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SIMULATION TESTS OF THE FACTORS AFFECTING IFR TRAFFIC CAPACITY AT CHICAGO O'HARE AIRPORT

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SUMMARY

This report describes a simulation study of high-density air traffic operations at Chicago O'Hare Airport under instrument flight rule conditions. In the current O'Hare Airport master plan, six tangential runways are proposed with the terminal building in the center of the field. The purpose of this study was to determine the configuration of these runways and associated airways structure to accommodate the maximum flow of arrivals and departures at O'Hare Airport All tests were conducted through the use of the dynamic air traffic simulator at the Civil Aeronautics Administration Technical Development Center

The traffic demand rates forecast for O'Hare Airport were higher than the capacity of a single approach lane. Two approach lanes operating simultaneously appeared to be the practical maximum for the area. Two dual approach systems were studied· a converging system and a parallel system The converging system appeared to offer the best possibilities for high-capacity operations. However, neither system is authorized under present radar separation standards. Before a large amount of funds is spent on a facility to handle a sustained volume of instrument flight rule traffic in excess of the number achievable with one approach lane, it would be wise to make sure that simultaneous dual approaches will be approved by the Civil Aeronautics Administration Office of Flight Operations and Airworthiness and industry.

The tests showed that an airport capable of handling 80 to 100 instrument flight rule operations per hour will require a highly complex traffic control installation, with many more controllers and radio channels than are presently in use at any civil airport in the world today. A high degree of control regimentation and coordination will be required if such a complex operation is to function safely and efficiently.

Tests showed that a marked improvement in arrival rates of jet transport aircraft could be realized if these aircraft commenced their approaches from lower initial approach altitudes. The best rate was achieved with jets integrating with other aircraft in the normal manner leaving feeding fixes at altitudes of 4,000 feet and below. The best arrival rate achieved in simulation for a sample of 60 per cent jet aircraft was 55 per hour operating onto two independent runways.

Tests showed that the utilization of O'Hare Airport will be restricted considerably by operations at Glenview Naval Air Station. To a lesser degree they will be restricted by operations at Chicago Midway Airport. Because of interference between O'Hare and Midway, there appears

to be no practical use for two proposed runways, Nos. 2R-20L and 14L-32R, at O'Hare, therefore, as long as Midway Airport remains active, it is recommended that these two runways be omitted from the construction program.

INTRODUCTION

The purpose of this simulation program was to evaluate various runway configurations at O'Hare Airport and to investigate the route structure required to handle the large volume of traffic predicted for the Chicago area.

O'Hare Airport, which is shown in Fig. 1, is being developed as the civil jet airport for the Chicago area, since Chicago Midway Airport will not accommodate large civil jet transports due to runway length limitations It appears that the total amount of traffic forecast for O'Hare will exceed the instrument flight rule (IFR) capacity which can be handled by a single-lane approach system with present day radar separations However, as long as present separation standards apply, the addition of a second approach lane will not increase the acceptance rate above that of a single lane. In order to proceed with the simulation study, it was necessary to assume that special separation criteria would be authorized to take advantage of the increased facilities. For dual approaches, the O'Hare Airport design offered two basic possibilities: a converging approach system and a parallel approach system.

A study of the Chicago metropolitan area with O'Hare Airport operating at 30 per cent of the Midway traffic load was conducted early in 1955.[1] In September 1956, at the request of the Office of Air Traffic Control, the Technical Development Center (TDC) began an additional simulation study of the Chicago terminal area. By December 1956, a total of 23 tests involving flights of 1722 aircraft, including 292 jet-type, was completed. It was necessary to stop the work at this point to modify communications equipment and expand simulator capacity to accommodate the increased traffic densities necessary for the en route phase of the study An interim report, which covered the results of the simulation tests up to that time, was prepared. The second phase of the Chicago tests was postponed until November, 1957, due to the assignment of other projects of higher priority. Meanwhile, these projects provided much valuable experience on civil jet procedures which were applied to the O'Hare study.

The forecast percentage of civil jet traffic at O'Hare increased to 60 per cent by the time the second phase was started. The traffic samples used in the second phase reflected this increase

1 C. M. Anderson and F M. McDermott, "Dynamic Simulation Tests of Several Traffic Control Systems for the Chicago Metropolitan Area," Technical Development Report No 270, April 1955

Four radar-qualified Center controllers were detailed to TDC for the second phase of the simulation program which began on December 2, 1957. In addition, industry representatives were consulted to provide forecasts of future traffic demand and jet aircraft operating procedures. Fifty-four tests involving flights of 3925 aircraft, of which 2501 were civil jets, were completed in the second phase of the simulation. This made a total of 77 tests, with a total of 5647 flights of which 2793 were jets. Tests were concluded on December 12, 1957.

FUNDAMENTALS OF TRAFFIC CAPACITY

Present regulations require the use of at least three miles' radar separation between aircraft. To avoid violating this minimum standard, it is necessary to establish additional separation when a faster aircraft is turned on to final approach behind a slower one, since the separation between the aircraft will decrease on the final approach. An additional allowance is needed to compensate for the 'spread" or variation in approach speeds of the aircraft. As a result, the average approach separation which can be maintained using manual radar spacing procedures is around 4.5 miles. With an average approach speed around 140 mph, the theoretical capacity of a single runway (traffic lane) is average ground speed divided by the average separations or 140/4.5, or about 31 approaches per hour.

If the final approach is fed by radar control from a single holding fix, the acceptance rate is limited by the cumulative effects of communications lag and slow descent rates of some aircraft. These effects can be greatly reduced by use of a dual-feed arrangement.[2]

For sustained operations over a long period, it is necessary that the takeoff capacity equal the landing capacity. If an independent runway is available for takeoffs, this capability can be maintained without any reduction in the landing capacity just mentioned. However, if the landing runway, or a runway which intersects the landing runway, must be used for takeoffs, it is necessary to increase the separation between landing aircraft to allow time to "sandwich" takeoffs between successive landings. The amount of separation required to allow for this factor will vary with the specific runway configuration used, but it will seldom average less than six miles. Continuing from the above example, this will allow a maximum of 140/6 or about 23 instrument approaches per hour, with the same number of takeoffs. It follows then that any airport which has to handle a sustained demand rate greater than 20 to 25 approaches per hour requires an independent takeoff runway, if the demand exceeds about 30 approaches per hour under present separation rules, an additional approach path and landing runway is required.

[2] C. M. Anderson and T. K. Vickers, "Application of Simulation Techniques in the Study of Terminal-Area Air Traffic Control Problems," Technical Development Report No. 192, November 1953.

Whenever wind conditions require aircraft to circle the airport before landing, additional separation must be used between approaches to guard against the possibility of a missed approach climbing head-on into another aircraft on the letdown path. To avoid large reductions in the acceptance rate under certain wind conditions, it is desirable to establish, for each airport, instrument approach paths in two directions which are approximately opposite from each other.

Since the forecast demand rate at O'Hare exceeds 30 approaches per hour, the principal objective of this simulation program was directed toward studying the rates obtained with various dual simultaneous approach systems.

As the over-all capacity of a traffic system depends considerably on the number of independent flight paths which can function simultaneously, one aim in setting up the route and terminal systems for these tests was to minimize the amount of interference between airports by keeping the routes to each airport as independent of the routes of the other airport as possible. This, in turn, tended to keep the combined terminal-area acceptance rate at a maximum

Another aim of this program was to set up runway configurations which would permit O'Hare Airport to maintain maximum capacity under two approximately opposite wind directions This concept was adopted because it was realized that schedule reliability will become increasingly important when jet speeds and operational costs are considered, therefore, it will become even more necessary that airport capacities remain as high as possible regardless of the direction of the prevailing wind. The location of Midway Airport prevents ideal application of this objective. Consideration was given to the use of a second operating direction for each airport, and the ability of one airport to shift operating direction independently of the other.

Other important factors that have a bearing on the capacity of the O'Hare Airport include the effect of facilities having varying degrees of desirability or usability. For example, if jet takeoff requirements require the extension of runways beyond the basic 8,000-foot length proposed on the original O'Hare master plan, it may be physically impossible to extend all runways an equal distance The resulting complication would be that one of a pair of runways might be undesirable or unusable due to aircraft gross weight. The probability of one of a pair of nonparallel runways becoming undesirable or unusable due to cross-wind components could also limit the airport capacity. If all arrival runways are not equipped with high intensity approach lights and runway and taxi lights of equal usability, one may be more desirable than another

The highly complex control system necessary to handle a large volume of traffic cannot function efficiently if controllers are forced into negotiations with pilots for a runway other than the one assigned.

If certain runways at O'Hare are extended to intersect others, the runways crossed will no longer be independent, and the capacity will be reduced accordingly.

TEST ASSUMPTIONS

Radar and Communications Coverage.

It was assumed that dependable primary or secondary radar coverage would be available within a radius of 70 nautical miles of Midway Airport and that direct air/ground/air communication would be possible with all aircraft operating under instrument flight rules within this area.

Jet Operation.

It was assumed that all civil jet operations would be handled at O'Hare Airport and that runway occupancy times for jet aircraft would not exceed those of the propeller (prop) aircraft. It was assumed that jet aircraft would be able to "hold" within the dimensions specified by TSO-N20a for holding reservation areas. Jet operating characteristics used in these tests are summarized in Table I.

Up to the present time, no experience has been attained in operating civil jet aircraft on instruments under high-density traffic conditions. One of the critical operating characteristics of these aircraft which have not been defined completely as yet, is the turning rate which such aircraft will use in approach patterns. Although such aircraft will use a 1 1/2°-per-second turning rate at high altitudes and speeds, the altitude and speed limits below which they will be able to make standard 3°-per-second turns are not known. In lieu of this information, all turns of jet aircraft were made at the 1 1/2°-per-second rate. This assumed rate made approach control operations more difficult. However, it is believed that any error introduced by this procedure would be on the conservative side, since the 3° standard rate of all aircraft in the approach pattern would tend to increase airport acceptance rates.

Shuttle Flights.

It was assumed that no fixed-wing shuttle flights would operate between O'Hare and Midway Airports. It also was assumed that all helicopter flight paths would be independent of fixed-wing flight paths.

Other Airports and Areas

It was assumed that O'Hare Approach Control would vector all Glenview arrivals for a straight-in approach to Runway 17 at Glenview. It was assumed that Bong AFB, Meigs Airport, and DuPage County Airport would not be operating under instrument flight rules. It was assumed that Detroit, Cleveland, and the outer Chicago Air Route Traffic Control (ARTC) sectors would be able to handle the traffic inputs and outputs simulated in these tests.

Obstructions.

It was assumed that the WBBM, WGN, and WMAQ antenna towers would not interfere with a normal instrument approach to Runway 9R at O'Hare Airport

Separation Standards.

It was assumed that present radar separation standards would be modified to permit the operation of dual approach lanes

EVALUATION CRITERIA

Traffic Capacity.

The most important criterion of airport performance is the capacity or acceptance rate These data were determined during the simulation tests by subjecting the airport to traffic loads in excess of its normal capacity and measuring the number of actual operations per hour

Controller Workload.

At the present time the communications workload is the only portion of the entire load that can be measured accurately. However, it forms a rough index of controller workload as there usually is a high correlation between the amount of control and the amount of communications activity

Pending the development of a quantitative method of measuring the other factors involved in the total human control workload, it has been found useful to employ subjective analysis, by the controllers themselves, to determine the relative workloads of various systems. Subjective opinions were therefore used in evaluating the systems tested.

CONTROL PROCEDURES

General.

Since the en route airway structure surrounding the Chicago metropolitan area is dependent to a large degree upon the placement of the holding fixes in the terminal areas, the terminal area was studied first.

Two terminal area IFR rooms were simulated. The layout of the O'Hare IFR room is shown in Fig 2. Controller staffing varied according to the terminal area configuration being simulated.

In most tests, four O'Hare approach controllers were required and usually worked two to a scope. The layout used for the Midway IFR room is shown in Fig. 3. One radar controller operated from this location. Small flight progress boards were used for posting flight data. To obtain optimum acceptance rates, each approach controller used a separation table designed for the particular system being simulated. An example of this table is shown in Fig. 4.

The separation table was computed to make allowance for the following factors:

1. The three-mile radar separation minimum
2. Normal variations in approach speed between aircraft of the same speed category.
3. The speed differential between successive aircraft of different speed categories.

Curved reference lines, spaced at radii of three, five, and seven miles from the approach gates, were marked on the radar maps to serve as guides in securing the specified separation between aircraft. Additional separation required for the various phases tested was applied from other tables, as noted in the description of these tests.

Arrivals and departures operating on routes within a radius of 80 nautical miles of Chicago were simulated. Four experienced radar controllers from the Chicago ARTC Center controlled this traffic utilizing two superimposed panoramic radar displays (SPANRAD) as shown in Figs. 5 and 6. This traffic was segregated by radio frequencies so as to allow two controllers, operating from one SPANRAD, to control all the arriving traffic at O'Hare, Midway, and Glenview Airports. Departing flights from these airports were controlled from the other SPANRAD by the other two controllers. Small target markers were used to combine radar position information with the aircraft's flight-plan information. Flight-identity, route, and altitude information was posted on these markers Whenever practicable, short-range clearances were issued to the towers for departing flights.

Blocked altitudes were used at certain route intersections to minimize the amount of coordination necessary. Whenever possible, tunneling of departures was held to a very short distance and the more heavily traveled routes had unrestricted climbs

Traffic Samples.

The traffic sample used in the en route simulation tests was based upon traffic densities forecast for the 1962 to 1965 period. This forecast was provided by the airport consultants to the city of Chicago as well as from published predictions. Table II shows the composition of this sample, as well as the samples used in the terminal-area simulation.

TERMINAL-AREA TESTS

Parallel Approach Courses.

Runways 14L and 14R at O'Hare were used in all tests of parallel approach lanes This landing direction was selected because of Midway airspace requirements. Three modes of operation were tested as detailed below.

A. Independent Operation. See Fig. 7A. Separation during approach was provided only with respect to other aircraft in the same lane, but without regard to traffic activities in the opposite lane. This mode of operation produced an acceptance rate of 56 aircraft per hour. Coordination between controllers was minimized. However, tests indicated that a slight overshoot of an aircraft turning on approach could produce a very hazardous situation with respect to an aircraft in the opposite lane, since the two approach lanes were only about 8,000 feet apart. Overshoots were quite common, particularly with jet aircraft turning at a rate of 1 1/2° per second.

B. Three-Mile Separation at Turn-On. See Fig. 7B. Normal separation was provided between successive aircraft in the same lane. In addition, at least three miles' separation was maintained from aircraft in the opposite lane until aircraft were established on the localizer courses. During the remainder of the approach it was not necessary to maintain longitudinal separation between aircraft in opposite lanes as long as such aircraft remained aligned on their respective approach courses. Controller coordination was somewhat greater than with Mode A operations. Total capacity for the two runways was 42 aircraft per hour

C. Altitude Separation at Turn-On. See Fig. 7C. Normal separation was provided between successive aircraft in the same lane. In addition, altitude separation was provided between aircraft turning on opposite approach lanes This was accomplished by moving the turn-on points at least five miles beyond the outer marker All aircraft turning into one final approach were kept 1,000 feet higher than the aircraft turning into the other final approach.

Although this procedure reduced the overshoot hazard at the turn-on point, the final-approach paths were somewhat longer than those used in Modes A and B in order to provide sufficient room for aircraft to lose the extra 1,000 feet altitude between the turn-on point and the approach gate. This extra final approach distance increased the possibility of overtaking on the final approach course. As as result, the initial separation between successive aircraft had to be increased, thus reducing lane capacity. The total acceptance rate of the two runways was 45 aircraft per hour. Controller workload was higher than Mode B due to the longer approach paths However, the coordination workload was very slight.

In general, the tests showed that parallel approach operations were somewhat handicapped because each runway could be fed only from one side. The inability to place feeding fixes at optimum locations reduced the acceptance rates attainable with the parallel configuration. Although the special procedures used in Modes B and C eliminated the overshoot hazard at turn-on, the hazard of two aircraft proceeding on parallel courses only 8,000 feet apart was still present Therefore, the alignment of aircraft on the final approach courses had to be watched very closely during the entire approach operation.

Converging Approach Courses.

The use of converging runways simplifies the feeding problem somewhat. At least one of the approach courses usually can be fed from both sides instead of from the outside only, as with a parallel configuration. Two modes of operation are possible, either independent or coordinated, as described below.

A Independent Operation. See Fig. 8A. Normal separation would be provided between aircraft in the same lane, but without regard to aircraft in the other lane In order to save simulation time, this mode was not tested, as no operational problems existed in this mode that were not encountered in the tests of the coordinated mode of operation. Theoretically, the total capacity of the independent system was between 55 and 60 operations per hour, approximately double that of two independent single runways.

The converging approach system provides excellent separation between all normal traffic lanes, as long as all approaches are completed normally. The two approach paths are independent of each other. Touchdown points for the two runways are approximately 1 1/2 miles apart. From the safety standpoint, the only questionable aspect of this operation is the fact that an aircraft missing approach on one of the two runways, and proceeding straight ahead, would cross the other runway. For this reason, simultaneous missed approaches by two aircraft on opposite runways conceivably could result in a collision hazard.

The likelihood of ever getting two missed approaches perfectly synchronized in such a fashion may be less than, for example, the likelihood of a four-engine aircraft losing all four engines simultaneously. A further deterrent to the collision hazard in this system is the fact that, even in the event of two simultaneous missed approaches, it still should be possible for the radar controller to guide one aircraft slightly offside and thus prevent a collision

To approach this problem in a practical manner, it may be feasible to permit independent operation of two converging but nonintersecting runways down to such weather minimums at which the possibility of a missed approach is still very remote. This procedure would take advantage of the high acceptance rates possible with independent dual-approach operations and yet not expose aircraft to a measurable collision hazard. It is believed that the provision of improved radio approach and lighting aids, as well as the growing use of ILS approach couplers, would tend to lower these minimums. Whenever weather conditions would fall below these arbitrary limits, independent approach operations would cease and the system would revert to the coordinated mode described below.

B Coordinated Operations. See Fig. 8B. Normal separation minimums would be provided aircraft in the same lane. In addition, special procedures would be utilized in clearing approaches in opposite lanes, to maintain a desired two-mile separation between all aircraft at the runway crossover point. This separation would be provided by the approach through the use of a special spacing table. This table aims at a desired separation of two miles at the crossover point, due to the normal variation in aircraft approach speeds it would have a one per cent probability of going as low as one mile. However, tests of this system indicated that even one mile separation at this point would be quite safe, as aircraft would be diverging rapidly after crossing that point.

The total arrival rate attained in these tests was 43 aircraft per hour. Controller workload was extremely high because successive approaches had to be directed to alternate runways in order to take advantage of the reduced crossover separations. To set up adequate separation, each controller had to know the kind of aircraft he was following in his own lane, as well as the kind of aircraft he was following in the opposite lane. It was found that this kind of highly coordinated operation, by four approach controllers, required a regular "firing order" so that each controller would have time to prepare for his next operation and to follow other aircraft in the proper sequence. Such teamwork required a very high degree of coordination and considerable practice before smooth results were achieved. It would not be recommended as a continuous control procedure, but only as a method of maintaining a moderately high acceptance rate under conditions when the weather was too poor to permit the independent operation of two approach lanes.

Comparison of Parallel and Converging Approach Systems

The basic approach systems tested are shown in Figs. 9, 10, and 11. Arrival rates of the various approach systems are shown in Fig. 12. It should be emphasized that none of these systems conforms to present separation standards.

An analysis of the parallel and converging systems showed that the parallel system had an advantage regarding the ability to cross-feed arrivals to equalize traffic flow in the two landing lanes. Tests showed that a surge of traffic coming from one direction could be divided easily to feed into the two parallel runways. With a converging approach system, such a procedure was not always practical as the distance between the feeder fixes for opposite runways involved much longer flight paths. A theoretical analysis indicated that when crossfeed could be used, delays would be about 50 per cent lower than they would be otherwise.

The wind will affect operations on both runways equally in a parallel system. In a converging system, unequal effects may force the system to operate temporarily as a single runway system and thus reduce system capacity. However, the greater distance between the normal flight paths of a converging runway system appears much safer than the side-by side operations of a parallel system.

Although, theoretically, the capacity of a single departure runway would be considerably higher than the capacity of a single arrival runway, simulation tests showed that a single departure runway could not handle a continuous traffic load equivalent to the input of two landing runways. Takeoff delays built up exorbitantly until an additional departure runway was provided. This led to the practical conclusion that an airport which requires a dual approach system also requires dual independent departure runways.

The O'Hare master plan, even as modified, does not provide space for two independent departure runways when any parallel approach system is used. However, a converging approach system provides the necessary departure facilities. This factor resulted in the final decision that the converging approach system offered the highest over-all capacity for O'Hare Airport. The converging approach configuration was used in the subsequent air route tests.

Controller Workload.

It was found that one controller could not control traffic efficiently from two fixes with a loading of 25 to 30 aircraft per hour even though his communications channel might be able to accommodate the load. This fact resulted in the assignment of but one fix to a controller. With a system requiring four fixes, this implies the use of four arrival controllers with separate frequencies.

In systems in which two approach lanes were controlled independently, the coordination between each pair of arrival controllers was the same as that required for any two-controller radar system, however, when restrictions were applied to the independent approach courses, as previously described, it was necessary to establish a definite rotation or sequence between controllers in order that coordination could be minimized and proper control exercised to comply with the separation standards used. When this sequence was not followed the capacity suffered accordingly.

Controlling departures at a rate of 40 to 60 per hour proved too much for one controller and one runway. To handle this volume, two runways were necessary, each with a separate departure radar controller. When tower personnel were required to issue long-range route clearances, an additional controller was necessary. It was assumed that ground control duties were performed by other personnel.

Table III gives some indication of the complex approach control facility that was necessary to handle air traffic from four feeder fixes to dual approach lanes. Tests indicated that the ARTC Center also would require some expansion to cope with this volume of traffic.

Jet Approach Procedures.

During the O'Hare terminal area simulation, it became evident that the altitude from which jets were fed to the ILS affected the arrival rate. In order to obtain data on this effect, a series of simulation tests were run in which the only variable was the altitude from which the jets were fed. The feeding altitudes were 20,000, 10,000, and 4,000 feet. Arrival rates and communications data are summarized in Fig. 13. It was found that the acceptance rate became progressively higher as the initial approach altitude leaving the holding fix was reduced. This was due to several factors which are discussed below.

The length of the approach path is a function of the altitude which must be lost For example, an approach from 20,000 feet requires an approach path about 40 miles long Long approach paths require a large number of aircraft on approach simultaneously in order to keep the final approach lane operating at top capacity. Tests showed that the more aircraft there are in the approach pattern, the higher the communications workload and the more inaccurate the final approach spacing This is because the controller's attention is divided between a larger number of aircraft so that he does not have enough time to do a precise spacing job. In addition, longer common paths increase the opportunity for deviations in speed to affect the spacing between successive aircraft.

Additional problems of jet operation are caused by the flight characteristics of the aircraft First is the relative lack of maneuverability associated with the very slow turning rate of 1 1/2° per second This requires controllers to plan the flight paths of such aircraft much further ahead. Much more time and maneuvering room are required than for aircraft which can make turns at 3° per second

Conversely, as shown in Fig. 14, a critical problem can be posed if the controller plans his vectoring procedure on the expectation that the aircraft will make a 1 1/2°-per-second turn, but instead the pilot makes a 3°-per-second turn. This points up the need for standardization of flight characteristics in the approach pattern.

Another jet control problem which is intensified by the use of high initial approach altitudes concerns the variable speeds of such aircraft during descent. This characteristic makes prediction and spacing operations extremely difficult for the controller. The problem can be minimized by having the aircraft leave the holding fix at low altitudes where normally it would be slowed down to a speed close to approach speed.

Simulation tests showed that the military-type teardrop pattern is poorly adapted for radar spacing operations. From the time the turn is started by an aircraft at the outer end of the pattern, very little can be done to adjust the spacing of thas aircraft behind the preceding aircraft The teardrop penetration approach requires more airspace than is available in the vicinity of O'Hare under the traffic densities tested. No satisfactory way was found to fit a teardrop penetration into the Chicago complex. For these reasons it is recommended that any military jets using O'Hare conform to the standard approach procedures used for civil jets.

It is believed that it will be possible, with improved primary or secondary radar, plus the use of a new traffic control computer which is under development, to slow jets to an intermediate speed during their last 100 miles of flight and thus be able to absorb most of their delay during a cruising descent. Jets then could enter the terminal area at low altitudes and thus facilitate the attainment of a high acceptance rate by the approach control system.

Interference Between Airports.

No way was found in simulation to operate Glenview independently of O'Hare. This was due primarily to the proximity of the two airports, Glenview being six miles northeast of O'Hare All Glenview IFR traffic was handled by the O'Hare tower and vectored to a position for handoff to Glenview GCA for a straight-in landing on Runway 17. It was found in simulation that O'Hare operations were affected by operations at Glenview in the following manner

1. During easterly wind conditions, a Glenview arrival or departure interrupted or stopped O'Hare departures

2 During westerly wind conditions, a Glenview arrival or departure interrupted or stopped O'Hare arrivals.

3. Arrivals were interrupted at O'Hare fixes as aircraft arriving from an upwind direction were handed off through the area of other fixes while being vectored to Glenview.

Under saturated traffic conditions, each IFR operation at Glenview cost at least one, and sometimes more, operations at O'Hare. If circling approaches were necessary at Glenview, this caused additional delay and subsequent reduction of capacity at O Hare.

There is barely enough space between Midway and O'Hare to operate southeast approaches at high rates at both airports today When east approaches are commissioned at O'Hare, Midway approach operations will be squeezed further Study showed that interference between the two airports could be reduced greatly if the present southeast approach at Midway could be replaced by an east approach to Runway 9 or a northeast approach to Runway 4. Obviously, this would require an expensive construction program. However, tests indicated that the change would enable Midway to continue operations at the present rate even when O'Hare was operating a dual approach system at maximum capacity.

Tests indicated that as long as Midway remains active, there is no reason for constructing Runways 2R-20L and 14L-32R at O'Hare, as these runways could not be used under IFR conditions.

During the simulation tests, it was assumed that radar guidance of missed approaches always would be possible. However, no airspace could be designated exclusively for missed approaches at either O'Hare or Glenview.

AIR ROUTE TESTS

Prior to the air route simulation runs, many hours were spent on a map study to determine an optimum air route structure for the Chicago area under east and west wind conditions. This study was conducted with the assistance of control personnel from the Chicago ARTC Center. As a result of this study, a route structure for each wind condition was selected for simulation purposes. Figures 15 and 16 show these routes. A list of location identifiers is presented in Table IV. Changes in the present route structure were kept at a minimum, as shown in Table V.

It was necessary to change the direction of flow on some of the routes because of the revised distribution of traffic using O'Hare. For instance, to balance the inbound O'Hare traffic volume more evenly, aircraft from the southeast were rerouted over Peotone and fed in with other traffic from the west. During the air route phase of the study, it was assumed that O'Hare IFR operations would be conducted on the following runways:

East wind condition - Landing Runway 9R and 14R
Takeoff Runway 9L and 2L

West wind condition - Landing Runway 20R and 27R
Takeoff Runway 27L and 32L

Insofar as possible, fixes used for opposite wind conditions were on extensions of the routes to former fixes.

During simulation the area under study was divided geographically into two sectors, with the exact boundaries varying somewhat, depending on the systems and flight operations being tested. Because of a basic limitation of the simulator which permitted only 24 aircraft to be operated simultaneously, it was not always possible to handle all arrival and departure operations simultaneously. In some cases only arrivals were run. In other tests only the departures were operated. In any case, full allowance was made for the airspace which would be used by the other aircraft.

Outer ARTC sectors were not simulated and the ability of the outer sectors to handle the traffic volume simulated was not analyzed. As traffic increases at O'Hare Airport, it is expected that further study of the en route flow from other centers will be necessary.

Arrivals appeared in the system approximately 80 miles from the airports. They were controlled through the ARTC territory by radar and handed off to approach control at the appropriate transfer points. Each controller was teamed with an assistant controller who handled the data-collection and display functions using flight progress boards and the interphone system.

The air route tests indicated that the routes depicted in Figs. 15 and 16 appeared practicable, however, at the traffic densities tested, it appeared that an additional independent eastbound route would be desirable to relieve the traffic load on the single O'Hare eastbound route which is illustrated It is believed that this route could be provided by the reassignment of existing routes east of Chicago.

The movement of IFR traffic at the densities simulated was heavily dependent on the use of air route radar throughout the area covered by the simulation tests. To expedite jet operations, it would be desirable to extend the high-altitude radar coverage to approximately 120 miles, particularly for the routes east of Chicago.

CONCLUSIONS

1. The location of Midway Airport will not permit IFR utilization of all runways in the O'Hare master tangential runway plan Placement of O'Hare feeding fixes in an optimum position cannot be realized because of the close proximity of Midway.

2 East and northwest approaches at Midway would permit a more practical vector area for Midway and would reduce interference between the two airports It also would enable O'Hare to shift operating direction without requiring a similar shift at Midway. The present southeast approach at Midway eliminates any possibility of departure traffic using the area between the two airports.

3. Navy Glenview IFR traffic should be controlled by O'Hare tower. Even then, one operation at Glenview will reduce capacity at O'Hare by one operation and under certain conditions perhaps by five operations

4. The military jet (teardrop penetration approach) is not compatible with a high-density operation at O'Hare. Military jet traffic should conform to civil jet procedures.

5. Civil jet arrivals are easier to integrate into an approach sequence if they are descended to lower altitudes on route. A higher landing rate then can be accomplished. This primarily is due to the lower true airspeeds possible, which result in a smaller radius of turn and less mileage to dissipate in descent If jet aircraft begin approach from higher altitudes such as 20,000 feet, the wide range of speeds with the slow turning rate make it difficult to space arrivals efficiently. This results in a marked reduction in landing rate. During the simulation tests, the best landing rate was accomplished when jet aircraft were handled in the normal manner of propeller-driven aircraft in approach patterns at the lowest altitude available. However, tests indicated that small spacing adjustments were very difficult to accomplish with jet aircraft due to their slow turning rates and high speeds. As a result, spacing inaccuracies reduce the acceptance rate of the approach system.

6. The departure rates simulated indicate the necessity for two independent airways to handle O'Hare eastbound flights

7. Routing for westbound O'Hare traffic will require use of the airspace in the vicinity of the proposed Bong AFB.

8 From the safety standpoint, the converging approach system appears superior to a parallel approach system The only questionable aspect of this operation is the fact that an aircraft missing an approach on one runway and proceeding straight ahead will cross the centerline of the other runway, therefore approaches by two aircraft missed simultaneously conceivably could result in a collision hazard It may be feasible to permit independent operation of the two approach lanes down to some weather minimums at which the possibility of a missed approach is still very remote. Below these arbitrary limits, a control procedure could be imposed which would provide positive separation at the crossover point in the event of a missed approach by any aircraft.

9. The control system used in this simulation placed a high degree of dependence on radar, creating a very high controller workload per aircraft. Communications channel loading and controller attention to accomplish optimum spacing dictated a maximum of one stack per controller for high-density operations. During high-density traffic operations one controller was required per departure runway with additional personnel for ground control duties. When tower personnel were required to deliver long-range air route clearances, an additional tower position was necessary.

10. Complex multiple runway feeding fixes require a large amount of airspace and a large number of controllers with discrete frequencies. Sustained high-traffic handling capacity by approach controllers vectoring to multiple runways requires close adherance to a predetermined order of sequencing

11. Using a 60 per cent jet aircraft sample, the maximum number of arrivals obtained in simulating the independent operation of two approach lanes was about 55 arrivals per hour. Any significant increase in IFR airport capacity will require radical changes in operating concepts and control equipment.

RECOMMENDATIONS

1. As soon as possible, steps should be taken to determine the conditions under which dual simultaneous approaches can be approved by the Office of Flight Operations and Airworthiness and accepted by industry.

2. As traffic increases at O'Hare an analysis of the traffic flow in adjacent en route centers should be accomplished.

3. If it is decided to provide for bidirectional coverage and dual simultaneous approaches at O'Hare Airport, the following phases of construction are suggested.

Phase I   Build Runway 9R - 27L

Landings on Runway 14R
Takeoffs on Runways 9C or 9R

Phase II.   Install ILS on Runway 27C (existing east-west runway)

Easterly wind condition	Westerly wind condition
Landings on Runway 14R Takeoffs on Runways 9R or 9C	Landings on Runway 27C Takeoffs on Runways 27L or 32L

Phase III. Build Runway 2L - 20R

Install ILS on 20R and 9R

Easterly wind condition	Westerly wind condition
Landings on Runways 9R and 14R	Landings on Runways 20R and 27C
Takeoffs on Runways 2L and 9C (Optional on 9R at expense of arrivals)	Takeoffs on Runways 27L and 32L

Phase IV   Replace Runway 9C - 27C with Runway 9L - 27R

Move ILS from 9C - 27C to 9L - 27R
Operations remain same as Phase III by substituting 9L - 27R in lieu of 9C - 27C.

4. Before Phase III operations are commissioned, consideration should be given to the elimination of the present southeast approach at Midway, replacing it with an approach to the east or northeast

5 As long as Midway remains active, it is recommended that O'Hare Runway 2R - 20L and 14L - 32R be omitted from the construction program.

TABLE I

JET SPEED PROGRAM USED FOR CHI - ORD SIMULATION

Jet Arrivals.

Cruise into terminal area until approaching clearance limit fix.

Altitude	Airspeed in Knots Indicated	True	Temperature, °C
20,000 and above	330	450	-20
16,000	260	345	-10
15,000	260	330	- 5
10,000	260	305	+ 5
5,000	240	260	+15

Jet Holding.

At clearance limit fix and immediate area.

Altitude	Airspeed in Knots Indicated	True	Temperature, °C
20,000 and above	230	315	-20
Start descent	250	340	-20
15,000	230	290	-10
10,000	230	260	- 5
6,000	225	245	+ 5
5,000	200	220	+15
4,000	190	200	+15
3,000	180	190	+15
2,000	160	160	+15

Jet Descent Rates.

Not in holding pattern. Three thousand feet per minute, slowly reducing to 500 feet per minute below an altitude of 6,000 feet.

In holding pattern. Standard rule of maximum normal rate of descent until 1,000 feet above assigned altitude, then 500 feet per minute.

TABLE I (cont'd)

Jet Climb Rates and Speeds.

Speed increasing to 230 knots true at two miles from airport. No turn or climb above 2,000 feet until beyond two-mile point. After two-mile point climb at an average of 1,500 feet per minute slowly increasing speed to 290 knots true. Use 290 knots until cruising altitude reached, then use cruise speed noted above. If held down below 5,000 for 20 or so miles, use speed of 260 true.

TABLE II

EN ROUTE TRAFFIC SAMPLE

250 aircraft in 2-hour sample

75% at O'Hare (Glenview) - 188 aircraft

168 at O'Hare
- 60% jets or 100 aircraft
- 40% propeller or 68 aircraft

20 at Glenview
- 10 jets
- 10 propeller

188 aircraft at O'Hare (Glenview)
- 100 arrivals
- 88 departures

25% at Midway - 62 aircraft - all propeller
- 36 arrivals
- 26 departures

Percentage of traffic by direction of flight:

50% to and from the East - sector between Muskegon and Washington, D. C.

30% to and from the Southeast, South and Southwest

10% to and from the West

10% to and from the North and Northwest

O'HARE TERMINAL AREA TRAFFIC SAMPLE

1956 60 flights in 2-hour sample
- 17% jets or 10 aircraft
- 83% propeller or 50 aircraft

1957 67 flights in 70-minute sample
- 60% jets or 40 aircraft
- 40% propeller or 27 aircraft

TABLE II (cont'd)

JET FEEDING ALTITUDE TERMINAL AREA TRAFFIC SAMPLE

40 flights in 60-minute sample - 100% jets

TABLE III

EQUIPMENT AND TOWER PERSONNEL REQUIRED BY A DUAL SIMULTANEOUS APPROACH SYSTEM CAPABLE OF OPERATING UNDER TWO WIND CONDITIONS

1. Equipment.
   - 4 ILS localizers
   - 4 glide paths
   - 8 compass locators
   - Two or four 75-Mc fan markers (2 probably will suffice on parallel system)
   - 4 sets approach lights
   - Primary or secondary radar complete with indicators as required.

2. Radio Frequencies.
   - 4 discrete approach control vector frequencies
   - 2 discrete departure frequencies
   - 2 discrete ground control frequencies
   - 1 discrete route clearance delivery frequency.
   - 2 discrete local controller frequencies

3. Personnel.*
   - 4 approach controllers
   - 2 departure controllers
   - 2 ground controllers
   - 1 route clearance delivery controller
   - 2 local controllers

*If monitoring function is required, 2 more controllers necessary. Does not include supervisors, who are necessary to coordinate, and flight-data personnel required. Does not include personnel, equipment or frequencies for Airport Surface Detection Equipment (taxi radar). Does not include any of the requirements of the air route control transition functions.

TABLE IV

CHICAGO AREA IDENTIFIERS

ALN - ALLEN
AMB - AMBOY
API - NAPERVILLE

BAS - BASS
BDF - BRADFORD
BLH - BULLHEAD

CAR - CARP
CGT - CHICAGO HTS.
CST - CUSTER

DPJ - DUPAGE

EDZ - KEDZIE
ELG - ELGIN
ELX - KEELER
EON - PEOTONE
EVN - EVANSTON

FRE - FREEPORT
FWA - FORT WAYNE

GEN - GENOA
GSH - GOSHEN

HEB - HEBRON
HIN - HINSDALE

JOT - JOLIET
JVL - JANESVILLE

KNX - KNOX

LAF - LAFAYETTE
LEM - LEMONT
LOP - LOOP

MEN - MENDON
MER - MERMAID
MCL - MCCOOL
MIL - MILLERSBURG
MKE - MILWAUKEE

NEG - NEW GLARUS
NIL - NILES

OBK - NORTHBROOK

PAP - PAPI
PCH - PERCH
PIA - PEORIA
PLL - POLO
PMM - PULLMAN
PNT - PONTIAC
PTW - PITTWOOD

RBS - ROBERTS
RFD - ROCKFORD

SGV - SUGAR GROVE
SHE - SHELBY
STB - STEAMBOAT
SYC - SYCAMORE

TAY - TAYLOR
TPN - TARPON
TRI - TRIUMPH

UNO - UNION

WFD - WHEATFIELD
WIF - WHITEFISH

TABLE V

SUMMARY OF CHANGES MADE IN AIRWAY CONFIGURATION

PROPOSED VOR CHANGES	REASON
1. NORTHBROOK VOR moved approximately 6 miles northeast.	To provide air space for 2 holding fixes east of O'Hare Runway 14.
2. O'Hare TVOR or VOR commissioned on airport.	Navigation aid for parallel independent routes for O'Hare and to establish holding fix radials.
3. MENDON, Mich. VOR commissioned.	Navigation aid for parallel independent routes for O'Hare.
4. McCOOL, Ind. VOR commissioned.	Navigation aid for parallel independent routes for Midway.
5. JOLIET, Ill. VOR relocated as programmed.	
6. ELGIN, Ill. VOR commissioned.	Basis of independent route system west of Chicago.

AIR ROUTE MODIFICATIONS AND ADDITIONS	REASON
1. Victor 97 extended from Hebron east to Victor 7.	To provide westbound route from O'Hare - Glenview.
2. Victor 100 relocated between O'Hare TVOR and Keeler VOR.	To provide independent eastbound O'Hare departure route.
3. Victor 116 relocated between O'Hare TVOR and Mendon VOR.	To redirect Chicago traffic toward O'Hare.
4. Victor 218 relocated from Perch to radial from O'Hare TVOR.	To divide traffic arriving O'Hare from the east.
5. Victor 84 relocated from Perch to radial from O'Hare TVOR.	To divide traffic arriving O'Hare from the east.

TABLE V (continued)

AIR ROUTE MODIFICATIONS AND ADDITIONS	REASON
6. Victor 92 relocated between Goshen VOR and McCool VOR.	Parallel independent route.
7. Victor 8 relocated to go from McCool VOR - Knox Intersection to Mercer VOR.	Parallel independent route.
8. Victor 10 relocated to go from Bradford VOR to Sugar Grove Ints. to Elgin VOR.	To redirect Chicago traffic toward O'Hare.
9. Victor 172 to go from Polo VOR to Sycamore to Elgin VOR.	Redirect Chicago traffic toward O'Hare.
10. Victor 100 North added between Rockford VOR and Northbrook VOR.	Shorter route to O'Hare during westerly wind conditions.
11. Victor 177 deleted.	
12. Victor 9 relocated between Milwaukee VOR and Joliet VOR.	To provide holding pattern and vector airspace.
13. Victor 7 relocated approximately over existing Victor 7 East.	To provide holding pattern and vector airspace.

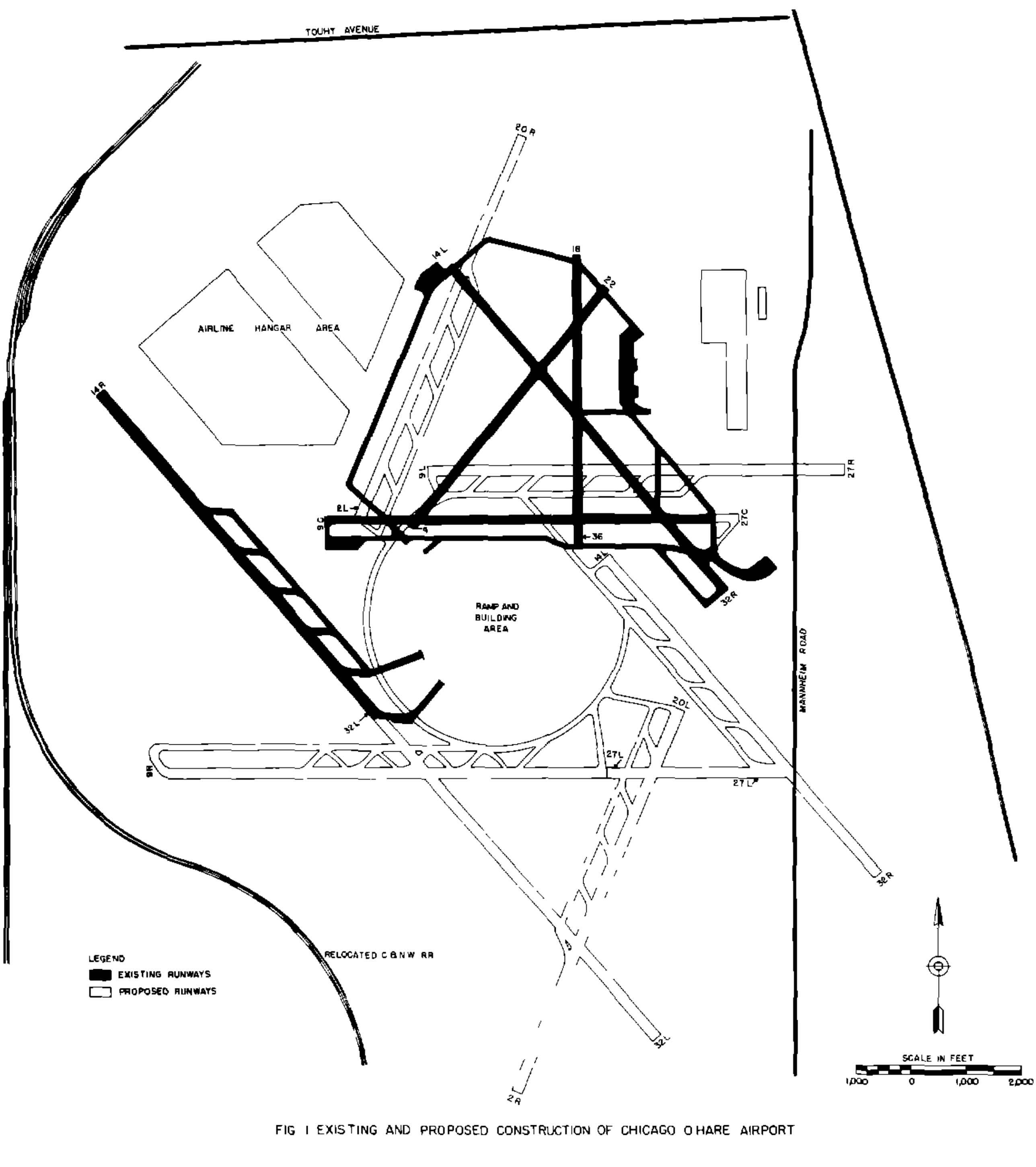

FIG 1 EXISTING AND PROPOSED CONSTRUCTION OF CHICAGO O HARE AIRPORT

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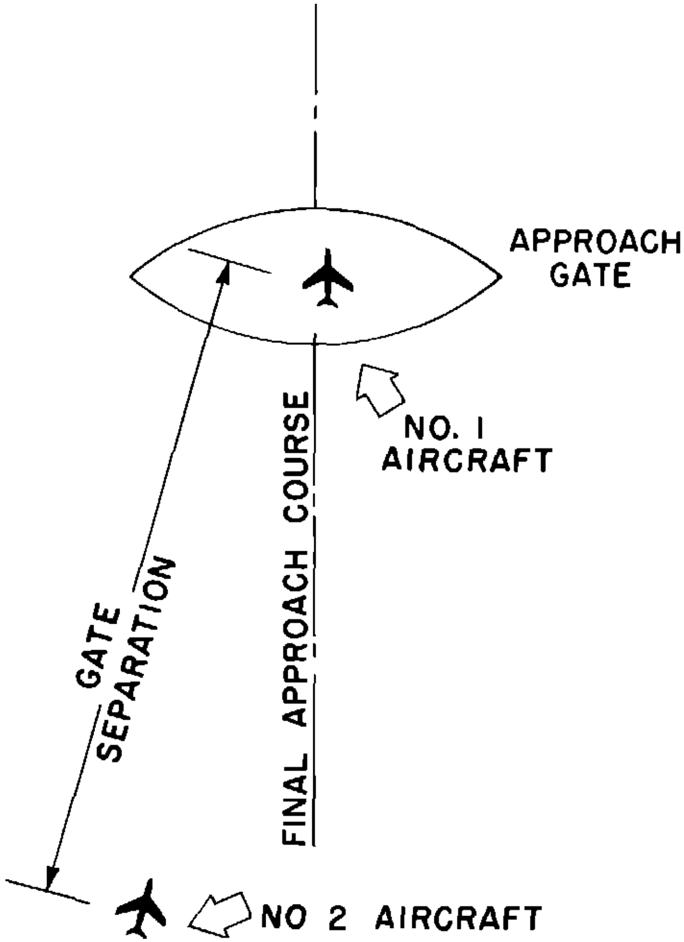
FIG 2 CONTROL ROOM LAYOUT SIMULATING O'HARE IFR ROOM

FIG. 3 CONTROL ROOM LAYOUT SIMULATING MIDWAY IFR ROOM



OPTIMUM AIRCRAFT SPACING

DISTANCE, APPROACH GATE TO TOUCHDOWN, 5 MILES

AIRCRAFT SEQUENCE		GATE SEPARATION (MILES)
NO I	NO 2	
S	M	5 1
S	F	5 5
S	J	6.6
M	S	3 1
M	F	4 5
M	J	5 8
F	S	3 0
F	M	3.5
F	J	5.2
J	S M F	3 0
SAME TYPE		4 0

AIRCRAFT CATEGORY		APPROX APPROACH SPEED	
		M P H	KT
S	SLOW	120	104
M	MEDIUM	140	122
F	FAST	150	130
J	JET	180	156

FIG 4 SPACING TABLE USED IN APPROACH CONTROL OPERATIONS

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FIG. 5 SPANRAD (SUPERIMPOSED PANORAMIC RADAR DISPLAY)

FIG 6 CONTROL ROOM LAYOUT SIMULATING CHICAGO ARTC CENTER

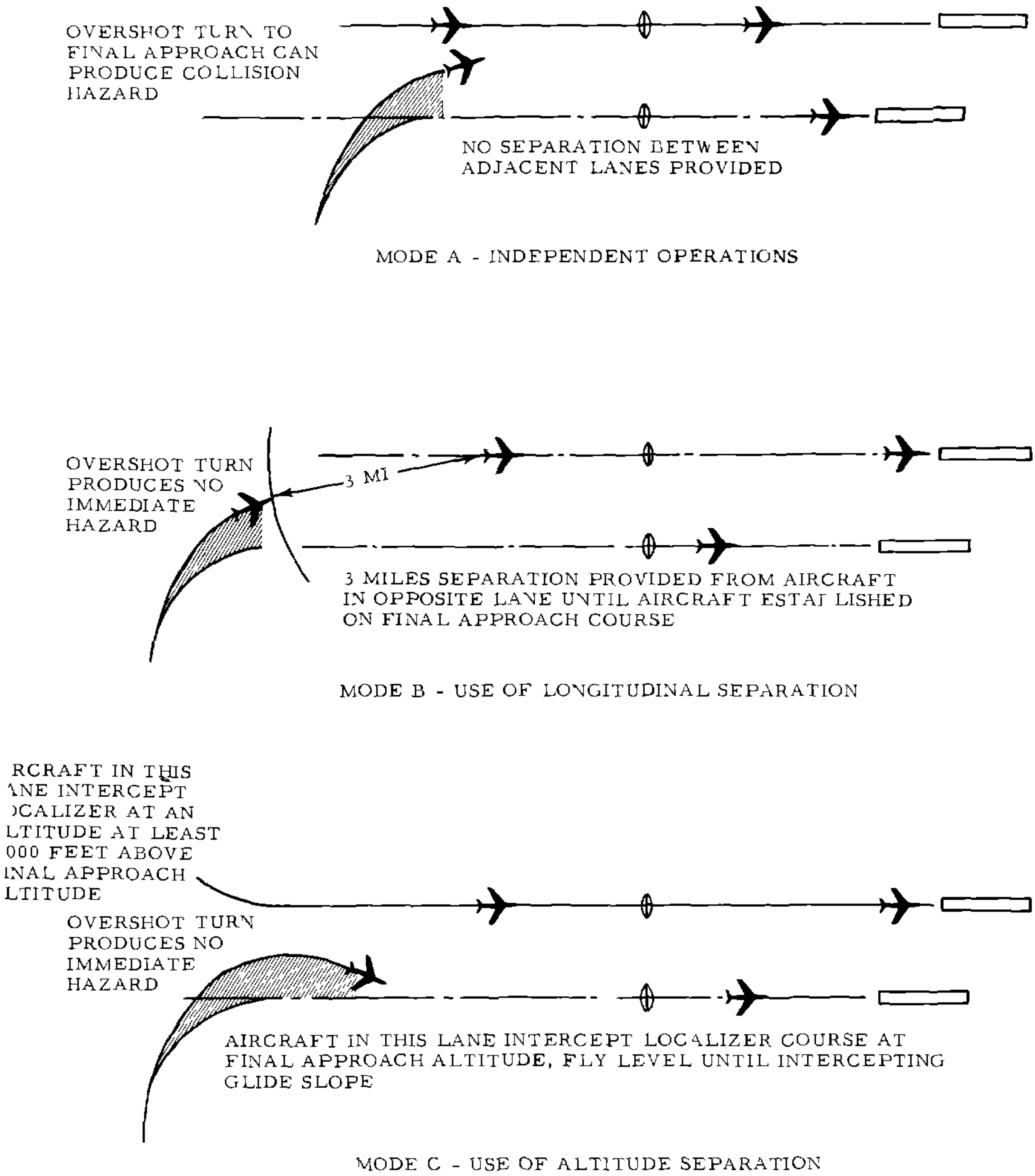
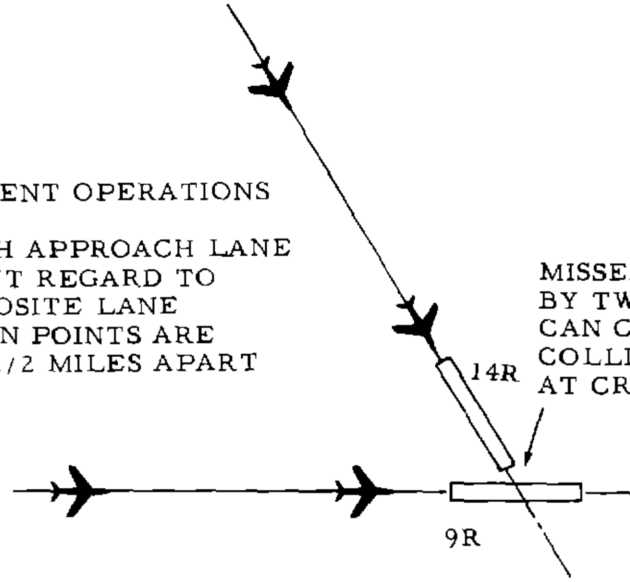


FIG 7 PARALLEL APPROACH OPERATIONS

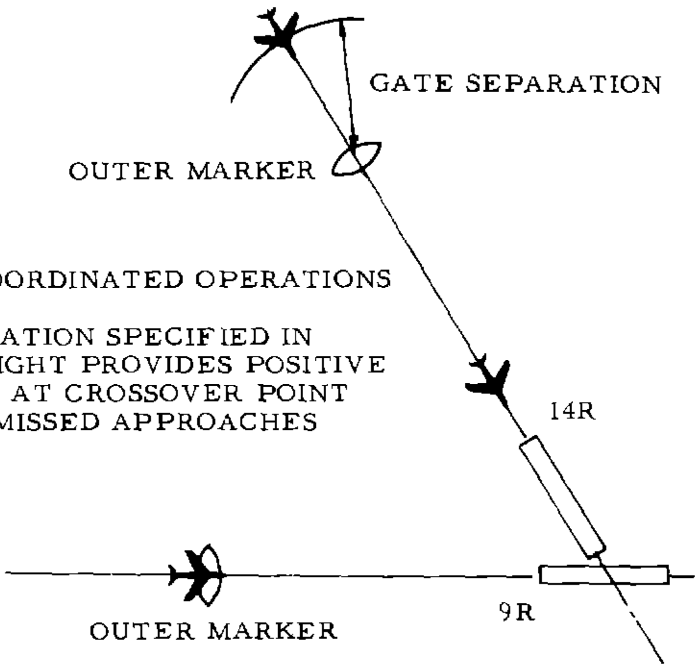
MODE A - INDEPENDENT OPERATIONS

OPERATIONS IN EACH APPROACH LANE CONDUCTED WITHOUT REGARD TO OPERATIONS IN OPPOSITE LANE NORMAL TOUCHDOWN POINTS ARE APPROXIMATELY 1 1/2 MILES APART



MODE B - COORDINATED OPERATIONS

GATE SEPARATION SPECIFIED IN TABLE AT RIGHT PROVIDES POSITIVE SEPARATION AT CROSSOVER POINT IN CASE OF MISSED APPROACHES



RUNWAY 14R

GATE SEPARATION			
SEQ 1	SEQ 2	SAME LANE	OPP LANE
S	M	4 8	2 0
S	F	5 3	2 5
S	J	6 5	4 0
M	S	3 3	0 2
M	F	4 4	1 4
M	J	5 4	2 7
F	S	3 0	-0 2
F	M	3 7	0 6
F	J	5 0	2 2
J	S	2 3	-1 0
J	M	2 9	-0 3
J	F	3 2	0 0
SAME		4 0	1 0

TYPICAL SPACING TABLE (COMPARE WITH FIG 4)

FIG 8 CONVERGING APPROACH OPERATIONS

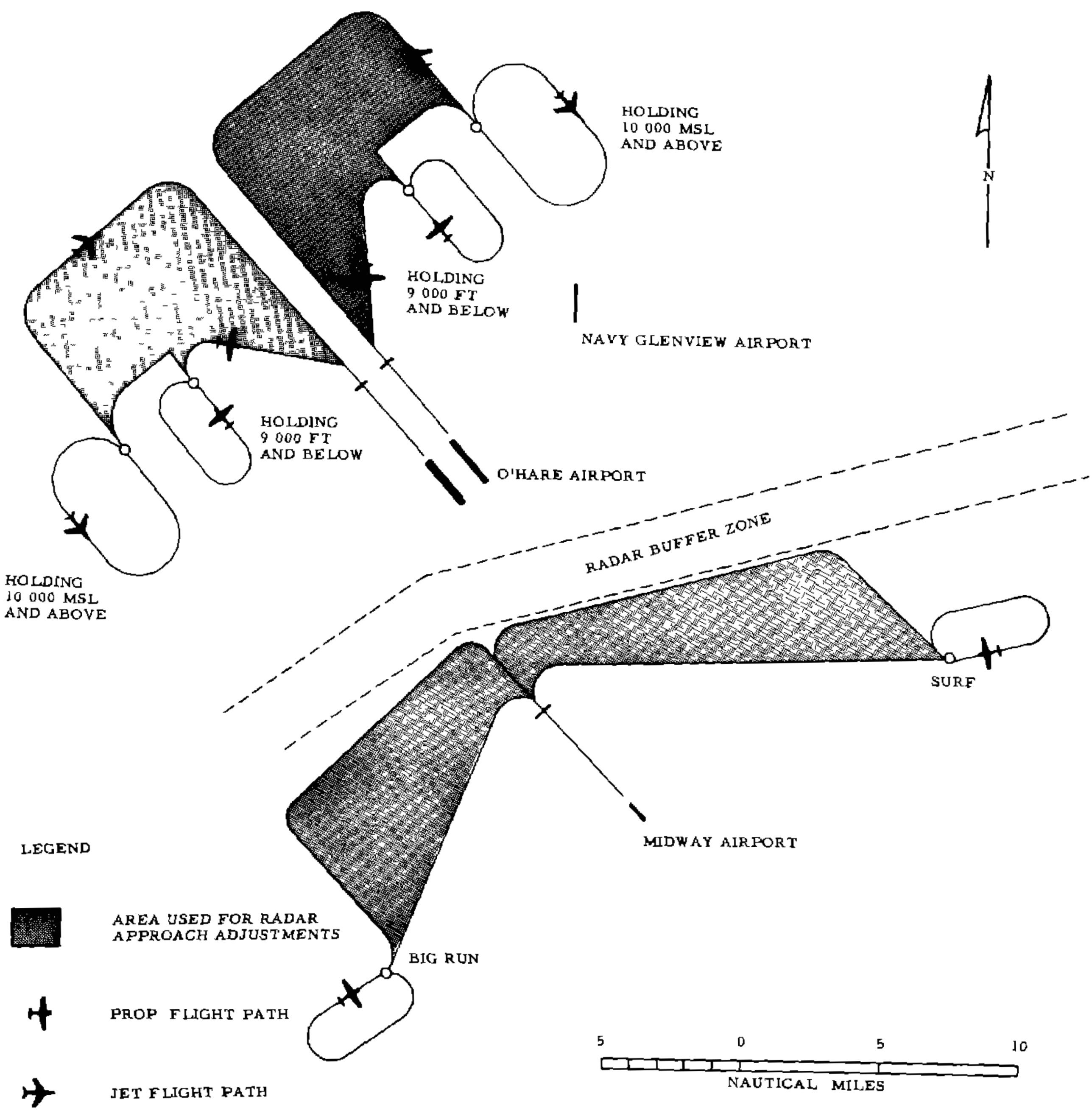


FIG 9 PARALLEL RUNWAYS SOUTHEAST OPERATIONS

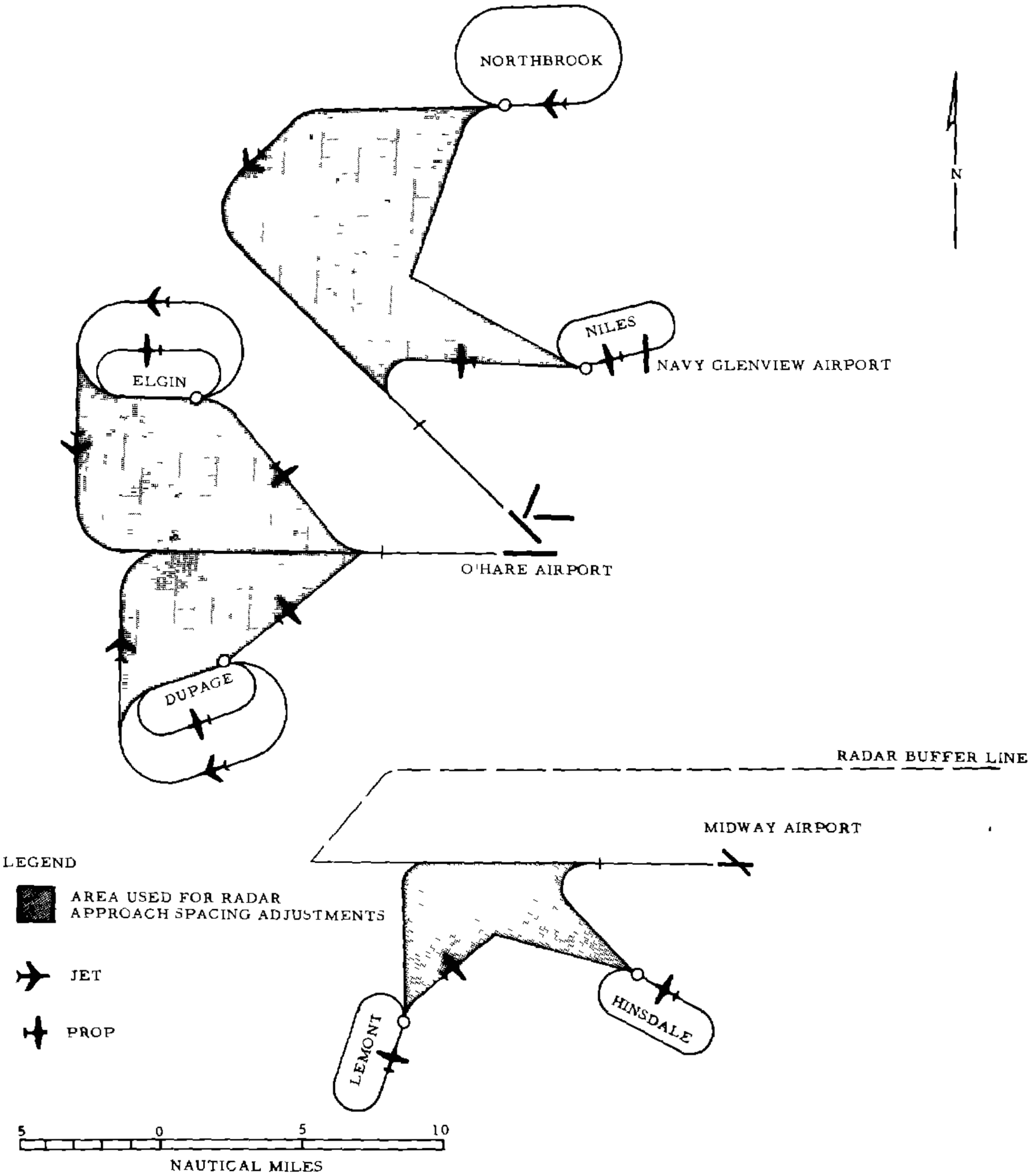


FIG 10 CONVERGING RUNWAYS EASTERLY OPERATIONS

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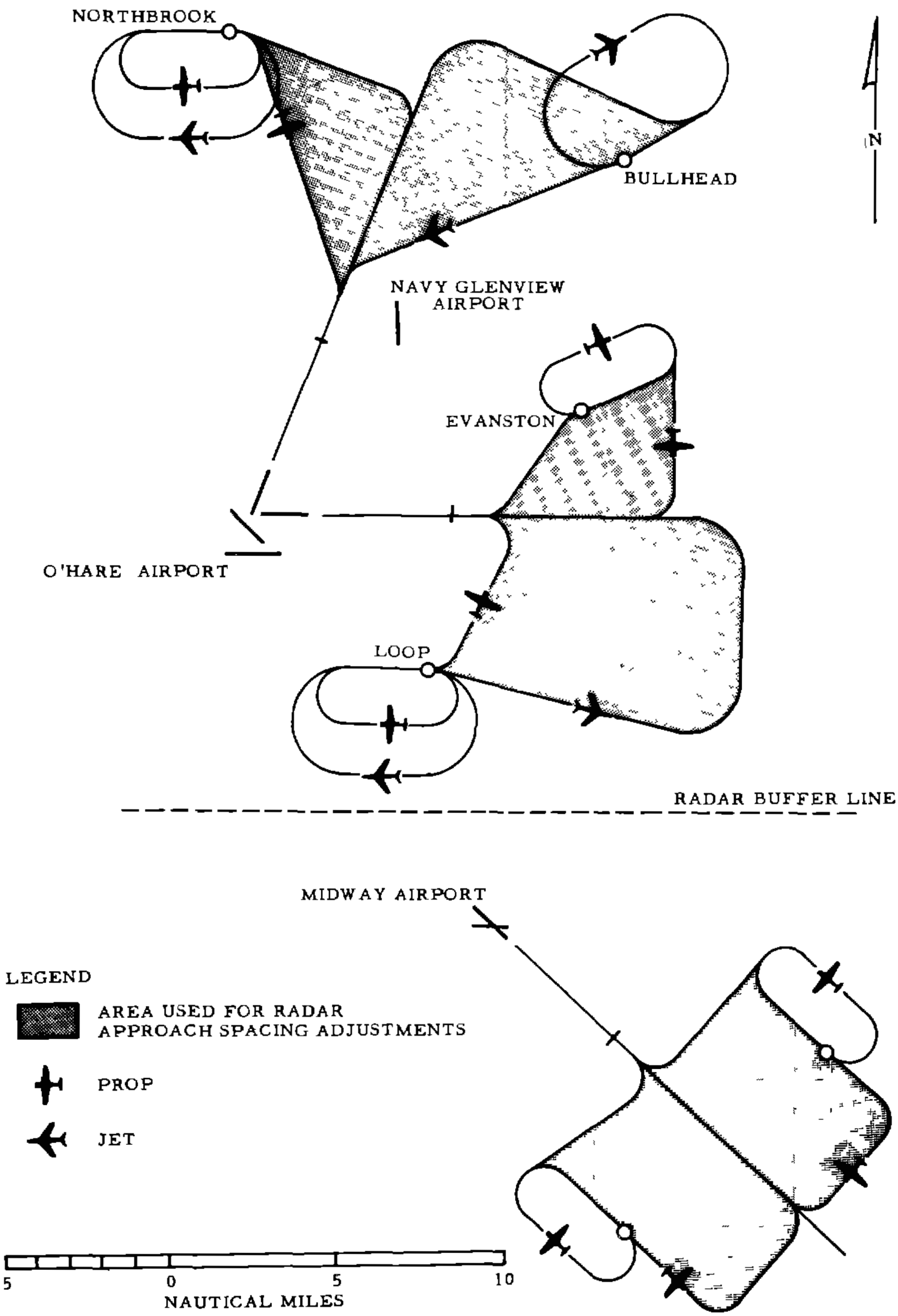

FIG 11 CONVERGING RUNWAYS WESTERLY OPERATIONS

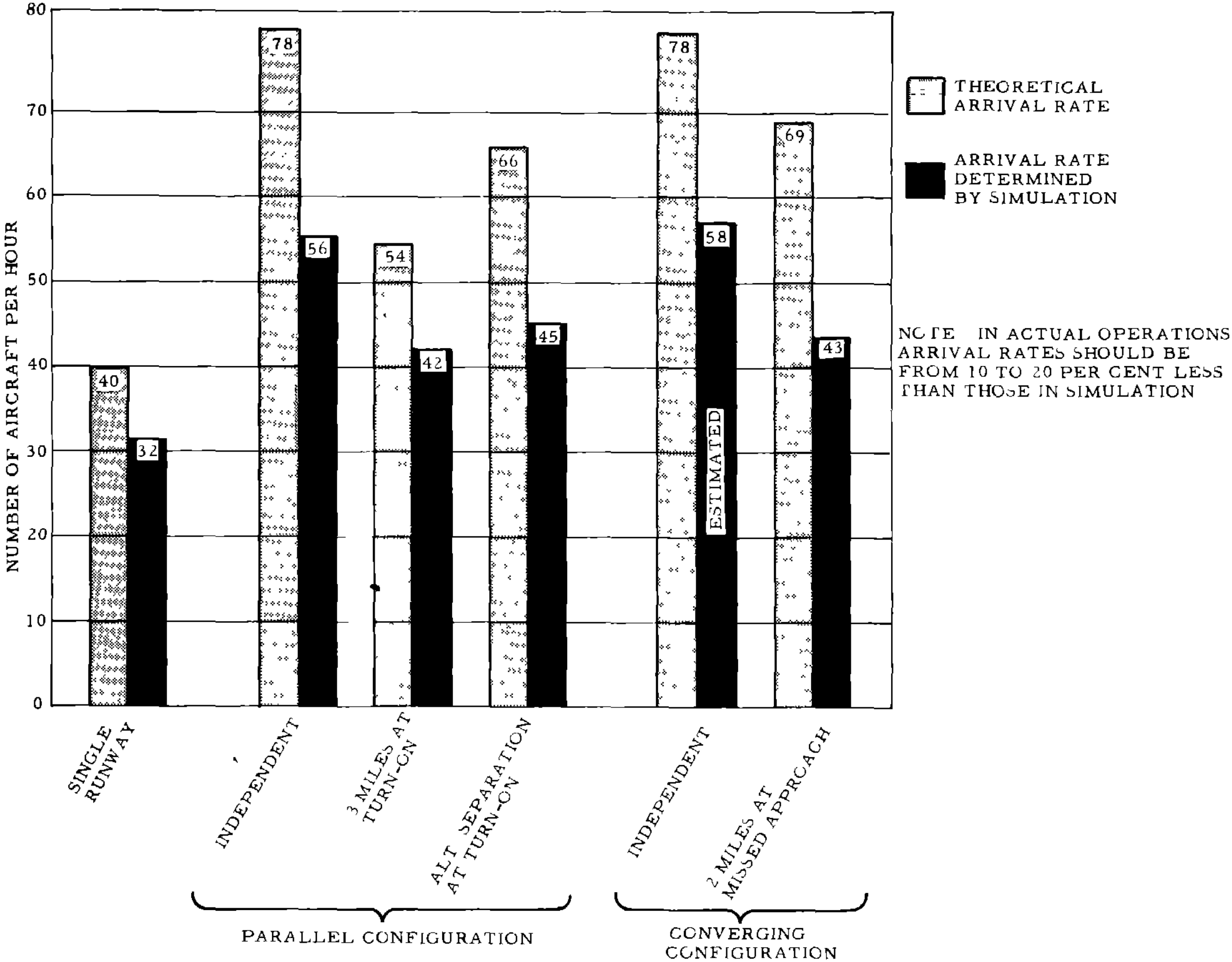

FIG 12 O'HARE ARRIVAL ACCEPTANCE RATES PER HOUR

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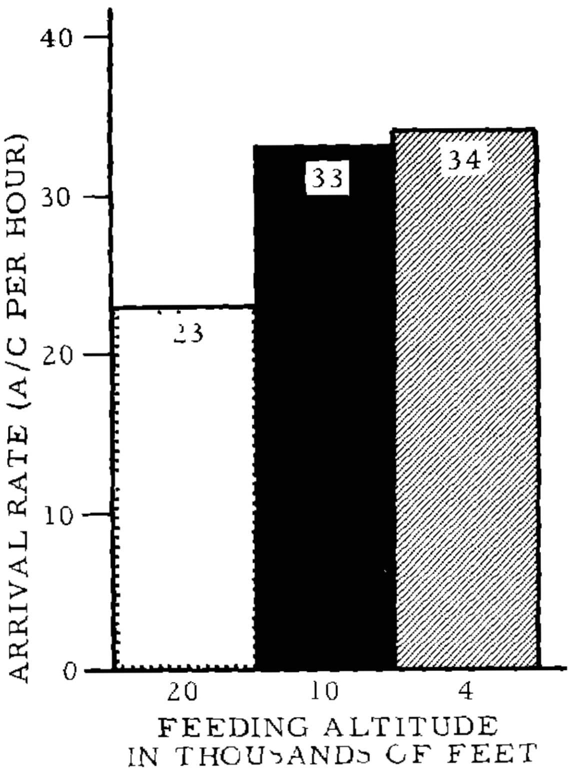

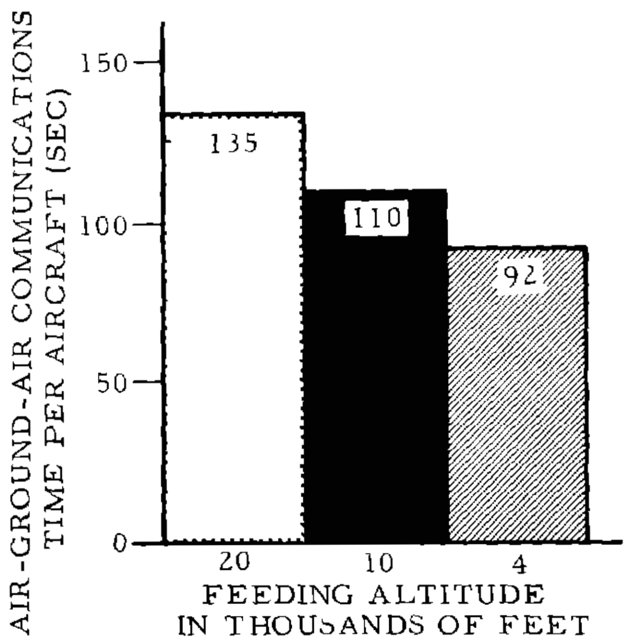

FIG. 13 AVERAGE ARRIVAL RATE AND COMMUNICATIONS TIME PER AIRCRAFT FOR ILS FEEDING OF JETS FROM 20,000, 10,000, AND 4,000 FEET

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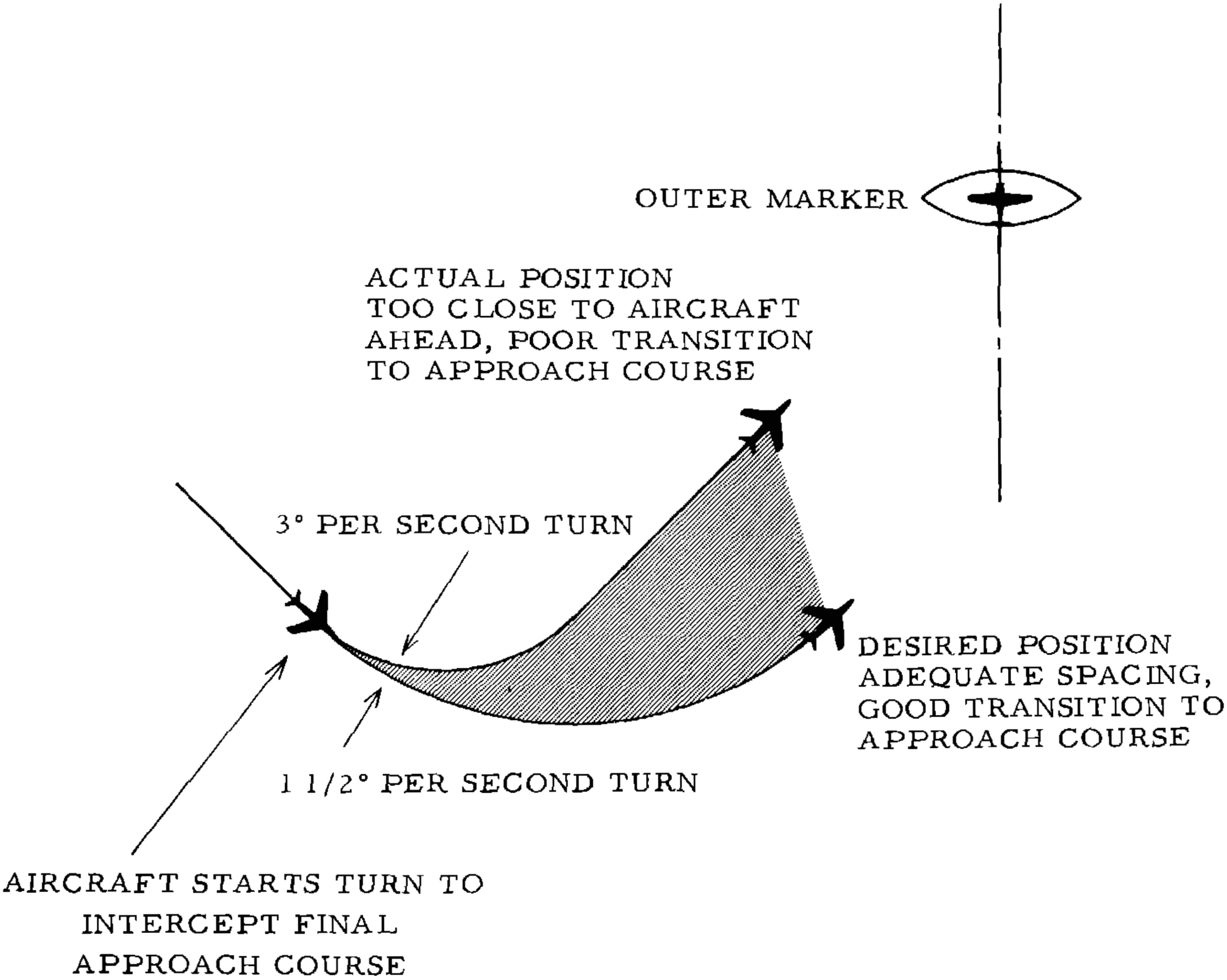
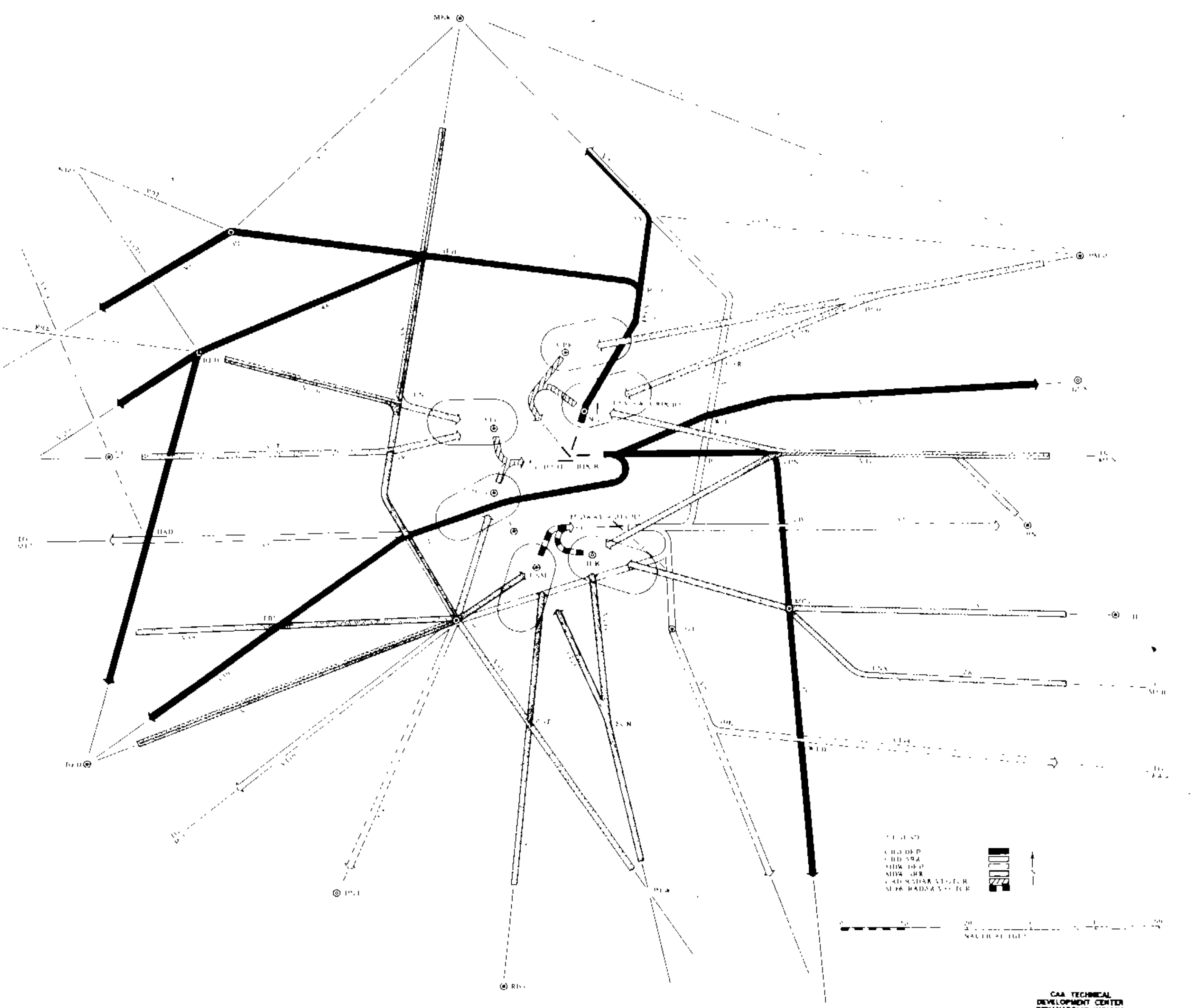


FIG. 14 EFFECT OF TURN RATE ON GATE SEPARATION AND APPROACH INTERCEPTION



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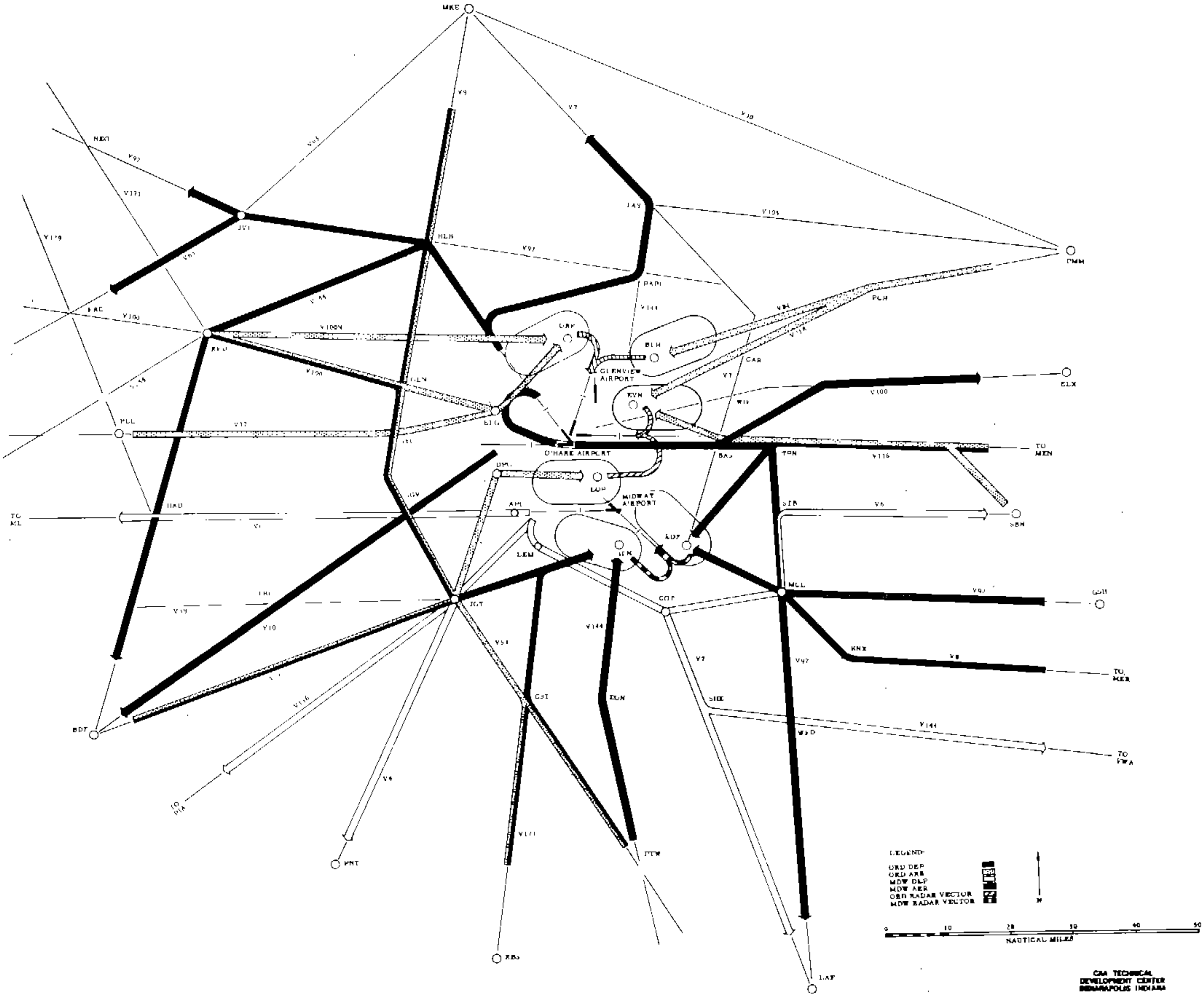

FIG. 16 CHICAGO AREA WEST OPERATION

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