972) - DTW Arrivals from Simulated Airports

3 and 4 depict how high altitude arrivals destined for DTW were increased by 16 flights, or approximately 31%. While it was not possible to achieve this balance of percentage increases in departure and arrival flights at all airports, it was felt that a reasonably realistic situation of arrival and departure high altitude traffic to and from the 186 selected airports was achieved adequately for simulation purposes through this process.

As previously stated, no additional airport pairs were created as a result of supplementing the number of high altitude flights to account for those departures or arrivals to or from other than the 186 selected airports. The reason for avoiding the creation of additional airport pairs was to limit the total number of routes that would be simulated to some manageable yet representative number.

An examination of actual high altitude flight plans derived from an analysis of ARTCC flight progress strips for a busy day in 1972 was conducted. This analysis revealed that in excess of 1400 routes were actually flown between the 910 airport pairs. These routes are depicted in Figure 5. This network of routes, actually flown, was judged to be sufficiently representative of the complex of presently used routes flown at and above 18,000 feet in 1972.

The next step in the development of traffic samples for simulation was to combine the data from the peak day IFR data tape with the information derived from the analysis of ARTCC flight progress strips since the actual routes flown were not included in the peak data. The data provided on the peak day tape, useful for simulation purposes, included the following for all flights:

- Aircraft Type
- Point of Departure
- Destination
- Requested Altitude
- Assigned Altitude*
- Proposed Time of Departure
- Actual Time of Departure*
- Filed True Airspeed

The data marked with an asterisk (*) above were not used since it was deemed more important that the traffic samples reflect as closely as possible traffic situations based on user requirements without reflecting departure delays or altitude assignments possibly imposed by the air traffic control system. The rationale here was that through the use of traffic samples based on system user requested altitudes and proposed times of departure, the best means of determining the simulated route structure(s) responsiveness to user requirements would be provided. An optimum, but in all probability unachievable condition would permit all aircraft to depart when desired without air traffic control imposed delay; fly via the requested route at the requested altitude(s) without air traffic control imposed route changes, restrictions to

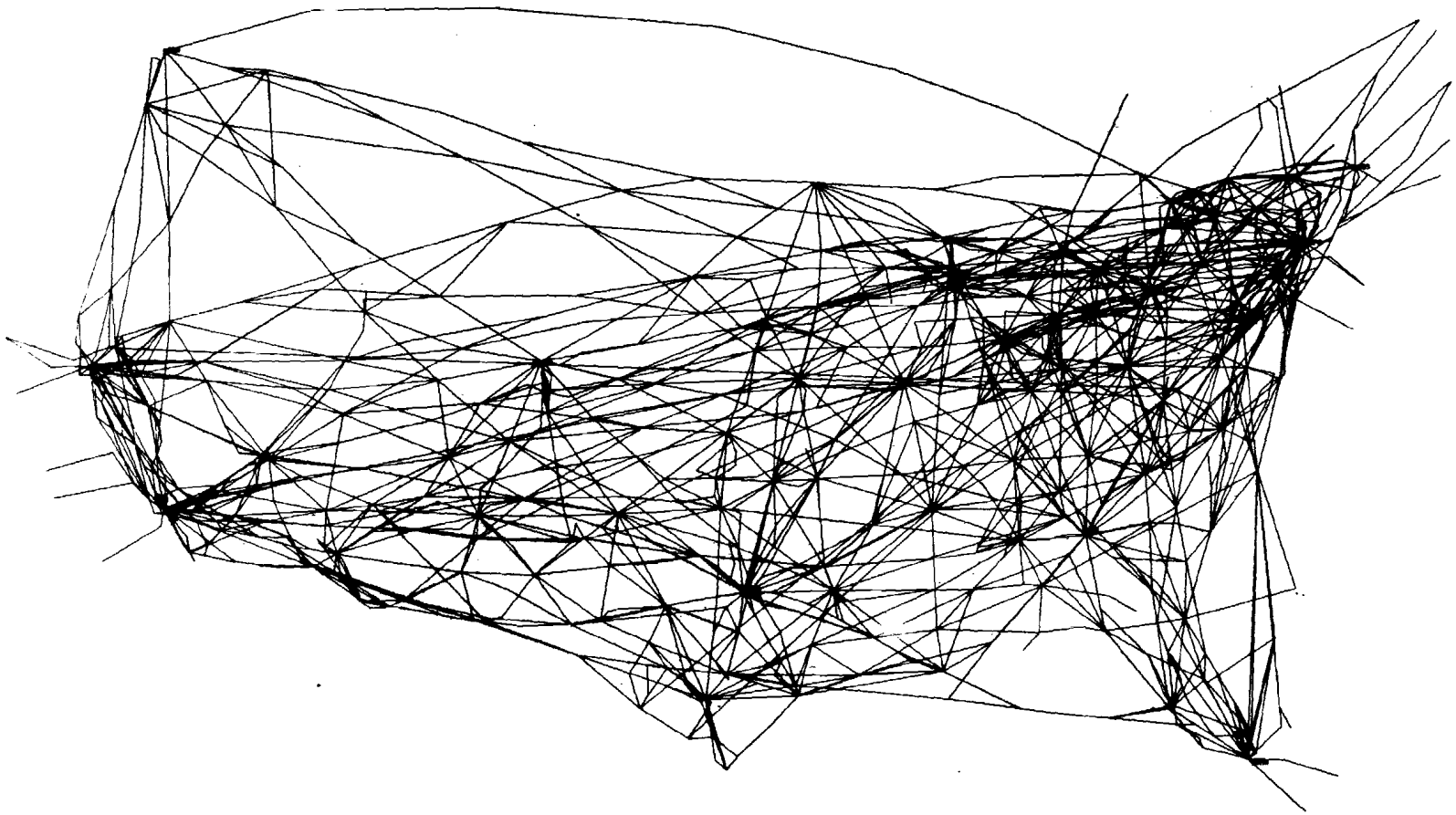

Figure 5 - Present High Altitude Route Structure as Simulated

climb or descend, or assignment of other than the requested altitude(s) of flight level(s); and at the same time provide for the safe conduct of flight. From both the user of the system and the air traffic controller's standpoint, the closer this optimum condition is approached the greater the benefit. The less air traffic control restrictions imposed, the greater the potential benefit to the user, and the less requirement for the controller to intervene, thus lowering his workload, and possibly increasing the system capacity. However, since fast time simulation does not provide for controller intervention such as imposing departure delays, altitude restrictions, etc., it was important that the simulation be conducted, and data be collected, in such a manner as to provide insight into the degree of increase/decrease in potential controller intervention requirements. The manner in which this problem was approached is described in the Simulation Measures section of this report.

The only exceptions to the use of requested altitudes and proposed times of departure for traffic sample preparation were under the following conditions:

- When the requested altitude was contrary to the hemisphere rule and would result in assignment of opposite direction traffic to the same altitude or flight level. In such cases, to avoid built-in conflicts, the altitude was modified by increasing/decreasing the altitude by 1000 or 2000 feet as appropriate.

- When two or more aircraft were proposed to depart from the same airport at the same minute, the departure times were modified so that a 32-second interval was provided between these flights on departure. (While recognizing that a 32-second interval between departures at most airports is unrealistic, it was used only to provide some separation between a series of departures to limit the frequency of aircraft entering the enroute environment in conflict with other departures, not to simulate terminal area operations.)

- In the case of supplementary departures described earlier, departure times were assigned through a statistical random selection process. Altitudes were assigned to the added flights by selection from those altitudes requested by other flights between the airport pair. For example, if traffic from airport "A" to airport "B" requested flight levels 310 and 350, the altitude for added flights from "A" to "B" would also be assigned either flight level 310 or 350. This approach to assignment of requested altitudes for added flights appeared to coincide with the apparent trend observed in the peak day data in which competition for a very limited range of altitudes between each airport pair prevailed.

In addition to the data used from the peak day tape, it was necessary to define not only the airports of departure and arrival for

each flight, but to identify the routes flown between each airport pair. As previously mentioned, ARTCC flight progress strips were analyzed for a busy day's traffic in 1972. As a result of this analysis, over 1400 routes were identified between the 910 airport pairs. The route definitions included SID's and STAR's when known, transitions, airways, and direct route segments. These routes are referred to in this report as the "Present High Altitude Structure," As anticipated, between a number of airport pairs, multiple routes were used. For example, eight routes from Chicago O'Hare Airport (ORD) to Los Angeles (LAX) were flown on the busy day.

It was next necessary to determine the distribution of aircraft over the multiple routes between airport pairs. Using ORD to LAX as an example, it was determined that approximately 50% of the traffic used one route; 30% of the traffic was divided equally between three routes; and 20% of the traffic was divided approximately equally over the remaining four routes. This distribution was approximated in the assignment of routes in the traffic samples.

While ORD to LAX traffic was used as an example, the multiple routes found between this airport pair was an extreme case (eight routes ORD to LAX and three routes LAX to ORD). There were only fifteen cases where three or more multiple routes from departure airport to arrival airports were found. In the remaining ninety cases of multiple routes, only two routes were used between each airport pair.

As previously stated, the types of aircraft flown in the 5-hour busy period of the 1969 peak day were known from the peak day data. For the purposes of simulation, these aircraft types were divided into aircraft performance categories. It was found that almost all high altitude flights fell into three basic general performance categories for which NAFEC provided performance characteristics. Analysis of the performance of these flights based on early simulation results and a review of the simulated performance characteristics with airline representatives indicated that a wider performance range was needed to represent different aircraft load conditions and operating practices.

Accordingly, the three categories were subdivided into three performance groups each, allowing for what was considered a reasonable performance range for average performance operations (50% of the flights within each category), light loaded-fast climbing (25%), and heavy loaded-slow climbing (25%). Within each category and subdivision, the filed true airspeed for each original flight was retained.

Having completed the processes described up to this point to develop a traffic sample for simulation purposes representative of traffic densities and distributions of the pre-1977 time period, it was now necessary to produce traffic samples which could be used to represent the 1977 to 1982 and post-1982 traffic situations. The purpose of these additional traffic samples was to permit testing of both the routes as flown in 1972 (Present High Altitude Structure) under present and postulated future peak traffic densities and to submit the high altitude RNAV route structure designs prepared by NAFEC to

the same traffic demands. The determination of just how much traffic and between what airport pairs the traffic should be added was a subjective process since traffic forecasts were not available for peak day, busy 5-hour periods, nor for combinations of departure-arrival airports (airport pairs). It was assumed that a simple percentage increase in traffic for the busy 5-hour period equal to the forecast annual traffic percentage increase would not be valid. For example, the January 1972 Traffic Forecast For Fiscal Years 1972 to 1982, prepared by the FAA Office of Aviation Economics, estimated an increase in IFR departures between 1971 and 1982 of more than 113%. It appeared to be totally unrealistic to assume for the purpose of the simulations that airports such as Chicago O'Hare, Los Angeles, Atlanta, etc., could accommodate 113% in traffic over the present busy 5-hour period of a peak or near-peak day. It was, therefore, determined that what appeared to be reasonable increases in the total traffic for the 5-hour period to be simulated would be used. It is not argued here that the traffic densities simulated are defendable as truly representative busy traffic periods specifically for 1977 to 1982 and post-1982 traffic but that they are adequate to determine the trend of the impact of the introduction of RNAV traffic under various traffic densities.

Appendix B shows the number of high altitude departures simulated in the three traffic samples used.* Traffic Sample 2 (representing 1977-1982 traffic) provided a 15% increase over Traffic 1 (representing pre-1977 traffic). Traffic Sample 3 (representing post-1982 traffic) provided a 31% increase over Traffic Sample 1. These limited percentage increases (compared to the annual increase forecasts) assumes that the major portion of the increased traffic will be distributed primarily over less busy periods.

The addition of the increased departures in Traffic Sample 2 and 3 was accomplished in the same manner as previously described for the addition of supplemental traffic for Traffic Sample 1.

ROUTE STRUCTURES

The Present High Altitude Route Structure was used in the simulations to provide baseline data for comparisions with the other route structures simulated. While NAFEC developed a number of high altitude RNAV route structure designs which were simulated as part of the total fast time simulation activities, this report is concerned only with three of the NAFEC RNAV structures since all the other structures were used only as a basis for the development of these three designs. Primarily, emphasis is placed on the final NAFEC design (Structure "C") in this report since it provided the most complete RNAV structure developed by NAFEC and incorporated a number of improvements in design over the other two (Structures "A" and "B"). In addition, a limited simulation was conducted of a preplanned direct high altitude flight environment as postulated for the post-1982 environment by the RNAV Task Force (Ref. 4).

*The absolute number of departues and percentage increases between Traffic Samples 1, 2, and 3 differ from those given in Reference 2. This is the result of an error in the manner in which departures were calculated previously in preparation of the subject report.

The flight paths for the direct high altitude flights are shown in Figure 6.

Structure "A", shown in Figure 7, was designed by NAFEC to provide high altitude RNAV routes between nominally 150 airport pairs selected from the 873 airport pairs within the contiguous United States previously discussed. The airport pairs selected for Structure "A" were initially those which exchanged the greatest number of high altitude flights. However, as the route structure was developed, additional airport pairs were added in the design bringing the total number of pairs included in Structure "A" to 189.* The logic for the selection of the additional airport pairs, for all structures, is included in Reference 3.

After completion of a number of preliminary simulation runs it was discovered that inadvertently the Structure "A" RNAV routes and the Present High Altitude Route Structure were plotted using different projection system in the simulation. This resulted in an unrealistic displacement when the RNAV structur was superimposed on the Present High Altitude Structure. The displacement of 10 to 12 miles in some areas was due to plotting of the Present High Altitude Route Structure using a geodetic projection while using a geocentric projection for the RNAV routes in Structure "A". This error was corrected and a common projection system (geocentric) was used for subsequent simulation tests. Since the network formed by superimposing the same RNAV routes over the present route structure using a geocentric projection for both route systems differed from the network formed by uisng different projection systems, Structure "B" was identified. All aspects of Structure "B" were identical to Structure "A" except in the network formed with the Present High Altitude Structure by using the common projection system. Structure "B" is shown in Figure 8.

The only purpose of retaining Structure "A" in this report is that it provided an unanticipated insight into the criticality or sensitivity of certain simulation measures to the exact placement of an RNAV route structure as it overlies or forms a network with the Present High Altitude Route System.

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* Some confusion may result to the reader of this report and the NAFEC report (Re. 3) due to what may appear as a discrepancy in the number of airports and airport pairs used in the nominal 150 airport pair designs. This is due to NAFEC's inclusion in the design airport pairs between which no traffic flew within the simulated 5-hour period. These additional airport pairs used by NAFEC are not among the 910 airport pairs discussed in this report and, in the absence of traffic, were not simulated. However, for NAFEC design purposes, the full 24 hours of peak day traffic was used rather than only the 5-hour period simulated. The same discrepancies will appear between these two reports for the nominal 250 airport pairs design also.

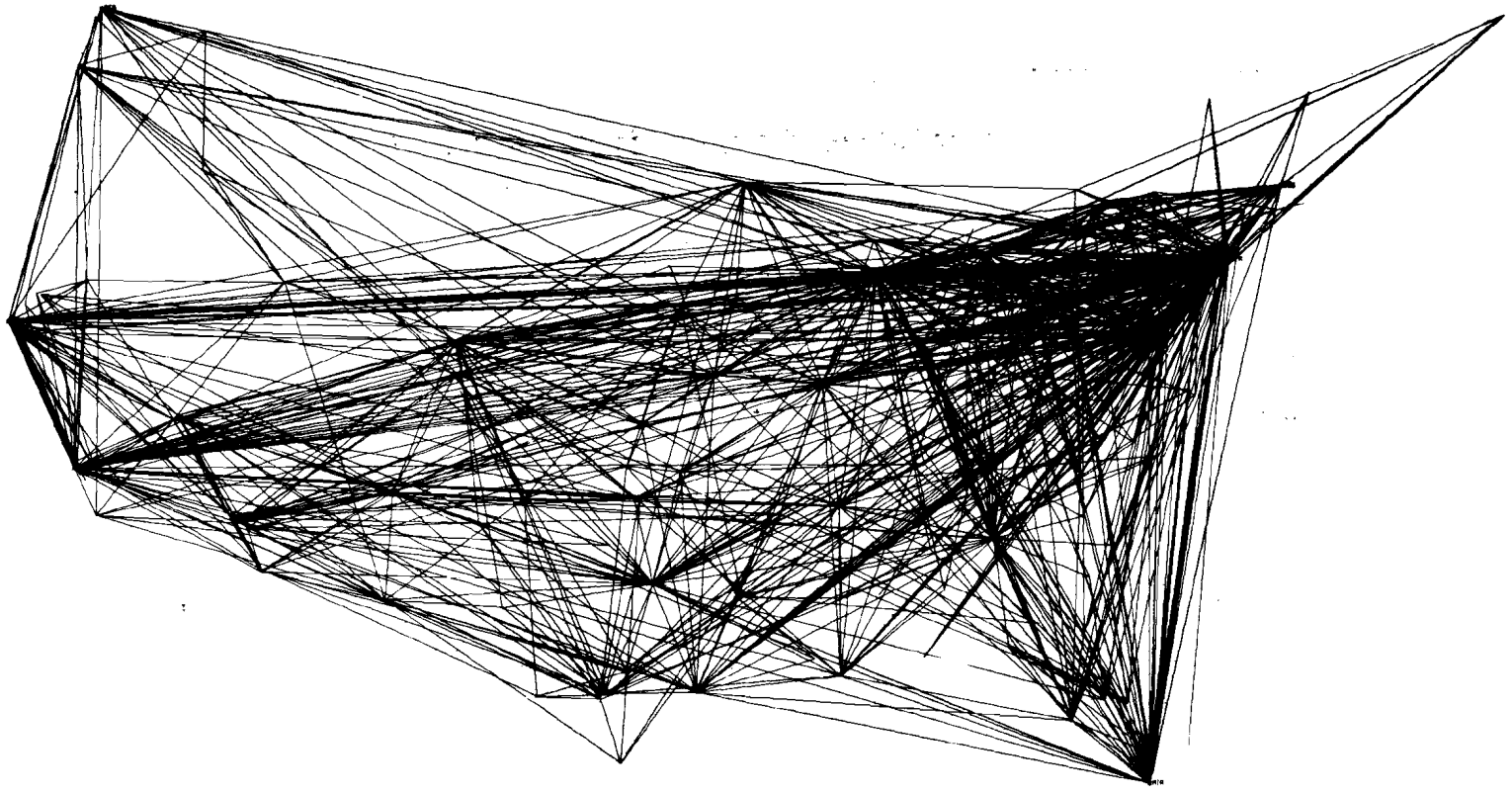


Figure 6 - Direct (Great Circle) Routes Between Simulated Airport Pairs

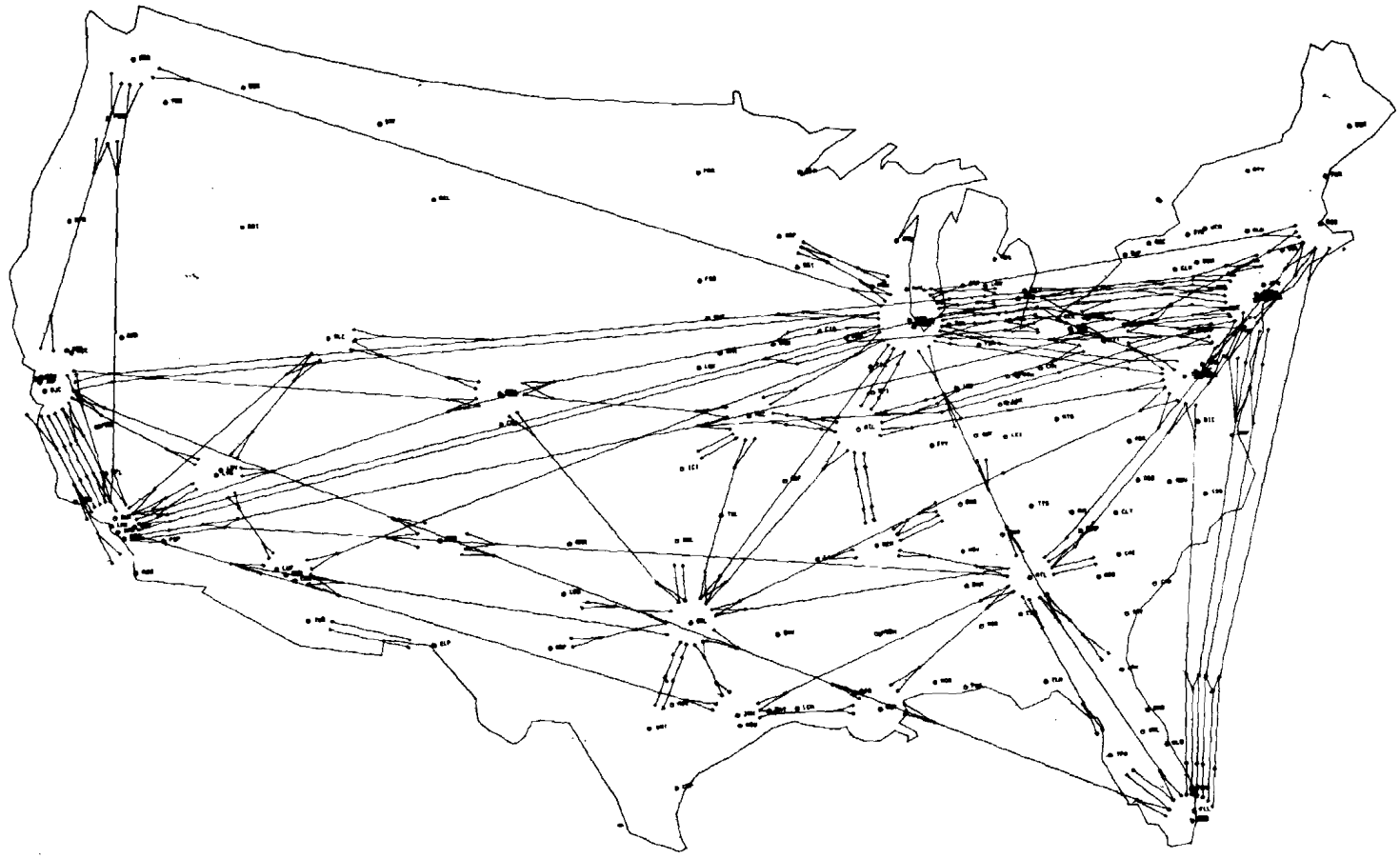


Figure 7 - RNAV High Altitude Route Structure A

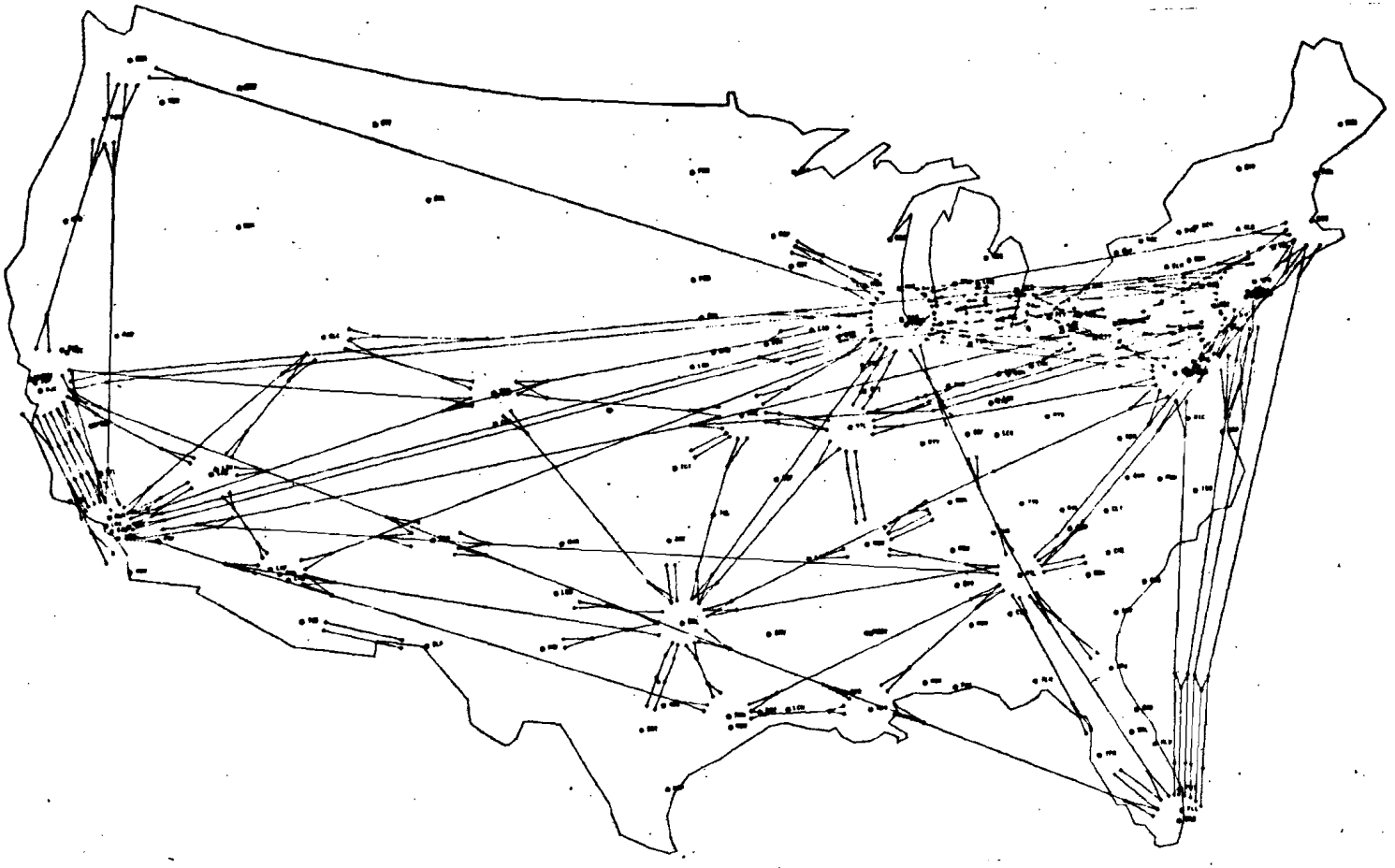


Figure 8 - RNAV High Altitude Route Structure B

It is not implied that the RNAV-VOR structure network resulting from the displacement would constitute a valid network design, but much of the simulation data of Structure "A" was found to be of value for comparison purposes.

Structure "C" was designed by NAFEC to provide high altitude RNAV routes between nominally 250 airport pairs selected from the 873 airport pairs within the contiguous United States. The structure included all the airport pairs of Structure "A" or "B" in addition to a number of pairs exchanging fewer high altitude flights. As was done in the development of Structure "A", additional logical airport pairs were introduced into the design with the result that Structure "C" was comprised of a total of 429 pairs selected from the 873 airport pairs within the contiguous United States rather than only 250. Structure "C" is shown in Figure 9.

Table 1 identifies the airport pairs joined by RNAV routes in Structure "A", "B", and "C".

Comments received on the Preliminary Fast Time Simulation Results Report (Ref. 2) raised the following points: 1) were the route structures simulated in fact to be implemented in the real world environment; 2) suggested that a route structure intended for actual use in the NAS should be fully coordinated with all appropriate organizations; and 3) the structure intended for implementation should be the one studied in the simulations. First it must be made clear that the RNAV high altitude structure designs simulated for payoff and evaluation were not intended for direct implementation for field use as per direction of the Air Traffic Service. However, this does not negate either the value of the design efforts conducted by NAFEC (Ref. 3), or the simulation results. The comment indicates a misunderstanding of the purpose of both efforts. It was not an objective of this initial NAFEC design effort to provide an optimum and implementable high altitude RNAV route structure. The necessity of massive coordination to achieve such a structure and the time required for its total design must be self-apparent to all interested parties. The magnitude of such an effort was outside the scope of this NAFEC activity. However, a purpose of the NAFEC design efforts in addition to determination of payoffs was to develop representative RNAV high altitude route structures based on the FAA/Industry Task Force design concepts to evaluate the concepts. In this process, certain modifications to these concepts were applied in the designs. The simulations in turn, among other purposes, provided data based on these designs indicating whether or not a benefit could be expected to the ATC system and the system user if in fact a similar design were implemented in the field. This is an appropriate use of simulation. If, however, the simulations were to be delayed until a total high altitude RNAV route structure, based on the RNAV Task Force concepts, were to be developed, coordinated, flight checked, etc., within the next several years, system/user payoff data would not be provided in a timely manner, nor could the simulations, conducted after completion of the final route design, be of any value in the development of that final design.

Figure 9 - RNAV High Altitude Route Structure C

TABLE 1

SIMULATED AIRPORT PAIRS IN RNAV ROUTE STRUCTURE DESIGNS

Airport Pairs	RNAV Structures		Airport Pairs	RNAV Structures		Airport Pairs	RNAV Structures	
	A & B	C		A & B	C		A & B	C
ABE-PIT	X	X	ATL-JFK	X	X	BAL-MSY		X
ABQ-DAL	X	X	ATL-LAX	X	X	BAL-OMA		X
ABQ-DEN		X	ATL-LGA	X	X	BAL-ORD	X	X
ABQ-ELP		X	ATL-MEM	X	X	BAL-PIT	X	X
ABQ-LAX	X	X	ATL-MIA	X	X	BAL-SEA		X
ABQ-MCC		X	ATL-MKE		X	BAL-STL	X	X
ABQ-MDW		X	ATL-MSY	X	X	BDL-CLE	X	X
ABQ-MIA	X	X	ATL-ORD		X	BDL-DCA		X
ABQ-ORD		X	ATL-PBI		X	BDL-DTW		X
ABQ-PHX		X	ATL-PHL	X	X	BDL-IAD		X
ABQ-SFO	X	X	ATL-PIT		X	BDL-MIA		X
ABQ-TUS		X	ATL-RDU		X	BDL-ORD	X	X
ADW-BKF		X	ATL-SAV		X	BDL-PIT	X	X
ALB-BUF		X	ATL-SDF	X	X	BHM-JAN		X
AMA-DAL		X	ATL-SFO		X	BHM-LGA		X
ATL-BAL	X	X	ATL-STL		X	BHM-MEM		X
ALT-BNA		X	ATL-TPA	X	X	BHM-ORD		X
ATL-BOS	X	X	AUS-DAL	X	X	BNA-DAL	X	X
ATL-BUF		X	AUS-ELP		X	BNA-DCA		X
ATL-CAE	X	X	AUS-IAH		X	BNA-MEM	X	X
ATL-CLE		X	BAL-BOS	X	X	BNA-ORD		X
ATL-CLT	X	X	BAL-BUF		X	BNA-PHL		X
ATL-DAL	X	X	BAL-CLE	X	X	BNA-PIT		X
ATL-DCA	X	X	BAL-CMH		X	BOI-DEN	X	X
ATL-DTW		X	BAL-DAL	X	X	BOI-PDX		X
ATL-EWR	X	X	BAL-DAY		X	BOI-SLC	X	X
ATL-GSO		X	BAL-DEN		X	BOS-BUF		X
ATL-IAD	X	X	BAL-DTW	X	X	BOS-CLE		X
ATL-IAH	X	X	BAL-LAX		X	BOS-DAL	X	X
ATL-JAX	X	X	BAL-MIA	X	X	BOS-DCA	X	X

TABLE 1

(Continued)

Airport Pairs	RNAV Structures		Airport Pairs	RNAV Structures		Airport Pairs	RNAV Structures	
	A & B	C		A & B	C		A & B	C
BOS-DTW	X	X	CLE-JFK	X	X	DAL-LGA		X
BOS-FLL	X	X	CLE-LAX	X	X	DAL-LIT		X
BOS-IAD	X	X	CLE-LGA	X	X	DAL-MAF	X	X
BOS-JFK		X	CLE-MDW	X	X	DAL-MEM	X	X
BOS-LAX		X	CLE-MKE		X	DAL-MIA	X	X
BOS-MIA	X	X	CLE-ORD	X	X	DAL-MKC	X	X
BOS-ORD	X	X	CLE-PHL	X	X	DAL-MSY	X	X
BOS-PHL	X	X	CLE-STL		X	DAL-OKC	X	X
BOS-PIT	X	X	CLE-TEB		X	DAL-ORD	X	X
BOS-ROC		X	CLE-TPA		X	DAL-PHX	X	X
BOS-SFO		X	CLT-DCA		X	DAL-SAT	X	X
BOS-STL		X	CLT-EWR		X	DAL-SFO	X	X
BUF-DCA		X	CLT-JFK		X	DAL-STL	X	X
BUF-DTW		X	CLT-LGA		X	DAL-TUS		X
BUF-EWR		X	CLT-ORD		X	DAY-DCA		X
BUF-LGA		X	CLT-PHL	X	X	DAY-JFK		X
BUF-ORD		X	CLT-PIT		X	DAY-LGA		X
BUF-PHL		X	CMH-DCA		X	DAY-STL		X
BUR-LAS	X	X	CMH-LGA		X	DAY-TEB		X
BUR-OAK	X	X	CMH-MDW		X	DCA-DTW	X	X
BUR-RNO		X	CMH-MIA		X	DCA-JAX		X
BUR-SFO	X	X	CMH-ORD		X	DCA-JFK	X	X
BUR-SJC	X	X	COS-MKC		X	DCA-LGA	X	X
CAK-ORD		X	DAL-DEN	X	X	DCA-MDW	X	X
CHS-DCA		X	DAL-ELP		X	DCA-MEM	X	X
CLE-DAL		X	DAL-IAD	X	X	DCA-MIA	X	X
CLE-DCA	X	X	DAL-IAH	X	X	DCA-MKE		X
CLE-EWR	X	X	DAL-JFK		X	DCA.MSP		X
CLE-IAD	X	X	DAL-LAX	X	X	DCA-ORD	X	X
CLE-IND		X	DAL-LBB	X	X	DCA-PIT	X	X

TABLE 1
(Continued)

Airport Pairs	RNAV Structures		Airport Pairs	RNAV Structures		Airport Pairs	RNAV Structures	
	A & B	C		A & B	C		A & B	C
DCA-SDF		X	DTW-IAD	X	X	EWR-MIA	X	X
DCA-STL	X	X	DTW-JFK	X	X	EWR-MKC		X
DCA-TYS		X	DTW-LAX	X	X	EWR-ORD	X	X
DEN-DTW		X	DTW-LGA	X	X	EWR-PIT	X	X
DEN-IAD		X	DTW-MDW	X	X	EWR-ROC		X
DEN-ICT		X	DTW-MIA		X	EWR-SFO	X	X
DEN-JFK		X	DTW-MKC		X	EWR-STL	X	X
DEN-LAS	X	X	DTW-MKE	X	X	EWR-TPA		X
DEN-LAX	X	X	DTW-MSP		X	FLL-JAX	X	X
DEN-LGA		X	DTW-ORD	X	X	FLL-ORD	X	X
DEN-MAF		X	DTW-PHL	X	X	FLL-PHL		X
DEN-MDW	X	X	DTW-PIT		X	FLL-PIT		X
DEN-MKC	X	X	DTW-SDF		X	FLL-TPA	X	X
DEN-MKE		X	DTW-SFO		X	FSD-MSP		X
DEN-MSP		X	DTW-STL		X	GEG-SFO		X
DEN-OKC		X	DTW-SYR		X	GSO-HPN		X
DEN-OMA		X	DTW-TPA		X	GSO-IAD		X
DEN-ORD	X	X	ELP-LAX		X	GSO-LGA		X
DEN-PDX		X	ELP-LSV		X	GSO-ORD		X
DEN-PHX		X	ELP-MAF		X	GSO-TEB		X
DEN-SEA		X	ELP-PHX		X	HPN-MDW		X
DEN-SFO	X	X	ELP-SAT		X	HPN-ROC		X
DEN-SJC	X	X	ELP-TUS	X	X	IAD-JFK	X	X
DEN-SLC	X	X	EWR-FLL	X	X	IAD-LAX		X
DEN-STL		X	EWR-GSO		X	IAD-LGA	X	X
DET-PHL		X	EWR-IAD		X	IAD-MIA	X	X
DSM-LAX	X	X	EWR-IAH		X	IAD-MSY		X
DSM-MSP		X	EWR-IND		X	IAD-ORD		X
DSM-ORD		X	EWR-JAX		X	IAD-SEA		X
DTW-EWR		X	EWR-LAX	X	X	IAD-SFO		X

TABLE 1
(Continued)

Airport Pairs	RNAV Structures		Airport Pairs	RNAV Structures		Airport Pairs	RNAV Structures	
	A & B	C		A & B	C		A & B	C
IAD-STL	X	X	JFK-ORF		X	LAX-RNO		X
IAH-JFK		X	JFK-PHI		X	LAX-SAT		X
IAH-LAX	X	X	JFK-PHX		X	LAX-SEA	X	X
IAH-LBB		X	JFK-SAN		X	LAX-SFO	X	X
IAH-MIA		X	JFK-SEA		X	LAX-SJC	X	X
IAH-MSY	X	X	JFK-SFO	X	X	LAX-SLC	X	X
IAH-ORD		X	JFK-SJC	X	X	LAX-SMF	X	X
IAH-SAT		X	JFK-STL	X	X	LAX-STL	X	X
IAH-SFO		X	JFK-TPA		X	LAX-TUS		X
IAH-STL		X	LAS-LAX	X	X	LGA-MEM		X
ICT-LUK		X	LAS-OAK	X	X	LGA-MIA	X	X
ICT-MDW		X	LAS-ONT	X	X	LGA-MKC		X
ICT-MKC	X	X	LAS-ORD	X	X	LGA-ORD	X	X
ICT-ORD		X	LAS-PHX	X	X	LGA-ORF		X
IND-JFK		X	LAS-RNO		X	LGA-PBI		X
IND-MEM		X	LAS-SFO	X	X	LGA-PIT	X	X
IND-STL	X	X	LAS-SJC	X	X	LGA-RIC		X
JAN-MEM		X	LAS-SLC	X	X	LGA-ROC		X
JAN-SHV		X	LAX-MEM		X	LGA-SDF		X
JAX-JFK		X	LAX-MIA		X	LGA-STL	X	X
JAX-LGA		X	LAX-MKC	X	X	MDW-MKC	X	X
JAX-MIA		X	LAX-MSP		X	MDW-MSP	X	X
JFK-LAS		X	LAX-MSY		X	MDW-PHX	X	X
JFK-LAS	X	X	LAX-OAK	X	X	MDW-PIT	X	X
JFK-MIA	X	X	LAX-OKC		X	MDW-SDF		X
JFK-MKE		X	LAX-OMA		X	MDW-SFO		X
JFK-MSP		X	LAX-ORD	X	X	MDW-STL	X	X
JFK-MSY		X	LAX-PDX	X	X	MEM-MSY		X
JFK-OAK	X	X	LAX-PHL	X	X	MEM-ORD		X
JFK-ORD	X	X	LAX-PHX	X	X	MEM-SDF		X

TABLE 1
(Continued)

Airport Pairs	RNAV Structures A & B	RNAV Structures C
MEM-SHV		X
MEM-STL	X	X
MGM-MSY		X
MIA-MSY	X	X
MIA-ORD	X	X
MIA-PHL	X	X
MIA-PIT		X
MIA-SFO	X	X
MIA-STL		X
MIA-TPA	X	X
MKC-MSP		X
MKC-ORD	X	X
MKC-SFO		X
MKC-STL	X	X
MKC-TUL		X
MKE-MSP	X	X
MKE-STL		X
MSN-MSP		X
MSP-OMA		X
MSP-ORD	X	X
MSP-SEA		X
MSP-SFO		X
MSY-ORD		X
MSY-TPA		X
OAK-ONT	X	X
OAK-ORD	X	X
OAK-PDX	X	X
OAK-RNO		X
OMA-ORD		X
ONT-SFO		X

Airport Pairs	RNAV Structures A & B	RNAV Structures C
ONT-SJC	X	X
ONT-SMF		X
ORD-PDX		X
ORD-PHL	X	X
ORD-PHX	X	X
ORD-PIT	X	X
ORD-RDU		X
ORD-ROC		X
ORD-SAN		X
ORD-SDF	X	X
ORD-SEA	X	X
ORD-SFO	X	X
ORD-SJC	X	X
ORD-SLC	X	X
ORD-STL	X	X
ORD-SYR		X
ORD-TPA		X
ORD-TUL		X
ORD-TUS		X
PDX-SFO	X	X
PDX-SLC		X
PHL-PIT	X	X
PHL-SFO		X
PHL-STL		X
PHX-SAN		X
PHX-SFO		X
PHX-STL		X
PIT-SDF		X
PIT-STL		X
PSP-SFO		X

Airport Pairs	RNAV Structures A & B	RNAV Structures C
RNO-SFO		X
SAN-SFO	X	X
SDF-STL		X
SEA-SFO		X
SFO-SLC		X
SFO-SNA	X	X
SFO-STL		X
SJC-SNA	X	X
STL-TUL		X
		X
		X
		X
		X
	189 Pairs	429 Pairs

PERCENTAGE OF TOTAL SIMULATED HIGH ALTITUDE TRAFFIC

	A & B	C
TFC Sample 1	39%	65%
TFC Sample 2	40%	65%
TFC Sample 3	39%	65%

RNAV PARTICIPATION LEVELS

One of the objectives of the fast time simulations was to identify the impact of various percentage mixes of RNAV and non-RNAV traffic in the high altitude environment. Five percentage mixes (henceforth referred to in this report as participation levels) were selected for simulation. For simulation of the present VOR/direct structure(the Present High Altitude Structure) a 0% RNAV participation was used. This selection was dictated by the requirement to simulate traffic as actually flown, as discussed in the Traffic Sample section of this report. Route Structures "A", "B", and "C" were simulated using 25%, 50%, 75%, and 100% RNAV participation levels while the preplanned direct route system was simulated using the 100% RNAV participation level only. Since the preplanned direct flight system was simulated as the post-1982 high altitude system proposed by the RNAV Task Force (Ref. 4) only RNAV traffic was assumed to exist at and above 18,000 feet.

In the process of analyses of the fast time simulation results, several approaches were used. While these approaches are discussed in the Simulation Measures section of this report, some discussion is required at this point to avoid any confusion that might result from subsequent references to RNAV participation levels in the presentation of data.

In the simulations, Route Structures "A", "B", and "C" were in turn superimposed on the Present High Altitude Route Structure so as to form networks of RNAV and VOR Routes. This allowed various approaches to be taken in isolating interactions between categories of traffic. Briefly, interactions could be measured as follows:

Case 1 - Between only traffic exchanged between those airport pairs included in Structures "A", "B", or "C" as appropriate (referred to in this report as selected airport pair traffic).

Case 2 - Between selected airport pairs' traffic plus between selected airport pair traffic and all other traffic.

Case 3 - Between all traffic in the simulation including selected airport pair traffic and all other traffic (total system interactions).

When the RNAV participation level is given in the presentation of data in this report, it should be remembered that the participation level refers to the percentage of RNAV operations between the selected airport pairs appropriate to the structure being discussed. For example, in Traffic Sample 2 there were 3842 simulated High Altitude flights departing within the 5-hour period of which 2500 were flights between the selected airport pairs in Structure "C". Therefore, when a measure is discussed for structure "C" based on a 50% RNAV participation level of Traffic Sample 2, it refers to the condition in which 1250 simulated flights used RNAV routes, (50% of the 2500 between selected pairs) not 1921 flights or 50% of the total 3842 simulated.

Still using the example of Structure "C", Traffic Sample 2, and 50% RNAV participation level, Case 1 would consider the interactions only between the 2500 flights (1250 RNAV and 1250 non-RNAV selected airport pair traffic combined), ignoring all other traffic. In Case 2, interactions would be considered only when at least one of the flights involved was one of the 2500 flights. Interactions not involving any of these flights between the selected airport pairs would not be considered. In Case 3, interactions between the total 3842 flights would be considered.

The number of RNAV flights included in each traffic sample at each RNAV participation level for each simulated route structure is presented in Table 2.

TABLE 2

RNAV FLIGHTS SIMULATED

		RNAV HIGH ALTITUDE ROUTE STRUCTURES					
		STRUCTURE A & B		STRUCTURE C		PRE-PLANNED DIRECT	
	RNAV PARTICIPATION LEVEL	NUMBER OF FLIGHTS	% OF TOTAL TRAFFIC SAMPLE	NUMBER OF FLIGHTS	% OF TOTAL TRAFFIC SAMPLE	NUMBER OF FLIGHTS	% OF TOTAL TRAFFIC SAMPLE
TRAFFIC SAMPLE 1	25% 50% 75% 100%	330 660 CONDITIONS NOT SIMULATED	10% 20%	CONDITIONS NOT SIMULATED		CONDITIONS NOT SIMULATED	
TRAFFIC SAMPLE 2	25% 50% 75% 100%	383 766 1148 1531	10% 20% 30% 40%	625 1250 1875 2500	16% 33% 49% 65%	CONDITIONS NOT SIMULATED	
TRAFFIC SAMPLE 3	25% 50% 75% 100%	435 870 1304 1739	10% 20% 30% 39%	CONDITIONS NOT SIMULATED		4401	100%

TEST MATRIX

A total of 22 5-hour periods were simulated, each representing one condition under study. As shown in table 3, the present High Altitude Structure was simulated using Traffic Samples 1,2,and 3, representing traffic densities for the pre-1977, 1977-1982, and post-1982 traffic loads respectively. The network formed by superimposing RNAV High Altitude Route Structure "A" upon the Present High Altitude Structure was simulated under 10 conditions. The conditions were formed by combinations of traffic samples and RNAV participation levels. This was done to permit comparisons between RNAV Structure "A" at all traffic densities when various RNAV participation levels were introduced and the Present High Altitude Route Structure. RNAV High Altitude Structure "B" was simulated only under four conditions. Since the simulation results for Structure "B" under conditions 9, 10, 11, and 12 were found to be extremely close to those for Structure "A" under conditions 5, 6, 7, and 8, it was determined that there would be no purpose in further tests of Structure "B" using Traffic Samples 1 and 3. Comparisons could be made between the present High Altitude Route Structure, Structure "A", and Structure "B" using Traffic Sample 2. RNAV High Altitude Structure "C", like Structures "A" and "B" was also superimposed on the present High Altitude Structure and was simulated under four conditions. While it would have been highly desireable to have examined Structure "C" using Traffic Samples 1 and 3 also, time and financial resources were not available. However, comparison can be made with the other route structures using Traffic Sample 2. The RNAV preplanned direct flight environment was simulated under only one condition since, according to the FAA/Industry RNAV Task Force Report (Ref. 4), this system was conceived as existing in a total RNAV high altitude environment of the post-1982 time period.

It has been suggested that when Traffic Samples 2 and 3 were used only the 100% RNAV Participation Level should be simulated since both these traffic samples were developed to represent post-1977 time periods. This suggestion was based on the RNAV Task Force concept of a 100% RNAV high altitude environment after 1977. While this concept was fully recognized during the planning and conduct of the simulations, certain factors had to be considered which influenced the approach taken.

The first of these factors was a limitation imposed on the RNAV high altitude route structure design efforts performed by NAFEC (Ref. 3). The Air Traffic Service had requested that the NAFEC design efforts be directed only toward development of designs sufficient for the purpose of payoff analysis and RNAV Task Force concepts evaluation. With or without this constraint it would not be feasible to develop a design in a timely manner for a total RNAV route structure connecting all of the 910 airport pairs simulated. The suggestion implies that such a design permitting all traffic in the high altitude airspace to fly via RNAV routes would be a prerequisite for the use of Traffic Samples 2 and 3 in the simulations. Since such a route structure did not exist,

TABLE 3

SIMULATION TEST CONDITIONS MATRIX

	PRESENT HIGH ALTITUDE ROUTE STRUCTURE	RNAV HIGH ALTITUDE ROUTE STRUCTURE "A"				RNAV HIGH ALTITUDE ROUTE STRUCTURE "B"				RNAV HIGH ALTITUDE ROUTE STRUCTURE "C"				RNAV PREPLANNED DIRECT FLIGHT
	% RNAV PARTICIPATION	% RNAV PARTICIPATION				% RNAV PARTICIPATION				% RNAV PARTICIPATION				% RNAV PARTICIPATION
		25%	50%	75%	100%	25%	50%	75%	100%	25%	50%	75%	100%	100%
TRAFFIC SAMPLE 1 (PRE-1977 TRAFFIC)	*1	*2	*3											
TRAFFIC SAMPLE 2 (1977-1982 TRAFFIC)	*4	*5	*6	*7	*8	*9	*10	*11	*12	*13	*14	*15	*16	
TRAFFIC SAMPE 3 (POST-1982 TRAFFIC)	*17	*18	*19	*20	*21									*22

The asterisk (*) and numbers indicate the conditions simulated.

certain projections are made in this report (based on the trends established using Traffic Sample 2 and 100% RNAV Participation Level and examining conflicts only between selected airport pair traffic) to estimate what might be expected if all aircraft in the high altitude airspace could use charted RNAV routes. As far as the actual conditions simulated, a 100% RNAV condition (that is, the condition in which all 3842 flights were RNAV traffic) could only be simulated for a preplanned direct RNAV environment since no route structure design as such was required.

The second factor was the interpretation of the time phases used in the FAA/Industry RNAV Task Force Report. The Task Force concept assumed a mix of high altitude RNAV and non-RNAV traffic in the 1972 to 1977 time period and a 100% high altitude RNAV environment after 1977. When the fast time simulations were being planned in 1973, it seemed unlikely that in four years all high altitude traffic would be RNAV equipped or that a charted RNAV route structure would be implemented providing routes and transitions for all airports served through the present high altitude route system. Now, in 1976, the likelihood of such an environment existing by 1977 appears less likely. Therefore, the simulation approach taken allowed for two points: 1) that the time phases used in the RNAV Task Force Report should be considered as a means of identifying phases of concept development, not actual times at which the conceptual changes occur; and 2) that traffic densities would increase above present levels (possibly as much as that used for Traffic Sample 3) while RNAV and non-RNAV traffic continue to share the high altitude airspace.

SIMULATION MEASURES

A number of measures were taken during the simulations. The most important of these was the number of "conflicts" which occurred in each condition tested. Due to the lack of controller intervention, which could not be provided in the fast time simulations, a measure was needed to indicate an increase/decrease in the requirement for controller intervention (an indication of controller workload and ATC imposed restrictions) between each condition. The term "conflict" is used in this report to describe any situation in which two simulated aircraft approached within less than 5 N. M. of each other with less than 1000 feet vertical seperation at or below 29,000 feet or 2000 feet vertical separation above 29,000 feet. While in a number of cases, this "conflict" criteria declares a conflict when no conflict condition existed (e.g., traffic in a climbing or descending attitude has passed just prior to violation of the altitude criteria), from the air traffic control standpoint,control intervention would be required to insure separation was maintained rather than leaving such situations to chance. It is also recognized that controller intervention would frequently occur when no actual conflict is imminent in the real world. This is due to a major extent to controllers' inclination to avoid the necessity for last minute actions and insuring an extra margin of safety by managing traffic and imposing restriction in advance of any urgent need for intervention. Therefore, the number of "conflicts"

as an indication of the frequency of controller intervention actions is probably a major understatement of the actual number of interventions which in fact would occur in the real world under like traffic conditions.

The importance of the "conflict" measures was the indices that they provided for comparison of overall controller intervention requirements.

The exact number of times intervention might be required is not the important factor in making comparisons between the test conditions. While it is always nice to be able to provide absolute numbers from a simulation that can be directly related to a real world environment, the critical issue is to provide quantitative data for comparisons between the conditions tested. For example, let us assume that by some means it could be determined that the potential for overtake conflicts in the real world environment which would occur using the Present High Altitude Route Structure and the traffic density of Traffic Sample 2 would equal 900 potential conflicts unless delays, altitude restrictions, etc., were imposed by the ATC system. It would be nice, in simulation of the same condition, to detect 900 potential conflicts also. However, this would not be necessary if simulation results are properly applied. If, in simulation of the present system only 300 potential overtake conflicts were detected rather than the 900, the number (300) can be used for comparision with the number of potential overtake conflicts detected in the simulation of a second condition. Let us say for the purpose of this discussion that 200 potential overtake conflicts were detected in the second condition simulated. Since the conflict measure was taken in the identical manner in the simulation of both conditions, a valid comparision can be made between the two values, 300 and 200. In other words, it can be stated that in the simulation of both conditions, the second condition had one-third less of this type of conflict than the first.

The "conflicts" measured are not only important as indices of controller workload, but provide some insight into how well each condition tested might be expected to serve the users of the system. As potential conflicts increase or decrease, the requirement for controller intervention increases or decreases also. In turn, any increase/decrease in controller intervention requirements can be expected to reflect in an increase/decrease in ATC restrictions imposed on the users of the system. Such restrictions may take the form of delays, undesireable altitude assignments, increased flight miles, restrictions to climb or descent, etc. The nature or form of the ATC restrictions which might be imposed as the result of controller interventions could not be determined through fast time simulation. However, some insight was provided through limited controller intervention tests described later in this report.

The following "conflict" measures were taken:

- System conflicts
  A measure of all conflicts between all simulated traffic, including selected airport pair traffic in addition to all traffic between all other airport pairs.
- Selected Airport Pair traffic conflicts
  A measure of all conflicts between only traffic between the selected airport pairs appropriate to the RNAV structure simulated.
- Conflicts involving Selected Airport Pair traffic
  A measure of all conflicts in which at least one of the aircraft involved was a flight between the Selected Airport Pairs appropriate to the RNAV structure simulated.
- Type of conflict
  A measure of the number of conflicts by types categorized as "overtakes," "intersection," diverge," "head-on," etc.
- Conflict duration
  The time from start of conflict (time at which vertical separation or five-miles horizontal separation ceases to exist) to end of conflict (time at which either vertical or horizontal separation is regained)
- Location of conflict by route
  A record of the routes and route segments involved at start of conflict and end of conflict.
- Altitudes of aircraft involved (in feet)
  The altitudes at start and end of conflict for each aircraft involved.
- Aircraft type by category
  The aircraft type category for each aircraft involved.
- ARTCC sectors involved
  The ARTCC sector(s) in which each conflict begins.
- Attitude of flight & rate of altitude change
  The attitude (climbing, descending, or level flight) of each flight involved and the rate of altitude change at start and end of each conflict.
- Airspeed
  The airspeed of each aircraft involved at start and end of each conflict.
- Location of each conflict by latitude/longitude
  The latitude and longitude of each aircraft involved at start and end of each conflict.
- Airport pairs involved
  The airport of departure and destination of each flight involved in each conflict.
- Navigation system
  A record of type of route being flown (RNAV or non-RNAV) for each flight involved.

In addition to conflict data, other measures were also collected during each fast time simulation run. These measures included the following:

- Route segment loading for each 15-minutes of simulation
  A count of the number of aircraft on each route segment taken at 15-minute intervals.
- Instantaneous count of traffic
  A count of all high altitude traffic in the simulation taken at 15-minute intervals.
- Total flights introduced
  A record of the total number of fights introduced into each simulation run.

SIMULATION ASSUMPTIONS

The nature of simulations (both fast time and real time) is such that some assumptions or ground rules must be established for the conduct of the simulation tests. Assumptions made for the definition of the environments tested are called Class 1 assumptions in this report to differentiate between this group and a second group of assumptions (Class 2) which were required for data collection and interpretation purposes. The following is a listing of the major Class 1 and Class 2 assumptions.

Class 1 Assumptions

1. Special use airspace is not considered as a constraint to high altitude RNAV route structure design. This assumption is based on the RNAV Task Force Report Action Plan (Ref. 4).
2. Airport capacity is not considered as a constraint in the simulation of increased traffic densities (other than the constraint represented by the 32-second minimum interval imposed between departures for any one airport for all traffic samples.) This assumption is based on the requirement to examine increased traffic densities for future time periods which probably exceed present busy airport capacities.
3. The high altitude RNAV structures simulated embody the features of, and are sufficiently representative for simulation purposes of, the high altitude routes which might be implemented at a future date in the National Airspace System, based on the Task Force concepts. The advantages/disadvantages of the route structures simulated provide an indication of what might be expected as a result of implementing an RNAV high altitude structure in the real world based on similar design concepts (Ref. 3) as those used in the simulated structures.
4. The RNAV participation levels simulated (0%, 25%, 50%, 75%, and 100%) might be present at any of the three traffic densities represented by Traffic Samples 1, 2, and 3. This assumption is required to determine the impact of a range in the percentage of RNAV operations in the high altitude airspace (Ref. 4). The specific RNAV participation levels selected for fast time simulation were chosen in order to be the same as those used for statistical analysis purposes in a terminal area RNAV simulation conducted at NAFEC (Ref. 6).

5. Traffic Sample 1, based on 1969 peak day traffic data, is sufficiently representative of traffic densities and distributions of a busy or peak pre-1977 five-hour period. It is recognized that the 1969 peak day data used for traffic sample development does not represent a condition which occurred on a single day in 1969, but rather a composite of the peak day traffic of each Air Route Traffic Control Center (ARTCC). However, in the absence of data for a single common day for all ARTCC's, this data base was used as the best available.
6. Traffic Samples 2 and 3, which include 15% and 31 % increases in traffic densities over Sample 1 are sufficiently representative of traffic densities and distributions to be used to represent busy or peak five-hour periods of 1977 to 1982 and post-1982 conditions.
7. Traffic loaded into the simulated route structures prior to the start of the selected five-hour data period provides for a realistic traffic build-up during the five-hour test period. High altitude traffic from the peak day tape for the six-hour period prior to the start time for data collection (2100Z) was analyzed and the traffic which could be assumed to be airborne at 2100Z was present on the appropriate routes and altitudes at the start of the data collection period.

Class 2 Assumptions

1. A totally optimum ATC system from the user point of view would permit all traffic to depart at system user desired times, climb and descend unrestricted by Air Traffic Control imposed constraints, and conduct flights at desired altitudes via desired routes. The closer this optimum condition is approached while not adversely affecting safety the greater the merit of the system.
2. Controller workload reduction is experienced as the need for controller intervention to insure separation between traffic is reduced. Therefore, a measure of benefit to both the ATC system user and the controller can be provided by testing conditions in which all flights are conducted as proposed in the flight plans, and measuring the number of times controller intervention would be required to avoid traffic conflicts (the lower the number of potential conflicts, the fewer ATC restrictions required).
3. A conflict rate as determined in fast time simulation of the Present High Altitude Route Structure using Traffic Sample 1 (pre-1977 traffic) provides an index of the present need for controller intervention and restrictions imposed on present traffic. Any percentage increase/decrease in conflicts resulting from the introduction of Traffic Sample 2 or 3 (1977 to 1982 and post-1982 traffic respectively), variations of RNAV participation levels, and RNAV route structures is representative of corresponding increase/decrease in controller workload related to conflict prevention and resultant ATC

flight restrictions imposed.

4. System capacity has a direct relationship to the number of potential conflicts. While other factors also have an impact on system capacity, where traffic can be increased in one condition over that of another and the number of potential conflicts remain the same or are reduced, a measure of system capacity (as influenced by the conflict potential) is provided.

SIMULATION RESULTS

ROUTE LENGTHS

Comparisons were made of the route lengths between airport pairs for the Present High Altitude Structure and RNAV High Altitude Structure "B" in the preliminary fast time simulation report (Ref. 2). This comparison showed that the RNAV routes were an average of approximately 1.8% shorter than the present high altitude route structure between the same airport pairs. It was also determined that the RNAV routes of Structure "B" were approximately 1.1% longer than the unmodified great circle routes between the same airport pairs. These comparisons did not take into account any increase/decrease in total flight miles that might result within terminal airspace from the introduction of RNAV routes or adherence to a wagon wheel concept (Ref. 5) within the subject terminal areas, nor did they consider any additional mileage that might be added in structure "B" or the modified great circle distance resulting from any possible requirement to by-pass special use airspace.

During the simulations, a count of high altitude traffic was made each 15-minute period. As the level of RNAV participation increased, a reduction in this instantaneous traffic count resulted. Figure 10 shows the reductions in the instantaneous traffic counts between 0% and 100% RNAV participation levels in Traffic Sample 2 when the Present High Altitude Structure was compared to the network formed when Structure "B" was superimposed on the Present Structure. Since traffic was counted at precisely the same times during each simulation run and the flights take off at the same times regardless of the RNAV participation level introduced, the instantaneous traffic counts are a direct reflection of the time in system for the traffic. In the fast time simulations the factor controlling the time in system for any given flight was the route length of the path to be flown. Therefore, the average reduction in traffic counts over the five-hour periods for the 0% and 100% RNAV participation levels for Structure "B" is in line with the data from the analysis of route length difference discussed in the previous paragraph. Comparison of the route mileage and flight miles (route miles times the number of aircraft using the route) have now been made between RNAV High Altitude Route Structure "C", the Present High Altitude Structure and unmodified great circle routes for all airport pairs included in Structure "C". While the same trends are evident, differences are more marked in the comparisons with Structure "C" than they were for Structure "B". Structure "C" showed 2.89% average savings in route mileage and 2.40% savings in flight miles compared to the Present High Altitude Structure and an approximate average increase of only 0.4% over unmodified great circle routes and flight miles. These comparisons are based on the 24-hour traffic of the 1969 peak day. A discussion of these mileage differences is contained in Reference 3.

SYSTEM CONFLICTS

In order to determine the effect of introducing additional routes

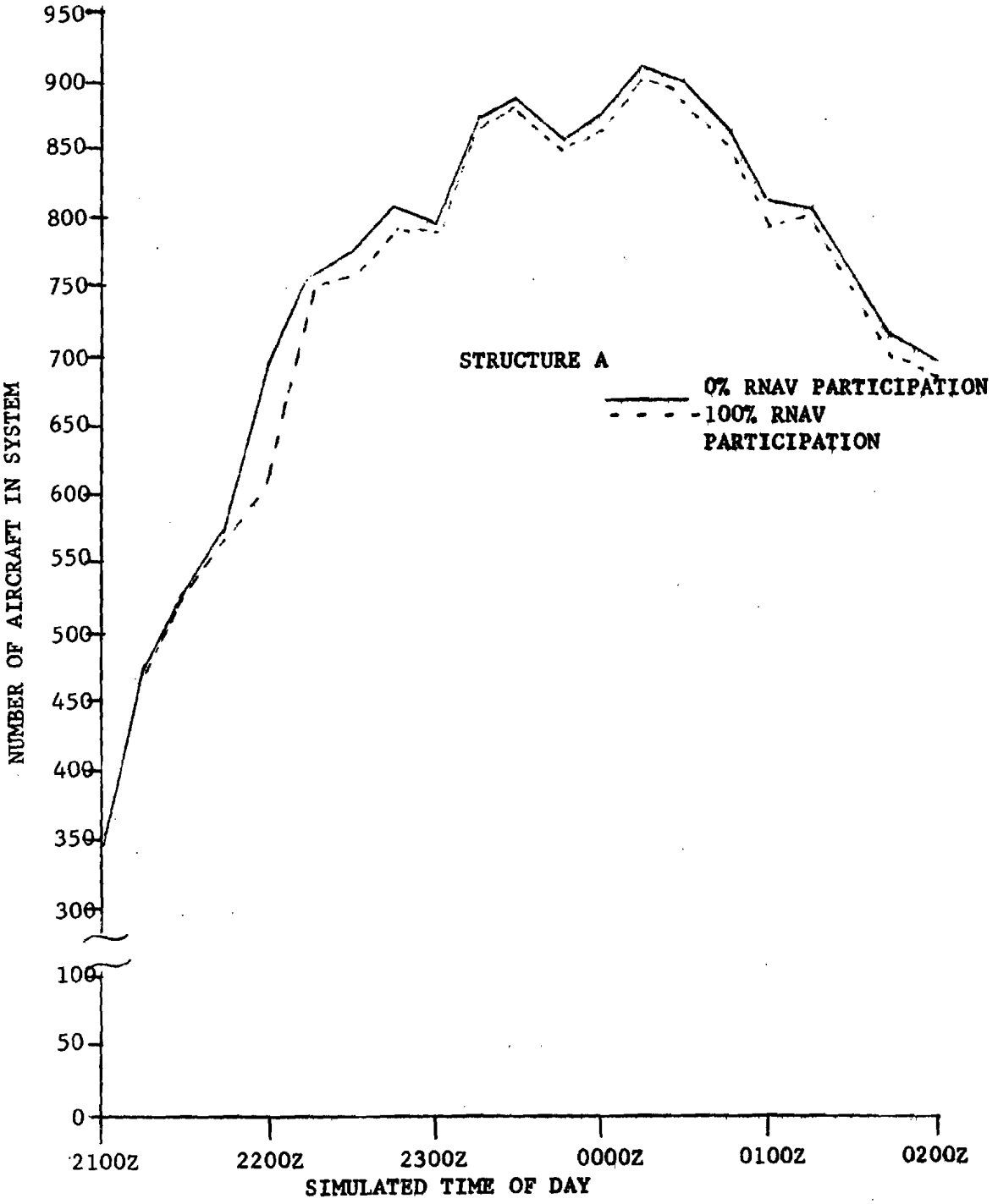


Figure 10 - Instantaneous High Altitude Traffic Counts

(RNAV routes) and RNAV traffic into the Present High Altitude Structure, conflicts were recorded during the simulations. It should be remembered that the number of conflicts which occurred in each simulation were counted to provide indices primarily of controller workload which would be required for conflict prevention, and ATC restrictions imposed on the system user. For this purpose conflict data were examined in a number of ways. This section addresses the total number of conflicts which occurred in each condition simulated and the distribution of conflicts between ARTCC high altitude sectors. The data presented in this section includes conflicts between all traffic simulated (both Selected Airport Pairs' Traffic for which RNAV routes were simulated and the airport pairs' traffic for which RNAV routes were not provided).

Figure 11 depicts the total number of conflicts (System Conflicts) which were detected in simulations of 13 of the conditions tested. These conditions included tests of the network formed by superimposing RNAV High Altitude Structure "A" on the Present High Altitude Structure with 0%, 25%, 50%, 75% and 100% RNAV Participation Levels using Traffic Samples 1, 2, and 3. In addition, the conflicts which resulted from the test of the RNAV Task Force pre-planned direct flight concept using Traffic Sample 3 is presented.

Several points are apparent from an examination of the data shown in figure 11. The pre-planned direct system presents the greatest number of conflicts. However, the system conflicts (1273) for the direct flight system was only approximately 1% greater than that of the Present High Altitude Structure (1260) shown for the 0% RNAV Participation Level using the same traffic density (Traffic Sample 3). However, as the RNAV Participation Level was increased to 50%, 75%, and 100% using Structure "A" and still using Traffic Sample 3, conflicts were 10% to 11% less in all cases than those of the direct flight system and ranged from 9% to almost 11% below that of the 0% RNAV Participation Level. While the increases in traffic density for Traffic Samples 2 and 3 over Traffic Sample 1 were approximately 15% and 31% respectively, conflicts in tests of the 0% RNAV Participation Level increased over Sample 1 by approximately 20.7% for Traffic Sample 2 and 57.7% for Traffic Sample 3. This points up both the sensitivity of the conflict measures to increases in traffic demand and the apparent need for modification/improvement to the Present High Altitude Route Structure to avoid future heavy increases in controller workload and ATC imposed restrictions.

In all conditions tested, with the exception of the direct flight system, an advantage was shown as the result of RNAV participation in reductions in systems conflicts. These reductions, found in Structure "A", ranged from approximately 5.8% to 12.4% below the 0% RNAV Participation Level, depending upon the traffic sample and Participation Level used.

An examination of the trend in system conflicts for RNAV High Altitude Structure "A" shows that the fewest conflicts occurred at the

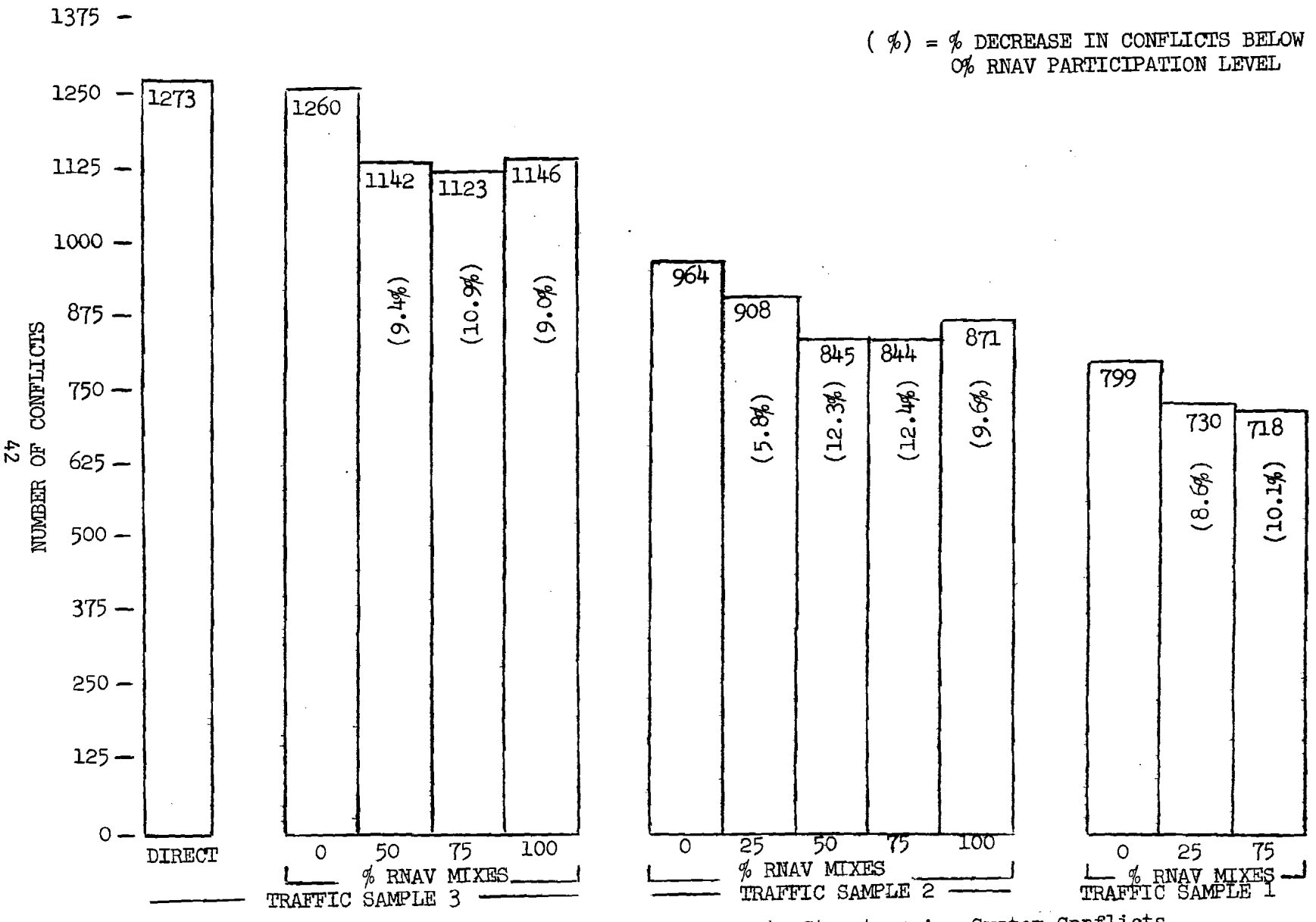


Figure 11 - RNAV High Altitude Route Structure A - System Conflicts

50% and 75% Participation Levels, with an increase at the 100% level. While the number of conflicts at the 100% RNAV Participation Level was still lower than that of the 0% Level, this increase identified a problem in the RNAV structure simulated. This problem was determined to be the result of an overloading of the RNAV routes as all traffic between the Selected Airport Pairs was shifted from the Present High Altitude Structure routes to the RNAV routes. As mentioned in the Traffic Samples section of this report, in a number of cases, traffic between airport pairs is distributed over several alternate routes. In the RNAV High Altitude Structure "A", due to the limited number of routes provided, traffic was restricted frequently to one or two routes, where in the Present High Altitude Structure the same traffic was distributed over a greater number of routes. RNAV High Altitude Structure "C", discussed later, did much to correct this problem.

Comparisons between Structure "A" and "B" are shown in Figure 12. Since RNAV High Altitude Structure "B" was identical to Structure "A" in all respects other than the map projection system, discussed in the Route Structures section of this report, comparisons between the networks formed by superimposing each of these two structures on the Present High Altitude Structure is of interest only in the examination of route network interactions caused by this adjustment. RNAV Structure "B" was only simulated using Traffic Sample 2.

The same trends in conflict reductions were found in both RNAV Structures "A" and "B". Conflict reductions were found ranging from 6.7% to 10.8% below the 0% RNAV Participation Level for Structure "B" as opposed to a range of 5.8% to 12,4% for Structure "A". The same trend of the lowest number of conflicts occurring at the 50% and 75% Participation Levels was found in Structure "B" and in Structure "A", as expected.

The System Conflicts detected when RNAV High Altitude Structure "C" was superimposed on the Present High Altitude Structure is shown in Figure 13 for comparison with Structure "B". Structure "C" was the most comprehensive high altitude RNAV structure developed by NAFEC and incorporated various design improvements (Ref. 3). Structure "C" provided RNAV routes for 429 airport pairs while Structures "A" and "B" provided RNAV routes for only 189 airport pairs. In addition, Structure "C" provided additional parallel routes between certain airport pairs for which simulations of structures "A" and "B" indicated additional routes were required.

A major improvement in the number of System Conflicts at all RNAV Participation Levels was found for Structure "C" in comparisons with both the Present High Altitude Structure and RNAV High Altitude Structure "B". The trend for an increase in System Conflicts at the 100% RNAV Participation Level is removed in Structure "C" indicating that the problem of RNAV route overload had been corrected to a major extent in the design.

Comments received on the Preliminary Fast Time Simulation Results

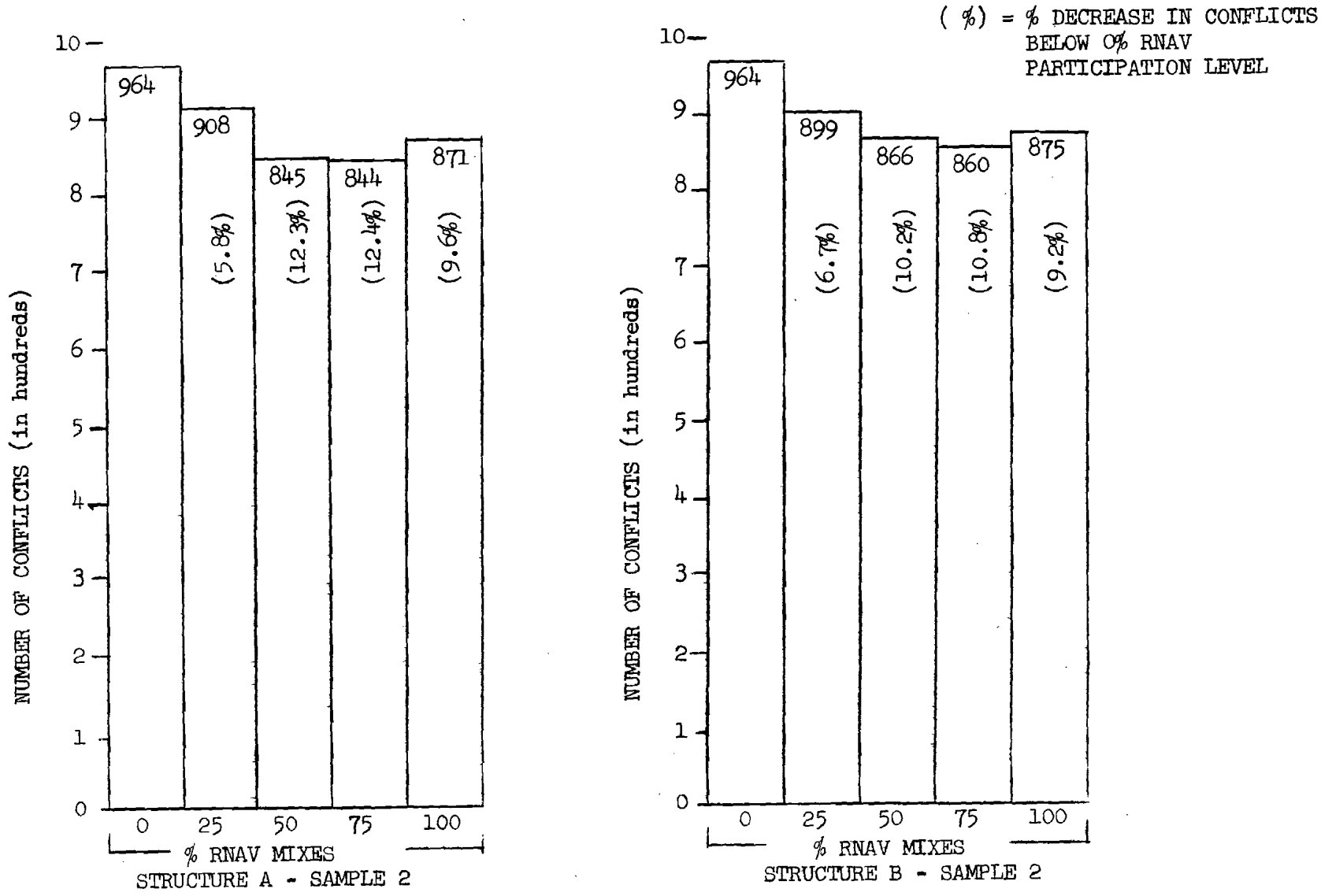


Figure 12 - RNAV High Altitude Structures A and B Comparisons of System Conflicts

(%) = % Decrease in Number of Conflicts Below 0% RNAV Participation Level

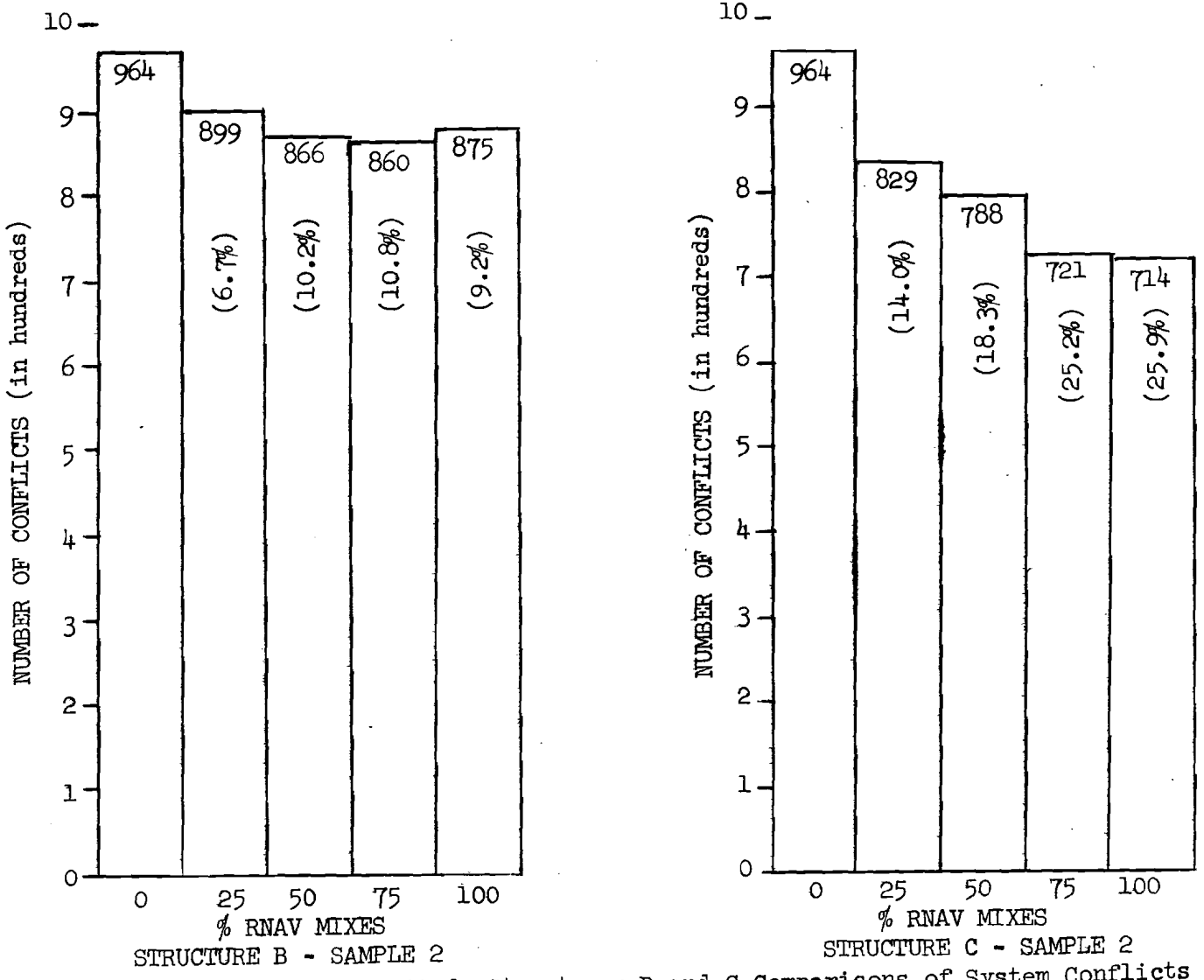


Figure 13 - RNAV High Altitude Structures B and C Comparisons of System Conflicts

Report, which did not include data on Structure "C", stressed the point that the reductions in the number of conflicts resulting from the introduction of RNAV routes/RNAV traffic was in actual numbers very small when distributed over all high altitude ARTCC sectors for the simulated five-hour period. That is, the 9.2% reduction in system conflicts found by comparison of the network formed by Structure "B" and the Present High Altitude Structure at the 0% and 100% RNAV Participation Levels represents a reduction of only 89 conflicts over the total five-hour period. Viewed in that light, a reduction of 9.2% does appear at first glance to be of little practical importance particularly when one assumes that the reduction should be averaged out, not only amoung all high altitude sectors, but for the five-hour period, yielding an hourly reduction of only approximately 20 conflicts per hour over the entire network. However, there are certain basic errors in this type of interpretation of the data. First, the assumption that the actual values (number of conflicts) provided by the simulations are the same number of times controller intervention would be required in the real world to prevent potential conflicts is erroneous. The data should be used as indices of what might be expected in the real world and percentage changes, rather than absolute values, are the important factor. Second, as shown in figure 14, conflicts are not distributed equally over all ARTCC sectors as was assumed by this interpretation of the data. A third error is the assumption that the conflicts would be more or less equally distributed over the five-hour period simulated. As shown in figure 15, conflicts were not distributed equally over the five-hour period.

It is appropriate to again stress the manner in which the simulations conflict data should be used. The actual numbers of conflicts must be considered as an index to what might be expected in the real world, not as absolute values. For example, in a report prepared by Stanford Research Institute (SRI), the Air Traffic Controllers' Contribution To ATC System Capacity in Manual and Automated Environments (Ref. 7), an analysis of controller workload for Sector 42 of the Oakland ARTCC was conducted. In the SRI report, it was stated that thirty minutes of the combined radar and handoff controllers' decision making time per hour would be required (in their model) to handle thirty aircraft per hour. This was based upon the peak morning and afternoon rush periods, experienced by that sector at the time the study was conducted (prior to 1973). The SRI controller workload model gave the following breakdown of the control team decision making time:

TABLE 4

Controller Decision--Making Time - 30 Aircraft Per Hour

Event	Minimum Decision-Making Time Required (Minutes)
Potential Conflicts	6
Handoffs	6
Pointouts/Coordination	3
Traffic Structuring and Workload	15
Management Total	30

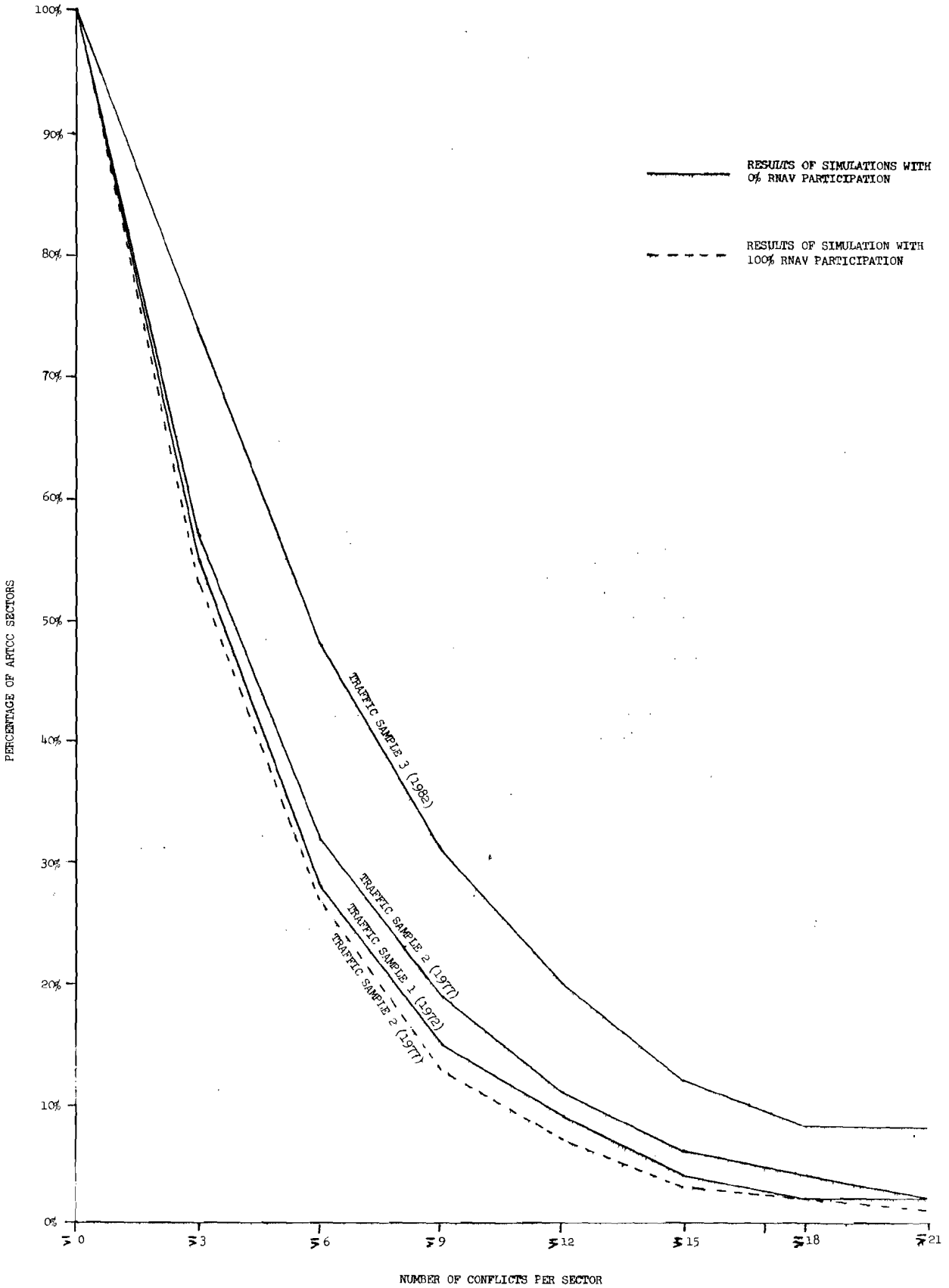


Figure 14 - Distribution of Conflicts by ARTCC Sector - Traffic Samples 1,2, &3

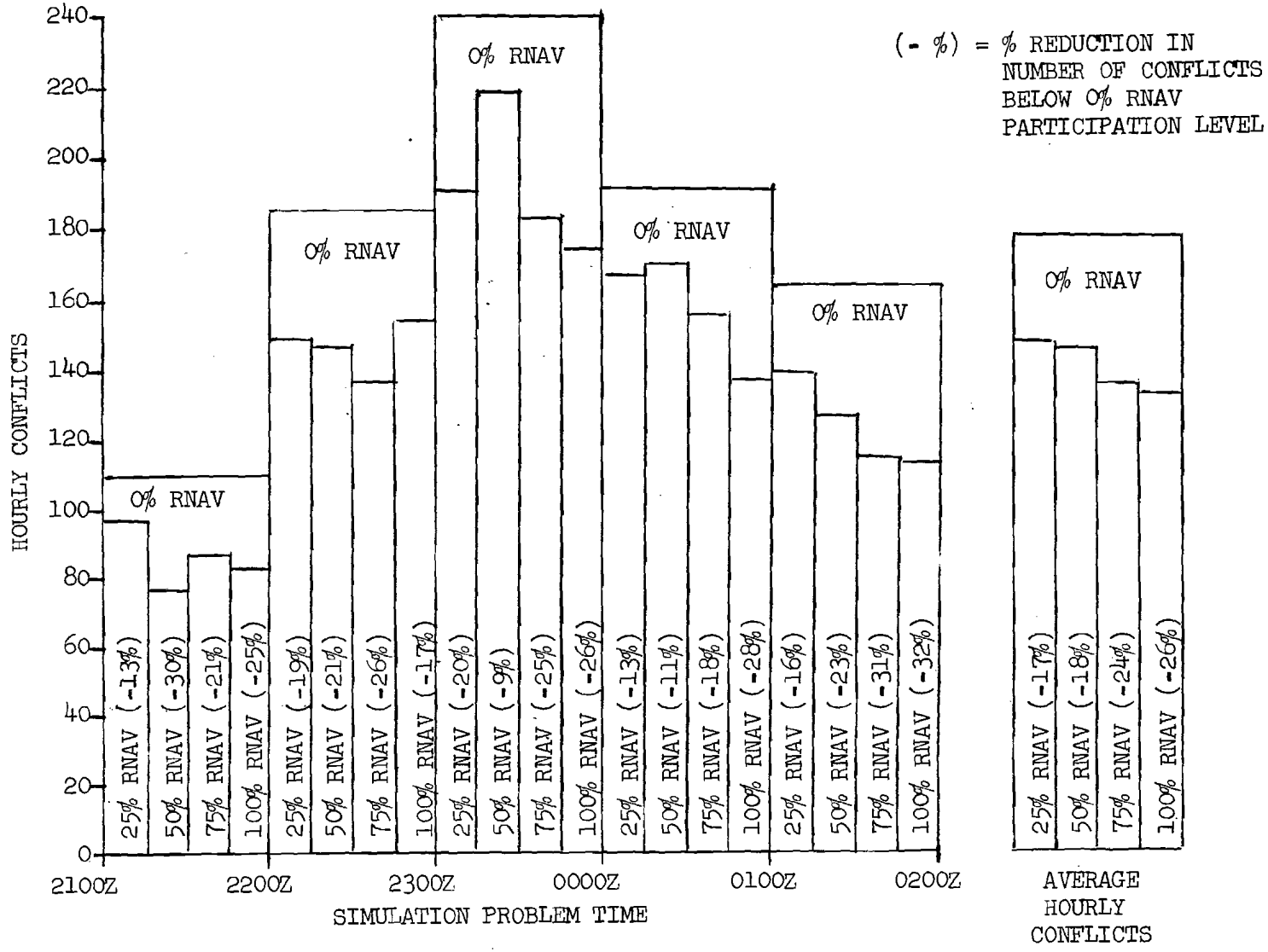


Figure 15 - Hourly Conflict Rates (Structure C - Traffic Sample 2)

The SRI model used one minute of decision making time per potential conflict in this model and assumed that handoffs and pointouts (a term used by SRI for identification of targets) and other coordination events were handled by the handoff controller (9 minutes), leaving the remaining twenty one minutes as decision making time attributed to the radar controller. Based on this model of 30 operations per hour through this sector, the radar controller spent approximately 28% of his decision making time in the resolution of six potential conflicts.

As discussed in the SRI report, it was concluded that decision making time would become a sector capacity limiting factor about when the radar controller was spending half of his time in decision making. The report stated that this condition would be reached at about 40 flights per hour through Sector 42 as shown below:

TABLE 5

Controller Decision Making Time - 40 Aircraft Per Hour

Event	Minimum Decision Making Time Required (Minutes)
Potential Conflicts	12
Handoffs	8
Pointouts/Coordination	4
Traffic Structuring and Workload Management	20
Total	44

The SRI model again used one minute of decision making time per potential conflict in the model and assumed that handoffs and pointouts and other coordination events were handled by the handoff controller (12 minutes), leaving the remaining 32 minutes as decision making time attributed to the radar controller. Based on the model of 40 operations per hour through this sector, the radar controller spent approximately 37% of his decision making time in the resolution of twelve potential conflicts. An examination of tables 4 and 5 shows that the model uses a constant value of .5 minutes per flight for traffic structuring and workload management by the radar controller regardless of the traffic density and as previously mentioned, a constant of one minute of decision making time per potential conflict. Based on the SRI model of Sector 42, and accepting the position that thirty-two minutes of decision making time per hour for the radar controller is a controlling factor for the capacity of the sector, the importance of a reduction in the number of conflicts becomes apparent. A reduction of one conflict would save one minute of decision making time which, according to the model, is equal to the traffic structuring and workload management time for two additional flights. Accordingly, a 10% reduction in potential conflicts would permit a 6% increase over the 40 flight sector capacity; a 20% reduction in potential conflicts would permit a 12% increase; etc.

During the fast time simultations the maximum number of conflicts found for the Oakland ARTCC Sector 42, under all conditions tested, was 13 distributed over the five-hour period. A conflict rate of 12 or even 6 potential conflicts per hour was never detected. Assuming that the distribution of conflicts by time for Sector 42 is the same as that for the entire system as shown in figure 16, it is probable that approximately only four potential conflicts (30% of the total) occurred within Sector 42 in any single hour, or only 33% of those projected in the SRI Sector 42 capacity model (table 5) and approximately 67% of those of the 30 flight model (table 4). Simulation conflict data was analyzed by sector and by time for the entire system, but not by time for each sector. The actual number of potential conflicts by sector for any selected hour is not known. However, it would be incorrect to assume that the 13 conflicts for the five-hour simulated period or the estimated four conflicts for the worst case hour should be accepted as absolute measures of the number of conflicts which might be expected in the real world for Sector 42. It would also be risky to assume that the number of simulated conflicts should be multiplied by some stated quantity to derive a real world conflict estimate. It is reasonable, however, to recognize the fact that real world conflicts would be considerably higher than those detected in the simulations. From a purely subjective standpoint, it does not appear to be unreasonable to assume that only a portion of the real world potential conflicts were detected in the fast time simulations. The use of percentage increase/decrease in simulation conflicts as a measure of system/user benefit remains valid even though the number of simulation conflicts is undoubtedly substantially less than those that would exist in the real world without ATC imposed restrictions.

The distribution of System Conflicts by sector was examined. While recognizing that the introduction of a high altitude RNAV structure, such as Structure "C", would probably result in modification to ARTCC sector boundaries, existing sectors were used to identify the geographic areas in which simultated conflicts occurred. The data presented in table 6 and figure 16 are for Traffic Sample 2 and compare the numbers of conflicts which were detected in the simulation of 0% and 100% RNAV Participation Levels using the network formed by RNAV High Altitude Structure "C" and the Present High Altitude Structure.

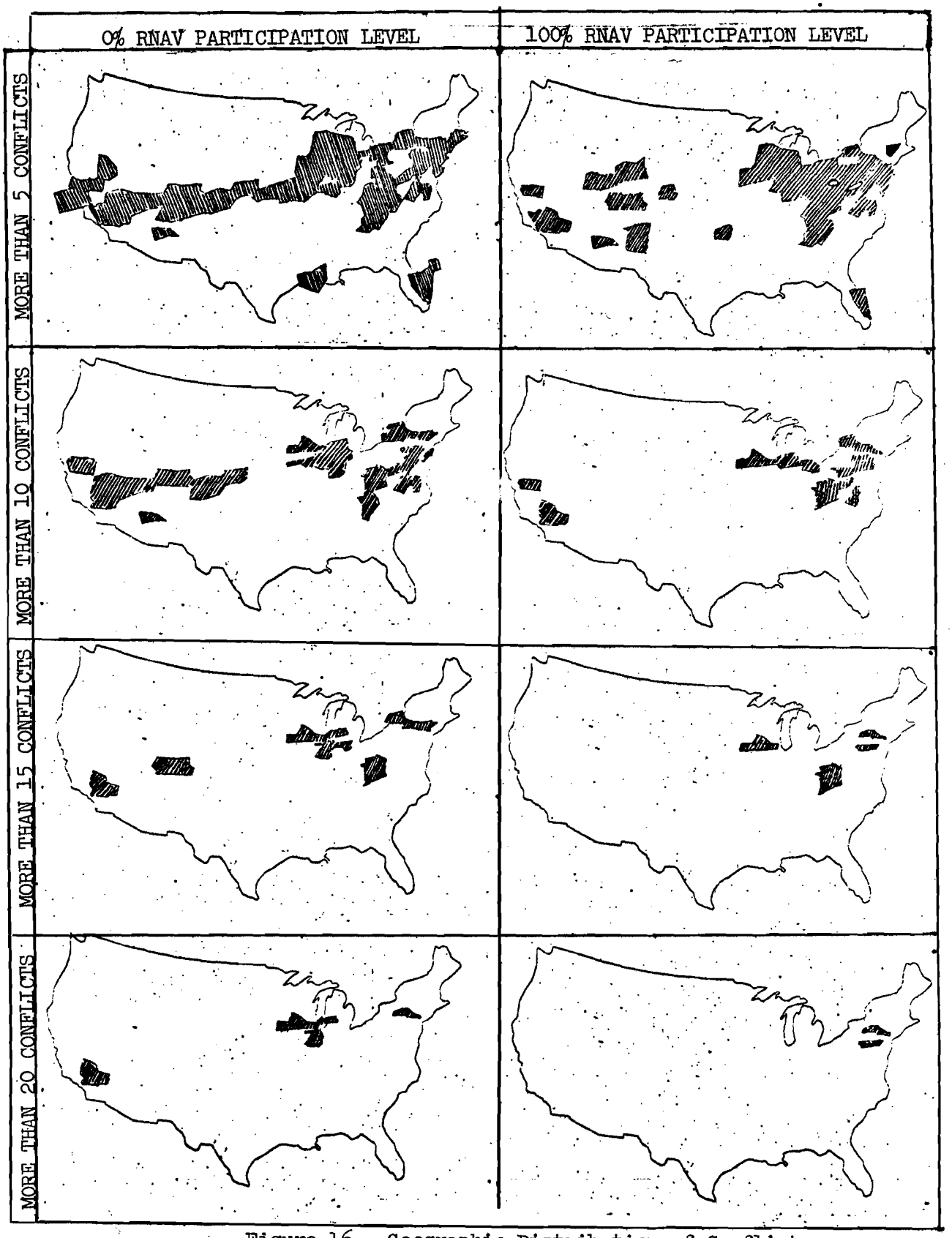


Figure 16 - Geographic Distribution of Conflicts

TABLE 6

Conflicts by Sector

Number of Conflicts in ARTCC Sector	Number of ARTCC Sectors in which Conflicts Occurred: 0% RNAV Participation Level	100% RNAV Participation Level
More Than 20 Conflicts	5	2
More Than 15 Conflicts	10	4
More Than 10 Conflicts	27	15
More Than 5 Conflicts	57	48
1 or More Conflicts	170	155

The number of sectors with the higher conflict counts (more than 10 conflicts during the simulated five-hour period) were substantially lower for the 100% RNAV Participation Level than for the 0% level. The benefit in the reduction in the total number of system conflicts found for Structure C using Traffic Sample 2 (26% less conflicts) from those found for the Present High Altitude Route Structure becomes more apparent when the reduction impacts to a major extent on those sectors with the higher conflict rates. For example, there were 143 ARTCC sectors having from one to ten system conflicts using the Present High Altitude Structure as opposed to 140 ARTCC sectors at the 100% RNAV Participation Level using the network formed with RNAV Structure C (a reduction of approximately only 2% in the number of sectors). However, where the conflict rates were higher (more than ten), the number of sectors involved is reduced from 27 to 15, or a 44% reduction in the number of sectors having these higher conflict counts, indicating that the RNAV Structure C provided the greater benefit in conflict reductions where the benefit was most needed.

Figure 16 graphically illustrates the distribution of system conflicts by sector. Due to the introduction of RNAV Structure C, conflicts are redistributed geographically to some extent. This is most apparent in the illustration of the ARTCC sectors having more than five conflicts each. The chain of sectors extending from California to New York in the present system is broken in the 100% RNAV Participation Level and some sectors to the north and south of a line formed by the chain appear in the RNAV structure. The rest of Figure 16 shows graphically the reductions of the number of sectors having more than ten conflicts. It is important to note that while a substantial improvement resulting from the introduction of 100% RNAV in Structure C is apparent, two sectors in the vicinity of New York had high conflict rates. This appears to be a fault in the RNAV structure design which is discussed in reference 3.

Figure 17 depicts the distribution of system conflicts by time for the network formed by RNAV Structure C and the Present High Altitude Structure for all RNAV Participation Levels using Traffic Sample 2. At all levels of RNAV participation, a peak number of conflicts occurred between 2315 G.M.T. and 2330 G.M.T. The "worst hour" (the hour in which the most conflicts occurred) fell about the mid-point of the simulated five-hour period. The worst hour for the 25%, 50%, 75%, and 100% RNAV Participation Levels consistently showed fewer conflicts than that of the 0% RNAV Participation Level (reductions of 21%, 14%, 26% and 27% respectively).

Figure 18 compares the time distribution of conflicts for the 0% and 100% RNAV Participation Levels when simulated using RNAV Structure C and the Present High Altitude Route Structure network. The instantaneous traffic counts for each fifteen-minute period are presented in the figure to illustrate the relationships of conflicts to traffic density. In the lower illustration in figure 18, there is a rather well marked relationship between traffic density and conflicts for the 0% RNAV Participation Level. However, in the top illustration of the 100% RNAV Participation Level, there is very little relationship shown, indicating that the use of well designed RNAV routes tend to provide a capability to accomodate peaks in total traffic considerably better than the Present High Altitude Structure.

Figure 19 provides a comparison of the numbers and types of total System Conflicts for both networks formed by the Present High Altitude Structure with RNAV High Altitude Structure B and with Structure C. Since traffic in the 0% RNAV Participation Level uses only the Present High Altitude Structure in both networks, the data is identified only as the 0% RNAV Level once for each measure rather than repeated for each network structure.

Marked reductions are found for both RNAV Structures B and C at RNAV Participation Levels of 25% to 100% in the number of overtake conflicts. The reduction in overtake conflicts for Structure B range from 25% at the 100% RNAV Participation Level to 32% at the 50% RNAV Participation Level. Structure C shows reductions of 37% at the 100% RNAV Participation Level to 49% at the 50% Participation Level. Since potential overtake conflicts are frequently resolved in the Air Traffic Control system by assignment of an altitude other than requested by the pilot, it can be reasonably assumed that a reduction in overtake conflicts would be reflected in less frequent assignment by ATC of other than pilot desired altitude.

An increase is found in the number of intersection conflicts at all RNAV Participation Levels except the 100% Level of Structure C. The worst case of this increase is found for the 50% RNAV Participation Level of Structure B (23% increase over 0% RNAV Participation). In Structure C, the worst case, also at the 50% Participation Level, shows an increase of 19% compared to the 0% RNAV Participation Level.

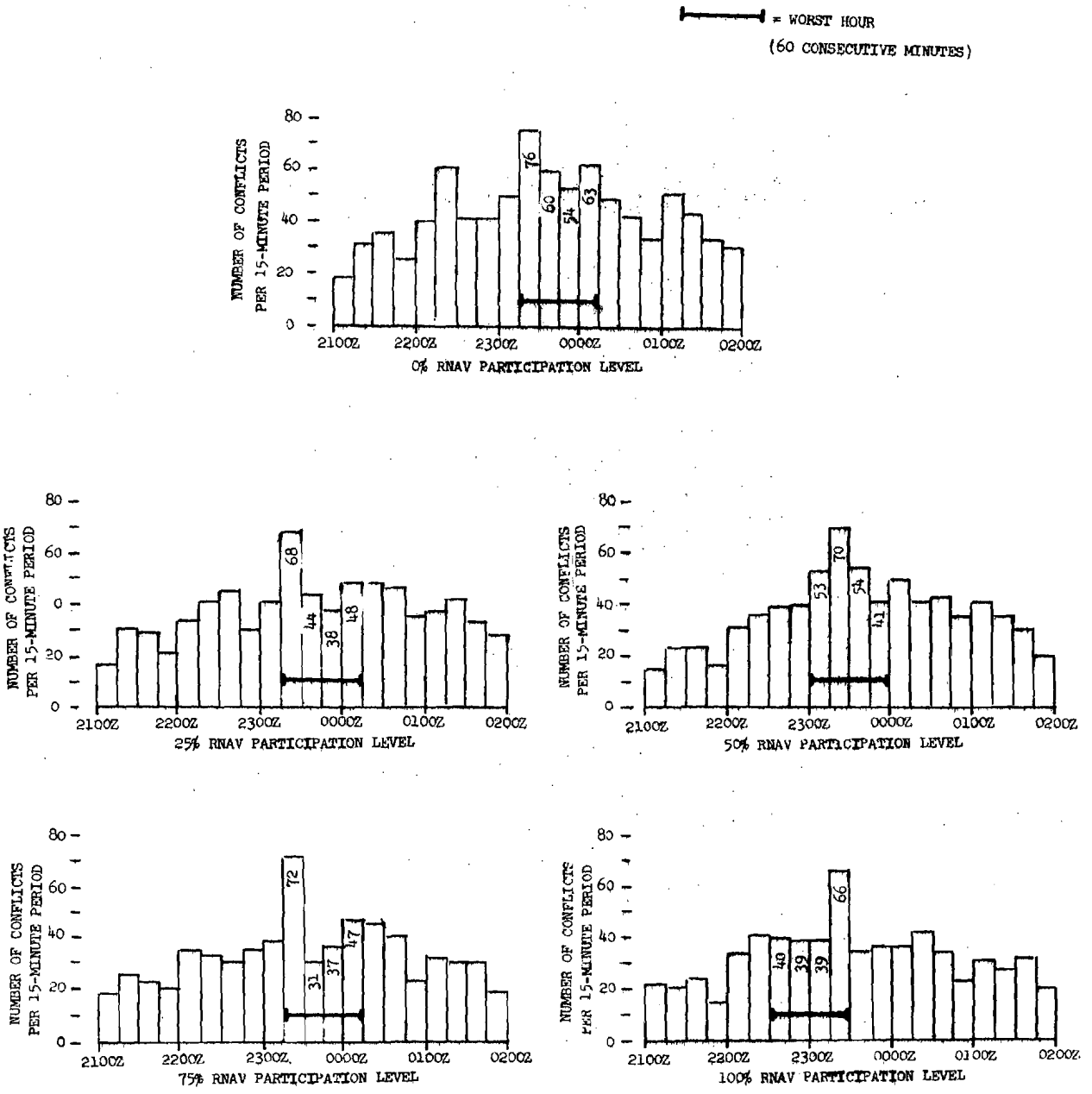


Figure 17 - System Conflicts by 15-minute Periods - RNAV High Altitude Structure 3

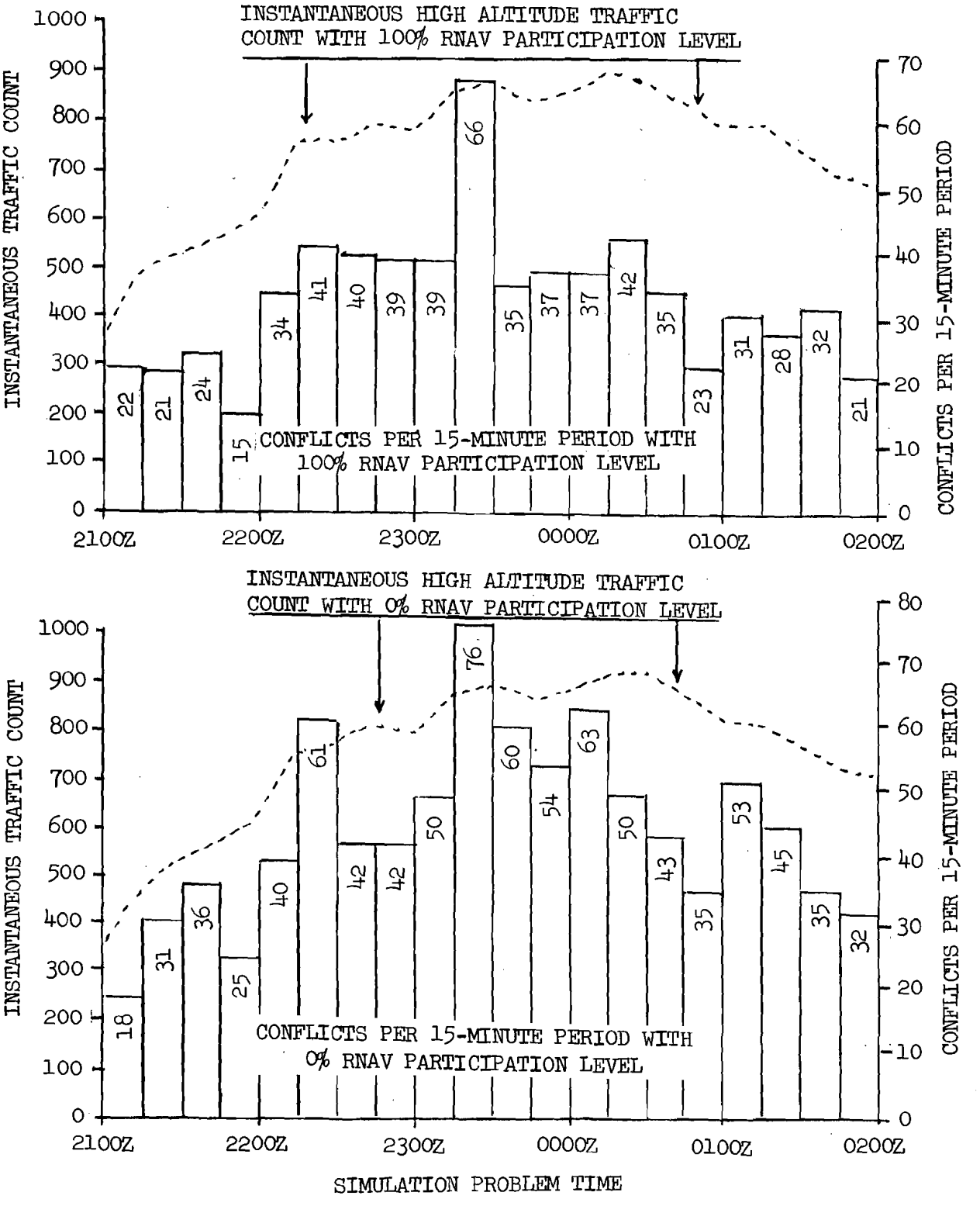


Figure 18 - Instantaneous High Altitude Traffic vs System Conflict Rates

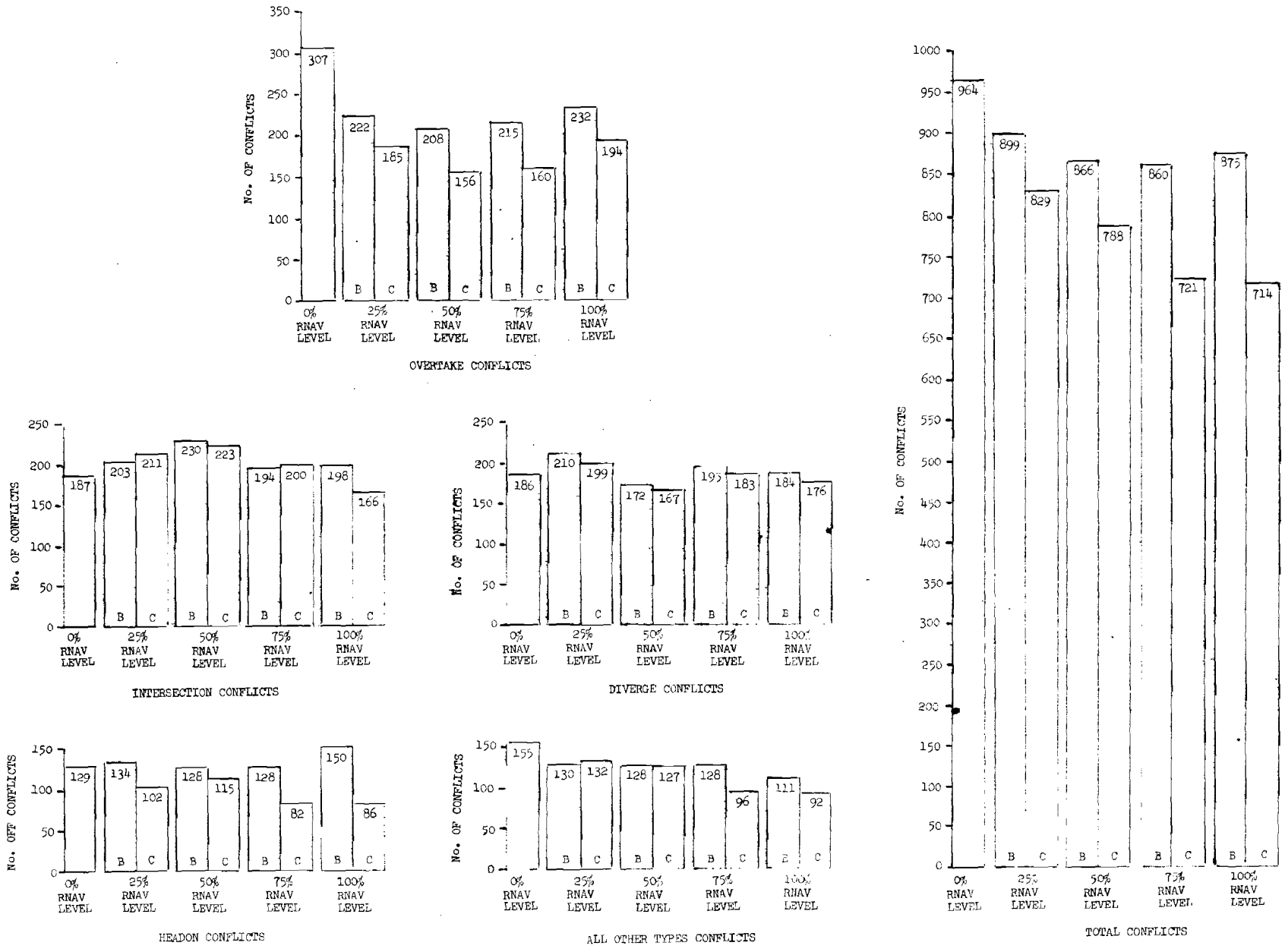


Figure 19 - System Conflicts by Category - High Altitude Structures B and C

A reduction of 11% however, is found for the 100% RNAV Participation Level of Structure C. The increases in intersection conflicts was the result of a "worst case" condition created by overlaying the RNAV routes on the Present High Altitude Structure since no effort was made in the NAFEC RNAV High Altitude route structure design process, nor in the fast time simulations to correct or modify either of the route systems (RNAV or VOR) to provide compatibility between the two route structures. Therefore a major increase in intersections formed by crossing routes resulted which in turn increase the probability of intersection conflicts. However, it will be seen later in this report, when only conflicts between Selected Airport Pair traffic are analyzed, intersection conflicts for both RNAV Structures "B" and "C" were lower when all traffic considered (all Selected Airport Pair traffic) used RNAV routes than when the same traffic all used the Present High Altitude Route Structure.

An advantage for RNAV was found for Structure C at all but the 25% Participation Level in the measure of diverge conflicts. These reductions in diverge conflicts do not appear to be of any major significance since they range only from 2% to 5% when compared against the 0% RNAV Participation Level. However, it is interesting to note that diverge conflicts for Structure C are consistently lower than for Structure B for each Participation Level. This difference is one of the results of the improvements in design for Structure C over Structure B.

Headon conflicts in Structure C were consistently less than those of the Present High Altitude Structure showing reductions in the number of conflicts ranging from 12% to 36% depending on the RNAV Participation Level. RNAV Structure B shows no improvement in this measure over the Present High Altitude Structure. In fact, a 16% increase in headon conflicts was found at the 100% Participation Level of Structure B. The major improvement in this measure found for Structure C over both Structure B and the Present High Altitude Structure can be attributed to the extended independent climb and descent segments for arrival and departure flights provided in RNAV High Altitude Structure C described in reference 3.

All other types of conflicts not classified as overtake, intersection, diverge, or headon were grouped together. This group includes conflicts such as proximity (conflicts between traffic whose flight paths do not actually converge with, cross, overlie, or diverge from each other, but do approach to a point where less than five miles separation existed), start-up (conflicts between traffic at time of entry into the problem), and converge conflicts (conflicts between traffic whose paths converge and then follow a common course). Since the incidence of these types of conflicts was quite low, they have been grouped together as a single measure. As shown in figure 19, both Structures B and C show a marked reduction in the number of conflicts in this group. Structure B provided reductions ranging from 16% at the 25% RNAV Participation Level to 28% at the 100% RNAV Participation Level.

The reductions for Structure C ranged from 15% at the 25% Participation Level to 41% at the 100% RNAV Participation Level.

The reductions in total conflicts are also shown in figure 19. RNAV High Altitude Structure C shows a major and consistent improvement at all RNAV Participation Levels over Structure B, reflecting improvements made by NAFEC in Structure C (the final NAFEC design of RNAV routes serving 429 airport pairs). The reductions in the total number of conflicts for Structure C at the 25% through 100% RNAV Participation Levels compared to the 0% Participation Level range from 14% to 26% at the 25% and 100% RNAV Participation Levels respectively. These total reductions are generally the result of the major decreases in three of the five categories of conflicts shown in figure 19. When intersection and diverge conflicts are combined, it is found that there is an increase for Structure C of 37, 17, and 10 conflicts for the 25%, 50%, and 75% RNAV Participation Levels over the 0% Level. At the 100% Participation Level, a reduction of 31 conflicts is found. When the remaining three conflict measures are combined (overtake, headon, and other types of conflicts), reductions for Structure C of 172, 193, 253, and 219 conflicts at the 25%, 50%, 75%, and 100% Participation Levels respectively are found. In other words, each added conflict at the 25%, 50%, and 75% Participation Levels over that of the 0% RNAV Participation Level for the combined intersection and diverge conflict measures is more than compensated for by decreases in the number of the other three conflict measures as shown in table 7.

TABLE 7

Comparisons of Combined System Conflict Types
(Increase (+)/Decrease (-) Compared to 0% RNAV Participation Level)

	Intersection and Diverge Conflicts Combined	All Other Conflicts Combined
25% RNAV Participation	+37 conflicts (+10%)	-172 conflicts (-29%)
50% RNAV Participation	+17 conflicts (+ 5%)	-193 conflicts (-33%)
75% RNAV Participation	+10 conflicts (+ 3%)	-253 conflicts (-43%)
100% RNAV Participation	-31 conflicts (- 8%)	-219 conflicts (-37%)

The previous discussion has been concerned with the number and types of conflicts and the distribution of conflicts by ARTCC sector. Some additional insight into the potential impact of conflicts on both controller workload and the system user is provided by analysis of conflict duration. Since no controller intervention was provided in the fast time simulations all conflicts detected simply ran their course. The start time and end time for each conflict was recorded. The conflict was detected and recorded at the time either vertical or horizontal separation was lost and was ended at the time either vertical or horizontal separation was regained as the result of speed differential, altitude change, or course divergence.

Of primary interest in this analysis are those conflicts of longer durations. From the controller's point of view, conflicts of long duration may require one or more of the following actions:

- Radar vectoring or RNAV offset over a longer period of time than conflicts of short duration

- More frequent assignment of undesired altitudes to allow traffic to pass

- Increased inter-sector coordination

- Longer imposition of climb/descent restrictions than for conflicts of shorter duration

- In some cases, rerouting of traffic

Any of the above, except perhaps inter-sector coordination, has an undesireable impact on the system user.

As shown in figure 20, conflict duration was considerably lower at the 100% RNAV Participation Level than at the 0% Level using RNAV Structure C and Traffic Sample 2. Twenty-six percent (139 conflicts) of all conflicts at the 0% Participation Level lasted 192 seconds or longer, while only 19% (79 conflicts) at the 100% RNAV Participation Level lasted 192 seconds or longer. This distribution of conflicts by duration indicates that when 2500 RNAV flights were introduced into a mixed RNAV-VOR environment, reductions are found in conflict durations and thereby some additional advantage provided to both the controller and system user.

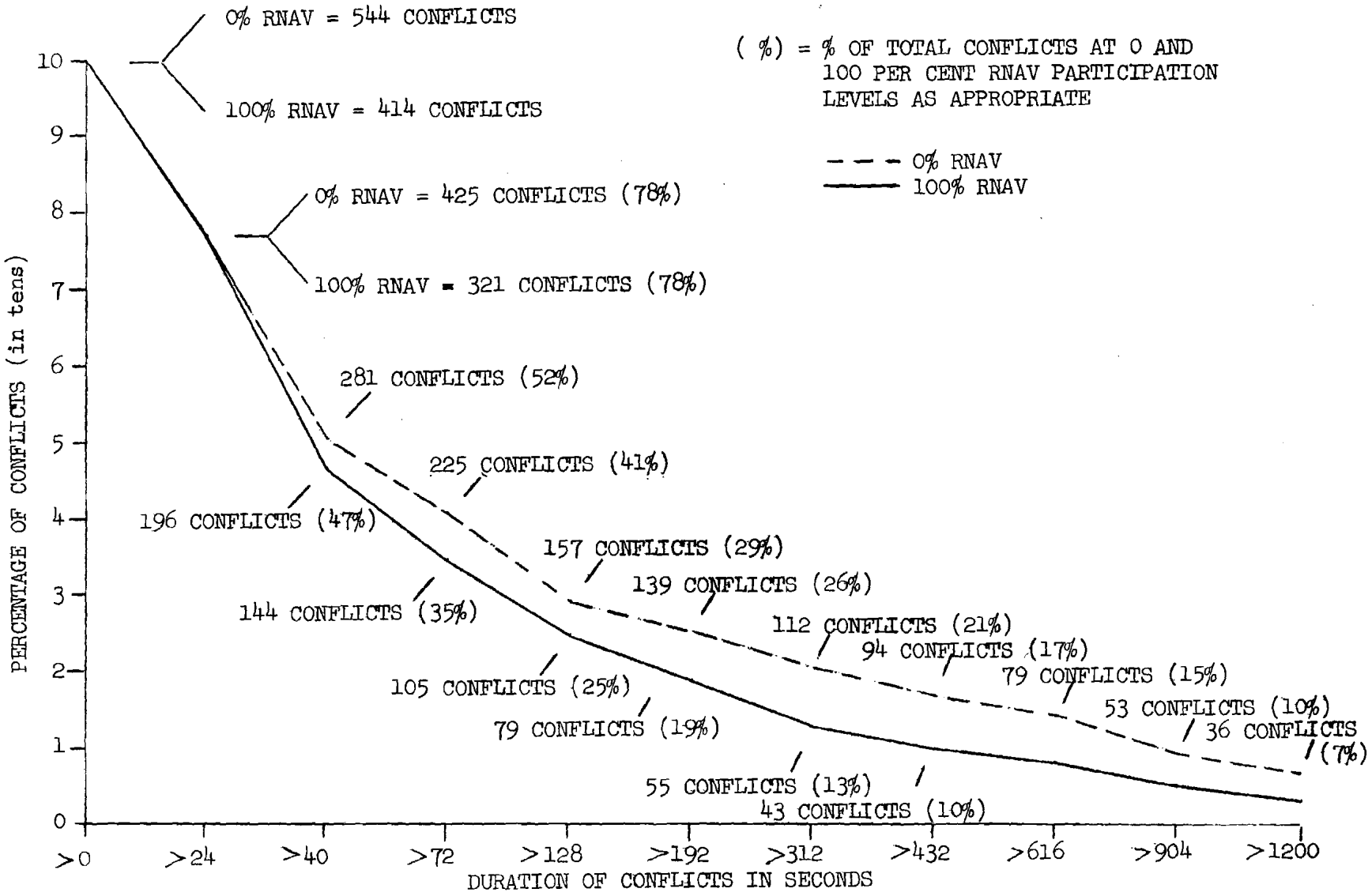


Figure 20 - Distribution of Conflicts by Duration

SELECTED AIRPORT PAIRS' TRAFFIC CONFLICTS

The number and types of conflicts which occurred only between flights exchanged between the Selected Airport Pairs of RNAV High Altitude Structure B and Structure C using Traffic Sample 2 are presented in figure 21. The data presented here excludes all conflicts in which both aircraft involved were not of the 1523 flight exchanged between the 189 Selected Airport Pairs of Structure B (for the Route Structure B measures) or not of the 2500 flights exchanged between 429 Selected Airport Pairs of Structure C (for the Route Structure C measures). In the conduct of the fast time simulations all traffic was flown including that of both Selected and Non-selected Airport Pairs so that the conflicts presented here were included in the System Conflicts previously discussed.

As expected, the conflict counts for Structure C are higher than for Structure B due to the 64% increase in Selected Airport Pair traffic of Structure C. However, similar trends are found in some of the conflict type data. This is particularly marked in the overtake conflicts category. For both structures the lowest number of overtakes naturally occurred at the 50% RNAV Participation Level when traffic was evenly divided between RNAV and Present High Altitude Structure, and were highest at the 0% and 100% RNAV Participation Levels where all traffic was flying via the Present High Altitude Structure or, in the 100% RNAV Participation Level via the RNAV routes. While Structure B shows a small increase (3%) in overtake conflicts at the 100% Participation Level, Structure C shows a 27% decrease.

The number of intersection conflicts show similar trends for Structures B and C with the highest conflict counts at the 50% RNAV Participation Levels. This results from an increase in the intersecting flight paths that are created with half of the traffic flying the Present High Altitude Structure while the other half fly the RNAV routes. It should be stressed again that the RNAV routes of both Structures B and C were not specifically designed by NAFEC to be compatible with the Present High Altitude Structure. It is natural under this condition that an increase in intersection conflicts would result in all but the 0% and 100% RNAV Participation Levels. Since only 1523 Selected Airport Pairs' flights using routes between 189 Airport Pairs are included for Structure B, the intersection conflict counts are much lower than those of the more extensive Structure C, with 2500 flights and 429 Selected Airport Pairs.

The headon conflict data do not show similar trends for the two structures. While Structure C shows a reduction in headon conflicts at 25%, 50%, 75%, and 100% RNAV Participation Levels with the greatest reduction at the 100% Participation Level, Structure B shows an increase at the 75% and 100% Levels over the 0% RNAV Participation Level. As previously mentioned, this design problem of Structure B was corrected by NAFEC in the development of Structure C through the use of extended climb and descent route segments at departure and arrival airports.

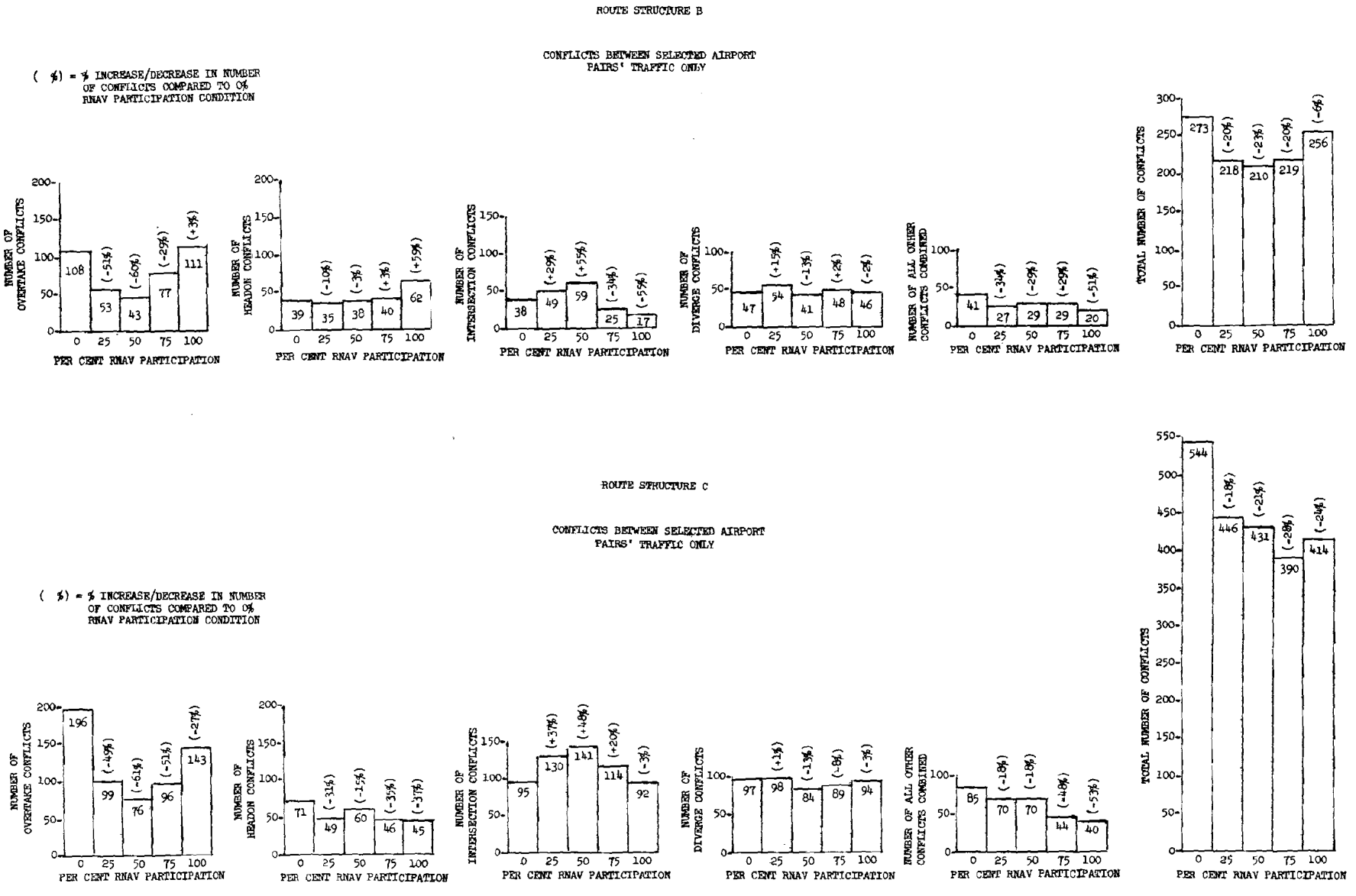


Figure 21 - Conflicts Between Selected Airport Pairs' Traffic by Category - RNAV High Altitude Structures B and C

The diverge conflict data appear to indicate no particular trends. However, those conflict types identified in figure 21 as "all other conflicts combined" show a decrease in number at all RNAV Participation Levels from 25% to 100% Levels. While Structure B does not show a continuing decrease as RNAV Participation is increased, Structure C indicates such a trend with the exception of the constant 18% reduction at both the 25% and 50% RNAV Participation Levels.

When the total number of conflicts between Selected Airport Pairs' traffic is examined, only slight similarity can be found in the trends for the two structures. Whereas the fewest number of conflicts are found at the 50% RNAV Participation Level of Structure B with a marked jump at the 100% Level, Configuration C shows the lowest number of conflicts at the 75% RNAV Participation Level with only a slight increase at the 100% Level. This difference between the two structures is the result of the improved design features incorporated in NAFEC's design for Structure C. In addition, Structure B shows only a 6% decrease in total conflicts at the 100% Participation Level while Structure C shows a 24% reduction.

In the discussion of the System Conflicts, intersection and diverge conflicts were combined for comparison with the remaining three measures (overtake, headon, and "all other conflicts combined"). When this is done for Selected Airport Pairs" traffic conflicts, similar results are found. Slight increases in the number of combined intersection and diverge conflicts are found at the 25%, 50%, and 75% Participation Levels with a slight decrease at the 100% Participation Level for Structure C. Increases of 36, 33, and 11 conflicts were found for the 25%, 50%, and 75% Participation Levels respectively. On the other hand, these increases were outweighed by decreases of 134, 146, 166, and 124 conflicts in the remaining three categories combined at the 25%, 50%, 75%, and 100% RNAV Participation Levels respectively as shown in table 8.

TABLE 8

Comparison of Combined
Selected Airport Pair Traffic Conflict Types
(Increase (+)/Decrease (-) Compared to 0% RNAV Participation Level)

	Intersection and Diverge Conflicts Combined	All Other Conflicts Combined
25% RNAV Participation	+36 conflicts (+19%)	-134 conflicts (-38%)
50% RNAV Participation	+33 conflicts (+17%)	-146 conflicts (-41$)
75% RNAV Participation	+11 conflicts (+ 6%)	-166 conflicts (-47%)
100% RNAV Participation	- 6 conflicts (- 3%)	-124 conflicts (-35%)

An analysis of the number of conflicts between Selected Airport Pairs' traffic only was performed to determine the effect of adding airport pairs

and traffic to form an estimate of the reduction in conflicts which might be expected if all simulated traffic (3842 flights rather than only 2500 flights) had used RNAV routes. For the purpose of this extrapolation, four data points were used, as shown in figure 22. Thirty-seven of the airport pairs exchanging the most flights were chosen for Data Point I. These 37 airport pairs exchanged a total of 617 flights or an average of 16.7 flights per airport pair. Seventy-two additional airport pairs were added to those chosen for Data Point I, bringing the total airport pairs to 109 for Data Point II. These 72 airport pairs exchanged 662 flights, or an average of 9.2 per airport pair, and brought the total traffic to 1279 flights exchanged between the airport pairs at Data Point II. An additional 320 airport pairs and their 1221 exchanged flights were added to those included in Data Point II and were used for Data Point III. These 320 airport pairs exchanged an average of 3.8 flights per pair. Since the RNAV route structure simulated did not serve the remaining 481 airport pairs and their 1343 exchange flights which are included for Data Point IV, the conflicts detected at this point only were found for the 0% RNAV Participation Level. The 481 airport pairs added for Data Point IV exchanged an average of 2.8 flights per airport pair. Table 9 provides a tabular presentation of the data presented in figure 22.

TABLE 9

CONFLICT DATA vs. SELECTED AIRPORT PAIRS

		DATA POINTS			
		I	II	III	IV
NUMBER OF SELECTED AIRPORT PAIRS		37	109	429	910
SELECTED AIRPORT PAIRS' TRAFFIC		617	1279	2500	3843
AVERAGE NUMBER OF FLIGHTS PER ADDED AIRPORT PAIR		16.7	9.2	3.8	2.8
ACCUMULATIVE AVERAGE NUMBER OF FLIGHTS PER SELECTED AIRPORT PAIR		16.7	11.7	5.8	4.2
NUMBER OF CONFLICTS BETWEEN SELECTED AIRPORT PAIRS' TRAFFIC	WHEN ALL TRAFFIC USED THE PRESENT HIGH ALTITUDE STRUCTURE	76	224	544	964
	WHEN ALL TRAFFIC USED THE RNAV HIGH ALTITUDE STRUCTURE	49	148	414	---

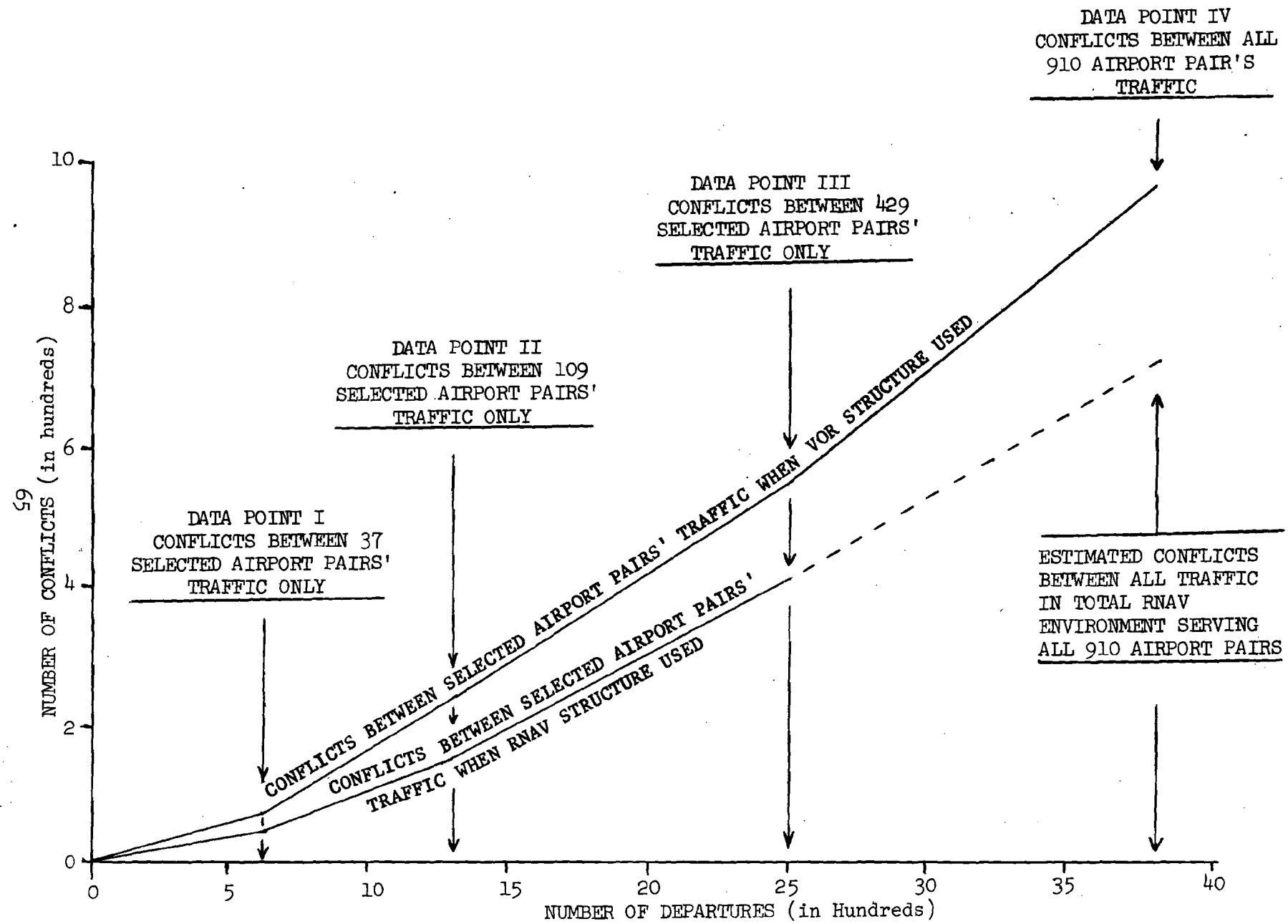


Figure 22 - Accumulative Conflicts Between Subsets of Airport Pair's Traffic

Direct comparisons can be made at Data Points I, II, and III between the number of conflicts between only Selected Airport Pairs' traffic for the 0% and 100% RNAV Participation Levels. An analysis of the data for the 0% RNAV Participation Level shows that the 617 flights for Data Point I were involved in an average of 0.12 conflicts per flight. When 662 flights were added to bring the total Selected Airport Pairs' traffic to 1279 for Data Point II, there was an increase of 148 conflicts, or an increase of 0.22 conflicts per added flight. At Data Point III, where 1221 flights are added, bringing the total to 2500, conflicts are increased again by 320, for an average increase of 0.26 conflicts per added flight. When the 1343 flights were added at Data Point IV, bringing the total traffic to 3843 flights, the total number of conflicts between these flights rose to 964, giving an average increase of 0.31 conflicts per added flight.

The 100% RNAV Participation Level data shows that the average number of conflicts per flight at Data Point I was 0.08; for the additional flights at Data Point II the average was 0.13 per added flight; and at Data Point III, the average was 0.22 per added flight. This marks a consistent improvement in reduced potential conflicts compared to the 0% RNAV Participation Level for the three data points as illustrated in figure 22.

Since it should be expected that the similarity of trends for both the 0% and 100% RNAV Participation Levels at Data Points I, II, and III would continue at Point IV if data were available for the 100% RNAV at that Point, a segmented line is used in figure 22 to project the conflict trend for the 100% RNAV Participation Level for a complete RNAV high altitude structure serving all 910 airport pairs. This shows a 26% reduction (as found for the system conflicts previously discussed) at Data Point IV. The line so formed appears to be a reasonable projection based on the other three data points. A further analysis of conflicts involving Selected Airport Pair traffic is discussed later in this report which further supports a projection of a 26% reduction in the number of conflicts in a total RNAV high altitude environment.

CONFLICTS INVOLVING SELECTED AIRPORT PAIRS' TRAFFIC

The number of occurrences in which at least one of the aircraft involved was Selected Airport Pair traffic was recorded. All conflicts which did not involve at least one flight between the Selected Airport Pairs is not counted in this measure so as to identify only the impact of the introduction of RNAV traffic and routes on the total high altitude route system.

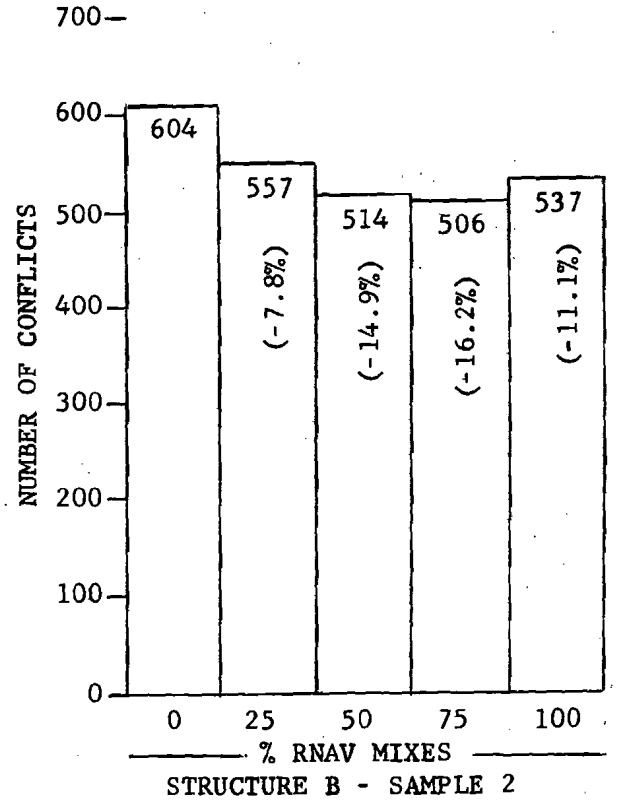
Figure 23 compares the numbers of conflicts for this measure for all RNAV Participation Levels for the two networks formed by the Present High Altitude Structure and RNAV Structures B and C using Traffic Sample 2. The general trends shown for this measure are similar to those shown in figure 19 for System Conflicts. However, since conflicts not involving Selected Airport Pair traffic are excluded from this measure, the percentage changes in the number of conflicts between RNAV Participation Levels become more marked. For example, in Structure C, there was a reduction of 26% at the 100% RNAV Participation Level when conflicts between all traffic (System Conflicts) are counted, while in this measure a reduction of 29% is found at the 100% Participation Level, since there were 106 system conflicts in which Selected Airport Pair traffic was not involved. The value of this measure over the System Conflict measure is the discreet identification of the impact on the number of conflicts in which Selected Airport Pair traffic are involved, thereby calling out the effect of the introduction of certain numbers of RNAV flights into the route system and ignoring all conflicts between other traffic which are not affected by the introduction of RNAV traffic.

The measure allows for the examination of conflict data for the 1523 flights exchanged between the 189 Selected Airport Pairs of B and for the 2500 flights exchanged between the 429 Selected Airport Pairs of Structure C and the interaction of these flights with the total 3842 flights in the system in Traffic Sample 2.

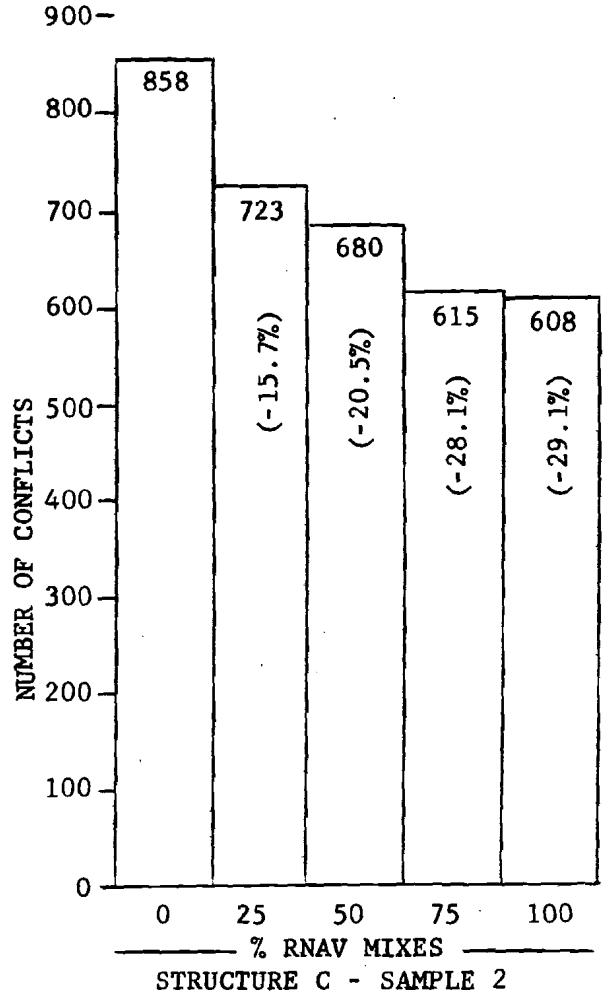
As shown in table 10 both RNAV Structures B and C show an improvement for all RNAV Participation Levels over the 0% RNAV Level. Again, as in the previous measures discussed, RNAV High Altitude Route Structure C shows an improvement over Structure B and a very marked improvement over the Present High Altitude Structure. This improvement is expressed in the reduced conflict potential expected as the percentage of RNAV traffic is increased. Using the network formed by RNAV Structure C and the Present High Altitude Structure, it was found that the Selected Airport Pairs' traffic (2500 flights) were involved in 858 conflicts or one conflict per 2.91 flights when none of the traffic used the RNAV routes. When all 2500 flights used the RNAV routes, the number of conflicts in which these flights were involved dropped to 608 or one conflict per 4.11 flights, a 29% improvement.

An analysis of the conflict data was conducted to determine some reasonable estimate of the reduction in conflicts which might be expected if a total RNAV structure were provided (rather than the 429 airport pair

(- %) = % DECREASE IN CONFLICTS BELOW 0% RNAV PARTICIPATION LEVEL



STRUCTURE B - SAMPLE 2



STRUCTURE C - SAMPLE 2

Figure 23 - RNAV High Altitude Structure B and C - Conflicts Involving Selected Airport Pairs' Traffic

TABLE 10

NUMBER OF SELECTED AIRPORT PAIR FLIGHTS
vs NUMBER OF CONFLICTS

	RNAV PARTICIPATION LEVEL	NUMBER OF FLIGHTS USING RNAV ROUTES	NUMBER OF CONFLICTS *1	RATIO OF NUMBER OF CONFLICTS TO SELECTED AIRPORT PAIR TRAFFIC	PERCENTAGE IMPROVEMENT OVER 0% RNAV PARTICIPATION LEVEL
RNAV STRUCTURE B	0%	0	617	1 x 2.47	---
	25%	381	552	1 x 2.76	11%
	50%	762	519	1 x 2.93	16%
	75%	1142	513	1 x 2.97	17%
	100%	1523	528	1 x 2.88	14%
RNAC STRUCTURE C	0%	0	858	1 x 2.91	---
	25%	625	723	1 x 3.46	16%
	50%	1250	682	1 x 3.67	21%
	75%	1875	615	1 x 4.07	28%
	100%	2500	608	1 x 4.11	29%

The ratio of the number of conflicts to Selected Airport Pair traffic is the number of total Selected Airport Pair flights (1523 for Structure B and 2500 for Structure C) divided by the number of conflicts at each RNAV Participation Level.

*1 Only conflicts involving Selected Airport Pair traffic are counted.

RNAV structure) and all traffic used the RNAV routes. To accomplish this, five data points as shown in figure 24 were selected so that trends in the numbers of conflicts and the relationships to the number of Selected Airport Pairs and traffic could be examined. The thirty-seven busiest airport pairs exchanging 617 flights (an average of 16.7 flights per pair) were selected to provide the first data point (Data Point I). A second group of airports (72 airports) were selected which exchanged 662 flights or an average of 9.2 flights per pair and were added to the first 37 airports bringing the total airport pairs to 109 and traffic exchanged to 1279 flights (Data Point II). The remaining 320 airport pairs which exchanged 1221 flights (an average of 3.8 flights per pair) used in RNAV Structure C were added to the first two groups selected for Data Point III. Since RNAV High Altitude Structure C did not serve the remaining 481 airport pairs which exchanged 1343 flights (an average of 2.8 flights per pair) in Traffic Sample 2, Data Point IV, which includes these flights, pertains only to the Present High Altitude Structure. Data Point V represents the mixed environment provided when the 100% RNAV Participation Level of the network formed by RNAV Structure C and the Present Route Structure was simulated using Traffic Sample 2 (2500 RNAV flights and 1343 non-RNAV flights). Table 11 summarizes the data shown in figure 24.

Direct comparisons can be made at Data Points I, II, and III between the number of conflicts involving Selected Airport Pair traffic for the 0% and 100% RNAV Participation Levels using Traffic Sample 2. An analysis of the data for the conditions in which all Selected Airport Pairs' traffic use the Present High Altitude Route Structure finds that the 617 flights for Data Point I were involved in 331 conflicts for an average of 0.54 conflicts per flight. When 662 flights were added to bring the total Selected Airport Pairs' traffic to 1279, there was an increase of 224 conflicts, or an average increase of 0.39 conflicts per added flight at Data Point II. At Data Point III where 1279 flights are added, only 303 additional conflicts occurred, giving an average increase in the number of conflicts of 0.34 conflicts per added flight. At Data Point IV, 1343 additional flights were again added, bringing the total flights to 3843 (100% of Traffic Sample 2), and conflicts were only increased by 106, or an average of 0.08 conflicts per added flight. This minimum increase in the number of conflicts can be attributed to the low exchange rates between the 481 airport pairs added at Data Point IV and probably reflects the fact that some portion of the 1343 flights traverse less congested portions of the airspace.

An analysis of the data for the conditions in which all Selected Airport Pairs' traffic use the RNAV routes of Structure C finds that the 617 flights for Data Point I were involved in 204 conflicts or an average of 0.33 conflicts per flight. When the 662 flights were added to Data Point II, there was an increase of 164 conflicts for an average of 0.25 conflicts per added flight. At Data Point III where 1343 flights were added, the average increase in conflicts was 0.20 per added flight. At each Data Point, the number of conflicts are lower when the Selected Airport Pairs' traffic use the RNAV routes than when using the Present High Altitude Structure. While no data is available for Data Point IV,

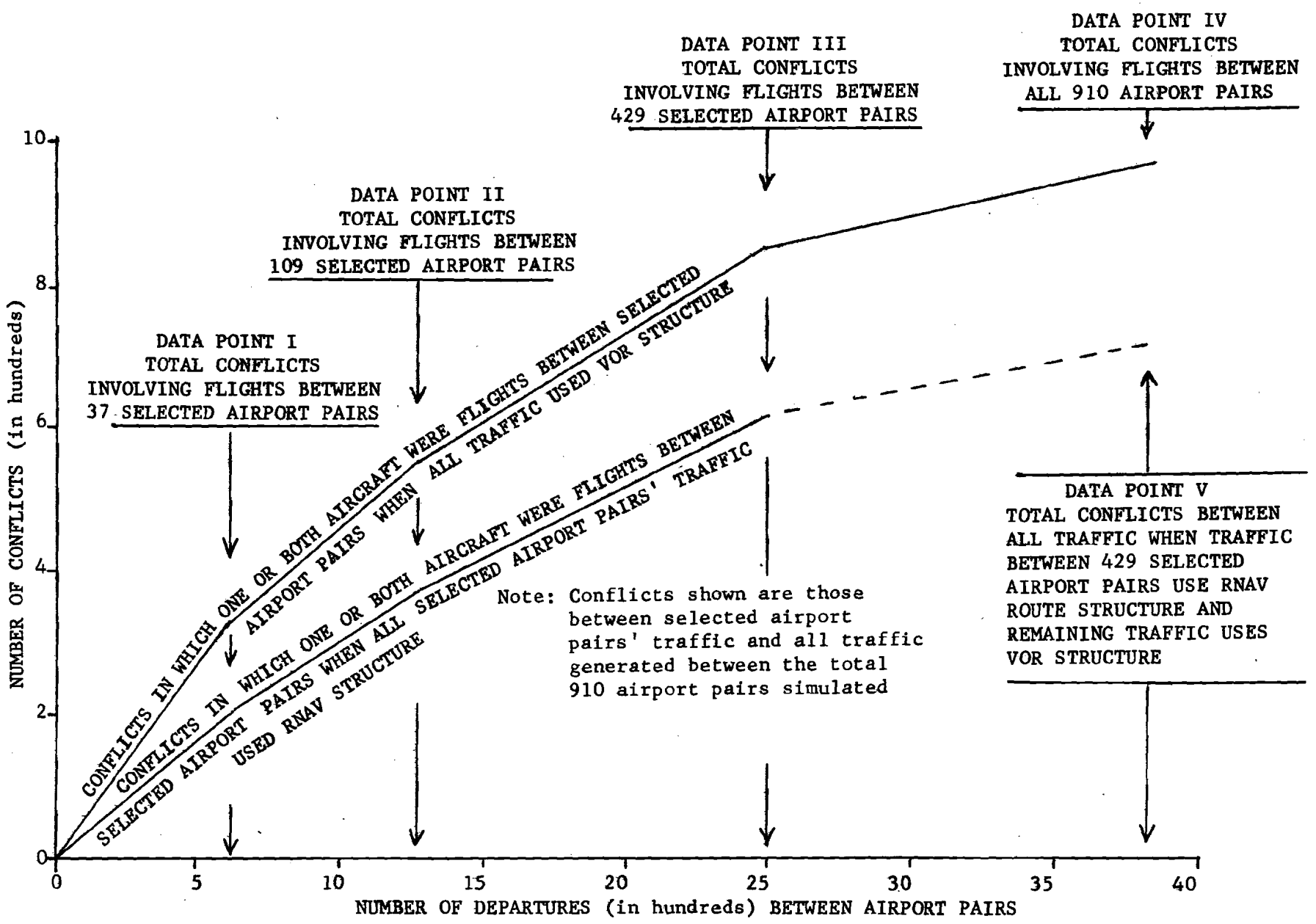


Figure 24 - Accumulative Conflicts Involving Traffic of Subsets of Airport Pairs

since the NAFEC RNAV Route Structure was not designed to accomodate the total 3843 flights, Data Point V is presented for the condition in which 2500 flights used the RNAV structure and the remaining traffic used the VOR or Present High Altitude Structure. Data Point V, however, considers the total 3843 flights as Selected Airport Pairs' traffic. The added 1343 flights at Data Point V increased the total number of conflicts by 106 or an average of 0.08 conflicts per added flight (the same increase found for Data Point IV).

The trends found in this measure strongly indicate that, assuming a 100% RNAV environment, a minimum reduction of at least 26% in the number of potential conflicts could be expected when compared to the Present High Altitude Structure.

TABLE 11

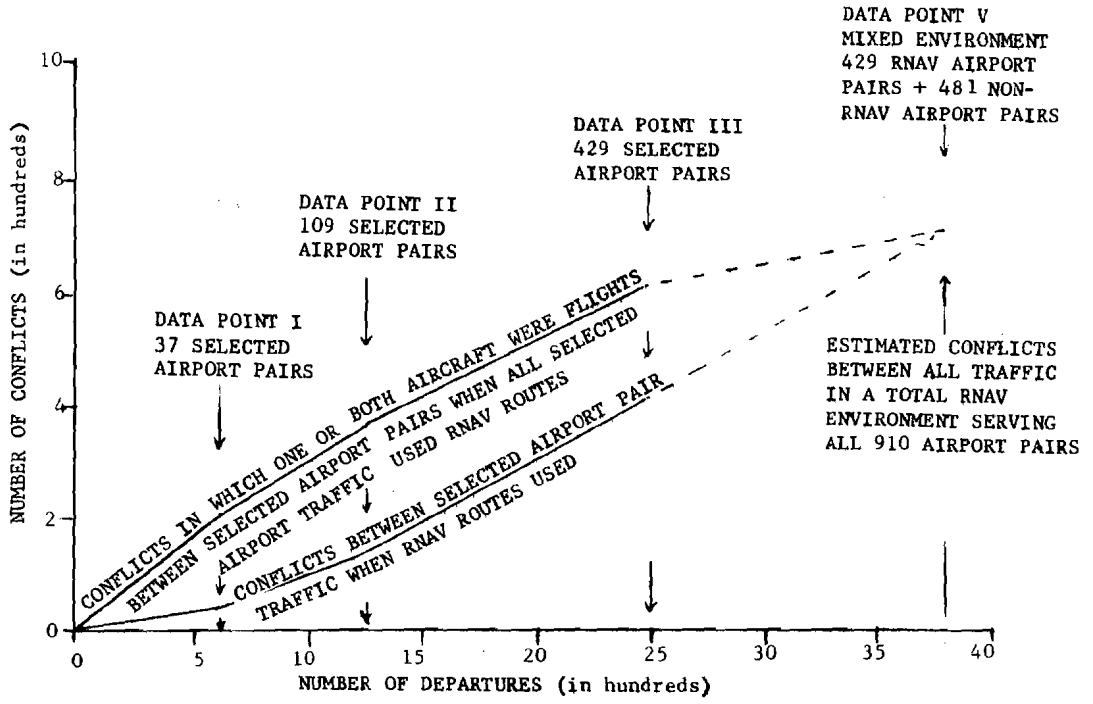
CONFLICT DATA vs. SELECTED AIRPORT PAIRS

		DATA POINTS				
		I	II	III	IV	V
Number of selected airport pairs		37	109	429	910	910
Selected airport pairs' traffic		617	1279	2500	3843	3843
Average number of flights per added airport pair		16.7	9.2	3.8	2.8	2.8
Accumulative average number of flights per selected airport pair		16.7	11.7	5.8	4.2	4.2
Number of conflicts involving selected airport pair's traffic	When all selected airport pair traffic used Present High Altitude Structure.	331	505	858	965	--
	When all selected airport pair traffic uses RNAV High Altitude Structure C	204	368	608	--	--
	When 2500 flights use Structure C RNAV routes and remaining 1343 flights use Present High Altitude Structure	--	--	--	--	714

Figures 25 and 26 depict the conflict trend lines described in this and the previous section to illustrate the relationships of conflicts between Selected Airport Pair traffic only and conflicts involving Selected Airport Pair traffic (conflicts in which at least one of the flights involved was Selected Airport Pair traffic). The space between the two lines in each figure represents the number of conflicts between Selected Airport Pair traffic and other (non-selected Airport pairs) traffic. For example, in figure 25, there were 76 conflicts between only Selected Airport Pair traffic at Data Point I, 255 conflicts in which only one of the flights involved in each conflict was Selected Airport Pair traffic; and a total of 331 conflicts involving Selected Airport Pair traffic (76 + 255 = 331).

The marked similarity in the shapes formed by the two lines in each figure is of interest in that they illustrate the close correspondence in the relationships of the two types of conflicts depicted. In figure 25, where all traffic used the Present High Altitude VOR Structure and in figure 26, where Selected Airport Pair traffic used the RNAV routes, the ratios of the two types of conflicts for the two conditions at each data point are markedly similar as shown in table 12.

The similarities in trends and conflict ratios gives a degree of confidence in the projected number of conflicts estimated for a total high altitude RNAV environment. While the estimated reduction of 26% for a total RNAV environment is more or less arbitrarily arrived at by assuming that a total RNAV environment would yield the same number of conflicts as the mixed environment tested, all the data appears to support a projected decrease in the number of conflicts of this approximate magnitude.



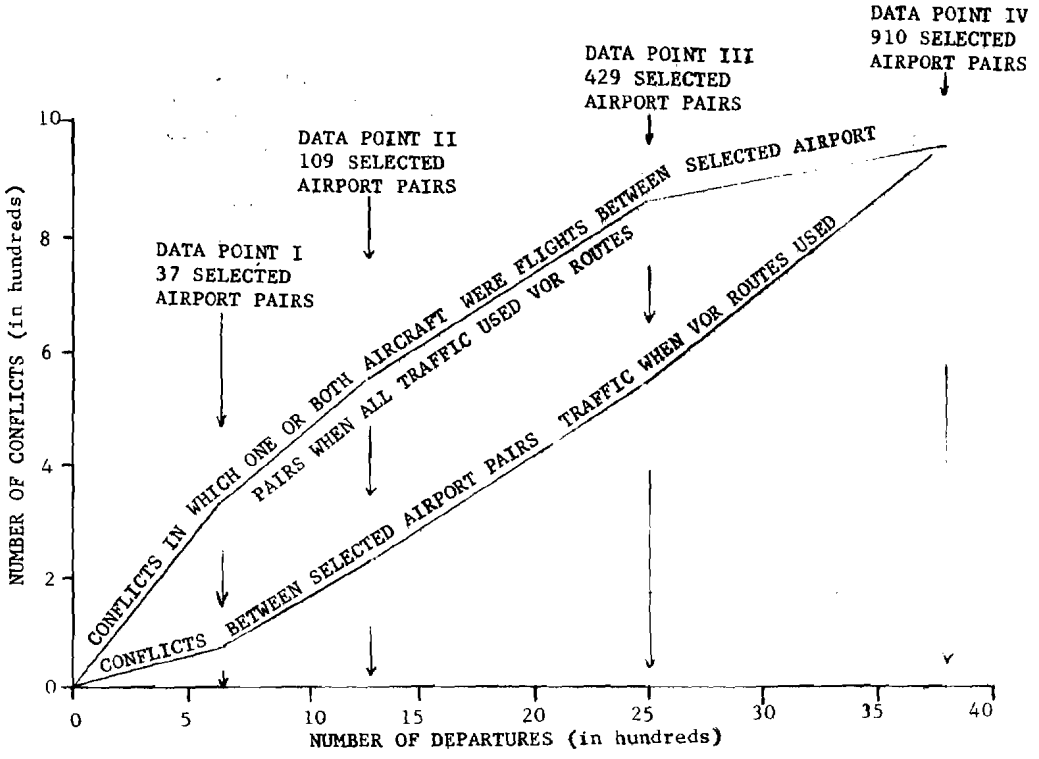


Figure 25 - Composite of Accumulative Conflicts - Present High Altitude Route Structure

TABLE 12

CONFLICT RATIOS

		CONFLICT COUNTS AT DATA POINTS			
		I	II	III	IV
All traffic using Present High Altitude Structure	(1) Conflicts in which both aircraft involved were Selected Airport Pair Traffic	76	224	544	964
	(2) Conflicts in which one or both aircraft involved were Selected Airport Pair Traffic	331	505	858	964
	Ratio of (1) to (2) above	1x4.19	1x2.25	1x1.58	1x1
2500 flights using RNAV routes & all others using VOR routes	(3) Conflicts in which both aircraft involved were Selected Airport Pair Traffic	49	148	414	est. 714*
	(4) Conflicts in which one or both aircraft involved were Selected Airport Pair Traffic	204	368	608	est. 714*
	Ratio of (3) to (4) above	1x4.16	1x2.49	1x1.47	1x1

Since only 2500 flights used the RNAV routes of RNAV High Altitude Structure C, the total system conflicts for the network formed by Structure C and the present High Altitude structure for the 100% RNAV participation level are used here as an estimate of the conflict count had all traffic used RNAV routes.

CONTROLLER INTERVENTION TESTS

Since controller intervention was not provided in the fast time simulations, a system was developed to playback in real time selected portions of the fast time simulations so that some limited examination of controller-traffic situation interaction could be made. For these tests, the network formed by RNAV High Altitude Structure B and the Present High Altitude Structure were used since Structure C had not been developed at that time. As discussed in the Preliminary Fast Time Simulation Results Report (Ref. 2), tests were conducted in which three Boston Air Route Traffic Control Center controllers were used to determine how a controller would prevent the potential conflicts which resulted in the fast time simulations. After the conflicts were categorized, the most prevalent types of conflicts were selected for controller intervention tests. The situations were played back in real time exactly as they had occurred in the fast time simulations. A cathode ray tube was provided for the controller as a substitute radar display. Information was provided for each flight through both a script prepared in advance and through calling up for display in alphanumeric form, information on any target the controller wished. It was not the intent of these tests to subject the controller to pressures normally associated with busy periods of air traffic control, but rather to determine how the controller would resolve problems through the use of present techniques for comparison with the manner in which the same controller would use RNAV functions to resolve the same problems. After a brief dscription of how he might use RNAV "offset" and "direct-to-waypoint" instructions, each controller was asked to use RNAV instructions when he thought they provided a suitable means of controlling the traffic. If he felt that the use of RNAV instructions would work to his disadvantage or a disadvantage to the traffic, he was requested to resolve the problems in any manner that seemed best fitted to the problem. It should be pointed out that while the controllers used in these tests were experienced in the use of radar control, they were basically unfamiliar with the application of RNAV procedures.

During these tests, simulated radio contacts by the controller were recorded and control instructions affecting the ground track of the aircraft cleared were drawn by the test observers on previously computer generated pictures of the conflict situations (See figures 27 and 28 . Since the computer generated-targets did not respond to controller instructions, it was necessary to closely monitor the sequence and timing of control instruction when successive clearances were based on completion of some previous clearance issued.

While these tests were limited in nature, it is interesting to note that the communication data and general comments received from the three controllers is consistent with the data derived in the real time simulation completed in 1974 at NAFEC. Although the controller intervention tests referred to in this paper were of a high altitude RNAV environment and the real time simulation at NAFEC was of a terminal area, communications data show markedly similar trends as shown in figures 29 and 30. A substantial decrease was found in both communi-

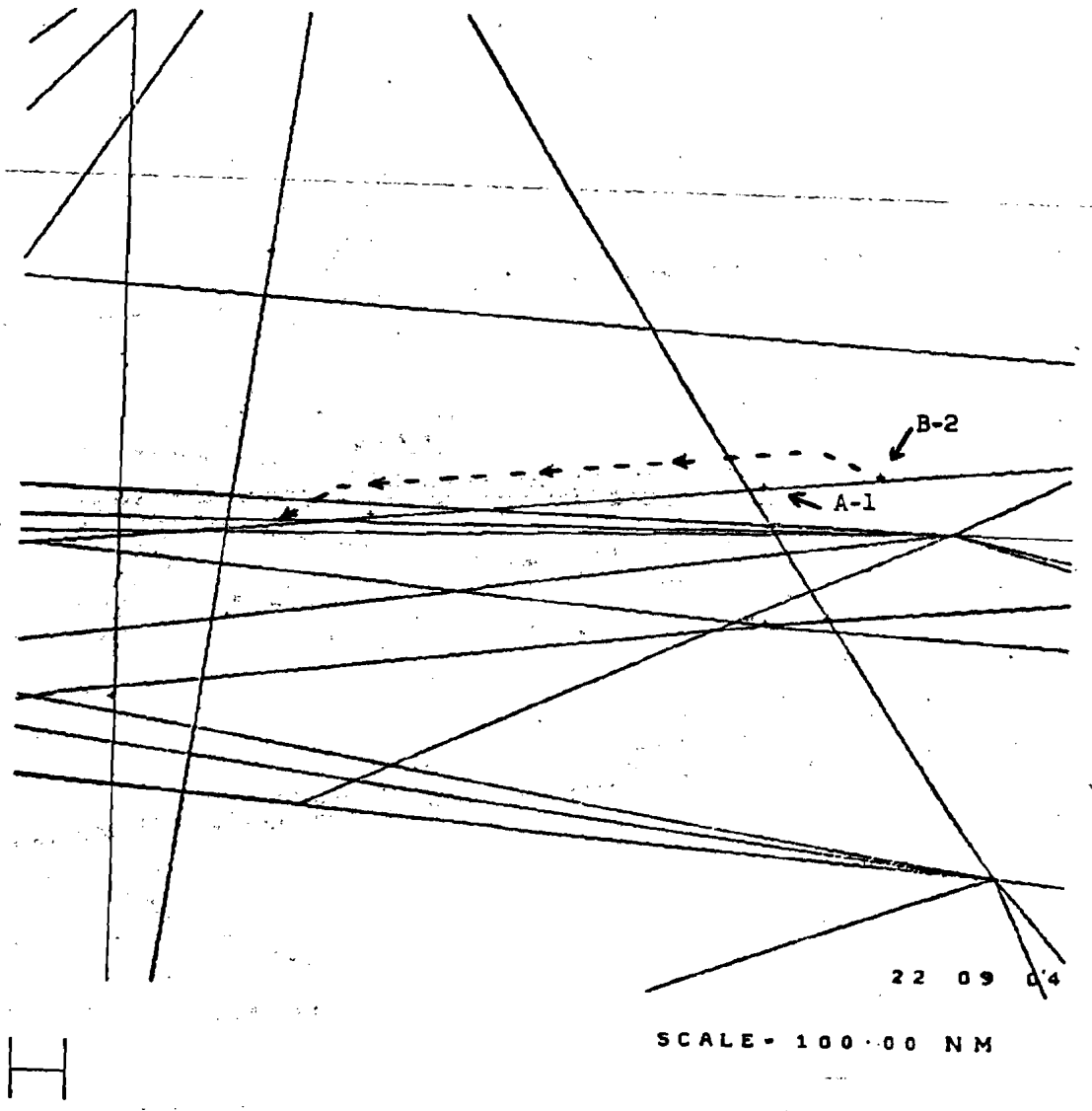


Figure 27 - Target Positions Prior to Conflict

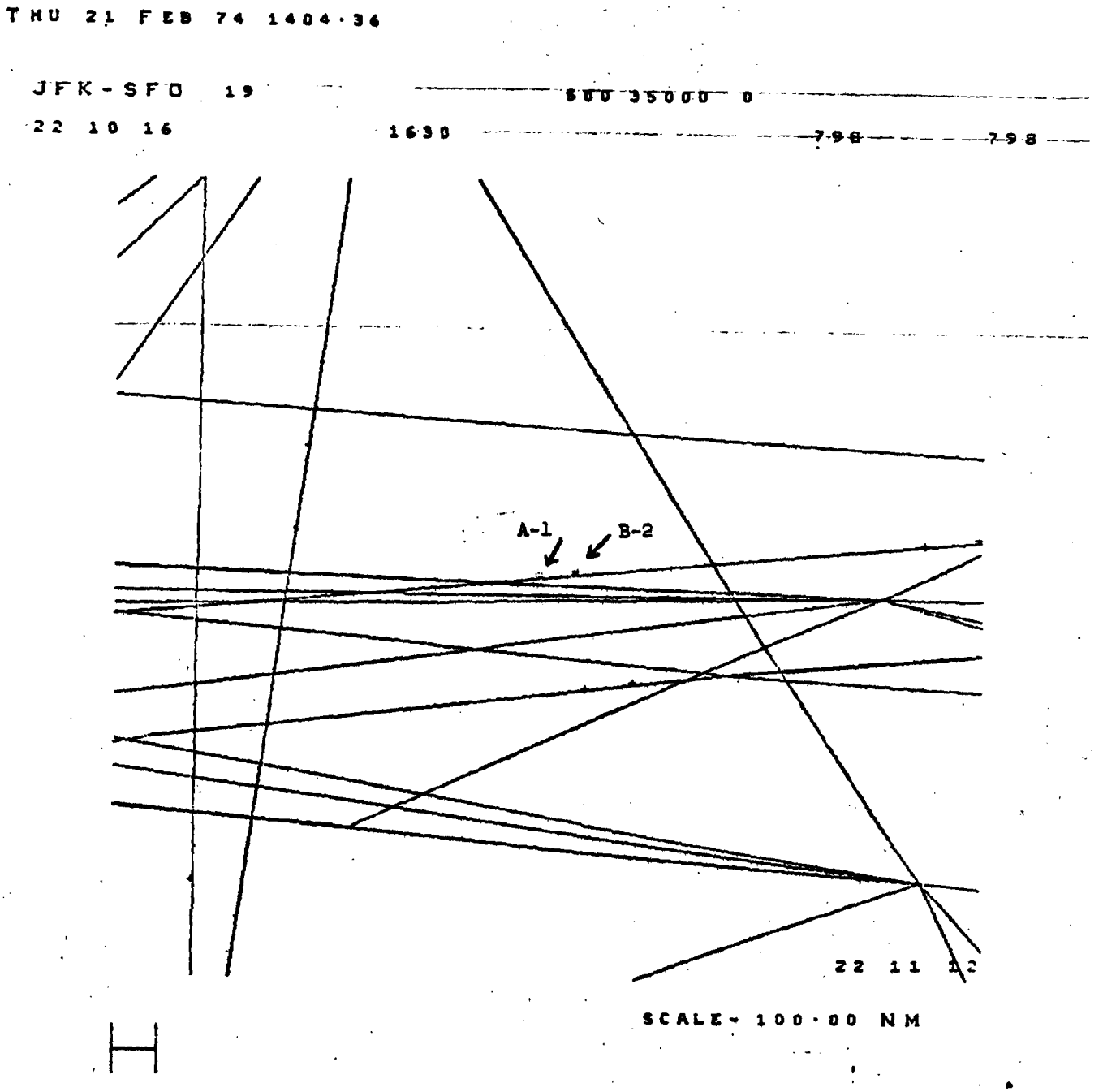


Figure 28 - Conflict Situation if not Resolved

NOTE: The graphs below depict the results of the controller intervention tests conducted as an adjunct to the high altitude fast time simulations together with the results of the real time simulation of the JFK terminal environment conducted at NAFEC.

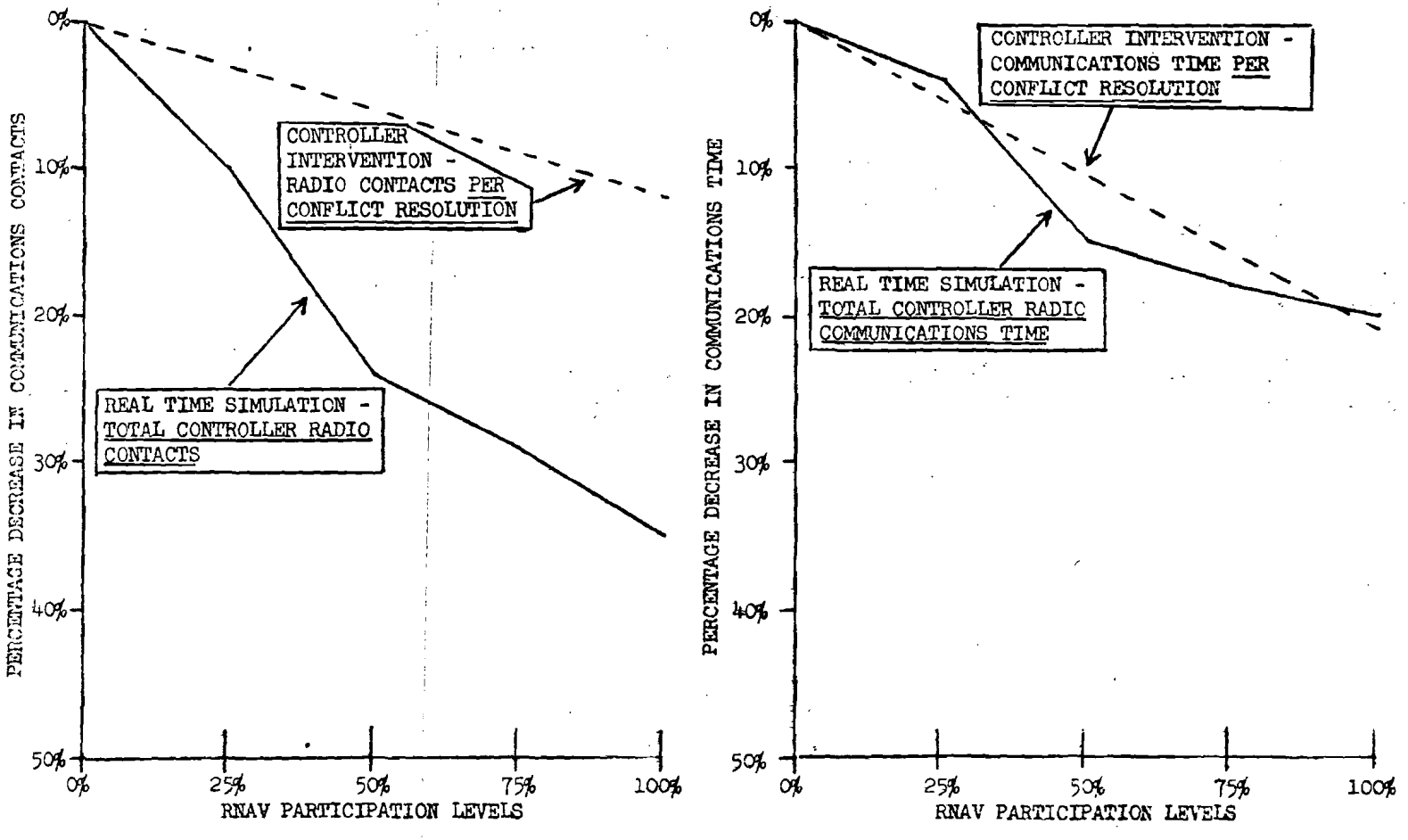


Figure 29 - Comparisons of Controller Intervention Tests/Real Time Simulation Communications Data

Note: The graph below depicts the results of the controller intervention tests together with the results of the real time simulation of the JFK terminal environment conducted at NAFEC. The graph illustrates the general similarity found in the two sets of data.

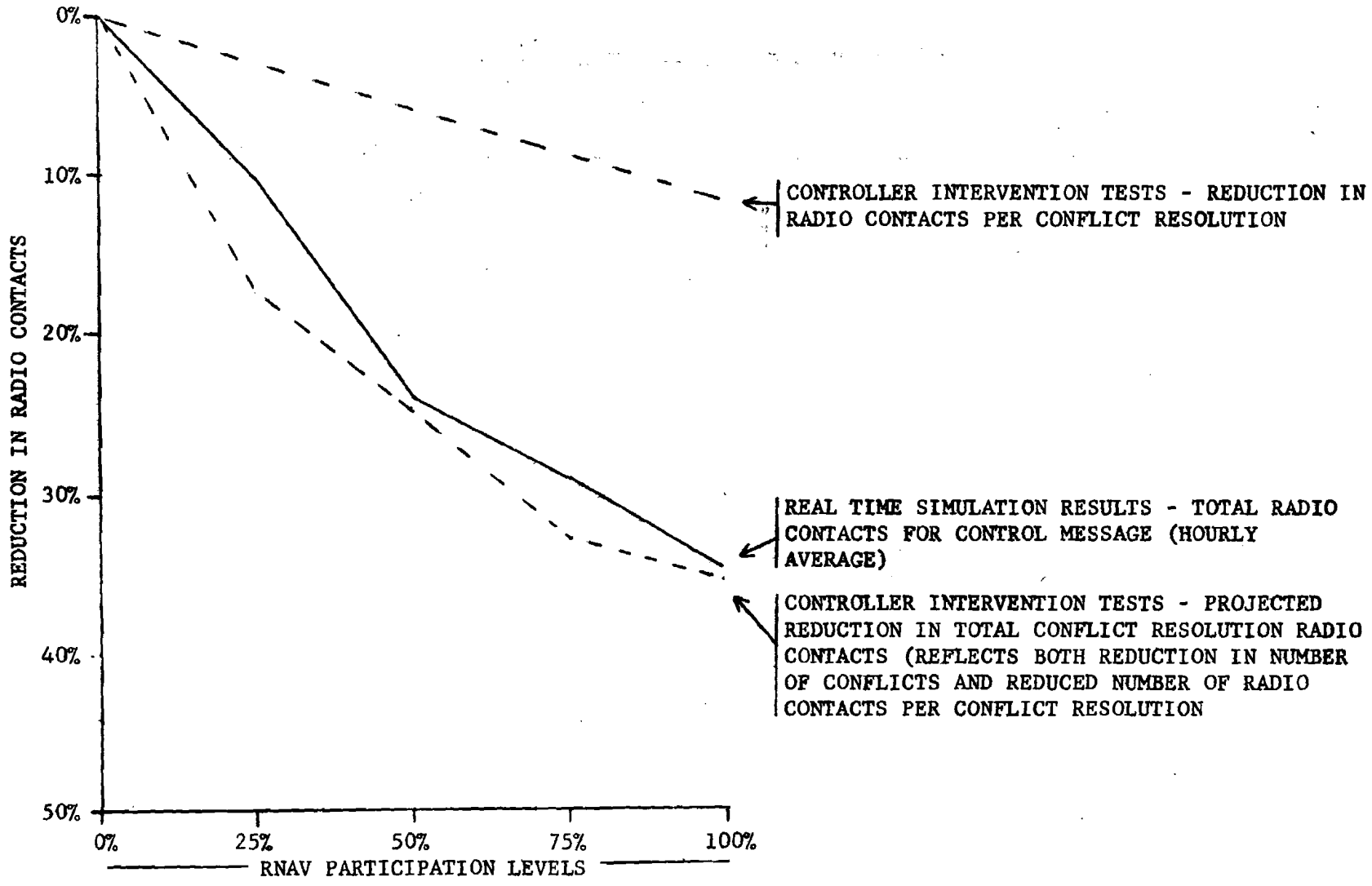


Figure 30 - Projected Reductions in Radio Contacts - Structure C (Projection Considers Both Reductions in Conflicts and Contacts per Conflict)

cations contacts and radio talk time, for both the controller intervention tests and the real time simulation through the use of RNAV.

A comparison was made of the average duration of restriction imposed by the controllers in the intervention tests. It was found that the average duration of restrictions imposed in RNAV resolution tests were 20% shorter than those imposed in non-RNAV intervention tests. It is probable that this reduction of the duration of restrictions reflects to some degree less time at undesireable altitude and some reduction in other altitude restrictions, path stretching, etc., impacting on the cost of flight operations.

The use of RNAV as a control tool was discussed with the controller test subjects. In general, there was controller acceptance of the use of RNAV procedures (which were almost exclusively the use of offsets) rather than radar vectors.

Two points were made by the controllers which indicated recognition of potential RNAV benefits from the controller point of view. The use of assignment of specified offset distances appeared to be of value, not only in reduced controller workload, but provided a measure of increased safety. The controller felt that this precluded (or reduced) the chances that an aircraft might fly further than desired from the route as sometimes does happen when a radar vector is issued and the controller becomes involved in other activities neglecting to issue further radar vectors as needed. The second point made was the suitability of offsets as a substitute for radar vectors. One controller particularly noted that the two (offsets and radar vectors) were frequently interchangeable as far as achieving the same desired results and that less contacts were required to parallel a given course through use of an RNAV offset than through radar vectors.

While the simulated video map presented on the controller's display was obviously more complex than what is provided today, it was not intended to provide more than a depiction of all RNAV and VOR jet routes within a 100 mile area of interest. In many cases, this created such a complex of lines that some means of reduction of this clutter will be required in actual facility operations if the combined RNAV and jet VOR route network created such a complex of lines.

As previously mentioned, further data on controller workload and system user impact will result from the planned enroute real time simulations to be conducted at NAFEC. The first enroute real time simulation is scheduled for completion in FY-76.

SUMMARY OF MAJOR RESULTS

While fast time simulations were conducted of the five route structures described in earlier sections of this report, only four of the five will be discussed in this section. However, to refresh the reader's memory and for clarification, the five structures are identified below.

1. The Present High Altitude Structure (high altitude flight paths as flown in 1972) serving 910 airport pairs.

2. A system of great circle routes between the 910 Airport Pairs representative of the FAA-Industry RNAV Task Force concept of a pre-planned direct route system for the post-1982 time period.

3. A network formed by adding on top of the Present High Altitude Structure (1 above) RNAV routes between 189 of the 910 airport pairs (Structure A).

4. A network formed by correction of the map projection system used for the above network. All other aspects of this and the above network remained identical (Structure B).

5. A network formed by adding on top of the Present High Altitude Structure (1 above) RNAV routes between 429 of the 910 airport pairs (Structure C).

Structure A, which was corrected to provide Structure B, is not discussed in this summary. The terms "Structure B" and "Structure C" will be used to refer to the networks formed as described in (4) and (5) above.

ROUTE LENGTHS

The RNAV routes of Structure B were an average of 1.8% shorter than the Present High Altitude Routes between the same 189 airport pairs. The RNAV routes of Structure C were an average of 2.9% shorter than the Present High Altitude Routes between the same 429 airport pairs. This change between route Structures B and C is probably the result of the inclusion of 240 additional airport pairs in Structure C over Structure B. However, for both structures, the RNAV route lengths represent a considerable improvement over the Present Route Structure when thought of in terms of dollars and barrels of oil which could be saved over a one-year period as a result of route length reductions. The aviation forecasts for fiscal years 1975-1986 published by the U. S. Department of Transportation, dated September 1974, estimates that jet fuel consumption will reach 11,632,000,000 gallons a year in 1980. A savings of as little as 1% in fuel consumption per year would equal a daily savings of almost 320,000 gallons.

TOTAL SYSTEM CONFLICTS

In tests of the Present High Altitude Structure using Traffic Samples 1, 2, and 3 (representing peak 5-hour traffic periods for the present, 1977-1982, and post-1982 traffic demands respectively), conflicts increased over Traffic Sample 1 by 20.6% in Traffic Sample 2, and 57.8% in Traffic Sample 3. The increase of 57.8% found for Traffic Sample 3 underlines a need for improvement in the present route structure to hold potential conflicts within reasonable bounds. No effort is made here to define "reasonable" bounds, but an increase of almost 58% in the number of potential conflicts seems something less than "reasonable."

Comparisons of Configuration B using Traffic Sample 2 showed some reduction in the number of conflicts as traffic was moved from the VOR routes to RNAV routes. The reductions over the 0% RNAV Participation Level were 6.7%, 10.2%, 10.8%, and 9.2% for RNAV Participation Levels of 25%, 50%, 75%, and 100%, respectively. Using Structure C, which provided a more extensive RNAV route system and incorporated improvements in design over Structure B, the reductions in conflicts were 14%, 18%, 25%, and 26% at the four Participation Levels respectively. Structure C was not simulated using Traffic Sample 3, but some estimate of the potential conflicts which might be expected can be made if it is assumed that the increase in conflicts for Structure C will be the same ratio as the increase in conflicts for Structure B between Sample 2 and 3 as shown below:

Given: R = 1146 (number of conflicts for Structure A using Traffic Sample 3)

S = 871 (number of conflicts for Structure A using Traffic Sample 2)

T = 714 (number of conflicts for Structure C using Traffic Sample 2)

X = Number of conflicts for Structure C using Traffic Sample 3

Then: $\frac{R}{S} = \frac{X}{T}$, or $\frac{1146}{871} = \frac{X}{714}$

And X = 940 (Number of conflicts for Structure C using Traffic Sample 3)

As shown in figure 31, based on the above assumption, it is estimated that Structure C could accomodate the traffic of Traffic Sample 3 (a 31.4% increase over Traffic Sample 1) with an increase of only 17.6% in the number of conflicts over those of the Present High Altitude Structure using Traffic Sample 1. An increase in conflicts of 17.6% over Traffic Sample 1 is more acceptable than the 57.8% found for the Present High Altitude Structure. Figure 31 also depicts the estimated increase in

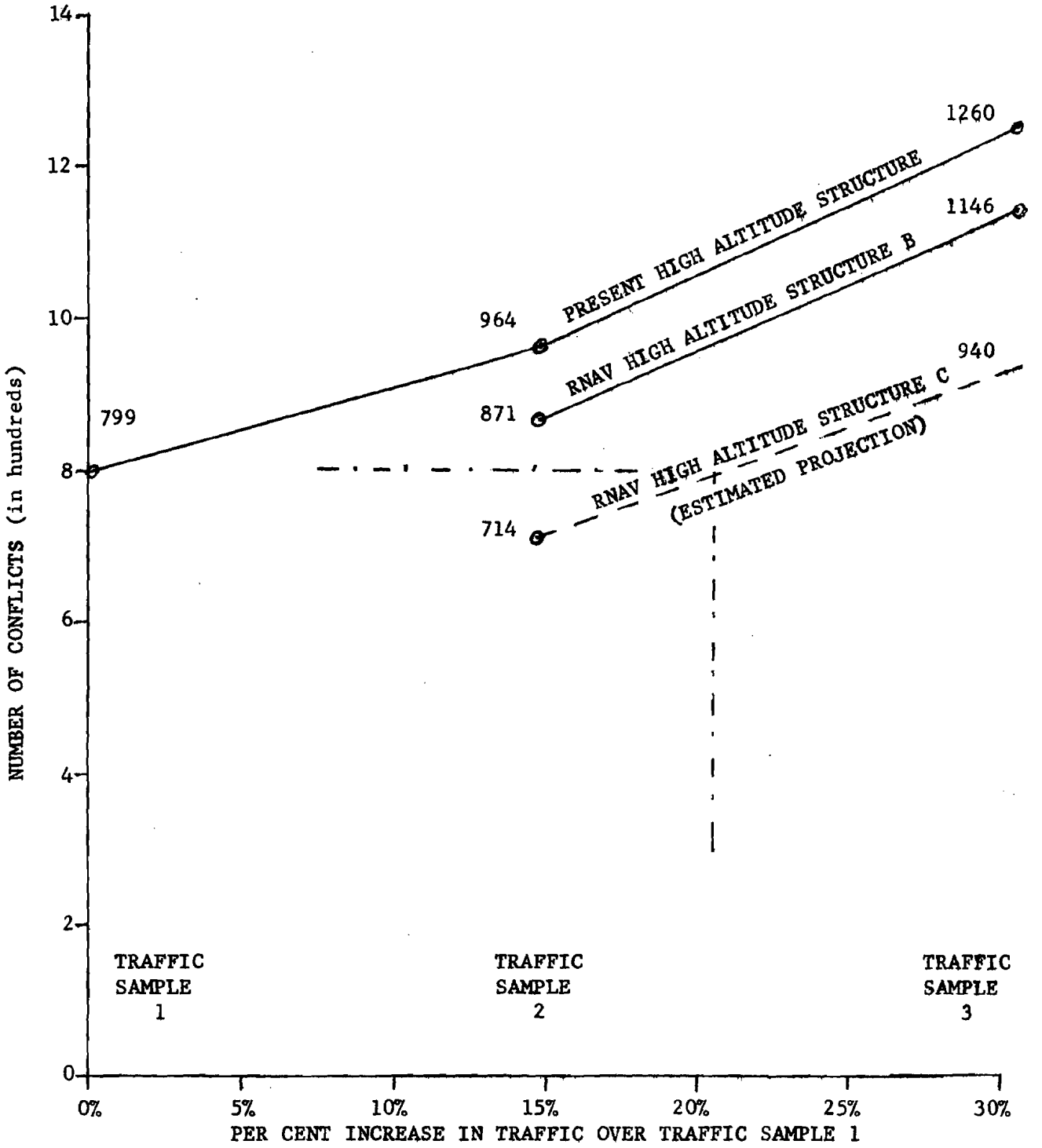


Figure 31 - Relative Traffic Densities to Conflict Rates - Traffic Samples 1, 2, and 3

traffic over Sample 1 (21%) that could be accomodated using RNAV High Altitude Structure C with no increase in conflicts over those found for the Present High Altitude Structure using Sample 1.

With the exception of the pre-planned direct route representing the RNAV Task Force post-1982 concept, all levels of RNAV Participation from 25 to 100 percent showed a decrease in the number of conflicts when compared to the 0% Participation Level for the three traffic samples and both RNAV Structures B and C. The greatest improvement was found in Structure C, which was the most extensive RNAV structure and incorporated design improvements over the previous NAFEC structures. The pre-planned direct route structure yielded the highest conflict count of any of the systems simulated.

The distribution of conflicts by sector shows that in a large majority of cases, conflicts were substantially reduced in those sectors which currently have relatively high potential conflict rates (based on simulation results) when 100% RNAV Participation using Structure C is compared to the 0% Participation Level.

The distribution of conflicts by time shows that using Traffic Sample 2, 24 to 30 percent of all conflicts in Structure C occurred within a one-hour period when tested using 0% through 100% Participation Levels. However, a comparison of the worst hour for each Participation Level shows the following reductions in the number of conflicts compared to the 0% RNAV Participation Level.

- 25% Participation Level = 21% reduction
- 50% Participation Level = 14% reduction
- 75% Participation Level = 26% reduction
- 100% Participation Level = 27% reduction

The reductions in the number of conflicts per hour of the simulated five-hour period for Structure C are depicted in figure 32. The broad bars, against which the hourly conflicts for the 25 through 100 percent RNAV Participation Levels are superimposed, represent the number of conflicts for each hour for the 0% RNAV Participation Level to facilitate comparisons for each hour.

When intersection and diverge System Conflicts are combined as a single measure and compared to all other System Conflicts combined, using RNAV High Altitude Structure C and Traffic Sample 2, the increase over the 0% RNAV Participation Level found for the 25%, 50%, and 75% Participation Levels in the combined intersection and diverge conflicts is outweighed by the decrease in all other conflicts as shown in table 7, page 58 which shows that for each added intersection/diverge conflict there was a reduction of 4.65, 11.35, and 25.30 in the number of all other conflicts combined at the 25%, 50%, and 75% RNAV Participation Levels respectively.

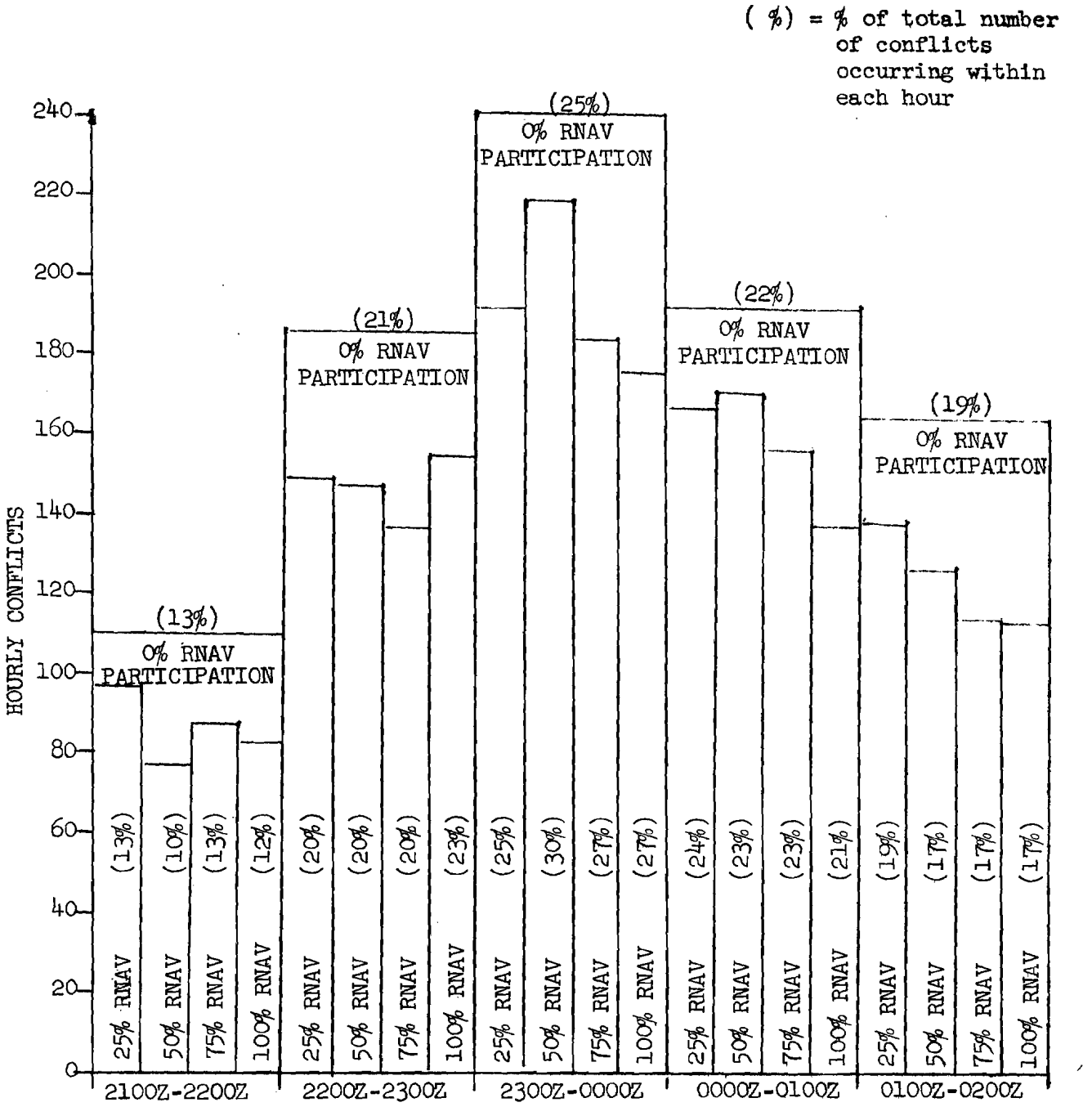


Figure 32 - Hourly Conflicts Rates - Percentage Distribution by Hour (Structure C)

The distribution of conflicts by duration shows that when controller intervention is not used, conflict duration is shorter at the 100% RNAV Participation Level than at the 0% Participation Level. This measure tends to indicate a potential for less undesireable altitude assignment due to the shorter conflict duration.

CONFLICTS BETWEEN SELECTED AIRPORT PAIRS' TRAFFIC

Analyses of the conflict data for those conflicts in which both aircraft involved were Selected Airport Pairs' traffic shows a marked improvement in Structure C over both the Present High Altitude Route Structure and RNAV High Altitude Structure B. While some increase in the number of total conflicts for Structure C was found between the 75% and 100% RNAV Participation Levels, a reduction of 24% was still found for the 100% RNAV Level when compared to the 0% RNAV Level. This small increase in the number of conflicts between the 75% and 100% Participation Levels appears to indicate further modification/improvement should be made to Structure C to accomodate the full load of Selected Airport Pair traffic at the 100% Participation Level. However, in general the reductions in conflicts at all RNAV Participation Levels is similar to that found in the System Conflict measures.

When intersection and diverge conflicts are combined as a single measure and compared to all other conflicts combined, using RNAV High Altitude Structure C and Traffic Sample 2, the increase over the 0% RNAV Participation Level found for the 25%, 50%, and 75% Participation Levels in the combined intersection and diverge conflicts is outweighed by the decrease in all other conflicts as shown in table 8, page 63. As shown in the table, for each added intersection/diverge conflict there was a reduction of 3.72, 4.42, and 15.09 in the number of all other conflicts combined at the 25%, 50%, and 75% RNAV Participation Levels respectively.

CONFLICTS INVOLVING SELECTED AIRPORT PAIRS' TRAFFIC

In the analyses of those conflicts in which one or both aircraft involved were Selected Airport Pairs' traffic, it was found that conflict reductions of 27% to 38% were found when comparing 0% and 100% RNAV Participation Levels for subsets of airport pairs. Based on these reductions and those found for the same subsets of airport pairs when only conflicts between Selected Airport Pairs' traffic was counted, it has been estimated that a total High Altitude RNAV Route Structure accomodating the total traffic simulated would yield approximately a 26% reduction in conflicts compared to the Present High Altitude Structure.

CONTROLLER INTERVENTION TESTS

Due to the nature of the controller intervention tests conducted as an adjunct to the fast time simulations, only limited data were available. While limited, these results are important, particularly in the light of data from a real time simulation conducted at NAFEC. Although the NAFEC simulation (Ref. 6) was of terminal RNAV operations

as opposed to the fast time simulation which was concerned with high altitude enroute operations, controller communications were reduced in both simulations as a result of the introduction of RNAV. In addition, controller reaction to the use of RNAV functions were similar and favorable in both simulations. This was more clearly marked in the NAFEC simulation as experience was gained in the use of RNAV procedures. In the controller intervention tests, controller comments during the tests tended to indicate a like controller attitude. In both simulations, it was found that RNAV instructions could be used by controller for the management of traffic under their control. In the controller intervention tests, it was found that restrictions imposed to provide separation between RNAV traffic were of shorter duration than those used to separate non-RNAV traffic.

CONCLUSIONS

The following conclusions are based on the results of fast time simulations of high altitude route structures conducted at Lincoln Laboratory. In some instances the conclusions are influenced by the results of controller intervention tests which were conducted as an adjunct to the fast time simulations and by the results of an RNAV simulation conducted at NAFEC (Ref. 6). Where these influences are reflected in these conclusions, they are identified.

1 - A well designed charted RNAV high altitude route structure, based on design concepts similar to those used in the final NAFEC high altitude RNAV route design (Structure C) can be implemented to form an RNAV-VOR high altitude route network which will provide benefits to RNAV equipped users and the ATC system without unfavorable impact on non-RNAV operations. These benefits, available in a mixed RNAV-VOR environment, will increase as the percentage of RNAV system users increase.

a. The requirements for controller intervention and the imposition of ATC restrictions will be reduced in a mixed RNAV-VOR charted high altitude route environment as a result of reductions in the number of potential conflicts as the percentage of RNAV system users increase.

b. High altitude RNAV charted routes, similar to those simulated, should provide a minimum average savings in flight miles (route miles times number of flights using the route) of approximately 1.8% compared to the Present High Altitude Structure. A savings of 1.8% in flight miles is estimated to yield a savings of approximately 570,000 gallons of jet fuel daily based on 1980 estimated fuel consumption rate.

c. Additional savings to the system user accrue as the result of increased availability of optimum cruise altitudes due to reductions in the number of potential overtake conflict situations. This reduction in potential overtake conflicts is the result of an increase in the number of available routes between departure and arrival airports provided in the RNAV-VOR network simulated.

d. As a result of the reduction in the average duration of potential conflicts, the duration of ATC imposed restrictions (primarily altitude restrictions) will be reduced as the percentage of RNAV system users increases.

e. Increased ATC system capacity is anticipated in a mixed RNAV-VOR charted high altitude environment due to reductions in the number of potential conflicts/controller intervention actions. This reduction was found to be most pronounced in those ARTCC sectors which had high potential conflict counts in the simulation of the Present High Altitude Structure.

f. While intersection and diverge type potential conflicts are increased in most cases as the result of the introduction of RNAV routes and traffic in a predominantly VOR high altitude route system, this increase is offset by major reductions in all other types of potential conflicts. The increase in intersections found as the result of the complex RNAV-VOR intersecting routes would be reduced in the real world as VOR routes are re-aligned to be compatible with new RNAV routes or are deleted as RNAV routes are added as proposed by the RNAV Task Force.

g. The network of RNAV-VOR routes simulated represented a worst case situation in that neither the RNAV routes nor existing VOR routes were modified to provide compatibility between the two route systems. The RNAV routes were designed without regard to the location of existing VOR routes and were simply overlaid on the VOR structure with no attempt made to optimize the network formed. The optimization was beyond the scope of the NAFEC design work and the evaluation.

h. The potential for head-on conflicts is reduced through use of discrete climb and descent RNAV route segments which will reduce the requirement for radar vectoring and the imposition of climb and descent altitude restrictions during transition to and from cruise altitude.

i. As evident in the controller intervention tests, video map clutter, resulting from the requirement to provide both RNAV and VOR route information to the controller, presents a problem requiring resolution.

j. Based on the controller intervention tests and the NAFEC simulation (Ref. 6) a savings in controller communications time and radio contracts result from the introduction of RNAV traffic. These savings increase as the percentage of RNAV traffic increases.

2 - A total charted RNAV high altitude environment will provide, as a minimum, the same degree of advantages to both the system user and the ATC system as was found for the mixed RNAV-VOR environment. In addition, certain problems unique to a mixed RNAV-VOR environment would no longer exist or would be minimized in a total charted RNAV high altitude route structure environment.

a. The video map clutter associated with an RNAV-VOR mixed environment would not exist in a total RNAV environment.

b. The intersection conflict potential will be reduced as VOR routes which intersect with RNAV routes would be deleted. While some additional RNAV routes would be required, the overall result would be a reduction in the total number of intersecting routes.

c. The total number of potential conflicts would be reduced or, as a minimum, remain the same as those found for the mixed RNAV-VOR environment, since the RNAV-VOR route networks simulated represent a worst case situation due to the interaction of traffic on the two route systems which were not designed to be compatible.

3 - The introduction of charted RNAV routes in the high altitude environment offers the potential of accomodating increased traffic for the post-1982 period while minimizing the number of potential conflicts and controller workload associated with conflict prevention/resolution.

4 - The introduction of a pre-planned direct uncharted RNAV route system as proposed by the FAA-Industry RNAV Task Force would result in the highest number of potential conflicts of all systems simulated. Tests of the present high altitude structure and particularly the charted RNAV-VOR route networks yielded lower potential conflict rates than the pre-planned direct route system. The potential reduction in flight miles inherent in a direct route system may be completely offset by an increase in the number of potential conflicts and controller workload.

ACKNOWLEDGMENT

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APPENDIX A

AIRPORTS CONSIDERED

ABE	CID	FSD	LHR	ONT	SHV
ABQ	CLE	FWA	LIT	ORD	SJC
ADW	CLT	GEG	LRF	ORF	SJU
AGC	CMH	GGG	LSV	ORL	SKF
ALB	COS	GRR	LUF	ORY	SLC
AMA	CRW	GSB	LUK	PBI	SLN
ATL	CVG	GSO	LYH	PDX	SMF
AUS	CVS	GSP	MAF	PHL	SNA
AVL	DAB	HNL	MBS	PHX	SNN
BAD	DAL	HPN	MCC	PIA	SPI
BAL	DAY	HSV	MCO	PIT	SPS
BDL	DCA	HTS	MDT	PSP	SSU
BGM	DEN	HYA	MDW	PTY	STL
BGR	DET	IAB	MEI	PUB	SUU
BHM	DLF	IAD	MEM	PVD	SUX
BKF	DMA	IAH	MEX	RAL	SYR
BKL	DSM	ICT	MFD	RDU	TCM
BNA	DTW	IND	MGM	RFD	TEB
BOI	ELM	IPT	MIA	RIC	TIK
BOS	ELP	JAN	MKC	RIV	TLH
BSM	END	JAX	MKE	RND	TOL
BTR	ERI	JFK	MLI	RNO	TPA
BUF	EVV	LAN	MSN	ROA	TRI
BUR	EWR	LAS	MSP	ROC	TUL
CAE	FAT	LAX	MSY	SAN	TUM
CAK	FCO	LBB	NAS	SAT	TUS
CBM	FDY	LEX	NQI	SAV	TYS
CGX	FFO	LFI	OAK	SDF	VAD
CHA	FLL	LGA	OFF	SEA	YNG
CHD	FNT	LGB	OKC	SFO	YUL
CHS	FPO	LGW	OMA	SGF	YYZ

APPENDIX B

TRAFFIC SAMPLES

AIRPORT PAIRS	EXCHANGED FLIGHTS SAMPLE 1	SAMPLE 2	SAMPLE 3	AIRPORT PAIRS	EXCHANGED FLIGHTS SAMPLE 1	SAMPLE 2	SAMPLE 3
ABE-DET	2	3	3	AMA-OFF	1	1	2
ABE-FLL	1	1	1	AMA-OKC	1	1	2
ABE-PIT	5	6	7	AMA-PUB	3	3	3
ABQ-AMA	4	4	4	ATL-BAL	5	5	5
ABQ-CHD	6	8	10	ATL-BDL	3	3	3
ABQ-COS	2	3	3	ATL-BNA	5	5	5
ABQ-DAL	4	5	7	ATL-BOS	5	6	6
ABQ-DEN	6	8	10	ATL-BUF	4	4	5
ABQ-ELP	3	4	6	ATL-CAE	8	8	9
ABQ-LAX	5	6	6	ATL-CHS	2	3	3
ABQ-LBB	2	2	3	ATL-CLE	4	5	5
ABQ-LRF	3	3	4	ATL-CLT	5	5	5
ABQ-LUF	3	4	4	ATL-CRW	2	3	3
ABQ-MCC	3	4	5	ATL-CVG	4	4	4
ABQ-MDW	1	1	2	ATL-DAB	1	1	1
ABQ-MIA	1	1	2	ATL-DAL	3	3	4
ABQ-MKC	2	2	2	ATL-DAY	4	4	6
ABQ-ORD	1	2	2	ATL-DCA	6	8	9
ABQ-PHX	4	5	6	ATL-DTW	3	4	5
ABQ-RND	6	6	7	ATL-EWR	5	6	6
ABQ-SFO	2	2	2	ATL-GSO	2	2	2
ABQ-SPS	3	4	4	ATL-IAD	2	3	4
ABQ-TUS	4	4	5	ATL-IAH	7	8	8
ADW-BJF	2	2	2	ATL-IND	3	4	4
ADW-CBM	2	3	3	ATL-JAN	2	2	2
ADW-FFO	4	6	7	ATL-JAX	5	6	7
ADW-IPT	1	2	2	ATL-JFK	6	8	10
ADW-MKC	1	1	1	ATL-LAX	3	4	4
ADW-OFF	3	3	4	ATL-LEX	2	2	2
ADW-RND	3	3	3	ATL-LGA	6	6	7
AGC-JFK	2	2	2	ATL-LGB	1	1	2
AGC-MDW	1	2	3	ATL-MCO	3	5	6
AGC-OKC	2	2	3	ATL-MEM	4	5	5
ALB-BUF	5	6	6	ATL-MIA	7	9	11
ALB-CLE	1	1	1	ATL-MKE	1	2	2
ALB-DTW	2	2	2	ATL-MSY	9	11	13
ALB-ORD	2	2	2	ATL-ORD	11	13	15
AMA-BKF	2	2	3	ATL-ORF	1	1	2
AMA-DAL	2	3	4	ATL-PBI	4	4	5
AMA-DLF	1	1	1	ATL-PHL	5	7	7
AMA-ELP	1	2	2	ATL-PIT	6	8	9
AMA-END	3	3	4	ATL-RDU	3	3	3
AMA-ICT	1	2	2	ATL-RIC	2	2	2
AMA-LUF	1	1	2	ATL-SAT	2	2	3
AMA-MEM	1	2	2	ATL-SDF	5	5	6

TRAFFIC SAMPLES

AIRPORT PAIRS	EXCHANGED FLIGHTS SAMPLE 1	SAMPLE 2	SAMPLE 3	AIRPORT PAIRS	EXCHANGED FLIGHTS SAMPLE 1	SAMPLE 2	SAMPLE 3
ATL-SFO	4	5	5	BDL-CLE	3	3	3
ATL-SHV	1	2	2	BDL-DCA	2	2	2
ATL-STL	5	6	7	DBL-DTW	2	2	2
ATL-TLH	1	1	1	DBL-FDY	1	2	2
ATL-TPA	9	11	13	BDL-IAD	1	1	1
ATL-TRI	1	2	2	BDL-LAX	1	1	1
ATL-TYS	1	1	1	BDL-MIA	3	4	4
AUS-DAL	5	7	9	BDL-ORD	7	8	9
AUS-ELP	4	4	4	BDL-PHL	2	2	2
AUS-IAD	2	2	2	BDL-PIT	3	3	4
AUS-IAH	8	9	10	BDL-ROC	5	5	6
AUS-MEM	1	1	1	BGM-BOS	2	2	3
AUS-AVL	2	3	3	BGM-JFK	1	2	2
BAD-END	5	6	6	BGR-JFK	4	4	5
BAD-NQI	9	10	13	BGR-TEB	2	3	3
BAD-OFF	1	1	2	BGR-TEB	2	3	3
BAD-RND	2	2	2	BHM-JAN	10	10	12
BAD-VAD	3	4	4	BHM-LGA	3	3	4
BAL-BHM	2	2	3	BHM-MEM	2	2	2
BAL-BOS	4	4	5	BHM-MIA	4	5	5
BAL-BOS	4	4	5	BHM-ORD	3	4	4
BAL-BUF	2	2	2	BHM-SHV	1	1	2
BAL-CLE	3	3	3	BHM-TYS	2	2	2
BAL-CMH	3	4	4	BKF-CHD	2	3	3
BAL-CVG	2	2	2	BKF-CUS	1	1	2
BAL-DAB	2	2	2	BKF-LSV	2	2	2
BAL-DAL	4	4	5	BKF-LUF	3	3	4
BAL-DAY	3	3	3	BKL-CMH	2	2	2
BAL-DEN	1	1	2	BKL-PHL	2	3	3
BAL-DTW	1	1	2	BNA-DAL	2	2	2
BAL-IAH	2	3	4	BNA-DCA	7	7	9
BAL-LAX	2	3	3	BNA-LAX	2	2	2
BAL-MIA	1	1	2	BNA-LGA	1	1	2
BAL-MSY	3	3	4	BNA-MEM	8	8	8
BAL-NAS	1	2	2	BNA-ORD	2	3	3
BAL-OMA	3	3	4	BNA-PHL	5	5	5
BAL-ORD	6	7	8	BNA-PIT	5	5	5
BAL-PHL	2	2	2	BNA-TUL	2	2	2
BAL-PIT	2	2	3	BOI-DEN	1	1	2
BAL-RDU	4	4	4	BOI-GEG	2	2	2
BAL-ROC	2	2	2	BOI-MKC	1	1	1
BAL-SAT	1	2	2	BOI-PDX	8	9	10
BAL-SEA	2	2	2	BOI-SLC	6	8	10
BAL-SJU	2	2	2	BOS-BUF	5	5	6
BAL-STU	2	2	3	BOS-CLE	6	7	8
BAL-YUL	2	2	2	BOS-CLT	3	3	3

TRAFFIC SAMPLES

AIRPORT PAIRS	EXCHANGED FLIGHTS SAMPLE 1	SAMPLE 2	SAMPLE 3	AIRPORT PAIRS	EXCHANGED FLIGHTS SAMPLE 1	SAMPLE 2	SAMPLE 3
BOS-DAL	3	4	4	CAE-DCA	2	2	2
BOS-DCA	14	15	18	CAE-EWR	3	4	4
BOS-DET	3	3	3	CAE-STL	1	1	2
BOS-DTW	5	6	7	CAK-EWR	2	2	2
BOS-FLL	3	3	4	CAK-ORD	4	5	5
BOS-IAD	5	6	7	CBM-GSB	2	2	2
BOS-JFK	8	10	11	CBM-LFI	3	3	4
BOS-LAX	8	10	11	CBM-TYS	1	1	2
BOS-LGW	3	3	3	CGX-CNH	2	3	3
BOS-MDT	5	5	5	CHA-CVG	2	2	2
BOS-MIA	8	9	10	CHA-DAL	2	2	3
BOS-ORD	17	19	21	CHA-SDF	2	3	3
BOS-ORY	4	5	5	CHD-CVS	3	4	5
BOS-PHL	11	13	14	CHD-END	3	3	3
BOS-PIT	6	8	9	CHD-IAB	3	3	3
BOS-ROC	2	3	4	CHD-LSV	4	5	6
BOS-SFO	6	7	8	CHD-SPS	2	2	2
BOS-SNN	3	4	4	CHD-TUS	1	2	2
BOS-STL	1	1	2	CHS-DCA	3	3	4
BOS-TPA	1	2	2	CHS-ORF	5	5	5
BSM-COS	2	3	4	CID-MKC	5	5	5
BSM-DLF	6	7	9	CID-ORD	7	9	10
BSM-DMA	2	2	2	CLE-CLT	1	1	1
BSM-ELP	1	1	2	CLE-DAL	4	5	7
BSM-LFI	2	2	2	CLE-DCA	9	11	13
BSM-LUF	1	1	2	CLE-DEN	2	2	2
BTR-DAL	1	1	2	CLE-ELM	4	4	4
BTR-IAH	6	7	8	CLE-EWR	6	8	9
BTR-SHV	1	2	3	CLE-FLL	1	1	1
BUF-DAY	2	2	2	CLE-FWA	3	3	3
BUF-DCA	1	1	1	CLE-HYA	2	3	3
BUF-DTW	6	6	6	CLE-IAD	3	3	3
BUF-EWR	6	7	8	CLE-IND	5	5	5
BUF-FDY	1	1	1	CLE-JFK	4	6	7
BUF-LGA	5	6	7	CLE-LAN	3	3	3
BUF-MIA	2	2	3	CLE-LAX	4	4	5
BUF-ORD	6	7	8	CLE-LGA	7	8	10
BUF-PHL	4	5	6	CLE-MDW	4	4	5
BUF-PIT	4	5	6	CLE-MFD	2	3	3
BUR-FAT	2	2	2	CLE-MIA	2	3	4
BUR-LAS	4	5	6	CLE-MKE	4	5	6
BUR-OAK	4	4	4	CLE-MSP	3	3	4
BUR-RNO	3	3	3	CLE-ORD	10	12	13
BUR-SFO	8	9	11	CLE-PDX	1	1	1
BUR-SJC	10	11	13	CLE-PHL	7	8	9

TRAFFIC SAMPLES

AIRPORT PAIRS	EXCHANGED FLIGHTS SAMPLE 1	SAMPLE 2	SAMPLE 3	AIRPORT PAIRS	EXCHANGED FLIGHTS SAMPLE 1	SAMPLE 2	SAMPLE 3
CLE-RFD	2	2	2	CVG-STL	5	5	5
CLE-SFO	2	3	3	CVG-TYS	5	5	5
CLE-STL	4	4	5	CVG-YNG	1	1	1
CLE-SYR	2	3	3	CVS-LRF	2	3	3
CLE-TEB	1	1	2	CVS-LSV	4	4	4
CLE-TPA	2	2	2	CVS-LUF	4	5	5
CLT-CMH	2	2	2	CVS-RND	6	7	8
CLT-DCA	5	5	5	CVS-SKF	1	2	2
CLT-DTW	1	1	2	DAB-MIA	4	4	4
CLT-EWR	4	4	5	DAL-DEN	5	7	9
CLT-JFK	1	1	1	DAL-ELP	8	10	10
CLT-LGA	2	2	2	DAL-IAD	3	4	6
CLT-ORD	3	3	3	DAL-IAH	22	24	26
CLT-PHL	4	4	5	DAL-JFK	9	11	12
CLT-PIT	4	4	4	DAL-LAS	1	1	2
CLT-TPA	1	1	1	DAL-LAX	8	10	12
CLT-YYZ	1	1	1	DAL-LBB	10	12	13
CMH-DCA	6	6	9	DAL-LGA	1	1	2
CMH-EWR	1	1	1	DAL-LIT	9	10	11
CMH-GSO	1	1	2	DAL-MAF	7	7	7
CMH-IND	2	2	2	DAL-MCO	1	1	2
CMH-JFK	3	4	5	DAL-MEM	7	9	10
CMH-LGA	3	3	4	DAL-MIA	2	3	3
CMH-MDW	4	4	4	DAL-MKC	4	4	5
CMH-MIA	3	4	4	DAL-MSY	7	9	11
CMH-ORD	1	2	2	DAL-OKC	3	4	4
CMH-STL	3	3	4	DAL-ORD	9	11	13
COS-END	2	2	2	DAL-PDX	3	3	3
COS-FFO	1	2	2	DAL-PHL	1	1	1
COS-IAB	2	2	2	DAL-PHX	2	2	3
COS-MCC	4	5	5	DAL-ROC	1	2	2
COS-MKC	2	2	2	DAL-SAT	11	13	13
COS-ORD	2	2	2	DAL-SDF	2	2	2
COS-PHX	2	2	2	DAL-SEA	1	2	2
COS-SKF	1	2	3	DAL-SFO	8	10	11
COS-TCM	3	4	4	DAL-STL	5	5	5
CVG-DAL	2	2	2	DAL-TUL	2	2	2
CVG-DAL	2	2	2	DAL-TUS	1	1	2
CVG-DCA	5	5	5	DAL-DCA	2	2	2
CVG-DTW	5	6	7	DAY-HPN	1	2	2
CVG-JFK	2	2	2	DAY-JFK	4	5	5
CVG-LAX	1	1	1	DAY-LGA	1	1	2
CVG-LGA	6	7	9	DAY-MDW	2	2	2
CVG-ORD	10	12	14	DAY-ORD	9	11	12
CVG-PHL	1	1	2	DAY-PHL	1	1	1
CVG-PIT	5	6	6				

TRAFFIC SAMPLES

AIRPORT PAIRS	EXCHANGED FLIGHTS SAMPLE 1	SAMPLE 2	SAMPLE 3	AIRPORT PAIRS	EXCHANGED FLIGHTS SAMPLE 1	SAMPLE 2	SAMPLE 3
DAY-PTL	7	8	10	DEN-MSY	2	2	2
DAT-STL	2	2	2	DEN-OKC	1	1	2
DAT-TEB	1	1	2	DEN-OMA	5	6	7
DAT-TYS	1	2	3	DEN-ORD	16	18	20
DCA-DTW	6	7	8	DEN-PDX	3	3	4
DCA-GSP	2	2	2	DEN-PHL	2	2	2
DCA-HPN	1	1	1	DEN-PHX	6	7	9
DCA-HSV	3	3	4	DEN-RAL	2	3	4
DCA-IAH	2	3	4	DEN-RFD	1	2	2
DCA-IND	1	1	2	DEN-RND	2	2	3
DCA-JAX	7	8	9	DEN-SAT	1	2	2
DCA-JFK	2	3	4	DEN-SEA	6	7	9
DCA-LEX	3	3	4	DEN-SFO	7	9	11
DCA-LGA	5	6	7	DEN-SJC	2	2	2
DCA-MCO	2	3	3	DEN-SLC	9	11	12
DCA-MDW	3	4	6	DEN-STL	6	7	8
DCA-MEM	3	4	5	DEN-SUX	4	4	5
DCA-MIA	6	7	8	DEN-TUL	4	5	7
DCA-MKE	3	4	4	DET-PHL	2	2	2
DCA-MSP	4	5	6	DLF-DMA	1	1	1
DCA-ORD	10	12	14	DLF-RND	2	2	2
DCA-PBI	2	2	2	DLF-SKF	4	5	6
DCA-PIT	5	5	6	DMA-LSV	4	5	6
DCA-PCD	3	4	4	DMA-LUF	2	3	3
DCA-ROC	2	2	2	DMA-OFF	2	2	2
DCA-SDF	3	3	3	DMA-RIV	6	7	9
DCA-STL	6	7	9	DMA-RND	2	2	2
DCA-SYR	5	6	6	DMA-SUU	1	1	2
DCA-TPA	1	1	1	DSM-LAX	2	3	4
DCA-TYS	5	7	8	DSM-MKC	2	2	2
DEN-DTW	4	4	4	DSM-MSA	5	5	5
DEN-FSD	2	2	2	DSM-ORD	9	11	12
DEN-IAD	4	4	5	DSM-STL	3	3	3
DEN-ICT	5	6	8	DTW-EWR	6	7	8
DEN-JFK	4	4	5	DTW-IAD	1	2	2
DEN-LAS	6	8	10	DTW-IND	4	5	6
DEN-LAX	13	15	17	DTW-LAX	7	9	10
DEN-LGA	2	2	2	DTW-LGA	14	16	18
DEN-LGB	2	2	2	DTW-LHR	3	4	5
DEN-MAF	2	2	2	DTW-MDW	2	2	3
DEN-MDW	1	2	2	DTW-MIA	3	3	4
DEN-MEM	1	1	1	DTW-MKC	3	4	5
DEN-MKC	8	9	10	DTW-MKE	6	7	8
DEN-MKE	1	1	2	DTW-MSP	5	6	8
DEN-MSP	6	8	10	DTW-MSY	1	1	2

TRAFFIC SAMPLES

AIRPORT PAIRS	EXCHANGED FLIGHTS SAMPLE 1	SAMPLE 2	SAMPLE 3	AIRPORT PAIRS	EXCHANGED FLIGHTS SAMPLE 1	SAMPLE 2	SAMPLE 3
DTW-ORD	18	19	21	EWR-MKC	1	1	2
DTW-PHL	10	11	13	EWR-NAS	1	2	2
DTW-PIT	2	2	2	EWR-OKC	1	2	2
DTW-RDU	1	2	2	EWR-ORD	13	15	17
DTW-ROC	4	4	4	EWR-PIT	7	9	11
DTW-SDF	3	3	5	EWR-RDU	5	7	8
DTW-SFO	2	2	2	EWR-RIC	2	2	2
DTW-SNN	2	2	2	EWR-ROC	2	2	3
DTW-STL	5	7	8	EWR-SDF	1	1	1
DTW-SYR	5	6	7	EWR-SFO	3	5	6
DTW-TPA	2	2	2	EWR-SJU	1	1	1
ELM-PIT	3	3	3	EWR-STL	1	1	2
ELP-LAX	5	7	8	EWR-SYR	3	3	3
ELP-LSV	6	8	10	EWR-TOL	2	2	2
ELP-LUF	1	1	1	EWR-TPA	2	3	3
ELP-MAF	4	4	4	EWR-TYS	1	1	1
ELP-NQI	8	10	12	EWR-YNG	4	4	4
EEP-PHX	3	4	6	FAT-LAS	3	3	4
ELP-SAN	1	1	1	FAT-LAX	8	10	10
ELP-SAT	3	3	4	FAT-SFO	1	2	2
ELP-SFO	1	1	2	FAT-SJX	1	1	2
ELP-SLC	2	2	3	FCO-JFK	6	7	8
ELP-TUS	3	4	4	FFO-IND	2	2	2
END-FFO	3	3	3	FFO-LFI	1	1	2
END-IAB	7	9	11	FFO-PIT	1	1	2
END-OFF	3	3	3	FFO-TIK	2	2	2
END-SKF	3	3	3	FLL-JAX	2	2	2
END-TUL	4	4	4	FLL-JFK	6	7	8
ERI-TUL	2	2	2	FLL-ORD	4	5	5
EVV-MEM	2	3	3	FLL-PHL	3	4	4
EVV-ORD	4	4	4	FLL-PIT	2	2	2
EWR-FLL	2	2	2	FLL-TPA	9	10	12
EWR-FWA	2	2	2	FNT-IND	1	1	1
EWR-FWA	2	2	2	FPO-JFK	5	6	7
EWR-GSO	4	6	8	FSD-MSP	2	2	2
EWR-GSP	2	2	3	FSD-ORD	2	2	2
EWR-HTS	2	2	2	GEG-ORD	3	3	3
EWR-IAD	5	7	8	GEG-PDX	7	7	8
EWR-IAH	4	5	7	GEG-SEA	5	6	7
EWR-IND	2	2	3	GEG-SFO	3	3	3
EWR-JAX	2	2	3	GGG-TRI	2	2	2
EWR-LAX	6	8	10	GRR-SLC	3	4	4
EWR-LEX	2	2	2	GSB-LFI	2	2	2
EWR-LYH	4	4	4	GSB-LFI	2	2	2
EWR-MBS	1	1	2	GSB-SKF	1	2	2
EWR-MIA	6	8	9	GSB-TIK	3	4	4

TRAFFIC SAMPLES

AIRPORT PAIRS	EXCHANGED FLIGHTS SAMPLE 1	SAMPLE 2	SAMPLE 3	AIRPORT PAIRS	EXCHANGED FLIGHTS SAMPLE 1	SAMPLE 2	SAMPLE 3
GSO-HPN	1	1	2	IAH-MEM	5	5	5
GSO-HSV	2	2	2	IAH-MIA	2	2	4
GSO-IAD	3	3	3	IAH-MKC	1	1	2
GSO-LGA	3	3	3	IAH-MSY	15	16	18
GSO-ORD	3	3	3	IAH-ORD	4	5	5
GSO-TEB	2	2	2	IAH-PHL	2	2	2
HPN-MDW	3	3	4	IAH-PIT	1	1	2
HPN-MSP	2	3	4	IAH-SAT	1	1	1
HPN-MSY	2	2	2	IAH-SFO	1	1	1
HPN-PHL	3	4	5	IAH-SHV	2	2	2
HPN-PIT	1	1	1	IAH-STL	2	3	4
HPN-RDU	1	1	2	IAH-TPA	1	1	2
HPN-ROC	2	3	3	IAH-TUL	3	3	4
HPN-YUL	1	1	1	ICT-LUK	2	2	3
HPN-YYZ	3	4	5	ICT-MDW	2	2	2
HSV-MCO	2	2	2	ICT-MKC	6	6	7
HSV-MEM	1	1	1	ICT-OMA	2	2	2
HSV-MGM	2	2	2	ICT-ORD	4	4	4
HSV-MSY	5	7	8	ICT-SEA	1	1	1
HSV-ORD	2	2	2	IND-JFK	2	3	3
HSV-STL	2	2	2	IND-LAX	1	1	2
IAB-LUF	3	4	5	IND-MEM	4	4	5
IAB-STL	1	1	2	IND-PHL	2	2	2
IAD-JFK	1	1	2	IND-PIT	2	2	2
IAD-LAX	9	10	12	IND-STL	7	8	10
IAD-LGA	3	4	5	IND-TPA	1	1	1
IAD-MIA	1	1	1	JAN-MEM	3	5	6
IAD-MSY	2	2	2	JAN-SHV	5	5	6
IAD-NAS	1	1	2	JAX-JFK	5	5	5
IAD-OAK	1	1	2	JAX-LGA	2	2	2
IAD-ORD	5	6	7	JAX-MIA	3	3	4
IAD-PHX	2	2	2	JAX-ORD	1	2	2
IAD-SEA	1	1	2	JAX-SSU	2	2	2
IAD-SFO	4	5	6	JAX-TPA	3	4	4
IAD-SNN	2	2	2	JFK-LAS	3	3	4
IAD-STL	1	2	2	JFK-LAX	15	17	19
IAD-SYR	1	1	2	JFK-LGW	3	3	4
IAD-TUL	1	1	1	JFK-LHR	10	11	12
IAH-HPN	3	3	3	JFK-MCO	4	4	6
IAH-IAD	4	4	4	JFK-MEM	1	2	2
IAH-ICT	3	3	3	JFK-MEX	4	5	6
IAH-JFK	2	2	2	JFK-MIA	20	22	24
IAH-LAX	5	6	8	JFK-MKE	4	5	6
IAH-LBB	4	4	4	JFK-MSP	5	6	8
IAH-MAF	2	2	2	JFK-MSY	6	6	8

TRAFFIC SAMPLES

AIRPORT PAIRS	EXCHANGED FLIGHTS SAMPLE 1	SAMPLE 2	SAMPLE 3	AIRPORT PAIRS	EXCHANGED FLIGHTS SAMPLE 1	SAMPLE 2	SAMPLE 3
JFK-NAS	3	4	5	LAX-MSY	4	5	6
JFK-OAK	2	2	2	LAX-OAK	12	14	15
JFK-OKC	2	2	2	LAX-OKC	5	6	8
JFK-ORD	8	9	11	LAX-OMA	2	2	2
JFK-ORF	1	1	2	LAX-ORD	19	21	23
JFK-ORY	8	9	10	LAX-PDX	4	5	6
JFK-PBI	3	3	3	LAX-PHL	12	14	15
JFK-PDX	2	2	2	LAX-PHX	10	12	14
JFK-PHX	3	3	3	LAX-PIT	1	2	2
JFK-SAN	2	2	2	LAX-PTY	1	2	2
JFK-SEA	4	5	6	LAX-RNO	2	2	3
JFK-SFO	9	10	12	LAX-SAT	2	2	3
JFK-SJC	1	2	2	LAX-SEA	10	11	13
JFK-SJU	12	13	14	LAX-SFO	37	38	40
JFK-SLC	1	2	2	LAX-SJC	15	16	18
JFK-SNN	4	5	6	LAX-SLC	10	12	14
JFK-STL	3	4	4	LAX-SMF	16	18	20
JFK-SYR	2	3	4	LAX-STL	6	8	10
JFK-TPA	2	3	4	LAX-SUU	1	2	2
JFK-YUL	4	5	6	LAX-TUM	1	2	2
JFK-YYZ	3	4	5	LAX-TUS	3	3	5
LAN-ORD	2	2	2	LEX-ROA	2	2	2
LAS-LAX	30	31	33	LFI-MCC	2	2	2
LAS-LGB	1	1	2	LGA-LUK	2	3	3
LAS-LUF	2	3	3	LGA-LYH	2	2	2
LAS-MKC	1	1	2	LGA-MBS	2	2	2
LAS-OAK	2	2	2	LGA-MEM	1	2	2
LAS-OKC	1	1	2	LGA-MIA	7	8	9
LAS-ONT	3	3	4	LGA-MKC	3	3	4
LAS-ORD	9	11	13	LGA-OMA	2	2	2
LAS-PHX	4	5	7	LGA-ORD	28	30	32
LAS-PSP	2	2	2	LGA-ORF	2	2	2
LAS-RNO	5	7	9	LGA-PBI	5	5	5
LAS-SAN	3	3	4	LGA-PIA	2	2	2
LAS-SFO	11	13	15	LGA-PIT	7	9	11
LAS-SJC	1	1	2	LGA-RDU	2	2	2
LAS-SLC	8	9	11	LGA-RIC	3	4	4
LAS-TUS	1	1	2	LGA-ROA	2	2	2
LAX-HNL	4	5	6	LGA-ROC	7	7	9
LAX-MEM	2	2	3	LGA-SDF	5	5	7
LAX-MEX	2	2	3	LGA-STL	9	11	13
LAX-MIA	4	4	5	LGA-TYS	3	3	3
LAX-MKC	6	6	8	LGA-YUL	3	4	5
LAX-MKE	1	1	2	LGA-YYZ	11	12	13
LAX-MSP	4	5	5	LGB-SFO	6	7	8

TRAFFIC SAMPLES

AIRPORT PAIRS	EXCHANGED FLIGHTS SAMPLE 1	SAMPLE 2	SAMPLE 3	AIRPORT PAIRS	EXCHANGED FLIGHTS SAMPLE 1	SAMPLE 2	SAMPLE 3
LIT-SHV	4	4	5	MIA-SJU	5	6	7
LIT-STL	4	4	4	MIA-STL	3	3	4
LRF-NQI	3	3	3	MIA-TPA	11	12	14
LRF-RND	1	1	2	MIA-TUM	1	2	2
LRF-VAD	3	3	4	MKC-MSP	5	5	6
LSV-LUF	13	14	15	MKC-ORD	15	16	18
LSV-OMA	1	1	2	MKC-PHL	2	2	2
LSV-RND	1	2	2	MKC-PHX	1	1	1
LSV-SKF	1	1	2	MKC-PIA	1	1	2
LUF-MCC	3	3	4	MKC-SDF	3	3	3
LUF-TIK	2	2	2	MKC-SEA	1	1	2
LUK-MKE	2	3	3	MKC-SFO	4	4	5
LUK-SAV	2	2	2	MKC-STL	11	13	15
MAF-SAT	2	2	2	MKC-SUX	5	5	5
MBS-ORD	6	7	7	MKC-TUL	5	5	6
MCO-TLH	3	3	3	MKE-MSP	8	9	10
MDT-PIT	2	2	3	MKE-PIT	2	2	2
MDW-MKC	1	1	2	MKE-SFO	2	2	2
MDW-MSP	9	10	12	MKE-STL	5	6	6
MDW-PHX	3	4	4	MKE-TPA	1	2	2
MDW-PIT	1	2	2	MLI-MSP	2	3	3
MDW-RIC	1	2	2	MSN-MSP	1	1	2
MDW-SDF	3	4	4	MSP-OMA	4	4	5
MDW-SFO	1	1	2	MSP-ORD	19	21	22
MDW-STL	5	6	8	MSP-PDX	1	2	2
MEI-TYS	6	7	8	MSP-PHL	3	4	4
MEM-MIA	1	1	1	MSP-PHX	1	1	2
MEM-MKC	1	1	1	MSP-SAT	1	1	2
MEM-MSY	3	5	6	MSP-SEA	7	7	7
MEM-OKC	2	2	2	MSP-SFO	5	5	6
MEM-ORD	4	6	7	MSP-SLC	2	2	2
MEM-PIT	2	2	2	MSP-STL	2	2	2
MEM-SDF	1	1	1	MSP-YYZ	1	2	2
MEM-SHV	1	1	1	MSY-ORD	1	1	2
MEM-STL	9	10	11	MSY-SAT	2	2	2
MEM-TYS	3	3	3	MSY-SHV	3	3	3
MFD-MGM	3	3	4	MSY-STL	1	2	2
MGM-MSY	2	3	3	MSY-TPA	4	5	7
MIA-MSP	1	1	1	NQI-SKF	3	4	4
MIS-MSY	6	6	9	NQI-TIK	6	7	8
MIA-ORD	9	10	12	OAK-HNL	1	1	1
MIA-PHL	6	7	8	OAK-ONT	2	2	2
MIA-PIT	4	5	6	OAK-ORD	3	3	4
MIA-SDF	1	1	2	OAK-PDX	1	1	1
MIA-SFO	2	3	3	OAK-PHX	1	1	1

TRAFFIC SAMPLES

AIRPORT PAIRS	EXCHANGED FLIGHTS SAMPLE 1	SAMPLE 2	SAMPLE 3	AIRPORT PAIRS	EXCHANGED FLIGHTS SAMPLE 1	SAMPLE 2	SAMPLE 3
OAK-RNO	1	1	2	PHL-LHR	1	1	2
OKC-PDX	2	2	2	PHL-PIT	11	12	14
OKC-SFO	1	1	2	PHL-ROC	3	4	4
OKC-STL	1	1	2	PHL-SDF	2	2	2
OMA-ORD	8	9	11	PHL-SFO	2	2	3
OMA-SFO	2	2	2	PHL-STL	2	3	3
ONT-SFO	10	11	12	PHL-SYR	5	5	5
ONT-SJC	5	6	6	PHL-TPA	2	2	3
ONT-SMF	2	2	2	PHX-PSP	4	4	4
ONT-TIK	2	2	2	PHX-SAN	9	9	9
ORD-ORF	1	2	2	PHX-SFO	2	2	3
ORD-ORY	2	2	2	PHX-SKF	1	1	2
ORD-PBI	1	1	2	PHX-STL	3	4	4
ORD-PDX	5	6	7	PIT-PVD	1	1	1
ORD-PHL	16	18	20	PIT-SDF	3	5	5
ORD-PHX	7	9	10	PIT-SFO	1	2	2
ORD-PIT	8	9	11	PIT-STL	1	1	1
ORD-RDU	5	5	5	PIT-SYR	5	5	6
ORD-ROC	5	7	7	PIT-TOL	3	4	4
ORD-SAN	5	5	5	PIT-TYS	2	2	2
ORD-SDF	2	2	3	PSP-SFO	1	2	2
ORD-SEA	9	11	13	PVD-SYR	1	1	2
ORD-SFO	17	19	21	RIV-SKF	2	2	2
ORD-SJC	1	1	2	RNO-SJC	2	2	2
ORD-SLC	16	17	19	RNO-SLC	3	3	5
ORD-SUX	1	2	2	RNO-SMF	1	2	2
ORD-SYR	2	2	2	SAN-SEA	3	3	4
ORD-TOL	4	5	5	SAN-SFO	6	6	7
ORD-TPA	4	5	7	SDF-STL	7	7	7
ORD-TUL	4	5	6	SDF-TPA	2	2	2
ORD-TUS	3	4	6	SEA-SFO	13	14	16
ORD-TYS	3	3	3	SEA-SLC	2	2	2
ORD-YNG	3	3	3	SEA-STL	3	4	5
ORF-PHL	2	2	2	SFO-HNL	5	6	7
ORL-SAV	2	2	2	SFO-SLC	6	7	9
PBI-PHL	1	1	2	SFO-SNA	6	8	10
PBI-PIT	2	2	2	SFO-STL	4	4	5
PBI-TLH	2	2	2	SGF-TUL	2	2	2
PBI-TPA	2	2	2	SHV-TUL	3	4	6
PDX-RNO	3	4	4	SJC-SNA	4	5	5
PDX-SEA	3	3	3	SKF-TIK	2	2	2
PDX-SFO	8	10	12	SLC-SLN	2	2	2
PDX-SLC	5	6	6	SPI-STL	2	3	4
PDX-STL	1	1	2	STL-TPA	2	2	4

TRAFFIC SAMPLES

AIRPORT PAIRS	EXCHANGED FLIGHTS SAMPLE 1	SAMPLE 2	SAMPLE 3	AIRPORT PAIRS	EXCHANGED FLIGHTS SAMPLE 1	SAMPLE 2	SAMPLE 3
STL-TUL	4	5	5				
STL-TUS	1	2	2				
SUU-HNL	3	3	4				
SUU-TCM	5	5	5				
TEB-YYZ	2	2	2				
TLH-TPA	1	2	2				