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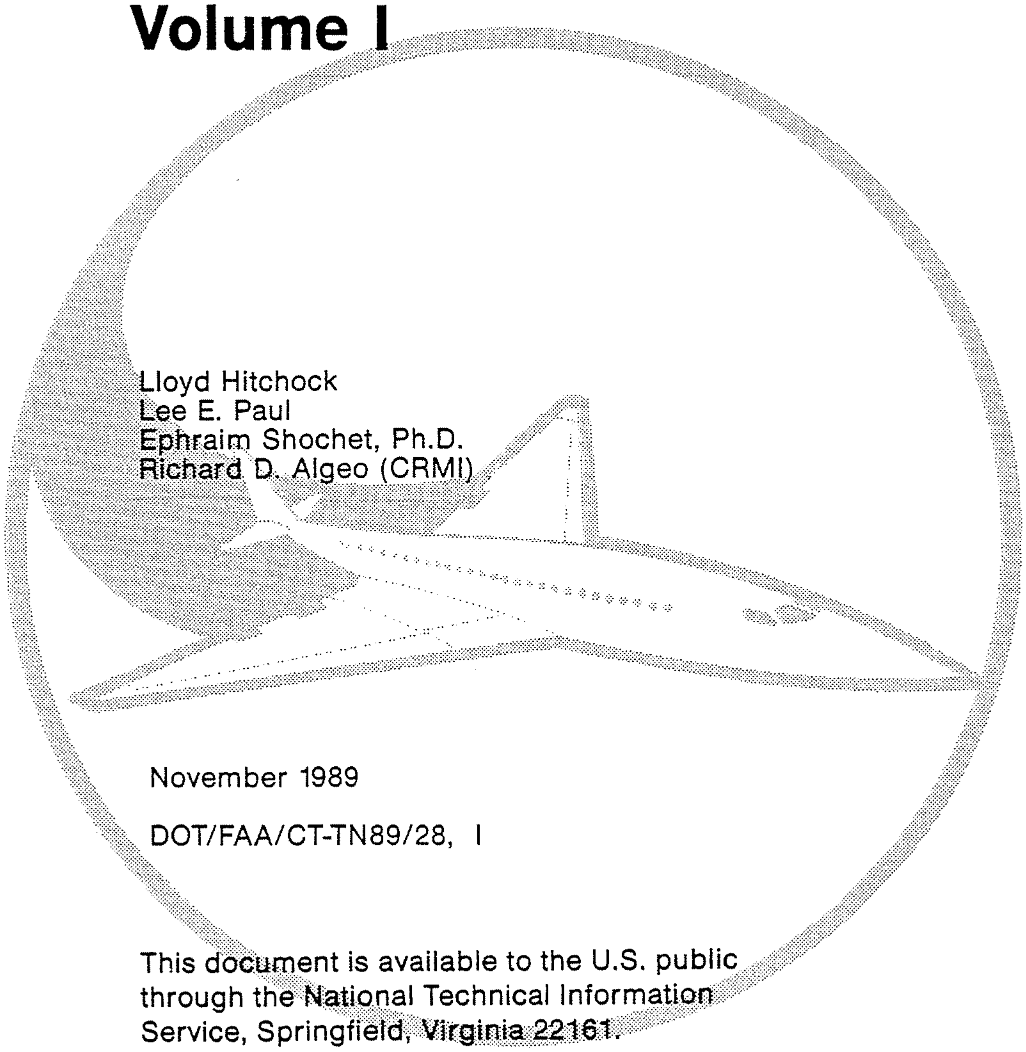
Dallas/Fort Worth Simulation
Volume I



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November 1989

DOT/FAA/CT-TN89/28, I

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16. Abstract

At the request of the Director, Southwest Region, the Technical Center conducted a series of dynamic, real-time, air traffic control simulations of selected aspects of the D/FW Metroplex Air Traffic System Plan. Using D/FW controllers as subjects, the simulations provided an opportunity evaluate proposed changes in area flow patterns and traffic management and to experience simultaneous approaches to the four parallel runway configuration under consideration for D/FW. The results of these simulations demonstrated that, even when faced with up to twice their normal traffic load, the controllers could maintain a smooth and safe flow of traffic using the new configurations proposed for the D/FW area.

The D/FW Evaluation Team declared that the "parallel arrival routes, separate altitudes for high performance turboprops, increased departure routes, and stratified sectors all proved to be valuable controller tools." In addition, simulation of the four simultaneous parallel approaches led the Evaluation Team to "enthusiastically endorse the concept of four simultaneous approaches to the D/FW airport" and to affirm that "in each and every case the concept proved to be safe" even though frequently challenged by the unlikely conditions of 30 degree blunders without communications.

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PREFACE

This report documents a series of air traffic control (ATC) simulations performed at the Federal Aviation Administration (FAA) Technical Center. These real-time ATC exercises were conducted to evaluate selected aspects of the Dallas/Fort Worth (D/FW) Metroplex Air Traffic System Plan for enhanced operations. This report is organized into three volumes.

Volume I contains the main body of the report. It includes a detailed description of the objectives of the study and of the technical approach and test methods that were used. In addition, the combined results of the study and conclusions are presented.

Volume II consists of appendices D, E, and F to the report which are referenced in Volume I. These appendices contain the graphic and quantitative plots for the blunder situations which required controller action during the evaluation of the proposed D/FW modifications. The blunders are separated on the basis of the number of runways that were threatened; one, two, or three.

Volume III contains an edited videotape of the D/FW simulation exercises. This volume is subject to limited distribution.

ACKNOWLEDGEMENTS

This project would not have been possible without the continual support of the Dallas/Fort Worth Task Force which was actively involved from the initial concept, through planning the airspace, routes, and traffic samples, through the conduct of the simulation, and into the data analysis. The Task Force was led by Ron Uhlenhaker and included Edward Carruth, Robert Deering, Dana Jones, and later, Allen Crocker.

The entire staff of the National Airspace System Simulation Facility (NSSF) nursed this simulation through a change in software and computers. Special thanks go to George Kupp, assisted by Hank Smallacombe, the controllers who tested and refined the system, trained the simulator operators, and executed the scenarios; John Dempsey who kept the displays running and did much of the troubleshooting; and Dan Warburton, Don Anderson, Frank Coffman, Dorothy Talvaccia, and Scott Doucette who were modifying software almost till the last run.

Consultants involved in the preparation of this report include Dr. Norm Lane and Dr. Robert Wherry who developed the Projected Closest Point of Approach (PCPA) metric and assisted in the analysis and interpretation of the data, and Colonel Paul Stringer who assisted in the assessment of the operational implications of the study.

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EXECUTIVE SUMMARY

The Federal Aviation Administration (FAA) Technical Center conducted a series of dynamic, real-time simulations of selected alternatives for the proposed traffic enhancement modifications for the Dallas/Fort Worth Airport complex as detailed in the D/FW Metroplex Air Traffic System Plan. A selected sample of the proposed modifications to the traffic patterns in the D/FW area was evaluated including the proposal to conduct simultaneous operations to the four parallel runways which have been proposed for D/FW. During the simulation, in order to exercise D/FW's proposal to conduct simultaneous approaches to four runways, selected aircraft were directed to deviate (blunder), in accordance with a structured scenario, from their assigned localizer paths by either 10, 20, or 30 degrees. Two thirds of these blundering aircraft were also designated to simulate a complete failure of their communication systems.

The results of these simulations demonstrated that, even when faced with up to twice their normal traffic load, the controllers of the D/FW facility could maintain a smooth and safe flow of traffic using the new configurations proposed for the D/FW area. In their summary report, the D/FW Evaluation Team declared that the "parallel arrival routes, separate altitudes for high performance turboprops, increased departure routes, and stratified sectors all proved to be valuable controller tools." In addition, simulation of the use of the four simultaneous parallel approaches to the proposed D/FW runway configuration led the Evaluation Team to "enthusiastically endorse the concept of four simultaneous approaches at the D/FW Airport" and to affirm that "in each and every case the concept proved to be safe" even though frequently challenged by the extremely unlikely conditions of 30 degree blunders without communications.

BACKGROUND

This simulation effort supported the Dallas/Fort Worth (D/FW) Task Force by providing a dynamic, real-time operational test of the Task Force's proposal for expanded airport utilization and its revised airspace plan. The Task Force had developed a detailed and comprehensive plan for increasing the capacity of the D/FW Metroplex (see appendix A) and wanted to evaluate selected aspects of the proposed changes. Real-time simulation, conducted in the National Airspace System (NAS) Simulation Support Facility (NSSF), provided the team members, and selected tower and center controllers, with hands-on exercises, observations, and the data necessary to evaluate the critical aspects of the new features of the D/FW Metroplex Air Traffic System Plan. The simulations were accomplished in the following two phases:

Phase 1: This phase provided an evaluation of the initial implementation of the D/FW Metroplex Air Traffic System Plan's concepts for using additional routes, navigational aids (NAVAIDs), runways, and en route and terminal radar approach control (TRACON) traffic flows.

Phase 2: This phase investigated the feasibility and safety of conducting four simultaneous parallel approaches at D/FW under Instrument Meteorological Conditions (IMC).

The D/FW Metroplex Air Traffic System Plan is designed to provide procedures for conducting operations within the D/FW terminal area for the period 1990 through 2005.

The principal features of this plan include:

1. Parallel arrival routes to D/FW over all cornerposts regardless of flow. The use of parallel arrival routes would be contingent upon both runway availability and traffic demand.

2. Parallel arrival routes to satellite airports based on destination.

3. Four turbojet departure routes; north, south, east, and west.

4. Separate arrival and departure altitudes for a selected population of high performance turboprop aircraft.

5. Increased arrival capacity for both D/FW and satellite airports.

6. Increased departure capacity for both D/FW and satellite turbojet departures.

7. A 30-nautical mile (nmi) Terminal Control Area (TCA) based on the D/FW VORTAC.

8. Development of a real-time traffic management system for the D/FW terminal area.

9. Development of procedures for simultaneous Instrument Landing System/Microwave Landing System (ILS/MLS) approaches to four parallel runways.

In view of the large expenditure of personnel and financial resources which would be required to implement this plan, it was decided that the more significant changes should be evaluated by simulation prior to their adoption in order to confirm their effectiveness.

To accomplish this, the director of the Southwest Region requested this simulation by letter (ASW-1 to ADL-1, June 23, 1987, entitled "Request for Dallas/Fort Worth (D/FW) Simulation"). This request was approved by the Associate Administrator for Development and Logistics on August 18, 1987, and the Technical Center was directed to proceed with the proposed simulations.

Virtually all of the changes proposed in the D/FW Plan can be implemented under existing regulations and standards. The one exception is the simultaneous use of four parallel runways for approaches under IMC. The separation between these runway centerlines (see figures 1 and 2) meets current requirements for simultaneous ILS/MLS approaches (Federal Aviation Administration (FAA) manual 7110.65, chapter 5, paragraph 26), but existing, published, missed approach procedures would no longer be valid and would have to be updated.

METHODOLOGY

The D/FW ATC Simulation, which was conducted at the FAA Technical Center, was designed and conducted in accord with the following:

SIMULATION FACILITY.

At the FAA's Technical Center, Air Traffic Control (ATC) simulations are run using the NAS Simulation Support Facility (NSSF). Physically, the NSSF consists of two SEL computers, the simulator "pilot" complex, and the main ATC Laboratory (which houses the controller and monitor positions). The NSSF supports real-time, interactive simulation of en route and terminal airspaces. The NSSF can be configured to match any facility's current operations by emulating existing traffic densities and mixes, radars, NAVAIDs, video maps, and/or communications. It has the further ability to examine proposed changes in airspace operations such as new and different routes and procedures, additional runways, modifications of separation standards, additional traffic demands, and the introduction of new technology (new radars, MLS's, modified displays, automated alerts, etc.).

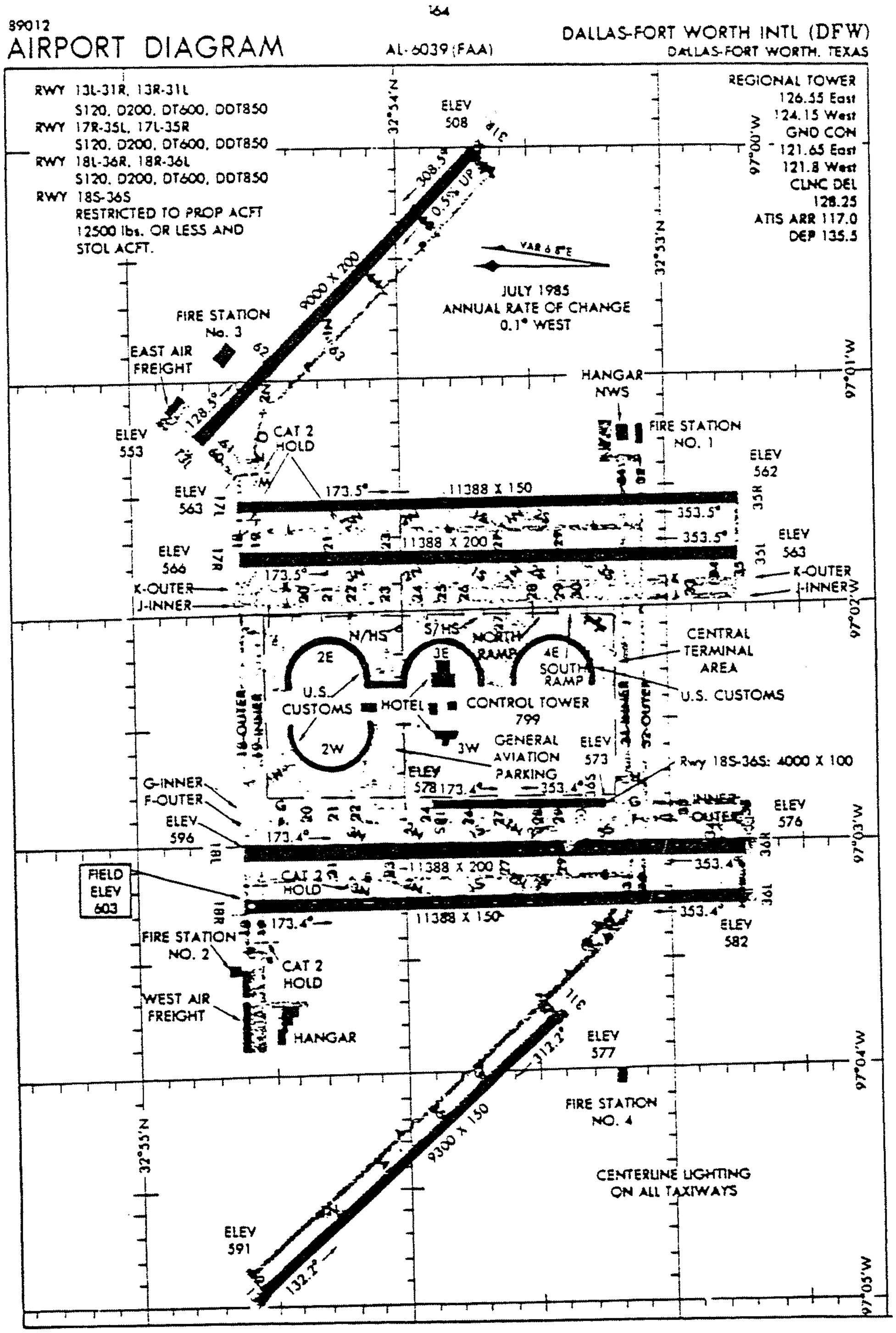


FIGURE 1. CURRENT D/FW CONFIGURATION

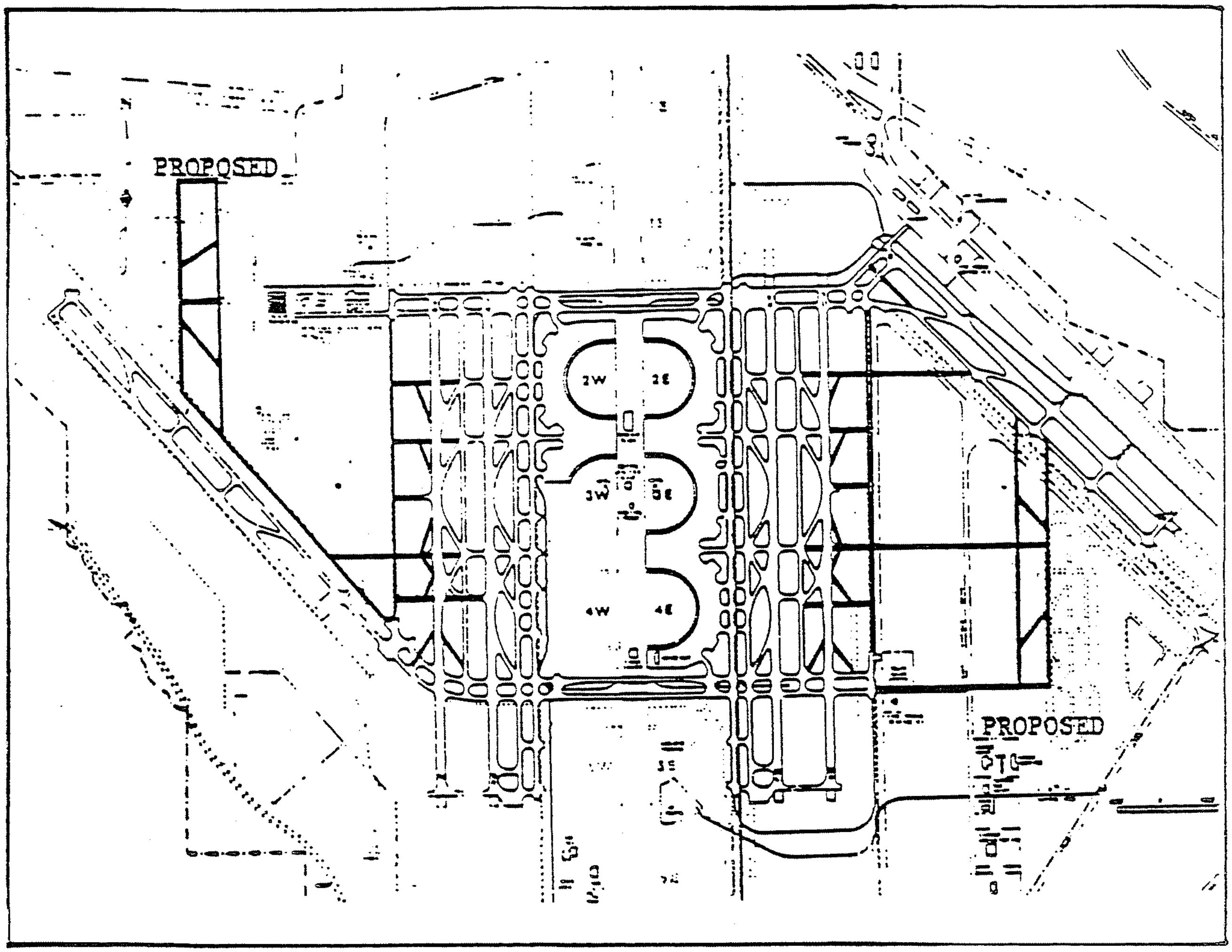


FIGURE 2. PROPOSED D/FW CONFIGURATION

Participating controllers work in the ATC Laboratory (see figure 3) which has eight digital displays, with their associated keyboard data entry and communication equipment, which are similar to, but not identical with, the standard Automated Radar Terminal System (ARTS) and en route plan view displays (PVD's), consoles, and keyboards (see figure 4). The simulated radar displays used accurately present aircraft position but, as currently implemented, do not provide any track history by reproducing the "tails" seen on actual radar scopes. The ATC Laboratory is configured so that the subject controllers can function in a manner that comes as close as possible to the way they would operate in the actual environment with full controller-to-controller, controller-to-pilot (simulator operator), and pilot-to-controller communications available for normal use. The ATC Laboratory is currently limited to six active displays or control positions and up to two "ghost" positions, which are used to control background and/or preprogrammed traffic. A maximum of 55 aircraft can be controlled at any given time. When larger simulations are needed, the airspace must be divided into smaller configurations of the positions of interest and each position is then studied in isolation. Maps and routes with display information based upon either present or proposed operations are used for simulated sectors and their displays. Patch-in telephone communications and computer linking serve to simulate sector operation in a realistic fashion. Where available, an analysis of the subject facility's past flight strips is used as the basis for the definition of a realistic mix of aircraft, routes, and identifiers. The Simulator Pilot Complex (figure 5) houses the simulation pilots (operators) and their aircraft control consoles. The simulator operators are voice-linked with the controllers in the ATC Laboratory and convert their traffic control directives into keyboard entries, which initiate the required computer simulation of the desired aircraft response. All aircraft responses are modifiable and are programmed to be consistent as possible with the type of aircraft which is being simulated. The simulator "pilots" also initiate communications to the controllers in the ATC Laboratory and provide them with any required procedural reports, emergency notifications, etc.

The analyses of NSSF based simulations typically rest upon:

1. Observations and judgments of the ATC specialists who use the simulated system as gathered through independent reports, questionnaires, debriefings, and group discussions.

2. An analysis of the second-by-second computer records of each aircraft's position and altitude, recordings of pilot and controller actions, and selected quantitative statistics reflecting safety, work load, capacity, delays, etc.

3. Observations of supervisors and system planners made during the course of the simulations.

FIGURE 3. NSSF CONTROL AREA

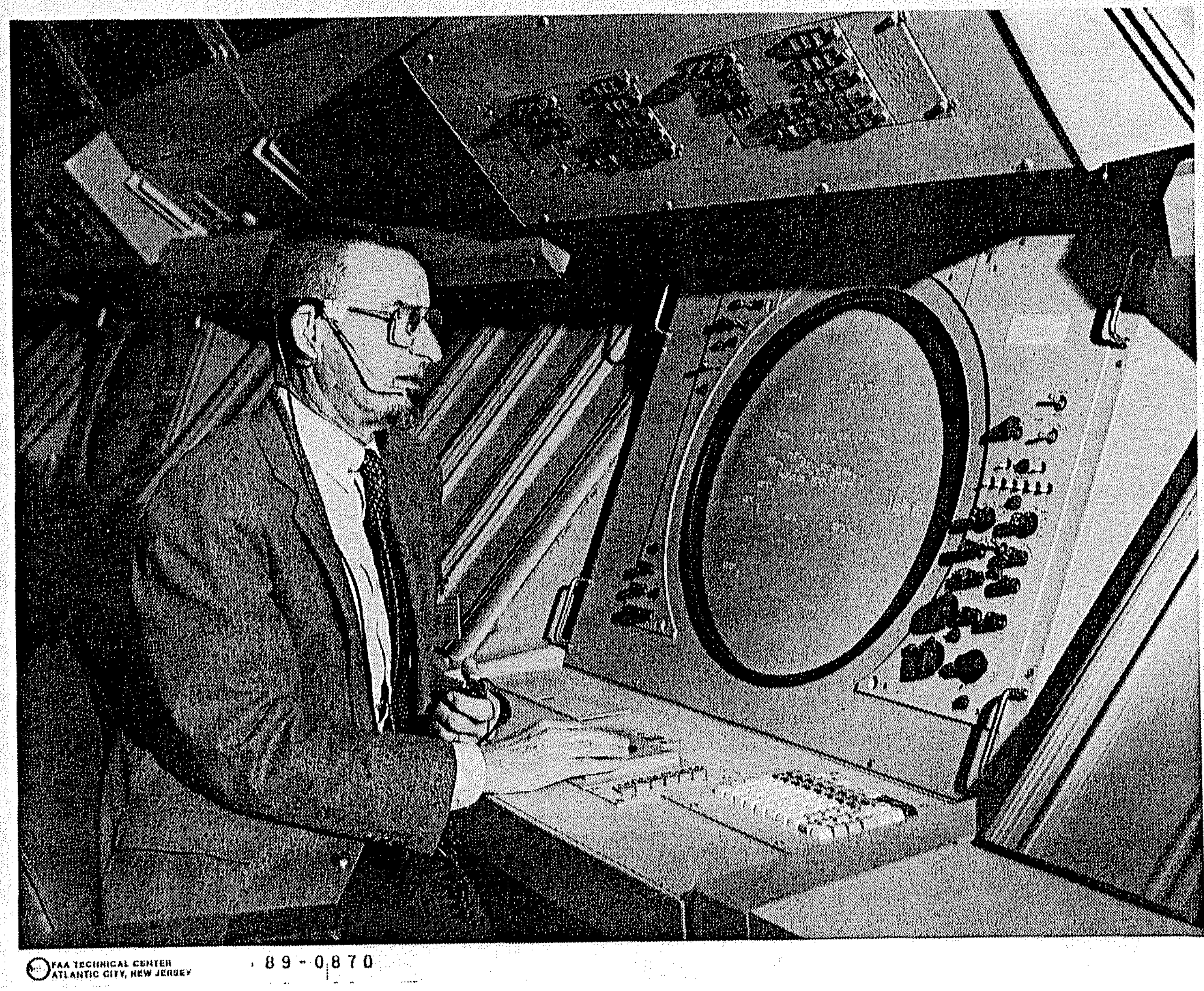


FIGURE 4. SIMULATED CONTROLLER POSITION

FAA TECHNICAL CENTER ATLANTIC CITY, NEW JERSEY 89-0871

FIGURE 5. PART OF SIMULATOR PILOT COMPLEX

SIMULATION DESCRIPTION.

Implementation of the full D/FW Metroplex Air Traffic System Plan would have encompassed more traffic than could be simulated in the NSSF at one time. As stated previously, the NSSF is limited to six active displays or control positions, one or two positions for background or preprogrammed traffic, and the simultaneous presentation of up to 55 aircraft. To scale the effort to the NSSF capacity and also avoid bringing too many tower and/or center controllers to the Technical Center at one time, the system was subdivided into a number of configurations, each containing the necessary positions to examine part of the plan.

The traffic samples used in the D/FW simulations were based upon flight strips and computer printouts taken from the D/FW TRACON and the Fort Worth Air Route Traffic Control Center (ARTCC) and consisted of representative aircraft types, ID's, and routes. The range of traffic densities was selected to permit the simulations to exercise the maximum system capacity for each portion of the system being evaluated.

Maps and routes with display information based on present and proposed operations were developed for all of the simulated sectors and their associated displays. Realistic patch-in telephone communications and computer links were prepared for the sectors in each configuration.

CONFIGURATIONS. The arrival, departure, and terminal interfaces proposed by the D/FW Metroplex Air Traffic System Plan were evaluated through the use of the nine configurations shown in table 1. The details supporting the definition of these configurations are contained in appendix A of this report which contains the summary of the D/FW Metroplex Air Traffic System Plan. The initial En Route and Terminal Area air traffic configurations were considered a "first cut" at implementing the airport and airspace changes described in the D/FW Plan. The simulation was designed to explore the strengths, and identify any potential weaknesses, of representative portions of the overall plan and to provide a basis for suggesting improvements where needed. All En Route and Terminal Area configurations were evaluated with traffic levels which built up to a 100 percent increase (twice normal) in operation rate. Performance in the management of traffic within the D/FW area was measured relative to the following factors:

1. The ability of the controllers to move the simulated levels of traffic smoothly and efficiently.

2. The judgments of the Task Force observers that D/FW operations could be run as the plan proposed.

3. The controller's judgments of each configuration's controllability, desirability, and associated workload as expressed in their questionnaires and by their comments which were collected upon the completion of each run.

TABLE 1. ATC TRAFFIC CONFIGURATIONS USED IN THE D/FW SIMULATIONS

Config	Purpose	Sectors Included
A	Verify parallel arrival route structure & ARTCC sector	BUJ LO & INT, DECOD HI, MASTER
B	Verify parallel departure route structure & ARTCC sector interface	LAKE LO & INT, TXK HI, GHOST
C	Verify ARTCC/terminal ARR interface w/terminal ARR routes	D/FW APP (EAST (130) FEEDERS HI & LO), BUJ LO & INT, DECOD, HI, GHOST
D	Verify ARTCC/terminal DEP interface w/terminal DEP routes	D/FW DEP (DFW, DA1 EAST), LAKE LO & INT, TXK HI, GHOST
E	Verify E term parallel ARR route for D/FW E side & N satellites	D/FW E FEEDER, HI D/FW W FEEDER PARALLEL, HIGHOST
F	Love field interaction	AR-1, AR-2, AR-3 AR-4, AR-5, GHOST
G	Verify term parallel ARR for D/FW W side	AR-1, AR-2, AR-4, AR-5, GHOST
H	Four simultaneous approaches	AR-1, AR-2, AR-3 AR-4
I	Verify interaction between BRP INT, BRP LO, D/FW ARR'S & SPS FHW MIL activity	BRP LO & INT, SPS HI MASTER

Evaluation and validation of Configuration H, the assessment of four simultaneous approaches, was more complex. Since there is no precedent for running four simultaneous approaches under instrument conditions, it was necessary to determine if the D/FW system was manageable as proposed in the D/FW Metroplex Air Traffic System Plan. This was done by "stressing" the system by introducing a variety of unexpected contingencies to determine whether the controller(s) could cope with them safely and expeditiously. The simulations were designed to determine whether approaches could be aborted anywhere before reaching the point where landing is continued to touchdown under any circumstance (visual separation has been established, the aircraft reports that the lights/runway are in sight, or the aircraft is 1 mile or less short of the runway), on any of the four localizers and still permit the controller to reestablish standard separation between the go-around aircraft and any other traffic which might be on final approach. To facilitate an evaluation of these conditions, the simulations deliberately programmed traffic conflicts that would require controller intervention. The criteria of success was the controllers' ability to detect a problem aircraft, vector it back to the localizer, or, if that was not possible, issue course and/or altitude changes to any other aircraft threatened by the problem aircraft to keep all affected aircraft apart while initiating a redirection of all aircraft back to a point where they might reenter the approach sequence. When traffic samples were designed with longitudinal spacing problems and overtakes that would require speed control and/or go-arounds, the samples were pretested to insure that the necessary problems were, indeed, present. To facilitate traffic sample development, a few samples were prepared, tested, and then sifted in among the runways with the aircraft renamed so that the controllers could not spot the replays. Controllers were also rotated among the monitoring positions on successive runs so that they would not "learn" a specific sequence for a specific position.

PILOT ERRORS AND BLUNDERS. Special scenarios of scripted "blunders" were prepared. These scripts provided for the generation of blunders in accord with the following rules:

1. A time for the initiation of each blunder was selected from a sample of random intervals so that the average time between blunders was 3 minutes and the actual intervals between blunders were between 1 and 5 minutes.

2. The runway to which the blundering aircraft was assigned was selected at random so that each of the four runways being used had an equal probability of being selected.

3. The direction of turn for each blunder was chosen so that aircraft on outside runways were always turned inward toward the other runways, while aircraft on an inside runway were given an equal chance of going either to the right or to the left.

4. The magnitude of each blunder was chosen so that the blundering turn had a 60 percent chance of being a 30 degree deviation from the assigned localizer, a 20 percent chance of being a 20 degree deviation, and a 20 percent probability of deviating by 10 degrees.

5. A decision was also made for each blundering aircraft as to whether the pilot would respond to further clearances after the blunder had been initiated. The probability that a blundering aircraft would experience such a "communications failure" was 66 percent for the D/FW simulation.

6. Each blunder was required to be independent, i.e., not confounded with the activities or consequences of another blundering aircraft. Therefore, any blunders which began within 61 seconds of the initiation of a previous blunder were considered "simultaneous" and the control problems posed by both aircraft were extracted from the general data base.

Data from previous studies suggest that the relative position of the aircraft at the time of blunder initiation is important in how the resultant conflicts are resolved. Since initial position is difficult to control with precision and repeatability, a large number of blunders were introduced into the D/FW simulations to provide an adequate analysis sample.

ANALYSIS

METHOD. The primary method used to evaluate the Phase I simulations of the proposed changes to traffic management within the D/FW area rested upon an analysis of the controllers' opinions, as collected by the questionnaires, and the comments and conclusions of the subject controllers generated during the postrun debriefing sessions. The primary analysis of the Phase II evaluation of the four simultaneous parallel approaches was a detailed review of the time-indexed plots of the ground tracks of the aircraft involved in the approach control problems. Figure 6 is a representative sample of these plots. To reduce clutter on the plots, the time scale, represented by the sequential numbers appearing beside each ground track, was modified to be displayed in seconds since run initiation divided by ten. Thus, in the sample plot shown in figure 6, the aircraft tracks begin at time hack 322 which is 3220 seconds (or just over 53.5 minutes) after the run began. The graphic information contained in these plots was augmented by summary sheets of numeric data (See figure 7) which show altitude and speed data for each of the aircraft involved in a conflict, or potential conflict, situation. The Track Codes used to annotate aircraft activities associated with these data are defined in table 2. These graphic plots were linked to the beginning of a "blunder" and the time scale was adjusted to show what was happening for 30 seconds before the blunder was initiated, and then continued for an additional 150 seconds after the onset of the blunder. In addition, printouts were made of all

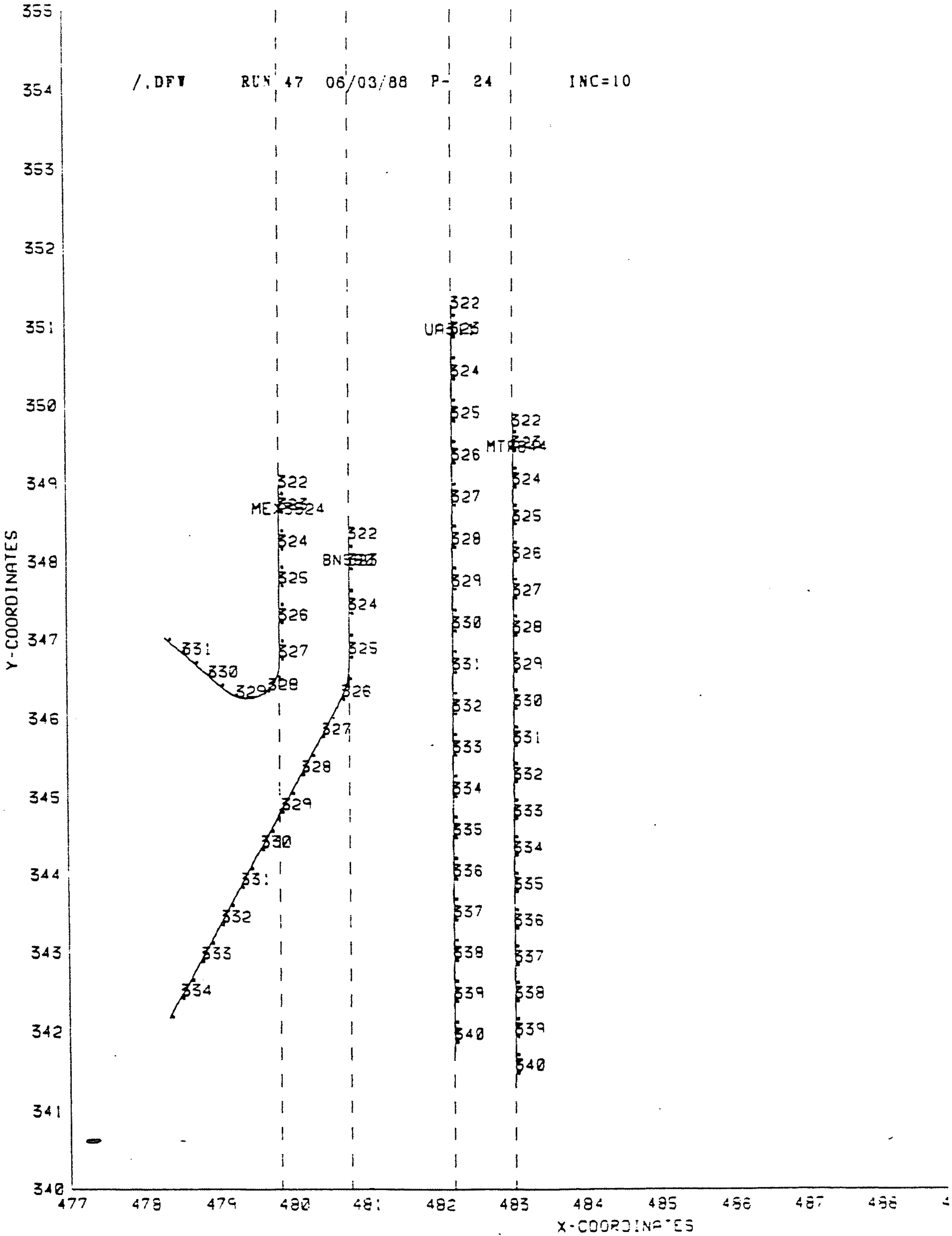


FIGURE 6. REPRESENTATIVE SAMPLE OF D/FW
FOUR RUNWAY APPROACHES

DATE OF RUN 06/03/88 RUN - 47 PLOT - 24

BN580 ACTUAL FLIGHT:

INC	TIME	X	Y	ALT	TRACK	DISTANCE
322	3223	480.795	348.292	4818	1060	.00
323	3229	480.795	347.954	4709	1060	.34
324	3239	480.795	347.392	4527	1060	.90
325	3249	480.795	346.832	4346	1060	1.46
326	3259	480.704	346.286	4165	1000	2.02
327	3269	480.450	345.801	3984	1000	2.58
328	3279	480.152	345.320	3804	1000	3.13
329	3289	479.874	344.659	3623	1000	3.69
330	3299	479.598	344.350	3442	1000	4.24
331	3309	479.332	343.382	3261	1000	4.79
332	3319	479.046	343.406	3080	1000	5.34
333	3329	478.773	342.931	2900	1000	5.89
334	3339	476.508	342.457	2719	1000	6.44

MEX3824 ACTUAL FLIGHT:

INC	TIME	X	Y	ALT	TRACK	DISTANCE
322	3223	479.842	348.947	3994	1060	.00
323	3229	479.842	348.665	3982	1060	.28
324	3239	479.842	348.194	3857	1060	.75
325	3249	479.842	347.725	3732	1060	1.22
326	3259	479.842	347.256	3608	1060	1.69
327	3269	479.842	346.788	3483	1060	2.16
328	3279	479.669	346.366	3239	1000	2.62
329	3289	479.269	346.276	2996	1000	3.08
330	3299	478.887	346.531	2843	1000	3.54
331	3309	478.540	346.823	2510	1000	4.00

FIGURE 7. SAMPLE QUANTITATIVE SPEED, ALTITUDE AND POSITION DATA

TABLE 2. D/FW SIMULATION AIRCRAFT TRACK CODES

Code	Definition
1	On Flight Plan
2	On Flight Plan - Take Off
1000	Off Flightpath - On Vectors
1060	Flying ILS Approach
1061	Homing to ILS Approach
1062	Flying ILS Localizer
1063	Homing to ILS Localizer
1065	At ILS
1066	Flying to ILS Intercept
1067	Drifting from ILS
1100	Initiating Missed Approach
1101	Flying Missed Approach
1102	At MAP - Check for Missed Approach
1200	Initiate Landing Maneuver
1201	Landing
1202	Touchdown - Deceleration

"pilot" responses to communications from the controller. Detailed second-by-second digital printouts of these data were available, if needed, to resolve any uncertainties about what actually happened during a simulated approach sequence.

The data obtained during the approaches to the parallel runways were separated into three groups based upon the number of runways threatened by the blundering aircraft.

METRICS. In addition to the graphic data plots, several new quantitative metrics were utilized to enhance the understanding of both the severity of the traffic control problems posed during the simulations and the ability of the controllers to resolve them in a timely and effective fashion. The first of these measures used was the Aircraft Proximity Index (API). This index represents a weighted measure of the potential hazard associated with combinations of lateral and vertical separation. A three-dimensional representation of this weighted index is shown in figure 8. Details of the computation of the API are described in appendix B of this report.

While the API can provide very useful information, it is not affected by the relative motions of the aircraft involved, but reflects only the distance between them. Therefore, to provide additional quantitative information on the D/FW ATC simulation outcomes, a vector-based measure, the Predicted Closest Point of Approach (PCPA) was developed. This index, which is mathematically defined in appendix C of this report, provides a second-by-second prediction of how close two subject aircraft will come to each other if nothing is done to alter their current conditions. In addition, the PCPA calculations also provide a second-by-second measure of how long it will be until the PCPA actually occurs; i.e., how long does the controller-pilot team have to achieve a resolution of the situation before it reaches its worst case point. A sample of these indices, plotted on the same time frame as that used for their corresponding graphic data plots, is shown in figure 9.

At the completion of each data run, each subject controller completed the questionnaire shown in figure 10. These questionnaires were analyzed for each traffic configuration to document the controllers' subjective opinions regarding the challenge posed by the traffic problems, his willingness to use the proposed airspace configuration, and the realism of the simulation.

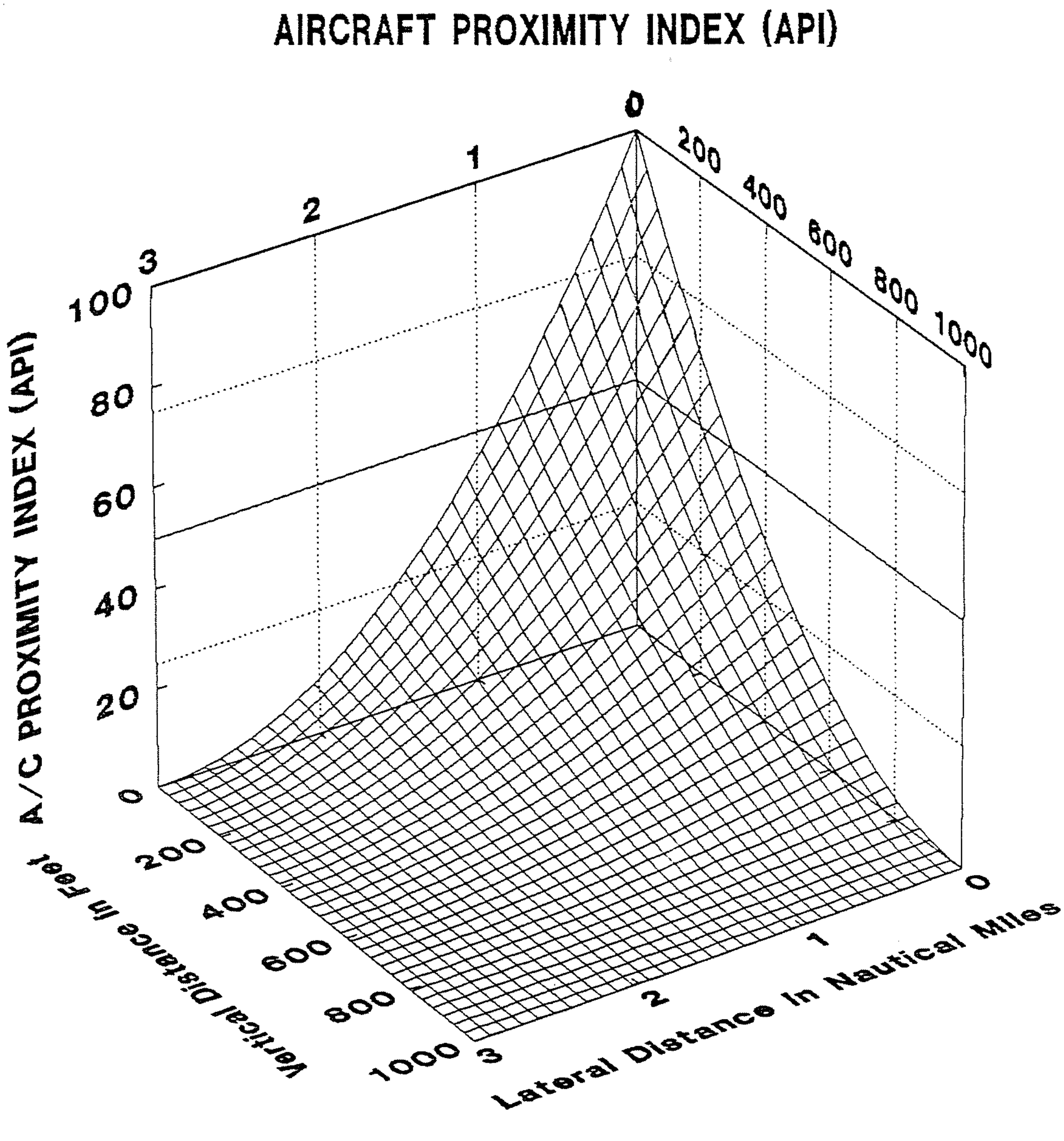


FIGURE 8. API INDEX AS A FUNCTION OF LATERAL AND VERTICAL SEPARATION

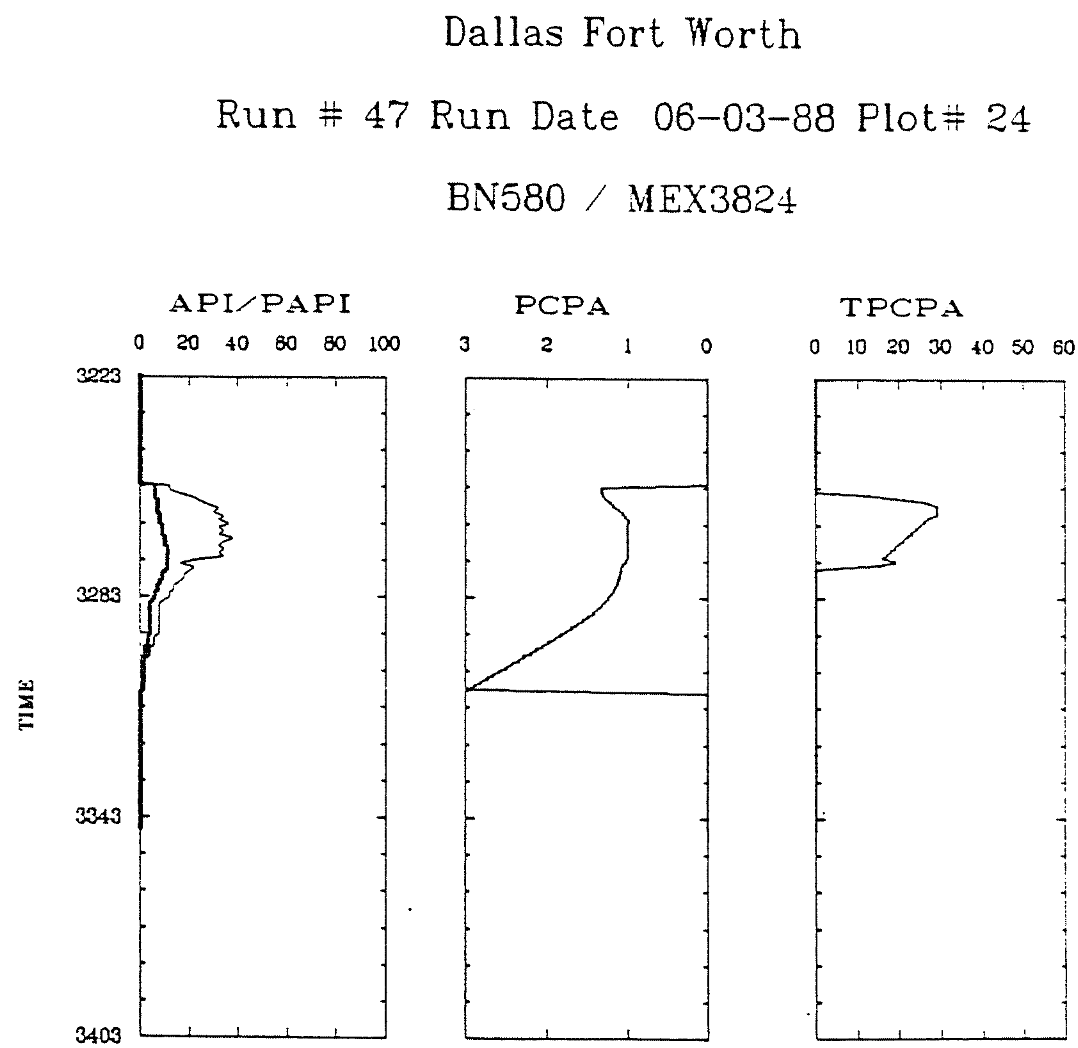


FIGURE 9. SAMPLE PLOTS OF THE QUANTITATIVE INDICES

QUESTIONNAIRE - D/FW SIMULATION

(One per controller per test session.)

Controller Code No:.____, Date:__ __-88, Start time__:__, Position:______

PLEASE FILL OUT THIS BRIEF QUESTIONNAIRE ON THE RUN YOU HAVE JUST COMPLETED.

1. Except for deliberately introduced incidents, how realistic did you feel this traffic?

0	1	2	3	4	5
VERY ARTIFICIAL					VERY REALISTIC

2. How hard to you feel you had to work on this run?

0	1	2	3	4	5
NOT HARD AT ALL					VERY HARD

3. How well do you feel you were able to control the traffic in this run, using this system?

0	1	2	3	4	5
CONTROL IS QUESTIONABLE					CONTROL IS GOOD

4. If the conditions of this run (volume of traffic, procedures, geography) were offered at your facility, how would you feel?

0	1	2	3	4	5
STRONGLY OPPOSE					STRONGLY FAVOR

COMMENTS:

FIGURE 10. D/FW SIMULATION QUESTIONNAIRE

PROCEDURES. The basic time unit used for analysis was a 3-minute period which was initiated by each individual blunder and included the subsequent events in the airspace which were triggered by that blunder. For each blunder, the available data were examined to determine if a situation occurred which was, or was not, successfully handled by the controller(s). The data available for each run included the time-indexed track plots, X, Y, and Z coordinates of each aircraft in the affected airspace as a function of time, time plots of API, PCPA, and time to reach closest point of approach, along with all "pilot" actions associated with controller communications.

During the D/FW simulations, the system was challenged by over 175 blunders. The graphic plots of each blunder were visually examined to determine if any conflicts were sufficiently severe as to justify further examination. In addition, as an aid in identifying those situations that might merit a more detailed analysis, a decision tree was developed which applied step-by-step decision rules to each set of blunder-generated conflicts. These rules, and their sequence of application, are shown in figure 11. It should be emphasized that these criteria were developed only as an analysis tool and are not, in any way, intended to represent a recommended set of traffic management standards.

First, if no involved aircraft was predicted to come within 0.5 nmi slant range (about 3000 feet) of any other aircraft, the blunder associated with that aircraft was not subjected to a more detailed analysis. It is recognized that a technical loss of separation would not occur until the 2000-foot No Transgression Zone (NTZ) was breached. However, the 3000-foot criterion was retained as a more conservative identifier and to correspond to the analyses performed in other simulation studies.

Second, if the PCPA was under 0.5 nmi, altitude separation at the time of PCPA was examined. If separation was greater than 500 feet, the blunder was not considered for further analysis.

Third, if a possible threat was identified from the first two rules, the time remaining until PCPA would be reached was determined. This is the time available to a controller to intervene and change the system state. If more than 30 seconds remained to take action, it was the judgement of traffic control personnel assigned to the Technical Center that the control problem was manageable and the blunder situation was not subjected to additional analysis.

Note that the first three rules involve predicted values, that is, the momentary estimated outcomes if there were no further controller intervention. This is a conservative strategy that identifies whether or not the aircraft was under potential threat at any point.

The blunders remaining after application of the first three rules were defined as "potential problems," that is, there was, at some

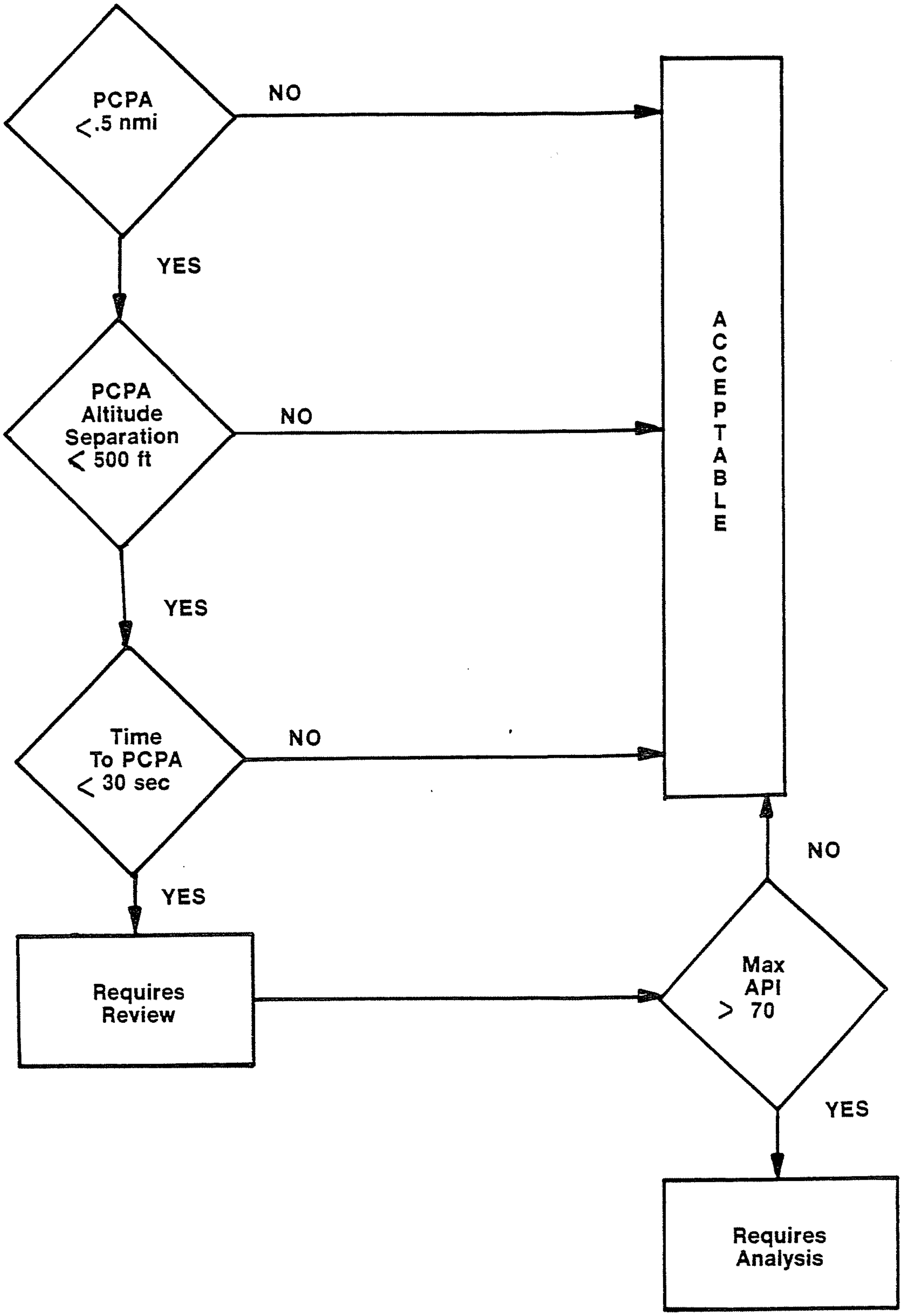


FIGURE 11. PROBLEM IDENTIFICATION DECISION TREE

time in the simulation, a possibility that the aircraft would pass close together. Because these computations of PCPA and time to PCPA are momentary estimates, constantly changing as the aircraft respond to controller intervention, it is possible for a blunder which shows a near-zero (collision) PCPA to result in an outcome in which the aircraft involved never actually come into close proximity. Thus, the final rule which was applied involved the maximum value of the API which occurred during the 3-minute blunder analysis time period. If the maximum API was less than 70, that blunder sequence was not considered for more detailed consideration. Otherwise, the blunder was classified as a "verified problem." For the verified problems, a detailed analysis would be carried out to determine the precise location of each involved aircraft throughout the event.

RESULTS

At the conclusion of the simulations, the D/FW Evaluation Team enthusiastically endorsed the proposed parallel arrival route structure. Even at traffic loads as high as twice the normal rate for the D/FW area, the representatives of the D/FW Program Office felt that "positive control was always in force." This judgement was reflected in the controllers' responses to the questionnaires as recorded at the conclusion of each run. As shown in figure 12, the average controllability rating for the parallel arrival route simulations remained consistently high throughout the range of traffic densities tested. As would be expected, workload was judged to increase as traffic load increased (see figure 13). However, even at 200 percent of normal traffic density, workload was still judged to be less than "3" on a scale of "0" to "5." In the opinion of the Evaluation Team, handling a doubled traffic load, using the proposed parallel routing structure, imposed about the same controller workload as that "experienced during today's peak periods." The controllers also judged the simulations used to evaluate the Interface between the ARTCC/Terminal Arrivals and Terminal Arrival Routes (Configuration C) to be highly controllable and that the workload imposed by this configuration was modest (see figure 14). The same was true for the Departure Interface (Configuration D) as shown in figure 15. The controllability of the east parallel arrival routes for east side D/FW and the northern satellites was also judged to be high with a relatively low associated workload (see figure 16). At both 150 percent and 175 percent of normal traffic flow, the Love Field Interaction simulation (Configuration F) was considered to have a controllability rating of 3.875 to 4.00 on the 5-point scale with a very low assessed workload (see figure 17). The simulation of the D/FW west side parallel arrival routes (Configuration G) was also considered controllable at both 175 percent and 200 percent of normal traffic with moderate workload assessments (see figure 18).

As previously stated, the simulation of simultaneous operations to D/FW's four primary runways yielded 175 blunder induced conflict situations. Of these, 13 were initially defined as "Problems" using either the criteria contained in the decision tree shown in

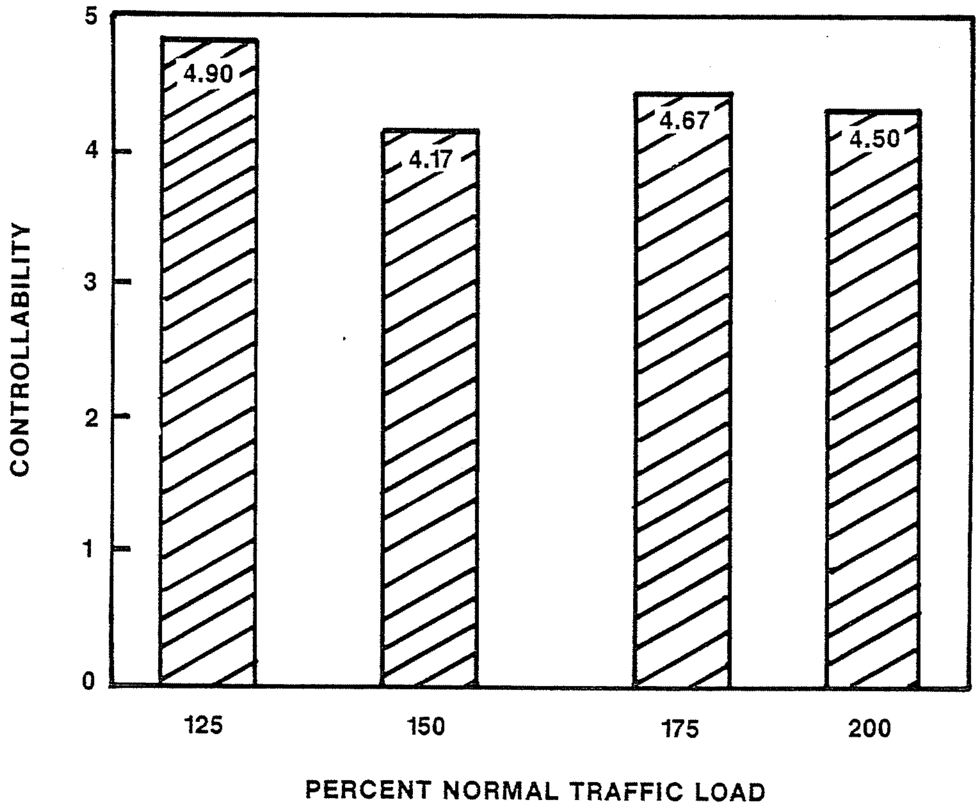


FIGURE 12. AVERAGE CONTROLLER ESTIMATES OF PARALLEL ARRIVAL ROUTE CONTROLLABILITY AS A FUNCTION OF TRAFFIC LOAD.

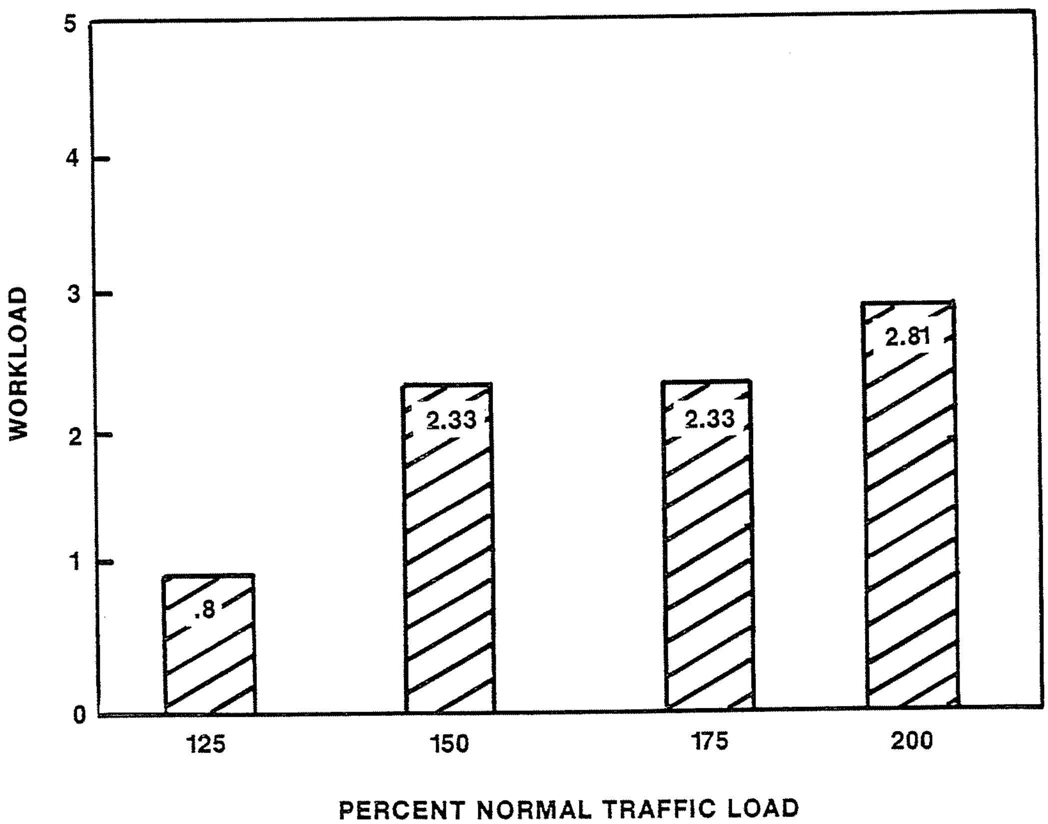


FIGURE 13. AVERAGE CONTROLLER ESTIMATES OF WORKLOAD FOR PARALLEL ROUTES AS A FUNCTION OF TRAFFIC LOAD

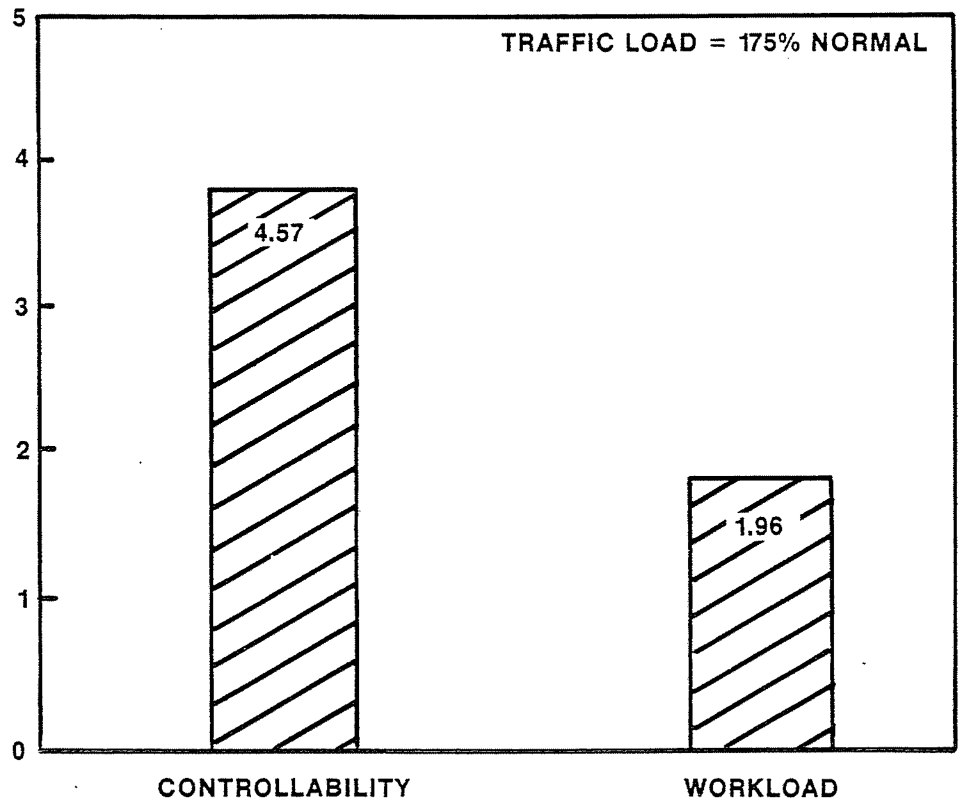


FIGURE 14. CONTROLLER ESTIMATES OF ARTCC TERMINAL ARRIVAL INTERFACE CONTROLLABILITY AND WORKLOAD

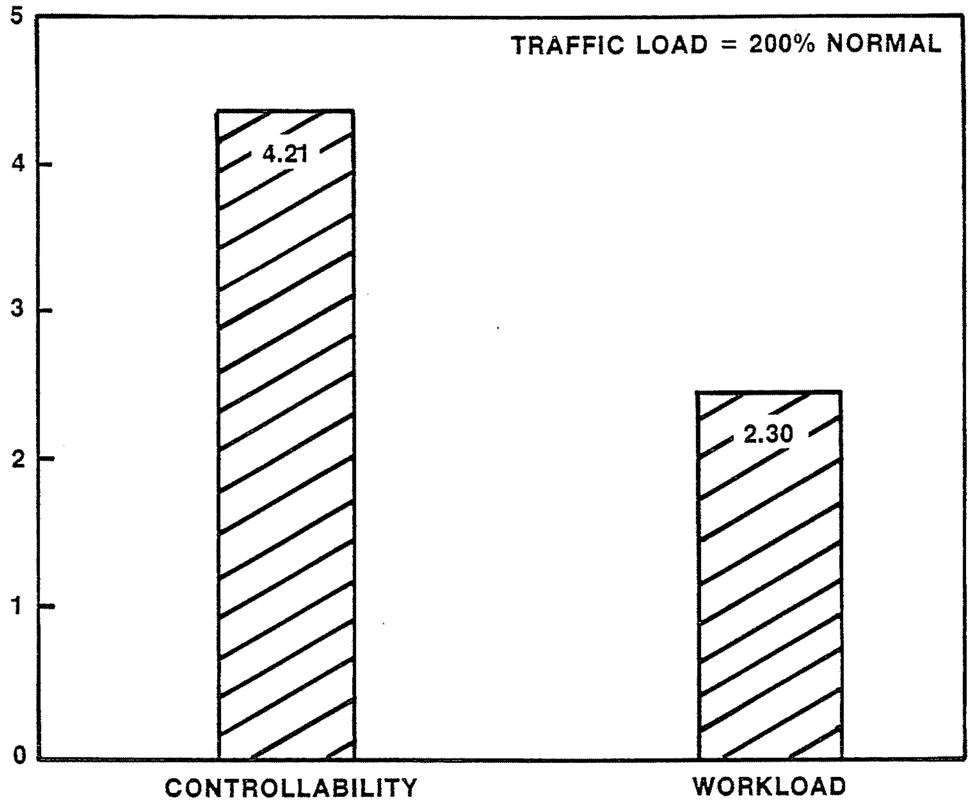


FIGURE 15. CONTROLLER ESTIMATES OF ARTCC TERMINAL DEPARTURE ROUTE INTERFACE CONTROLLABILITY AND WORKLOAD.

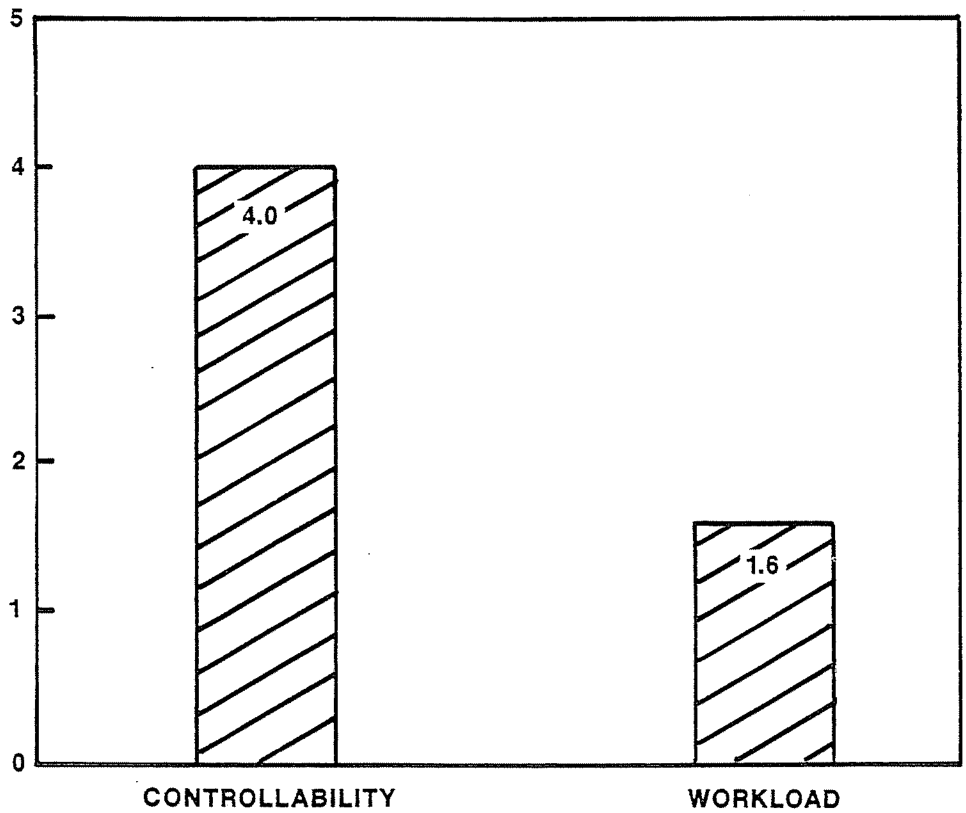


FIGURE 16. CONTROLLER ESTIMATES OF EAST SIDE D/FW PARALLEL ARRIVAL ROUTE CONTROLLABILITY AND WORKLOAD

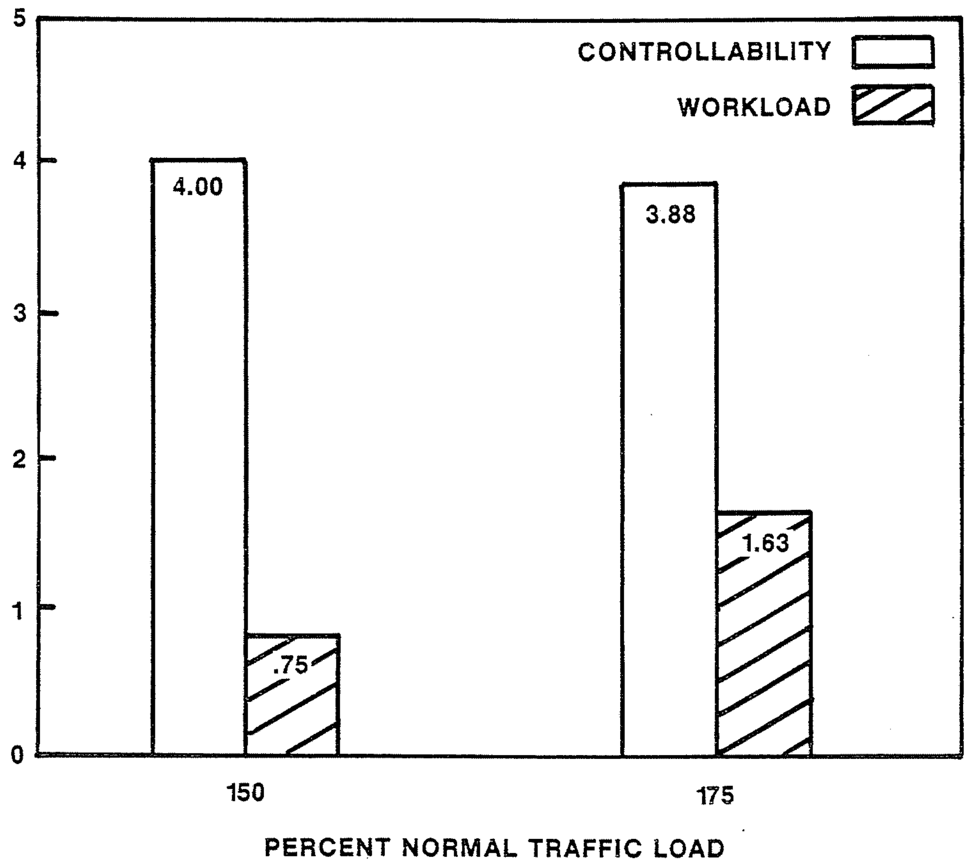


FIGURE 17. CONTROLLER ESTIMATES OF LOVE FIELD INTERACTION CONTROLLABILITY AND WORKLOAD.

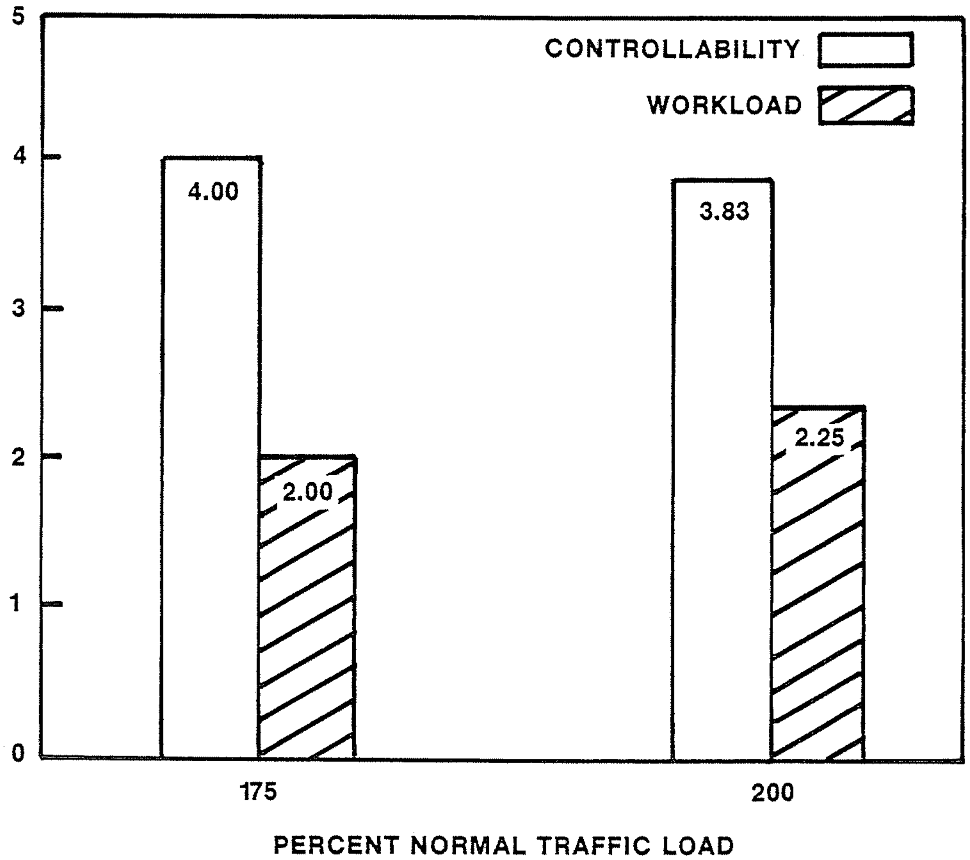


FIGURE 18. CONTROLLER ESTIMATES OF D/FW WEST SIDE PARALLEL ARRIVAL CONTROLLABILITY AND WORKLOAD.

figure 11 or on the basis of the initial estimations of closure derived from visual inspection of the plots. Aided by members of the D/FW Program Office, a close inspection was made of each of these 13 conflicts. Eight of the 13 were found to have occurred during the last two simulation runs in which a deliberate attempt was made to overwhelm the controllers by introducing a series of non-programmed control challenges. It should be noted that the subject controllers objected to the problems introduced in these runs, not only because they were unrealistic, but also because they violated other separation standards as well. One of these eight conflicts was found to involve simultaneous blunders which, according to the rules of the simulation, eliminated this run from consideration as part of the general analysis. In another five of this group of eight conflicts, the simulator pilots were either unresponsive to, or acted in such a way that their responses conflicted with, the controller directions as documented by the records of the Evaluation Team observers. These five conflicts were also eliminated from further analysis. Of the remaining five conflicts, one was found to be both a simultaneous blunder and also involved unrealistic aircraft actions, one involved a simulator pilot error, and, based upon the Evaluation Team documentation, three were found to represent additional situations in which the "pilots" were either unresponsive to the controllers inputs or acted in opposition to the controllers' advisories. Thus, out of 175 blunder induced conflicts, only two were found to merit more detailed examination.

The graphic plot of the first of these two conflicts is shown in figure 19. In this case, a Delta Airlines aircraft, DL551, inbound to runway 17L, began a communications out (NORDO) 30 degree blunder to the left, which put it into a potential conflict with a Chaparral aircraft, CPL3512, which was then on the localizer for runway 16L. CPL3512 was vectored out to the left to avoid the encroaching Delta aircraft. At run-time 2530 seconds, shown as 253 on the graphic plot, the two aircraft came to within just over 1400 feet (1413.97) laterally with an 18-foot difference in altitude. Reference to both the graphic plot and the associated digital data (see table 3) indicates that CPL3512 did not begin its avoidance turn until almost 30 seconds after DL551 began its blunder. The length of this delay raises the possibility that this might be another instance in which the "pilot" might have been, at least initially, unresponsive to the controllers request. As is shown in figure 20, the second conflict involved the same two runways. In this instance, another Delta flight, DL263, also became a 30 degree NORDO blunder to the left, threatening a general aviation aircraft, N729CC. N729CC was turned to the left to resolve the conflict. At 1230 seconds run-time, 123 on the plot, these two aircraft came within approximately a quarter of a nmi (1598.07 feet) of each other with a difference in altitude of 78 feet (see table 4). Here again, for reasons which cannot be specified, the avoidance turn did not begin until well over 30 seconds after the initiation of the blunder. It should be noted that, even with such delays, the aircraft involved in these two conflict situations

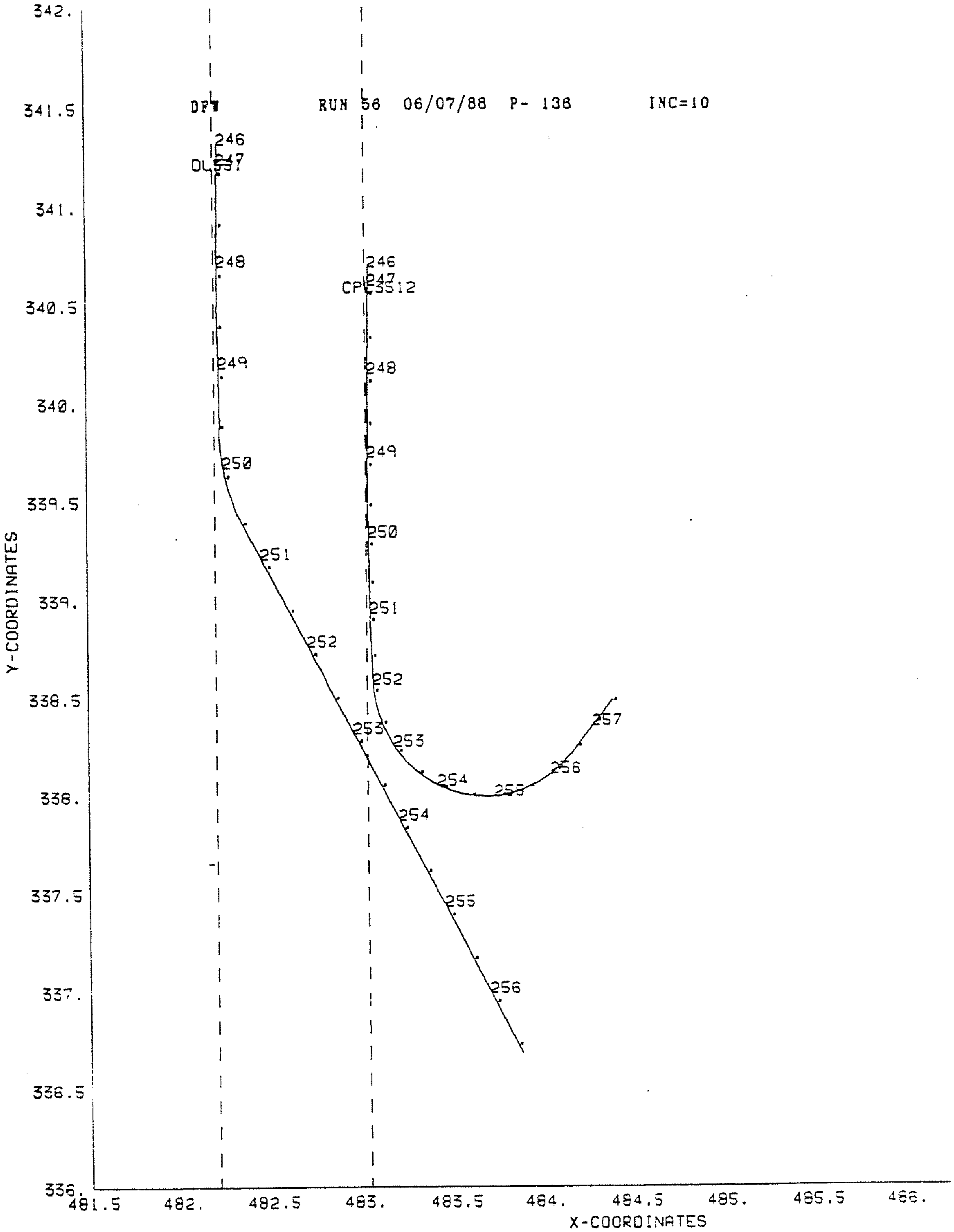


FIGURE 19. GRAPHIC PLOT OF DL551 AND CPL 3512 CONFLICT.

TABLE 3. DL551 AND CPL 3512 CONFLICT DATA

03/29/89 14:01:44 TASK # 1900013A

DATE OF RUN 06/07/88 RUN - 56 PLOT- 136

DL551 ACTUAL FLIGHT:

INC	TIME	X	Y	ALT	TRACK	DISTANCE
246	2467	482.237	341.321	2534.	1060	.00
247	2469	482.236	341.218	2550.	1060	.10
248	2479	482.231	340.702	2383.	1060	.62
249	2489	482.237	340.187	2217.	1067	1.13
250	2499	482.259	339.675	2051.	1000	1.65
251	2509	482.467	339.209	1885.	1000	2.16
252	2519	482.716	338.763	1719.	1000	2.67
253	2529	482.965	338.319	1553.	1000	3.18
254	2539	483.214	337.875	1387.	1000	3.69
255	2549	483.463	337.433	1221.	1000	4.20
256	2559	483.709	336.991	1055.	1000	4.70

CPL3512 ACTUAL FLIGHT:

INC	TIME	X	Y	ALT	TRACK	DISTANCE
246	2467	483.059	340.695	2225.	1060	.00
247	2469	483.058	340.603	2201.	1060	.09
248	2479	483.053	340.153	2030.	1060	.54
249	2489	483.051	339.724	1966.	1060	.97
250	2499	483.053	339.313	1856.	1067	1.38
251	2509	483.060	338.933	1751.	1060	1.76
252	2519	483.075	338.571	1652.	1067	2.12
253	2529	483.183	338.253	1571.	1000	2.47
254	2539	483.427	338.052	1788.	1000	2.78
255	2549	483.743	337.993	2038.	1000	3.11
256	2559	484.056	338.113	2288.	1000	3.44
257	2569	484.239	338.357	2533.	1000	3.78

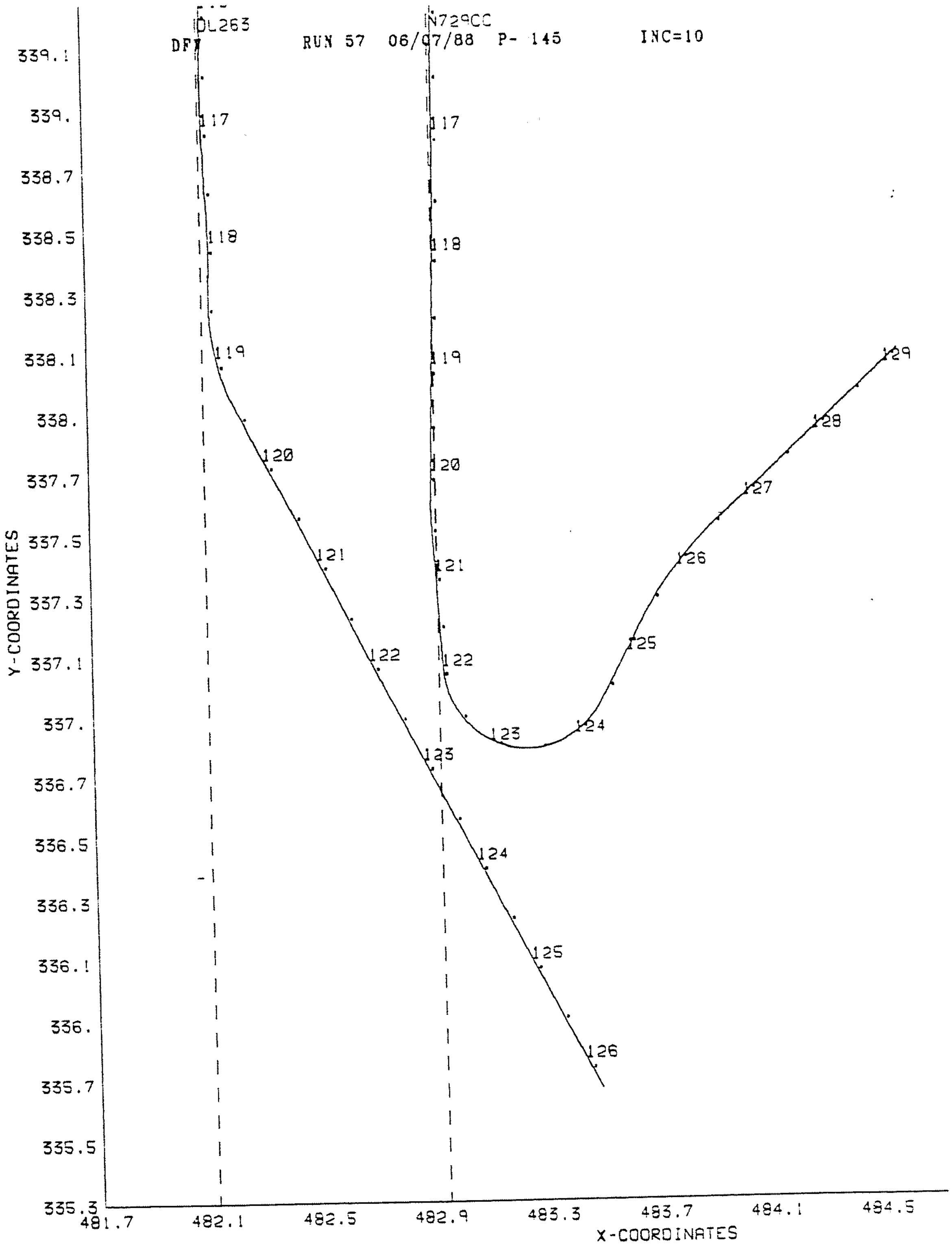


FIGURE 20. GRAPHIC PLOT OF DL263 AND N729CC CONFLICT

TABLE 4. DL263 AND N729CC
CONFLICT DATA

03/29/89 13:46:55 TASK # 1FCC010[illegible]

DATE OF RUN 06/07/88 RUN - 57 PLOT- 145

DL263 ACTUAL FLIGHT:

INC	TIME	X	Y	ALT	TRACK	DISTANCE
115	1156	482.224	339.462	1987.	1060	.00
116	1159	482.223	339.347	1950.	1060	.11
117	1169	482.221	338.964	1826.	1067	.50
118	1179	482.239	338.580	1702.	1060	.88
119	1189	482.257	338.199	1578.	1000	1.26
120	1199	482.421	337.856	1455.	1000	1.65
121	1209	482.607	337.524	1331.	1000	2.03
122	1219	482.792	337.192	1208.	1000	2.41
123	1229	482.976	336.860	1084.	1000	2.79
124	1239	483.164	336.529	960.	1000	3.17
125	1249	483.348	336.199	837.	1000	3.55
126	1259	483.532	335.869	731.	1000	3.92

N729CC ACTUAL FLIGHT:

INC	TIME	X	Y	ALT	TRACK	DISTANCE
115	1156	483.053	339.435	1902.	1060	.00
116	1159	483.052	339.355	1867.	1060	.13
117	1169	483.050	338.937	1755.	1060	.55
118	1179	483.043	338.541	1649.	1067	.94
119	1189	483.033	338.166	1546.	1060	1.32
120	1199	483.023	337.814	1461.	1060	1.67
121	1209	483.034	337.483	1372.	1067	2.00
122	1219	483.054	337.171	1286.	1060	2.32
123	1229	483.217	336.924	1204.	1000	2.63
124	1239	483.518	336.945	1244.	1000	2.94
125	1249	483.709	337.212	1494.	1000	3.28
126	1259	483.894	337.490	1744.	1000	3.61
127	1269	484.138	337.718	1994.	1000	3.94
128	1279	484.397	337.935	2244.	1000	4.28
129	1289	484.656	338.153	2494.	1000	4.62

retained a minimum lateral distance between them of at least 1400 feet.

An analysis was conducted on the API data generated during the simultaneous parallel runway simulations. When the API distributions were plotted as a function of distance between runways (see figure 21), the data confirmed the controllers' contention that the runway separations present in the proposed D/FW configuration are such that even a 30 degree blunder poses little or no threat to any runway other than the one that is immediately adjacent to that of the blunderer with 5000 to 5800-foot separation. As shown in figure 21, half of the API's associated with 5000 to 5800-foot runway separation conflicts were approximately 10 or less. An API of 10 would be produced by two aircraft at the same altitude passing within 2 nmi of each other or by two aircraft crossing with 670 feet vertical separation. Three-fourths of the measured API's were approximately 30 or less (equal to two aircraft at the same altitude passing within about 1.25 nmi of each other or crossing with approximately 450-foot difference in altitude). Similarly, half of the API's generated by conflicts involving the 8000-foot separation between runways were approximately 6 or less.

As would be expected, the highest API's were the result of blunders which threatened aircraft on a runway which was either 5000 or 5800 feet away. Since runway separations of this magnitude are currently considered to be acceptable for simultaneous, parallel ILS/MLS operations, the distribution of API's generated by these conflicts could be considered to be the base-line for existing operations should current approaches ever be challenged by 30 degree NORDO blunders. Since the indices generated for all the other runway separations are well below those for the 5000 to 5800-foot separation, it is reasonable to assume that adding additional approaches to the D/FW runway configuration would not significantly degrade safety. As might be expected, the API's associated with 20 degree blunders are noticeably less than those resulting from 30 degree deviations (see figure 22) and those generated as the products of 10 degree blunders are even lower (see figure 23).

As shown in figure 24, the impact of loss of communications upon the API distributions was not as great as might be expected. While the communicating aircraft showed some advantage at the upper end of the distribution, the highest values of API were approximately the same for both communicating and NORDO aircraft.

Following the Technical Center exercises, the D/FW Evaluation Team prepared three reports which documented their impressions and conclusions which were gained during their participation in the D/FW simulations. The controllers felt that these experiences in the simulation environment strongly supported the full implementation of the D/FW Task Force's Enhancement Plan. These three controller generated reports are incorporated into this report as appendices D, E, and F.

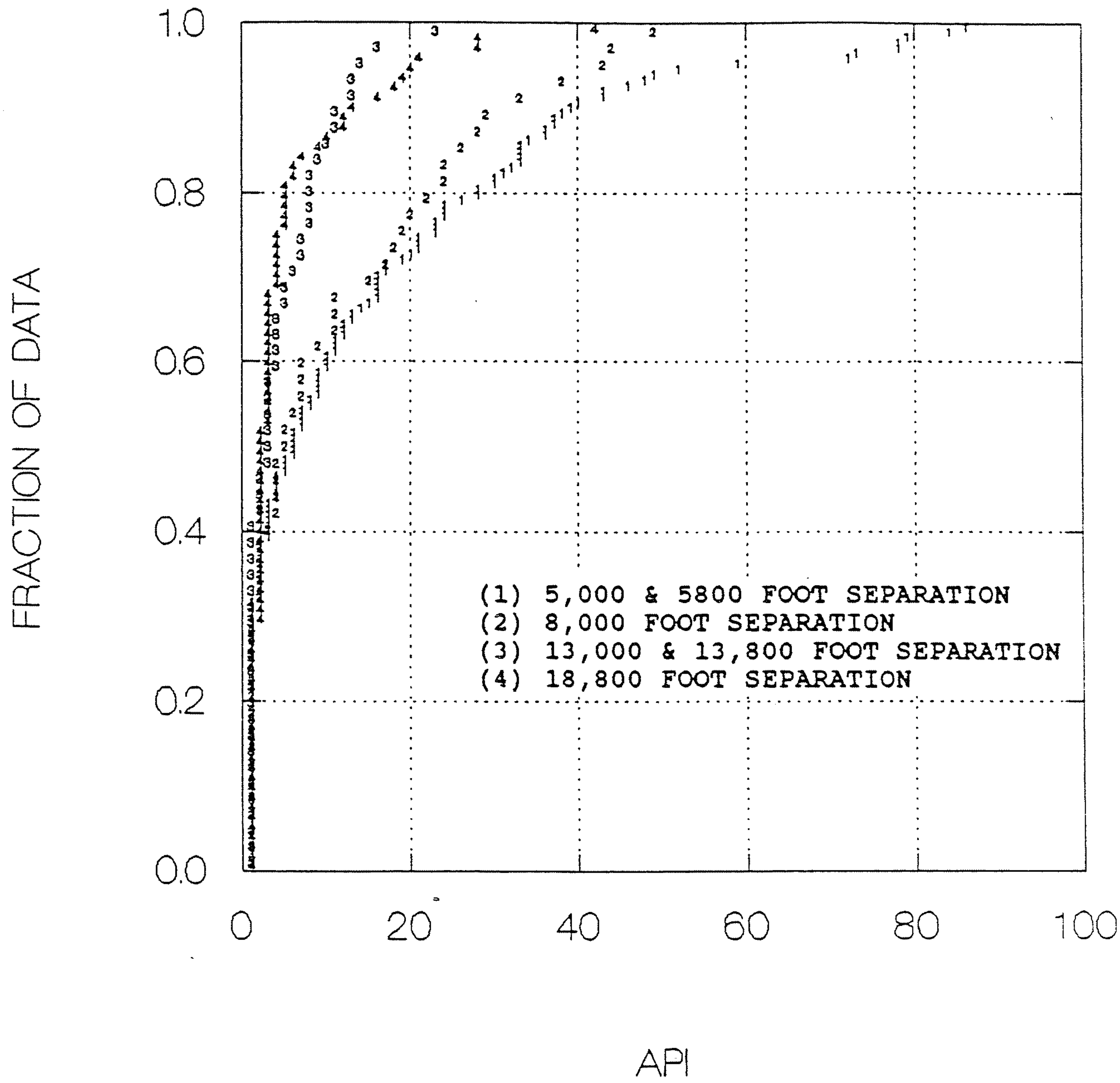


FIGURE 21. CUMULATIVE DISTRIBUTIONS OF API AS A FUNCTION OF RUNWAY CENTERLINE SEPARATION (30 DEGREE BLUNDERS)

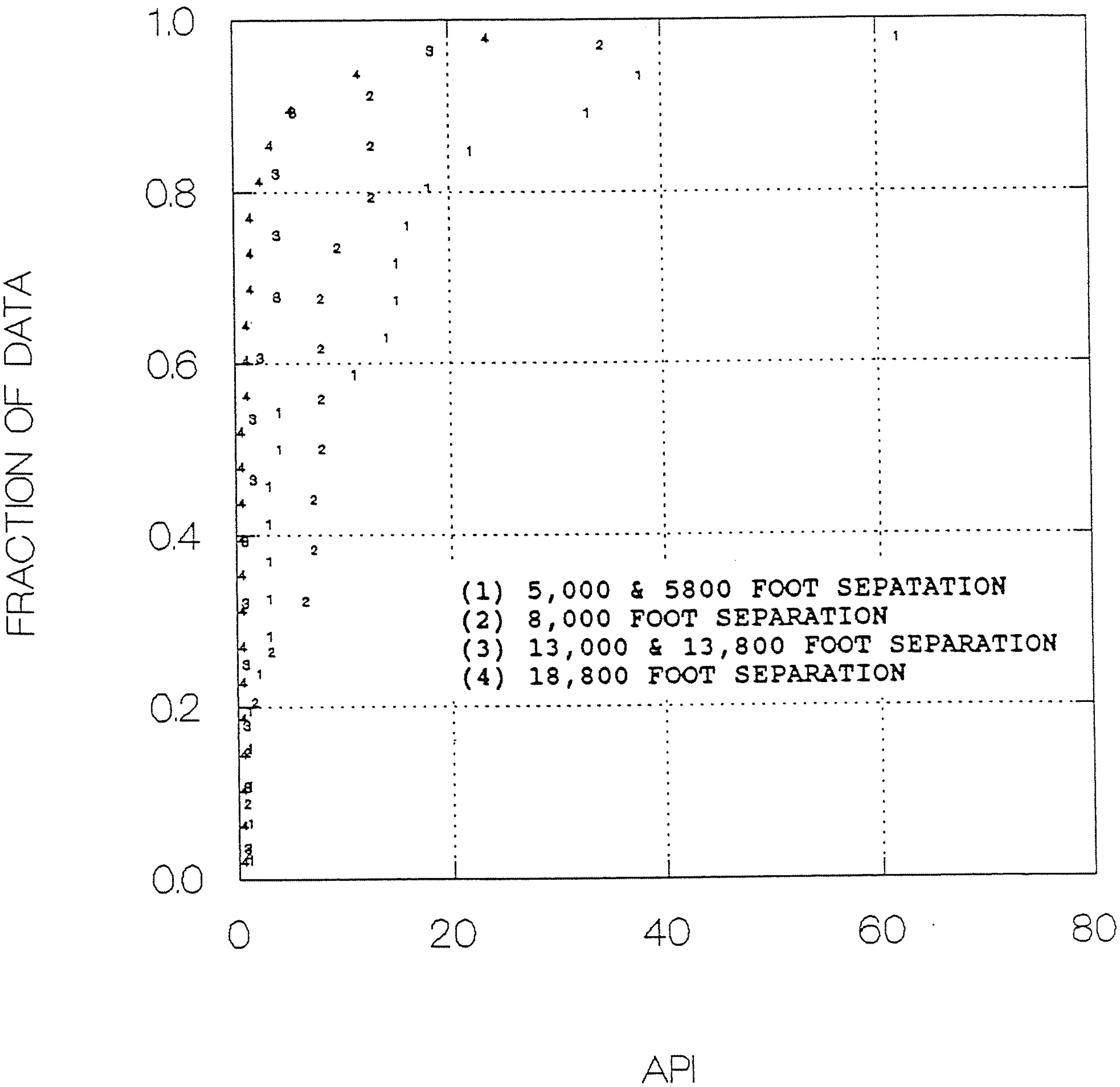


FIGURE 22. CUMULATIVE DISTRIBUTIONS OF API AS A FUNCTION OF RUNWAY CENTERLINE SEPARATION (20 DEGREE BLUNDERS)

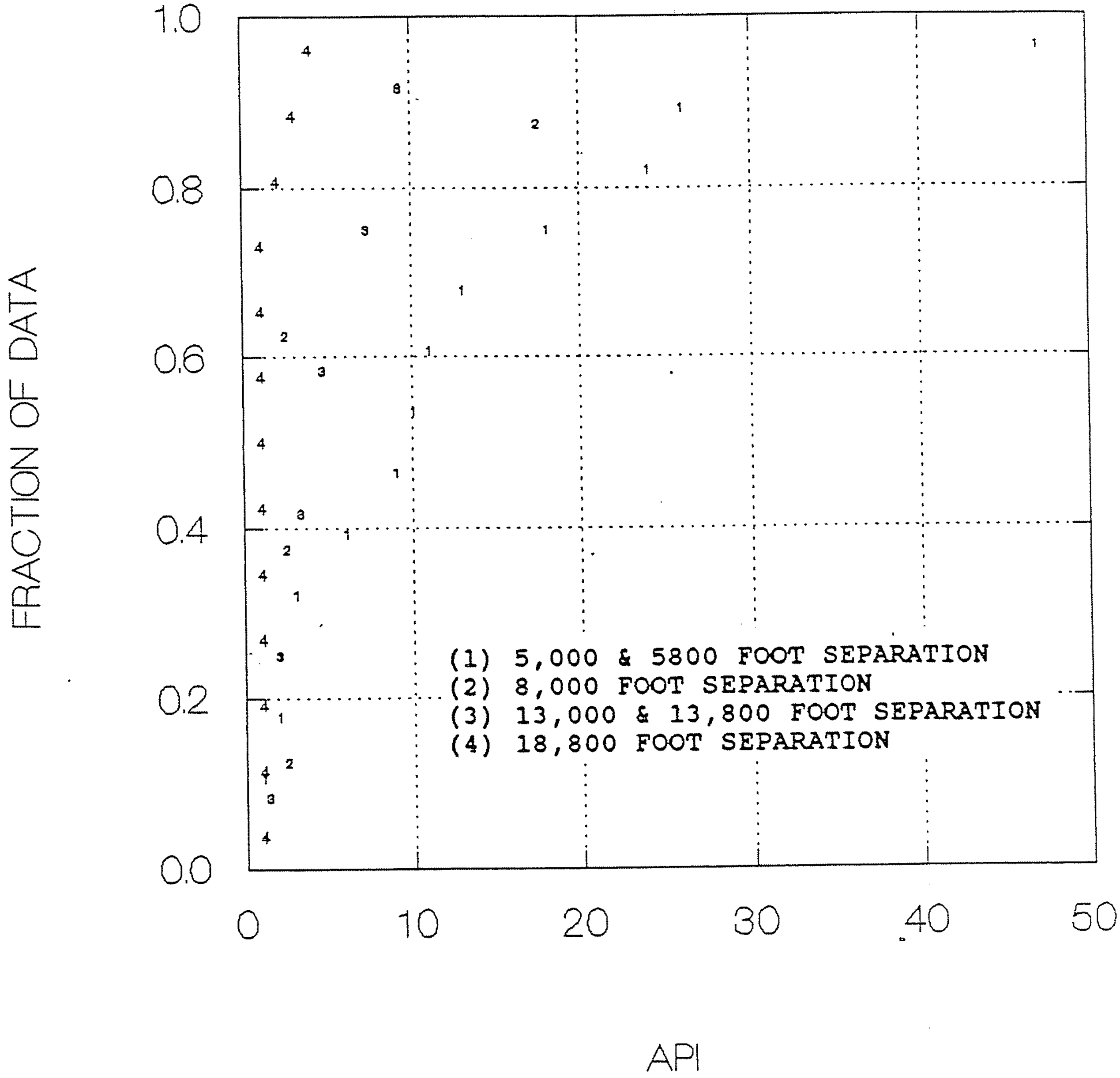


FIGURE 23. CUMULATIVE DISTRIBUTIONS OF API AS A FUNCTION OF FUNWAY CENTERLINE SEPARATION (10 DEGREE BLUNDERS)

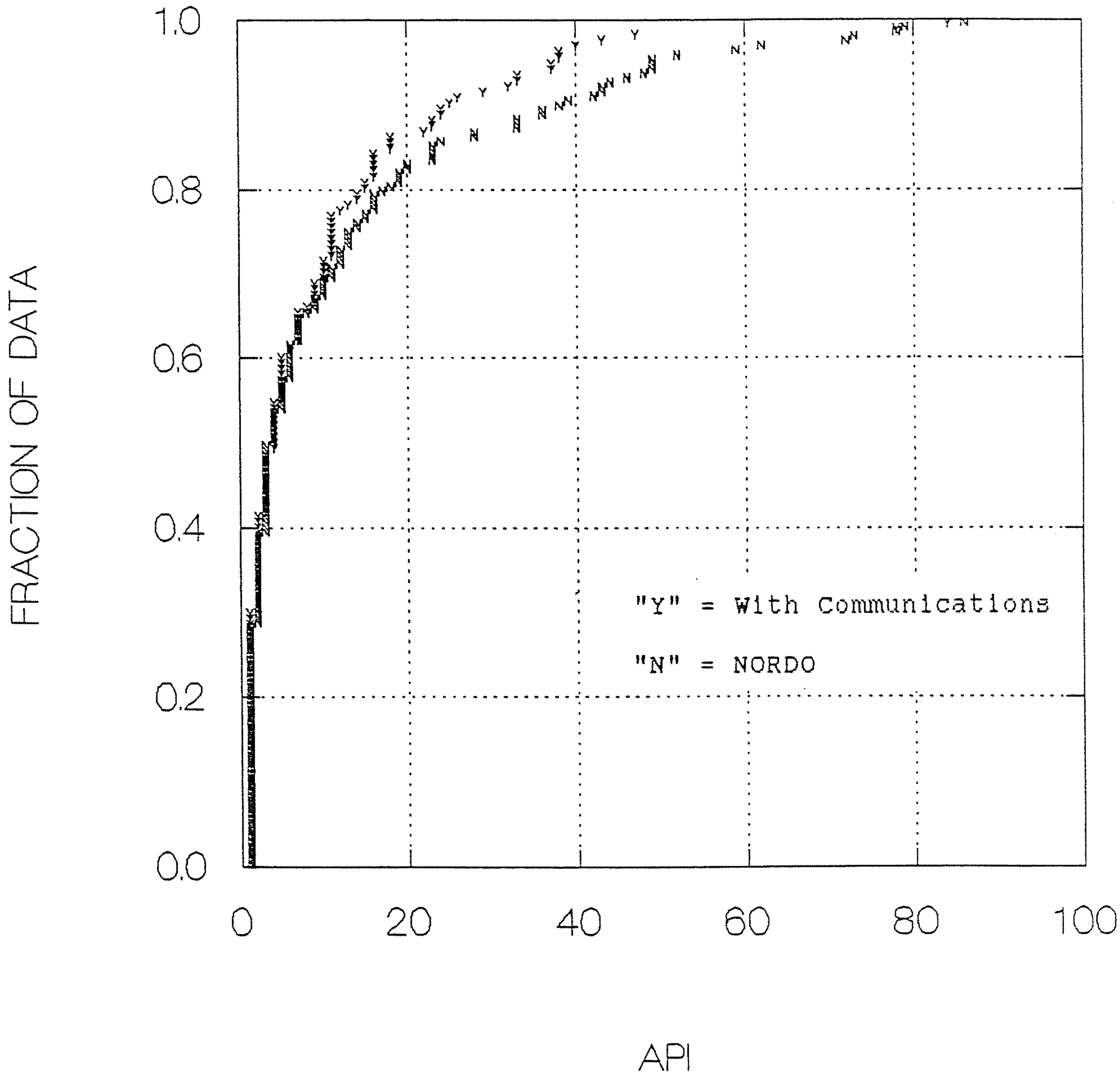


FIGURE 24. CUMULATIVE DISTRIBUTIONS OF API AS A FUNCTION OF COMMUNICATIONS AVAILABILITY.

A sampling of graphic plots of the blunders not identified as problems during the four simultaneous runway operations are included in appendix G which is contained in Volume II of this report. Appendix G-1 contains those encounters in which the blundering aircraft threatened only one runway. Appendix G-2 and G-3 contain those blunders which threatened two and three runways, respectively. The volume of plots generated by this simulation was such that it was necessary to delete some from Volume II of this report. Those removed were ones in which there happened to be no aircraft on any of the threatened runways or the temporal separation between aircraft was such that no evasive action by any other aircraft was required. A complete set of the plot data is available upon request.

CONCLUSIONS

The experience gained through the Dallas/Fort Worth (D/FW) simulations led the subject controllers to endorse fully the concepts incorporated in the D/FW METROPLEX Air Traffic System Plan. The post-simulation questionnaire responses documented the controllers findings that the revised area traffic flows were both desirable and controllable even at twice the normal traffic flow. The simulations of the simultaneous quadruple parallel runway approaches demonstrated that such operations could be conducted without incident even when the system was repeatedly challenged by aircraft blundering 30 degrees off course without communications.

APPENDIX A

D/FW METROPLEX AIR TRAFFIC SYSTEM PLAN

D/FW METROPLEX

Air Traffic System Plan

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

D/FW METROPLEX

Air Traffic System Plan

U.S. Department of Transportation
Federal Aviation Administration
Southwest Region

EXECUTIVE SUMMARY

The DFW Metroplex Air Traffic System Plan presented is designed to provide procedures for the DFW terminal area for the period 1995 through 2005.

The principal points of this proposal include:

a. Parallel arrival routes to DFW over all cornerposts regardless of flow. The use of parallel arrival routes is contingent upon runway availability and traffic demand requirements.

b. Parallel arrival routes to satellite airports based on destination.

c. Four turbojet departure routes: North, South, East, and West.

d. Separate arrival and departure altitudes for a selected group at high performance turboprop aircraft.

e. Increased arrival capacity for both DFW and satellite airports.

f. Increased departure capacity for both DFW and satellite turbojet departures.

g. A 30 NM TCA based on the DFW VORTAC.

h. Development of a real time traffic management system for the DFW terminal area.

i. Development of four simultaneous ILS approach procedures.

The concepts expressed in this proposal are realistic and operationally conceivable. Based on statistical analysis, the capacities of the air traffic system expressed in this proposal will exceed the forecasted traffic demand for the 1995 through 2005 time period.

BACKGROUND

The formation of the DFW TRACON/Fort Worth Center Task Force came about as a result of various proposals to make substantial changes in the DFW area that involved the addition or relocation of key NAVAID's. Some of these proposals conflicted in design and scope, addressing primarily short range concerns and remedies to existing problems. Of immediate concern to the Air Traffic Division, Southwest Region, was the question of long range needs and whether or not various elements of these proposals were compatible with the future needs of our system. It was decided the best response to these questions would come from a group of air traffic personnel from the two facilities responsible for managing the system on a daily basis.

In December 1986 the following personnel were selected to serve on this task force:

Mr. Ed Brestle, Controller, Fort Worth ARTCC
Mr. Pat Carruth, Controller, Fort Worth ARTCC
Mr. Robert Deering, Controller, Fort Worth ARTCC
Mr. Alvin DeVane, Controller, DFW TRACON
Mr. Tom Gassert, DFW AFS
Mr. Hugh Hartley, ASW-537
Mr. Warren D. Kneis, Supervisor, DFW TRACON
Mr. Craig Mitchell, Supervisor, Fort Worth ARTCC
Mr. Ron Uhlenhaker, Controller, DFW TRACON

The committee defined a set of major problem areas, established goals, planning guidelines, and evaluated various proposals and concepts on which to base the design of the system that would evolve from this effort. Many weeks of research and observation ran parallel to discussions on problem definition and system design considerations. The most significant element in this effort was that ATC system planning was being done in anticipation of future needs rather than attempting to overtake and control an existing problem that gathers momentum and becomes more complex with time.

METHODOLOGY

It was considered necessary that the committee follow a well disciplined course and structure that would lead to a well defined statement of the problem and objectives that must be met by the future system and planning considerations to guide in it's design. They covered nearly every aspect of the en route and terminal systems, from the lack of capacity and flexibility of the arrival/departure route structure to airspace constraints that limited the ability of the terminal system to function efficiently during peak periods. Specifically, the committee grouped their concerns in six major areas.

1. Inadequate capacity of the en route airway system.
2. Terminal airspace constraints.
3. Military special operating areas.
4. Inefficient handling of high performance turboprop aircraft.
5. Traffic management.
6. Limited capability of the DFW ARTS IIIA system.

The en route system currently uses a network of airways that merge all arrival traffic, regardless of destination over four common points entering the terminal area. In addition, only one center sector adjoining the terminal area is presently stratified, a situation to be corrected if the system is to accommodate the future demand. These factors in addition to military special operating areas which restrict traffic transiting through high density airspace, such as the Bridgeport low sector, impose operational limitations that severely reduce efficiency and ultimately result in delays to arriving and departing traffic.

The existing four cornerpost system which was designed in 1966, has served the system quite well since DFW opened just over 14 years ago. However, traffic volume and complexity has grown to the point that the limited size of the approach control airspace has, itself, become a constraint to efficient operations, that particularly affects arrival traffic. During simultaneous IFR approach conditions the final runways 17L and 18R are restricted to 17 nautical miles which limits the number of aircraft turning onto the localizer outside Penny and Yohan to only one or two aircraft at most. Such confinement of the arrival vector airspace results in longer, more time consuming vectors and a higher level of complexity which ultimately impacts efficient spacing of traffic on final.

The existing procedures for handling the high performance turboprop aircraft are inefficient for the aircraft operator and equally inefficient for the system as well. These aircraft are routinely kept at low altitudes (usually 4,000 feet and below) along with much slower traffic, creating a more complex traffic situation and an added workload factor that ultimately causes a reduction in handling capability at the positions working these aircraft.

Traffic management is a major concern. The system that is currently in place is in need of improvement in the area of supervision which has a direct bearing on the effectiveness of operational decisions. There is a critical need for overriding control and oversight to ensure credibility, consistency, and timely response in the decisionmaking process. Our metering system has done well in the years it has served in the management of arrival traffic to this area, but it has limitations that must be recognized and corrected if it is to deal with the demands that are forecasted for the next 10 to 15 years. More efficient options must also be made available in holding situations to maintain an efficient and continuous flow of traffic to the final approach course.

The ARTS IIIA system currently in use at the DFW TRACON is presently lacking in track storage capacity which requires procedural adjustments that are often inconsistent with efficient operations during peak periods. This system will not be capable of handling the large volumes of traffic forecasted in the comparatively short term covered through the year 1995. Three radar systems will be necessary to optimize system capabilities for all traffic within the terminal area.

The committee next established a planning strategy through four basic goals or objectives. They are as follows:

1. Adopt and use a systems approach to planning.
2. Improve the DFW arrival/departure system.
3. Improve the satellite arrival/departure system.
4. Develop an independent high performance turboprop system.

The task force agreed that a systems approach to planning was essential. The system was defined consisting of three basic elements -- the airspace, a valuable but limited asset; the FAA as the managers of that airspace; and the users as the owners of the airspace. The net result of this thinking was to shape the new system by first taking best advantage of the airspace which, in turn, will enable us, the managers, to provide continued quality service for the ultimate good and benefit of the users.

This philosophy was next applied to the remaining three objectives. First, improvement must be made to the overall arrival and departure system serving DFW. The expected demands of the future would require substantial increases in capacity, both at the airport and within the systems that control and manage the critical transition between the terminal and en route operating environments. This could only be accomplished by first simplifying and reducing the complexity of the control situation itself. Adding more routes to and from the terminal was part of the answer. Eliminate the crossing and over traffic problem within approach control airspace was another. Providing a separate and discrete system for satellite and high performance turboprop traffic was the third and perhaps the most important factor that pulled the whole equation together. Opening up the approach control airspace and allowing expansion of the DFW TCA, was the key to the ultimate solution. Additional runways at DFW was the obvious solution to improve airport capacity. Finally, the development of new and improved procedures to gain the full potential of this new airport/airspace system became the overall objective of the task force.

The present system was evaluated and it was determined that the problems would only become more complex with time and the increasing demands placed on the system forecasted for the period 1995 and beyond. The ultimate remedy would come through; the segregation of traffic by type and destination; more strict regimentation of traffic flows through fix balancing and improved traffic management techniques and procedures.

The task force met with all major users, various airport management representatives, and government agencies who had an interest in future airport planning and development in this area. Several meetings were held with representatives of the U.S. Air Force, Navy, and the NATO training command at Sheppard AFB. In order to become totally familiar with each others problems and operating environment, all members of the task force observed operations at the DFW TRACON and Fort Worth Center for several days. The task force sent a team to Chicago and Atlanta primarily to observe traffic management and the interface between the center sectors feeding approach control and the terminal operation itself while another member of the committee made a trip to the New York TRACON. Through this experience and information a plan was developed that will meet the demands forecasted for the next 10 to 15 years and beyond.

SUMMARY

The analysis of traffic demands projected for the period beginning 1990 indicates that traffic in the DFW terminal area will increase by as much as 100 percent over the course of 10 years. Half of this increase will occur by the year 1991. To illustrate, the DFW traffic count for 1986 was 575,961 which, when combined with satellite and other operations, totaled 1,003,642 TRACON operations. These figures, from reliable projections, will grow to an annual operation of 863,480 at DFW and 1,480,000 total TRACON operations by 1991. Three new airports capable of handling large turbojet aircraft are also currently under construction. The inability to handle the increasing complexity and traffic demands during this period will lead to delays that ultimately will threaten the growth and stability of the aviation community serving this area. Significant improvement, involving numerous changes to the methods of moving traffic through the ATC system serving the Dallas/Fort Worth area is an absolute and obvious necessity. Therefore, a plan must be developed that, through expansion of the approach control airspace and increasing the number of arrival/departure routes, will elevate the system capacity to a level that will meet or exceed that required to accommodate the anticipated growth through the year 2005. This plan will also recommend further revision of the DFW Airport Master Plan to include two new runways, with associated taxiways and the instrumentation to make it a viable contribution to the improved capacity of that airport.

PROBLEM AREAS

- Inadequate Capacity of the Enroute Airway System.
- Terminal Airspace Constraints.
- Military Special Operating Areas.
- Inefficient Handling of High Performance Turboprop Aircraft.
- Traffic Management.
- Limited Track Capacity of the DFW ARTS IIIa System.

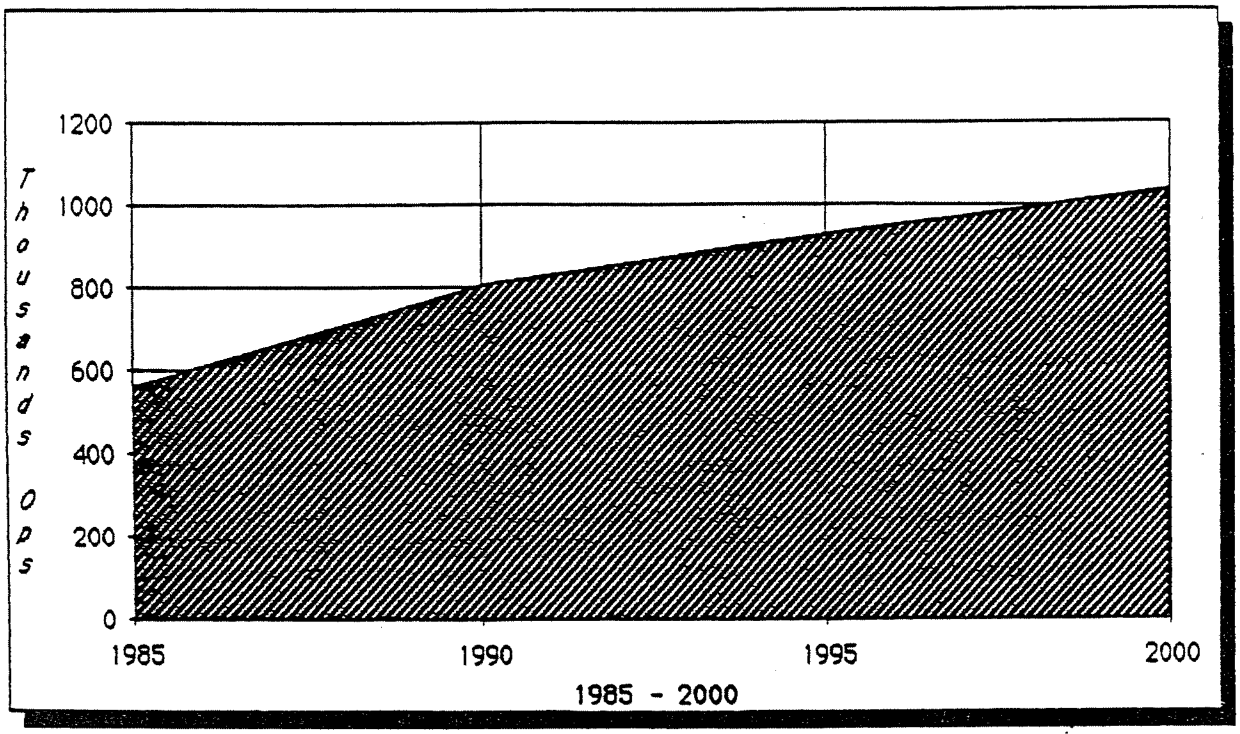
GOALS

- SYSTEMS APPROACH
- IMPROVE DFW ARRIVAL/DEPARTURE SYSTEM
- IMPROVE SATELLITE ARRIVAL/DEPARTURE SYSTEM
- DEVELOP INDEPENDENT HIGH PERFORMANCE TURBOPROP SYSTEM

PLANNING CONSIDERATIONS

- SEGREGATION OF TRAFFIC
- REGIMENTATION OF TRAFFIC
- MANAGEMENT OF TRAFFIC

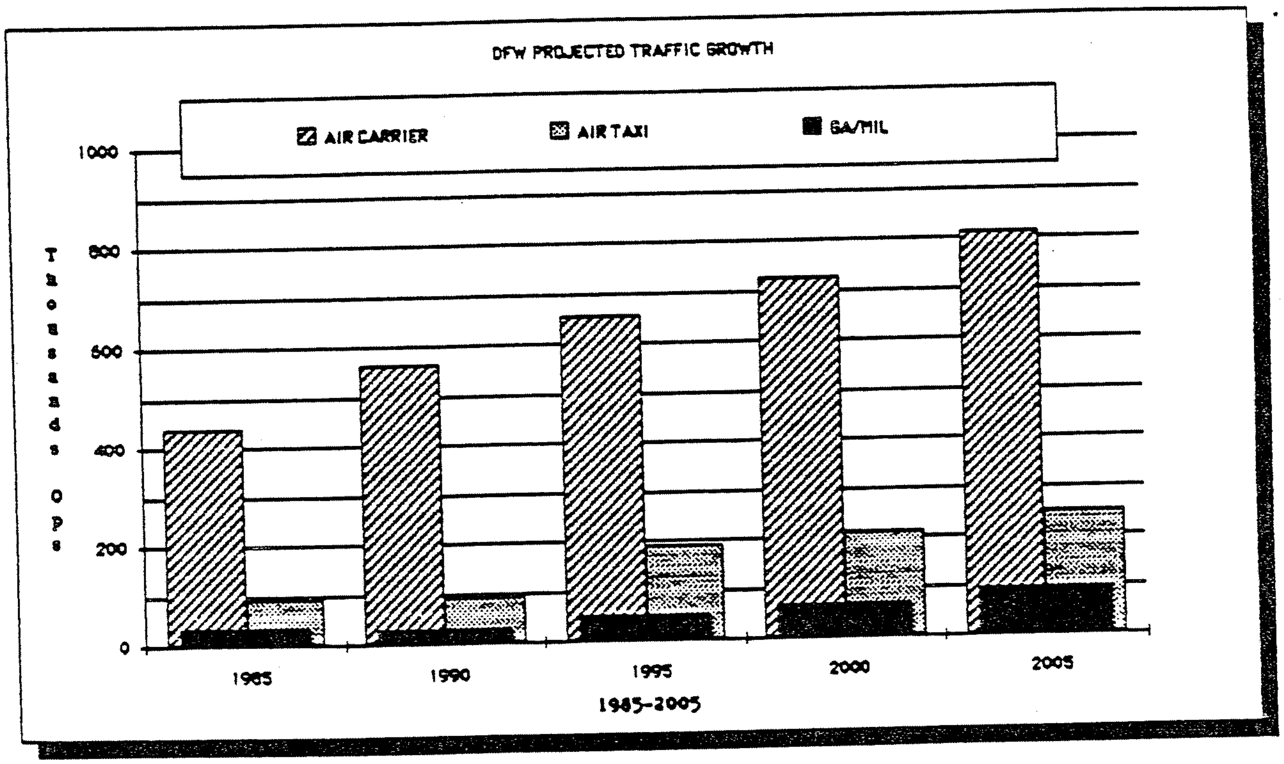
DFW IFR FORECAST



DFW Airport Forecast (Revised 4/1/87)

	1985	1990	1991	1995	2000	2005
Air Carrier	441,681	566,190	618,263	654,153	727,139	811,600
Air Taxi	93,039	192,504	199,680	212,784	234,000	250,773
Comb. GA/Mil	27,142	42,500	45,540	57,700	69,600	83,954
Total	561,862	801,194	863,483	924,637	1,030,739	1,146,327
Avg Dly Ops	1,539	2,195	2,366	2,533	2,824	3,141
Avg Peak hr Ops	120	171	184	197	220	244

*Based on current peak hour scheduling trends for nine busiest periods of peak day. This constitutes 65% to 70% of all scheduled operations.



Revised4/28/87

DFW AIRPORT TRAFFIC GROWTH

YEAR	AIR CARRIER	% Chg.	AIR TAXI	% Chg.	GENERAL AVIATION	% Chg.	MILITARY	% Chg.	TOTAL	% Chg.
1974	274,342		38,453		17,464		571		330,830	
1975	282,026	2.80	44,137	14.78	15,368	-12.00	585	2.45	342,116	3.41
1976	294,231	4.33	47,990	8.73	17,050	10.94	492	-15.90	359,851	5.18
1977	305,362	3.78	60,406	25.87	19,358	13.54	641	30.28	385,767	7.20
1978	316,054	3.50	67,131	11.13	22,649	17.00	701	9.36	406,535	5.38
1979	336,616	6.51	83,611	24.55	25,148	11.03	716	2.14	446,091	9.73
1980	344,355	2.30	91,391	9.30	27,228	8.27	849	18.58	463,823	3.97
1981	352,738	2.43	93,252	2.04	25,570	-6.09	691	-18.61	472,251	1.82
1982	324,766	-7.93	96,712	3.71	20,592	-19.47	700	1.30	442,770	-6.24
1983	326,872	0.65	85,787	-11.30	22,268	8.14	606	-13.43	435,533	-1.63
1984	409,278	25.21	91,784	6.99	22,720	2.03	782	29.04	524,564	20.44
1985	441,474	7.87	93,045	1.37	26,136	15.04	1,010	29.16	561,665	7.07
1986	471,668	6.84	80,352	-13.64	22,813	-12.71	1,128	11.68	575,961	2.55
Avg Chg.		*4.86*		*6.96*		*2.98*		*7.17*		*4.91*

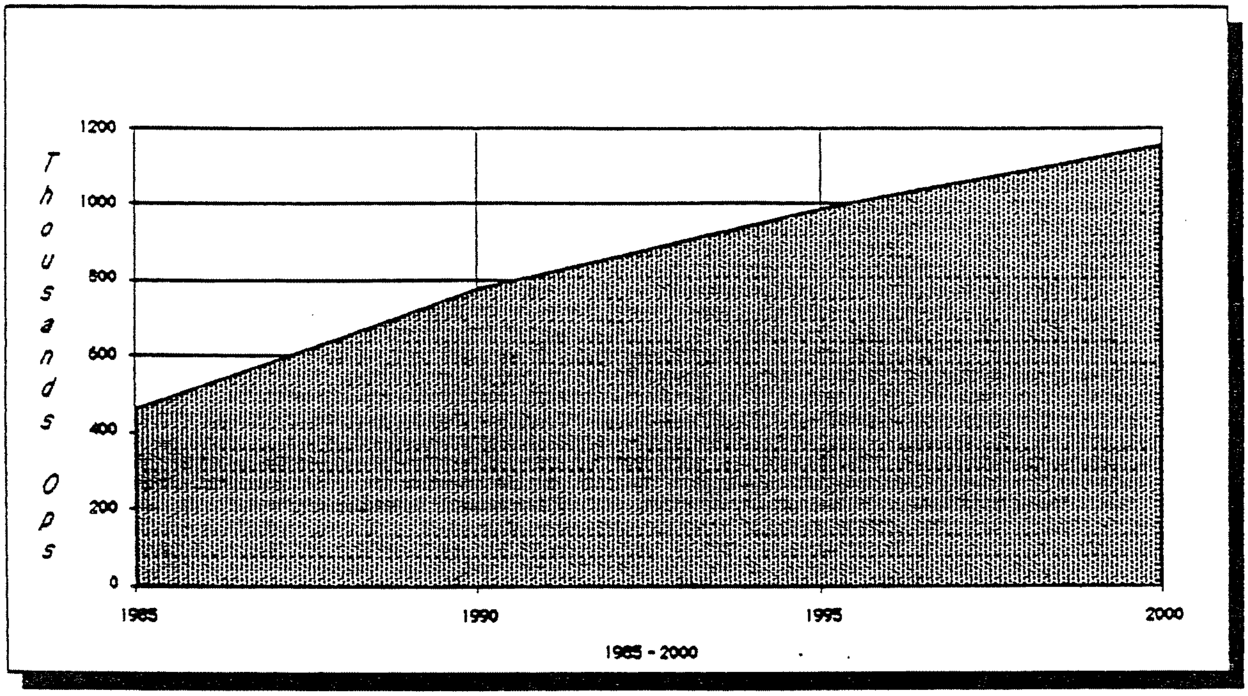
PROJECTED GROWTH

1990	566,190	20.04	192,504	139.58	42,500	86.30	801,194	39.11
1995	654,153	15.54	212,784	10.53	57,700	35.76	924,637	15.41
2000	727,139	11.16	234,000	9.97	69,600	20.62	1,030,739	11.47
2005	811,600	11.62	250,773	7.17	83,954	20.62	1,146,327	11.21

Note: Projected Growth combines General Aviation and Military traffic forecast.

Revised 4/1/87

SATELLITE IFR FORECAST



	1985	1990	1995	2000
Air Carrier	* 99,881	101,000	116,000	133,000
Air Taxi	44,766	51,000	59,250	70,500
General Aviation	275,085	420,050	619,440	779,610
Military	44,000	44,000	44,000	44,000
Total	463,732	616,050	838,690	1,027,110

**NOTE*: *1985 IFR Figures represent actual annual traffic totals.*

SATELLITE TRAFFIC GROWTH

YEAR	AIR CARRIER	% Chg.	AIR TAXI	% Chg.	GENERAL AVIATION	% Chg.	TOTAL*	% Chg.
1975	N/A		N/A		100,650		148,207	
1976	N/A		N/A		105,560	4.88	152,416	2.84
1977	25,315		14,489		119,342	13.06	177,613	16.53
1978	39,668	56.70	21,951	51.50	134,868	13.01	208,255	17.25
1979	52,511	32.38	26,270	19.68	149,639	10.95	243,772	17.05
1980	66,247	26.16	23,256	-11.47	155,095	3.65	253,924	4.16
1981	76,086	14.85	26,947	15.87	175,876	13.40	317,568	25.06
1982	88,675	16.55	27,532	2.17	155,659	-11.50	307,620	-3.13
1983	97,685	10.16	26,612	-3.34	181,195	16.41	344,396	11.96
1984	107,867	10.42	36,102	35.66	257,343	42.03	441,598	28.22
1985	99,881	-7.40	44,766	24.00	275,085	6.89	464,254	5.13
1986	85,683	-14.21	35,897	-19.81	257,660	-6.33	424,013	-8.67
Avg Change		*16.18*		*12.69*		*9.68*		*10.58*

PROJECTED GROWTH

						DFW	GRAND TOTAL
1990	265,647	51,000	464,050	780,697	Add	801,194	1,581,891
1995	265,647	59,250	663,440	988,337	Add	924,637	1,912,974
2000	265,647	70,500	823,610	1,159,757	Add	1,030,739	2,190,496

REVISED 4/1/87

Terminal Forecast: Dallas Love Field

	1985	1990	*1990
Air Carrier	86,000	101,000	265,647
Air Taxi	51,000	57,000	57,000
General Aviation	162,000	213,000	194,319
Military	2,000	2,000	2,000
Total	301,000	373,000	518,966

**Note:* *Increase in air carrier traffic reflects repeal of Wright Amendment. Reduced GA activity due increase in air carrier operations.*

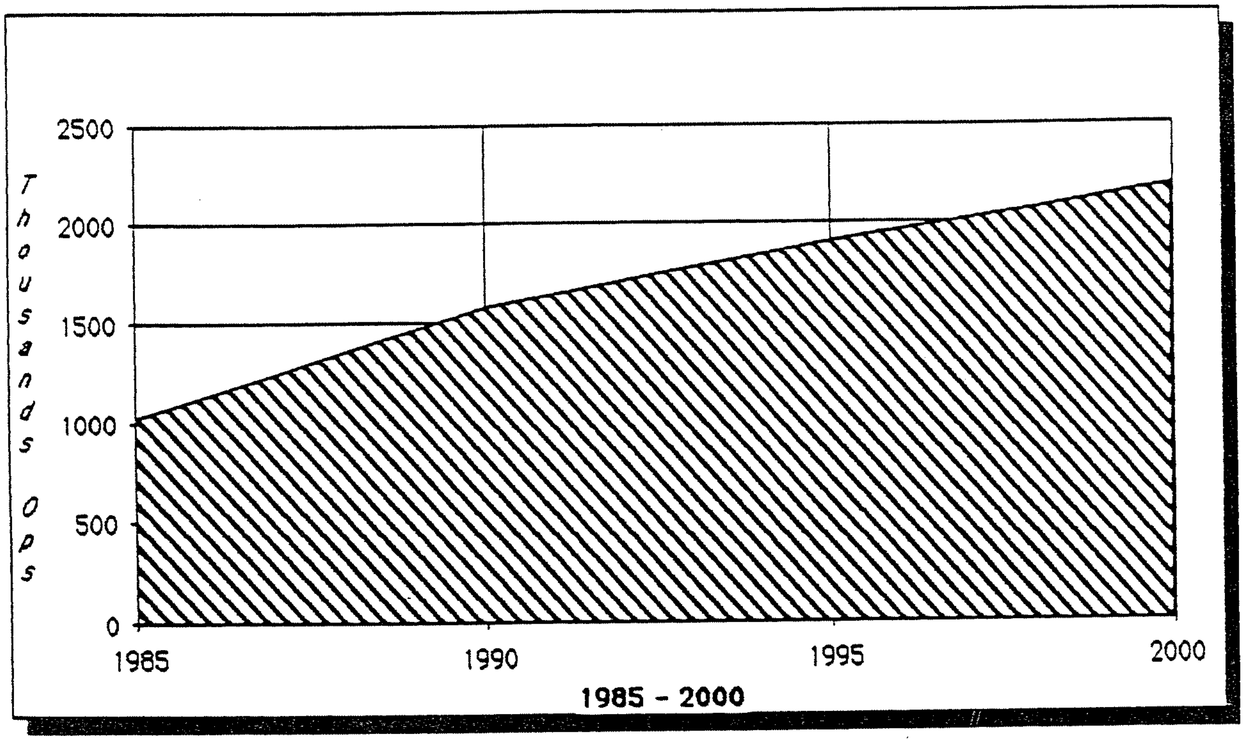
DAL Terminal Facilities:

Air Carrier Gates	28
Commuter Gates	2
Total	30

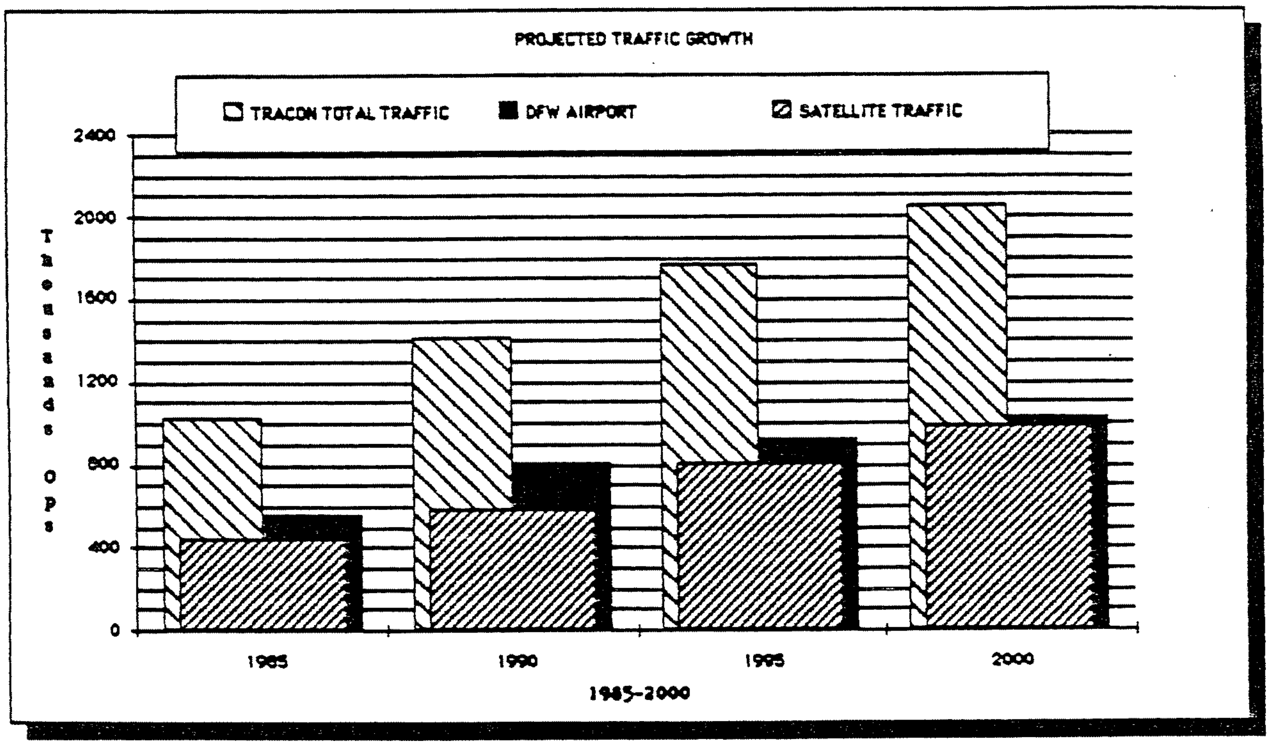
Improved Baggage facilities.

New 5,000 place parking garage

TRACON IFR FORECAST



	1985	1990	1995	2000
Satellite Traffic	463,732	780,697	988,337	1,159,757
DFW Forecast	561,862	801,194	924,637	1,030,739
Total	1,025,594	1,581,891	1,912,974	2,190,496



Revised 4/28/87

Forecast: IFR Operations

(Revised: Repeal of Wright Amendment)

Satellite Traffic	1985	1990	1995	2000
(100%) Air Carrier	*99,881	265,647	265,647	265,647
(75%) Air Taxi	44,766	51,000	59,250	70,500
(56%) General Aviation	275,085	420,050	619,440	779,610
(100%) Military	44,000	44,000	44,000	44,000
Total	463,732	780,697	988,337	1,159,757

**NOTE: 1985 IFR figures represent actual annual traffic totals.*

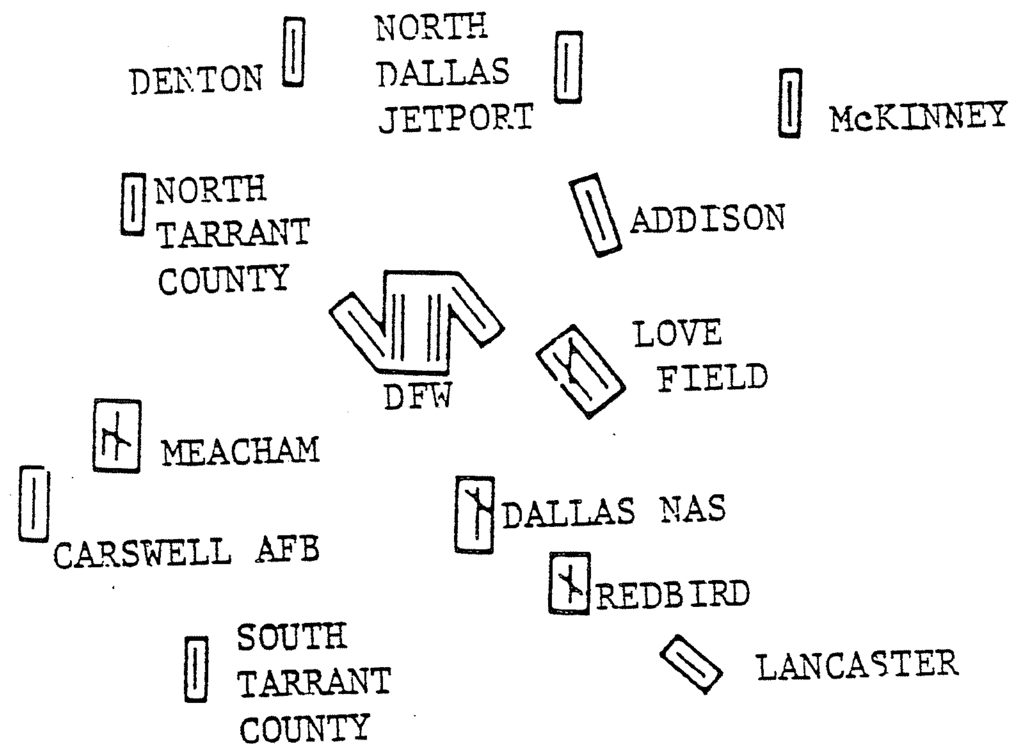
DFW Airport Forecast (Revised 4/1/87)	1985	1990	1995	2000
Air Carrier	441,681	566,190	654,153	727,139
Air Taxi	93,039	192,504	212,784	234,000
Combo. GA/Mil	27,142	42,500	57,700	69,600
Total	561,862	801,194	924,637	1,030,739

Combined DFW/Satellite IFR Forecast

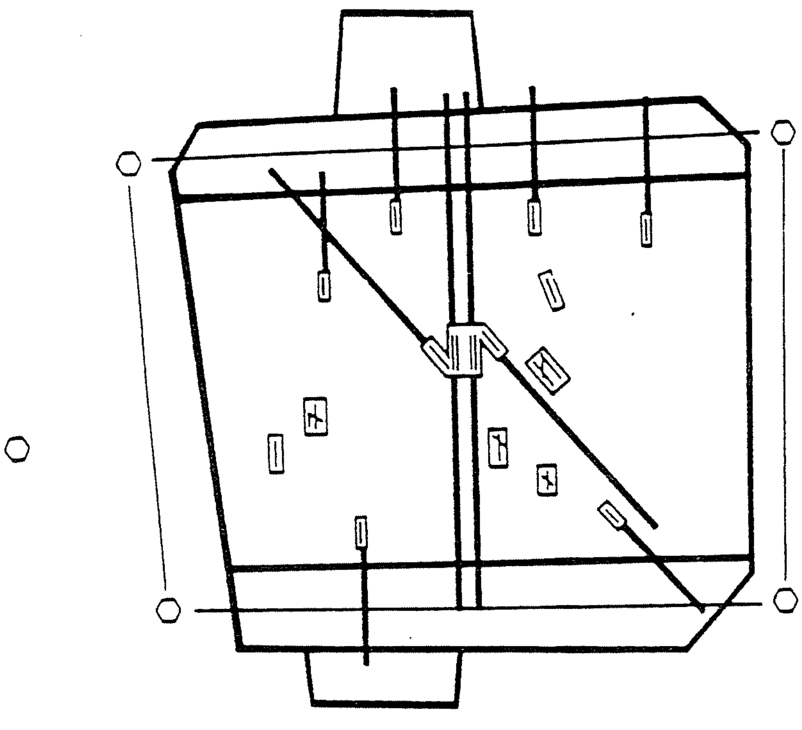
	1985	1990	1995	2000
Total	1,025,594	**1,581,891	1,912,974	2,190,496

***NOTE: 54.2% increase over 1985 IFR traffic.*

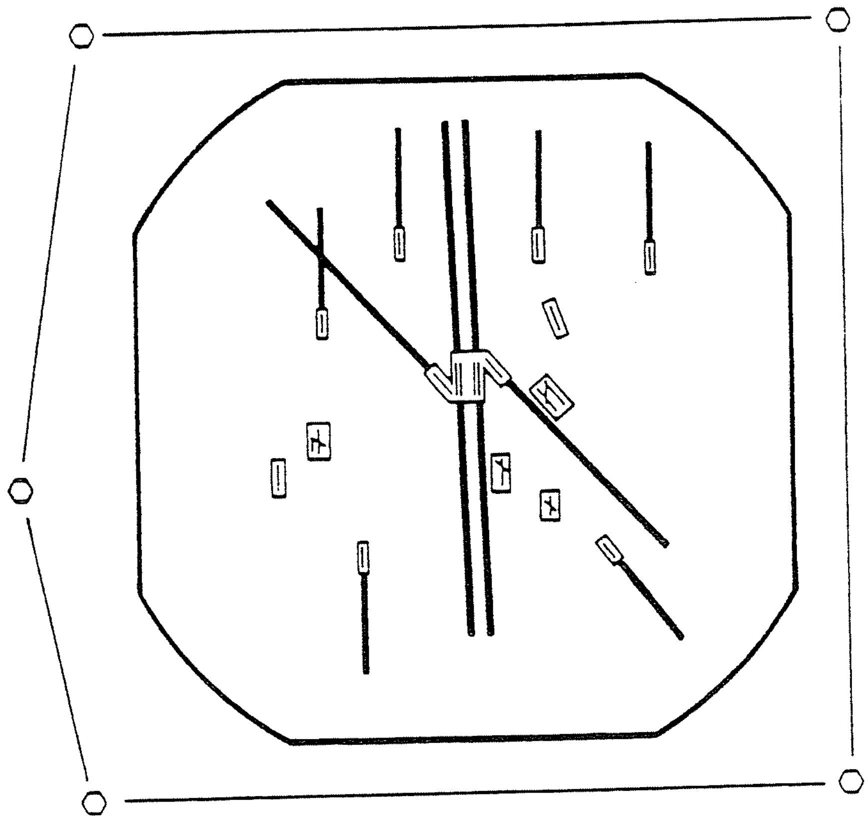
DALLAS - FORT WORTH AREA AIRPORTS



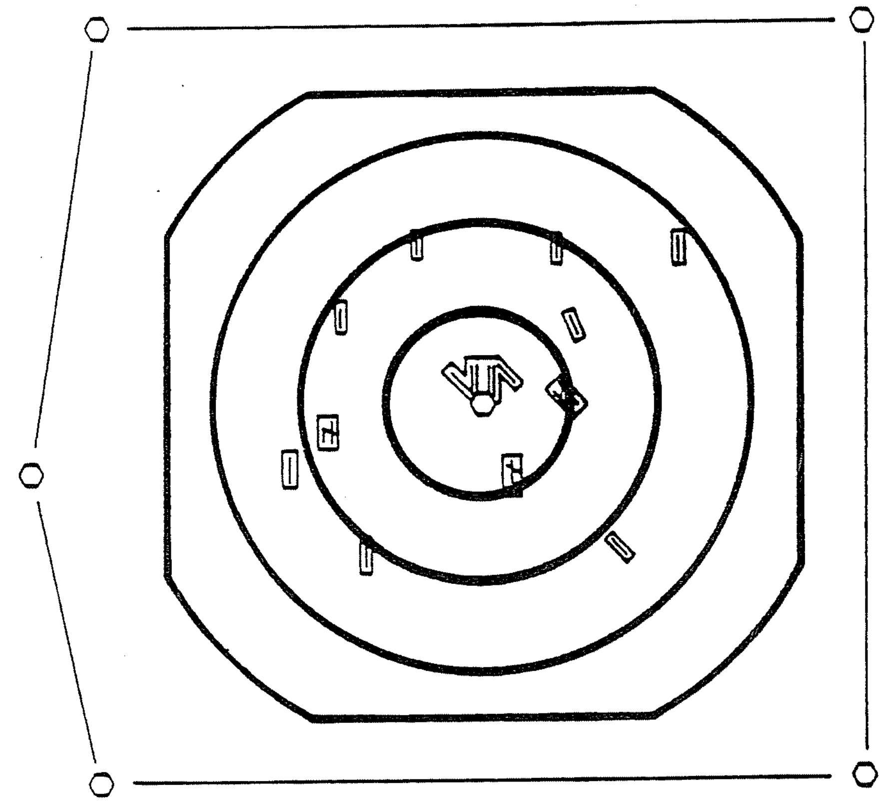
DFW APPROACH CONTROL
CURRENT AIRSPACE



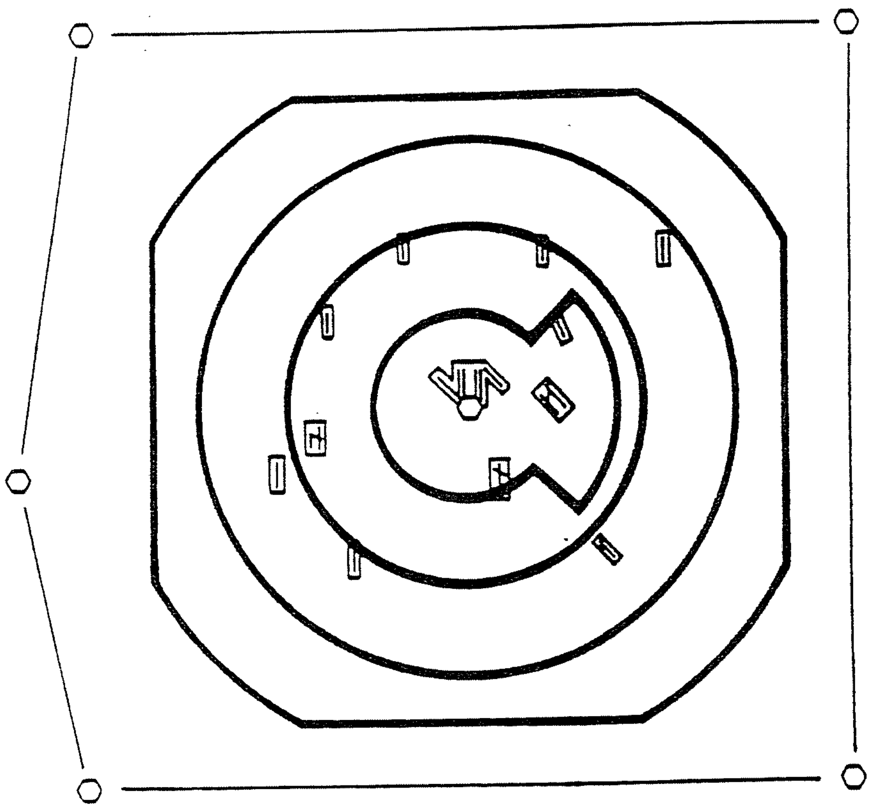
DFW APPROACH CONTROL
PROPOSED AIRSPACE
AND RELOCATED CORNERPOST



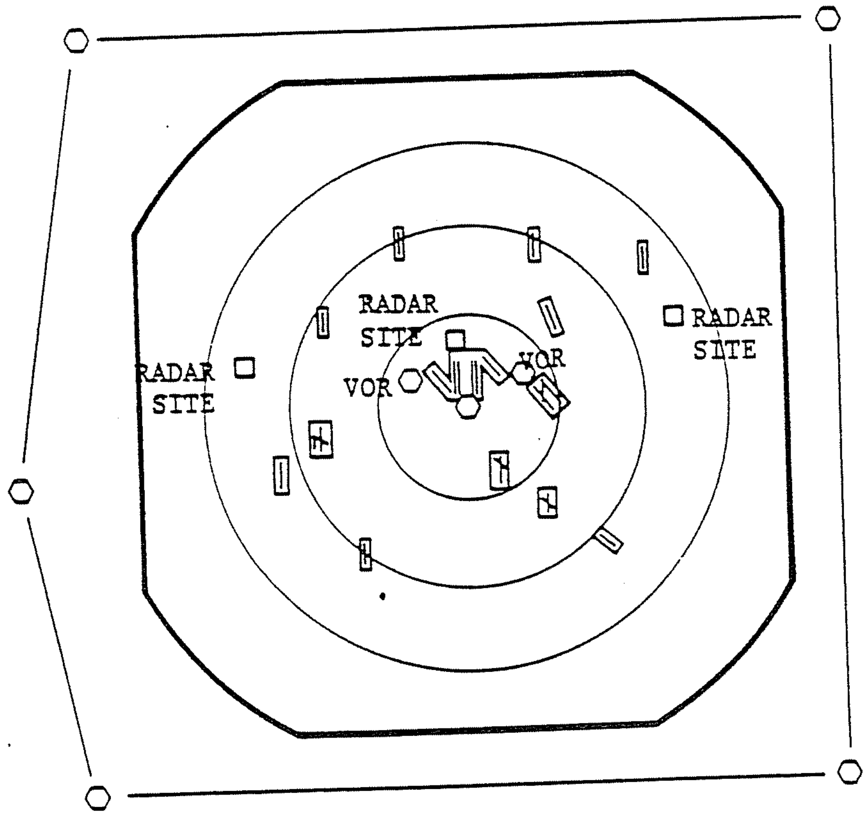
PROPOSED TCA



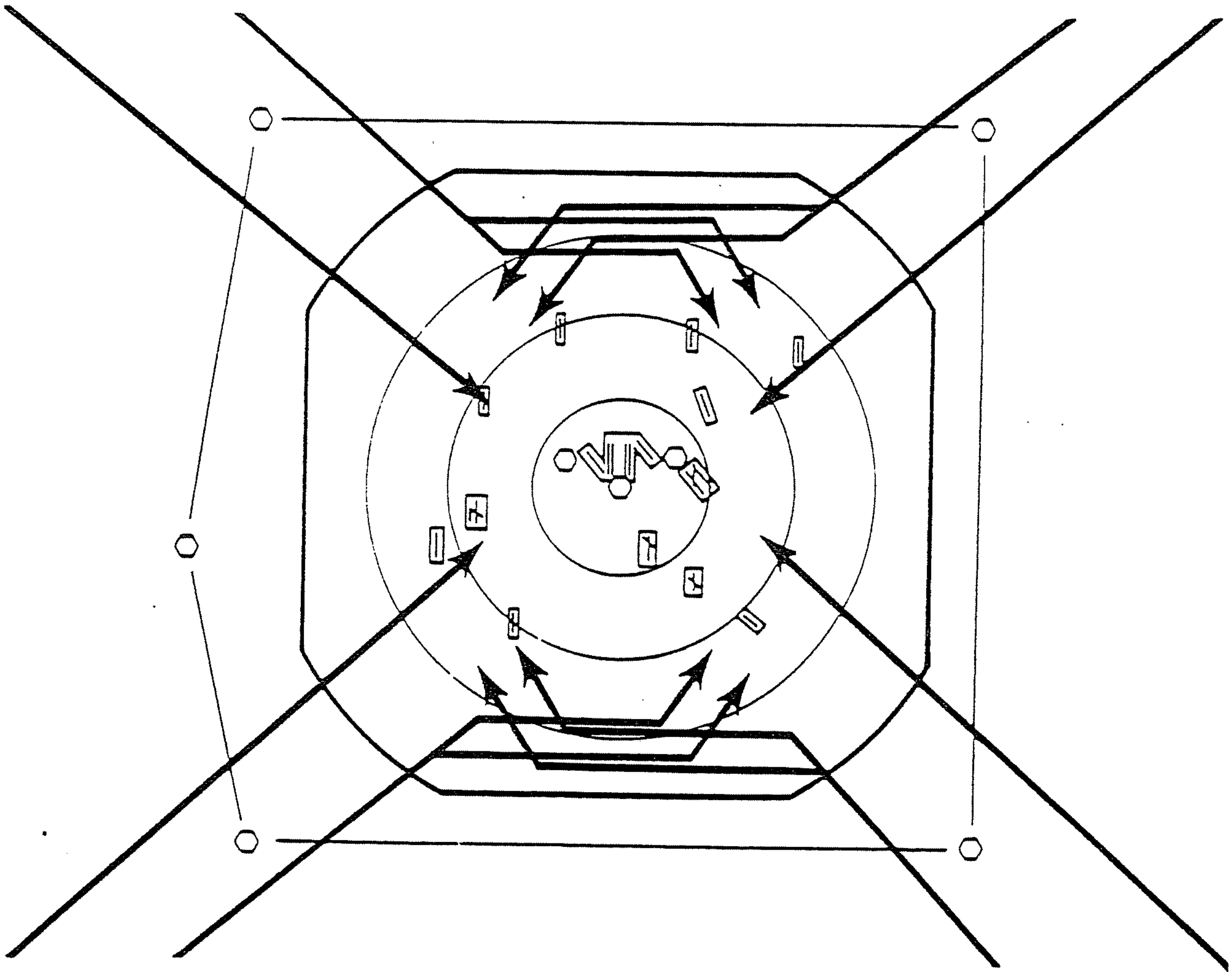
PROPOSED TCA
WITH LOVE FIELD EXTENSION



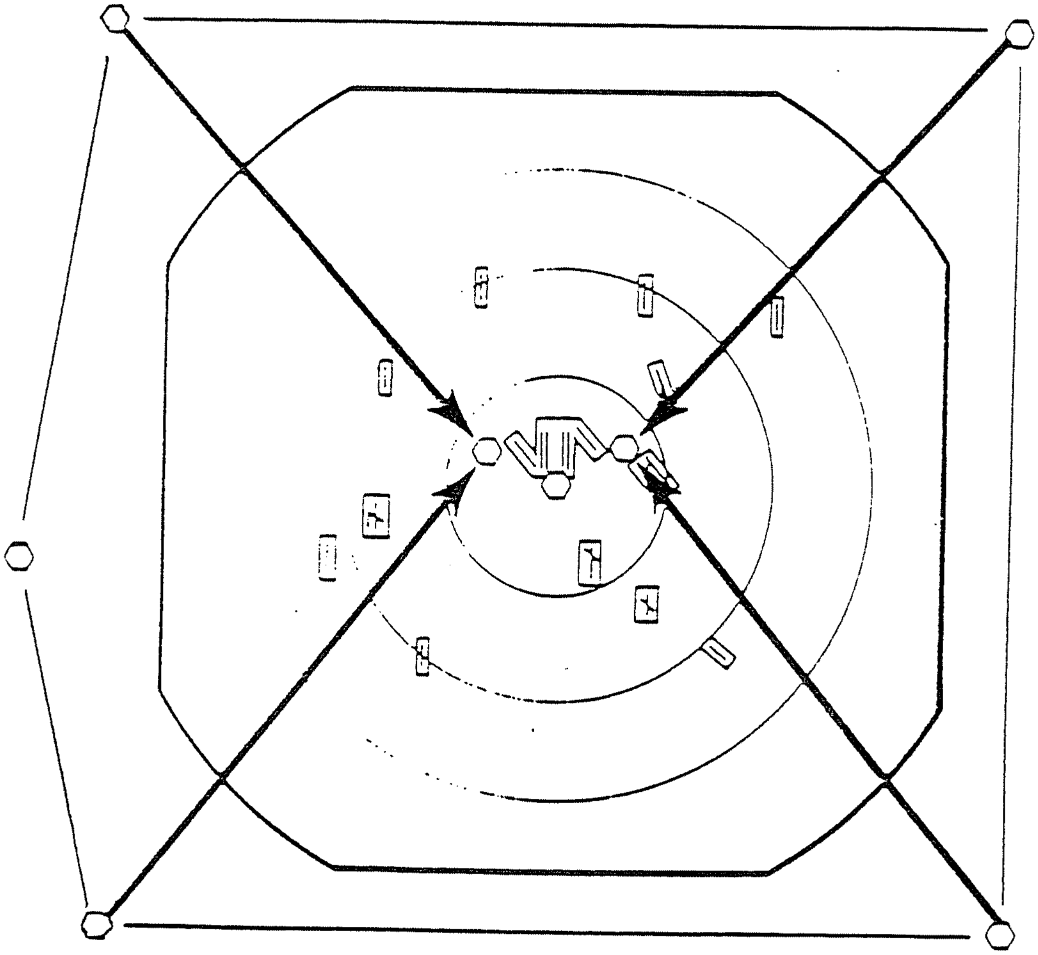
RADAR SYSTEMS AND
INTERIOR VOR LOCATIONS



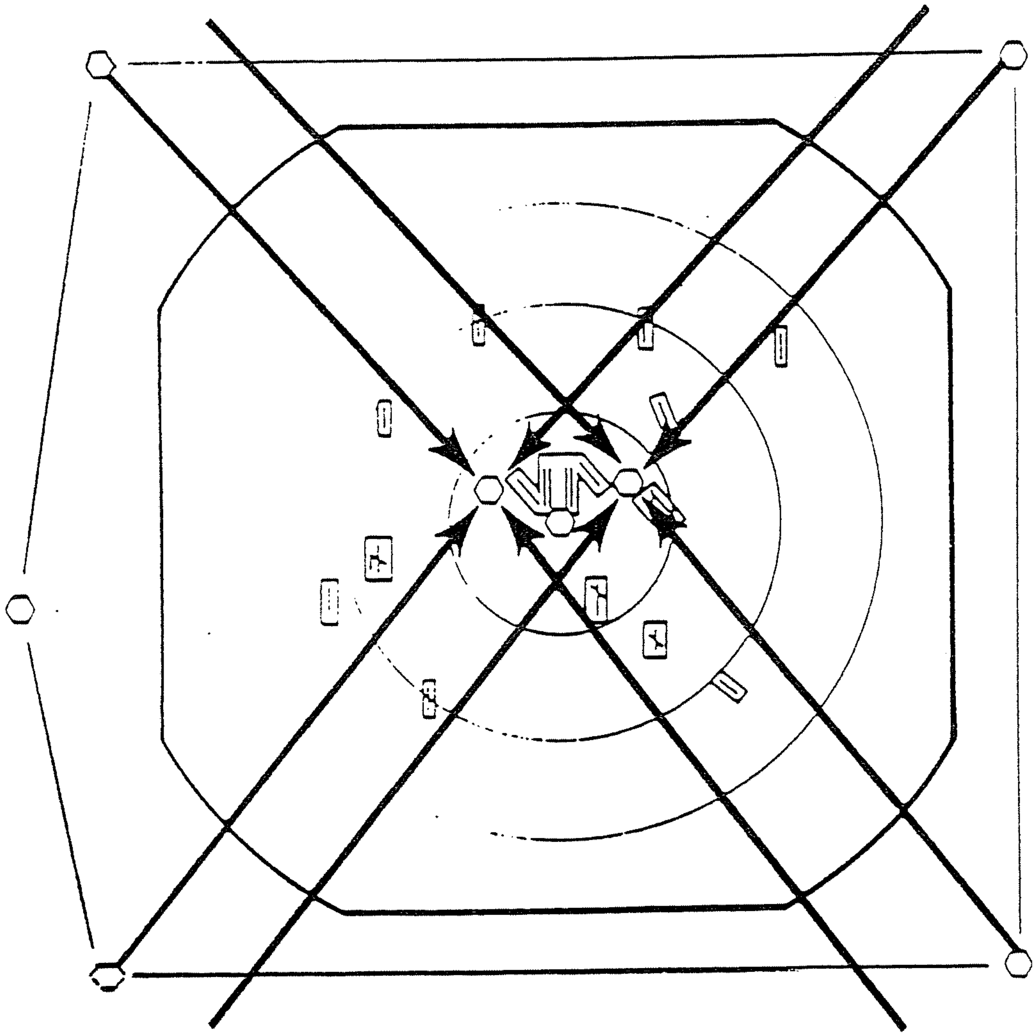
SATELLITE ARRIVALS



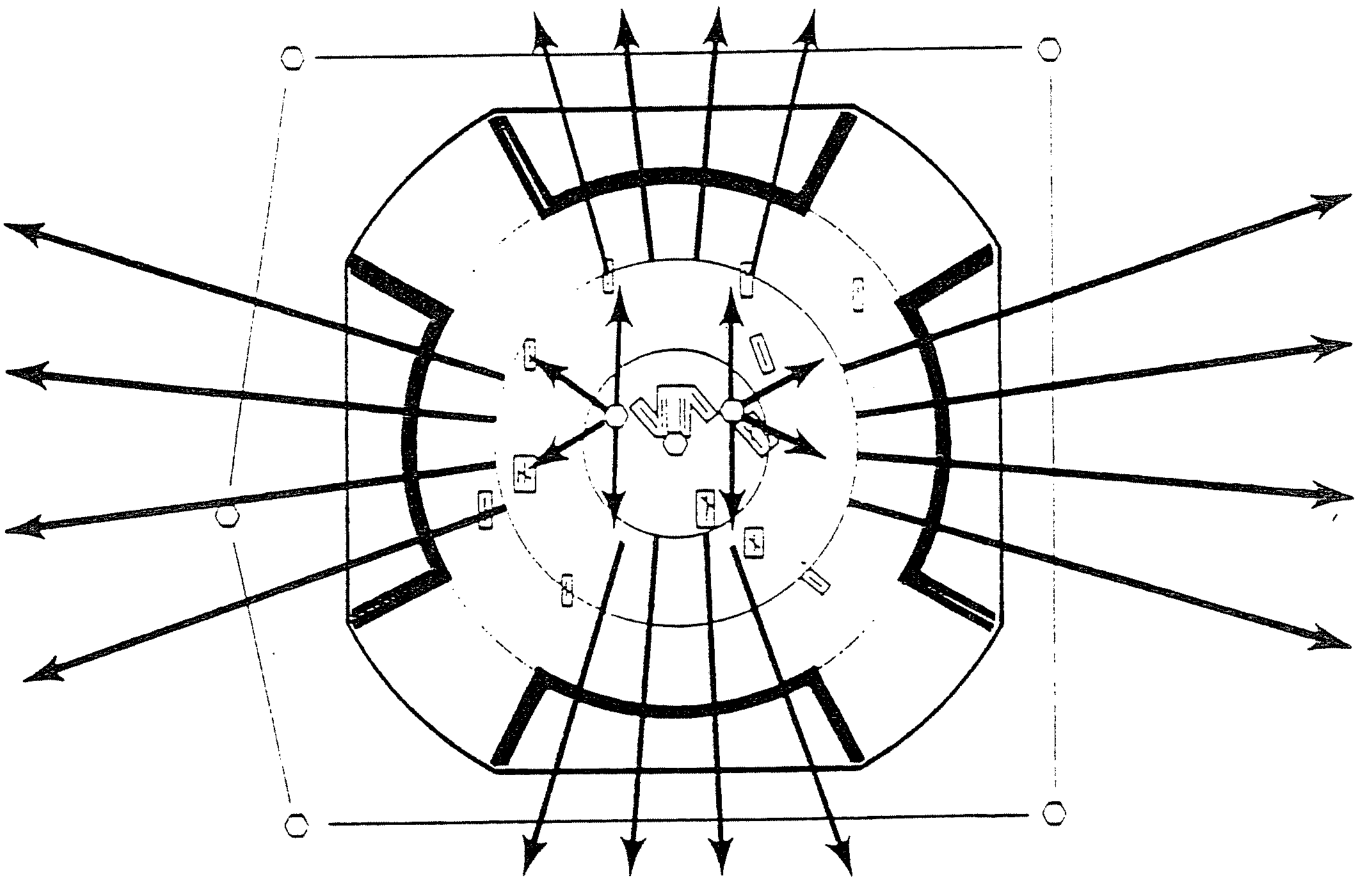
DFW PRIMARY ARRIVAL



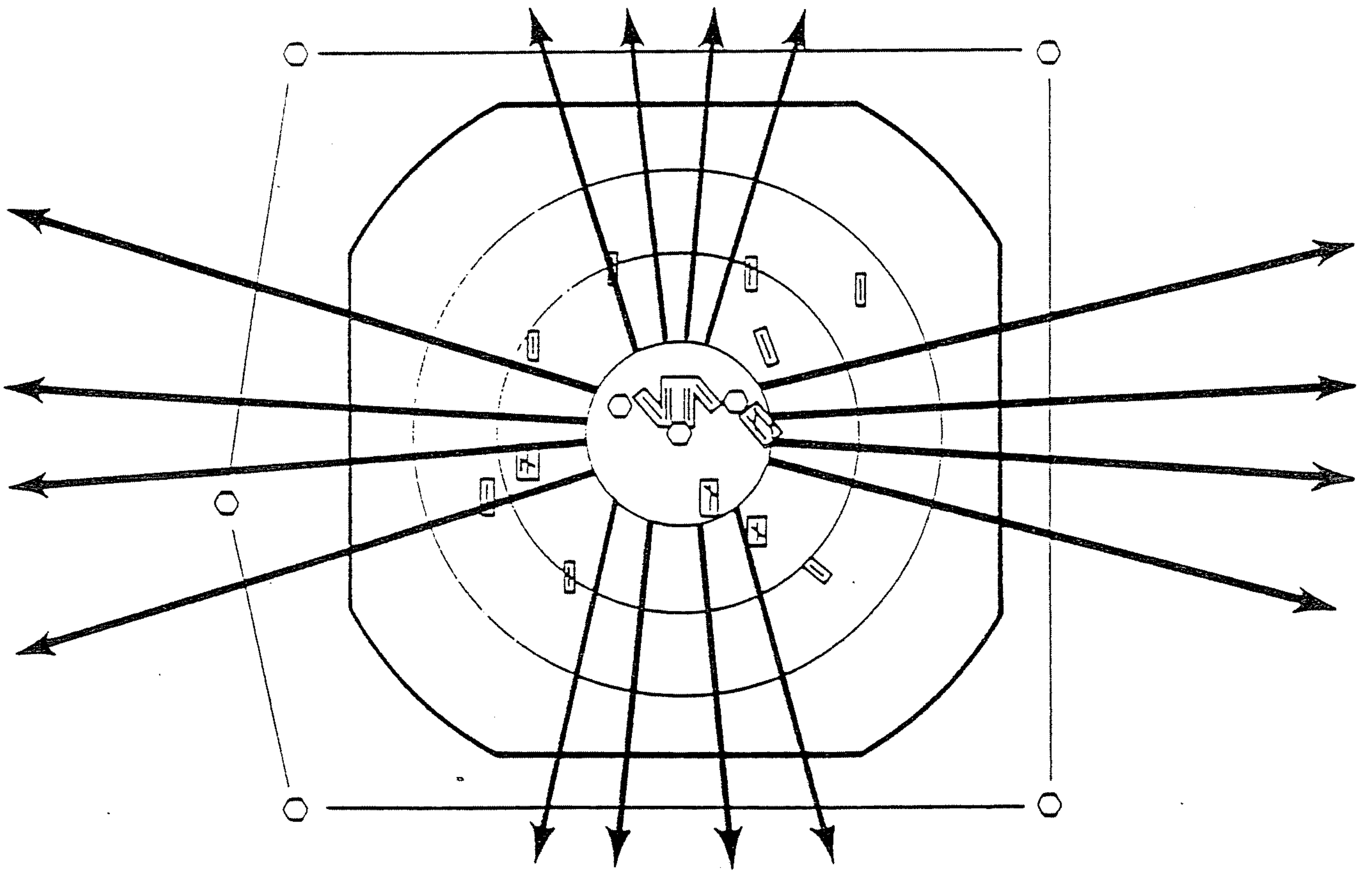
DFW PARALLEL ARRIVALS



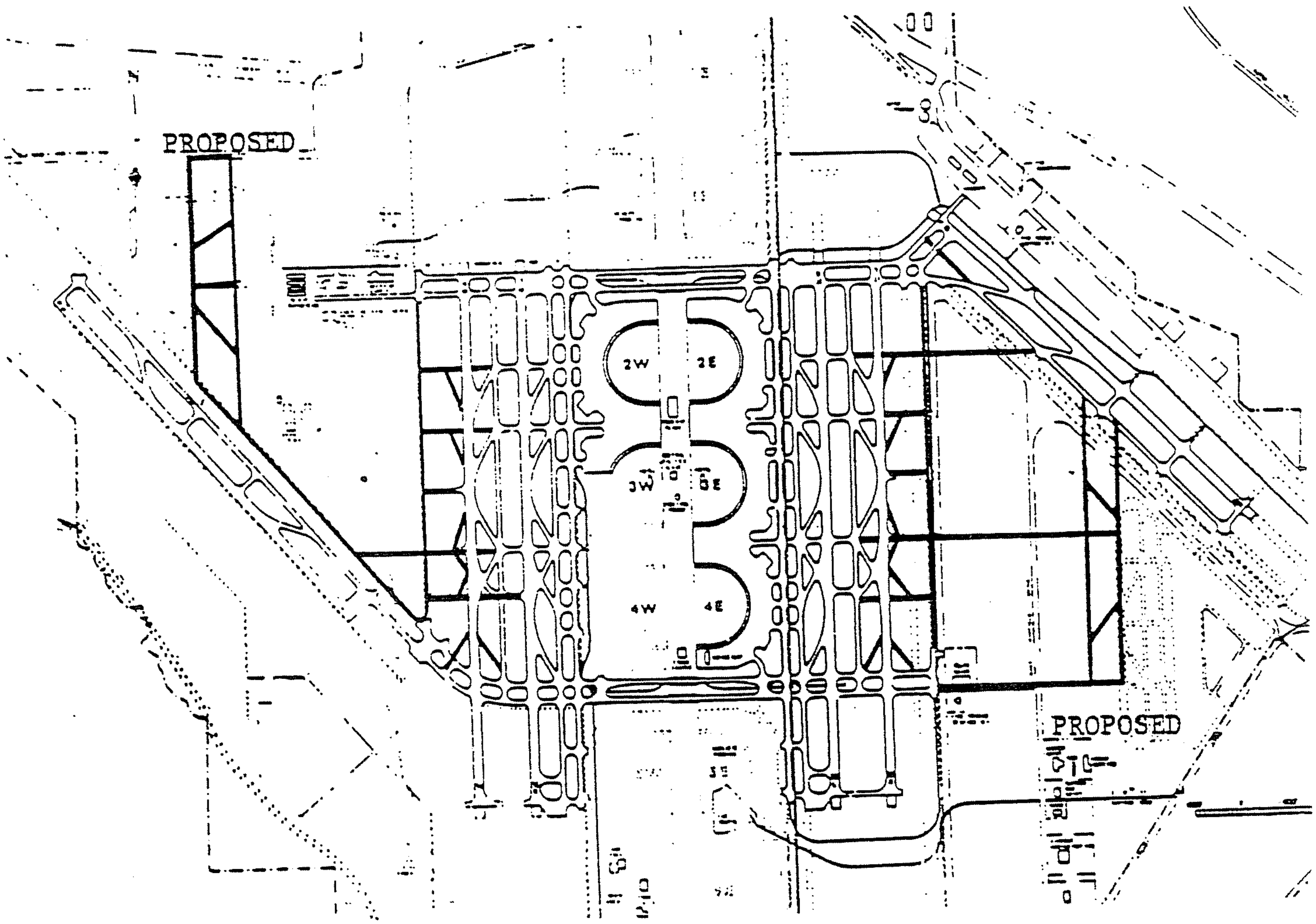
PROP AND TURBOPROP DEPARTURES



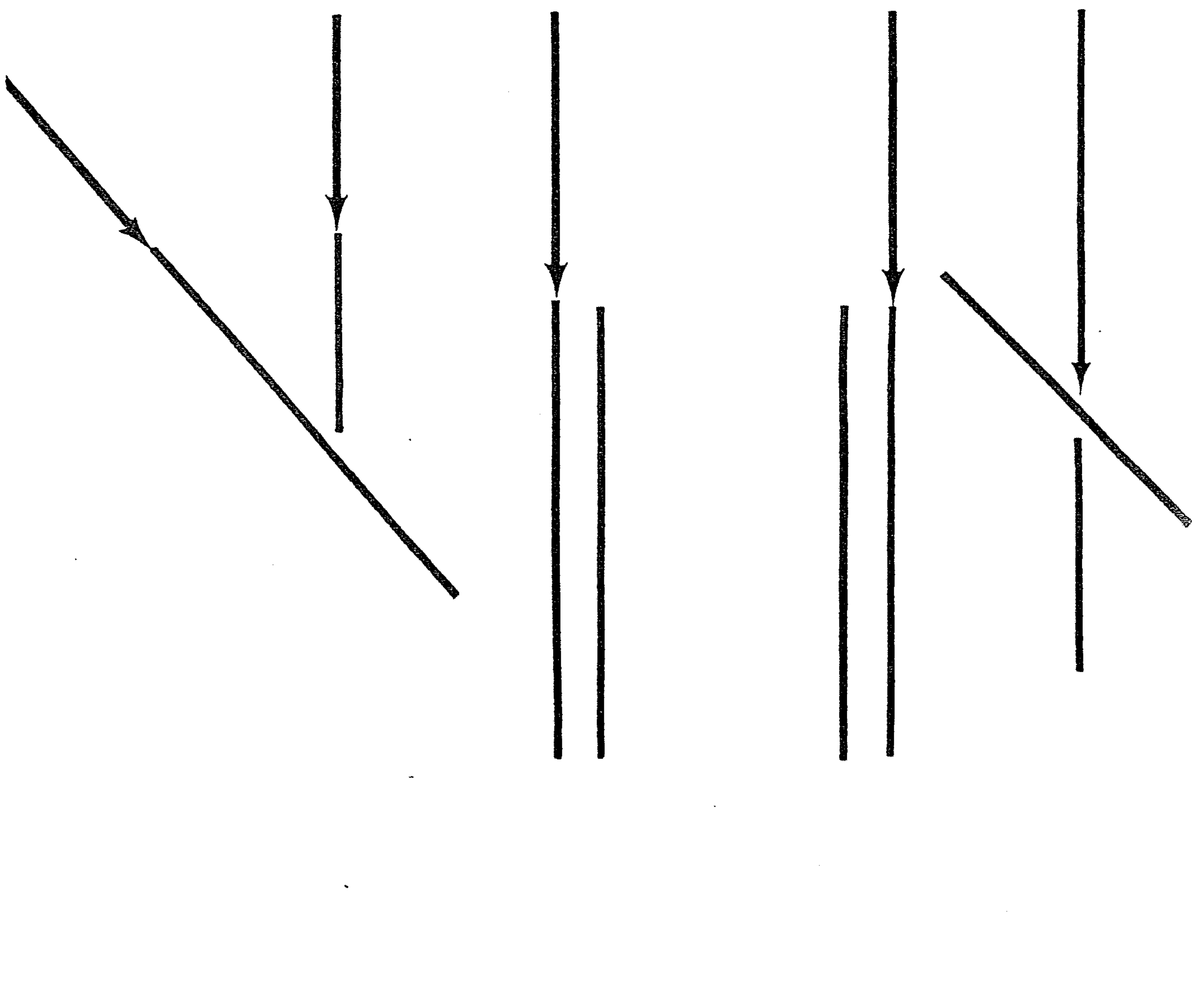
TURBOJET DEPARTURES



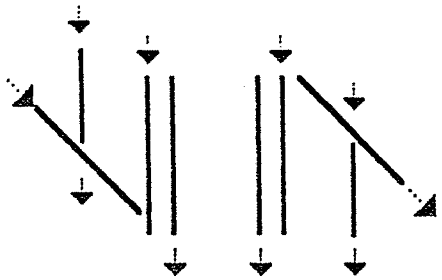
PROPOSED NEW RUNWAYS & TAXIWAYS



PROPOSED FOUR SIMULTANEOUS APPROACHES
SOUTH FLOW

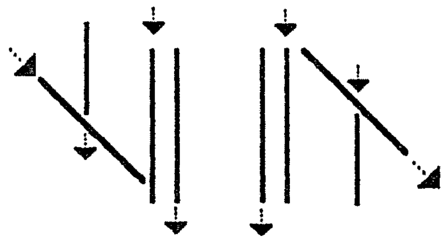


SOUTH FLOW



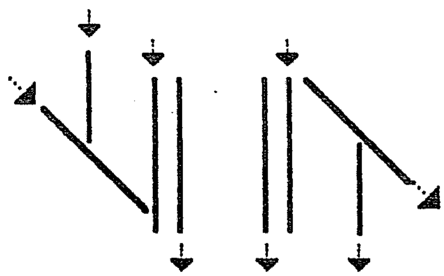
Weather down to 3,500' - 5 miles — Land 5 Runways, Depart 5 Runways

Arr/Dpt Capacity: 296
Flow Rates: 160



Weather down to 1,600' - 5 miles — Land 4 Runways, Depart 4 Runways

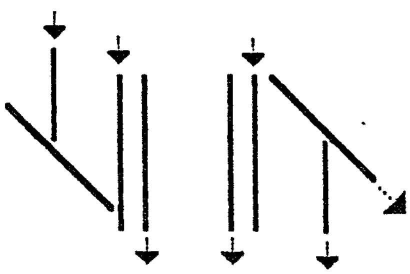
Arr/Dpt Capacity: 250
Flow Rates: 130



Weather down to 800' - 2 miles — Land 4 Runways, Depart 4 Runways

Arr/Dpt Capacity: 228
Flow Rates: 108

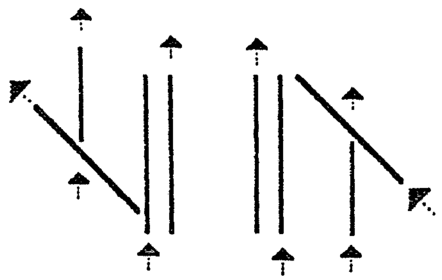
Note: Non-simultaneous approaches to rwys 16R/13R



Weather down to 200' - 1/2 mile — Land 3 Runways, Depart 4 Runways

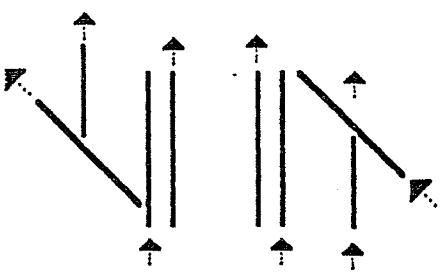
Arr/Dpt Capacity: 180
Flow Rates: 80

NORTH FLOW



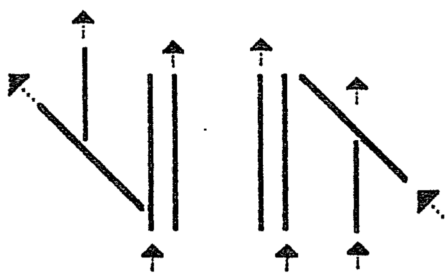
Weather down to 3,500' - 5 miles — Land 5 Runways, Depart 5 Runways

Arr/Dpt Capacity: 296
Flow Rates: 160



Weather down to 1,600' - 5 miles — Land 4 Runways, Depart 5 Runways

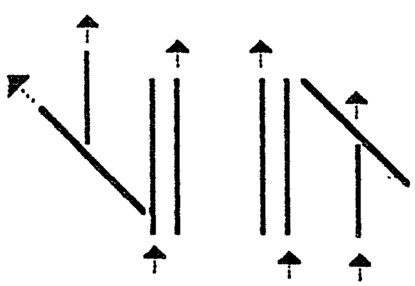
Arr/Dpt Capacity: 268
Flow Rates: 130



Weather down to 800' - 2 miles — Land 4 Runways, Depart 5 Runways

Arr/Dpt Capacity: 250
Flow Rates: 102

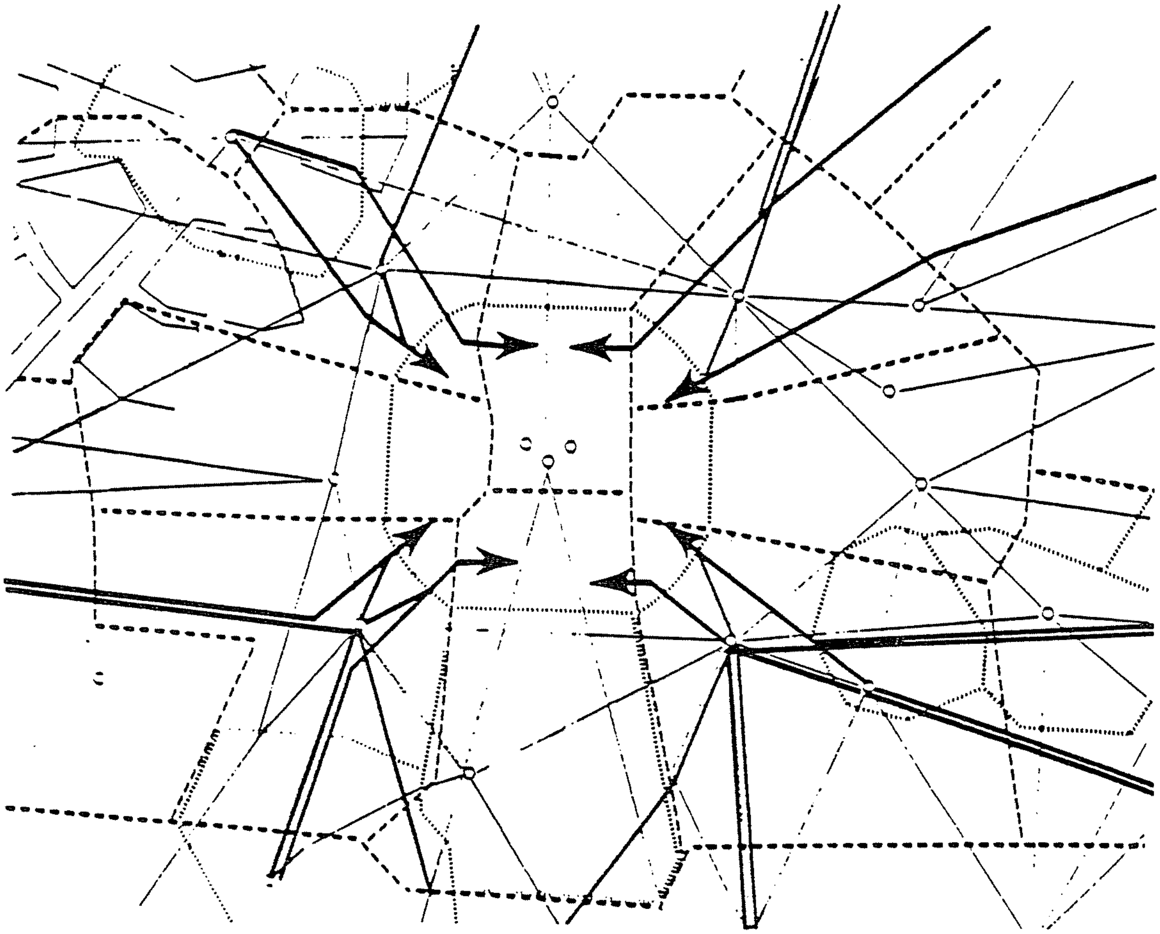
Note: Non-simultaneous approaches to rwys 34R/31R.



Weather down to 200' - 1/2 mile — Land 3 Runways, Depart 5 Runways

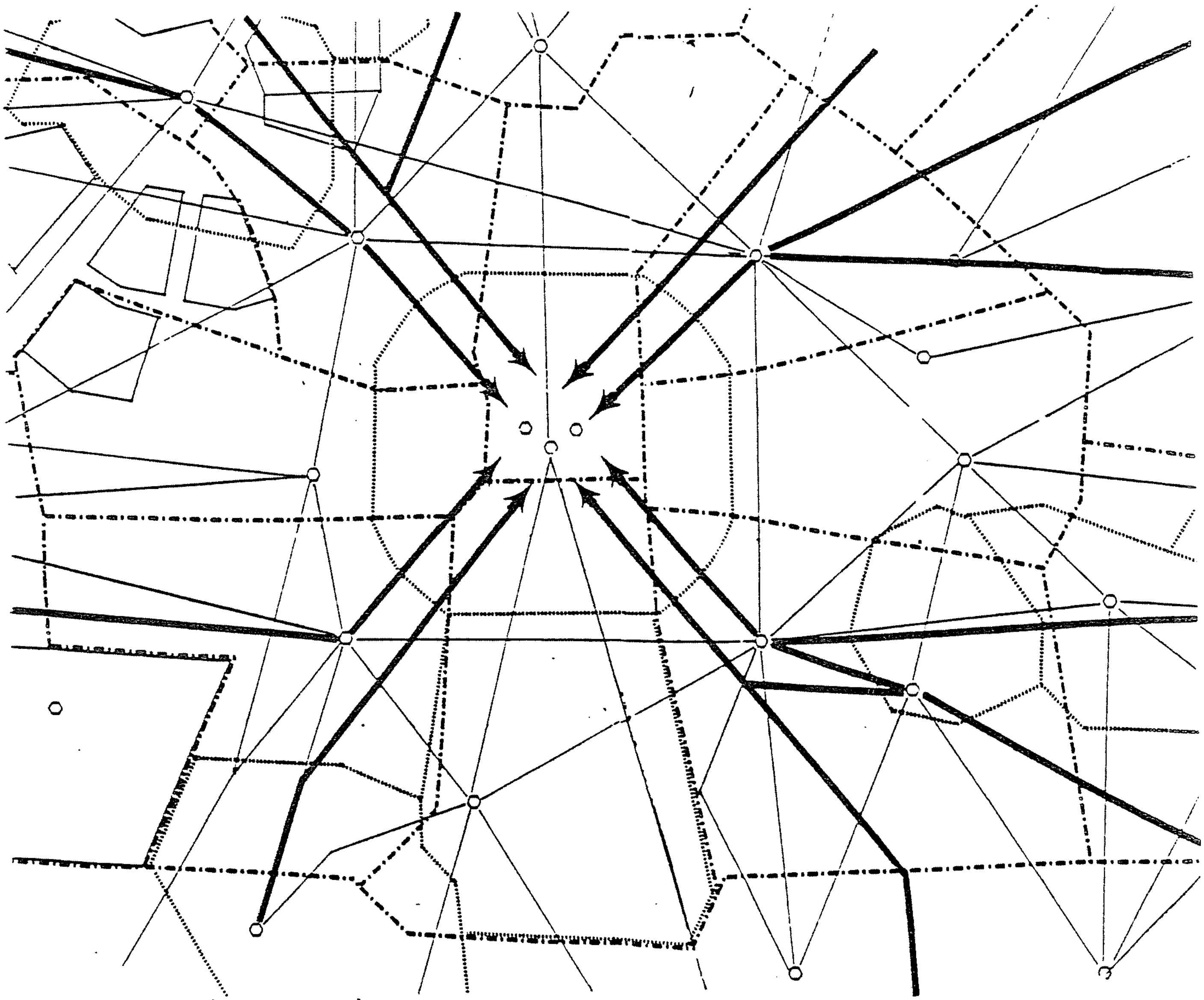
Arr/Dpt Capacity: 210
Flow Rates: 80

SATELLITE ARRIVALS - ENROUTE

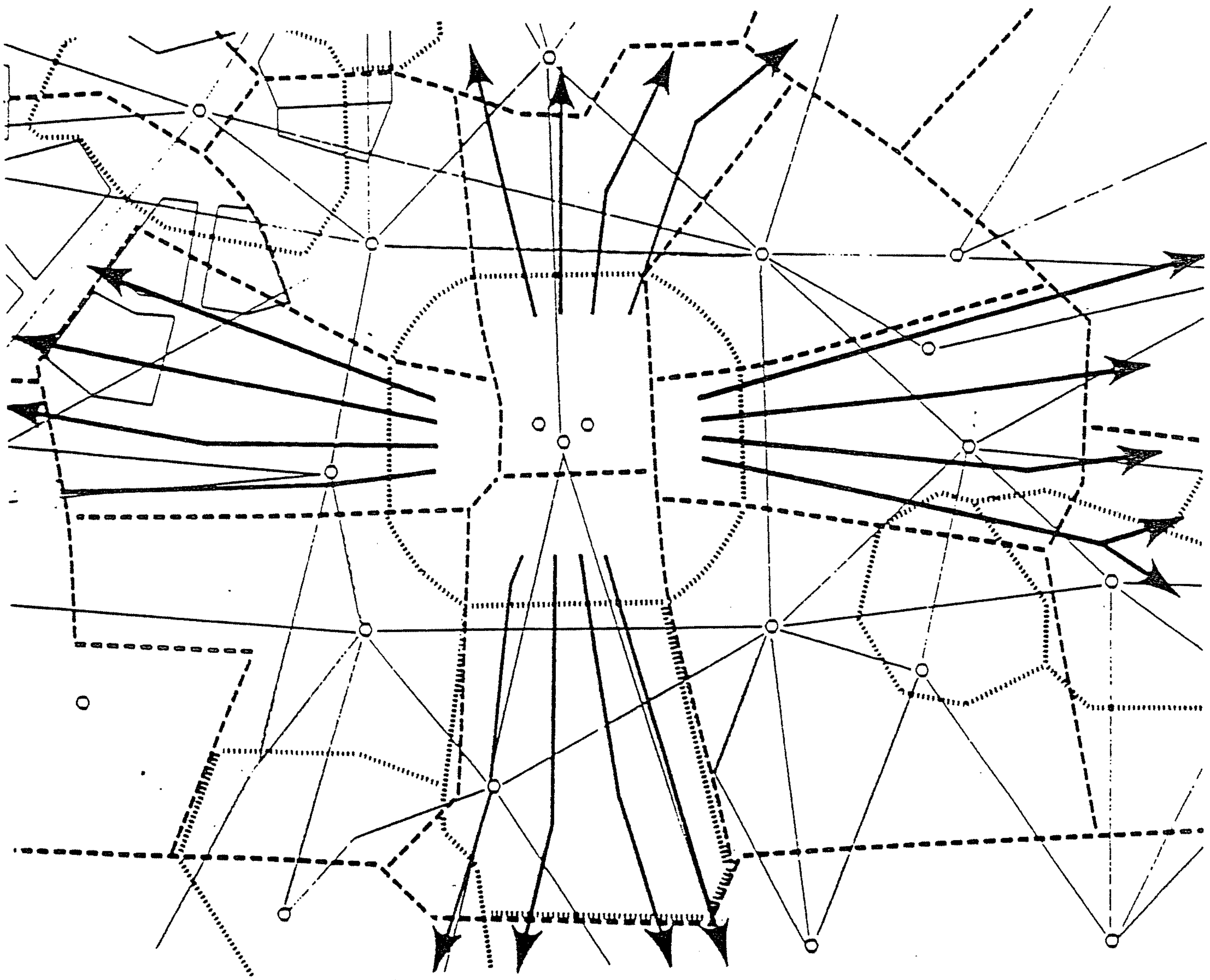


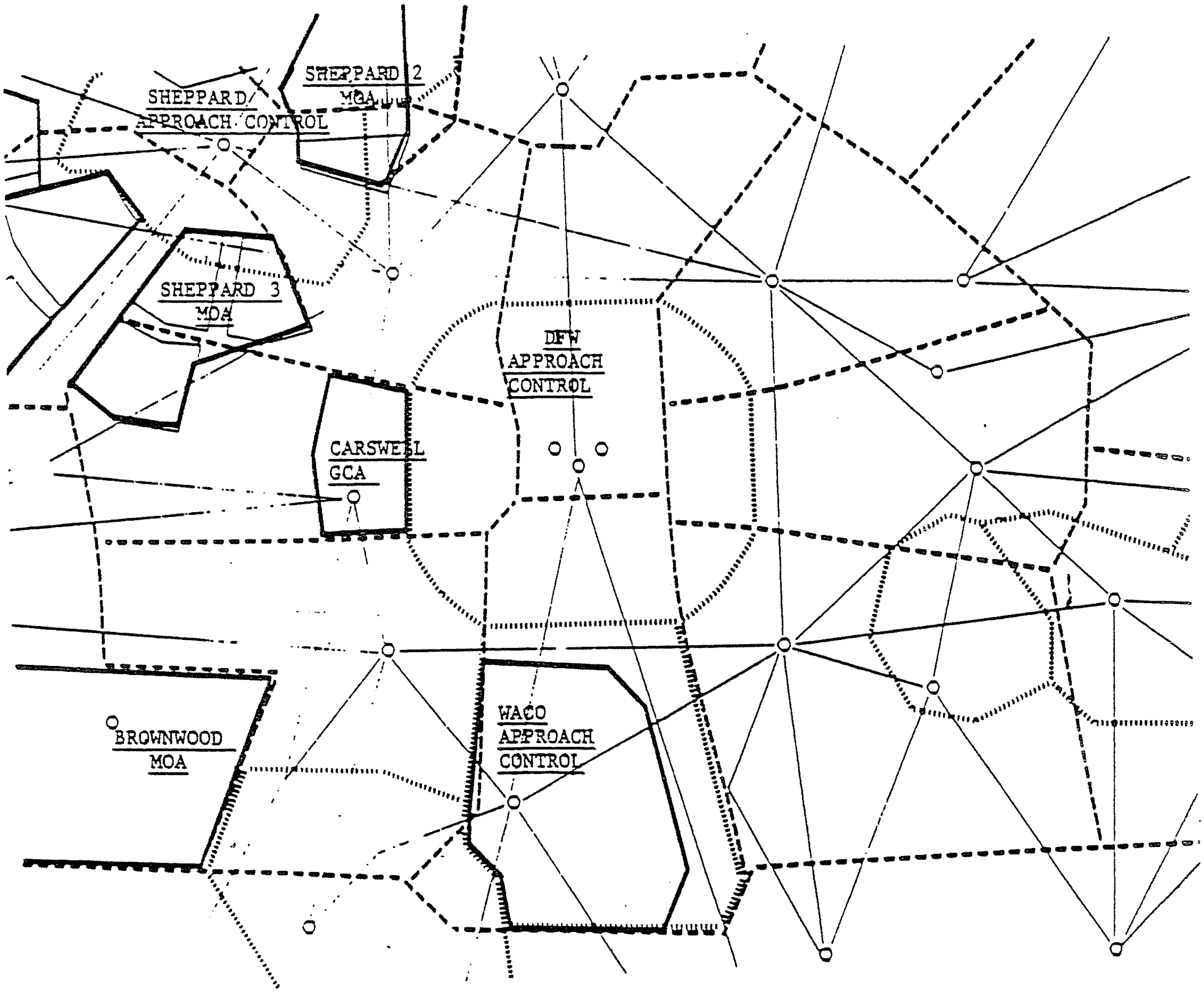
DFW PARALLEL ARRIVALS

ENROUTE



TURBOJET DEPARTURES - ENROUTE





SHEPPARD 2
MOA
SHEPPARD/
APPROACH CONTROL
SHEPPARD 3
MOA
DFW
APPROACH
CONTROL
CARSWELL
GCA
BROWNWOOD
MOA
WACO
APPROACH
CONTROL

DFW Projected Growth vs Capacity by 2005

Hourly Airport Capacity (VFR)	296
Number of peak hrs	9
Total Peak Hr Operations[1]	2,664
Average Total Daily Operations	3,806
Potential Growth based on capacity[2]	1,298,450
Projected total traffic for year 2005	1,146,327
Surplus Capacity	152,123

Notes:

1/This figure represents 70% of total daily capacity-based operations.

2/Assumes ceiling/visibility trends of:

At least 5,000'/5	*80%*
Between 3,500'/5 and 1,600'/5	*10%*
Below 1,000'/3	*10%*

TRACON MAXIMUM ARRIVAL CAPABILITY/2005

Maximum Arrival Capability	=	300
Projected Demand Year 2005	=	2,190,496
Average Daily Operations	=	6,001
Total Peak Hour Operations	=	4,200
Total Peak Hour Arrival Operations	=	2,100
Average Peak Hour Arrival Demand	=	233

USER BENEFITS

- Increased Capacity for the DFW Area

- Development of Separate Arrival and Departure System for High Performance Turboprops

- Redesign of DFW TCA

- Reduced User Delays

- Improved Safety

USER DELAY COST PROJECTION 1986-1995

DFW TRAFFIC	1986	Pct/Ttl
Total Ops	575,936	------
Air Carrier Ops	471,653	81.89%

1986 DFW DELAY EXPERIENCE (in Hours)

	Arrival	Departure
All Air Carrier	6,355	11,075
All DFW Users	7,760	13,520

Note: [1] These figures were developed based on the delay experience of one major airline at DFW.

1986 DELAY COST

	Arrival[1]	Departure[2]	Total
All Air Carrier	$11,477,130.00	$11,176,890.00	$22,654,020.00
All DFW Users	$14,014,560.00	$13,644,384.00	$27,658,944.00

Note: [1] Arrival delay cost based on $30.10 per minute.
[2] Departure delay cost based on $16.82 per minute.

DELAY COST PROJECTIONS[1] (All Users)

	Ttl Ops	Pct Inc°/1986	Cost
1986 Traffic	575,936	------	$27,658,944.00
1991 Traffic	863.483	49.93%	$41,469,055.00
1995 Traffic	924,637	60.55%	$44,406,435.00

Note: [1] Assumes no system improvements.

NON—IMPLEMENTATION IMPACT

- Increase in User Arrival and Departure Delays and Associated Costs

- Limits the Maximum Potential Growth of DFW Airport and Associated Industries

- Limits the Maximum Potential Growth of the North Tarrant Airport and Associated Industrial Development

- Limits the Maximum Potential Growth of the North Dallas Corridor

HUMAN RESOURCE CONSIDERATIONS

- **Air Traffic**

  -No PCS Moves Required
  -Increased Staffing
  DFW Approach Control: ________ 48
  Fort Worth ARTCC: ________ 48
  Traffic Management: ________ 3
  Waco Approach Control: ________ 1
  -Training for New Routes and Procedures
  -Improved Parking and Security for Employees

- **Airway Facilities**

  -No PCS Moves Required
  -Increased Staffing
  Electronic Specialist: ________ 2
  Environmental Specialist: ________ 1
  -Training for New Automation Equipment
  -Improve Parking and Security for Employees

SUMMARY OF DEFICIENCIES

Operational

- Airspace Procedures
- Automation
- Runways

Electronic Systems

- NAVAIDS
- Radar
- ARTS
- Displays
- Communications

Structure

- TRACON
- ETG
- Equipment Rooms
- Employee Parking

ASSUMPTIONS

Engineering Considerations to Meet Requirements

Equipment Availability

Equipment Cost Based on Last Contract Price

Land Considerations

Utilizing State-of-the-Art Technology (Cost vs Benefit)

NAS Plan

SYSTEM/FACILITY REQUIREMENTS

	Cost Estimates
NAVAIDS	$ 13.3M
Establish two VOR/DME's	
Establish four VORTAC's	
Establish Landing AIDS	
Other Requirements	
RADAR	5.5M
Establish one ASR-9	
Relocate one ASR-9	
Automation	
Terminal	26.8M
Establish ARTS-IIIE	
Establish Additional Position at Waco	
En Route	1.4M
Establish Additional Positions at Fort Worth ARTCC	
Communications	
Terminal	1.6M
Establish Additional Air/Ground Frequencies	
Relocation of Existing Air/Ground Frequencies	
Expand Capabilities of Existing Equipment	
Establish Additional Waco Air/Ground Frequency	
En Route	1.3M
Establish Additional Air/Ground Frequencies	
Relocation of Existing Air/Ground Frequencies	
Expand Capabilities of Existing Equipment	
Structure	15.9M
Expand TRACON Building	
New ATCT Structure	
Electronics	
Refurbish Existing TRACON Space	
Provide Parking Lot	
Total	65.8M

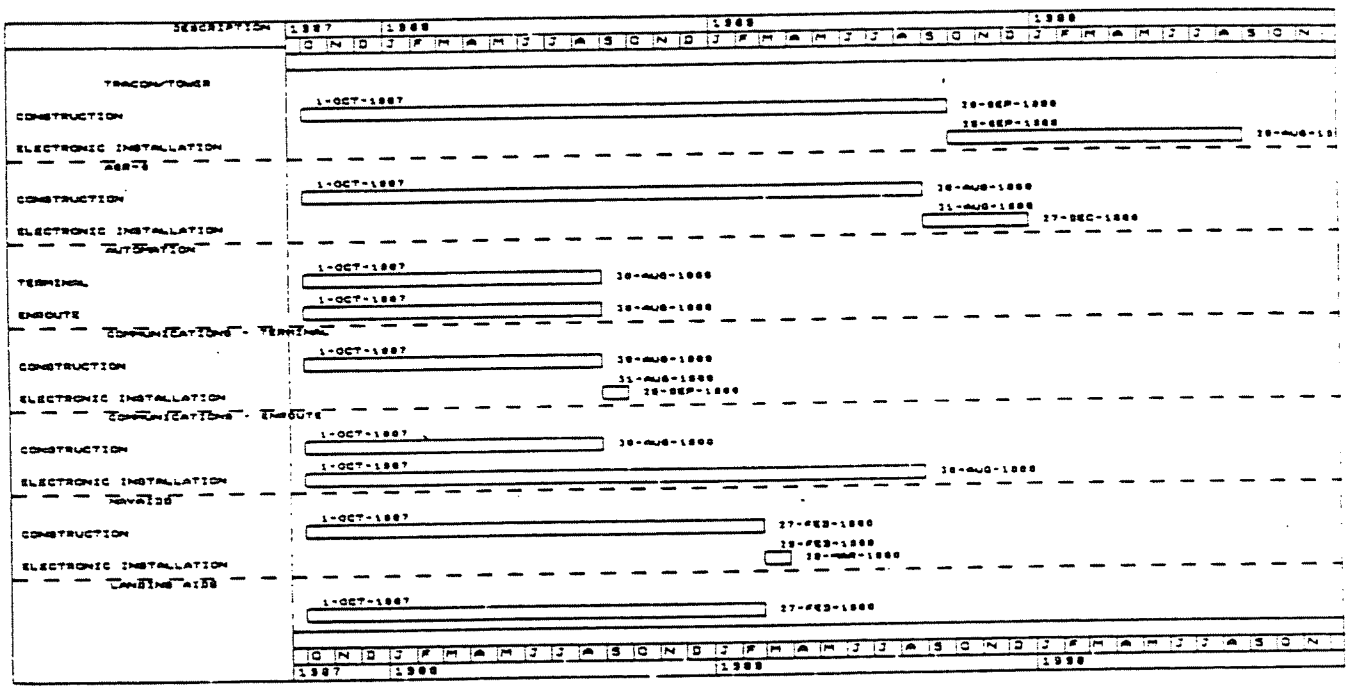
DFW Metroplex System Plan
Cost Estimate Summary

Project/Activity	Land	Const.	Elect.	Equip	Total
	Cost Per Program Area ($1,000)				
Navaids					
Est. 2 Doppler VOR/DME's	325	800	210	300	1,635
Est. 4 Cornerpost VORTAC's	155	1,600	380	380	2,515
Est. 4 ILS (GS, LOC, OM, MM)	1,600	700	600	1,200	4,100
Est. 4 MALSR's	0	960	0	1,600	2,560
Est. 4 RVR's	0	200	245	140	585
Est. 2 DME's (colocated with Love LOC's)	0	0	50	60	110
Est. 1 Compass Locator	*	250	30	15	295
Loop Cable	0	1,500	0	0	1,500
TOTALS					13,300
Radar					
Est. 1 ASR-9	*	1,500	250	2,000	3,750
Relocate 1 ASR-9	*	1,500	250	0	1,750
TOTALS					5,500
Automation					
Terminal					
Est. ARTS-IIIE	0	0	510	26,120	26,630
Est. Additional Waco Position	0	10	50	110	170
TOTALS					26,800
En Route					
Est. Additional Positions at ZFW ARTCC	0	50	180	1,170	1,400
TOTALS					1,400
Communications					
Terminal					
Est. Additional A/G Frequencies	*	440	120	250	810
Relocate Existing A/G Frequencies	0	0	60	0	60
Expand Capabilities of Existing Equip.	0	0	150	535	685
Est. Additional Waco A/G Frequencies	0	0	20	25	45
TOTALS					1,600
En Route					
Est. Additional A/G Frequencies	*	275	170	310	755
Relocate Existing A/G Frequencies	*	300	30	120	450
Expand Capabilities of Existing Equip.	0	0	15	80	95
TOTALS					1,300
Structure					
Expand TRACON Building	0	4,900	0	0	4,900
New ATCT Structure	0	7,000	0	0	7,000
Electronics	0	0	750	1,250	2,000
Refurbish Existing TRACON Space	0	1,000	0	0	1,000
Provide Parking Lot	0	1,000	0	0	1,000
TOTALS					15,900

*Possible Land Costs

D/FW METROPLEX SYSTEM PLAN SCHEDULE

(FOR PLANNING PURPOSES ONLY)



NAS Plan Projects

Microwave Landing System (MLS) - JHZ RWY	7/88
Airport Surveillance Radar (ASR-9) - QZB & ADS	11/88
Mode S (Beacon Replacement) - QZB & ADS	6/91
Airport Surface Detection Equipment (ASDE) - DFW	11/88
Terminal NEXRAD - DFW	1/91
Enhanced LLWAS - DFW	1/89
Flight Data Input/Ouput (FDIO) - DFW	9/88
Radio Control Equipment (RCE)	8/89
Voice Switching and Control System (VSCS) - ZFW	4/91
Weather Communications Processor (WCP) - ZFW	6/92
Central Weather Processor (CWP)	CY-95/96
D-Brite - DFW	5/89
Host Computer - ZFW	CY-93/94
Advanced Automation System (AAS) Initial Sector Suite Subsystem (ISSS)	CY-95/96
Tower Control Computer Complex (TCCC)	CY-95/96
Terminal Advanced Automation (TAA)	CY-95/96
Area Control Computer Complex (ACCC)	CY-95/96

D/FW METROPLEX IMPROVEMENTS

DFW AIRPORT DEVELOPMENT

Delta Airlines Terminal	30M	
American Airlines Terminal	765M	
Planned Airfield Development	102.4M	
Projected Airfield Development	40M	
Total		937.4M
NORTH TARRANT COUNTY AIRPORT		24M
SOUTH TARRANT COUNTY AIRPORT		25M
DALLAS LOVE FIELD		30M
D/FW METOPLEX PLAN		
Facilities and Equipment		65.8M

DALLAS-FORT WORTH INTERNATIONAL AIRPORT

° Current Terminal Construction		
Delta Air Lines Satellite		$30 M
° Planned Terminal Development		
American Airlines		
Option 1	$469 M	
Option 3	$726 M	
Option 5	$765 M*	$765 M
[*Only option supported by FAA]		
° Planned Airfield Development (Preapplication filed)		
°New Runway 16L/34R	$37.1 M	
°Taxiway System for Capacity & Efficiency	$35.0 M	
°Runway extensions	$21.3 M	
°Miscellaneous	$ 9.0 M	$102.4 M
° Additional Projected Development		
°New Runway 16R/34L	$40.0 M	$ 40.0 M
Total Estimated Cost of Development		$937.4 M

APPENDIX B

AIRCRAFT PROXIMITY INDEX DESCRIPTION

BACKGROUND

Air Traffic Control (ATC) simulation is an essential research tool for the improvement of the National Airspace System (NAS). Simulation can never offer all of the complexity and subtlety of the real world, with live radar, actual aircraft, full communications systems, and the rest of the ATC environment, but it can provide an intensive exercise of key portions of the system -- with controllers in the loop.

Proper use of simulation starts with carefully defining the questions to be answered and then developing a simulation environment which includes the features that could influence the process under study. The selection of a simulation environment, the development of scenarios, the choice of data to be recorded, and the method of analysis are part science, part art.

An important benefit of simulation is that it permits the exploration of systems, equipment failures, and human errors that would be too dangerous to study with aircraft, or that occur so rarely in the system that they cannot be fully understood and evaluated. A current example of this use has to do with the introduction of blunders in parallel runway instrument approaches. (A blunder is defined as an unexpected turn towards an adjacent approach by an aircraft already established on the instrument landing system (ILS)).

The introduction of large numbers of system errors is a useful way to study safety, but the analysis of the outcomes of these incidents is not always simple or clear cut.

SAFETY EVALUATION

CONFLICTS.

The occurrence of a conflict in normal ATC operations is considered prima facie evidence of a human or system error. Identifying (and counting) conflicts under a variety of normal conditions is one way to expose a system problem.

A conflict is defined as the absence of safe separation between two aircraft flying instrument flight rules (IFR). At its simplest, safe separation requires: (a) the aircraft must be laterally separated by 3 or 5 nautical miles (nmi), depending on distance from the radar, (b) vertical separation by 1,000 or 2,000 feet, depending on altitude or flight level, or (c) that both aircraft are established on ILS localizers.

There are refinements of the above rules that take into consideration the fact that one aircraft may be crossing behind another, or that an aircraft has begun to climb or descend from a previous altitude clearance. There are special "wakes and vortices" restrictions for aircraft in trail behind heavy aircraft.

Since actual conflicts are rare, every event leading up to them and all the information available on the onset and resolution is carefully analyzed. The emphasis is on the intensive investigation of the particular event.

In scientific investigation, the intensive study of a single individual or a particular event is called the "idiographic" approach. This is often contrasted with the "nomothetic" approach: the study of a phenomenon or class of events by looking at large numbers of examples and attempting to draw general conclusions through the application of statistics.

The idiographic approach is mandatory for accident or incident investigation where the goal is to get as much information as possible about a unique event in order to prevent future occurrences.

In a simulation experiment, where the goal is to make a comparison between two or more systems (two vs three or four runways, 4300- vs 3000-foot runway spacing, etc.) and to generalize beyond the simulation environment, the nomothetic approach is most appropriate. This means generating a large number of events and statistically analyzing the outcomes with respect to the system differences.

There is much to be gained by studying the individual conflicts in a simulation as an aid to understanding the kinds of problems that occur and to generate hypotheses about how a system might be improved for subsequent testing. But the evaluation of the systems under test requires the use of all of the valid data, analyzed in as objective a manner as possible. Valid data in this context means that it was collected under the plan and rules of the simulation and was not an artifact, such as a malfunction of the simulation computer or distraction by visitors.

SLANT RANGE.

If it is important to go beyond the counting of conflicts - measurement of the distance between the conflicting aircraft pair is required. The most obvious measure is slant range separation: the length of an imaginary line stretched between the centers of each aircraft. Over the course of the incident that distance will vary, but the shortest distance observed is one indication of the seriousness or danger of the conflict.

The problem with slant range is that it ignores the basic definition of a conflict and is insensitive to the different standards that are set for horizontal and vertical separation. A slant range distance of 1,100 feet might refer to 1,000 feet of vertical separation, which is normally perfectly safe, to less than 0.2 nmi of horizontal miss distance, which would be considered by most people to be a very serious conflict.

Slant range, per se, is too ambiguous a metric to have any real analytical value.

AIRCRAFT PROXIMITY INDEX (API).

The need exists for a single value that reflects the relative seriousness or danger. The emphasis here is on "relative," since with the nomothetic or statistical approach, an absolute judgment of dangerous or safe is useful, but not sensitive enough. The requirement is to look at the patterns of the data for the different experimental conditions and determine whether one pattern indicates more, less, or the same degree of safety as another.

Such an index should have to have certain properties.

1. It should consider horizontal and vertical distances separately, since the ATC system gives 18 times the importance to vertical separation (1,000 ft vs 3 nmi).

2. It should increase in value as danger increases, and go to zero when there is no risk, since the danger in the safe system is essentially indeterminate.

3. It should have a maximum value for the worst case (collision), so that users of the index can grasp its significance without tables or additional calculations.

4. It should make the horizontal and vertical risk or danger independent factors, so that if either is zero, i.e., safe, their product will be zero.

5. It should be a nonlinear function, giving additional weight to serious violations, since they are of more concern than a number of minor infractions.

The API is designed to meet these criteria. It assigns a weight or value to each conflict, depending on vertical and lateral separation. API facilitates the identification of the more serious (potentially dangerous) conflictions in a data base where many conflictions are present. One hundred has been chosen, somewhat arbitrarily, for the maximum value of the API.

APPROACH.

During a simulation API can be computed whenever a conflict exists. For convenience, this is taken to be when two aircraft have less than 1,000 feet of vertical separation and less than 3.0 miles of lateral separation. It is computed once per second during the conflict. The API of the conflict is the largest value obtained.

API considers vertical and horizontal distances separately, then combines the two in a manner than gives them equal weight; equal in the sense that a loss of half the required 3.0 nmi horizontal separation has the same effect as the loss of half the required 1000 feet of vertical separation.

COMPUTATION.

The API ranges from 100 for a midair collision to 0 for the virtual absence of a technical confliction. A linear decrease in distance between the aircraft, either vertically or laterally, increases the API by the power of 2.

Computation is as follows:

D_V = vertical distance between aircraft (a/c) (in feet)
D_H = horizontal distance (nmi (6,076'))
API = $(1,000-D_V)^2*(3-D_H)^2/(90,000)$

To simplify its use, API is rounded off to the nearest integer, i.e.,

API =INT$((1,000-D_V)^2*(3-D_H)^2/(90,000)+.5)$

The rounding process zeros API's less than 0.5. This includes distances closer than 2 nmi and 800 feet. The contour plot in figure A-1 demonstrates the cutoff for API = 1.

See tables A-1 and A-2 for typical values of API at a variety of distances.

Figure A-2 is a three-dimensional plot showing the relationship between API and vertical and horizontal separation graphically. Figure A-3 shows the same information in a slightly different way. Anything outside the contour at the base is "0." In figure A-4 a contour plot of API for horizontal and vertical distances from 0 to 500 feet is shown, with 300-foot and 500-foot slant range distances superimposed.

DISCUSSION

The index is not intended as a measure of acceptable risk, but it meets the need to look at aircraft safety in a more comprehensive way than simply counting conflictions or counting the number of aircraft that came closer than 200 feet, or some other arbitrary value.

It should be used to compare conflicts in similar environments i.e., an API of 70 in en route airspace with speeds of 600 knots is not necessarily the same concern as a 70 in highly structured terminal airspace with speeds under 250 knots.

Since the API is computed every second, it may be useful to examine its dynamics over time as a means of understanding the control process.

TABLE A-1. TYPICAL VALUES

Vertical Distance (D_V)	Horizontal Distance in Nautical Miles (1 nmi = 6076') (D_H) in Feet																
	3	2.5	2.0	1.5	1.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0.05	0.01	0
1000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
900	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1
800	0	0	0	1	2	2	2	2	3	3	3	3	3	4	4	4	4
700	0	0	1	2	4	4	5	5	6	6	7	7	8	8	9	9	9
600	0	0	2	4	7	8	9	9	10	11	12	13	14	15	15	16	16
500	0	1	3	6	11	12	13	15	16	17	19	20	22	23	24	25	25
400	0	1	4	9	16	18	19	21	23	25	27	29	31	34	35	36	36
300	0	1	5	12	22	24	26	29	31	34	37	40	43	46	47	49	49
200	0	2	7	16	28	31	34	38	41	44	48	52	56	60	62	64	64
100	0	2	9	20	36	40	44	48	52	56	61	66	71	76	78	80	81
-0-	0	3	11	25	44	49	54	59	64	69	75	81	87	93	97	99	100

TABLE A-2. ADDITIONAL VALUES

D_H	D_V	API
3.0	1000	0
3.0	0	0
0	1000	0
2.0	667	1
2.0	500	3
2.0	333	5
2.0	250	6
2.0	100	9
2.0	0	11
1.5	667	3
1.5	500	6
1.5	333	11
1.5	250	14
1.5	100	20
1.5	0	25

D_H	D_V	API
1.0	667	5
1.0	500	11
1.0	333	20
1.0	250	25
1.0	100	36
1.0	0	44
0.5	667	8
0.5	500	17
0.5	250	39
0.5	100	56
0.5	0	69
0.1	667	10
0.1	500	23
0.1	250	53
0.1	100	76
0.1	0	93

D_H	D_V	API
0.05	667	11
0.05	500	24
0.05	333	43
0.05	250	54
0.05	100	78
0.05	0	97
0.01	667	11
0.01	500	25
0.01	333	44
0.01	250	56
0.01	100	80
0.01	0	99
0	667	11
0	500	25
0	333	44
0	250	56
0	100	81

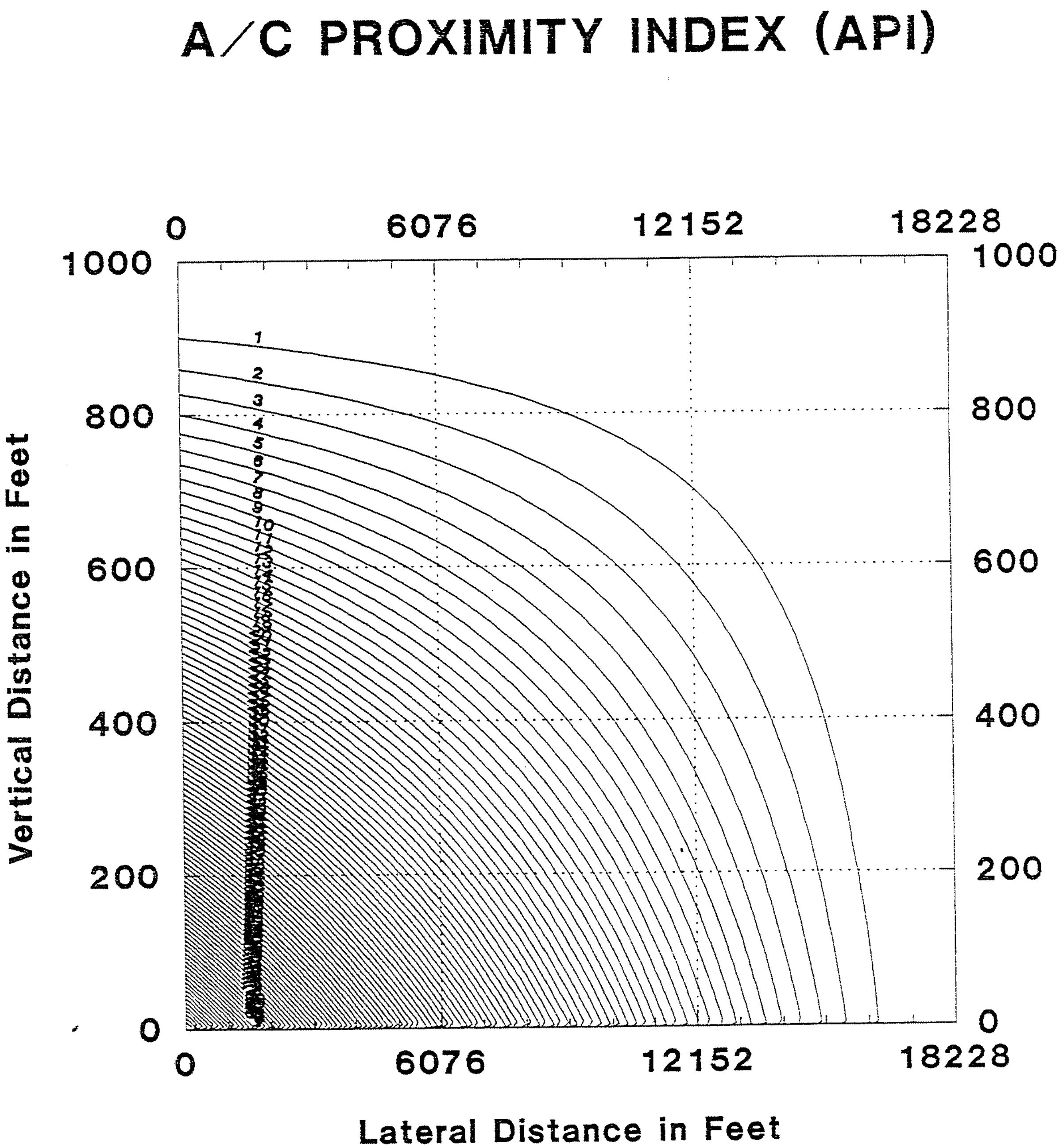


FIGURE A-1. CONTOUR PLOT

This is a contour plot of API showing the values of API for the horizontal separations of 0 to 3 nmi, and vertical separation of 0 to 1,000 feet. Values less than API = 0.5 round to zero. This includes a/c separated by as little 1.6 nm horizontally and 850 feet vertically.

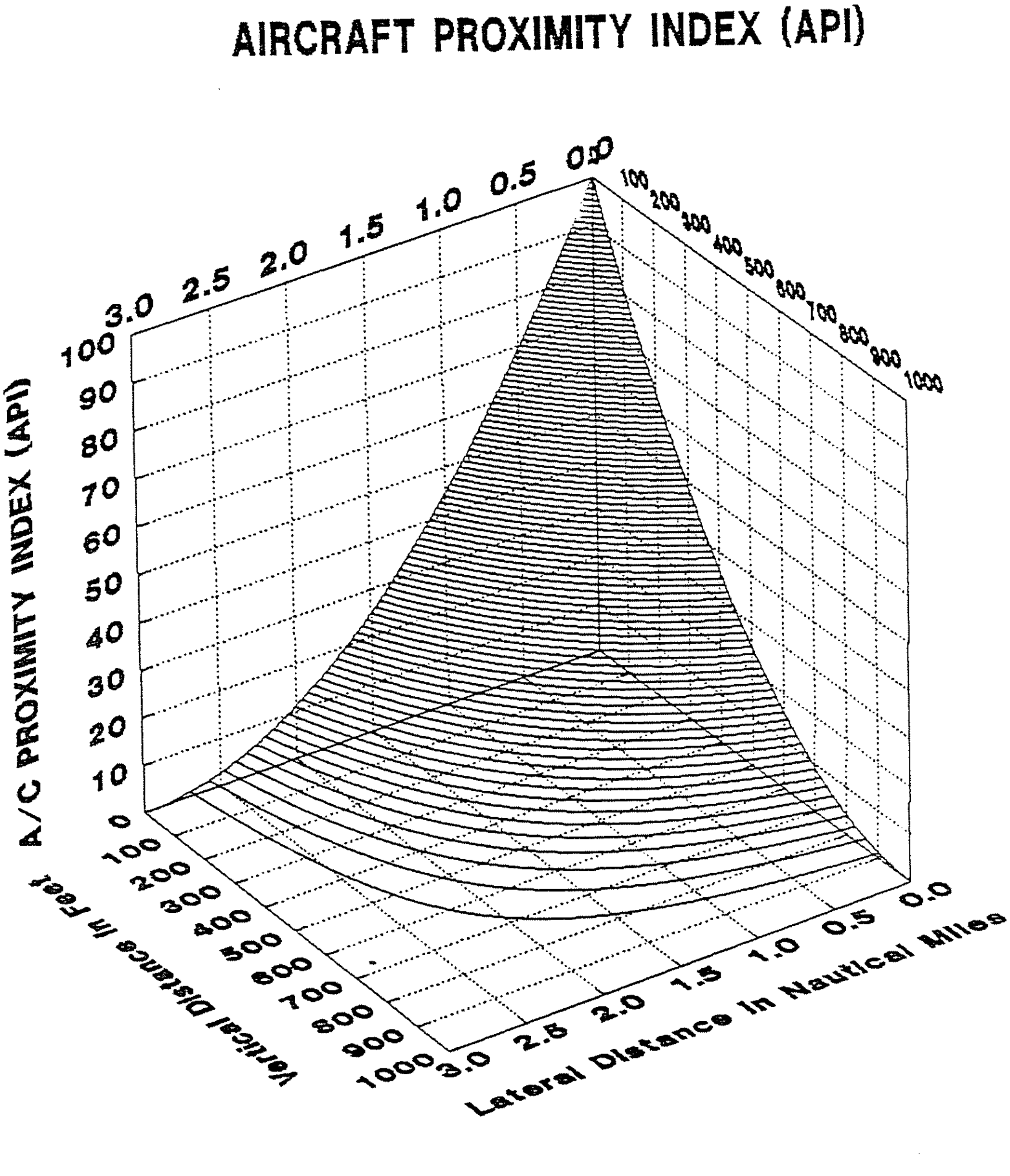


FIGURE A-2. THREE-DIMENSIONAL CONTOUR PLOT

Three-dimensional contour plot of API, for horizontal separations of 0 to 3 nmi, and vertical separations of 0 to 1,000 feet.

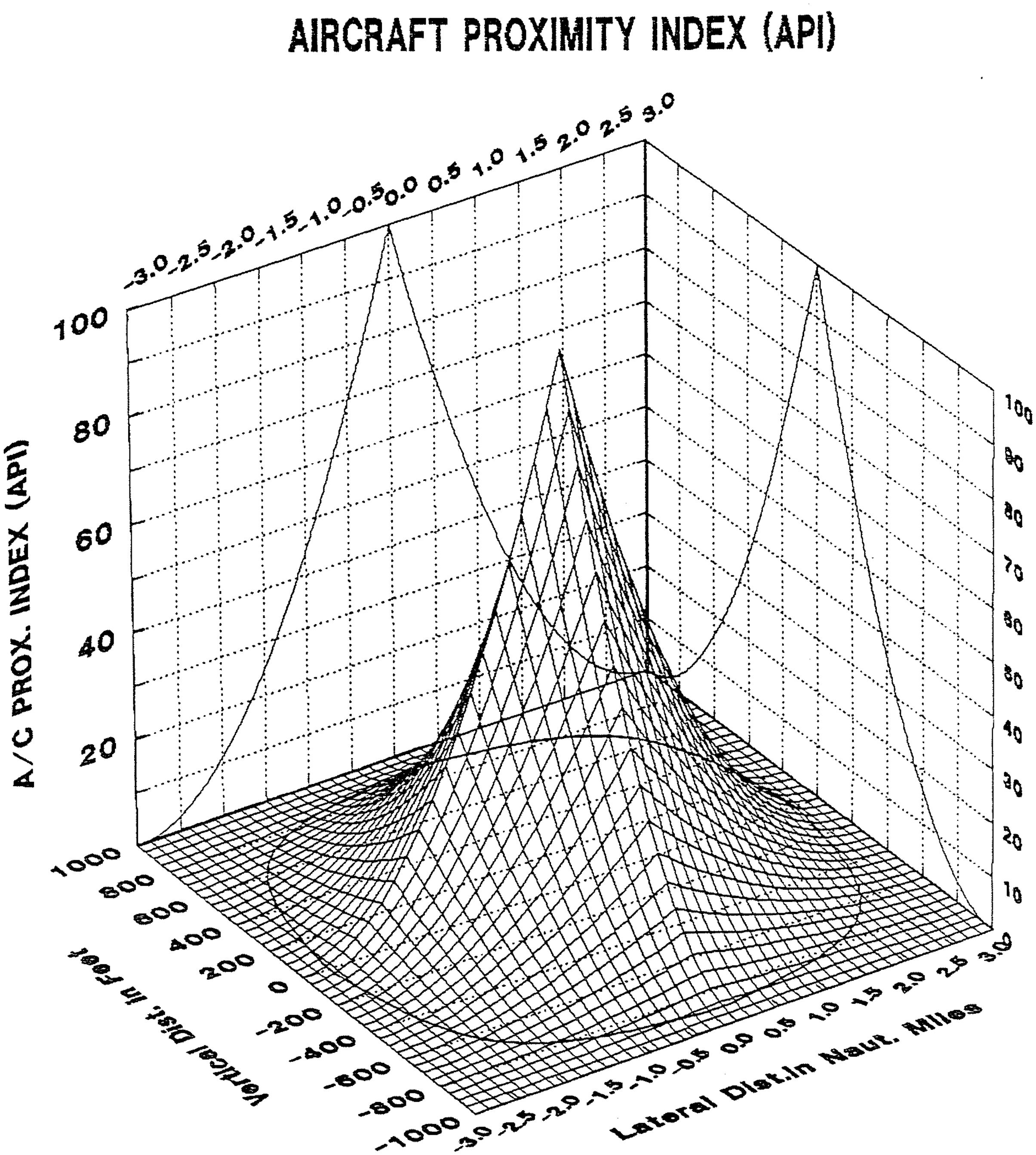


FIGURE A-3. THREE-DIMENSIONAL CONTOUR PLOT

Left vertical plane shows API vs horizontal distance with vertical distance = 0. Right vertical plane shows API vs vertical separation with horizontal distance = 0. Right vertical plan shows API vs vertical separation with horizontal distance = 0.

Plot may be interpreted by considering one a/c at the center of the base plane, while the height of the figure shows the API for another a/c anywhere else on the base plane.

The contour on the base plane shows the boundary between API = 0 and API = 1.

A/C PROXIMITY INDEX (API)

API VALUES FOR SLANT RANGES OF 300 AND 500 FEET

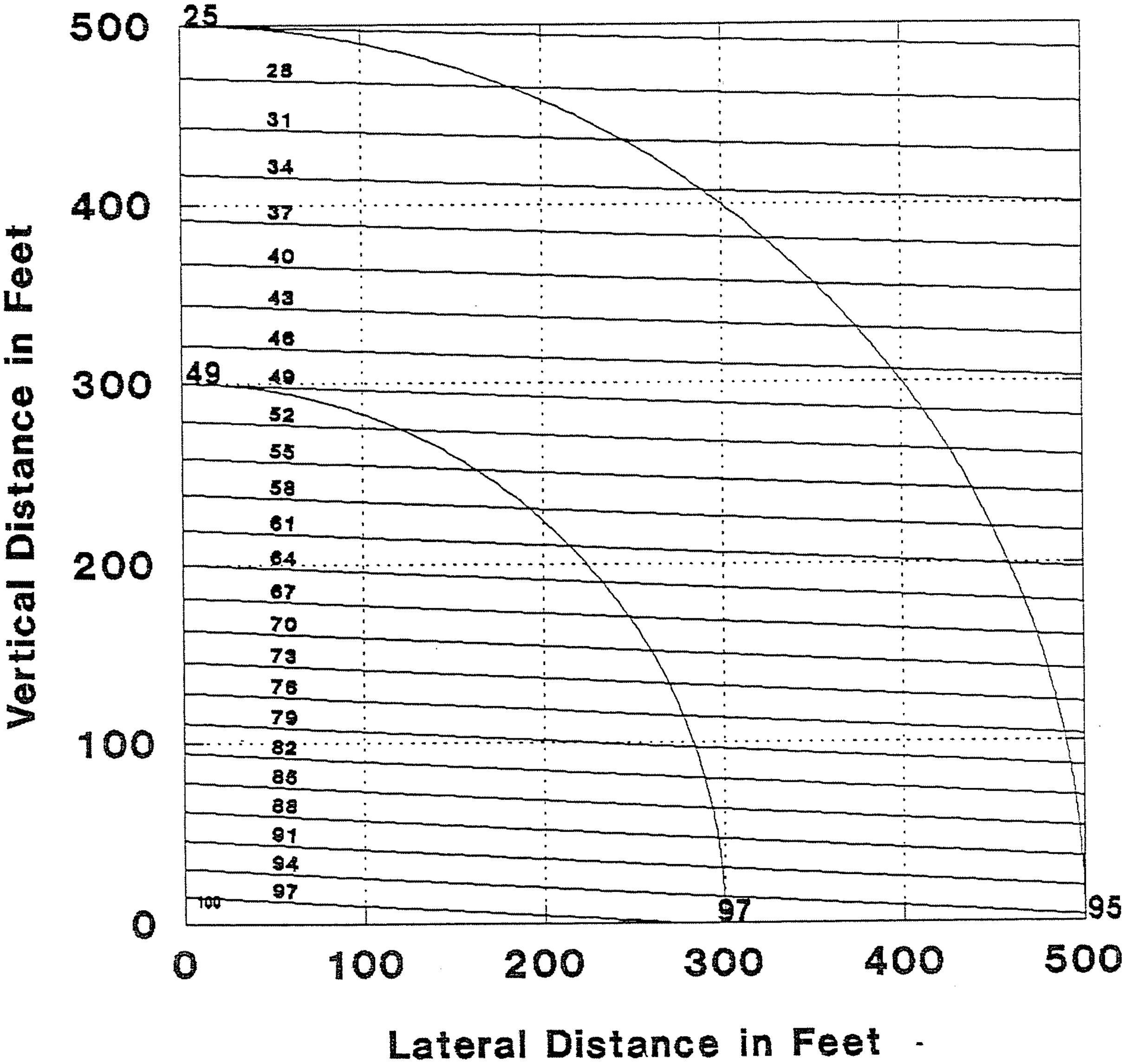


FIGURE A-4. CONTOUR PLOT OF API FOR HORIZONTAL AND VERTICAL DISTANCES OF 0 TO 500 FEET, SHOWING SLANT RANGE CONTOURS OF 300 AND 500 FEET

This plot shows the API values (the small numbers, inside the square running from 25 at the top to 100 at the bottom) for equal API contours (the slightly sloping horizontal lines) for horizontal and vertical distances of 0 to 500 feet. API values range from 25 (500 feet vertical, 0 horizontal separation) to 100 (0/0).

The 500-foot slant range contour has API values ranging from 25 to 95, depending on amount of vertical component. The 300-foot slant range contour runs from API = 49 to 97. Using API as a criterion, 500-foot slant range can be more dangerous than 300-foot.

APPENDIX C

PROJECTED CLOSEST POINT OF APPROACH (PCPA) COMPUTATIONS

CALCULATION OF PCPA AND TIME-TO-PCPA

Consider two aircraft (A and B) having X, Y, and Z spatial positions (coordinates) at Time i; that is:

Position of A/C_A at $Time_i$ = $X_{A_i}, Y_{A_i}, Z_{A_i}$, and (1.1)

Position of A/C_B at $Time_i$ = $X_{B_i}, Y_{B_i}, Z_{B_i}$, and (1.2)

The same A/C also have X, Y, and Z locations at Time i + 1:

Position of $A/C_A = X_{A_{i+1}}, Y_{A_{i+1}}, Z_{A_{i+1}}$ at Time = i +1. (2.1)

Position of $A/C_B = X_{B_{i+1}}, Y_{B_{i+1}}, Z_{B_{i+1}}$ at Time = i +1. (2.2)

The change in locations of the two aircraft between $Time_i$ and i +1 will be (subtracting eqs. 1.1 from 2.1 and 1.2 from 2.2):

$$\Delta X_A = X_{A_{i+1}} - X_{A_i};\ \Delta Y_A = Y_{A_{i+1}} - Y_{A_i};\ \Delta Z_A = Z_{A_{i+1}} - Z_{A_i} \quad (3.1)$$

$$\Delta X_B = X_{B_{i+1}} - X_{B_i};\ \Delta Y_B = Y_{B_{i+1}} - Y_{B_i};\ \Delta Z_B = Z_{B_{i+1}} - Z_{B_i} \quad (3.2)$$

The slant range (SR) between A/C_A and A/C_B at $Time_i$ =

$$SR_{AB_i} = \left[\left(X_{A_i} - X_{B_i}\right)^2 + \left(Y_{A_i} - Y_{B_i}\right)^2 + \left(Z_{A_i} - Z_{B_i}\right)^2\right]^{.5} \quad (4.0)$$

Assuming that both A/C continue along the vectors defined by their locations at $Time_i$ and $Time_{i+1}$, then SR at Time "s" later will be found by

$$SR_{AB_{i+s}} = \Big[\left(\left(X_{A_i} + s\cdot\Delta X_A\right) - \left(X_{B_i} + s\cdot\Delta X_B\right)\right)^2 + \left(\left(Y_{A_i} + s\cdot\Delta Y_A\right) - \left(Y_{B_i} + s\cdot\Delta B_i\right)\right)^2 + \left(\left(Z_{A_i} + s\cdot\Delta Z_A\right) - \left(Z_{B_i} + s\cdot\Delta Z_B\right)\right)^2\Big]^{.5} \quad (5.0)$$

$$= \left[\left(\left(X_{A_i} - X_{B_i} \right) + s \left(\Delta X_A - \Delta X_B \right) \right)^2 \right.$$

$$+ \left(\left(Y_{A_i} - Y_{B_i} \right) + s \left(\Delta Y_A - \Delta Y_B \right) \right)^2 \tag{5.1}$$

$$\left. + \left(\left(Z_{A_i} - Z_{B_i} \right) + s \left(\Delta Z_A - \Delta Z_B \right) \right)^2 \right]^{.5}$$

$$= \left[\left(X_{A_i} - X_{B_i} \right)^2 + s^2 \left(\Delta X_A - \Delta X_B \right)^2 + 2s \left(X_{A_i} - X_{B_i} \right) \left(\Delta X_A - \Delta X_B \right) \right.$$

$$+ \left(Y_{A_i} - Y_{B_i} \right)^2 + s^2 \left(\Delta Y_A - \Delta Y_B \right)^2 + 2s \left(Y_{A_i} - Y_{B_i} \right) \left(\Delta Y_A - \Delta Y_B \right)$$

$$\left. + \left(Z_{A_i} - Z_{B_i} \right)^2 + s^2 \left(\Delta Z_A - \Delta Z_B \right)^2 + 2s \left(Z_{A_i} - Z_{B_i} \right) \left(\Delta Z_A - \Delta Z_B \right) \right]^{.5}$$

$$= \left[SR_{AB_i}{}^2 + s^2 \left(\left(\Delta X_A - \Delta X_B \right)^2 + \left(\Delta Y_A - \Delta Y_B \right)^2 + \left(\Delta Z_A - \Delta Z_B \right)^2 \right) \right.$$

$$+ 2s \left(\left(X_{A_i} - X_{B_i} \right) \left(\Delta X_A - \Delta X_B \right) + \left(Y_{A_i} - Y_{B_i} \right) \left(\Delta Y_A - \Delta Y_B \right) \right.$$

$$\left. \left. + \left(Z_{A_i} - Z_{B_i} \right) \left(\Delta Z_A - \Delta Z_B \right) \right) \right]^{.5}$$

Since the X, Y, Z and Δ_X, Δ_Y, Δ_Z values are known for each aircraft, we can let:

$$C_1 = \left[\left(\Delta X_A - \Delta X_B \right)^2 + \left(\Delta Y_A - \Delta Y_B \right)^2 + \left(\Delta Z_A - \Delta Z_B \right)^2 \right] \tag{6.1}$$

and

$$C_2 = \left[\left(X_{A_i} - X_{B_i} \right) \left(\Delta X_A - \Delta X_B \right) + \left(Y_{A_i} - Y_{B_i} \right) \left(\Delta Y_A - \Delta Y_B \right) + \left(Z_{A_i} - Z_{B_i} \right) \left(\Delta Z_A - \Delta Z_A \right) \right] \tag{6.2}$$

Substituting these values into the previous equation

$$SR^2{}_{AB_{i+s}} = SR^2{}_{AB_i} + s^2C_1 + 2s\,C_2 \tag{7.0}$$

Differentiating $SR_{AB_{i+s}}$ with respect to s, we obtain

$$\frac{SR^2{}_{AB_{i+s}}}{d_s} = 2C_1\,s + 2C_2 \tag{7.1}$$

To find the minima, we set the left side of Eq. (7.1) to zero and solve for "s".

$$o = 2C_1s + 2C_2$$

$$s = \frac{-C_2}{C_1} \tag{8.0}$$

Solving for "s", we can now solve for $SR^2{}_{AB_{i+s}}$ using Eq. (7.0) and, taking the square root we obtain the projected slant range at $Time_{i+s} = (SR^2{}_{AB_{i+s}})$.

Thus, for any two consecutive (and simultaneous) views of any two aircraft, their positional data (X, Y, and Z) can be used to predict both the slant range at PCPA and the time to reach the current projection of PCPA. It should be noted that if "s" is negative, the aircraft are diverging and projecting of PCPA becomes the current slant range. If "s" is zero, (which occurs when C_2= 0), the A/C are on parallel courses at identical speeds and the predicted CPA will also equal the current slant range.

Finally, with regard to the prediction of PCPA, the X, Y, and Z coordinates for each aircraft can be predicted for $Time_{i+s}$;

$$\dot{X}_{A_{i+s}} = X_{A_i} + s\Delta X_A \,;\; \dot{Y}_{A_{i+s}} = Y_{A_i} + s\Delta Y_A \,;\; \dot{Z}_{A_{i+s}} = Z_{A_i} + s\Delta Z_A$$

$$\dot{X}_{B_{i+s}} = X_{B_i} + s\Delta X_B \,;\; \dot{Y}_{B_{i+s}} = Y_{B_i} + s\Delta Y_B \,;\; \dot{Z}_{B_{i+s}} = Z_{B_i} + s\Delta Z_B$$

These values can be used to compute the PAPI value for the PCPA projected for $Time_{i+s}$.