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CHICAGO AREA AIR TRAFFIC FLOW AND DELAY ANALYSIS
SUMMARY REPORT
VOLUME I

COOK RESEARCH LABORATORIES
COOK TECHNOLOGICAL CENTER
MORTON GROVE, ILLINOIS

A Division of
Cook Electric Company
Chicago

VOLUME I

SUMMARY REPORT

CHICAGO AREA TRAFFIC FLOW AND DELAY ANALYSIS

by

Cook Research Laboratories

Cook Technological Center

Morton Grove, Illinois

prepared for the

Operations Analysis Division

Bureau of Research and Development

Federal Aviation Agency

under

Contract FAA/BRD - 42

September 15, 1959

ORGANIZATION OF THIS REPORT

This report is organized in three Volumes

Volume I is the summary report on this project It summarizes the entire program and contains conclusions and recommendations for future action

Volume II contains detailed supporting analyses and descriptive information prepared in the course of the project

Volume III, bound in separable sections, contains the basic tabular data which were the source material for the analysis

RESPONSIBILITY

The Cook Research Laboratories, and not the United States Government, are responsible for the accuracy, views, and facts presented in this report

This program was conducted by the Cook Research Laboratories under the direction of Dr J R. Downing, Director, and Mr Alton D. Anderson, Associate Director The Automatic Control Systems Section of these Laboratories, under the direction of Mr W Grant Leslie and Mr Thomas J Dunsheath, administrative and technical heads, respectively, were assigned the responsibility for the completion of this project Mr W Leysath was Project Engineer and directed the over-all data collection and analysis tasks Mr J Cronin, while primarily responsible for the analysis of weather data, made significant contributions to all aspects of the project

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Thelma A. Dunbar Editor
Report Section

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In all cases, we appreciate the complete cooperation we have received

While it is not possible to acknowledge our thanks to all individuals whose cooperation materially assisted this program, the following were of continuous assistance, and the merits of this program are to a large measure due to their aid

Mr Ralph Hottman, Air Traffic Supervisor, Chicago
Mr Raymond Belanger, Chief, Chicago Air Route Traffic Control Center
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Mr George Niles, Chief, O'Hare Tower
Mr J R Fulks, Meteorologist in Charge, Chicago Forecast Center

Throughout the program, the guidance of Mr Norman R Smith, Project Director for the Operations Analysis Division of the Bureau of Research and Development of the Federal Aviation Agency, has been of inestimable value, and we are deeply appreciative of his constant advice, encouragement, and direction

FOREWORD

The past decade has seen the volume of air traffic in the continental United States grow at a more rapid rate than the capacity of the air traffic control system Forecasts of the air traffic through 1975 predict that the volume of air traffic will increase at an accelerated rate Currently, the volume of air traffic exceeds the system capacity in some areas under adverse weather or other operational conditions Consequently, deficiencies of the present air traffic control system are limiting the efficient use of the available air space

In recognition of the fact the air space is a vital natural resource, Congress has established the Federal Aviation Agency Although the responsibilities of this agency are many and varied, one of its most important objectives is the development of an advanced air traffic control system to achieve a more efficient utilization of the air space These objectives form the broad responsibilities of the Bureau of Research and Development of the Federal Aviation Agency

The program of the Bureau of Research and Development of the Federal Aviation Agency provides for the attainment of these objectives through the orderly steps of Operational Analysis, System Analysis, System Experimentation, and Equipment Development The program has two broad goals (1) the improvement of the air traffic control system through the application of existing state-of-the-art technology by the year 1963, and (2) advanced research and development to achieve a superior air traffic control system for the period beyond 1963

To support such a program the acquisition and analysis of data which describe the current air traffic control system are of vital importance

The broad objectives of such a project are to analyze the nature, volume, and flow of air traffic and the distribution, magnitude, and cause of delays, both in the air and on the ground Accordingly, the Operations Analysis Division has instituted a number of such data collection and analysis programs A study of the New York area has been completed. Concurrently, a series of study programs for the Chicago, San Francisco, and Atlanta areas was conducted This report presents the analysis for the Chicago area as performed by Cook Research Laboratories

VOLUME I

TABLE OF CONTENTS

TABLE OF CONTENTS (cont'd)

LIST OF ILLUSTRATIONS

LIST OF TABLES

SUMMARY

During the months of February, March, and April, 1959, the Cook Research Laboratories collected data for the purpose of performing an analysis of the air traffic flow and air traffic delays in the Chicago Area The objectives of this analysis were to determine the nature, volume, and flow of air traffic and the distribution magnitude, and cause of delays, both in the air and on the ground

For selected days during this period, data included flight progress strips, radar photographs, on-the-spot observations of ground movements, magnetic tape recordings of communication channels, weather records, and pilot questionnaires

The following observations are made as a result of the analyses performed on the collected data

(1) Observations pertaining to IFR traffic operating under the control of the Chicago Air Route Traffic Control Center

(a) The air traffic is composed predominantly of commercial aircraft

(b) A majority of the traffic is inbound to or outbound from the Chicago terminal area

(c) The essential characteristic of the air traffic is a radial flow into and out of the Chicago Terminal Area, predominantly in the east, west, and south sectors (see Figures

1 and 2)

(d) The airways structure, except in the immediate vicinity of Chicago,seems well designed to handle this traffic flow

(e) The major portion of aircraft which are inbound to or outbound from the Chicago Terminal Area operate through Midway Airport

(f) Over 90% of the delays in the Chicago Area are associated with inbound aircraft which are held in the approach patterns designed for Midway Airport Other delays are relatively infrequent

(2) Observations pertaining to aircraft which were delayed while awaiting clearance to land at Midway

(a) During periods of prolonged adverse weather conditions when the Midway Approach Radar is operative, approach transition delays (per delayed aircraft) average 16 minutes duration (Table 4 Volume I)

(b) During similar periods of prolonged adverse weather conditions when Midway Approach Radar is inoperative for significant periods, approach transition delays (per delayed aircraft) average 35 minutes duration (Table 4 Volume I)

(c) The length of the forecast delay into Midway is a primary reason for aircraft diversions to alternate destinations

(d) The total cost of these delays and diversions to the operators of aircraft when the radar is operative and when it is inoperative

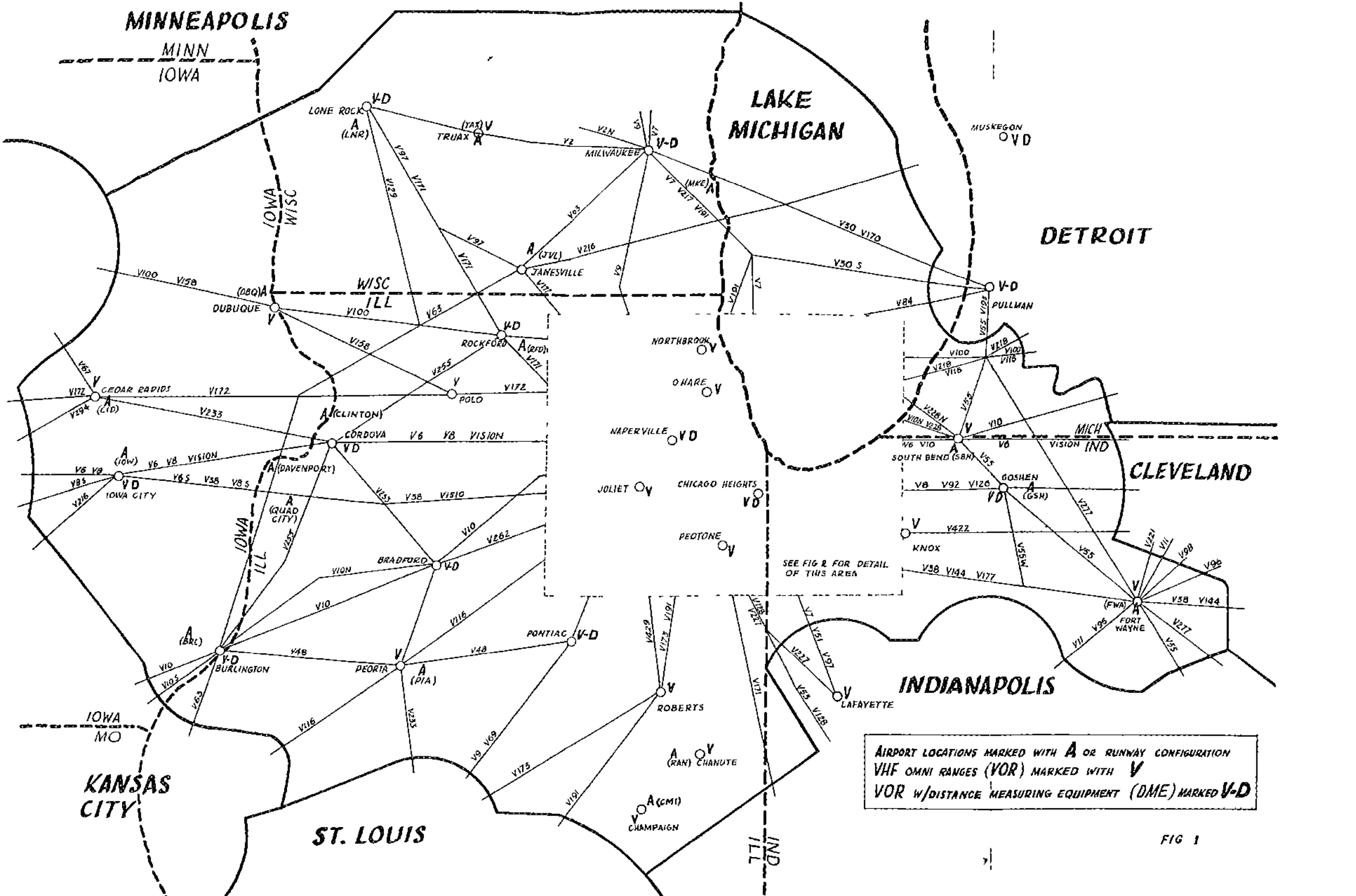
MINNEAPOLIS
MINN
IOWA
LAKE MICHIGAN
DETROIT
CLEVELAND
INDIANAPOLIS
ST. LOUIS
KANSAS CITY
IOWA WISC
WISC ILL
IOWA ILL
IOWA MO
MICH IND
ILL IND
LONE ROCK
TRUAX
MILWAUKEE
MUSKEGON
JANESVILLE
DUBUQUE
ROCKFORD
PULLMAN
NORTHBROOK
O HARE
CEDAR RAPIDS
POLO
CLINTON
CORDOVA
DAVENPORT
IOWA CITY
QUAD CITY
NAPERVILLE
JOLIET
CHICAGO HEIGHTS
PEOTONE
SOUTH BEND
GOSHEN
KNOX
FORT WAYNE
BRADFORD
BURLINGTON
PEORIA
PONTIAC
ROBERTS
LAFAYETTE
CHANUTE
CHAMPAIGN
SEE FIG 2 FOR DETAIL OF THIS AREA
AIRPORT LOCATIONS MARKED WITH A OR RUNWAY CONFIGURATION
VHF OMNI RANGES (VOR) MARKED WITH V
VOR W/DISTANCE MEASURING EQUIPMENT (DME) MARKED V-D

FIG 1

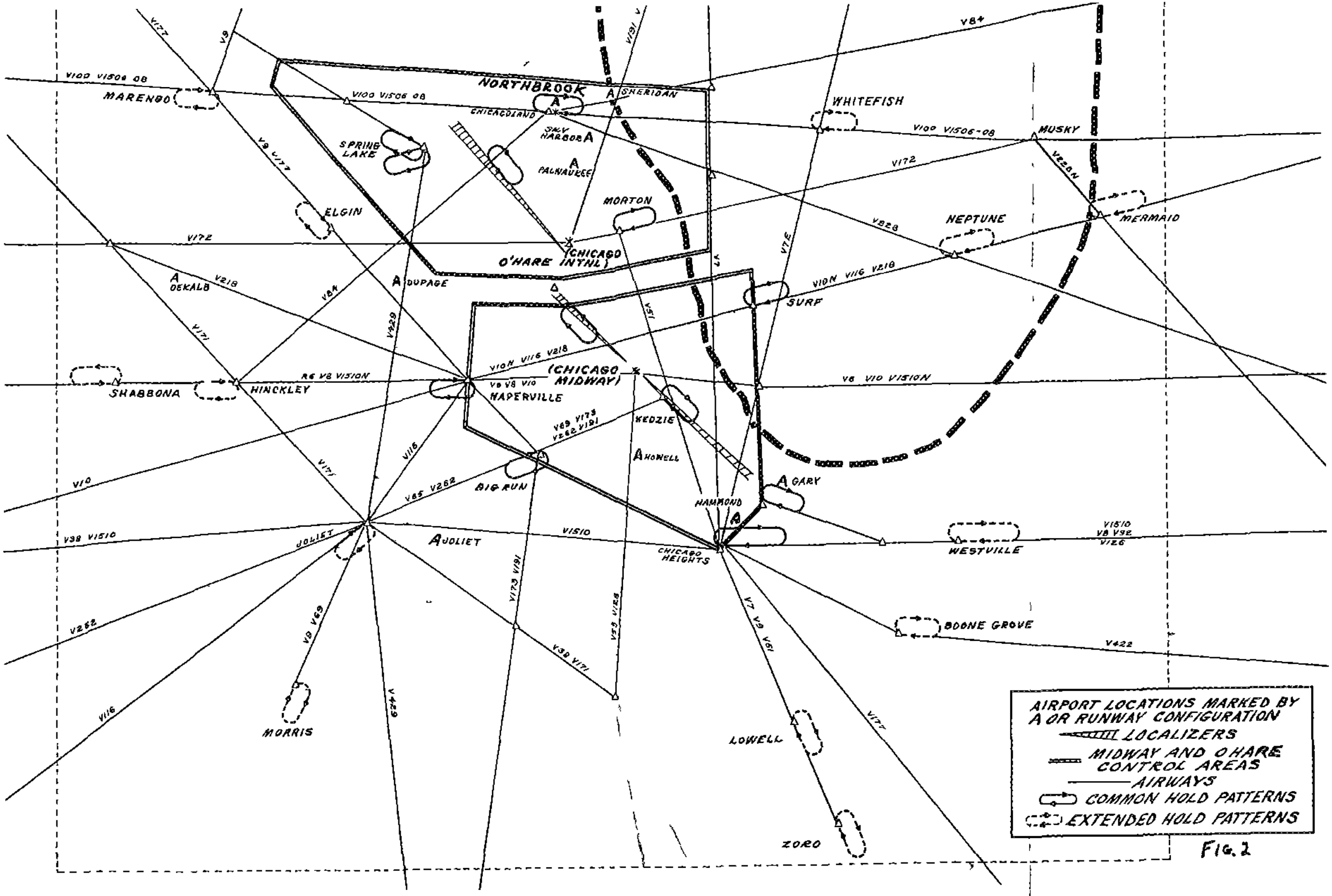
NORTHBROOK
SHERIDAN
CHICAGOLAND
SKY HARBOR
PALWAUKEE
MARENGO
SPRING LAKE
ELGIN
WHITEFISH
MUSKY
MERMAID
NEPTUNE
MORTON
(CHICAGO O'HARE INTNL)
DEKALB
DUPAGE
SURF
(CHICAGO MIDWAY)
SHABBONA
HINCKLEY
NAPERVILLE
KEDZIE
HOWELL
BIG RUN
GARY
HAMMOND
JOLIET
CHICAGO HEIGHTS
WESTVILLE
BOONE GROVE
MORRIS
LOWELL
ZORO
AIRPORT LOCATIONS MARKED BY A OR RUNWAY CONFIGURATION
LOCALIZERS
MIDWAY AND O HARE CONTROL AREAS
AIRWAYS
COMMON HOLD PATTERNS
EXTENDED HOLD PATTERNS

FIG. 2

for significant periods is $27,000 00 and $121,000 00 per day, respectively (Table 4, Vol I)

(e) Approach transition delays occur because

<u>(1)</u> Under radar approach rules and procedures the acceptance rate of Midway approach control is less than the inbound traffic rate during peak periods

<u>(2)</u> With radar inoperative, the acceptance rate of Midway approach control is limited by the regulations governing time separations and is much less than the inbound traffic rate during peak periods

(f) Regardless whether radar is operative, approach transition delays are lengthened when

<u>(1)</u> Thunderstorm or heavy cumulus activity is present in any portion of the holding structure

<u>(2)</u> The operation of the Kedzie navigational homer is erratic

(3) Observations pertaining to the influence of the weather on air traffic control in the Chicago area

(a) Inadequate integration exists between weather forcasting services and air traffic control groups in the Chicago Area, i e pilot reports of weather received by air traffic controllers are not available for use by weather forcasting services, and controllers are not sufficiently aware of the weather at the points in the area where control delays are instituted

(b) It is questionable whether the locations of approach holding fixes in use in the Chicago Area are compatible with climatological conditions

(c) It is questionable whether the orientation of the instrumented runways are compatible with the climatological conditions.

(4) Observations pertaining to ground operations at Midway and O'Hare when these operations are not hindered by the weather

(a) Delays at Midway due to arriving aircraft waiting for space at the gate constitute the largest number of delays on the ground

(b) During the periods of this survey, delays on the ground at O'Hare occurred relatively infrequently

(c) It is, however, expected (based on FAA National Airport Plan - 1959) that in the very near future a significant portion of Midway's commercial traffic will transfer to O'Hare Airport Therefore, in the future, this situation may be reversed.

(5) Other significant observations are that

(a) The orientation of the instrumented approaches into Midway and O'Hare are in conflict

(b) Additional navigational aids are needed

On the basis of the above observations, the following major recommendations are made (additional information regarding conclusions and recommendations is included in Section E)

(1) Backup approach radar should be installed immediately at Midway Airport Concurrently, the control tower should be redesigned to provide more room in the cab and in the Instrument Approach room

(2) An additional navigational aid, located to the west of O'Hare Airport should be installed immediately to assist, temporarily, in resolving the conflict between O'Hare departing and Midway arriving IFR traffic

(3) The O'Hare Approach Radar should be relocated to eliminate a critical blind spot south of the field

(4) Procedures and equipment should be developed in the near future to improve and increase the weather information flow between air traffic control, airborne pilots, and weather forecasting services

(5) A study should be initiated in the near future to establish the optimum orientation of the instrumented approaches into Midway and O'Hare This study should include an analysis of the wind direction, force, and gustiness when ceilings are at or near minimum values Minimum visibility values should not be used as criteria in this analysis since low visibility alone is not associated with bad flying weather, and will not be associated with the surface wind related to instrument approaches

(6) Plans for dual instrumented runways at O'Hare should be accelerated to insure early implementation, based on the study referenced in (5) above

(7) A study of Radar Approach procedures should be initiated in the near future to ascertain:

(a) Whether the use of computational display would enable the approach controller to more nearly realize the theoretical rate under current separation rules

(b) Whether the availability of backup radar would justify a revision of current separation rules

A Objectives of the Project

The objectives of this project are to provide complete and accurate quantative analyses of aircraft movement in flight in the Chicago Air Route Traffic Control Area and on the ground at Midway and O'Hare Airports The analyses are to show the nature, volume, and flow of air traffic both in the air and on the airport surfaces In addition, the analyses are to establish the distribution, magnitude, and cause of delays that occur during periods of heavy demand upon the air traffic control system A second major objective of this program is to collect and organize a large amount of basic data for future analysis and simulation

The objectives therefore include the collection and recording of data, the statistical analysis of the data, and analysis of the system

These objectives were contractually established by the delineation of several specific tasks as follows

Task 1 entailed the collection and analysis of flight progress strips for four selected days, the codification of the information thereon in punched card form, and the organization and tabulation of these data by aircraft flight number and reporting fix position

Task 2 entailed the analysis of the data of Task 1 supplemented by data from other sources, to establish the number, distribution, and reason for delay to airborne aircraft in the Chicago Area

Task 3 entailed an analysis of the data of Task 1, supplemented by data from other sources, to establish the reasons for diversions

Task 4 entailed the collection of radar scope photographs, and the preparation of motion and still pictures graphically depicting the air traffic movements in the Chicago Area

Task 5 entailed an analysis of the data of Task 1 to establish the number of flight strips prepared and the number of flight strips required for each flight route flown in the Chicago Area

Task 6 entailed the collection and analysis of data for aircraft movements on the airport surfaces at Midway and O'Hare Airports

Task 7 entailed an analysis of weather in the Chicago Area, and its correlation to delayed or diverted flights

Task 8 entailed analysis of hidden delays, i e , delays resulting from route structure limitations, or procedural restrictions over and above those deliberately introduced by the controller for separation purposes

Task 9 entailed an analysis of the magnitude and time occurrence of changes made in flight progress strips

Task 10 entailed the collection and tabulation of data for VFR traffic in the Chicago Area

Task 11 entailed the collection of voice recordings of the communications on ground-air-ground channels to supplement the data of other tasks

Task 12 entailed the establishment of recommendations and conclusions on the basis of the above analysis

B Description of the Chicago Air Traffic Control System

The Chicago Air Traffic Control (ATC) Area (see Fig 1) encompasses portions of five states Michigan, Indiana, Illinois , Iowa, and Wisconsin Measured from Chicago, the area extends approximately 125 miles to the east, 140 miles to the north, 120 miles to the south, and 225 miles to the west

The area is essentially void of natural hazards, and with the exception of three small restricted areas, is all free airspace The area is covered by an airway structure in which radial routes converging at the Chicago Terminal Area predominate, but which also provides excellent east-west routes for transcontinental flights

The Chicago Terminal Area, which contains Midway, O'Hare and Glenview airports, in addition to many smaller airports, has been designated as a high density air traffic zone

The airway structure is marked by a variety of navigational aids These include 2 TVOR's, 16 VOR's, 1 VORTAC, 11 VOR-DME's, and 10 low frequency ranges Instrument Landing Systems (ILS) and/or Ground Controlled Approach (GCA) are installed at Madison, Midway, Milwaukee, O'Hare, Rantoul, Fort Wayne, Glenview, Moline, and South Bend

Commercial carriers serve, in addition to Midway and O'Hare, 15 other airports within the Chicago Air Route Traffic Control Center's area

Military operations are regularly conducted at Fort Wayne, Glenview, O'Hare, Rantoul and Madison

The air traffic throughout the airway structure which operates under Instrument Flight Rules (IFR) is controlled by the Chicago Air Route Traffic Control (ARTC) Center located at the extreme western edge of Miway Airport in southwest Chicago Control is maintained through the use of flight progress strips prepared from information received via land line or ground-air-ground communication channels, and posted at progress boards representing reporting positions or airway intersections In general, the procedures followed in the Chicago ARTC Center (CARTCC) are identical to the standard procedures in use throughout the country as specified by regulations

For purposes of control, the CARTCC is organized into 14 sectors Each sector is normally manned by a controller and assistant. Four of these sectors, which monitor traffic at Surf, Gary-Kedzie, Big Run, and Naperville, control inbound traffic awaiting transfer to Midway Approach Control Two additional sectors, equipped with an 80 mile range Plan Position Indicator (PPI) remote display of an FPS-8 radar, vector outbound traffic from Midway until they reach clearance altitude An additional radar position equipped with a 100 mile PPI display of this radar is used to vector inbound jet aircraft to O'Hare Airport The peak watch at the CARTCC is composed of 36 men

High altitude jet traffic above 24,000 feet is monitored by the Flight Following Service operating at the Peoria Ground Controlled Intercept (GCI) Site

Over 50 percent of the activity at the CARTCC is concerned with the control of inbound or outbound Midway traffic When adverse weather conditions necessitate IFR approaches into Midway, aircraft are held at Naperville, Big Run, Gary-Kedzie, and Surf under control of the CARTCC Control is transferred to Midway Approach Control when the aircraft is cleared to below 6000 feet, although the transition altitude may vary, dependent upon conditions, by mutual agreement If prolonged delays exist, aircraft are, in addition, held in outlying patterns at Lowell, Joliet, Elgin, Neptune, Westville, and Mermaid Flow control is instituted by the CARTCC when delays (per flight) approach 40 minutes, and only restricted numbers of inbound aircraft are accepted by the CARTCC

The majority of flight strips are prepared by hand, although an IBM 650 computer is used to automatically prepare flight strips for traffic from the west The limited time that an aircraft is under control when approaching from the east or south precludes its use in these sectors. All updating is done by hand

Midway airport is located in the southwest section of the City of Chicago, and occupies an area of exactly 1 square mile O'Hare Airport is located 14 miles northwest of Midway on 6080 acres of land owned by the City of Chicago

The close proximity of these two airports which handle traffic to or from Chicago causes several problems First, Midway traffic to the north must detour, generally to the east, to avoid the O'Hare control zone Similarly, O'Hare traffic to the south must detour, generally to the west, to avoid the Midway control zone Secondly, a much more serious situation is occasioned by the unfortunate orientation of the instrumented runways at both fields The departures from the instrumented runway at O'Hare, 14R, extend directly into the approach zone of the instrumented runway, 13R, at Midway The area between these airports has been divided to allow approximately 3 miles for departures on 14R at O'Hare to turn east or west, 3 miles for a buffer zone, and 8 miles for approach zone at Midway However, the advent of commercial jet operations from O'Hare on 14R (which is 8838 feet long), coupled with the limited turning ability of these aircraft, causes a frequent source of conflict Rectification of this situation is mandatory

Control procedures at Midway and O'Hare are similar

Under IFR conditions, inbounds are accepted by approach control at the specified holding patterns at agreed upon altitudes. They are radar vectored to final approach, maintaining a minimum of 3 miles separation, or, when the radar is inoperative, timed approach procedure is used Final approach is by ILS with GCA advisory available at Midway Clearance to land on the active runway is issued by the Local Controller and taxi instructions are issued by the Ground Controller

Departing Aircraft are cleared to taxi by the Ground Controller, issued en route clearance by the En Route Coordinator, cleared to the active runway and takeoff by the Local Controller and controlled subsequent to takeoff by the Departure Controller until such time as they are handled over to the CARTCC

For detailed descriptions of approach control procedures refer to Appendices Aand B, Vol II

C. Method of Analysis

1 Periods of Observation

During the period from February through April, 1959, data were collected and analyzed for selected days

Air traffic was analyzed for 24 hours on February 26, March 26, April 10, and April 27 These periods were selected after the fact. The criteria for selecting a day suitable for analysis were that IFR weather prevailed for extended periods throughout the 24 hour day, that significant delays were experienced, that the traffic count exceeded 1600 flights, and that all major equipment was operative Due to an extensive series of approach radar outages at Midway the last of these criteria could be satisfied only partially. Flight count history did not exist, rather, a history of strip counts was used to estimate flight counts. The days were therefore selected on the basis of a specific number of flight strips prepared and a count of 1600 flights never appeared. Data for ground traffic were collected and analyzed for seven periods on February 3, February 6, and February 11 at Midway, on February 19 and February 28 at O'Hare, and on March 22 at both Midway and O'Hare In each case the data collection period was of approximately 8 hours duration. The days for ground observation were selected before the fact, and were chosen on the basis of an anticipated large volume of airport operations under VFR conditions Even so, the period of February 3 contains a portion of IFR traffic

A brief description of the weather[1/] for the periods of air traffic analysis is as follows

<u>26 February, Thursday, 0600 GCT</u>

The area was covered by a stagnant polar air mass of great depth which moved eastward very slowly under the influence of westerly winds aloft A weak trough in the winds aloft passed over the area during midday accompanied by a band of light precipitation and followed by clearing weather

<u>26 March, Thursday, 0600 GCT</u>

A complex storm area moved from Oklahoma towards the Chicago area During the period the original storm weakened and a new one developed near Quincy, Illinois. This new storm passed south of Chicago on an eastward course, causing a considerable amount of thunderstorm activity throughout the period along a line from west to east through Central Illinois and Southern Indiana

<u>10 April, Friday, 0600 GCT</u>

The area was covered by a shallow and stagnant cold continental air mass Aloft, winds from the southwest carried moist air over the surface

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1/ Detailed descriptions, graphs, and charts in C. 4 of Volume II air early in the day The winds aloft veered to northwesterly as a trough in the westerlies passed over the area Precipitation accompanied the change in the winds aloft, and clearing followed

<u>27 April, Monday, 0500 GCT</u>

A weak storm area existed in Kansas and a line of weather extended eastward from it This storm area intensified during the day while moving northeastward into western Illinois The line of weather extending eastward from the storm became intense No landings were made at Midway Airport for 40 minutes from 0318 to 0358 GCT due to gusty beam winds associated with thunderstorm activity

In general, 26 February and 10 April were similar days weatherwise, and air traffic operations and control were not affected to any great extent on these days Also, 26 March and 27 April were similar days weatherwise, the first characterized by a "grown" storm moving from the southwest and passing eastward to the south of Chicago, the second characterized by a young and intensifying storm of similar movement Air traffic operations and control were considerably disrupted on both days Although it appears that the weather of the 27th of April was more intense and affected the area for a longer period of time than that of the 26th of March, traffic was handled much more expeditiously on the 27th of April since approach control radar was operating all day whereas it was inoperative most of the 26th of March

The weather on the days of ground traffic analysis was generally good

As none of the conclusions presented herein relate specifically to the weather existing during ground test days, this material is presented in detail in Sections B 2 and C 4, Vol II

2 Sources of Data

Sources of data included the following

(1) Flight Strips

The primary source of data for the tabulation of flights in the Chicago ATC area was obtained from flight strips prepared in the Chicago ARTCC, Midway tower, O'Hare tower, Peoria tower, Rockford tower, South Bend tower, and Milwaukee tower

Although these strips were the basic source of data, they have several limitations from an analytical point of view Cross checking with radar photographs and radio recordings indicates that the following types of errors or omissions may exist

(a) An incorrect group of hour digits may be written on ARTC strips, especially when long delays occur

(b) Either the actual time of arrival, or the actual time of departure, or both, may be missing from both ARTC and tower strips

(c) A few cases exist where no record is made of delays Also, when several delays are recorded on a single flight strip, nonstandard codes and methods are used to designate the hold

Occasionally, the flight strip will indicate a delay at a fix geographically distinct from the actual holding fix

(d) Aircraft sometimes follow routes different from those shown on the flight strips without any indication of a change

(e) Occasional errors exist in reporting times over fixes Estimated speed is usually incorrect after the first few reporting fixes and is rarely updated

It should be emphasized that the above limitations apply to the usefulness of flight strips as sources of data for after-the-fact analysis, and not to their deficiencies as a real time record of control information

(2) Radar Scope Photographs

Both the FPS-8 radar display at the CARTCC and a repeater at the ASR-3 radar at O'Hare field were photographed at a rate of 2 frames per minute throughout the entire test period from February through April

Except for an occasional blind spot and nonlinearities in the vicinity of the center of the radar displays due to the beamwidth of the radar, the radar photographs are the most accurate source of position data available However, this source must be supported by other sources since no aircraft identification is possible with the radar photographs alone

(3) Communication Channel Recordings

Six radio frequency channels were continuously monitored by special 24 hour tape recorders These frequencies, Surf, Chicago Heights, Naperville, Radar East, Radar West, and Goshen, gave a representative sample of communications procedure in the CARTCC and proved to be the most fruitful sources of data available The radio frequencies used by the transitional fix controllers, Surf, Naperville, and Chicago Heights, were monitored by Cook personnel for weather data, reporting times, and unusual situations Since almost all data displayed on the ARTC flight strip are obtained through radio communications, most flights can be followed more accurately from data on the tapes than from data on the strips Also, additional information on items such as navigation equipment failure,weather data, and declared emergency can be obtained from this source and nowhere else It is, however, extremely costly to monitor these data extensively

(4) On-the-Spot Observations

Data on ground traffic were collected at Midway and O'Hare by organized teams of Cook Research Laboratories' employees as observers Walkie-talkies were used to coordinate the team activities and to maintain time synchronism These teams were assisted by FAA controllers, particularly to monitor communication channels, and to identify reasons for ground delay Also, data was collected for VFR traffic by direct observation of operations at Midway, O'Hare, Meigs, Sky Harbor, Palwaukee, Glenview, and Howell airports

(5) Pilot Questionnaire Cards

(a) VFR pilot questionnaire cards were distributed to pilots who accomplished VFR flights on 22 March, and the returned cards were used in the VFR tabulations of Table K, Vol III

(b) General pilot questionnaire cards were distributed to every commercial airline office and military group at Meigs, O'Hare, Midway, and Glenview

In addition, these post cards were placed on the registration desk of every general aviation facility at these fields. This form, BB-04-R050 (Fig 5, Vol II) requested information on delays, reasons for delays, duration of delays, positions where delays were encountered, and rerouting information These post cards were available to pilots throughout the entire air test period from the middle of February to the end of April Unfortunately, there was a dropoff in daily returns of these cards after the first few weeks and the last two test periods had very few returns to aid in the delay analysis The hold times indicated on these cards are generally approximations and are not considered extremely accurate, however, the reasons for delays and positions of delays' occurrence give a great deal of additional insight into the delays' problem The data could not be used in a quantitative sense

(6) Sources of Weather Data

(a) For Ground Test Day Analysis

Teletype weather records collected from Midway Weather Bureau Air Station

(b) For Air Test Day Analysis

Teletype weather records collected from Midway Weather Bureau Airport Station (WBAS) or the U. S Weather Bureau (USWB) Flight Advisory Weather Service (FAWS) unit, University of Chicago Upper air analyzed charts collected from Midway WBAS and the National Meteorological Center (NMC) Analyzed surface charts collected from FAWS unit, University of Chicago, and Midway WBAS Missing Data (e g , rasondes) copied from historical teletype data files of USWB research office, University of Chicago Tape recordings of the Naperville, Surf, and Chicago Heights control positions of the CARTC center

(c) For Forecasting Ground Test Day Weather

Teletype data facsimile charts, and regional synoptic and forecast verbal discussions as supplied by FP-1 transmissions

(d) For Determining Area Weather Conditions on Tentative Air Test Days

O'Hare WBAS teletype and facsimile records

3 Analysis Procedures

The basic procedures for the analysis of air traffic data consisted of sorting flight strips by flight, preparing IBM punched cards for each strip, and tabulating the punched cards by flight and reporting point From these tabulations, summaries of data on traffic flow, routes, updatings, etc , were obtained by inspection

The analysis of delays and diversions required the use of the above tabulations, correlated with tape recorded data, radar data, and weather data To some extent, the returned pilot questionnaire cards assisted in analyzing delays It should be pointed out that the analysis of delays required considerable judgment on the part of the analyst, and to some extent certain human errors affected the evaluation

The tabulated data collected by on-the-spot observations of ground traffic were placed in punched card form, and were machine processed for the most part

The weather data were prepared in descriptive and graphical form for correlation to the digital data

D Analysis of Data

1 Traffic Flow

The volume and nature of IFR air traffic using the CARTC area was analyzed by ownership category and traffic classification The results are tabulated in Table I, Vol I of this table, inbound refers to flights having origins exterior to and destinations interior to the CARTC area, outbound refers to flights having origins interior to and destinations exterior to the CARTC area, while over and local refer to flights having both origin and destination exterior and interior to the CARTC area, respectively It is seen that there is reasonable consistency in traffic volume and nature between the several test periods, and that the traffic in the CARTC area is composed predominantly of commercial inbound or outbound flights.

Analysis of the 548 inbound flights of February 26 indicates that 61 percent were inbound to Midway and 8 percent were inbound to O'Hare The remainder, 31 percent, were destined to other airports within the CARTC area On the average, of course, the same percentage distribution of points of origin will apply to outbound flights Similar analysis applied to the other sample periods yields essentially the same distribution Further, 54 percent of the local flights in the

TABLE I

NATURE AND VOLUME OF IFR AIR TRAFFIC IN THE CARTC AREA

	Thursday 26 February	Thursday 26 March	Friday 10 April	Monday 27 April
Total Number of Flights	1557	1378	1548	1513
Distribution by Traffic Class				
Percent Inbound	35 2	39 2	37 9	35 7
Percent Outbound	36 9	37 0	38 5	36 6
Percent Local	13 0	14 2	11 1	17 4
Percent Over	14 9	9 6	12 5	10 3
Distribution by Ownership Class				
Percent Commercial	81 0	79 4	70 6	79 5
Percent Military	8 2	8 2	15 5	7 0
Percent General	10 8	12 4	13 9	13 5

area have Midway as an orgin or destination and 3 percent have O'Hare as an origin or destination Of the total number of flights in the CARTC area, 51 percent have Midway airport as an origin or destination, and 6 percent have O'Hare Airport as an origin or destination

Table 2, Vol I, contains information on the flow of IFR traffic in and through the CARTCC 1/ Percentages of the total days traffic as established from flight strips, are indicated for 2 hour periods It is noted that 75 percent of the total day's traffic occurs between 1400 and 0200 GCT and is distributed quite evenly over that period.

In summary, the IFR Air Traffic in the CARTC area is predominantly commercial traffic Because it is largely a scheduled operation, it shows a reasonable consistency from day to day The major traffic flow is into or out of Midway Airport Analysis of Routes indicates that the main flow of traffic proceeds along radial paths in the east, west, and south sectors, which is consistent with the geographic location of the CARTC area in the Continental United States

At the time of the survey, certain trends were operative There is expected to be a progressive transfer of commercial traffic from Midway to O'Hare (see FAA National Airport Plan - 1959), and commercial jet operations into and out of O'Hare will be accelerated Currently, Air Defense Command activities are being curtailed at O'Hare but there is a trend toward increased Air National Guard and Air Force Reserve

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1/ 26 February was used since it was the most normal day, weatherwise and operationally, of the 4 days specified

TABLE 2

TIME DISTRIBUTION OF IFR TRAFFIC IN THE CARTC AREA
on 26 February 1959

Two Hour Period Beginning, GCT	Percent
0600	2.6
0800	1.8
1000	2.5
1200	4.9
1400	11.0
1600	13.2
1800	13.1
2000	13.3
2200	13.9
0000	10.9
0200	8.7
0400	4.1

operations at this airport The latter, being of a training nature, may not contribute extensively to IFR traffic in the area

A general growth in commercial traffic is expected [1/] In addition, it is anticipated that an increasing number of overseas operations along polar routes to Europe or North Asia will be conducted from the Chicago Area This will augment the traffic to the north Finally, the activity of general aviation is expected to increase significantly in the future [1/] although the extent to which this increase in traffic will increase IFR operations is difficult to evaluate

With the type of traffic flow described, i e , a converging flow predominantly to a single airport, it would be expected that during periods when the acceptance rate for arrivals is limited at this airport due to weather or other conditions, a serious condition of airborne delays and diversions to alternate destinations would develop This aspect of the analysis is presented in the next section

2 Delays, Diversions, and Cancellations (of IFR Flight Plan)

In the process of analyzing delays in the Chicago Area, it was found that they fall into two broad types, Approach Transition delays and En Route Delays

Approach Transition Delays occur to aircraft waiting to approach and land at their destination airport

En Route Delays are rather isolated and distributed throughout the airway structure Refer to Tables 11, 12, 13, and 14, Vol II

Departure Transition Delays were not found to exist in the Chicago Area

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1/ Based on National Requirements for Aviation Facilities 1956-75 May 1957

Table 3 is a summary of the incidence of delays and diversions in the CARTC area during the four test periods It is observed that approach transition delays predominate

Although En Route Delays are of some significance, a detailed examination of the factors leading up to them did not reveal any central related cause We,therefore, were unable to arrive at recommendations and conclusions to affect their reduction Presumably, more adequate scheduling and prediction and improved communications between adjacent centers or other control activities, currently under development by the FAA, will reduce their significance

Although there are five reasons for diversions listed, it is seen that 69 percent of all diversions occur as a result of control delays

The four diversions listed as caused by company reasons are further discussed in C 4 a under 26 March, Vol II, and might really be due to inadequate ramp area and/or gates at O'Hare Field

It should also be noted that on 26 February, 18 flights cancelled IFR as a result of control delay

It is an established fact that, on 26 March, aircraft destined for Chicago airports diverted before coming under CARTC control There is also the probability that flights scheduled for Chicago airports were cancelled at departure point Unfortunately, we were unable to perform any quantitative analyses on these incidents This could only be accomplished through complete access to all carrier records in their respective operations bases

TABLE 3

SUMMARY OF DELAYS AND DIVERSIONS
IN CARTC AREA

Delay Incident

	Thursday 26 February	Thursday 26 March	Friday 10 April	Monday 27 April
Total Number of delays	137	459	112	285
Number En Route	24	3	6	5
Number During Approach Transition	113	456	106	280

Diversion Incident

	Thursday 26 February	Thursday 26. March	Friday 10 April	Monday 27 April
Diversion Resulting from Control Delay	0	33	0	1
Diversion Resulting from Weather Delay	0	6	0	2
Diversion Resulting from Weather Conditions (Field Closed or Missed Approach)	2	3	0	3
Diversion Resulting from Company Reasons	0	4	0	0
Diversion Resulting from Emergency in Flight	0	2	0	0
Total Diversions	2	48	0	6

The extremely large number of Approach Transition Delays constitute the major problem area in the Chicago Area Further operational factors that describe this classification of delays are tabulated in Table 4, Vol I It should be observed that the operational significance of the characteristics of the delay pattern is highly variable from day to day, although the traffic load is relatively constant It is important to recognize that both 26 February and 10 April constituted periods when delays and diversions were acceptable, that 27 April constituted a period when delays and diversions were hazardous and very costly, and that 26 March constituted a period when delays and diversions were hazardous and extremely costly

In assigning the factors which are responsible for the magnitude of the delays, we consider the various operational and weather situations that occurred during these periods

It should be recognized that the data of Table 4 applied to flights into all airports in the Chicago Area These include Milwaukee, Fort Wayne, South Bend, etc , as well as Midway and O'Hare airports However, the delays occur predominantly to aircraft inbound to Midway For example, on 26 March, 92 percent of the delays tabulated occurred to aircraft approaching Midway Therefore, the operational and weather situation at Midway may be expected to be the prime factor in establishing the delay pattern

TABLE 4

SUMMARY OF DELAY AND DIVERSION ASSOCIATED WITH APPROACH TRANSITION

Delay Incident

	Thursday 26 February	Thursday 26 March	Friday 10 April	Monday 27 April
Total Number of Delays	113	423	106	279
Number During Peak Hour	27	60	24	38
Mean Duration, minutes	7 22	34 72	10 28	15 50
Maximum Duration, minutes	65	115	30	85
Total Delay, minutes	816	14,698	1090	4320
Cost at $6 00 per minute*	$4,900	$88,200	$6,054	$26,000

Diversion Incident

Number of Flights which Diverted due to Forecast and/or Actual Approach Transition Delay	0	33	0	1
Cost at $1000 per Diversion	$ 0	$ 33,000	$ 0	$ 1000
Total Cost of Delays and Diversions	$4,900	$121,000	$6,054	$27,000

* Based on Air Transport Association data, may be conservative

** It is impossible to determine the true cost of a diversion However, if we ignore schedule disruption, nonutilization of aircraft, passenger ill will, and Government required crew rest, and assume only that the average diversion involves one hour to alternate and one hour back (at a later time) at $6 00/min plus accommodations for 40 passengers at $10.00 per passenger, we arrive at a figure of approximately $1,000 00

The weather has been extensively anal ed and is presented in detail in Section C 4 , Vol II of this report The prime features of these factors are tabulated in Table 5, Vol I The effect each of these factors has on the magnitude of Approach Transition Delays is, from operational considerations, as follows

(1) When the Midway Approach Radar is inoperative, the airport acceptance rate is reduced from its normal IFR radar approach capacity This occurred for significant periods on 26 February and 26 March Actually, considerable difficulty was experienced with Midway Radar throughout the entire test period The radar is a newly installed ASR-2, and it was reported to be out of service 55 times during the months of January, February, and March, 1959 In explaining cause of delays, pilot questionnaires frequently referenced radar outage Daily preventive maintenance during off hours has temporarily corrected this situation

(2) When Midway Runways are closed due to weather, there is no alternative for an aircraft except to hold or divert This occurred for only 40 minutes on 27 April

(3) The duration of time that Midway Airport is below VFR minimums has a significant influence on the magnitude of delays as it necessitates IFR radar or nonradar approach procedures

TABLE 5

SUMMARY OF FACTORS WHICH RELATE TO APPROACH TRANSITION DELAYS

	26 February	26 March	10 April	27 April
Midway Approach Radar Inoperative*	6 hr.	10 5 hr	0	0
Midway Runways Closed	0	0	0	67 hr
Midway Weather Below 1400 ft Ceiling and 1-3/4 mile Visibility	9 hr	20 5 hr	4 hr	21 5 hr
Chicago Area Weather Aloft	Relatively Good Flying Weather	Relatively Bad, Somewhat Hazardous, Flying Weather	Relatively Good Flying Weather	Hazardous Flying Weather
Kedzie Homer Erratic	No	Yes	No	Yes

* This does not include period of shutdown for preventive maintenance during off hours

which reduce the airport capacity to well below its normal VFR rate (see Table 10, Page 45, Vol I)

(4) Chicago area weather aloft has an effect on the magnitude of delays when turbulence due to thunderstorm or heavy cumulus activity occurs at approach holding fixes or at adjacent feeder fixes The effect is twofold First, when thunderstorm activity exists along the inbound routes, aircraft may hold at an outlying fix until the activity abates, rather than proceed This situation existed on 27 April, although in the analysis it was not possible to make a distinct separation between aircraft holding for this reason and aircraft holding while awaiting clearance to approach holding points Secondly, when thunderstorm activity prevails at approach holding fixes, there is an attempt made to transfer aircraft to alternate holding points This is not always possible, as the latter may be already occupied This latter control activity increases the controlled aircraft movements in the vicinity of the Midway approaches, and undoubtedly is a contributary reason for delay In any event, holding in thunderstorms increases the apparent, if not actual, duration of the delay, and is very undesirable

(5) On occasion, the Kedzie homer is erratic during thunderstorm activity or precipitation periods and cannot be used Delays

are experienced by aircraft that cannot locate, or cannot maintain this marker and must be held at alternate fixes

In assessing the importance of these several factors, we recognize that 26 March and 27 April are very similar with respect to weather and traffic load While Midway was closed for a brief period on 27 April, the major distinction is that the Midway Approach Radar was inoperative for 10 5 hours on 26 March It is reasonable to assign the full cost of the additional delays on 26 March to this factor, i e , the cost of 10 5 hours of radar outage at Midway is approximately $94, 000, or $9, 000 per hour outage

Further, on 27 April, when Midway operated under IFR radar approach conditions for extended periods, the cost of the delays was $26, 000 00 While in any sequential service operation involving random events some delay is unavoidable, and a portion of this delay cost must be chargeable to weather aloft, it appears reasonable that the total cost would be reduced to one-half this value had an additional instrumented runway been available at Midway Thus, the cost of the delays chargeable to the limited availability of instrumented runways is $13, 000 per IFR day Finally, it appears extremely desirable that controllers be more aware of the weather conditions where aircraft are being held, that a greater flexibility in holding patterns to minimize the effect of the weather be established, and that the Kedzie homer be replaced by a more reliable facility Conclusions and recommendations to this effect are treated in a later section

A further insight into the quantitative relationship of approach handling rates to delays may be obtained by a consideration of the data of Table 6, Vol I This table compares the arrivals per hour at Midway under VFR conditions, under IFR approach conditions, and under IFR radar approach conditions The tabulation for VFR conditions was taken from the data for one of the days of ground traffic observation Because commercial traffic at Midway is a relatively consistent scheduled operation, the data for the VFR period represent closely the expected normal traffic load at Midway under any conditions The traffic load at Midway, due to general aviation, is much more variable A significant portion of this classification may be expected to remain on the ground during IFR periods

Reference to Table 6, Vol I, indicates that normal traffic at Midway is 26 0 commercial operations per hour, with maximum and minimum rates of 33 and 19 per hour, respectively Under timed approach procedures, the arrival rates at Midway are reduced to an average of 18 1 arrivals per hour, with the rate ranging between a minimum of 14 and a maximum of 22 per hour Under radar approach procedures, the arrival rate at Midway is 25 1 per hour, with the rate being extremely consistent throughout the period, ranging

TABLE 6

ARRIVAL TRAFFIC RATE AT MIDWAY UNDER VARIOUS CONDITIONS

Hour Period Beginning GCT	February 11 VFR Commercial Landings	February 11 VFR General Aviation Landings	March 26 IFR Timed Approach	April 27 IFR Radar Approach
1800	19	11	22	24
1900	23	6	14	27
2000	26	9	16	25
2100	23	4	22	26
2200	28	6	18	27
2300	30	8	20	23
0000	26	0	15	25
0100	33	1	18	25
	208	45	145	202
Av/hour	26 0	5 6	18 1	25.1

between 23 and 27 per hour

In any operational situation, if the arriving traffic rate exceeds the handing or service rate, the waiting time for arrivals tends toward infinity   It is seen that Radar Approach procedures allow a handling rate to be sustained which is marginal with regard to the normal expected arrival rate of commercial aircraft   Timed Approach procedures are totally inadequate, it would be expected that long delays and extensive diversions would result when the normal arrival rate is imposed on the limited handling rate of approach control under these conditions

It should be pointed out that the criteria of 3 minutes separation under timed approach procedures and 3 miles separation under radar approach procedures, assuming an approach speed of 120 miles per hour, leads to theoretical maximum rates of 20 and 40 per hour for these procedures, respectively   Thus, timed approach and radar approach operations are carried out with an efficiency of 90 5 and 63 0 percent, respectively   From the standpoint of the approach operator's decision function, the timed approach procedure is relatively simple and it is not surprising that the theoretical rate sanctioned by the rules is approached   On the other hand, radar approach procedures involve many estimations, predictions, and computations on the part of the approach operator   It would be expected that the theoretical rate would be much more difficult to realize under these conditions It is questionable whether approach operators using radar procedures could exceed by a significant amount therates established at Midway on April 27, the consistency of the rate sustained testifies to the fact that well-trained, conscientious personnel are employed in the process

3 Control Data

An analysis was made of the Control Data at the CARTCC This analysis was made from an examination of the en route flight strips, and entailed the determination of the flight strips required for each route, the extent of updating on each and the magnitude of the hidden delays in the control process The purpose of this analysis is to provide experimental data to assess the applicability of automatic computation to the air traffic control process

Tabulation of these data is presented in detail in Section C.5, Vol II Over 500 distinct flight routes were analyzed, and the distribution of the number of flight strips required for each was tabulated The frequency of updating was analyzed at over 100 reporting points for each hour of one test day Hidden delays were determined for inbound aircraft during the two peak hours of each test day over 58 flight route segments

In the absence of detailed knowledge of a proposed data processing computer these data do not lead directly to recommendations or conclusions Therefore, only general summary data and comments are presented here

During the four days analyzed, a total of 21,107 flight progress strips was prepared Table 7 is a tabulation of the number of strips prepared for each flight classification It is seen that inbound flights require the preparation of the greatest number of flight progress strips, followed by outbound, over, and local flights in that order The average number of strips prepared per flight is 3 92, 2 82, 3 06, and 5 08 for inbound, outbound, local, and over flights, respectively

In the control process, the estimated time of arrival is most frequently updated or revised, followed by altitude information especially for inbound and outbound operations Speed is very infrequently updated In order to improve control, the accuracy of timing should be improved Much more accurate ground speed estimation seems necessary This can be had only if airspeed reporting becomes more accurate and accurate wind directions and speeds are supplied to the pilot and/or controller

Hidden delays were analyzed by comparing the calculated flight time for a direct route from a peripheral fix to the approach holding fix (using entered ground speed and measured distance) to the actual elapsed time minus any known delays On the average, an inbound flight exhibits hidden delay of 7 35 minutes Similarly, the hidden delay between the approach holding fix and the outer marker at Midway

TABLE 7

TABULATION OF FLIGHT STRIPS PREPARED IN THE CHICAGO ARTCC

	Thursday 26 February	Thursday 26 March	Friday 10 April	Monday 27 April
Total Number	5408	4669	5649	5381
Percent Inbound	39 2	47 3	39 7	38 9
Percent Outbound	29 4	26.1	33.1	30 6
Percent Local	10 4	12 1	9 9	14 6
Percent Over	20 0	14 5	17 5	16.0
Average Number of Strips Prepared				
Per Inbound Flight	3 92			
Per Outbound Flight	2 82			
Per Local Flight	3 06			
Per Over Flight	5 08			

averaged 7 09 minutes

4 Ground Traffic

A summary of the data for ground traffic[1/] at Midway and O'Hare is presented in Tables 8 and 9, Vol I Salient points to be observed are; (1) traffic at Midway is predominantly commercial, (2) traffic at O'Hare is approximately equally divided between commercial, military and general aviation, (3) the total traffic at O'Hare is only about 40 percent of the total traffic at Midway, and (4) the commercial traffic at O'Hare is about one-seventh of the commercial traffic at Midway

With the exception of four hours on 3 February at Midway, all the operations were conducted under VFR procedures During the period of IFR operations at Midway, 103 departure and 73 arrival operations were conducted This fact accounts for the abnormal percentage of commercial operations at Midway on 3 February, during IFR periods, general aviation aircraft may be expected to remain on the ground, while commercial aviation aircraft may be expected to proceed on schedule if possible

A summary of the operation rates at Midway and O'Hare is shown in Table 10, Vol I, for IFR and VFR, respectively Due to the limited number of IFR operations, the confidence level of the value in the table for IFR operations is not high These statistics further illustrated the magnitude of Midway traffic when compared to

1/ Refer to Section C 3, Vol II for detailed analysis and supporting information

TABLE 8

SUMMARY OF GROUND TRAFFIC AT MIDWAY AIRPORT

Date	Tuesday 3 February	Friday 6 February	Wednesday 11 February	Sunday 22 March
Time Started, GCT	1830	1800	1800	1600
Time Ended, GCT	0230	0200	0200	2400
Total Number of Departures	187	268	270	252
Percent Commercial	96 0	82 5	83 0	85 3
Percent Military	0	0 3	0	0. 8
Percent General	4 0	17 2	17 0	13 9
Total Number of Arrivals	173	258	253	242
Percent Commercials	98 0	79 5	82 2	81 5
Percent Military	0	0 7	0	0 7
Percent General	2 0	19 8	17 8	17 8

TABLE 9

SUMMARY OF GROUND TRAFFIC AT O'HARE AIRPORT

Date	Thursday 19 February	Saturday 28 February	Sunday 22 March
Time Started, GCT	1900	1500	1600
Time Ended, GCT	0200	2300	2400
Total Number of Departures	115	90	110
Percent Commercial	29.6	24 5	41 0
Percent Military	45 2	40 0	19 0
Percent General	25 2	35 5	40 0
Total Number of Arrivals	112	97	104
Percent Commercial	27.7	26 8	40 4
Percent Military	44 6	38 2	28 8
Percent General	27 7	35 0	30 8

TABLE 10

SUMMARY OF THE AVERAGE OPERATION RATES AT MIDWAY AND O'HARE UNDER VFR AND IFR CONDITIONS

	MIDWAY		O'HARE
	VFR	IFR	VFR
Arrivals Per Hour	30 6	18 2	13 6
Departures Per Hour	31 2	25 7	13 7
Total Operations Per Hour	61 8	43 9	27 3

O'Hare traffic, i e , O'Hare traffic is only about 40 percent of that of Midway

A summary of the runway service time statistics is shown in Table 11, Vol. I Data are only presented for VFR operations, the analysis indicated that comparable values were somewhat higher under IFR conditions, but the limited number of samples under IFR conditions precludes judgments of any reasonable degree of confidence It was found that the distribution of service time could be expressed approximately as an Erlang function of K phases as indicated in the table [1/] It should be noted that an arrival at O'Hare requires about 20 percent more time on the runway and that a departure requires about 35 percent more time on the runway that similar operations at Midway Further, the standard deviation in both cases in proportionately greater at O'Hare than at Midway This was investigated in some detail While it would be expected that the longer runways available at O Hare would increase the departure occupancy time, this was insufficient to explain the total difference We conclude that differences are due to the distinct traffic conditions that exist at the two points The distribution for Midway characterizes an airport having largely commercial traffic, high traffic rate and close coordination between highly experienced pilots and controllers, while the distribution for O'Hare characterizes an airport having mixed traffic, moderate traffic rate and normal coordination between pilots of diverse experience and controllers

1/ Erlang Functions describe distributions intermediate between an exponential distribution (K=1) and a constant distribution (K = oo)

TABLE 11

SUMMARY OF RUNWAY SERVICE TIME STATISTICS UNDER VFR CONDITIONS

	Mean, Sec	Std Dev , Sec	Erlang K-Value
MIDWAY			
Departure Occupancy Time	53 5	21 7	6
Arrival Occupancy Time	49 0	11 9	17
O'HARE			
Departure Occupancy Time	72 0	34 4	4
Arrival Occupancy Time	59 6	22 5	7

Several additional important facts were noted relating to runway operations

First, the definition of runway occupancy time assumed uniqueness It was, however, observed that military departures at O'Hare were often conducted in groups with several moving aircraft on the runway at once In terms of our definition, aircraft subsequent to the first in the group would be assigned occupancy times equal to the difference between the time that the previous departing aircraft and the next departing aircraft cleared the runway threshold This value could range from essentially zero to a normal value To some extent, this incorrect formulation tends to reduce the mean and increase the standard deviation of departing operations at O'Hare Secondly, the time interval between consecutive arrivals and consecutive departures was analyzed Although this may serve as a measure as to how well the controllers adhere to separation rules, it revealed no useful operational information The reason for this is that the arrivals and departures are randomly mixed This was borne out by analyses made on individual runways The operational situation at Midway and O'Hare is such that the probability that an operation will be a departure or an arrival is independent of the classification of the previous operation

As may be expected, delays occur to aircraft on the ground An analysis of delays, exclusive of departure queue delays, was made (see Table G, Vol III for basic data on runup area time intervals).

For the 977 departures and 926 arrivals recorded at Midway, a total of 293 and 577 delays were incurred by departing and arriving aircraft respectively Thus, departure delays totaled 30 percent of the departure operations and arrival delays totaled 62 percent of the arrival operations These figures do not, of course, represent the percentage of aircraft delayed, since some experienced multiple delays.

Similar data for the 315 departure and 313 arrival operations at O'Hare indicate a total of 5 and 14 departure and arrival delays, representing percentages of 1 5 and 4 5 percent, respectively

At O'Hare, the most common reasons for delays were unfamiliarity with the field and awaiting clearance to cross active runway Other causes of delays were so infrequent as to be negligible The data for Midway are tabulated in Table 12, Vol I It should be noted the delays to aircraft awaiting airways en route clearance occur infrequently The most common delay for both departures and arrivals is awaiting clearance to cross the active runway Further, both departures and arrivals are delayed by other aircraft ground traffic Almost one-half of the delays to arrivals are due to waiting for gate space This latter is especially significant, since while delays at the active runway and delays due to ground traffic average only a few minutes duration, delays waiting for gate space range from a few minutes to over an hour

It should be pointed out that Midway Airport represents an extremely complex operational situation This is occasioned by the

TABLE 12

SUMMARY OF GROUND DELAYS AT MIDWAY

REASON FOR STOP	PERCENT OF TOTAL DELAYS	
	Departures	Arrivals
No Clearance to Cross Active Runway	57.7	29 4
Awaiting Airways Clearance	1 7	0
Emergency	0 7	0 2
Ground Aircraft Traffic	22 2	22 2
Gate Delay	1 4	45 9
Runup Outside Normal Area	8 2	0
Procedural Stop (Generally Active Runway)	5 8	0
Unfamiliarity with Field	1 3	1 6
Ground Vehicle Traffic	1 0	0 5
Weather	0 0	0 2

dual runways, and by the high traffic load imposed upon the runway-taxiway structure To reasonably interrelate the operational characteristics of Midway necessitates that the operations be expressible, at least approximately, in terms of a mathematical probabilistic model.

While a reasonable amount of effort was expended in this direction, we have been unable to arrive at a reasonably exact and detailed mathematical description of the operations, due largely to limitations of time It has therefore not been possible to develop significant recommendations for improvements nor to assess the relative economies that may be realized thereby For example, departure queue delays were analyzed and are tabulated in Table G, Vol III, but we have been unable to relate these delays to other operational factors Similarly, while gate delays constitute a significant occasion for delay at Midway, it is difficult to determine if additional gates are required, if the present number of gates should be reassigned, if gates should be shared or if gate occupancy time can or should be reduced

Further, the operations on the ground at Midway and O'Hare are in a state of transition It is expected in the near future that a large portion of commercial traffic now at Midway will transfer to O'Hare it is further expected that Midway will handle a much higher percentage of general aviation in the future than at present [1/]

[1/] Based on FAA National Airport Plan-1959 and National Requirement for Aviation Facilities 1956-75 May 1957

Since these general aviation aircraft will use service facilities other than the terminal, this change should greatly reduce gate delays at Midway Thus, while at present delay in getting in to a gate at Midway constitutes a most serious problem in the Chicago Area, it well may be that in the very near future this problem will be resolved and ground delays at O'Hare [1/] will be the serious occasion for ground traffic delays in the area

5 Weather

During the study, the magnetic tape recording for selected ground-air-ground communication channels was analyzed Collectively this represented approximately 120 hours of audio data This information was used to support the analysis of delays In addition, this source of data showed up several significant aspects of the relationship of weather to control procedures While it was not always possible to describe these factors statistically, they nevertheless are an extremely important part of the analytical aspect of this program

In monitoring the recordings, it was frequently noted that pilots report weather conditions to controllers However, an extensive search of teletype weather data did not reveal one instance where the pilots reports were made available for the general weather forecasting service This is illustrated in Table 13, Vol I and discussed

1/ A possible indication of this is described in C 4 a (1) (f) of 26 March Vol II

TABLE 13

WEATHER REPORTS BY PILOTS WITHIN THE CARTC AREA

Date	Area Weather Conditions	REPORTS ON TTY CIRCUITS Total	Located inside Tape Area	REPORTS ON CONTROL RECORDINGS (Not Relayed to TTY Circuits)
26 Feb	Good	17	6	4*
26 May	Bad	18	4	78
10 Apr	Good	29	6	14**
27 Apr	Bad	10	5	69***

* No Naperville Recording

** No Surf Recording after 1802Z

*** No Surf Recording

in Section C 4 Vol II

The information used in compiling Table 13 was gathered from the following sources

(1) A thorough search of the teletype records for the 24 hour periods covering each air test day was performed to determine how many Pireps [1/] were disseminated in the teletype circuits

(2) The available tape recordings of the Surf, Naperville and Chicago Heights control positions were monitored to determine how many Pireps were given to these control positions and how many discussions concerning the weather took place between pilots and controllers

A cross check was then made to disclose what percentage of the weather information generated on the control frequencies reached the teletype circuits On all four air test days this percentage was zero

Next, the teletype Pireps (i e those which were disseminated) pertaining to the area controlled by the Surf, Naperville, and Chicago Heights positions were segregated for comparison with the weather reports which were not disseminated

The origin of those Pireps taken from teletype records is not definitely known, but we assume that they are from these sources

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1/ Pilot reports of weather being experienced

(1) General aviation reports to towers

(2) General and Military aviation reports to operations offices after completion of flight

(3) Military aviation reports to Air Weather Service (AWS) offices

A further significant fact noted in monitoring the recording tapes was the frequency with which pilots reported thunderstorm activity and turbulence at the approach holding fixes This was especially true on 27 April and to some extent on 26 March. This activity was particularly prevalent at fixes to the south and southeast, i e., Gary and Kedzie The net result of adverse weather at the approach holding fixes is considerable "lost motion" in the control process due to moving aircraft from one fix to another, although since all holding patterns were extensively used, this was not always possible This observation raises two questions First, it is questionable whether the location of the holding patterns to the south are compatible with the winter storm tracks in this area [1/] Secondly, it is questionable whether the controllers have adequate weather information and forecasts to effectively cope with changing frontal conditions [1/]

This latter point was further illustrated by the frequency of disagreements between pilots and controllers as to weather conditions aloft This evidently arises because technical developments such as

[1/] Further discussion in Section C 4 , Vol II circular polarization and MTI have largely removed the indications of weather from the controller's radar while the developments of airborne weather radar have enhanced this information to the pilot [1/]

6 Runway Orientation

At present, Midway's ILS is lined up with runways 13 and O'Hare's ILS is lined up with 14R Plans for O'Hare specify that another parallel system be installed to utilize runway 14L Since O'Hare is located 14 miles northwest of Midway, a conflict already exists between Midway and O'Hare A buffer zone has been established between the two terminals to keep O'Hare (departing) traffic clear of the Midway Outer Marker

It seems logical to assume that, when Midway was enlarged the major runways' orientation was dictated by two things, one being the climatology of prevailing surface winds and the other the fact that a diagonal of a square is the longest straight line possible Later, when ILS was installed, it again seems logical to assume that runway 13 was chosen, first, because of its length and second, from climatological consideration of surface winds Other conditions may have entered into the decision as well, for instance, the city's growth pattern

When O'Hare's runway 14R was planned, it is also probable that it was done on the basis of climatological winds

In the early days of commercial aviation when no one considered

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1/ Further discussion in Section C 4 , Vol II such navigational facilities as ILS, it was logical to orient runways on the basis of climatological winds so that the wind would more often than not be blowing approximately down the runway from either direction

It is suggested that such planning is now out-dated and erroneous In establishing an instrument runway, climatology is still required but what is needed is the climatology of the surface wind when terminal ceiling values are near minimum, in other words, when the synoptic situation is such that the local weather is hazardous to approaching and landing aircraft

We are not aware of the particular climatological wind being discussed, and such a study is not included in the scope of this contract However, on the two bad weather days investigated, the surface winds at both Midway and O'Hare were predominantly east-northeast, and from a cursory mental review of general weather patterns over the Chicago area it is felt that east-northeast or north-east winds do normally exist with low ceilings If this is true, it is not logical to continue with the present plans for O'Hare

There are several interesting possibilities regarding what might be done in the future These are discussed here

(1) For the immediate future, instrument runways 04 at Midway and move the buffer zone south This will allow

(a) Safer use of ILS at Midway with northeast to east winds

(b) More maneuvering space off the end of the 14R

O'Hare, for commercial jet takeoffs

(2) If (1) is acted upon, at a later date Midway's 09 runways should be lengthened, probably to the west, and instrumented. Dependent upon FAA decision on separation of dual ILS runways, a dual system may be possible Concordant with this, it may be wise to lengthen runway 09 at O'Hare and instrument it

(3) If the existing runways and instrumentation are to be kept, it may be possible to establish a single approach control.[1/] Glide paths would slope downward to three runways from the northwest Two final stacks would be utilized to feed the three runways For instance, a stack near Spring Lake might feed Midway and one near Northbrook, O'Hare In this case, to insure vertical separation, the base altitude at Spring Lake could be 4000 feet while that at Northbrook would be 2000 feet Or it might be more advantageous to use Naperville for a feed into the Midway Outer Marker Either of these configurations might be utilized with a new hold pattern structure around the northern semicircle of Chicago to avoid the bad weather [2/] south of the Midway area

(4) Again considering one approach control authority, existing runways could be utilized with the ILS courses being repositioned

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1/ Single approach control would it appears, be easier solved if west-east runways were instrumented at both airports

2/ Refer to Section C 4 of Vol II

for approaches from the southeast This plan would require a feeder fix somewhere in the neighborhood of the present Kedzie marker for Midway inbounds and probably at Surf for O'Hare inbounds. In this case, base stack altitude at Kedzie might be 1500 feet and at Surf, 3000 to 4000 feet

Either (3) or (4) might result in complicated departure patterns, (3) for O'Hare westbound departures and (4) for Midway eastbound departures. If (3) were to be utilized, the hold pattern structure should be kept as far north as possible.

E. Conclusions and Recommendations

Conclusions and recommendations are presented in two broad categories

(1) Those that proceed directly from the analysis of data

(2) Those that were derived during discussions with cognizant air traffic control personnel in the Chicago Area.

1 Analytical Conclusions and Recommendations

a. Regarding Air Route Structure

Discussion

From an analysis of the traffic and delays thereto on the air route structure in the Chicago Area, we conclude that it is well designed to handle the current traffic load (with the exception of holding patterns in the immediate vicinity of the Chicago Terminal Area). We further conclude that areas of potential congestion will manifest themselves by excessive control activity in the CARTC area prior to producing a critical aircraft delay situation. Finally, we conclude that the traffic flow into airports outside the Chicago Terminal Area does not currently or potentially present a control problem

Recommendation

We recommend that Air Route Structure in the Chicago Area grow in an evolutionary manner to accommodate future traffic, and that the Federal Aviation Agency take those steps necessary to minimize the time between the recognition of a problem area and the implementation of equipment or procedures to correct it.

b Regarding Chicago Terminal Area

Discussion

From an analysis of the delays in the Chicago Area we conclude that delays to aircraft awaiting clearance to land at Midway constitute the largest problem area in the region Over 90 percent of all delays in the entire CARTC area occur due to these circumstances The reason for the delay pattern is the limited ability of approach control to handle aircraft under conditions of limited ceiling and visibility at a rate compatible with the commercial aircraft rate which has historically built up at Midway. Under IFR radar approach procedures, the handling rate is marginal and may be expected to cause delays and diversions having an economic cost of $27,000 00 per day. Under timed approach procedures, the handling rate is totally inadequate and may be expected to cause delays and diversions having an economic cost of $121,000.00 per day We conclude that radar approach procedures are mandatory under IFR conditions

Recommendation

We recommend that backup Approach Radar be installed immediately at Midway Tower For this installation to be effective it will be necessary to redesign the control tower to provide additional space

Discussion

Currently, flow control is instituted by the CARTCC when delays approach 40 minutes. We conclude that the decision to institute flow control should also be based on expected traffic load, forecast weather, and major equipment outages

Recommendation:

We recommend that the criteria for flow control be reformulated to include the factors discussed.

Discussion

It is well-known from queueing theory that waiting time is critically dependent upon the ratio of arriving traffic rate to approach handling rate when this ratio is near unity. We conclude that a moderate increase in approach handling rate under radar approach procedures would produce a large reduction in waiting time delays.

We further conclude that the separation rules currently in effect for radar approach procedures, i.e., 3 miles separation on final, are not unduly restrictive, since assumptions of reasonable final approach speed lead to theoretical approach handling rates of 40 per hour which exceed the rate currently being achieved by 60 percent. We do believe that the handling rate under radar approach procedure is limited by human factors, i.e., the complex computational, decision, sequencing, and memory functions necessary to efficient radar approach are beyond the capacities of the unaided human being

Recommendation

We recommend that a program be instituted by the Federal Aviation

Agency leading to the development of an efficient computational aid display for use at radar approach installations A tentative design objective should be to increase the approach handling rate under radar approach procedures to 32 per hour.

Recommendation

We recommend that a study be undertaken by the Federal Aviation Agency with objectives of determining whether the current radar approach separation rules could be relaxed under certain conditions, i e , availability of backup radar.

Discussion

From an analysis of tape recordings of ground-air-ground communication channels, we conclude that thunderstorm activity aloft is a significant contributory cause for delay in the Midway approach holding patterns Under these conditions, the Kedzie Homer is frequently erratic and cannot be located by pilots Further, we conclude that delays are augmented when aircraft are moved from one pattern to another to avoid adverse weather at their assigned holding patterns. Evidently, air traffic controllers are not aware of the expected weather sufficiently far enough in advance to anticipate such situations. We believe that a study of winter storm tracks would show that such conditions prevail most frequently in the south and southeast sectors, and question whether the location of holding patterns in these areas lead to optimum arrangement.

We conclude that pilot reports of weather conditions made to air traffic controllers are not further available for use by weather forecasting services We conclude that air traffic controllers have only limited weather information available, either from radar or other sources, and the advent of airborne weather radar is the occasion for frequent disagreement between pilots and controllers as to weather conditions along the route.

Recommendation

We recommend that the Kedzie Homer be replaced with a more reliable system

Recommendation

We recommend that a climatological study be made of the Chicago Area to ascertain

(1) The most favorable locations for holding patterns to minimize the effects of thunderstorm activity

(2) The most favorable orientation of the instrumented runways at Midway and O'Hare basing the study on the climatology of surface winds when terminal ceilings are near minimums

Recommendation

We recommend that a meteorological unit be established and operate as an integral part of the Chicago ARTC to perform the following functions in close co-operation with air traffic controllers

(1) Examine pilots reports and initiate transmission of same to general weather services

(2) Supply controllers with detailed weather and winds aloft information

(3) Make decisions as to hold patterns to be used

Recommendation

We recommend that special weather data processing equipment be developed to enable this unit to effectively perform its function

Recommendation

We recommend that all future air traffic control displays provide for the inclusion of weather information, either derived from weather radar or from a synthetic reconstruction.

Discussion

During this analysis, it was apparent that the instrumented runways at Midway and O'Hare are so oriented as to mutually interfere with each other

Recommendation

The instrumented runway at Midway should be changed to correct this condition The new orientation should be based on the results of the climatological study referenced above.

c. Regarding Airports

Discussion

We conclude that delays due to aircraft waiting for gate space at Midway Airport constitute a serious delay situation. We further conclude that the complexity of the operational situation at Midway, coupled with the fact that Midway Commercial Traffic is expected to decrease markedly in the near future, preclude economically supportable recommendations to correct this situation at this time

We conclude that temporary expedients may prove effective

Recommendation

We recommend that mobile gates be utilized at Midway to permit discharge of passengers and baggage from aircraft parked at points remote from the terminal, and that passengers and baggage be transported to the terminal by ground vehicles.

Discussion

Further, from discussions with O'Hare controllers, and considering the import of the FAA National Airport Plan's expectation of future traffic at O'Hare, we conclude that gate delays will rapidly become a major problem at O'Hare

Recommendation

We recommend that a study be immediately instituted to determine what number of gates will be required at O'Hare, where they should be located, and the placement and configuration of ramps and taxiways to facilitate the optimum utilization of these gates

Discussion

Although to date we have been unable to adequately interrelate the operational parameters that pertain to Midway Airport, we conclude that sufficient basic data have been collected on this program to support such an analysis. We believe that further operations analysis should be performed on these data, either by analysis or simulation, since the results have both specific applicability to Midway and general applicability in providing an understanding of the operations of a typical airport under conditions of extremely high traffic

Recommendation

We recommend that additional operational analysis of the operations at Midway Airport be performed to develop a mathematical model of the process. This analysis should include approach operations, active runway operations, taxiway operations, and terminal or parking area operations It should include an analysis of the local and approach controller's decision function.

Discussion

Although there is almost no delay to aircraft on the ground at O'Hare at present, we anticipate that the commercial traffic load at O'Hare will increase markedly in the next few years. By 1965, the traffic at O'Hare is expected to be the most dense in the country Current approach facilities, runways, taxiways, and parking area will undoubtedly not be capable of handling this traffic without excessive delays Further,current general aviation and military operations at O'Hare must be moved.

Recommendation

We recommend that the Federal Aviation Agency establish a special working group to provide the engineers responsible for O'Hare developments with traffic forecasts, airport design data, and other technical information as soon as it is available from current research programs.

Recommendation

We recommend that plans for dual ILS at O'Hare be accelerated, based on the study of climatological conditions recommended above.

Recommendation

We recommend that the Federal Aviation Agency take those steps necessary to facilitate general aviation operations at small airfields in the Chicago Area. For example, until recently, it was not possible for general aviation IFR departures to be conducted from Palwaukee or Sky Harbor (which are in the O'Hare control zone) because O'Hare could not receive the pilot's radio transmission from these airports

d Regarding Analysis Programs

We conclude that on the current program approximately 70 percent of the effort was expended in collecting and organizing data, 20 percent was spent in analysis, and 10 percent in report preparation. We believe that future programs would benefit if less emphasis were placed on data collection and tabulation, and more on analysis This does not necessarily mean that less original data should be considered, but rather that the reduction and analysis should consider selective samples of these data. The samples to be thoroughly analyzed for operational characteristics should be selected following a preliminary analysis of traffic load, and the sample size should be based on statistical considerations to give the precision desired.

2. Recommendations on the Basis of Knowledge Gained from Discussions with Air Traffic Control Personnel

a. Chicago Air Route Traffic Control Center

(1) Communications

(a) One (1) VHF channel to provide remote peripheral coverage northwest in the vicinity of Lone Rock

(b) One (1) local VHF channel to provide separate control for O'Hare traffic arriving from the East

(c) One (1) local VHF channel to provide separate control for O'Hare traffic arriving from the West

(d) One (1) UHF channel to provide area coverage for high altitude jet aircraft

(2) Center Arrangement and Equipment

(a) It is recommended that current plans for installation of scan conversion equipment be immediately augmented to include one (1) horizontal display and two (2) vertical displays in addition to the three (3) vertical displays authorized.

(b) It is recommended that future plans for a revised center layout include additional space to accommodate a total of 12 horizontal displays for primary control. Vertical displays should be retained only to provide backup service.

(3) Routes and Procedures

(a) It is recommended that current plans for a three-level airway structure in the Chicago Area be thoroughly examined and approved by Chicago ARTC personnel because of anticipated interlayer transition problems

(b) It is recommended that the policy defining responsibility for Flight Following Advisory Service to high altitude jets be clarified to allow the aircraft receiving such service to be controlled off the transcontinental jet system at altitudes above civil airways to facilitate transition to and from the lower controlled airspace. Further, we recommend that procedures be established to allow direct communication between the ARTC and aircraft receiving such service, rather than the current practice of relaying messages through the GCI site.

(c) It is recommended that all areas between airways within 100 miles of the Chicago Terminal Area at altitudes above 10,000 feet be designated a control area to facilitate transition of aircraft from terminal area control to airways control.

b. O'Hare Airport

(1) Communications

It is recommended that additional frequencies be provided to establish dual local and ground control

(2) Equipment

It is recommended that the following equipment be provided or modified

(a) One (1) VOR or TVOR be installed west of O'Hare Field to establish boundary within which jet aircraft departing on runway 14R and making right turn must stay to provide a well-defined buffer zone (NOTE Naperville, API, serves this purpose satisfactorily for left turns.)

(b) The ASR-3 radar antenna currently installed at the south side of the airport be relocated to eliminate a blind spot to the south.

(c) One (1) additional repeater position in the IFR room for the ASR-3 radar be installed in the tower to provide radar control of aircraft on local airway between Chicago and Milwaukee. Similar equipment should be installed at Milwaukee.

(3) Airport

(a) It is recommended that additional parking areas be located so they will not interfere with the dual taxiway system.

(b) We recommend that plans be initiated for the installation of a taxiway lighting and centerline guidance system in the near future.

(4) Procedures

It is recommended that procedures and rules be established to regulate the assignment of schedules by airlines in anticipation of the expected increased volume of traffic at O'Hare.

c. Midway Airport

(1) General

In view of the fact that Midway Airport has a high level traffic load now, and this load is not expected to decrease in the future, it is recommended that an airport modernization program be instituted which should consider, but not be limited to

(a) Construction of a new tower structure to provide more space for present and future expansion

(b) Change the instrumented runway from 13R to eliminate conflict with O'Hare departure traffic

(c) Extend runways 27 outside present airport boundary to accommodate instrument operations Two runways of equal length should be provided

(d) Provide high speed, or additional conventional, turnoff points on active runways.

(2) Communications

(a) It is recommended that a study be undertaken to establish the feasibility of providing clear VHF channel for issuing both radar advisory and landing clearance to inbound IFR aircraft on a common frequency

(b) It is recommended that closed circuit TV be installed to facilitate communications between the tower cab and IFR room, and between the tower and the CARTCC.

d. General

It is recommended that a program be established to revise the personnel recruiting procedures and policies. This program should include, but not be limited to, the following considerations.

(1) Potential recruits should be given a better awareness of their job responsibilities at their initial interview, and the initial interview should be uniform throughout the country

(2) The basic entrance requirements should be revised to remove some requirements (such as flight time) and to place greater emphasis on education, aptitude, and job attitude

(3) The selection and training program should include

(a) More attention to probable job suitability on the basis of measures in areas such as spatial visualization, coordination and other special aptitudes to be determined, and general intelligence

(b) More careful measurement of achievement in acquiring job knowledge and skills and proficiency in performing job tasks, particularly under stress

Minimum scores, or criteria, should be established in both areas and used to determine whether a prospective recruit should enter or remain in training

(4) Civil Service regulations should be revised to recognize the critical performance required of a controller. Specifically, the probationary period should be extended to one and one-half (1-1/2) or two (2) years, and the supervisor should have greater latitude in submitting reasons for discharge.