TECHNICAL DEVELOPMENT REPORT NO. 404

SIMULATION STUDIES OF A METERED APPROACH SYSTEM UTILIZING REMOTE HOLDING FIXES

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SUMMARY

This report describes the study of a transition and terminal approach control system, utilizing remote holding fixes 40 to 90 miles from the airport The system was developed by dynamic and analytic simulation techniques It may have application in the implementation of the data processing control equipment if it is found that a more simple system than is presently planned is desirable

A detailed method of sequencing arriving aircraft and releasing them from the holding fixes is described The application of computer techniques to the sequence-release method is outlined

To compensate for errors in aircraft speed estimates and changes in the airport acceptance rate, a small backlog of traffic is maintained in the transition-terminal area. This backlog occasionally causes some holding at close-in holding points, but it is believed that the backlog is necessary for system flexibility The system utilizes present-day radar vectoring techniques for spacing aircraft on the final approach It is capable of fitting departures into the arrival sequence in situations where the runway must be shared It also is capable of handling occasional VFR flights

INTRODUCTION

In February 1958, the Airways Modernization Board (AMB) requested the CAA Technical Development Center (TDC) to perform dynamic simulation tests of some specific transition and terminal area approach control concepts applied to the Idlewild Airport area These concepts were adopted for the Curtis Committee's Report[1] It also was requested that some dynamic simulation tests of jet aircraft approaches at Suffolk Airport, New York, be conducted The results of these tests were released to AMB in May 1958, and were listed as TDC Working Paper No 1[2] and Working Paper No 2[3], respectively

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[1] "Aviation Facilities Planning," a report by the President's Special Assistant, May 1957

[2] "A Preliminary Simulation Study of Speed Control and Path-Stretching Control Techniques," Working Paper No 1, CAA Technical Development Center, Limited Distribution, May 1958

[3] "Simulation Tests of Jet Arrivals at Suffolk AFB," Working Paper No 2, CAA Technical Development Center, Limited Distribution, May 1958

In November 1958, the AMB requested that the simulation program at TDC be broadened to include a study of operating principles and procedures associated with a high-capacity approach system, with a view toward implementing the General Precision Laboratories data processing equipment, now being developed under contract to the FAA This report describes a high-capacity approach control system, which was developed utilizing dynamic and analytic simulation techniques

It was planned to simulate this system using the digital computer at TDC, but because of the transfer of equipment and facilities to the National Aviation Facilities Experimental Center at Atlantic City, this phase of the program was postponed until such time when it can be performed at that facility However, this report contains the necessary information for setting up such a program

SEQUENCE RELEASE SYSTEM

Remote Holding

Although the present system of smoothing the flow of air traffic by holding aircraft close to the airport and vectoring from a few major fixes works well most of the time, a system where holding is done further out (between 40 and 90 miles from the airport) may have certain advantages

1 Delay would be absorbed at higher altitudes which is more efficient for jet aircraft

2 In many areas airspace is less in demand farther away from the airport This will be true particularly if the proposed increases in holding pattern width in TSO standards are made

3 The flow of traffic from the en route to the terminal area should be smoother than it is at the present time since most aircraft would have a relatively undelayed flight from cruising altitude to touchdown

4 Peaks in the approach controller's workload would be smoothed

There are, or course, some drawbacks to a system where delay is absorbed at a distance from the airport

1 When changes in the acceptance rate of the airport occur, there will, of necessity, be a lag in adjusting to the new acceptance rate because of the distance between the holding fixes and the approach gate

2 More advanced planning will be required to fit VFR flights and aircraft on short flights into the landing sequence

The system presented in this report minimizes these disadvantages

Sequencing

In the present terminal area system, the aircraft estimated to arrive first at a primary holding fix normally will be assigned the lowest altitude and be vectored to land first Although faster aircraft occasionally may overtake slower ones in the vector area, basically first-come-first-served sequencing works very well Remote holding presents a problem in sequencing and releasing aircraft, and often the aircraft which arrives at the holding fix first will not be the first to be released In an equitable system, aircraft should be released so as to land in approximately the same sequence as they would if not under control Therefore, the estimated time of arrival (ETA) at the airport should be determined for each aircraft before reaching the holding fix in order that a sequence can be established Graphical analysis of several traffic samples indicates that the simplest and most equitable method of sequencing is to place each aircraft in the sequence at approximately the same estimated time-to-go (time before arrival at the airport) This results in aircraft being sequenced in the same order as their ETA's, which fulfills the desired objective Figure 1 shows the results of some of these studies

Assuming the time-to-go for sequencing to be about 30 minutes, the ETA for each flight should be established at the fix just prior to 30 minutes-to-go Figure 2 shows the existing fixes for establishing the ETA's for aircraft of three different speeds approaching Idlewild Airport It can be seen that the faster aircraft will be sequenced farther from the airport than the slower aircraft When a flight passes the designated fix, its ETA is etimated, based on its altitude-speed profile and the forecast wind[4] In a few minutes, when the flight is estimated to have 30 minutes-to-go, it is given the next place in the sequence

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[4]An analysis of various methods of estimating the ground speed of aircraft is contained in "Wind Data for ETA," by Francis X McLaughlin, FIL Report No F-A2169-2, October 1958 The report states "The method found most suitable was correcting the average class speed for each aircraft with a speed vector derived from the Federal Air Weather Service 6-Hour Forecast

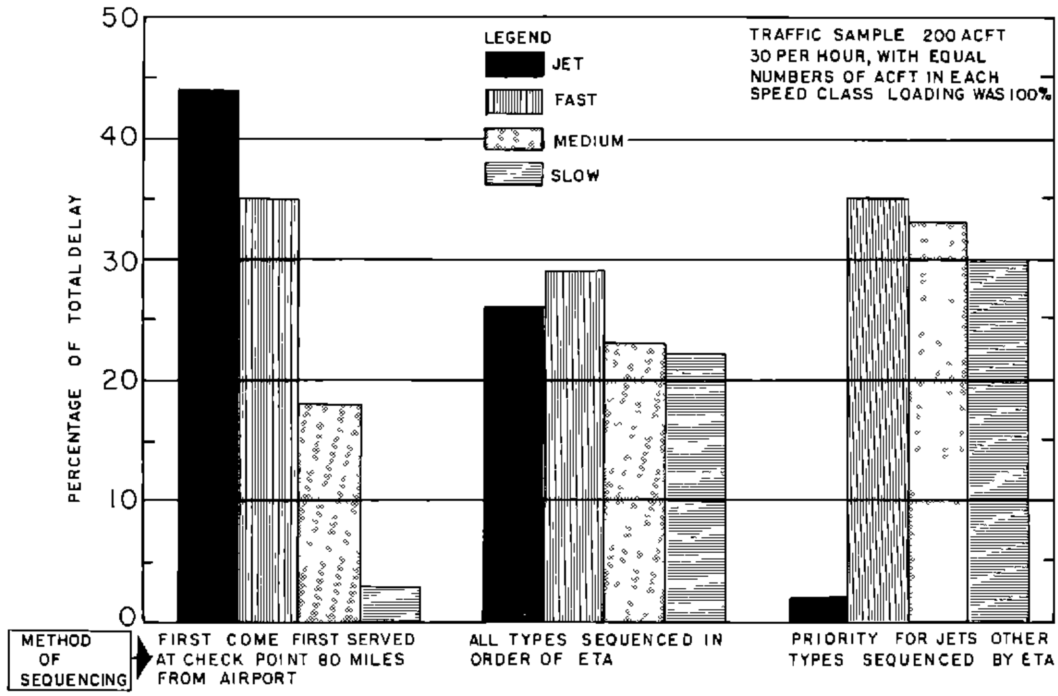

FIG 1 - EFFECT OF SEQUENCING METHOD ON DISTRIBUTION OF DELAY

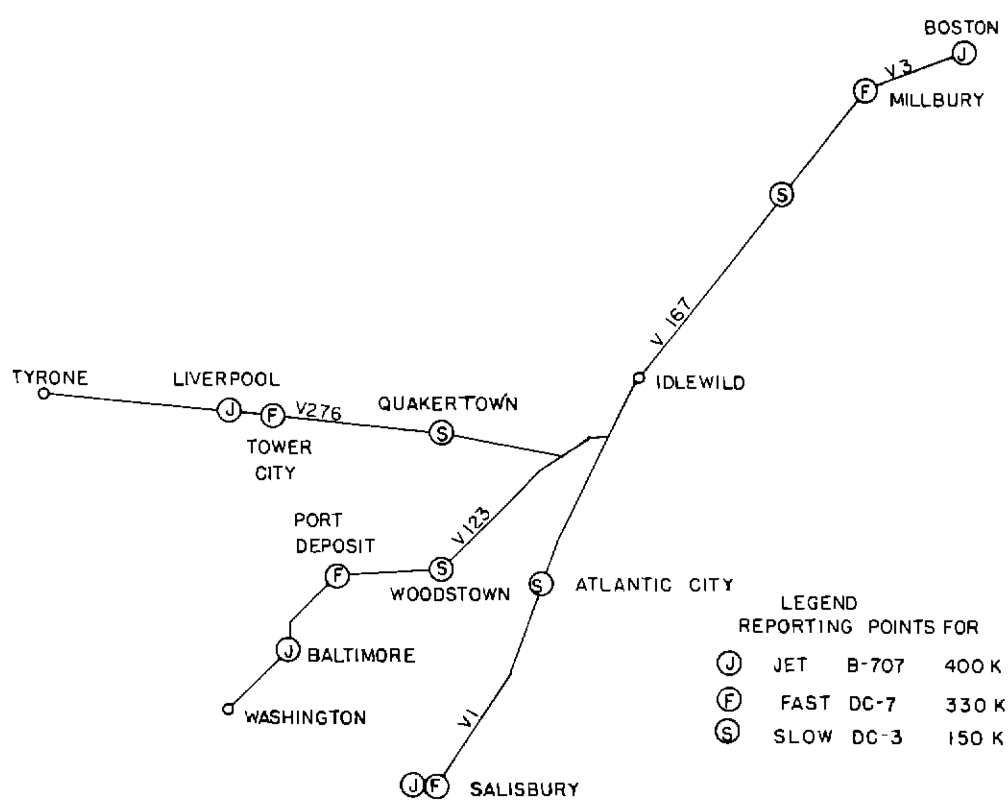

FIG 2 - REPORTING POINTS USED TO ESTABLISH ETA'S FOR IDLEWILD ARRIVALS

A small sample of traffic approaching Idlewild illustrates how the sequencing system works See Table I It can be seen that the ETA's for the jet aircraft, E 40 and U 22, are based on fixes (BAL and BOS) considerably farther from Idlewild than those for the slower aircraft The reports over the fixes are not necessarily in the same order as the ETA's However, the aircraft are placed in the sequence in the same order as their ETA's with 30 minutes-to-go, as shown in the table

TABLE I

SEQUENCING DATA FOR FIVE - MINUTE AIRCRAFT SAMPLE

Ident	Type	Reporting Fix	Time-to-Go from Reporting Fix (min)	Time Over Reporting Fix	Time Sequenced	ETA	Sequence Number
T 11	Constel-lation	Woodstock	32	1001	1003	1033	1
A 2	Convair	Atlantic City	35	1002	1007	1037	2
E 40	B-707	Salisbury	31	1007	1008	1038	3
X 31	DC-3	Hartford	42	0958	1010	1040	4
U 22	DC-8	Boston	34	1007	1011	1041	5

Release from Holding Fixes

As each flight approaches the 50-mile point, a decision should be made as to whether holding will be required, so that the pilot can prepare to hold if necessary An understanding of this step requires a knowledge of the method of release from the 50-mile point which is described in the following paragraphs

The altitude-speed profile and wind information give the best estimate of flying time from 50 miles to the airport for each aircraft This flying time is converted into units of arrival intervals For instance, if the current or predicted acceptance rate of the airport is 30 aircraft per hour, the average arrival interval is 2 minutes An aircraft requiring 18 minutes to fly from the 50-mile point would take nine arrival intervals Table II gives arrival interval information for three types of aircraft for five different acceptance rates

TABLE II

NUMBER OF INTERVALS FROM 50 MILES TO OUTER MARKER

Arrival Rate	Jet	Fast	Slow
40 A/C per hour (1 5 min)	12	14	18
36 A/C per hour (1 7 min)	11	13	17
30 A/C per hour (2 0 min)	9	11	14
24 A/C per hour (2 5 min)	7	9	11
20 A/C per hour (3 min)	6	7	9

Note Time in minutes from 50 miles to touchdown plus 4-minute backlog is 18 for jet aircraft, 22 for fast aircraft, and 28 for slow aircraft

This information is used to release aircraft from the 50-mile point As an example, if an aircraft, American 1, requires nine intervals to fly from the 50-mile point, it will not be released until there are just eight aircraft in the system scheduled to land before it After it is released, it will be the 9th aircraft in the system If American 1 has been sequenced 77th in the arrival sequence it will not be released until 68 aircraft have landed

If American 1 is approaching the 50-mile point and is about 4 minutes from it (or two arrival intervals from it, assuming an average arrival interval of 2 minutes), then three possibilities could exist

1 Sixty-eight aircraft already have landed and American 1 is cleared past the 50-mile point and into the transition-terminal area

2 Sixty-six aircraft have landed The chance that 68 aircraft will have landed when American 1 reaches the 50-mile point is good American 1 is cleared to the 50-mile point but probably will be released without holding

3 Less than 66 aircraft have landed American 1 is cleared to the 50-mile point and is released when 68 aircraft have landed Holding at the 50-mile point is almost a certainty

The sequence-release system works on the principle that each aircraft has a "trigger" number This is the number of aircraft which should have landed before the aircraft is released from the 50-mile point It is important to point out the release is not dependent upon the landing of a specific aircraft but upon the landing of a specific number of aircraft

Simulation Display

During dynamic simulation runs, a display was set up to provide an easy reference for releasing aircraft See Figure 3 Each horizontal

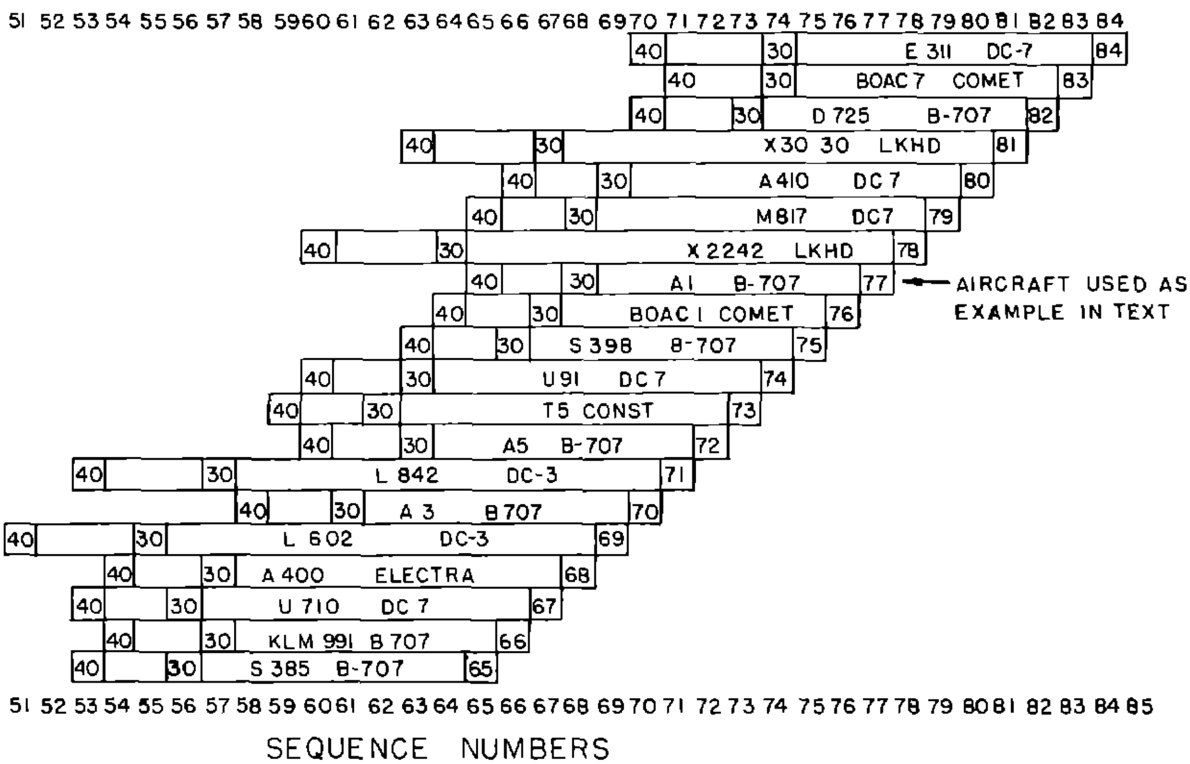

FIG 3 - SEQUENCE RELEASE DISPLAY USED IN DYNAMIC SIMULATION

bar represents an aircraft The right end of the bar is aligned with the sequence number which the aircraft has been assigned The reference marks, 30 and 40, represent different arrival rates The number of aircraft which should have landed before the aircraft is released is shown below and above the corresponding arrival rate American 1, which was used in the above example, is shown as the 77th in the sequence The sequence number directly below the 30 per hour mark is 68, which indicates that 68 aircraft should have landed before American 1 can be released from the 50-mile point

System Capabilities

During the dynamic simulation program, the sequence and release system was found to be capable of accommodating (1) occasional VFR arrivals, (2) departures, (3) changes in acceptance rate of the airport, and (4) different holding points for aircraft of different speed

1 When a VFR arrival entered the system, its ETA was determined and it was assigned a place in the arrival sequence During peak periods this caused aircraft with later ETA's to lose a place in the arrival sequence The VFR arrival then was held if necessary and released so as to land at or near its proper place in the sequence The system will work more smoothly without VFR arrivals but they can be accommodated in limited numbers

2 Departures were handled flexibly in much the same manner as VFR arrivals As soon as an aircraft requested taxi clearance the 50-mile release sequence was moved back one interval so that a gap was left in the arrival flow The departure then was released when ready and the temporary backup in the arrival flow was absorbed in the gap In actual operations, the specific way in which departures are fitted into the arrival sequence will be determined by the runways in use, the weather, and other factors In some cases, two or three departures can be released in one arrival interval so that the need for breaking the arrival sequence to accommodate departures will be minimized In any case, departures can be handled with a minimum of preplanning

3 When the airport acceptance rate changed, the reference number was changed on the sequence-release display as seen in Figure 3 For instance, when the acceptance rate increased from 30 to 40 aircraft per hour, each aircraft was released when the number of aircraft indicated by the 40 mark on its bar had landed In the example previously used, American 1 would be released when 65 aircraft had landed

4 In one simulation run, jets were held at the 50-mile point on each inbound airway while the slower aircraft were held at about the 35-mile point The number of arrival intervals required by the slower aircraft to fly from the 35-mile point was determined With this information, new release marks were incorporated in the display and used for the release of those aircraft during the simulation runs The system worked just as smoothly as before

SEQUENCE - RELEASE COMPUTER FUNCTIONS

A digital computer designed and programmed to carry out the sequence and release functions should have storage for aircraft speed-altitude profiles and geography Provision should be made for entering up-to-date wind and airport acceptance rate information Flight plan information should be entered as each aircraft enters the system and each landing should be recorded in the computer as it occurs A computer block diagram is shown in Figure 4

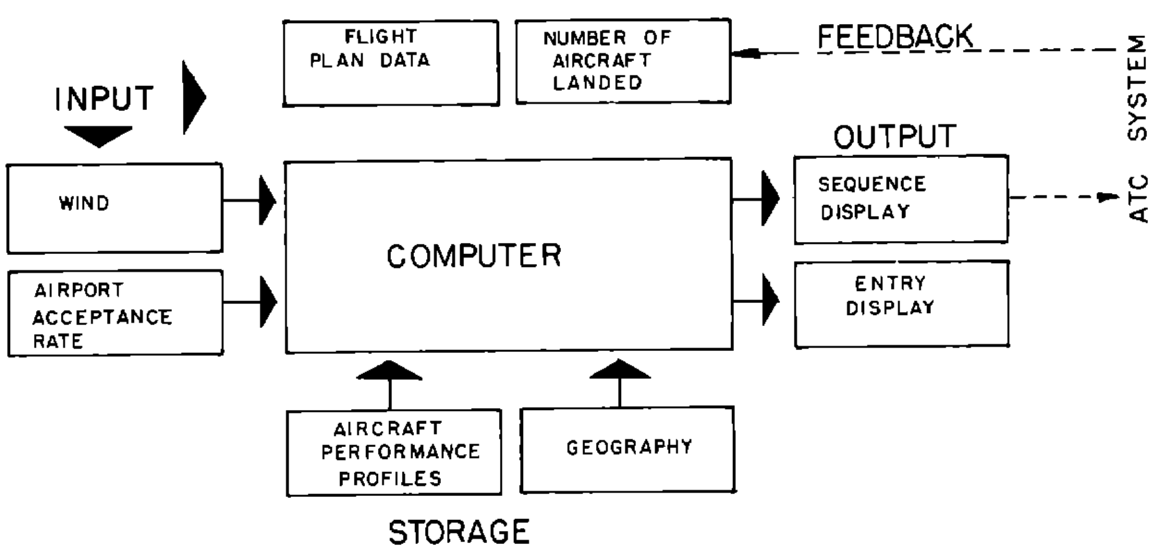

FIG 4 - COMPUTER BLOCK DIAGRAM

A brief description of the steps which are performed in computation is given below

1 Upon receipt of flight plans of arrival aircraft from adjacent centers and towers, the information is entered concerning identity, type, altitude, and route, and is shown in the entry display as illustrated in the first four columns below·

Ident	Type	Alt	Route	Fix	Time-to-Go from Fix (minutes)	Time Over	ETA
T 11	Constel-lation	150	V3 V167	Milbury	31	1002	1033
A 2	Convair	110	V3 V167	Hartford	31	1006	1037
E 40	B-707	270	V123	Baltimore	34	1004	1038

2 The computer uses the aircraft profile corrected for wind and searches the route for the fix just prior to 30 minutes-to-go This fix appears on entry display along with the time-to-go from the fix

3 The fix report is received from the aircraft and is entered into the computer

4 The ETA at Idlewild Airport is established

5 Thirty minutes before the ETA the aircraft is sequenced This involved a time delay in the computer between entry of the fix report and sequencing of the aircraft

6 Acceptance rate (average arrival interval) is applied to get an estimate of delay required (if any) and an estimate of delayed time of arrival

7 The delay is added to the ETA at the 50-mile point to get the estimated time of release from the 50-mile point

8 Profile and wind information is used to get the flying time from the 50-mile point to the airport This is divided by the average arrival interval to convert the flying time to arrival intervals The number of arrival intervals is subtracted from the sequence number to get the release number When this number of aircraft thus determined have landed, the aircraft is released from the 50-mile fix

9 Information determined in steps 1 through 8 appears in sequence display

Hold (Red)	Release (Green)	Sequence Number	Identification	Est Delay (min)	Est Release from 50 miles	Release Number
*	*	55	T 11	12	1023	44
*	*	56	A 2	10	1019	42
*	*	57	E 40	11	1031	48

10 As aircraft land, information is entered into the computer The computer keeps track of the sequence When the release number comes up, a red "hold" light next to the aircraft to be released changes to a green "release" light

The basic step for a VFR flight is to increase the release number of all aircraft with later ETA's by one This will result in later releases for these aircraft

The basic step for departures sharing the arrival runway is to increase the release number of arrival aircraft by a sufficient number to permit absorbing the departures

CONTROL IN TRANSITION AND TERMINAL AREA

The study described in Working Paper No 1[5] showed that metering aircraft into the transition-terminal area from the remote holding fixes was advantageous as far as terminal area workload was concerned However, it was found that unless aircraft speeds can be controlled very carefully and accurately, there is no particular benefit in using speed control and vectoring in an attempt to keep aircraft on a tight schedule. When errors in estimates of aircraft speeds and of existing winds were a factor, a rough metering of the flow of traffic from remote holding fixes coupled with normal approach control vectoring procedures achieved a high arrival rate (30 to 40 aircraft per hour) with a minimum workload

Since there are as yet no reliable data on the accuracies with which aircraft velocities can be maintained in the approach phase of flight, the system which is described here assumed accuracies expected

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[5] op cit

in normal operation today   In addition, it was assumed that there might be fluctuations in the airport acceptance rate from time to time

Although the sequence-release system fed aircraft into the transition area in accordance with an equitable sequence based on ETA's, control in the transition and terminal areas was based on a flexible sequence established in such a way as to maintain a maximum flow to the airport The landing sequence was not always the same as the original sequence based on ETA's, although it was a close approximation   There was one important feature in the release system which permitted maximum arrival rate and flexibility in the transition-terminal area   This consisted of releasing all delayed aircraft from the remote holding fixes before they had completed their total estimated delay   Normally the aircraft were released about 4 minutes early, thereby keeping a small backlog of aircraft close to the airport. This enabled the approach controllers to take advantage of increases in the airport acceptance rate when they occurred   It also compensated for a possible delay of up to 4 minutes between the release of an aircraft and the time it actually left the holding pattern   It is true that the backlog resulted in additional path stretching and some short holding delays   However, it appeared that this disadvantage was offset by the steady pressure it exerted on the approach system to maintain a maximum acceptance rate for the existing conditions

During dynamic simulation, this backlog was effected by adding 4 minutes to the estimated minimum flying time from 50 miles to touchdown   The total time, minimum plus backlog, then was converted to units of arrival intervals as shown in Table II   These, in turn, were used in the sequence-release display, Figure 3

The maximum sustained arrival rate during the simulation runs was about 40 aircraft per hour   This was accomplished with the route structure shown in Figure 5   Three en route transition controllers and two approach controllers operated the system with transfer of control from 30 to 40 miles from the airport   Both en route and approach control used SPANRAD displays as shown in Figure 6   The en route display was scaled to 1 inch 6 miles and the approach control display was scaled to 1 inch 2 miles   The excellent scale factor of the approach control display, which is about three times larger than the present ASR displays on a 30-mile range, permitted relatively relaxed operation of approach control even at the maximum acceptance rate

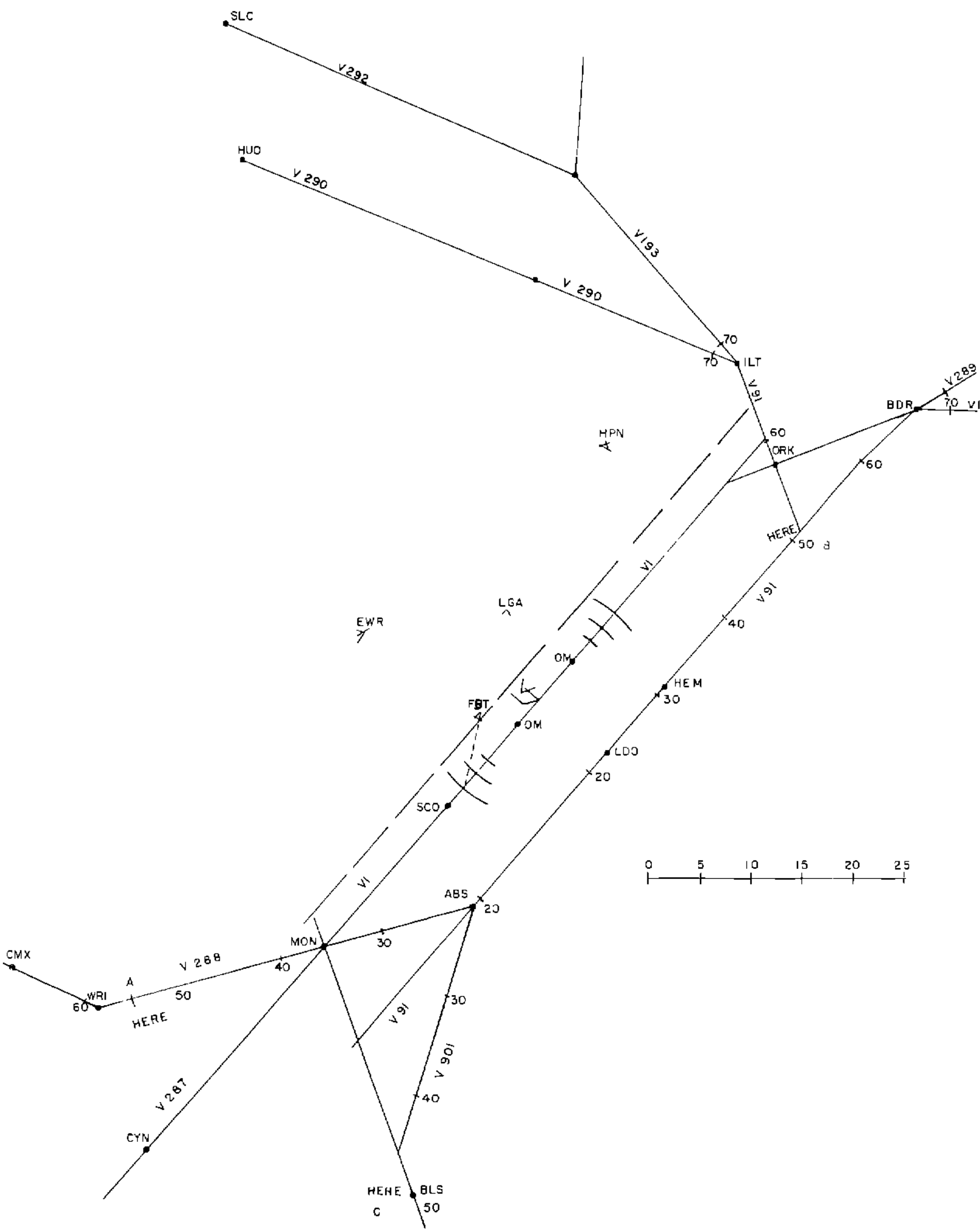

FIG 5 - ROUTE STRUCTURE USED IN DYNAMIC SIMULATION TESTS

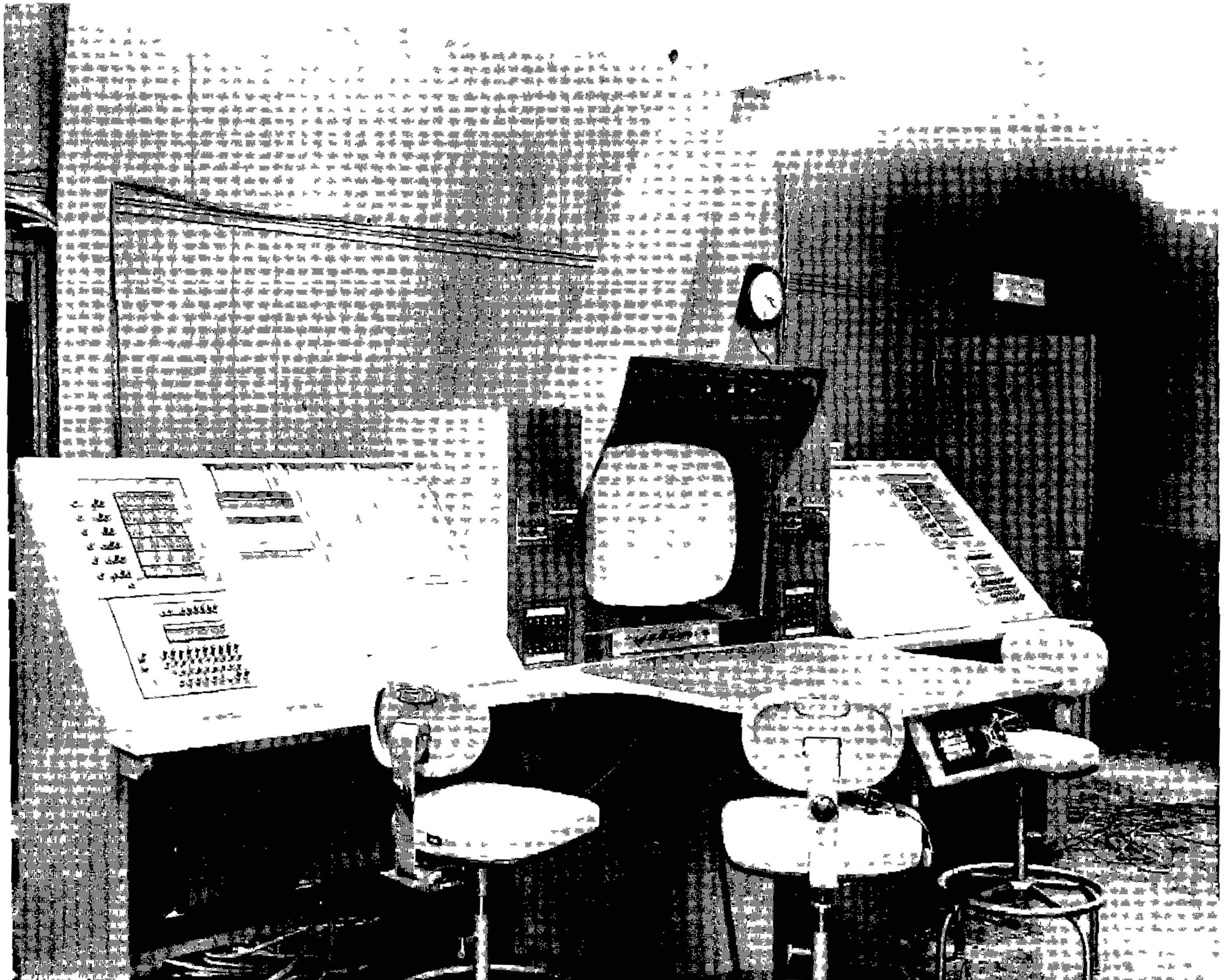

FIG 6 - SPANRAD DISPLAY USED FOR TRANSITION AND TERMINAL AREA CONTROL

CONCLUSIONS

1 It appears that metering, the regulation of traffic flow to avoid overloading any portion of the flight path, will be the most important function of any approach computer system

2 Simulation tests indicate that a simple approach system having a coarse metering function, plus a flexible precise spacing of aircraft on the final approach path, will produce an acceptance rate comparable with that of an approach system which utilizes a highly sophisticated computer, plus velocity control, to aim each aircraft at a definite landing time reservation

3 In the system described in this report, the necessary approach-spacing flexibility is provided by the layout of the approach paths plus deliberate maintaining of a small backlog of aircraft in the vicinity of the approach gate The latter feature provides a positive method of compensating for prior scheduling errors, and for maintaining an uninterrupted flow of aircraft over the approach gate

RECOMMENDATIONS

It is recommended that a study of this system be continued to

1 Determine optimum system parameters, including time-to-go for sequencing, size of backlog for a given acceptance rate, and so forth

2 Develop a digital computer program to perform the necessary system computations

3 Develop a simple analog computer for sequence and release

4 Apply this system to actual operations, and evaluate it for use as an interim system pending the development of more completely automatic approach systems