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DYNAMIC SIMULATION TESTS OF SEVERAL TRAFFIC-CONTROL SYSTEMS FOR THE SAN FRANCISCO-OAKLAND AREA

FOR LIMITED DISTRIBUTION

by

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SUMMARY

This report describes the evaluation of several proposed methods for increasing the IFR traffic capacity of the San Francisco-Oakland area. This program was conducted at the Technical Development Center of the Civil Aeronautics Administration through the use of the dynamic air-traffic simulator. Tests were directed toward the following major objectives:

1. Reassignment or relocation of arrival routes and departure routes to make them as independent of each other as possible.

2. Establishment of preferential routings to reduce center/tower coordination and to expedite the traffic on the most heavily traveled routes.

3. Establishment of independent dual-feeding systems for radar approaches to San Francisco and Oakland airports.

4. Rearrangement of routes to permit independent operation of a Radar Air Traffic Control Center (RATCC) in the Moffett NAS area.

Additional tests were made to study the application of distance-measuring equipment, application of dual-lane express airways (based on use of course-line or pictorial computers), and effects of possible realignment of the proposed Oakland ILS runway.

Based on the results of this test program, recommendations are made for:

1. An improved airway system which can be implemented in the near future with very little change in the layout of radio-navigation aids.

2. A further improved system which involves relocation or addition of several facilities.

3. A number of control procedures for expediting traffic flow and reducing controller workload.

INTRODUCTION

In February 1956, the CAA Office of Federal Airways requested the Technical Development Center to conduct a simulation study of the San Francisco-Oakland area air-traffic problem. In April, two TDC air-traffic-control specialists spent several days in the San Francisco-Oakland area observing traffic operations, gathering background material for the study, and discussing the proposed test program with representatives of the CAA Region 4 and the Washington office. The Region 4 office arranged to detail eight air-traffic controllers to TDC for the simulation runs. Franklin Institute Laboratories were requested to assist in the program by preparing traffic samples, drawing up new criteria for system evaluation, and analyzing the test results. The actual simulation runs were conducted throughout the month of May. During that period, many hours were spent by the controllers in conferences, discussing various ideas for changes in airway routings and control procedures, and detailed planning of the required tests. As a result, the final recommendations of this report represent ideas obtained from a large number of the personnel who participated in the program.

The various methods of airway arrangement and control procedures tested are referred to as "systems" in this report.

PRESENT PROBLEMS

A number of factors seriously restrict air-traffic flow in the San Francisco bay area. The most important factor is the high terrain which surrounds the airport area and dictates high minimum altitudes on most arrival and departure routes. The high terrain forces arriving aircraft to enter the terminal area at abnormally high altitudes. It also limits the coverage of terminal-area radar, and it seriously restricts the area available for radar-approach maneuvers. The high terrain tends to force departures into restricted channels, thereby lengthening departure routes and limiting the amount of control flexibility which can be employed.

Because the mountainous portions of the surrounding terrain are unsuitable for airport sites, the existing airports are clustered around the shore of the bay where their proximity to each other causes additional traffic problems. The major terminal airports at San Francisco and Oakland are only ten miles apart. Moffett NAS is very close to the San Francisco localizer course; Alameda NAS and Hayward Airport both are within six miles of Oakland Airport, directly on its normal arrival and departure paths. San Jose Airport is located within approximately five miles of Moffett NAS. Other military air bases located within a radius of less than 100 miles of the bay area are responsible for a number of the traffic problems of the bay area.

Due to heavy loads, low rates of climb, and the limited number of acceptable routes, transocean flights operating from Travis AFB cause a difficult problem because they conflict with northbound departures from both the San Francisco and Oakland Airports. At Hamilton AFB, located approximately 25 miles north of the San Francisco Airport, a large number of low-frequency (LF), radio-equipped aircraft are based. These aircraft operate through the bay area and cause a control problem under IFR weather conditions.

The altitudes below 10,000 feet on Victor Airway 23, within the Castle AFB RAPCON area, have been allocated to that facility. This allocation has the effect of raising the Oakland ARTC Center's minimum usable altitude to 10,000 feet on this airway between Modesto and Fresno; consequently, it causes traffic crossing this area to fly at excessively high altitudes.

A large percentage of the military aircraft operating from Hamilton, Travis, Moffett, and Alameda, are equipped with LF radio receivers only. This works an additional hardship on the controllers because the LF radio-range routes do not coincide with the VOR airway structure.

Restricted areas along the west coast present a serious problem to the rearrangement of the airway routes. It appears that any major improvement in the airway structure will require the elimination or alteration of some of those restricted areas.

Under the present system, eastbound San Francisco departures are routed over the Oakland range. This procedure tends to hold westbound San Francisco arrivals at undesirably high altitudes until they are close to their destination. Also, it prevents the eastbound departures from climbing to their cruising altitudes immediately.

The present delineation of authority between the Oakland ARTC Center and the approach-control towers causes lengthy interphone coordination due to a lack of standard center/tower transfer procedures. In addition, a large amount of intertower coordination is necessary in handling transbay flights, in clearing San Francisco eastbound departures across the Oakland range, and in feeding GCA approaches into Alameda NAS. These coordination procedures build up to a very high workload at the tower's flight-data positions.

The Oakland and San Francisco towers are handicapped by their lack of authorization to use radar control for any arrivals except trans-bay flights. Other arrivals are spaced on final approach through the use of timed-approach procedures. The transbay shuttle flights, which require considerable radar guidance, must be fitted into the timed-approach sequence at their destinations.

The direction of takeoff at the San Francisco Airport is particularly critical. Because of restrictions due to terrain, departures are limited as to the direction of climb. The lack of standard departure route in the bay area makes it difficult for the tower to assign consistently the most desirable runway for takeoff.

San Francisco and Oakland towers are faced with difficult traffic-flow problems during weather conditions which dictate takeoffs and landings to the south. Such weather exists approximately six per cent of the time in which IFR conditions prevail in the bay area. Oakland arrivals encounter high terrain north and northeast within five miles of the airport. Southbound departures from Oakland must make a right turn to stay away from the approach courses, and this can easily take them into the San Francisco control zone.

San Francisco arrivals, circling for south landings, have a clear approach; but they can easily extend their pattern into the Oakland control zone. South departures from San Francisco cannot make a right turn after takeoff due to the high terrain. Therefore, they must turn left and then parallel or cross the ILS approach course. This is very restrictive, and it increases the approach interval to the San Francisco Airport. All of these factors reduce airport capacity when south operations are necessary. Little improvement was shown in the simulation tests of south operations, even when radar-arrival and -departure control was used for all flights.

EVALUATION PROCEDURES

Equipment.

The basic simulation tests of the San Francisco bay area were conducted on the dynamic simulator. Three flight-progress boards were available for the ARTC Center. Center operating positions were equipped with interphone boxes and air/ground communications. The display boards were arranged as an arrival sector, D5; a departure sector, D6; and an en route sector, D8. Figure 1 shows the simulated Oakland ARTC Center sector and fix-posting arrangement. The simulated San Francisco tower was equipped with an arrival and departure radarscope, radio channels, and interphone communications. The Oakland tower was similarly equipped.

General Procedures.

In simulation tests subsequent to those on System 1, the Oakland and San Francisco towers were provided with dual holding stacks. Both stacks were controlled by a single controller using an ASR scope. Due to the lack of equipment, separate arrival scopes could not be provided for each stack.

With the use of arrival radar in the terminal areas, it often was possible to reshuffle the altitudes of arriving aircraft. This helped to prevent inverse stacking at the holding fixes, and it permitted the controller to bring first arrivals in first.

Both the San Francisco and Oakland Airports have the distinct advantage of wide taxi strips and large runup mats. This makes it possible to rearrange the aircraft into the most desirable departure sequence, thus reducing departure delays. For these simulation tests, departures at San Francisco and Oakland were cleared for takeoff without regard to the inbound flights. Because both airports are equipped with dual runways, it was believed that this procedure would cause no appreciable difference in the comparative results.

The only weather conditions considered in the simulation tests were those at or below circling minimums. It also was assumed that no on-top VFR altitudes were available, and all aircraft were assigned definite IFR altitudes.

During the initial test runs, simulation was based on the use of present runways and ILS courses. Subsequent discussions with Region 4 personnel disclosed that plans for a new runway at Oakland were well formulated. Therefore, in Systems 5 and 7, simulation tests were based on the new runway and ILS course of 293°. The contemplated ILS course will very nearly parallel the present Newark approach; and because of terrain, an ILS approach will be started in the vicinity of the Newark marker.

Traffic Samples.

Flight-progress strips were obtained from the Oakland ARTC Center, the San Francisco tower, and the Oakland tower, covering a recent day of typical IFR operations. Those records were analyzed to determine the period of heaviest traffic flow in the San Francisco bay area. A four-hour peak period, extending from 0800 to 1200 PST, was selected to form the input of the first traffic problem tested. Actual traffic constituted only 23 operations per hour. Additional flights were added to increase the density of the problem to 30 operations per hour so as to emphasize any bottleneck in the systems being tested.

Sample 1, with a density of 30 operations per hour, did not disclose the systems' bottlenecks to the desired degree on the first runs through the simulator; therefore, Sample 2, which had 38 operations per hour, was constructed. This sample covered a peak period from 1600 to 2000 PST, with additional flights added.

The final traffic sample from which the delay measurements were taken ran for 2 hours, 45 minutes, averaging 49 operations per hour in the bay area.

The following is a breakdown of the traffic at each airport:

	San Francisco	Oak-land	Ala-meda	Mof-fett	San Jose	Hay-ward	Total
Arrivals	49	14	3	7	3	1	77
Departures	34	16	5	3	2	0	60
Total Operations	83	30	8	10	5	1	137
Per Cent of Total	61	22	6	7	3	1	100

Oakland ARTC Center statistics revealed that of the flights entering and leaving the bay area, 50 per cent operated on routes to the south, 25 per cent to the east, 15 per cent to the north, and 10 per cent to the west (oceanic).

The actual traffic sample, obtained from the original flight-progress strips, contained a number of flights which passed through the bay area without landing, or which departed from airports immediately adjacent to the bay area. These flights were run through the system to provide a more realistic workload for the control sectors of the Oakland ARTC Center.

Controller Personnel.

In order to utilize the operational experience of controller personnel in the San Francisco bay area, eight controllers were detailed to TDC to assist in the evaluation. Four controllers from the Oakland ARTC Center, two from Oakland tower, and two from San Francisco tower manned the positions of operation during the simulation tests.

Control Facilities.

Oakland ARTC Center. ARTC simulation was confined to three flight-progress boards because of limitations in available facilities and personnel. Two controllers were assigned to each sector as shown in Fig. 1. Each of the bay area's arrival and departure sectors had one controller who handled air/ground communications and another who handled interphone traffic.

The D8 sector, which combined portions of three actual sectors, contained the strip postings for the fixes immediately adjacent to the bay area. All of the flights to or from the bay area operated through the D8 sector. Departures from Travis AFB and from Sacramento Airport to the bay area were posted and were coordinated with the appropriate bay-area sector. Flights en route over Sacramento, Modesto, and Williams were posted in the D8 sector to simulate all en route operations which would affect the climbs and descents of bay-area traffic.

Oakland Approach Control. Two radar indicators simulated ASR coverage within a range of 30 miles of the Oakland Airport. As shown in Fig. 2, one controller handled arrivals, one controller handled departures, and an assistant controller posted flight data and handled interphone communications with Oakland ARTC Center and San Francisco approach control. In addition to the Oakland Airport traffic, Oakland approach control handled arrival and departure operations at Alameda NAS and Hayward Airport.

San Francisco Approach Control. Two radar indicators simulated ASR coverage within a range of 30 miles of the San Francisco Airport. As shown in Fig. 3, one controller handled arrivals, one controller handled departures, and an assistant controller posted flight data and handled interphone communications with Oakland ARTC Center and Oakland approach control.

Because of the limited amount of equipment and personnel available, it was necessary for San Francisco approach control to handle departure clearances for operations at Moffett NAS and San Jose Airport. These operations supplied the ARTC Center with the traffic necessary to simulate normal traffic flow during tests of all except Systems 5 and 7. Procedures set up for Systems 5 and 7 assumed that operations at Moffett and San Jose would be handled by an independent RATCC located at Moffett NAS.

Measurements.

In order to compare new route systems with the present route system, it was necessary to make several tests of the present system. The aircraft delay times of the present system then were compared with the delays of the new route system. It must be pointed out that the numerical results of these tests should not be compared with those of actual operations because of the differences between laboratory and actual operating conditions.

Arrival delays were computed by comparing the theoretical time at which each arriving aircraft should be inbound over the approach fix (if no other traffic was involved) with the actual arrival times of the aircraft over the approach fix.

Departure delays were compiled by comparison of the proposed departure time and the actual departure time. Departure delays were incurred only when the routes were saturated or when the center and tower controllers could accept no more aircraft because of coordination workload. Figure 4 shows the average delays in each system.

One of the primary objectives of the simulation tests was to determine the most satisfactory routings. Because delay measurements alone are not indicative of the true value of a route system, the working controllers were asked to express their personal route valuations and comparisons in chart-questionnaire form. In discussions at the end of the simulation program, it was found that there was general agreement between the verbal opinions expressed by the controllers concerning each route system and the ratings which they had given on the rating forms. The results of this questionnaire are shown in Fig. 5.

The comparative system charts were used only for Systems 1 through 7 because only brief tests were conducted on the DME system and the multiple-route system.

TESTS WITH RADAR

System 1 (Present Route System).

The following illustrations pertain to System 1:

1. Airway configuration and navigation aids - Fig. 6.

2. Arrival routes - Fig. 7.

3. Departure routes - Fig. 8.

4. Delay measurements - Fig. 4.

Additions and changes in navigation aids.

1. To keep the map display as simple as possible, it was decided to use VOR facilities and routes wherever the low-frequency/medium-frequency (L/MF) route system paralleled the VOR routes.

2. No new facilities were added to the area for this phase of the tests.

Observations.

1. Except for arrivals from the south, there were few inbound routes which were independent of departure routes. San Francisco and Oakland lacked independent dual holding fixes for radar approaches. There was no area available for an independent RATCC operation at Moffett NAS.

2. The major departure delays to civil aircraft occurred to aircraft at San Francisco which were routed eastbound via the Oakland VOR, Modesto, and so forth. This routing required coordination between three agencies: San Francisco tower, Oakland tower, and Oakland ARTC Center. Most of the delay was due to intertower coordination; however, the delay was understandable in view of the congestion which occurred in the vicinity of the Oakland Airport due to the arrival traffic, transbay traffic, and Oakland/Alameda departures.

3. Departure delays to Moffett NAS and San Jose Airport were extremely high due to the heavy arrival traffic from the south on V25 and V107.

4. During peak periods of arrival traffic, a holding stack usually formed at the San Francisco outer marker, and the controllers reverted to timed-approach procedures.

5. Due to Moffett NAS and Oakland/Alameda traffic, inbounds to San Francisco from the south and east often could not descend below 8000 feet until within 10 miles of the airport. This produced large descent delays and increased the workload of the San Francisco radar controller.

6. During the first few tests, it was evident that the installation of arrival radar at the two civil terminals would be of considerable benefit at the present traffic densities. Efficient use of radar-vectoring procedures cannot be realized, however, until the areas are made more independent.

7. The radar display between San Francisco and Oakland Airports was very confusing due to arrivals, departures, and the transbay operations in the same general area.

8. In this test, most of the approaches were made on the ILS courses at the two civil airports. During some of the tests, however, certain Oakland arrivals made approaches from the Newark marker. With an approach such as this, San Francisco's radar-vectoring area on the north side of the ILS course was very restricted.

9. During the simulation tests in which arrival radar was in use, the transbay operations did not interfere appreciably with the other arrival traffic. When arrival radar was not in operation, however, transbay aircraft caused considerable delay in other traffic.

10. Flights westbound from Travis AFB at 4000 feet, the normal altitude assigned to these aircraft, restricted the efficient use of the Geyserville or Williams northbound departure routes from Oakland/San Francisco. Moving traffic through altitudes used by the Travis AFB westbound departures required considerable use of radar control applying some of the recent procedures outlined in the radar manual.

11. Southbound traffic from Oakland was routed east to the San Joaquin valley before proceeding south. Occasionally, some of the southbound traffic from Oakland was routed over San Francisco Gap and was merged with the San Francisco departures. The latter procedure again required three-way coordination.

12. Aircraft from the two large civil airports desiring to fly to San Jose in IFR conditions had no desirable route available without causing considerable interference with arriving aircraft. There did not appear to be an adequate solution to this problem.

13. Routings were adequate between the bay area and northern coastal cities such as Santa Rosa and Arcata; however, the two-way traffic flow on the airways made it impossible to use these airways for preferential departure routes from the bay area.

14. The departure and arrival sectorization of the bay area, in the ARTC Center, required considerable coordination between air-route controllers; however, the terms "arrival sector" and "departure sector" are misleading. In reality, the departure sector was doing a considerable amount of work for the arrival sector because many of the arrival-route fix postings had to be displayed on the departure sector board. With the present route structure, there appeared to be no better method of sectoring.

15. The Sacramento sector is one of the busiest sectors in the Oakland ARTC Center. North/south traffic was heavy, and approximately 30 per cent of the bay-area arrivals crossed over Sacramento.

16. The Oakland/Alameda traffic moved through the system smoothly because it was possible for the Oakland controller to vector aircraft from Bay Point and Newark to the Hayward marker for an ILS approach.

17. The southbound aircraft from San Francisco had an excellent departure routing.

18. Routings to and from the west were satisfactory. All arrival traffic from the west was routed over Farallon.

System 2.

The following illustrations pertain to System 2:

1. Airway configuration and navigation aids - Fig. 9.

2. Arrival routes - Fig. 10.

3. Departure routes - Fig. 11.

4. Delay measurements - Fig. 4.

Additions and changes in navigation aids.

1. New VOR at Farallon.

2. New VOR at Camp Beale.

3. New LFR at Hamilton AFB.

4. New radio beacon at Richmond.

5. Relocate Salinas VOR to Monterey.

6. Relocate Dixon radio beacon.

7. Relocate San Francisco VOR to Pacheco.

This long-range proposal was submitted by personnel of Region 4. The original proposal included some modifications to the Hamilton RAPCON area. These changes, which consisted of removing the Calistoga homing facility and installing a low-frequency range station near Hamilton AFB, were made to provide shorter departure routes from the Point Reyes VOR eastward to the Camp Beale VOR. Installation of these routes also required that the Dixon homing facility north of Travis AFB be eliminated. The purpose of these alterations was excellent in that eastbound traffic from the bay area could have preferential routings with very little additional route mileage.

For the purposes of this program, it was not considered desirable to base a system on alteration of these RAPCON areas because information was limited regarding the requirements of the jet aircraft operating in the Hamilton area. Should it be found later that this area can be altered in total size, however, it would be of considerable advantage to utilize these shorter routes to the east.

Observations.

1. Intertower coordination was considerably reduced because few of the San Francisco departures were routed over Oakland. Those which were routed in that direction were destined for Sacramento or other points in the San Joaquin valley. Considerably more of the eastbound traffic from San Francisco could have been cleared over the V6 routing because the Oakland/Alameda traffic did not keep this route busy at all times.

2. V27W provided a convenient bypass route for north/south traffic not landing in the bay area.

3. Southbound aircraft from San Francisco were provided dual routes, V27 and V27E.

4. Both Oakland and San Francisco Airports had two radio fixes to be used as clearance limits by ARTC. The Woodside and Leslie fixes were located in an excellent position to employ radar procedures into San Francisco.

If the Leslie pattern were to be used at minimum altitude, the Newark approach at Oakland could not be used. In this test, however, it was assumed that all approaches at Oakland were being conducted on the present Oakland ILS course, and the southeast course of the Oakland L/MF range had been moved to provide a straight-in approach from the Hayward marker beacon to the Oakland Airport. The two holding fixes for the Oakland Airport were not positioned as well as the two for San Francisco because both holding points were located on the same side of the ILS course; this made it difficult to vector aircraft to the Hayward marker with the proper spacing. At the traffic densities tested, Oakland tower radar controllers were able to do an excellent job from these patterns.

5. The transbay operation was considerably improved. Traffic from the east to San Francisco was rerouted over Modesto instead of Oakland. The elimination of Newark approaches resulted in additional space for vectoring and a less congested radar picture between the San Francisco and Oakland airports.

6. The use of short-range, clearance-limit procedures appeared advantageous. In the initial stages of using these procedures, the towers were given a specified block of altitudes to be used at certain intersections, and they could clear aircraft to these points without consulting the ARTC Center. Once the aircraft were arranged in safe order, and generally, while they were still en route to the short clearance point, the pilots were instructed to change to the ARTC frequency for further clearance. Although this procedure was expeditious when properly used, more efficient operation resulted when the ARTC controller issued the short clearance. Because this agency had more complete information concerning all present and future traffic, it often eliminated potential conflicts or took better advantage of vacant airspace.

7. Arrivals from the east were well segregated compared with results from the present system. The area over Sacramento was less congested because of this rerouting.

8. Arrivals from the south were well segregated for San Francisco Airport.

9. Arrivals from the north were well routed into the area. The use of these routes left Victor Airways 6, 197, and 27 open for use as preferential departure routes.

10. As in the present system, traffic at Moffett NAS and at San Jose continued to interfere with traffic arriving at San Francisco although not to the same degree as in the first bests because the area southeast of Moffett was bypassed by about one airway width in this arrangement. The Almaden holding pattern in the Moffett area was used by conventional aircraft awaiting approaches into Moffett or San Jose. Once Moffett traffic had left Victor 302W airway en route to Almaden, it no longer affected traffic en route to San Francisco.

The Almaden holding pattern was not separated from the jet approach area at Los Gatos, but this could be remedied by moving Almaden further southeast in the valley. Moffett and San Jose departures still were very much restricted.

11. The additional intersections created in routing arrivals from the east on Victor Airways 303 and 28 would increase the workload in the Modesto-Stockton sector.

12. Oakland arrivals from the south crossed San Francisco arrivals from the east at the Boardman intersection. This crossing point was too close to the terminal areas for aircraft to be arranged in optimum order or to descend to the minimum altitudes by the time they arrived at the terminal area.

The necessity of this crossing was obvious in view of the efforts to make the Oakland area independent of the San Francisco area. In subsequent systems this crossing point was moved further east.

13. This system did not provide as good a route for traffic from the bay area to the San Joaquin valley as does the present system.

14. The increase in flying distance on some of the preferential routings such as the Geyserville route for eastbound flights out of San Francisco, although good from an air-traffic-control viewpoint, was poor from an economical viewpoint. If these routes were used by aircraft flying long distances, however, the advantages of their use would outweigh the disadvantage of the increased flying involved.

15. This system would require the elimination of Restricted Area 280 and a portion of Warning Area 283.

System 3.

System 3 was not simulated; however, the desirable features of this system were incorporated in System 5.

System 4.

The following illustrations pertain to System 4:

1. Airway configuration and navigation aids - Fig. 12.

2. Arrival routes - Fig. 13.

3. Departure routes - Fig. 14.

4. Delay measurements - Fig. 4.

Additions and changes in navigation aids.

1. San Francisco VOR was relocated 15 miles southeast and was redesignated Campbell VOR. Because no new facilities were required by this system, it probably could become available with very little delay.

Observations.

1. Traffic from the east destined for Oakland was diverted so as to fly over Modesto and Livermore to the Pleasanton holding pattern. This removed a portion of the traffic from over Sacramento.

2. Although this route structure was essentially the same as that of the present system, departure delays were reduced by utilizing preferential routes similar to those used in System 2.

3. The only San Francisco departures routed over Oakland were those destined for Stockton, Modesto, Reno, and other airports in the San Joaquin valley.

4. Two holding patterns were provided for San Francisco and Oakland Airports.

5. Traffic from the south destined for San Francisco was routed over the Campbell VOR to the Woodside pattern. This provided the arrivals with an additional 15 miles in which to descend.

6. This system had the following disadvantages: Moffett arrivals and departures still were restricted seriously because of the heavy traffic using V25 and V107 into the bay area. San Francisco arrivals from Oakland were very difficult to control for the same reasons listed in the discussion of the present system. San Jose arrivals and departures were difficult to control. This was caused by the proximity of Moffett NAS and by San Francisco inbounds from the south. The use of preferential routes increased the mileage for many aircraft. The Woodside holding fix was a VOR-ADF intersection, and the route to this fix was an ADF route from the Moffett L/MF range station.

System 5.

This system, which represented the combined suggestions of all personnel engaged in the tests, included some of the better features of the other systems.

The following illustrations pertain to System 5:

1. Airway configuration and navigation aids - Fig. 15.

2. Arrival routes - Fig. 16.

3. Departure routes - Fig. 17.

4. Delay measurements - Fig. 4.

Additions and changes in navigation aids included the following new facilities:

1. VOR at Monterey.

2. VOR at Stockton.

3. VOR at Farallon.

4. VOR at Camp Cooke.

5. TVOR at San Jose Airport.

6. VOR near Los Banos intersection.

7. VOR near Grimes intersection.

8. TACAN at Moffett NAS.

In addition, the Modesto VOR was relocated to a point near Copper intersection and was redesignated as the Copper VOR.

Observations.

1. Independent routings to and from the bay area were provided for a distance of at least 45 miles.

2. Sufficient space was provided to permit a Navy RATCC to expedite traffic to and from Moffett NAS and San Jose Airport.

3. Dual routes were provided in the San Joaquin valley to aid in the control of the additional traffic routed into the valley from the south.

4. Castle RAPCON was provided with additional area by relocating the Modesto VOR. The additional space was not considered a requirement in the initial planning; but as can be seen in Fig. 17, it is a desirable feature of the dual-airway structure.

5. The addition of Grimes VOR extended the dual valley routes to the north, and it provided a dual east-west airway parallel with V200.

6. San Francisco and Oakland tower operations were independent for those routes with the heaviest traffic.

7. The control of transbay flights was improved although Oakland approaches were simulated on the new runway heading.

8. The use of short-range clearances and blocked altitudes at certain intersections reduced coordination among controllers. The blocked altitude plan was found most effective for the crossing of the dual valley routes by westbounds destined for the bay area.

9. A sufficient number of altitudes were available on the dual San Joaquin routes to handle the traffic in this sample. When dual airways were simulated, 14 additional north-south flights were added to the San Joaquin valley traffic sample.

10. The system had the following disadvantages: Portions of Restricted Area 280 and Warning Area 283 were utilized to provide necessary routes to and from the bay area. There was an increase in traffic flow over the Modesto-Stockton area facilities. This added to the Modesto sector workload. The Mission holding stack serving San Francisco, and the Pleasanton stack serving Oakland, have TSO separation. Due to mountainous terrain, however, Oakland approach control must exercise careful control of aircraft while vectoring from Pleasanton to the Oakland outer marker in order not to infringe on the San Francisco radar zone. The increase in flying distance due to preferential routings still was apparent, as in previous systems tested. Traffic from San Francisco and Oakland destined for San Jose still interfered with arrivals from the east and southeast.

System 6.

System 6 was not simulated; its desirable features were incorporated in System 7.

System 7.

The following illustrations pertain to System 7:

1. Airway configuration and navigation aids - Fig. 18.

2. Arrival routes - Fig. 19.

3. Departure routes - Fig. 20.

4. Delay measurements - Fig. 4.

Additions and changes in navigation aids included the following new facilities:

1. VOR at Stockton.

2. VOR at Monterey.

3. VOR at Farallon.

4. VOR at Camp Cooke.

5. VOR north of Sacramento.

6. TVOR at San Jose (programmed).

7. TACAN at Moffett NAS.

In addition, the San Francisco VOR was moved to Los Banos; and the Modesto VOR was moved 14 miles NNE of its present position.

Observations.

1. Dual routes were provided in the San Joaquin valley. San Francisco eastbound departures were routed around the Oakland terminal area by sending them via Geyserville and Williams.

2. Oakland and San Francisco arrival routes from the south were independent and were adequate for the simulated flow of traffic.

3. The Oakland and San Francisco towers were provided with dual holding fixes.

4. Moffett NAS was provided with an RATCC area. Castle AFB was provided with a RAPCON area.

5. A shorter departure route for southbound aircraft from Oakland was provided by utilizing R-60 to Stockton.

6. This system had the following disadvantages: San Francisco's Belmont holding pattern, located at midbay, was too close to the San Francisco and Oakland ILS courses. Its proximity restricted the available vector area into both airports. This restriction was particularly noticeable when Oakland arrivals were making LF approaches into the new runway.

The additional congestion caused by aircraft holding at Belmont was undesirable when vectoring transbay flights. These additional targets were quite confusing when weather conditions dictated south takeoffs and landings.

San Francisco arrivals from the east via V6 were routed over the Oakland range. San Francisco eastbound departures had an increase in mileage when routed via Geyserville and Williams. Oakland arrivals and departures were forced to cross the Dow intersection which was too close to the terminal area to permit optimum spacing.

TESTS WITHOUT RADAR

Simulation tests without radar were run on Systems 1 and 5. Delay comparisons of these tests are shown in Fig. 4. In these tests, Oakland arrivals were held at:

Newark at 4000, 5000, and 6000 feet.
Pleasanton at 6000, 7000, and 8000 feet and above.
Danville at 6000, 7000, 8000 feet and above.

San Francisco arrivals were held at:

San Francisco outer marker at 2000, 3000, 4000, 5000, and 6000 feet.
Mission at 7000, 8000, 9000 feet and above.
Woodside at 6000, 7000, 8000 feet and above.

Traffic from the Mission holding pattern en route to the San Francisco outer marker was held at 7000 feet until two minutes past Mission. It was found that if San Francisco's arrival radar failed, it would have no effect on Oakland's arrival operations. If Oakland arrival radar failed, however, it was found that Oakland would have to cease operations until San Francisco's Mission pattern was cleared of aircraft at altitudes up to 7000 feet.

CONCLUSIONS

Simulation tests indicated that the system which most nearly meets the criteria of objectives as set forth in the summary of this report is designated System 5.

Implementation of arrival radar control at Oakland and San Francisco towers would help to alleviate some of the traffic delay now occurring at these terminals. It was apparent that unless the present system structure and procedures were changed, efficient use of radar-vectoring procedure could not be realized.

There seems to be no adequate solution available to the south takeoff and landing problem, although the use of radar will be of some help.

Using the present route structure, air route traffic control was most effective when preferential routings were used for the aircraft making long-distance flights.

An analysis of the present route system points to a need for additional VOR facilities along the west coast.

The minimum reception altitudes (MRA) within 100 miles of the bay area, in many instances, are much higher than the minimum obstruction-clearance altitudes (MOCA). This results in the loss of several usable altitude levels to aircraft flying these routes. The MRA's could be lowered appreciably with the installation of additional VOR facilities. For instance, a VOR at the Geyserville intersection would lower the MRA on V25 between Point Reyes and Geyserville to 4000 feet, an increase of four usable altitude levels; between Geyserville and Lakeport, 7000 feet, an increase of six altitudes; between Lakeport and Red Bluff, 9000 feet, an increase of four altitudes. A VOR at Farallon would allow an MRA of 2000 feet between the Farallon and the Monterey area; and the route now served by V27W between Pedro and Davenport would have an MRA of 4000 feet, an increase of three usable altitude levels.

In the tests of the present system, excessive interagency coordination was evident. It is desirable to eliminate as much coordination as possible. All of the recommendations which follow have a bearing on this objective.

Many military aircraft, operating from west coast bases, presently are not adequately equipped with the necessary communications and navigation equipment to be controlled efficiently in the recommended system.

The alignment of the proposed ILS runway to be built at Oakland Airport reduces the airspace available to San Francisco and Oakland towers for vectoring arriving aircraft.

Several parts of the recommended system can be incorporated into the present system if it is possible to utilize certain ADF routes and portions of R-280 and W-283. Figure 21 indicates these possibilities.

At the present time there is a question as to where the San Francisco VOR should be relocated. The site selected should serve the present system and still should satisfy the requirements of the recommended system. With the installation of a TVOR at San Jose and the retention of the Moffett LF range, the area in the vicinity of the present San Francisco VOR site will not be without navigation aids.

RECOMMENDATIONS

It is recommended that:

1. System 5 or a similar system be implemented as rapidly as the necessary equipment becomes available.

2. Consideration be given to implementation of a route structure, as shown in Fig. 21.

3. Oakland ARTC Center be provided with at least an 80-mile surveillance radar and suitable large horizontal indicators. Past experience indicates that ARTC radar can be used most effectively when the arrival and departure routes are segregated as in System 5.

4. The bay area and adjoining sectors of the Oakland ARTC Center be furnished with direct-communication equipment to facilitate the control of aircraft within 125 miles of the bay area.

5. Radar-arrival control at San Francisco and Oakland be implemented at the earliest possible date.

6. Action be taken to require military aircraft operating in the bay area to be equipped with adequate communications for the proposed system.

7. As an interim measure, assuming that tower radar-arrival control soon can be implemented:

a. Oakland ARTC use the Moffett L/MF range and the Oakland VOR or L/MF range as clearance points for San Francisco traffic.

b. Oakland ARTC use Bay Point intersection and Newark marker as clearance points for Oakland and Alameda NAS traffic.

8. Provided that sufficient pilot/controller communications equipment is installed in the Oakland ARTC Center:

a. Oakland ARTC Center utilize segregated preferential routings in those directions having the heaviest flow of traffic.

b. In the interest of standardization, Oakland ARTC Center use short-range clearance whenever possible.

9. The proposed runway at Oakland Airport be realigned to approximately 283°. Figure 22 shows the improvement in the area between Mission and Pleasanton holding patterns.

10. The San Francisco VOR be relocated to the Los Banos area as a facility for providing dual routes in the San Joaquin valley.

11. Additional VOR facilities be sited within 100 miles of the bay area to provide VOR reception at the minimum obstruction-clearance altitude. This recommendation also was made by the Air Coordinating Committee as set forth in a letter dated May 2, 1956, REF: ACC 59-51C.

APPENDIX I

DME SYSTEMS

The simulator setup for the San Francisco bay study, comprising complex air-route and terminal-area layouts with an adequate number of experienced controllers, provided an excellent opportunity to evaluate two basic applications of DME in the traffic-control system.

Single-Lane DME Airways (System 5D).

The objective of this phase of the program was to determine the advantage of supplementing the present structure of single-lane VOR radial airways with range information obtained from DME. To simulate this feature, System 5 was modified by adding distance checks every 10 miles, as shown in Fig. 23. These checks were designated as distances from specific VOR's; for example, 40 MR indicated 40 miles from MR (Monterey) VOR. Using this system, the simulator pilots were able to interpolate their positions to the nearest mile.

Although five miles DME separation would have been ample for most of the system, a very conservative minimum of ten miles DME separation was used in this test. For aircraft established on specific courses, it was found that this application of DME provided many of the advantages of radar to the air traffic control system. No problems were encountered in applying DME separation. In some cases, departing pilots established their own separations through the controllers' use of the phraseology, "Maintain ten miles separation behind (aircraft identification) until reaching (altitude or point of divergence)."

Short clearance limits and special holding points were established, as needed, by reference to DME readings. One controller reported that common DME reports were extremely useful in changing the altitude of opposite-direction traffic. In airway-crossing operations, an aircraft could be assigned a definite crossing altitude to maintain between the two fore-or-aft DME readings which defined the limits of the crossed airway. For direct flights, a definite point for crossing an airway could be specified by reference to a DME reading from a specific station on the airway. In radar-control operations, specific DME-position reports assisted in obtaining definite target identification without the use of involved communications or turning procedures. All controllers agreed that DME was a very useful tool for traffic-control operations.

Only one run was made on this phase. Controllers had no previous practice in applying DME procedures. Results are shown in Fig. 4.

Dual-Lane Express Airways (System 5X).

The objective of this phase of the program was to determine the advantage of supplementing the present VOR-airway structure with additional airways which could be defined through the use of a relatively simple, VOR-DME, off-course computer in each aircraft. System 5 was used as the basis for this route structure, and a single parallel route was offset five miles from the centerline of each of the main airways, as shown in Fig. 24. Multiplying the number of airways by two multiplied the number of intersections by four. For convenience in defining flight routes, the new intersections were designated by number. The new offset airways carried the same basic Victor Airway numbers as the airways they paralleled, together with the letter A as a suffix. A new offset airway parallel to V150 was called V150A. On the maps, the offset airways were shown by dotted lines and the basic airways by solid lines.

This layout produced passing lanes similar to passing lanes on four-lane highways. To expedite this operation, a standard 30° lane-changing maneuver was employed, as shown in Fig. 25. Obviously, in this system DME-range information would have been available on all lanes. To isolate the advantages of the offset-airway feature, however, DME-position information was not employed in this test.

Air-route controllers who used this system agreed that the dual lanes provided greatly increased capacity and simplified control operations. The use of short-range clearances was greatly reduced, as in most cases departures could be cleared to destination at flight-plan altitude. The dual-lane intersections, which looked complex on the map, proved quite simple in operation. A single fix posting usually sufficed for a block of four intersections. The only special posting procedure necessary was an indication of which lane the aircraft occupied.

In the terminal area, each dual lane terminated in a separate holding pattern. This feature usually permitted independent traffic-feeding operations in each lane, except in the case of the secondary pattern on V113A at Livermore (LV) which overlapped V113 and required altitude separation from traffic on the latter airway.

Only one run was made on this phase. Controllers had no previous practice in handling dual-lane airway procedures. Results are shown in Fig. 4.

FIG. 1 AIR ROUTE TRAFFIC CONTROL SECTORS (SIMULATED)

FIG. 2 OAKLAND APPROACH CONTROL POSITIONS (SIMULATED)

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FIG. 3 SAN FRANCISCO APPROACH CONTROL POSITIONS (SIMULATED) CAA TECHNICAL DEVELOPMENT CENTER INDIANAPOLIS INDIANA

OAKLAND SIMULATION

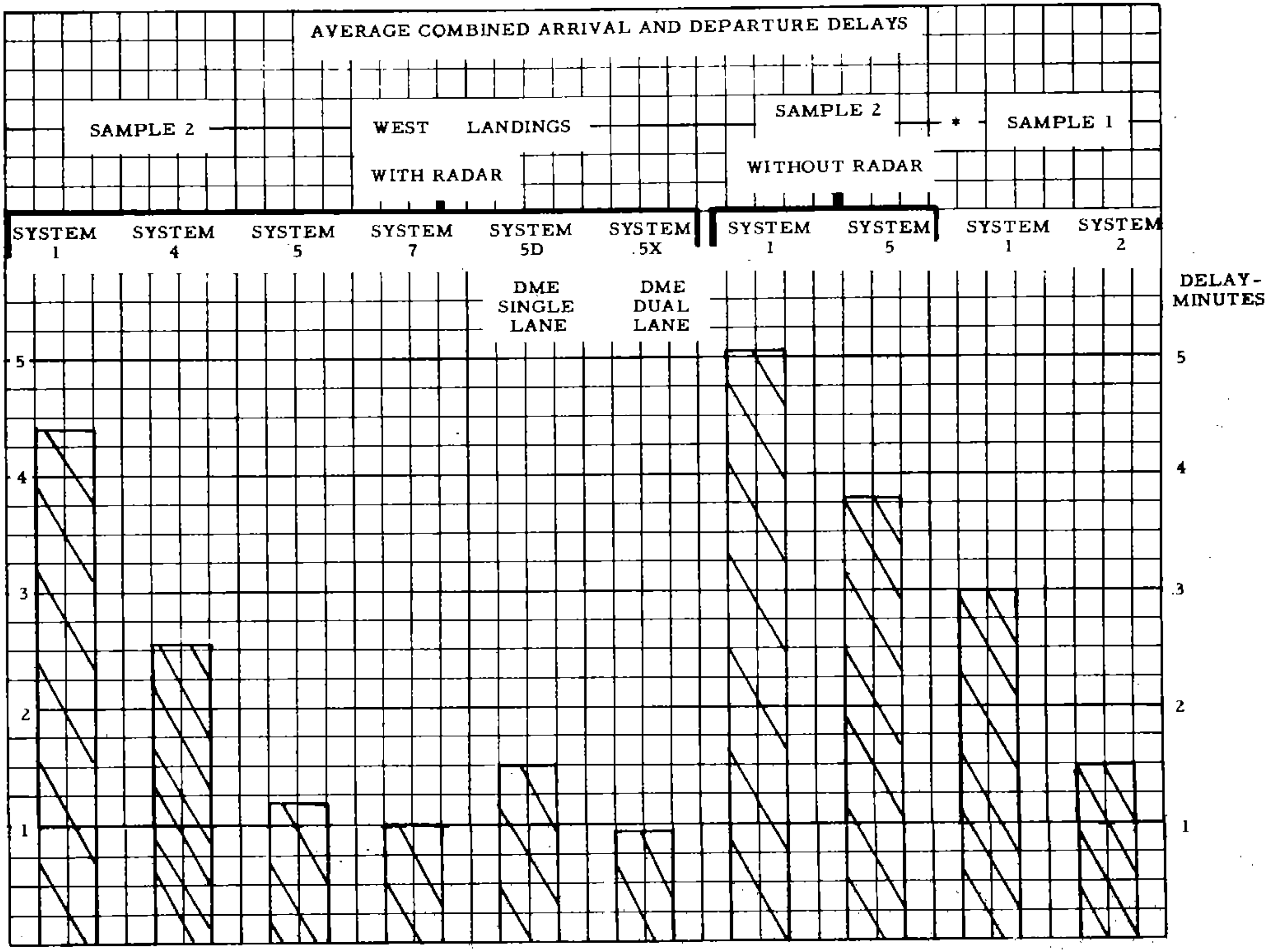
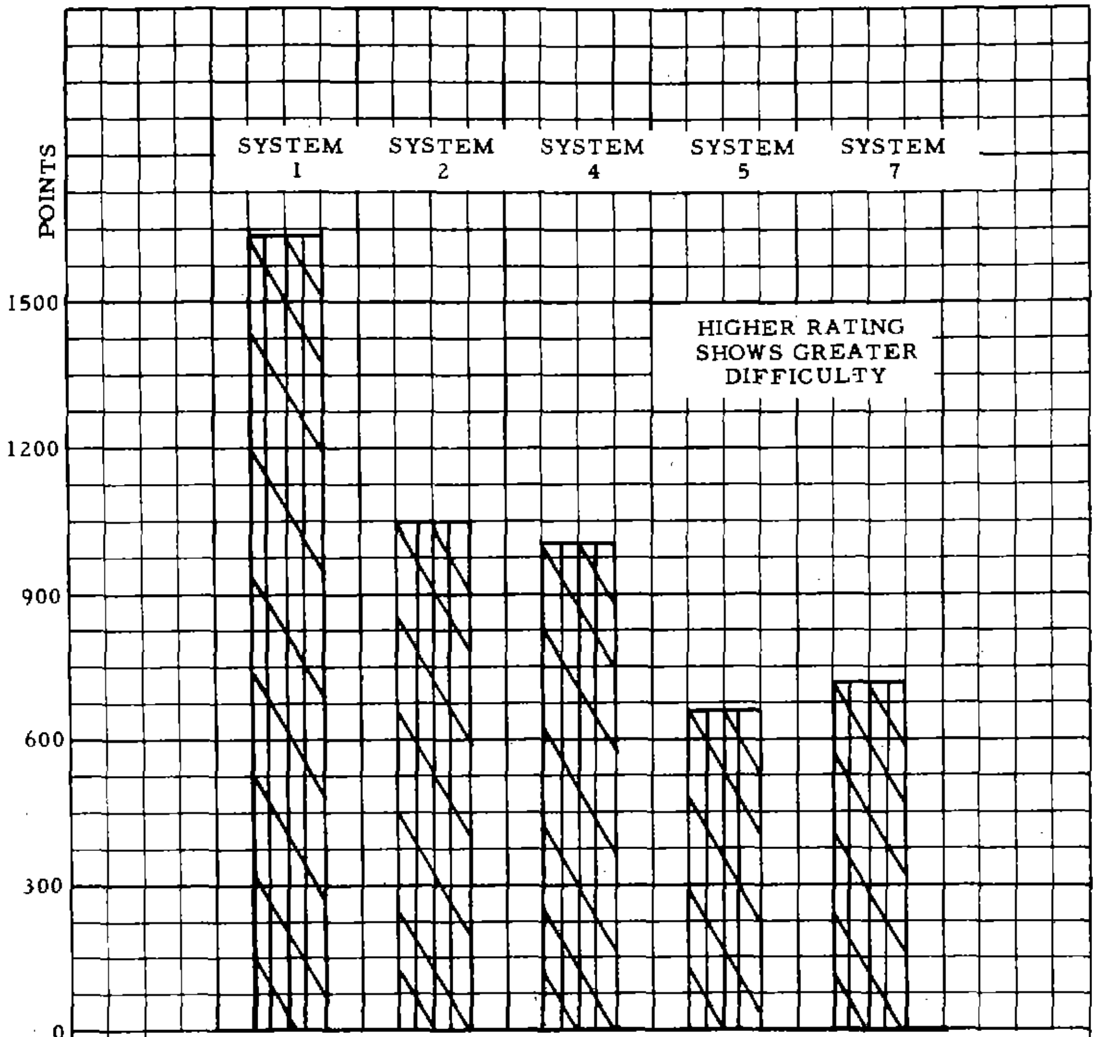


FIG. 4 AIRCRAFT DELAY MEASUREMENTS



*ALL SYSTEMS RATED BY 4 CENTER AND 4 TOWER CONTROLLERS. AREAS OF DIFFICULTY IN EACH SYSTEM WERE RATED AS FOLLOWS: INTOLERABLE - 20 POINTS; DIFFICULT - 10 POINTS; MODERATE - 5 POINTS; LIGHT - 2 POINTS.

FIG. 5 COMBINED RESULTS OF SYSTEM RATING CHARTS

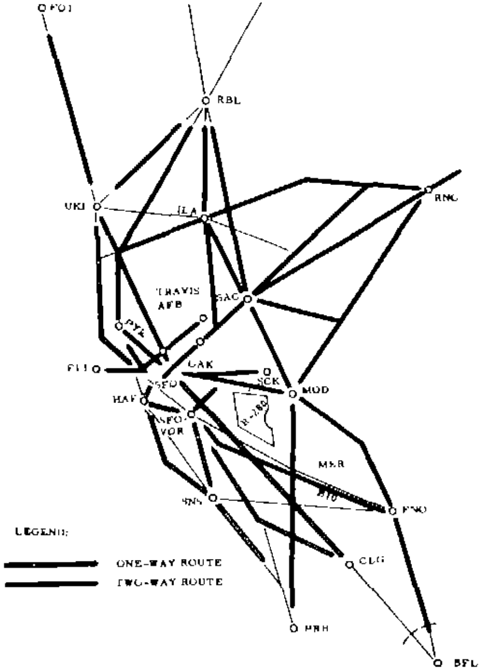


FIG. 6 SYSTEM I
AIRWAY CONFIGURATION (PRESENT ROUTE STRUCTURE)

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INDIANAPOLIS INDIANA

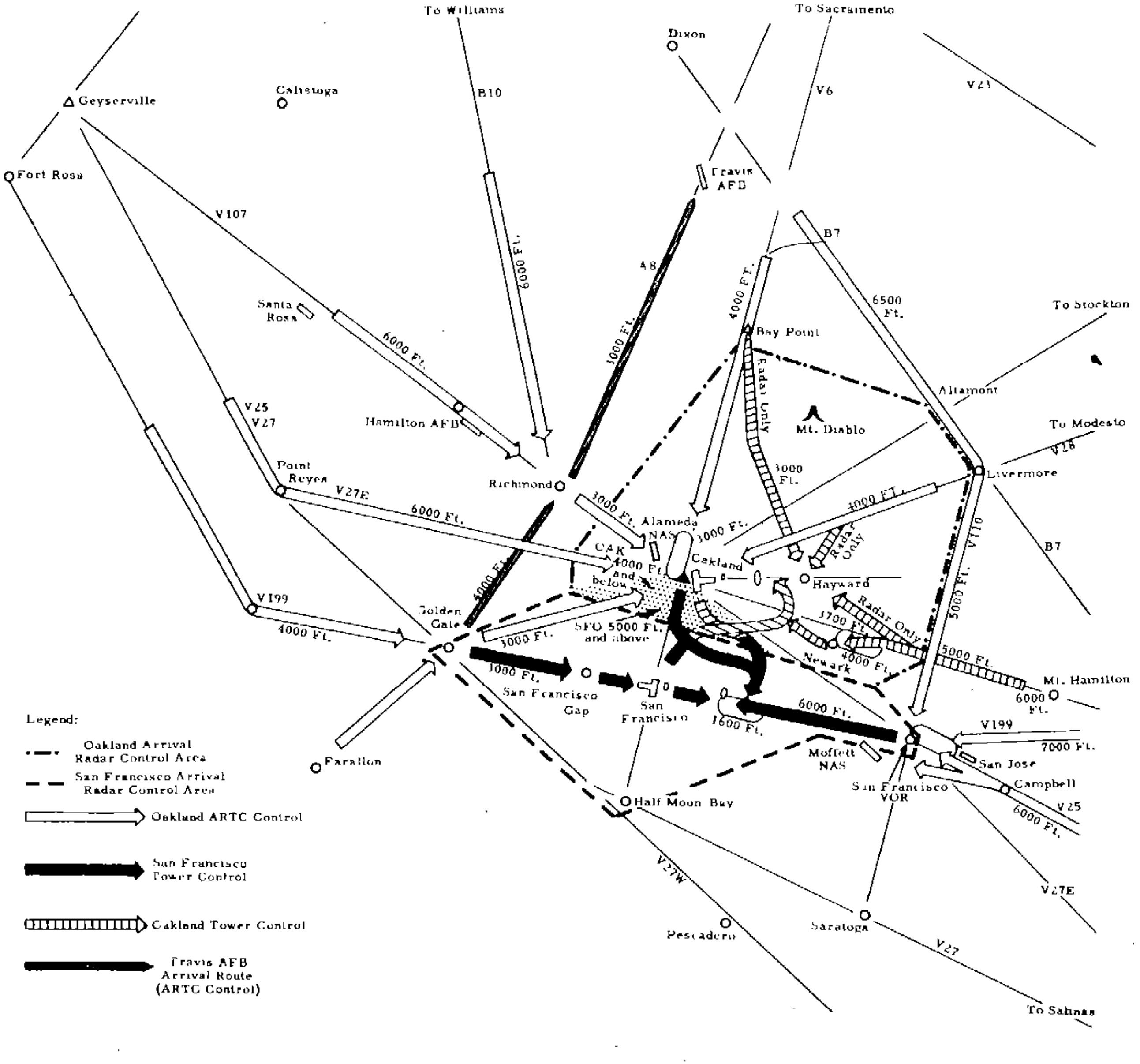

FIG. 7 ARRIVAL ROUTES - SYSTEM I

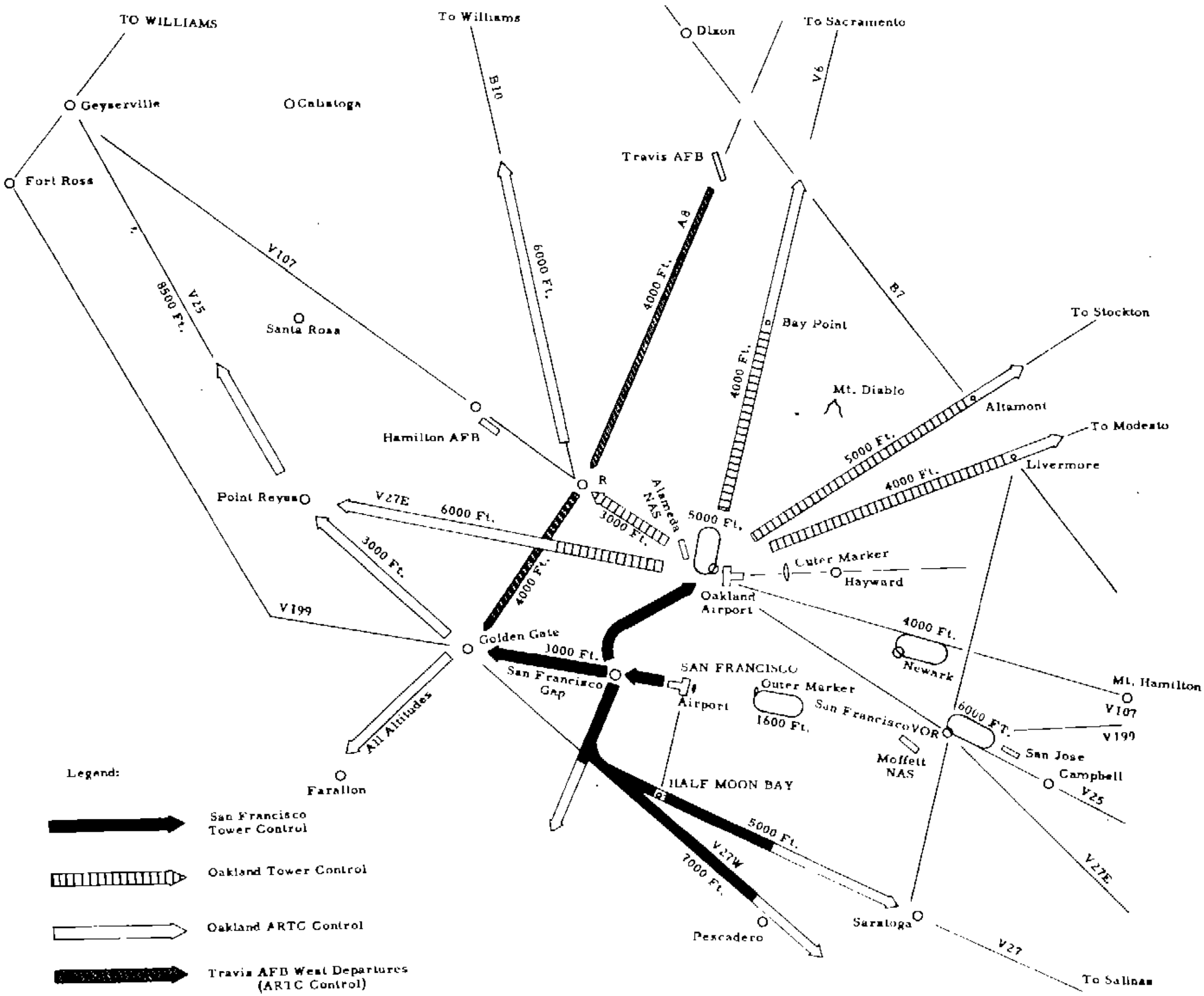

FIG. 8 DEPARTURE ROUTES - SYSTEM 1

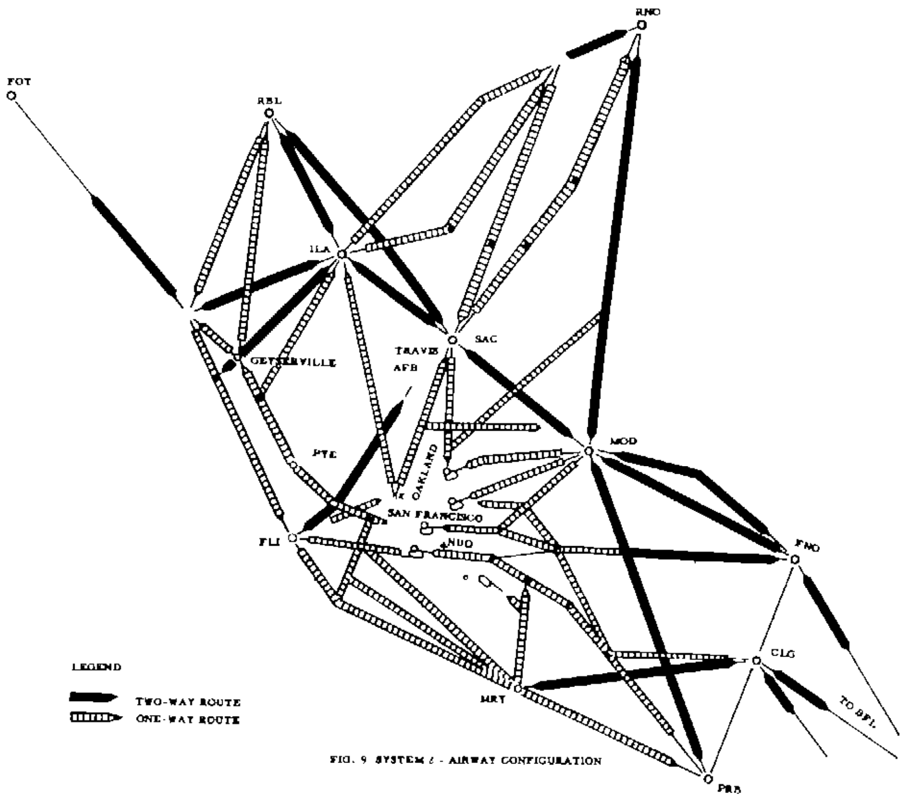

FIG. 9 SYSTEM 6 - AIRWAY CONFIGURATION

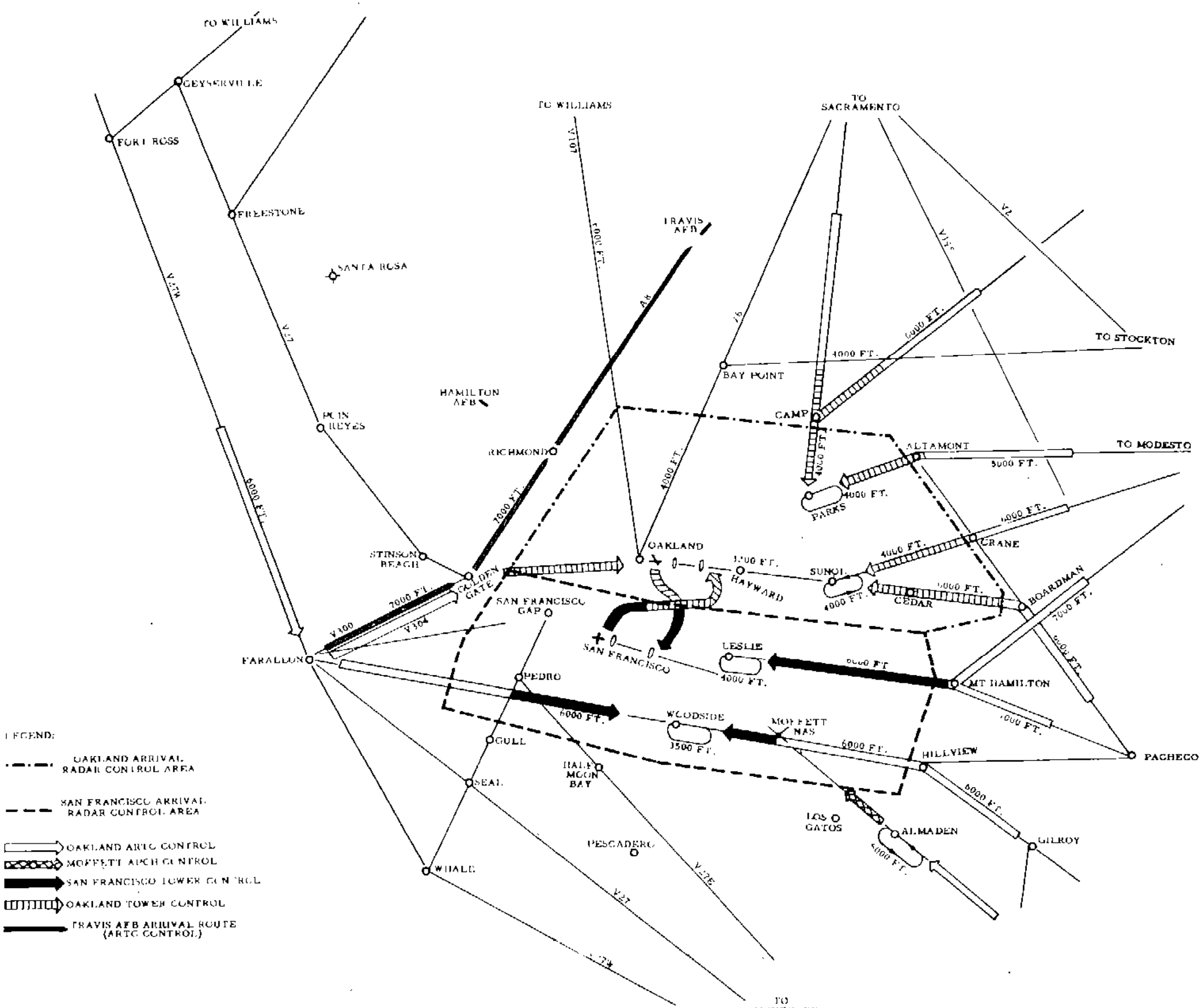

FIG. 10 ARRIVAL ROUTES - SYSTEM 2

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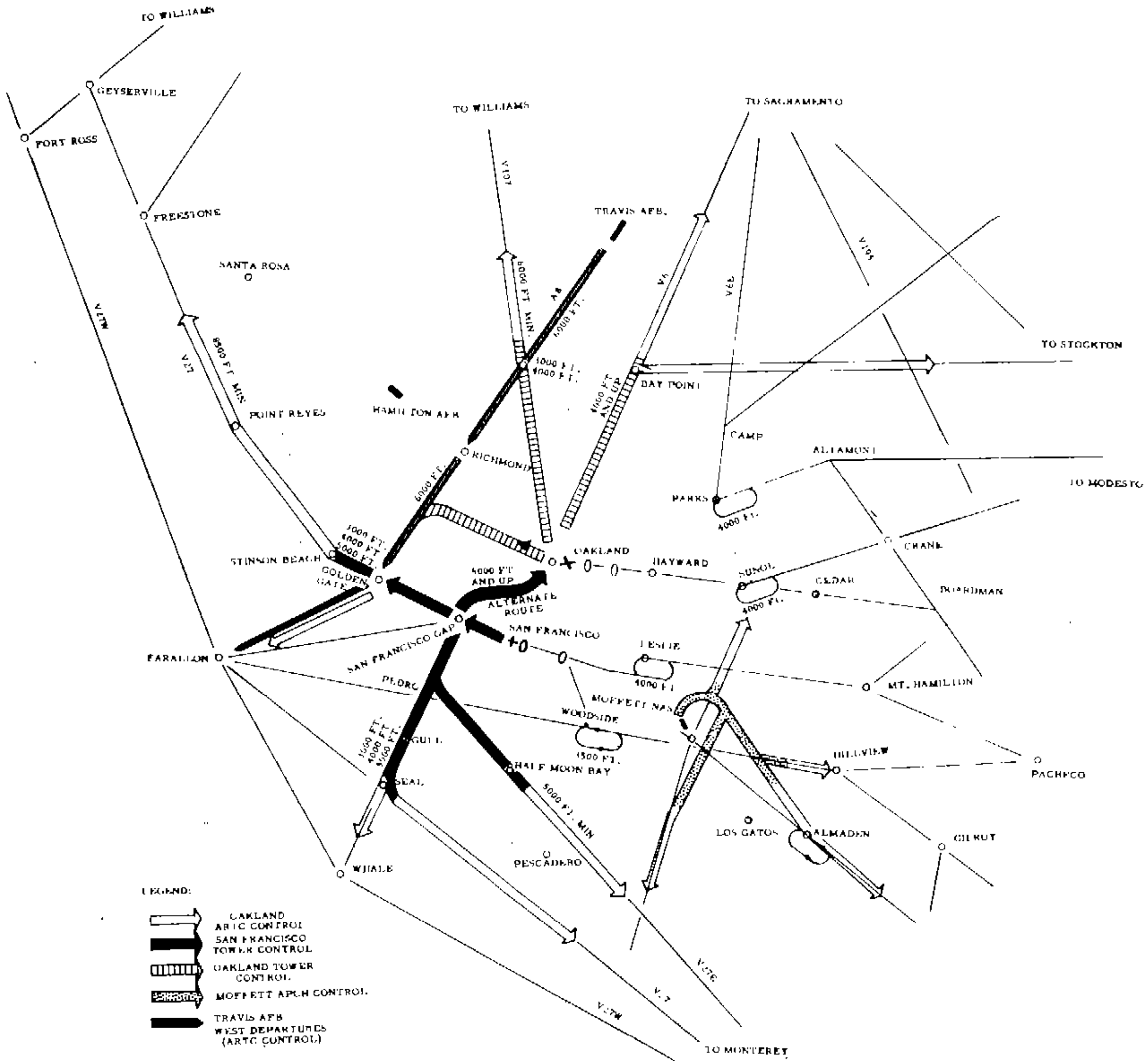

FIG. 11 DEPARTURE ROUTES - SYSTEM 2

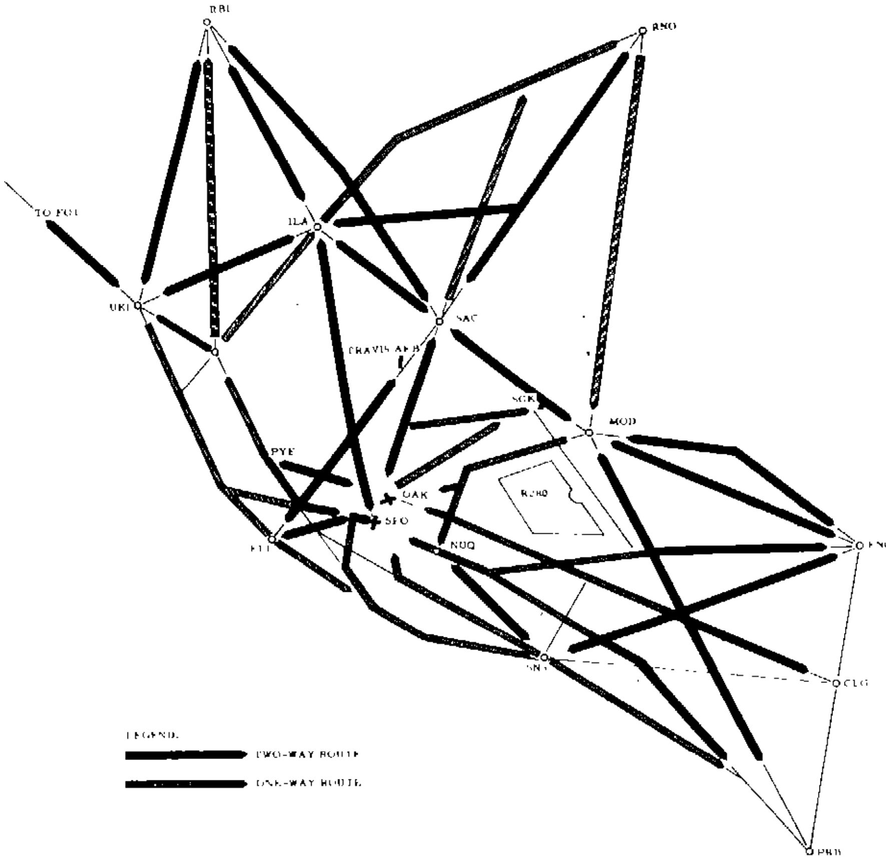

FIG. 12 AIRWAY CONFIGURATION - SYSTEM 4

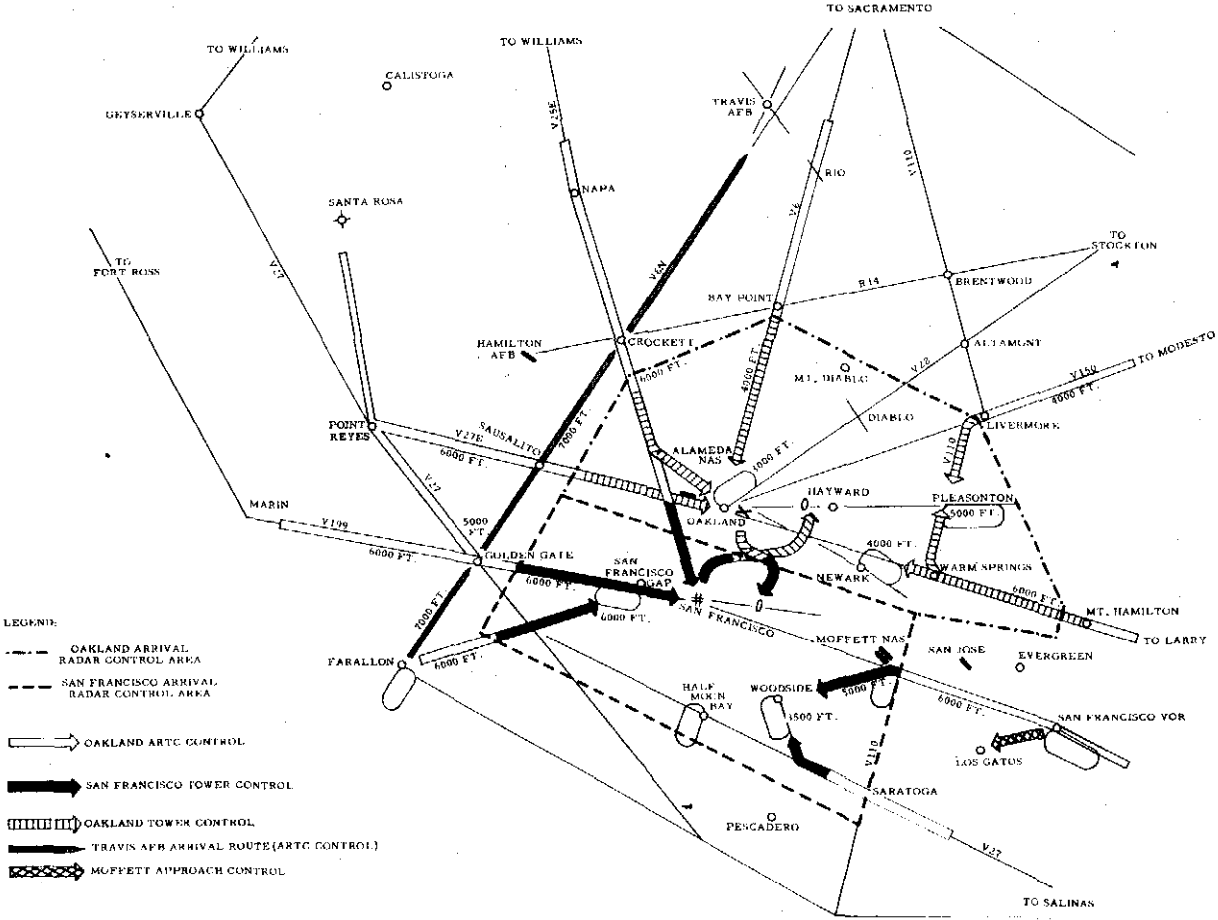

FIG. 13 ARRIVAL ROUTES - SYSTEM 4

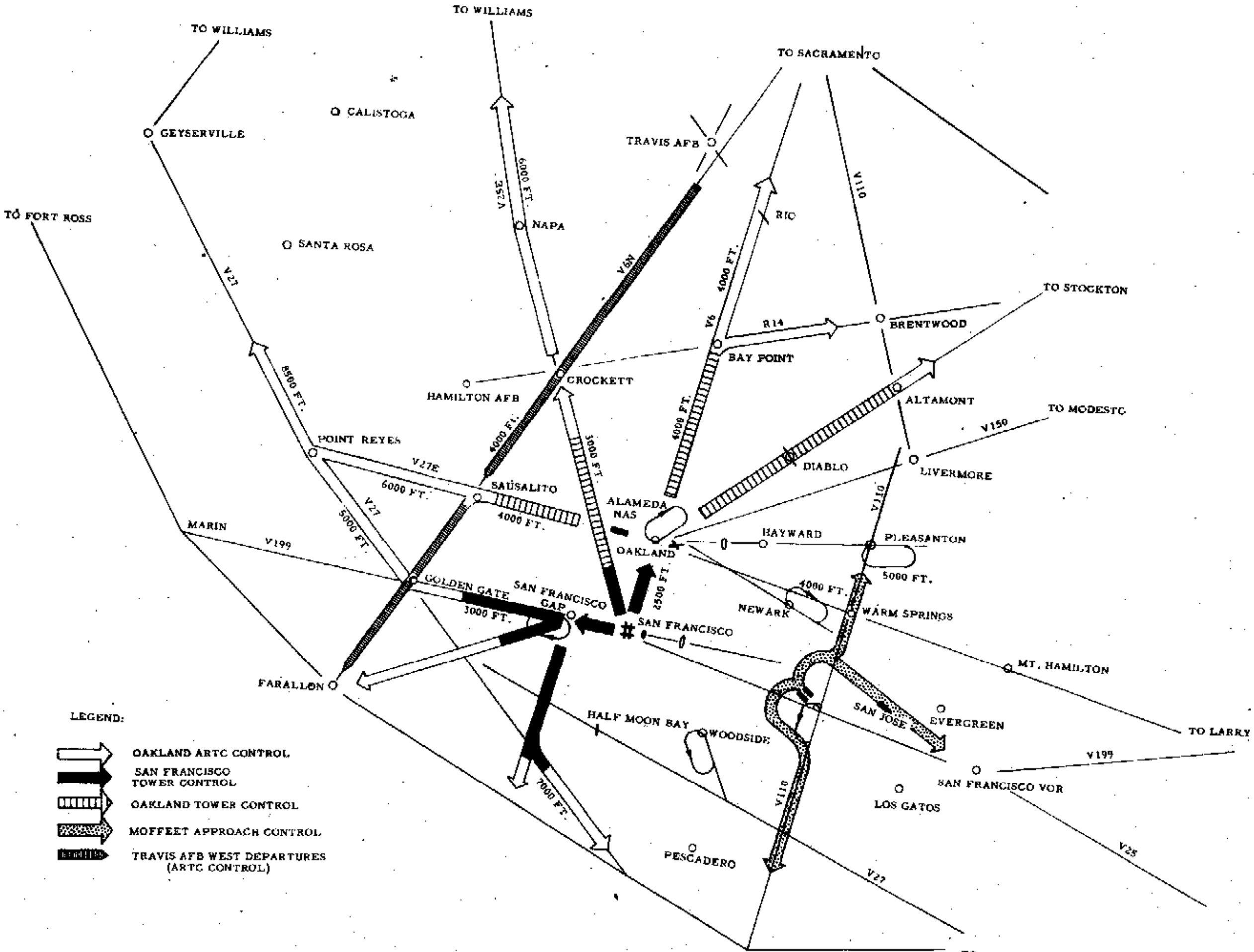

FIG. 14 DEPARTURE ROUTES - SYSTEM 4

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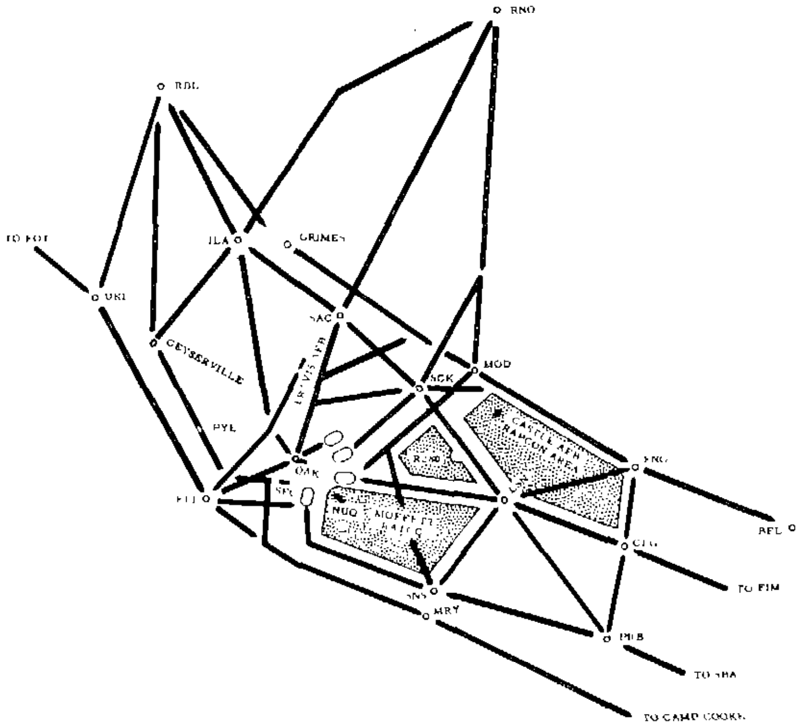

LEGEND:

ONE-WAY ROUTE

TWO-WAY ROUTE

FIG. 15 AIRWAY CONFIGURATION - SYSTEM 5

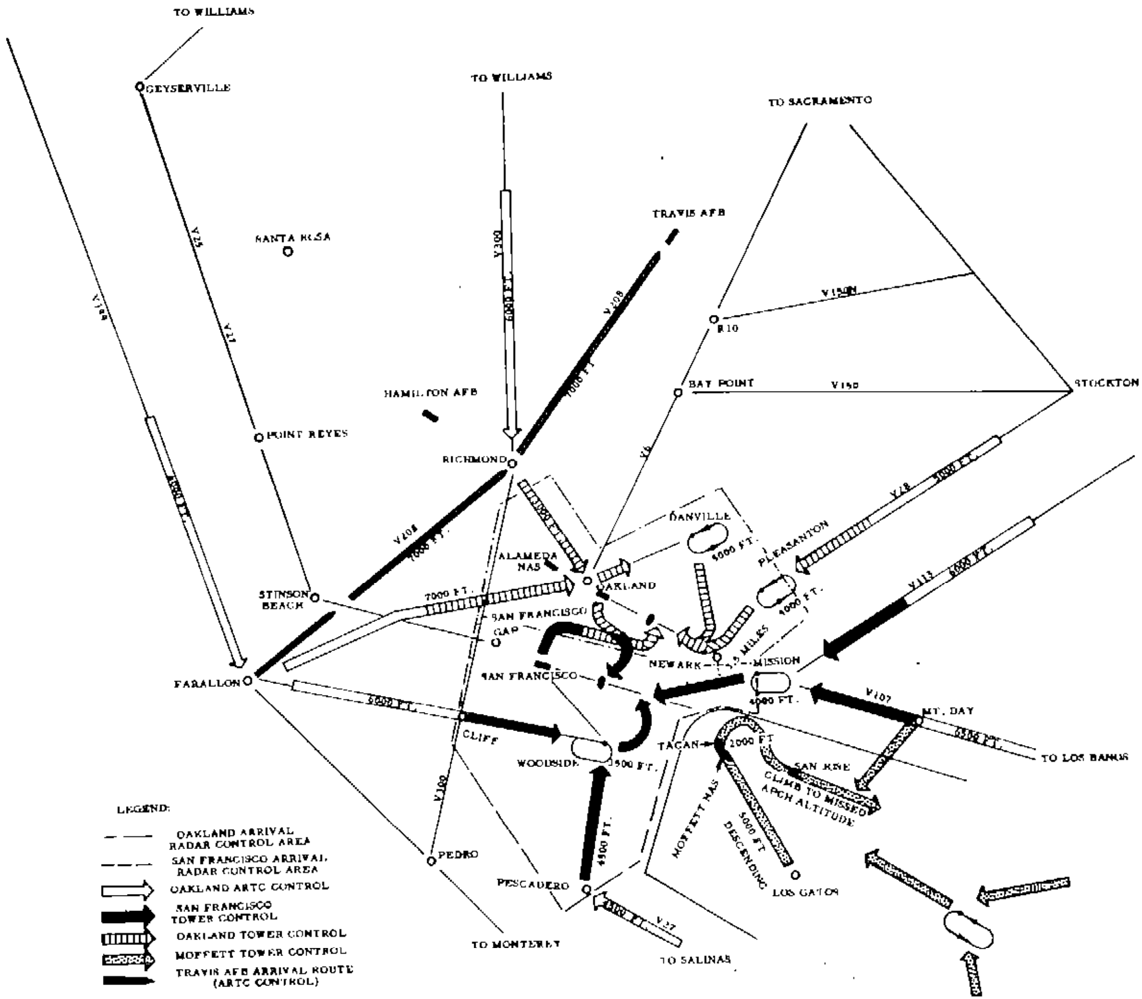

FIG. 16 ARRIVAL ROUTES - SYSTEM 5

CAA TECHNICAL DEVELOPMENT CENTER INDIANAPOLIS, INDIANA

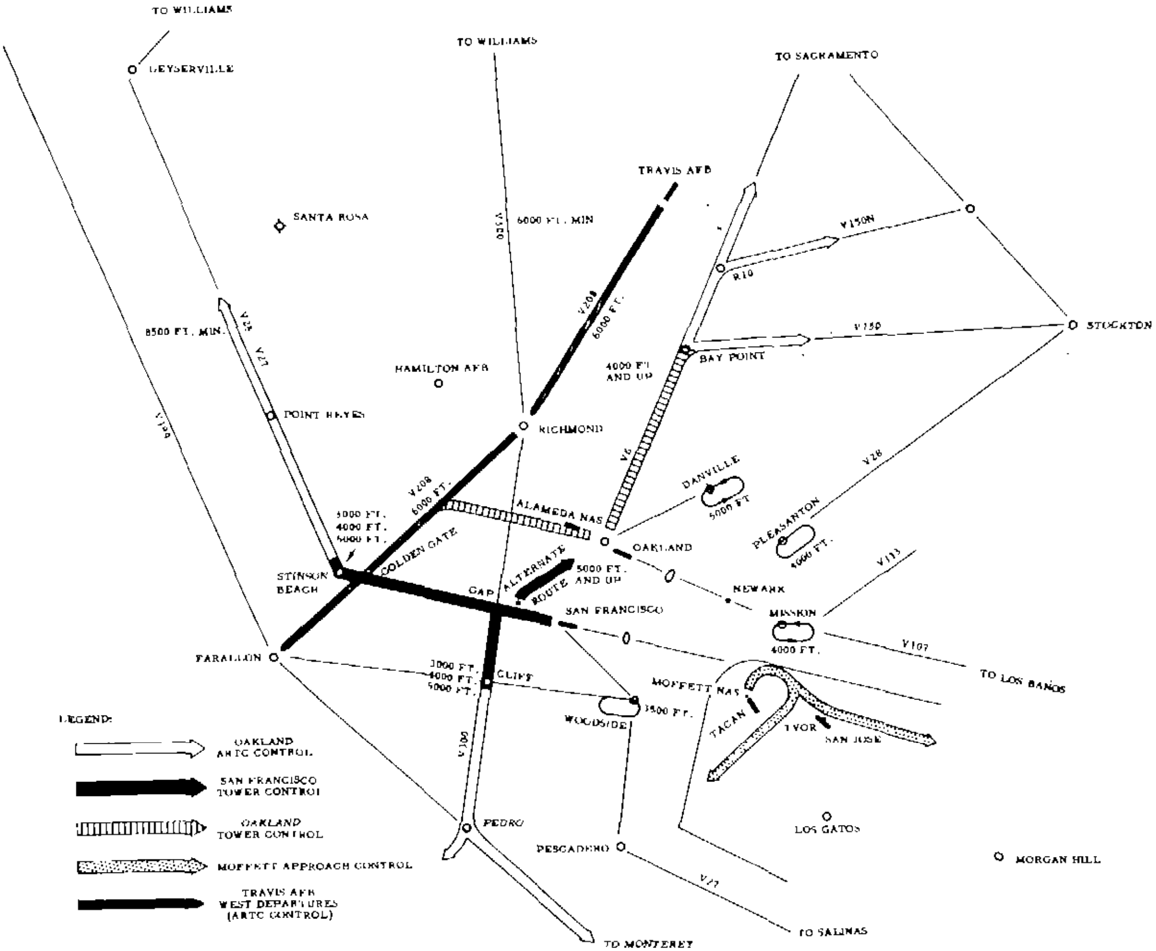

FIG. 17 DEPARTURE ROUTES - SYSTEM 5

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DEVELOPMENT CENTER
INDIANAPOLIS INDIANA

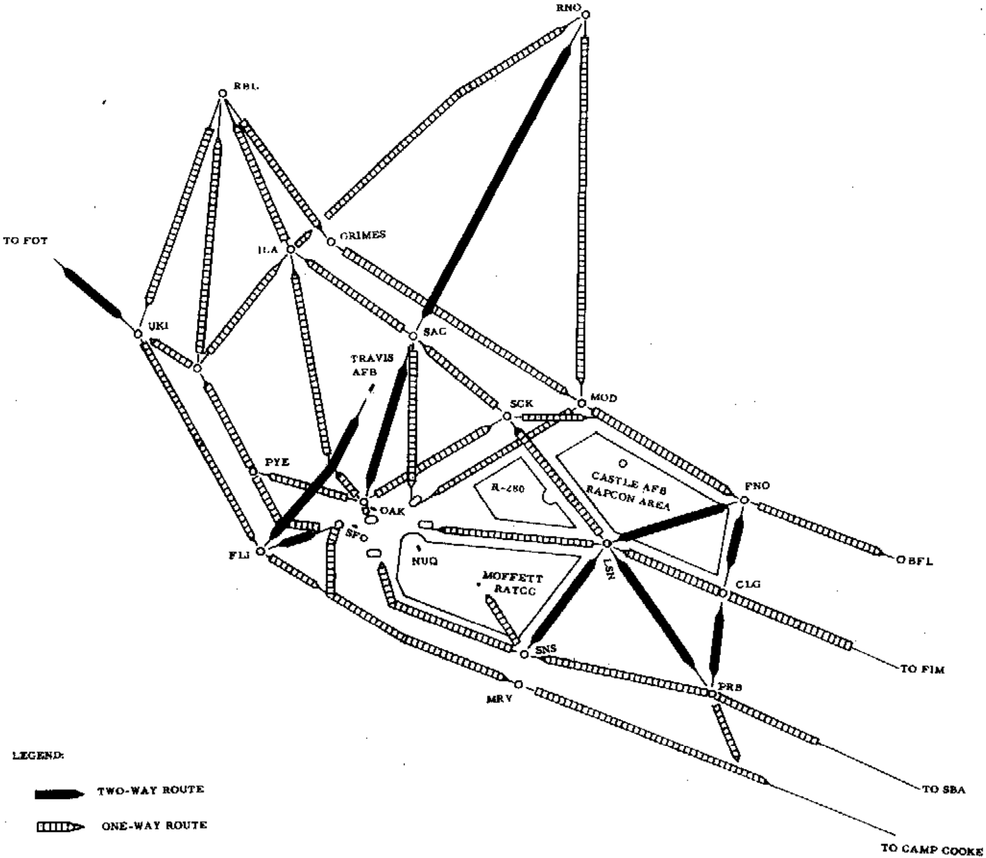


FIG. 18 AIRWAY CONFIGURATION - SYSTEM 7

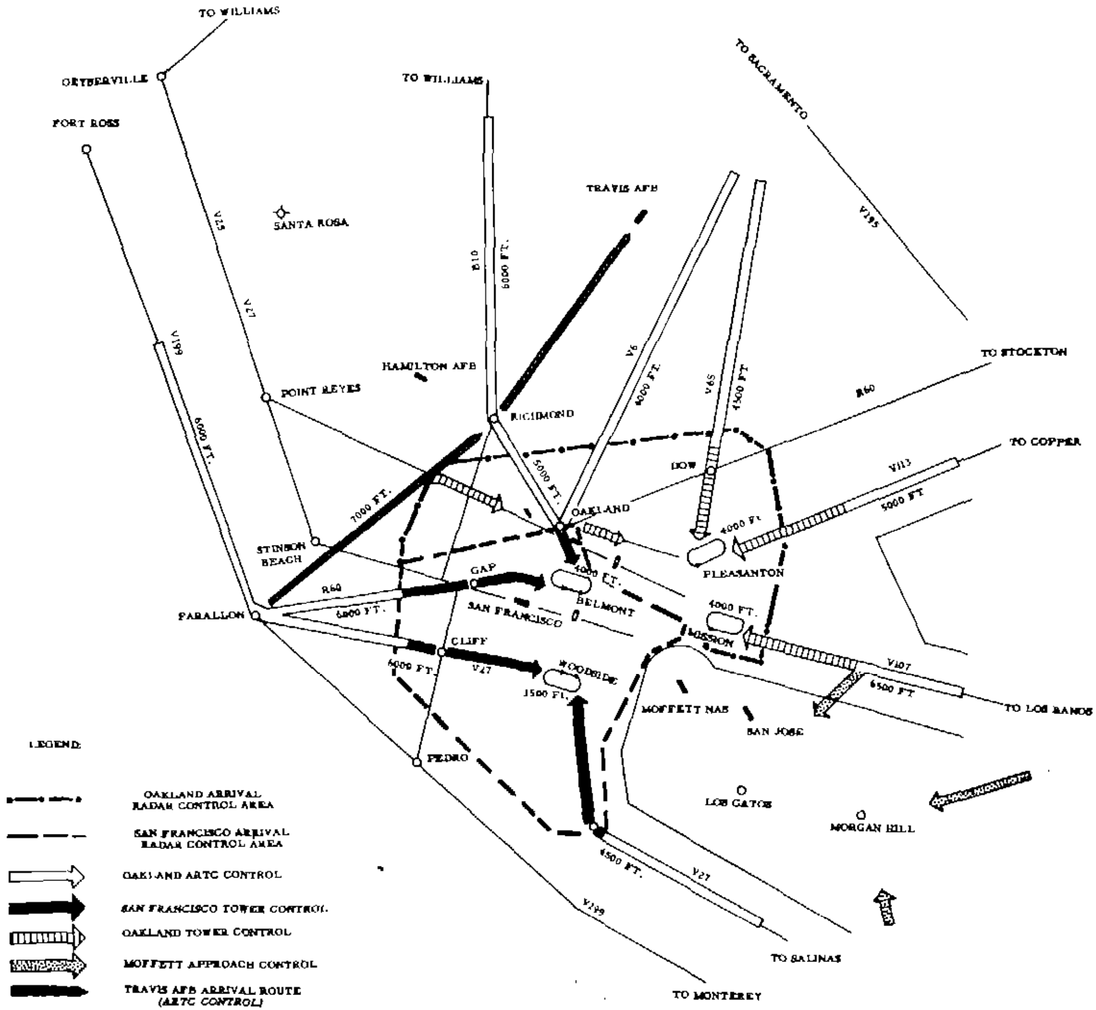


FIG. 19 ARRIVAL ROUTES - SYSTEM 7

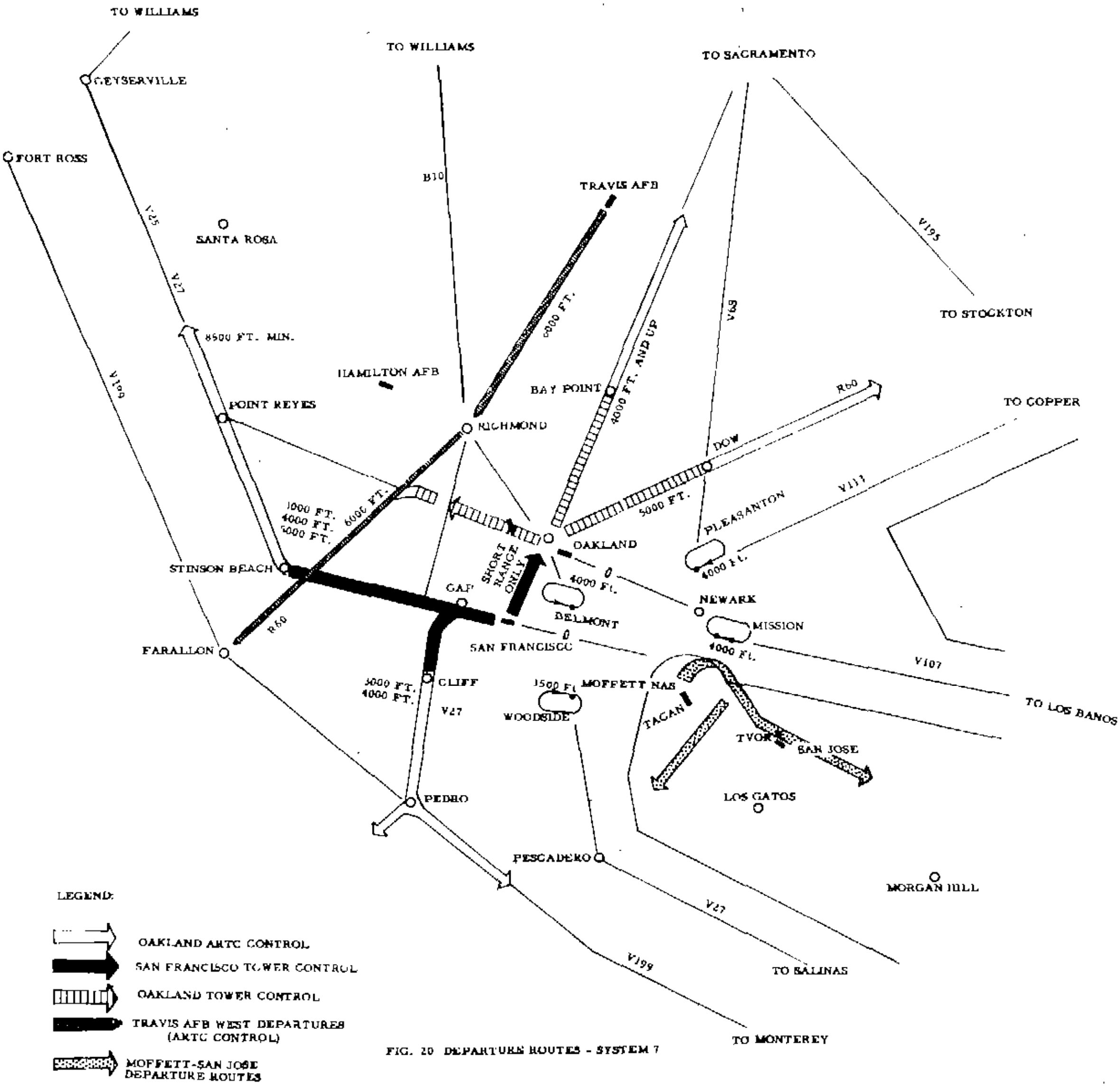


FIG. 20 DEPARTURE ROUTES - SYSTEM 7

CAA TECHNICAL DEVELOPMENT CENTER INDIANAPOLIS INDIANA

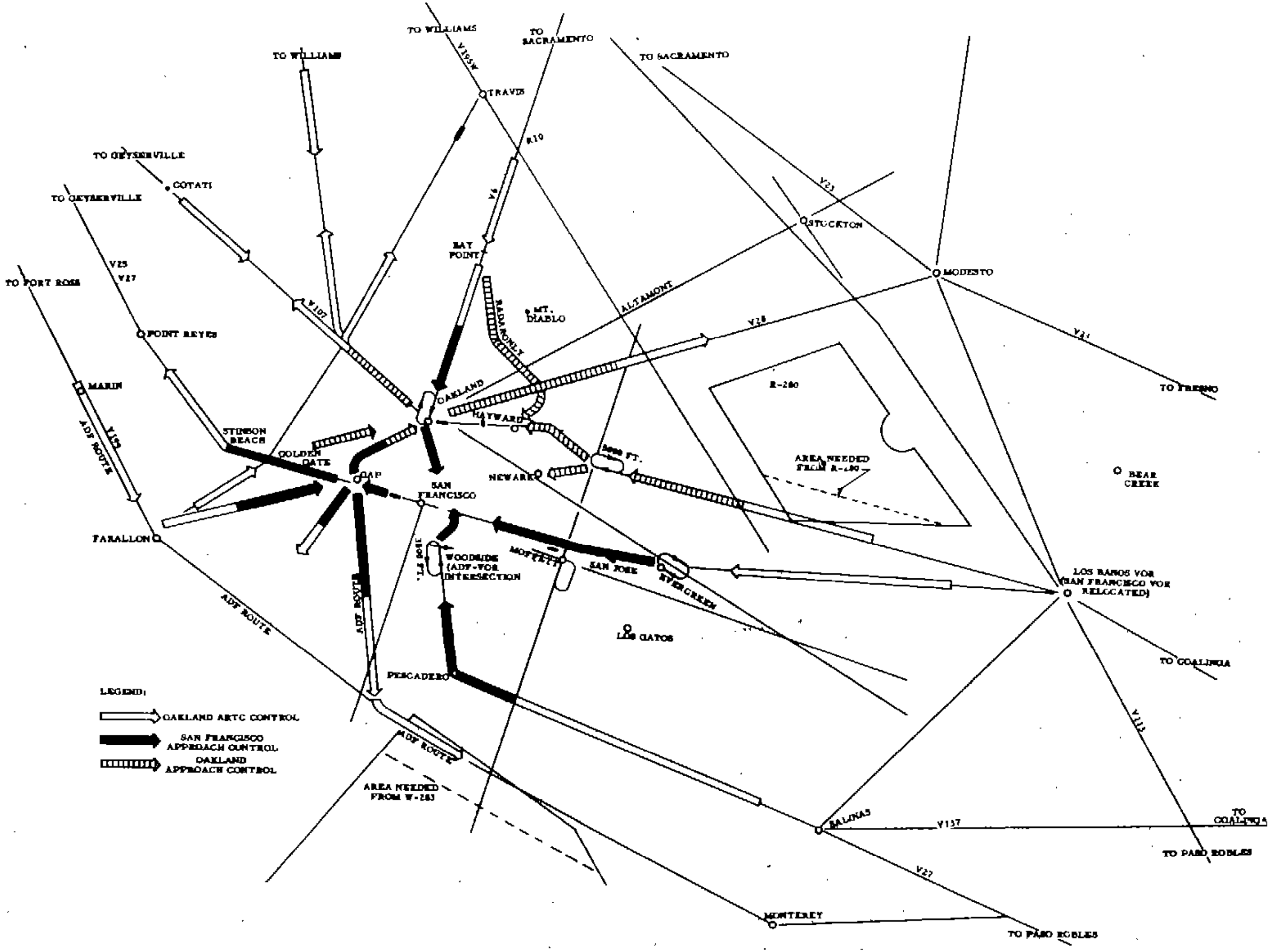
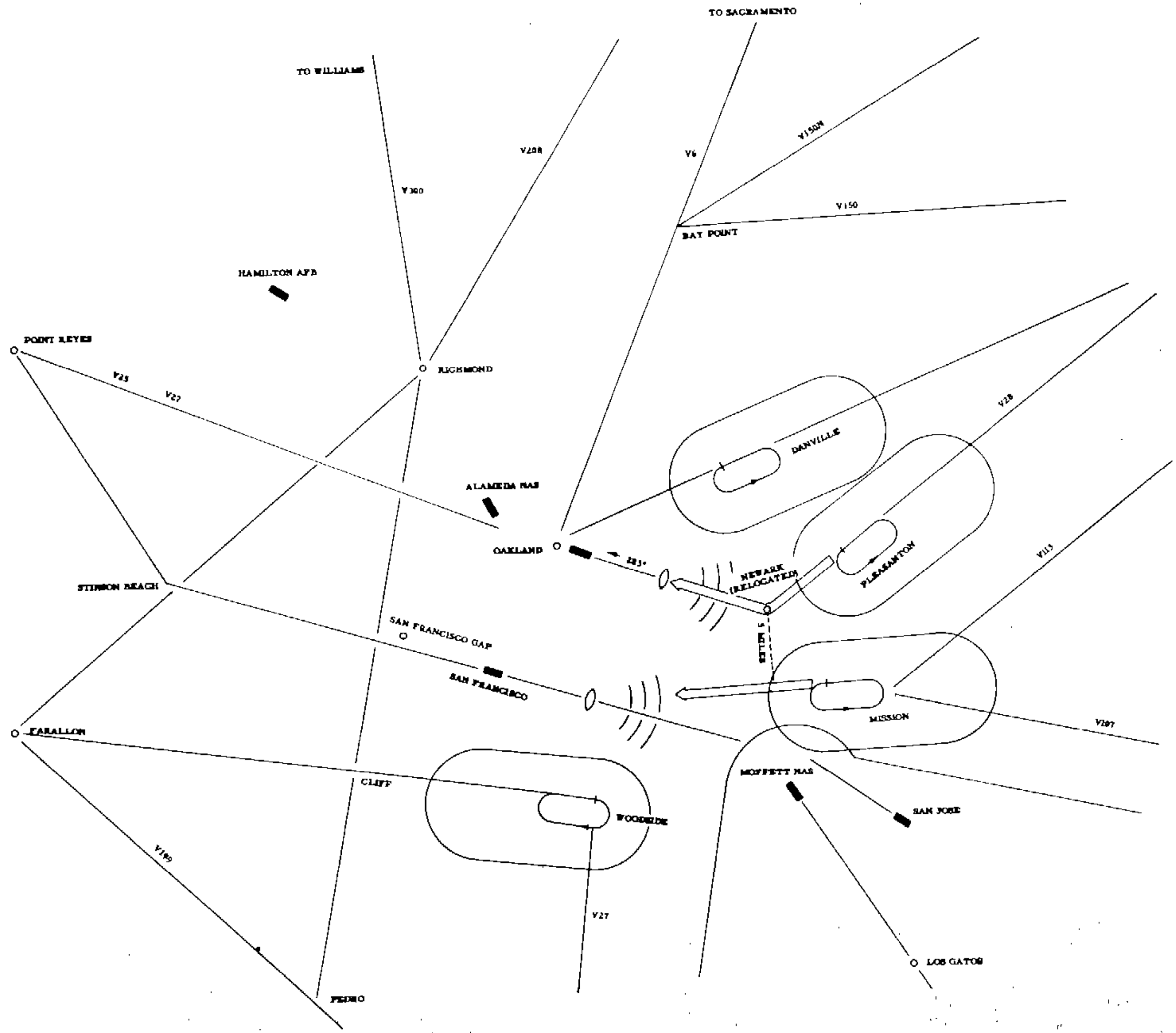


Fig. 21 ROUTE STRUCTURE PATTERNED AFTER RECOMMENDED SYSTEM USING PRESENT RADIO AIDS (EXCEPT THE RELOCATING OF THE SAN FRANCISCO VOR)


TO SACRAMENTO
TO WILLIAMS
V208
V6
V150N
V300
V150
BAY POINT
HAMILTON AFB
POINT REYES
RICHMOND
V25
V27
DANVILLE
V28
ALAMEDA NAS
OAKLAND
283°
NEWARK (RELOCATED)
PLEASANTON
V113
STINSON BEACH
SAN FRANCISCO GAP
SAN FRANCISCO
5 MILES
MISSION
V197
FARALLON
MOFFETT NAS
CLIFF
SAN JOSE
WOODSIDE
V199
V27
LOS GATOS
PEDRO

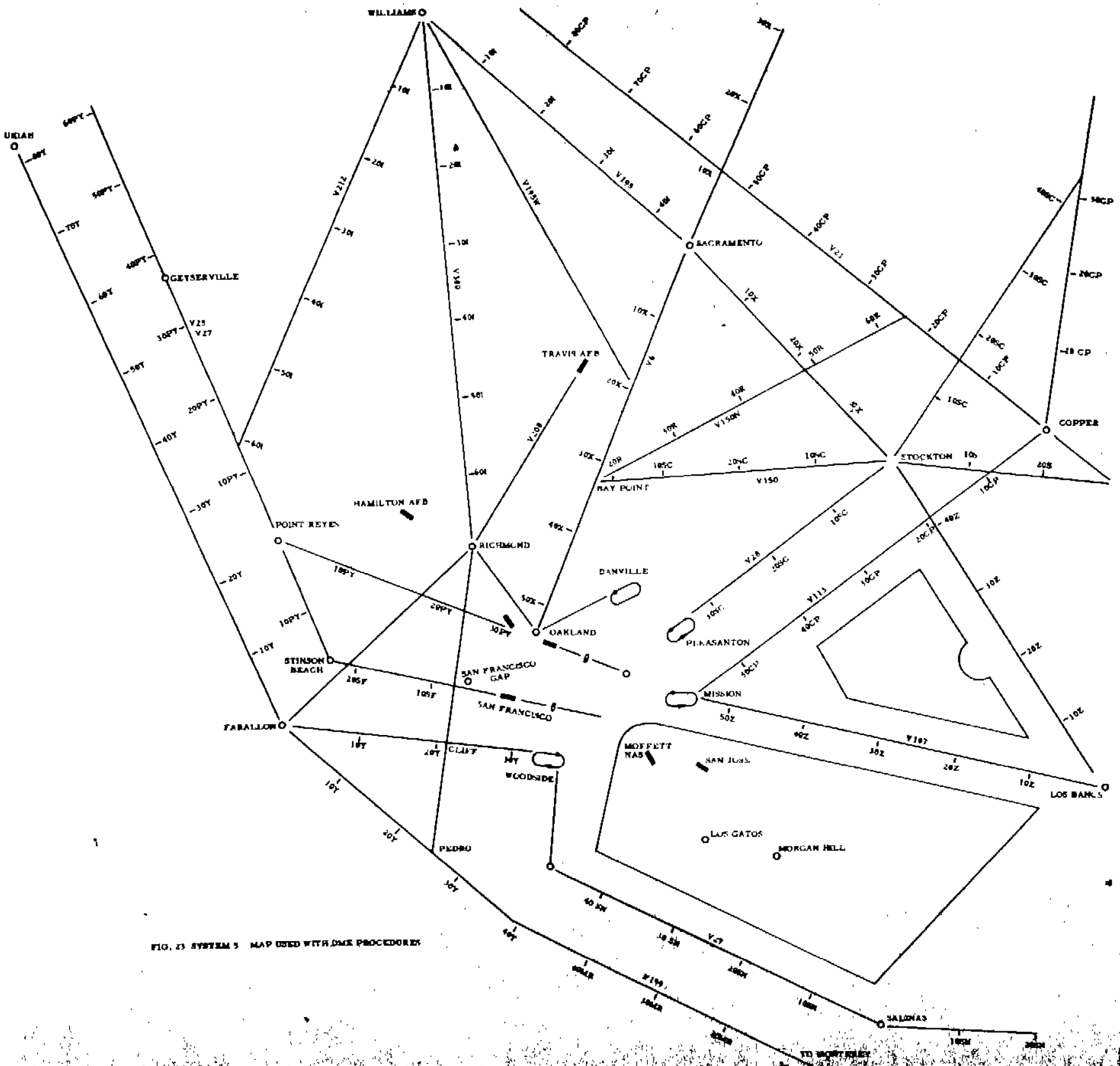
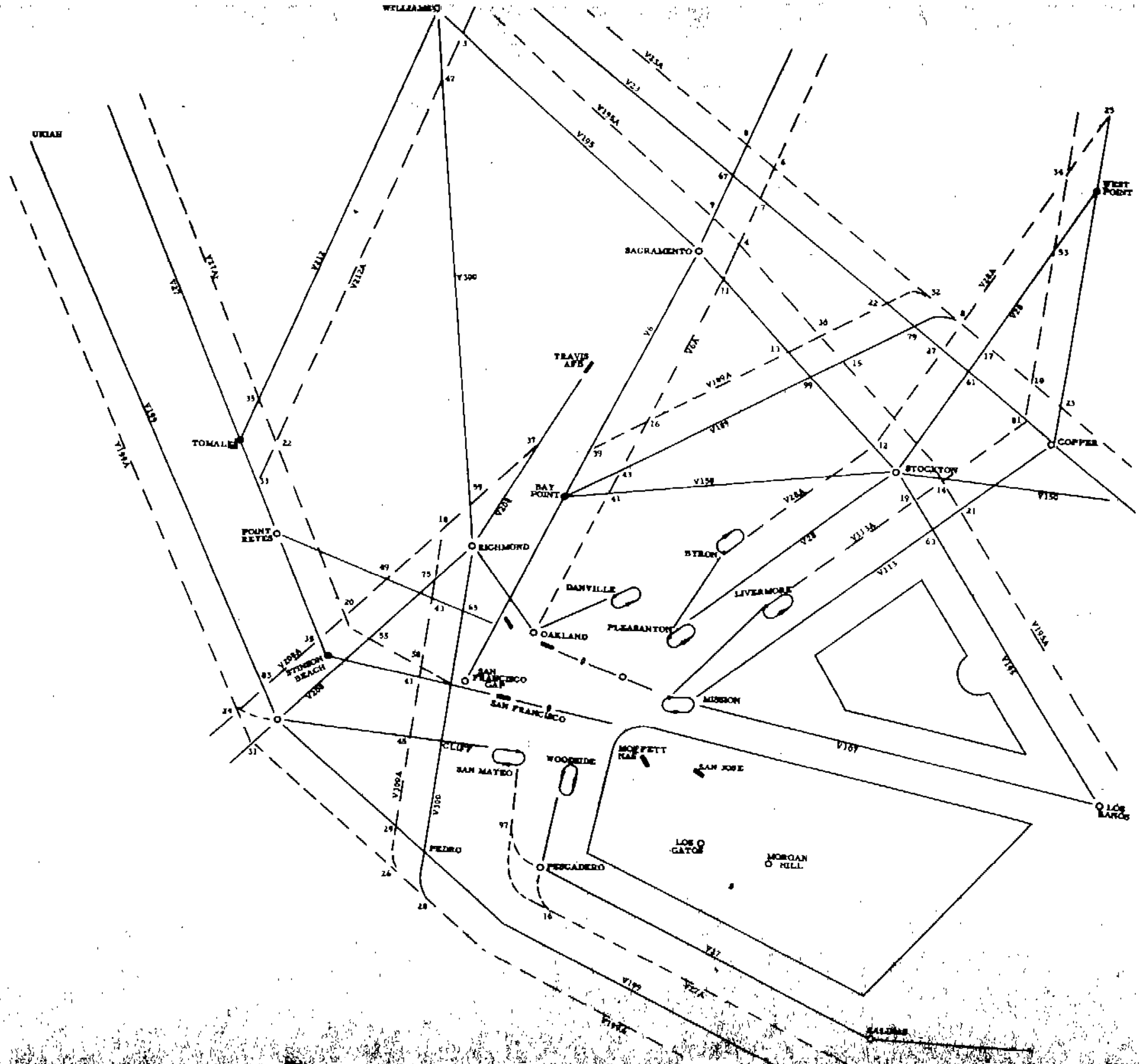


FIG. 23 SYSTEM 5 MAP USED WITH DME PROCEDURES



WILLIAMS
UKIAH
SACRAMENTO
TRAVIS AFB
TOMALES
POINT REYES
RICHMOND
BAY POINT
STOCKTON
WEST POINT
COPPER
BYRON
DANVILLE
LIVERMORE
PLEASANTON
OAKLAND
STINSON BEACH
SAN FRANCISCO GAP
SAN FRANCISCO
MISSION
CLIFF
SAN MATEO
WOODSIDE
MOFFETT NAS
SAN JOSE
LOS GATOS
MORGAN HILL
PESCADERO
PEDRO
LOS BANOS
SALINAS

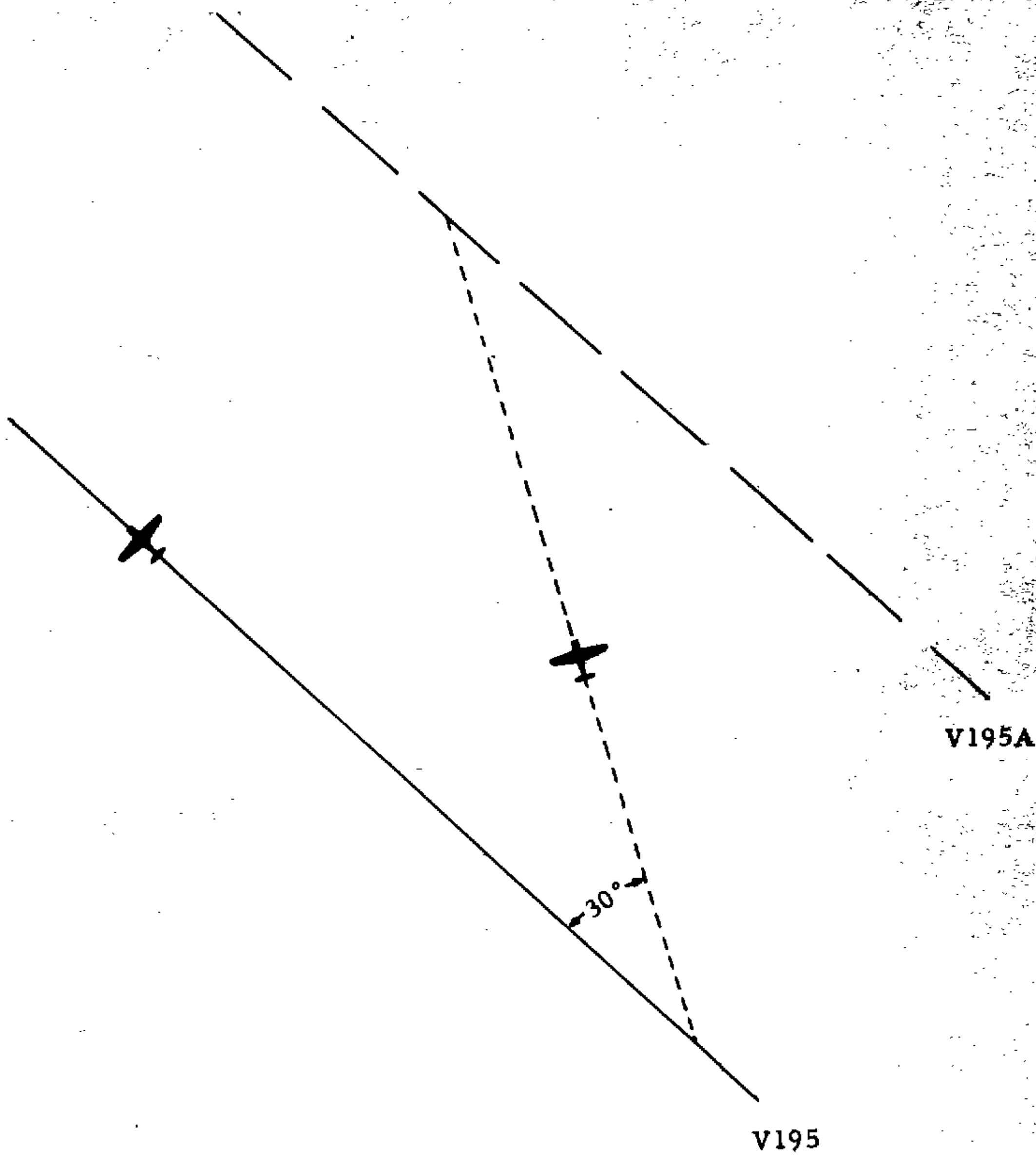


FIG. 25 PROCEDURE FOR CHANGING LANES ON DUAL EXPRESS AIRWAYS