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AIRSPACE ANALYSIS FOR PHASE II OF THE REGIONAL AIRPORT PLAN UPDATE PROGRAM

LEVEL II

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FINAL REPORT

Prepared For

METROPOLITAN TRANSPORTATION COMMISSION

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SAN FRANCISCO, CALIFORNIA 94128

Telephone: (415) 347-9521

March 16, 1979

Metropolitan Transportation Commission
Hotel Claremont
Berkeley, California 94705

Attention: Mr. Chris Brittle, Project Manager

Re: Airspace Analysis, Final Report

Gentlemen:

In accordance with our contract dated April 22, 1977, Peat, Marwick, Mitchell & Co. is pleased to submit the final report on the airspace analysis for Phase II of the Regional Airport Plan Update Program.

Respectfully submitted,

Peat, Marwick, Mitchell & Co.

PEAT, MARWICK, MITCHELL & CO.

AIRSPACE ANALYSIS FOR PHASE II OF THE REGIONAL AIRPORT PLAN UPDATE PROGRAM

FINAL REP[redacted]T

Prepared for

METROPOLITAN TRANSPORTATION COMMISSION
Berkeley, California

The preparation of this report was financed in part through an Airport System Planning Grant from the Federal Aviation Administration under the provisions of Section 13 of the Airport and Airway Development Act of 1970, as amended.

Prepared by

Peat, Marwick, Mitchell & Co.
San Francisco, California

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SUMMARY AND FINDINGS

The Metropolitan Transportation Commission (MTC) is updating the Regional Airport Plan for the nine-county San Francisco Bay Area, with a planning grant from the Federal Aviation Administration (FAA). As a part of this program, MTC retained Peat, Marwick, Mitchell & Co. (PMM&Co.) to analyze airspace conditions in the Bay Area. The purpose of the analysis is to assist MTC to determine the extent to which the airspace serving the air carrier and general aviation airports in the region will be able to accommodate future aviation activity.

The analysis is divided into two parts:

- A review of the organization of the Bay Area airspace
- An assessment of airspace capacity

In the review of the organization of the Bay Area airspace, PMM&Co. evaluated existing conditions and data on (1) jurisdictional relationships between different elements of the airspace system, (2) air traffic flows, and (3) airspace interactions between airports. The results of the evaluation are described in Chapter I of this report.

In the assessment of airspace capacity, PMM&Co. evaluated alternative combinations of aircraft demand and airspace-airport systems. These combinations included two different passenger allocations selected by MTC, the use of an additional airport for air carrier activity, and general aviation and military traffic forecasts.

The PMM&Co. airspace capacity model was applied to estimate the capacity of the Bay Area airspace under a variety of different operating conditions. The airspace capacity was compared with alternative forecasts of aviation demand in 1997 (the selected planning forecast year) provided by MTC. The comparisons of demand with airspace capacity led to findings concerning (1) the extent to which the Bay Area airspace will be able to accommodate future aviation activity, and (2) the locations of critical capacity constraints and airspace interactions.

The results of the capacity assessment are described in Chapter II of this report.

Bay TRACON Airspace

The Federal Aviation Administration (FAA) has established a Terminal Area Radar Approach Control (TRACON) to provide air traffic control (ATC) service to aircraft flying in the Bay Area airspace. Bay TRACON provides approach and/or departure control services for the following airports:

- Alameda Naval Air Station
- Hayward Air Terminal
- Livermore Municipal Airport
- Oakland International Airport
- Moffett Naval Air Station (at Sunnyvale)
- San Francisco International Airport
- San Jose Municipal Airport

The assessment of airspace capacity concentrated on Bay TRACON airspace because this airspace has the highest density of aircraft operations.

Airspace Capacity Model

The PMM&Co. airspace capacity model, a computerized analytical model that calculates the capacity of the airspace system and its elements, was used to assess the alternative airspace-airport systems.

The model assesses the relative aircraft flows on different routes in the airspace and considers the interactions between aircraft along the routes, at the airspace fixes, and on the runways, as defined in an airspace network.

A three-dimensional airspace network was established that consists of links and nodes representing the existing traffic flows in the TRACON airspace. Individual elements represent all applicable runway systems, arrival and departure routes, aircraft diverging and merging points, and aircraft flow crossing points. The model also uses a set of input parameters to determine the minimum separation required between aircraft operations throughout the airspace system.

Airspace Alternatives

MTC defined seven San Francisco Bay Area airport system alternatives for assessment in the Regional Airport Plan Update Program. The amount and distribution of general aviation and third-level air carrier activity was held constant in each alternative, but different allocations of passengers (and hence air carrier aircraft operations) were made for the three major airports--San Francisco International

Airport (SFO), Oakland International Airport (OAK), and San Jose Municipal Airport (SJC)--and a potential additional air carrier airport was included at one of four existing locations in the north bay.

On the basis of a preliminary review of the airspace and other implications of these seven alternatives, MTC selected two (Alternatives 1 and 3) for detailed airspace analysis.

Alternative 1 maintains the same relative distribution of passengers among the Bay Area airports that exists today. Alternative 3 has a revised distribution based on the Regional Airport Planning Committee (RAPC) recommended allocation of traffic among the Bay Area airports.

MTC also specified two additional theoretical alternatives to provide further quantitative data on airspace capacity. The theoretical alternatives concern a "balanced" system where it is assumed that each air carrier airport experiences the same ratio of demand to capacity in instrument flight rules (IFR) weather conditions.

Findings of Airspace Capacity Assessment

A series of computer runs of the airspace model were performed for the Bay Area airspace system corresponding to the various alternatives and combinations of conditions considered.

The most significant findings from the airspace analysis are presented below in the following categories:

- Airspace Demand and Capacity
- Congestion Impacts
- Redistribution of Air Traffic
- North Bay Airport
- Commuters, Military, and General Aviation
- Need for Further Airspace Analysis

Airspace Demand and Capacity. In 1997, MTC forecasts an IFR demand of almost 200 aircraft per hour in the Bay Area airspace system in the peak hour of the average day. With the present airspace configuration, the capacity is approximately 85 aircraft per hour in IFR weather conditions.

Therefore, in IFR weather conditions (which occur about 8% of the year) there will be a significant excess of demand over capacity. The excess will be largest in the evening arrival peak, between 6 p.m. and 8 p.m. It is likely that demand will regularly exceed capacity before 1997.

In VFR weather conditions, airspace capacity is about twice as large as in IFR weather conditions. An excess of demand over capacity will occur rarely in VFR weather conditions.

The excess of demand over capacity in IFR weather conditions can be attributed to relatively few elements of the Bay Area airspace system, particularly the final approach paths to each airport where air traffic from a number of arrival routes converges for landing.

Congestion Impacts. The excess of demand over capacity in IFR weather will result in significant congestion in the Bay Area airspace, and delays to aircraft as high as 90 minutes will occur.

The delays will cause significant impacts on the operation of the national airport system, such as:

- Cancellation of scheduled flights
- Delays at the origin airport for flights with destinations in the San Francisco Bay Area
- Diversions of arriving aircraft to airports other than their planned destination
- Reduced airspeed during the air route phase of flight
- Delays in holding patterns at points along the air routes
- Imposition of quotas on the maximum number of aircraft that can use the airports during peak hours

Note that demand during peak activity periods (e.g., summer months and holidays) will cause the airspace system to become even more congested than shown under the average day conditions analyzed in this report.

Redistribution of Air Traffic. A redistribution of traffic from San Francisco to Oakland and San Jose would increase IFR airspace capacity from approximately 85 operations per hour (Alternative 1) to almost 120 operations per hour (Alternative 3). Airspace congestion would, however, increase in the vicinity of San Jose Airport under Alternative 3. There would still be a significant excess of demand over capacity even with this redistribution.

If traffic were distributed among the three Bay Area airports to balance the ratio of demand to capacity at each airport (i.e., the same ratio at each airport), IFR capacity would increase to more than 150 operations per hour. This increase is achieved, in effect, by making full use of Oakland. Even with this increase there would still be a significant excess of demand over capacity.

In IFR weather conditions, the excess of demand over capacity can be eliminated only by allocating large numbers of aircraft operations to a north bay airport, or by making other significant changes to the airport and airspace system (e.g., by adding new runways). Approximately 30 operations per hour would have to be shifted to a north bay site during the peak arrival period to eliminate the excess.

North Bay Airport. Use of a north bay airport for significant numbers of air carrier aircraft operations would relieve IFR airspace congestion in the Bay Area. Air traffic destined to and from any of the four north bay airports considered could overfly and, hence, bypass Bay TRACON airspace.

Each of the four potential sites identified by MTC for the north bay air carrier airport (Travis Air Force Base; and Hamilton, Sonoma County, and Napa County Airports) is comparable in terms of airspace capacity.

Note that if the aircraft redistributed to the north bay airport were to make intermediate stops at San Francisco, Oakland, or San Jose to load additional passengers, the airspace capacity benefits gained by redistribution would be eliminated.

Commuter, Military, and General Aviation. An efficient air transportation system depends on adequate feeder service by commuter airlines into the major air carrier airports. If the growth in commuter activity exceeds projected levels, IFR airspace capacity could be reduced because of aircraft separation requirements. This adverse impact could be relieved if commuter aircraft could operate on independent airspace routes to facilities co-located with the facilities used by large air carrier aircraft.

Military operations at Alameda Naval Air Station and Moffett Naval Air Station decrease the airspace capacity of the Bay Area for civil aircraft. Arrivals into Alameda Naval Air Station interact with departures from Oakland International Airport and with general aviation traffic flying up the Bay.

General aviation activity constitutes approximately one-third of forecast IFR operations in the 1997 peak hour. These operations affect airspace capacity, particularly at San Francisco and San Jose airports, because additional aircraft separations are required to avoid wake turbulence generated by larger aircraft.

Some general aviation traffic that is currently routed up the middle of the Bay contributes to congestion over Oakland Airport. General aviation traffic in and out of Hayward Airport also interacts with Oakland's air carrier operations. The most heavily used general aviation airports for IFR training are Oakland and San Jose.

Relocating portions of the general aviation traffic away from the air carrier airports to other IFR airports would increase airspace capacity.

A review of general aviation VFR training areas shows that some VFR training areas are in the vicinity of air carrier arrival and departure routes; however, most training areas are in low-density airspace.

Need for Further Airspace Analysis. The severity of the future congestion in the Bay Area airspace strongly supports the need for further analysis to determine airspace improvements required to accommodate forecast demand.

Further analysis is required to:

- Quantify future delays
- Develop estimates of the cost of these delays
- Assist in reviewing the allocation of traffic to Bay Area airports
- Assist in developing revised airspace configurations and procedures
- Assess the need for airport improvements to relieve airspace congestion (e.g., new runways)
- Review the location of general aviation VFR training areas
- Review the need for ILS facilities at general aviation airports to relocate general aviation IFR training away from air carrier airports

I. ORGANIZATION OF BAY AREA AIRSPACE

The airspace over the nine San Francisco Bay Area counties serves a complex of airports that accommodates a wide range of civil and military aircraft types and activities. Exhibit A shows the nine counties with the locations of existing public use and military airports.

The use of the airspace over the nine San Francisco Bay Area counties is regulated by the Federal Aviation Administration (FAA). The FAA divides the airspace into different jurisdictions, each with its own volume of delegated airspace.

Air traffic flows within the airspace system include airline, military, and general aviation traffic. Most of the airline and military flights in the area are conducted in accordance with instrument flight rules (IFR). Much of general aviation traffic is conducted in accordance with visual flight rules (VFR) because of the varied nature of general aviation activities, equipment, and pilot experience.

The basic difference between IFR and VFR is that the pilot maintains control of spatial orientation of his aircraft by reference to <u>instruments</u> for IFR and by <u>visual</u> reference to the ground for VFR. Flight under VFR requires good visibility whereas flight under IFR can be accomplished when visibility is poor. Meteorological (weather) conditions that permit flight under VFR are prescribed in the Federal Aviation Regulations* in terms of visibility and distance from clouds.

Jurisdictional Relationships

Within the nine-county San Francisco Bay Area there are three major jurisdictional categories of airspace:

- Air Route Traffic Control Center Airspace
- Terminal Approach Airspace
- Air Traffic Control (ATC) Tower Airspace

These categories define a specific volume of airspace and the ATC facility that controls the airspace. Within these

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*Part 91, General Flight Rules, Paragraph 105, Basic VFR Weather Minimums.

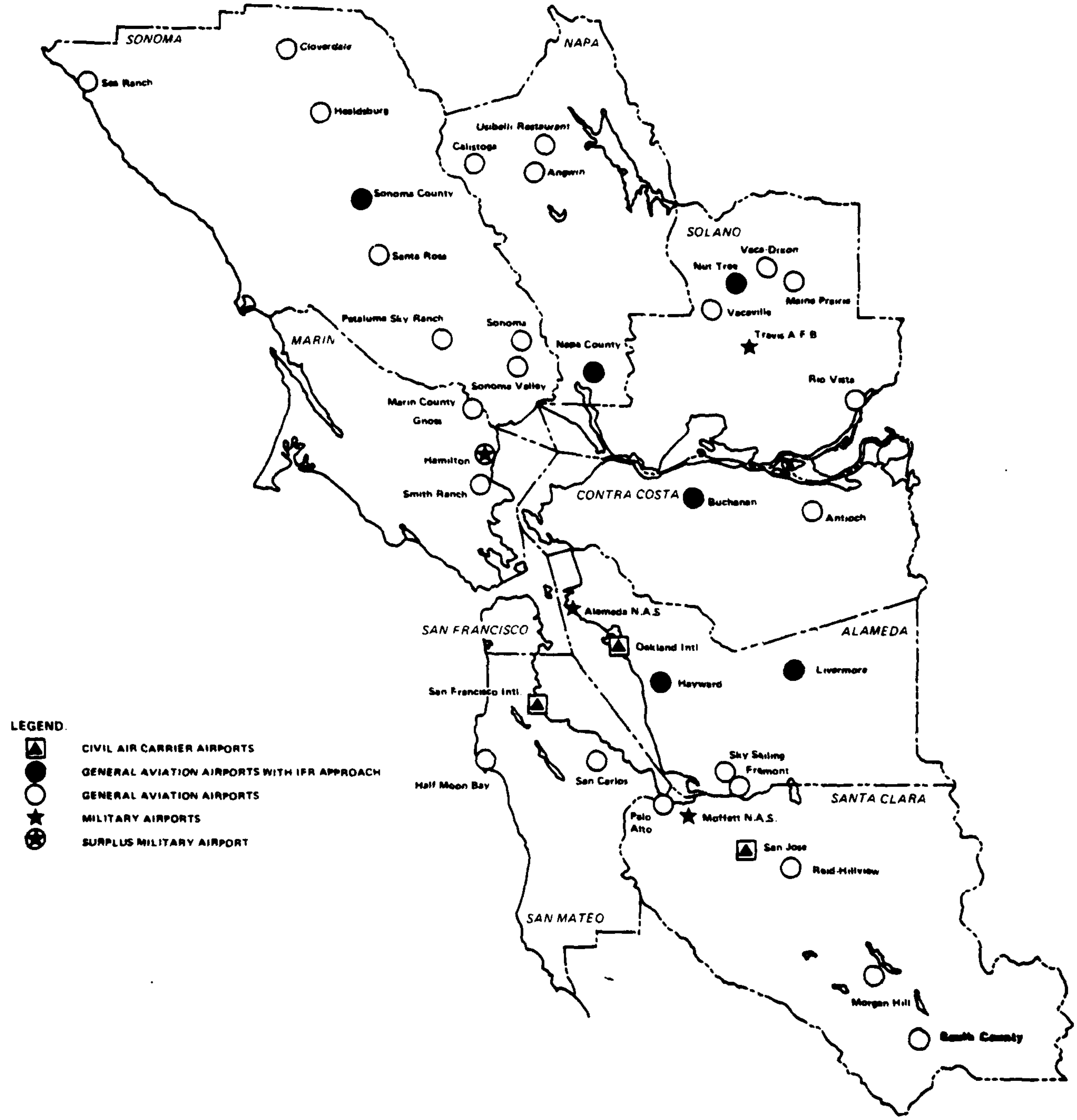

EXHIBIT A

AIRSPACE ANALYSIS FOR PHASE I
REGIONAL AIRPORT PLAN UPDATE PROGRA

NINE BAY AREA COUNTIE

PEAT, MARWICK, MITCHELL & CO JULY 197

major jurisdictional categories, other volumes of airspace are defined that establish controlled airspace (and sometimes specify additional requirements). These other volumes of airspace include:

- Control Zones
- Low Altitude Airways and Jet Routes
- Transition Areas
- Terminal Control Area (TCA)

The seven categories of airspace are discussed in the following paragraphs.

Center Airspace. The United States is divided into approximately 25 different areas for air traffic service to aircraft operating on IFR flight plans. Air traffic service is provided in these areas by the personnel and equipment of Air Route Traffic Control Centers (ARTCC or Center). The nine San Francisco Bay Area counties fall within the Oakland ARTCC area of responsibility.*

Terminal Approach Airspace. A Center may delegate airspace to local control facilities for IFR approach and departure control. Originally, Oakland ARTCC delegated airspace to five facilities in the nine Bay Area counties: San Francisco Approach Control, Oakland Approach Control, Moffett Approach Control, Hamilton Approach Control, and Travis Approach Control. Because of the proximity of the San Francisco, Oakland, and Moffett Approach Control areas, and a need for greater flexibility, they were combined into one facility--Bay Terminal Radar Approach Control (TRACON). In radio communications between pilots and controllers, Bay TRACON is referred to as "Bay Approach" or "Bay Departure," depending on the phase of flight.

The airspace delegated to Hamilton Approach reverted to Oakland ARTCC when the Air Force moved from Hamilton Air Force Base, but Travis Radar Approach Control (RAPCON) is still operated by the U.S. Air Force. Exhibit B shows the airspace delegated to the following approach control facilities:

- Bay Terminal Radar Approach Control (TRACON)

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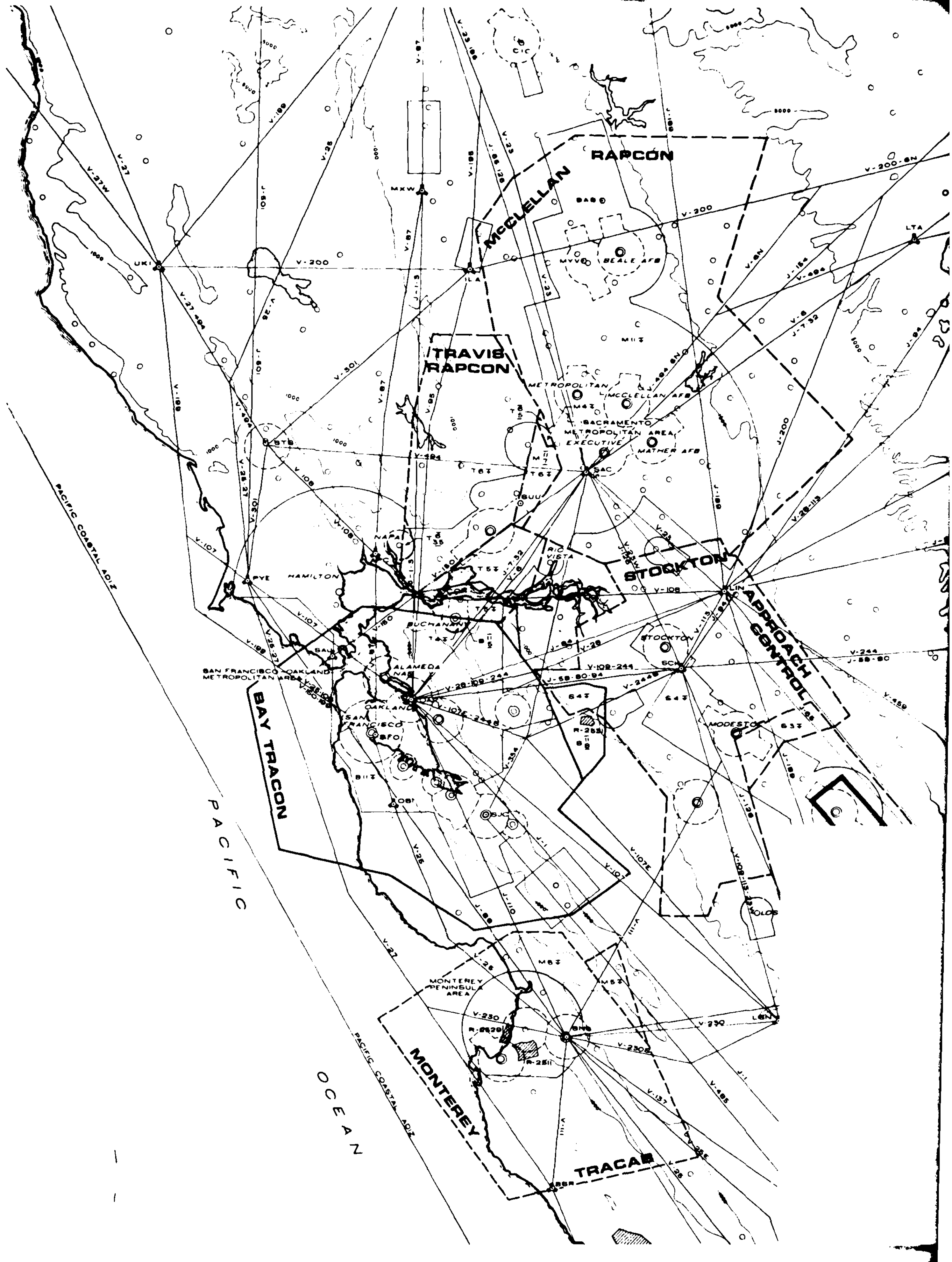
*Note that aircraft operating under VFR rules are not processed by ARTCC. VFR aircraft that file flight plans give position reports to Flight Service Stations (FSS). VFR aircraft that do not file flight plans are not required to contact FSS.



McCLELLAN
RAPCON
TRAVIS
RAPCON
STOCKTON
APPROACH
CONTROL
BAY TRACON
MONTEREY
TRACAB
PACIFIC
OCEAN
PACIFIC COASTAL ADIZ
SAN FRANCISCO-OAKLAND
METROPOLITAN AREA
SACRAMENTO
METROPOLITAN AREA
MONTEREY
PENINSULA
AREA
BEALE AFB
McCLELLAN AFB
MATHER AFB
METROPOLITAN
EXECUTIVE
OAKLAND
SAN FRANCISCO
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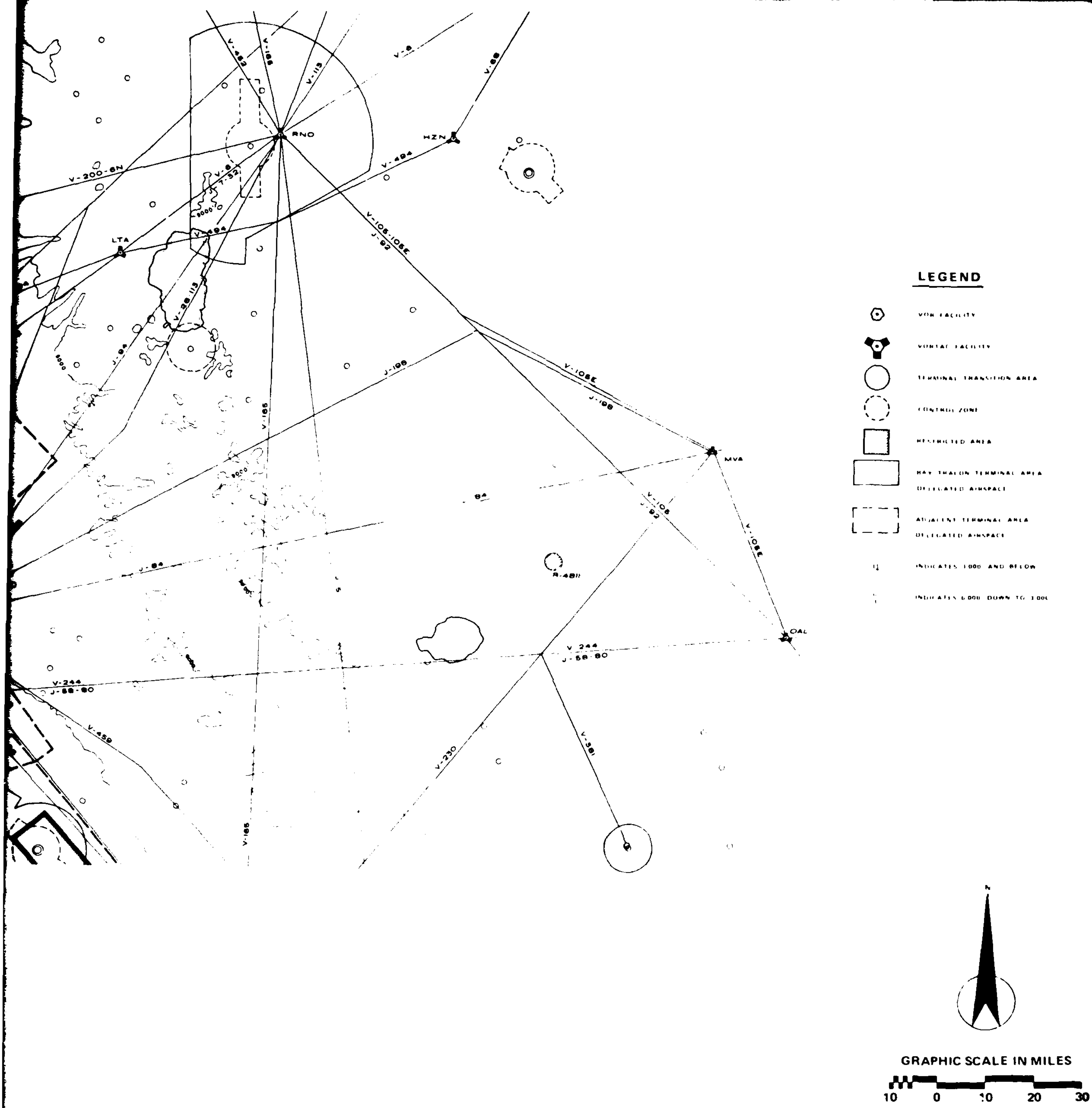

EXHIBIT

AIRSPACE ANALYSIS FOR PHASE
REGIONAL AIRPORT PLAN UPDATE PROGR

DELEGATED AIRSPAC

PEAT, MARWICK, MITCHELL & CO JULY 1

- Travis Radar Approach Control (RAPCON)
- McClellan RAPCON (Sacramento Approach Control)
- Stockton Approach Control (nonradar)
- Monterey Terminal Radar Approach (Control Tower) Cab (TRACAB)

In general, the altitudes controlled by these facilities are: Bay TRACON, 11,000 feet MSL and below; Travis RAPCON, 6,000 feet MSL and below; McClellan RAPCON, 11,000 feet MSL and below; Stockton Approach Control, 6,000 feet MSL and below; and Monterey TRACAB, 6,000 feet MSL and below.

IFR airports (i.e., airports with a published instrument approach for use in IFR weather conditions) within the nine Bay Area counties are listed below by the control facility that provides approach and/or departure control services:

Bay TRACON

Alameda Naval Air Station
Hayward Air Terminal
Livermore Municipal Airport*
Oakland International Airport
Moffett Naval Air Station (at Sunnyvale)
San Francisco International Airport
San Jose Municipal Airport

McClellan RAPCON

Rio Vista Municipal Airport

Oakland ARTCC (Oakland Center)

Napa County Airport
Sonoma County Airport (at Santa Rosa)

Stockton Approach Control

Livermore Municipal Airport*

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*Departures are handled by Bay TRACON because Livermore is within Bay TRACON airspace. However, approaches are handled by Stockton Approach Control. The final approach fix and holding airspace are within Stockton Approach Control's delegated airspace.

Travis RAPCON

Buchanan Field (at Concord)
Nut Tree Airport (at Vacaville)
Travis Air Force Base (at Fairfield)

McClellan RAPCON, Oakland ARTCC, Stockton Approach Control, and Travis RAPCON each control additional airports outside the nine Bay Area counties.

Airport Traffic Control Tower Airspace. An Airport Traffic Area is the airspace under the jurisdiction of an ATC Tower. It is defined as the area within five statute miles of an airport with an operating control tower, effective from the ground up to 3,000 feet above the airport. Airport Traffic Areas exist at the following Bay Area airports:

Alameda Naval Air Station
Buchanan Field
Hayward Air Terminal
Livermore Municipal Airport
Oakland International Airport

Moffett Naval Air Station
Napa County Airport
Palo Alto Airport
Reid-Hillview Airport
San Carlos Airport

San Francisco International Airport
San Jose Municipal Airport
Travis Air Force Base
Sonoma County Airport

The ATC Tower located at these airports exercises control of aircraft within the Airport Traffic Areas. Rules of aircraft operation within Airport Traffic Areas are prescribed in Federal Aviation Regulations.* Airport traffic areas may only be used when taking off or landing at these airports or when special permission (ATC clearance) has been obtained from the towers at these airports. Two-way radio communications must be maintained, and airspeed within Airport Traffic Areas is restricted.

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*Part 91, General Flight Rules, Paragraphs 70, Aircraft Speed; 85, Operating on or in the Vicinity of an Airport: General Rules; and 87, Operations at Airports with Operating Control Towers.

Control Zones. Control Zones have also been established at the airports listed above for Airport Traffic Areas. Horizontal dimensions of these control zones are shown on Exhibit B and are effective from the ground up to 14,500 feet MSL. VFR flight within a Control Zone requires that any cloud (or obscuration ceiling) be at least 1,000 feet above ground level and that three miles visibility exists except as provided for Special VFR flights in the Federal Aviation Regulations.* To use the provision of Special VFR a pilot must receive an appropriate ATC clearance, have one mile of visibility, and stay clear of clouds. Special VFR flights are permitted at all of the airports listed above, except San Francisco International Airport.

Low Altitude Airways and Jet Routes. Low Altitude Airways and Jet Routes are shown on Exhibit B. The Low Altitude Airways are known as Victor Airways and are shown with a "V" preceding their identification number. The Jet Routes are shown with a "J" preceding their identification number.

Victor Airways extend upward to 18,000 MSL. The Jet Routes are between 18,000 feet MSL and 45,000 feet MSL.

A Control Area provides controlled airspace for use with the Low Altitude Airways. In the Bay Area, a Control Area is established over the entire nine counties with a base or floor at 1,200 feet above ground level. This Control Area provides controlled airspace in addition to the Low Altitude Airways because of the complexity of the Victor Airways in the Bay Area, and because of the need for additional controller flexibility to process traffic.

Transition Areas. Transition Areas provide controlled airspace between the Control Zones and the airways for IFR arrivals and departures.** The base or floor of the transition areas is 700 feet above ground level.

Terminal Control Area. The San Francisco Terminal Control Area (TCA) was created to provide additional control for the mixture of high performance air carrier aircraft with low performance general aviation VFR aircraft. The boundaries and effective altitudes of the San Francisco TCA are shown

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*Part 91, General Flight Rules, Paragraphs 105, Basic VFR Weather Minimums, and 107, Special VFR Weather Minimums.

**Note that these transition areas differ from aircraft transitioning between the low altitude airway structure to the high altitude structure that takes place at 18,000 feet.

in Exhibit C. Aircraft operating rules and pilot qualification and equipment requirements are prescribed in Federal Aviation Regulations.*

The San Francisco TCA is a Group I TCA and an aircraft must have an air traffic control (ATC) clearance to enter. The pilot must hold at least a private pilot certificate, and the aircraft must be equipped with prescribed navigation radio receivers, two-way communications radio with appropriate frequencies, and a transponder (equipment that responds to radar interrogation) with certain specifications.

The upper limit of the TCA is 8,000 feet MSL for all areas. The base or floor of the TCA is at ground level in the central area around San Francisco International Airport. The floor increases in elevation, expanding outward. The floor of the outermost areas is as high as 6,000 feet MSL. The areas beneath the TCA permit aircraft access and egress to other airports in the area without entering the TCA.

Air Traffic Flows

Many factors influence air traffic flows, such as airport location, aircraft performance, urban development patterns, air traffic demand, terrain, and weather. These factors interact and require the operation of a complex set of routes and procedures to assure the safe and expeditious movement of air traffic within the nine-county airspace.

In the past, airports were often sited without regard to their effect on the surrounding community or their interactions with other airports. However, with the development of turbine-powered aircraft (with increased size, speed, and noise), larger areas of airspace are required to maneuver, occasionally causing airspace interactions between aircraft operations at neighboring airports. Sometimes, the aircraft are also required to follow special paths to avoid noise-sensitive land uses (e.g., urban residential development).

In the nine Bay Area counties, there are two groups of airports where proximity influences air traffic flow. The groups are the airports within the Travis RAPCON and Bay TRACON delegated airspaces.**

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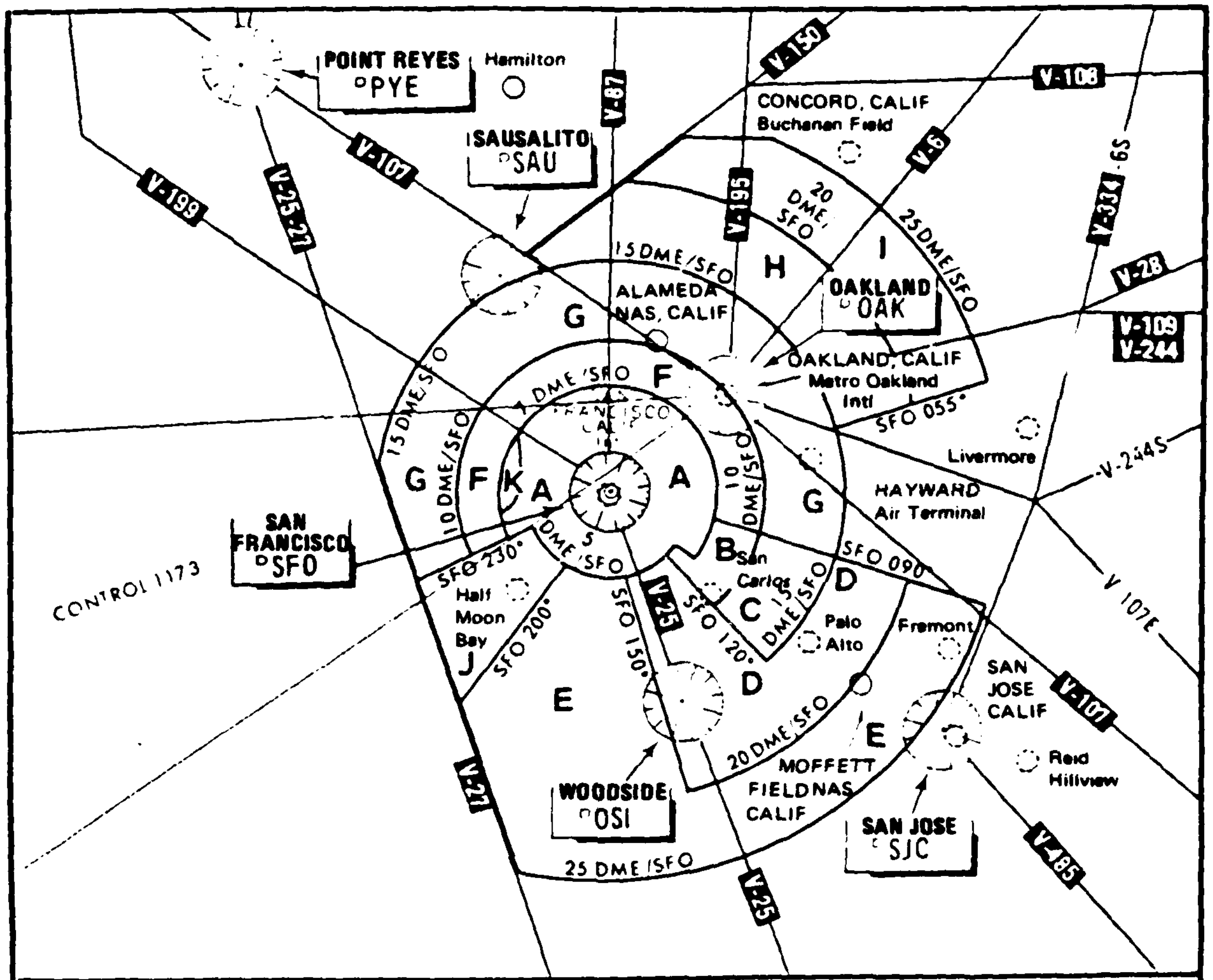
*Part 91, General Flight Rules, Paragraph 90, Terminal Control Areas.

**When Hamilton AFB was active there was some interaction between Hamilton Field, Napa County, and Sonoma County Airports. But at present, Napa County Airport and Sonoma County Airport essentially operate independent of each other.



TCA ALTITUDES

A	B	C	D	E	F	G	H	I	J	K
8000	8000	8000	8000	8000	8000	8000	8000	8000	8000	8000
GND	1500	2500	4000	6000	2100	3000	4500	6000	5000	1500

EXHIBIT C

AIRSPACE ANALYSIS FOR PHASE II
REGIONAL AIRPORT PLAN UPDATE PROGRAM

TERMINAL CONTROL AREA

PEAT, MARWICK, MITCHELL & CO JULY 1977

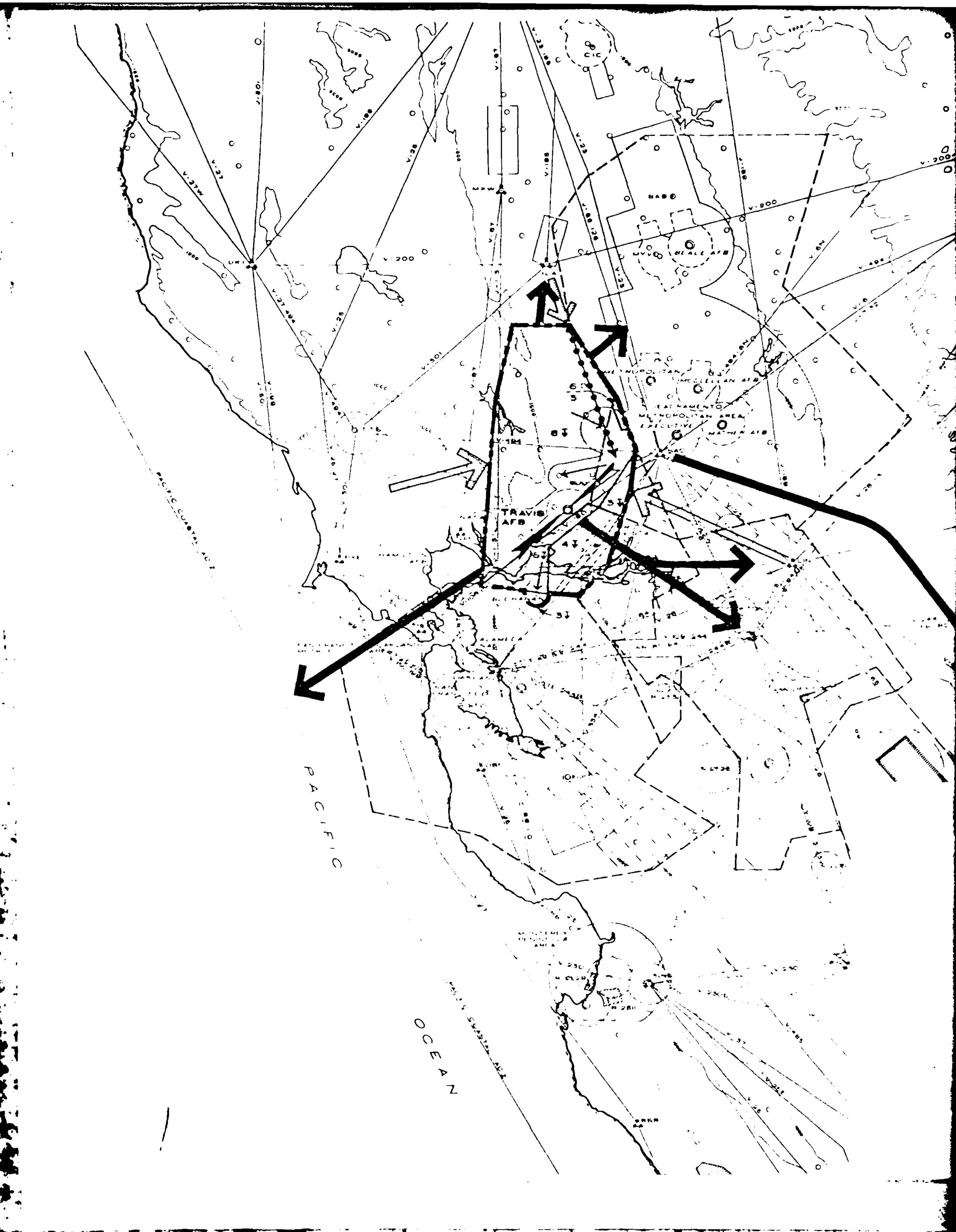
Aircraft operations in Travis RAPCON delegated airspace were evaluated by PMM&Co. in a previous study (Travis AFB Joint Use Feasibility Study, completed in 1976). Exhibit D shows arrival and departure air traffic flow routes for Travis RAPCON. The previous PMM&Co. study determined that aircraft arriving at Travis AFB from the south and east interact and pass through McClellan RAPCON airspace. An examination of Exhibit D shows that Travis RAPCON arrival and departure routes do not affect Bay TRACON airspace. Routes between airports in Bay TRACON airspace and airports in Travis RAPCON airspace have been established and are shown on Exhibits E and F.

Exhibits E and F also show air traffic flow routes used for arrivals and departures related to airports in Bay TRACON airspace. Because the airports in the Bay TRACON airspace are close to each other, the direction of IFR aircraft operations at each airport cannot be considered independently.

Two major air traffic flow plans have been established: the "West Plan" and the "Southeast Plan." Bay TRACON determines when the air traffic flow will change from one plan to the other plan and notifies each ATC tower. The decision is based primarily on weather conditions, particularly wind direction and velocity. Prevailing wind and weather conditions normally favor using the West Plan. Occasionally, a weather front approaches the Bay Area, strong winds from the south are experienced, and the Southeast Plan is put into effect.

Exhibit E shows air traffic flow routes for the West Plan, while Exhibit F shows air traffic flow routes for the Southeast Plan. Three-letter airport location identifiers are shown on routes to indicate utilization related to individual airports. The air traffic flow routes shown are mainly IFR routes, but VFR aircraft operating to and from San Francisco International Airport are under positive control while in the TCA and utilize certain routes shown. Also, VFR aircraft participating in radar advisory service operating to and from other airports in the area are occasionally requested to use certain routes shown.

<u>IFR Operations</u>. Before entering the Bay TRACON airspace, IFR arriving aircraft are cleared by the Air Route Traffic Control Center (ARTCC) for descent from en route altitudes to altitudes between 6,000 feet MSL and 11,000 feet MSL, depending on point of entry (i.e., arrival gate). Aircraft arriving from airports in adjacent airspace just north of Bay TRACON airspace enter at 4,000 feet MSL. As aircraft approach and enter the Bay TRACON airspace, air traffic control is transferred from ARTCC to Bay TRACON


TRAVIS AFB
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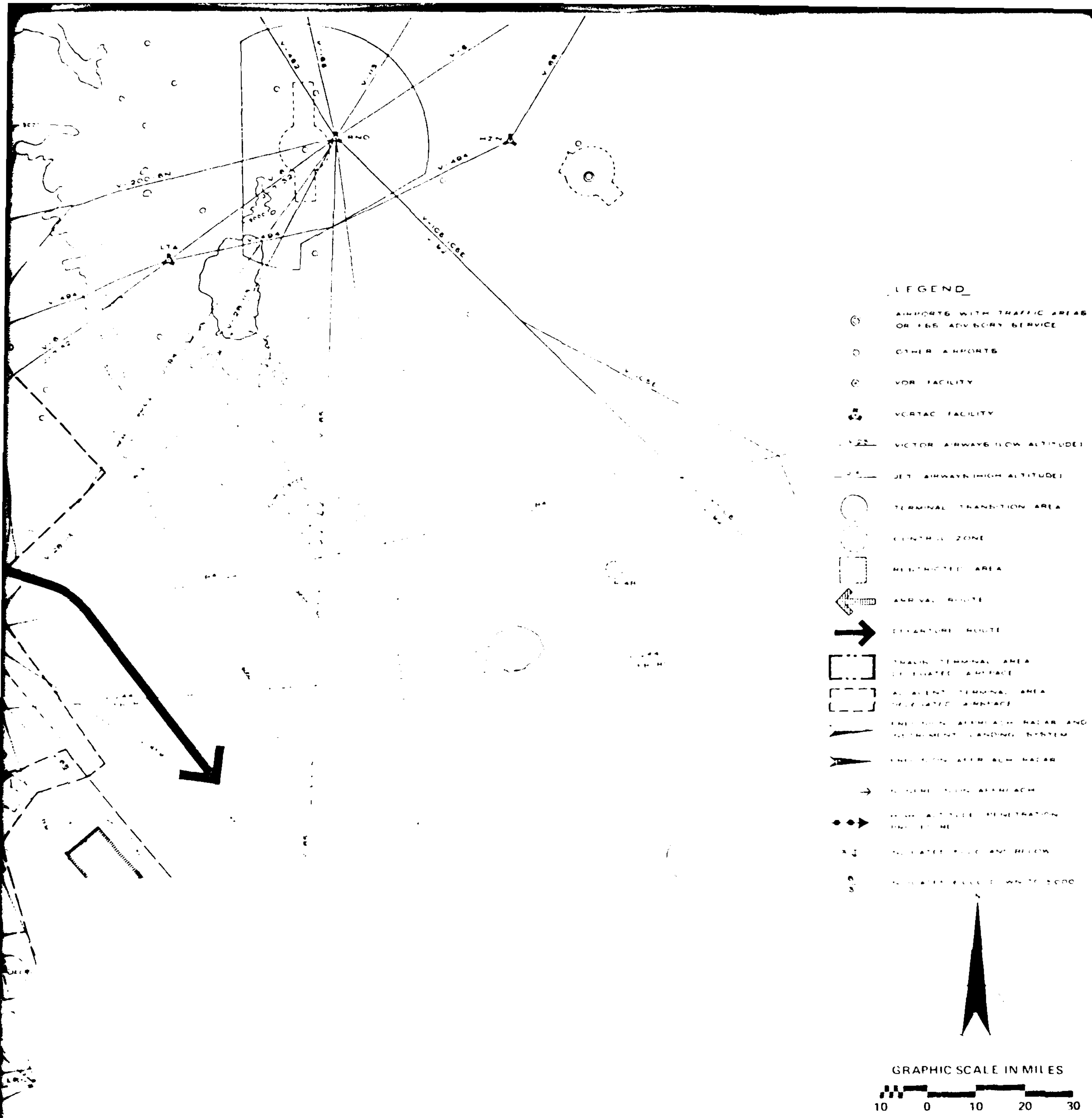

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AIRSPACE ANALYSIS FOR PHASE I

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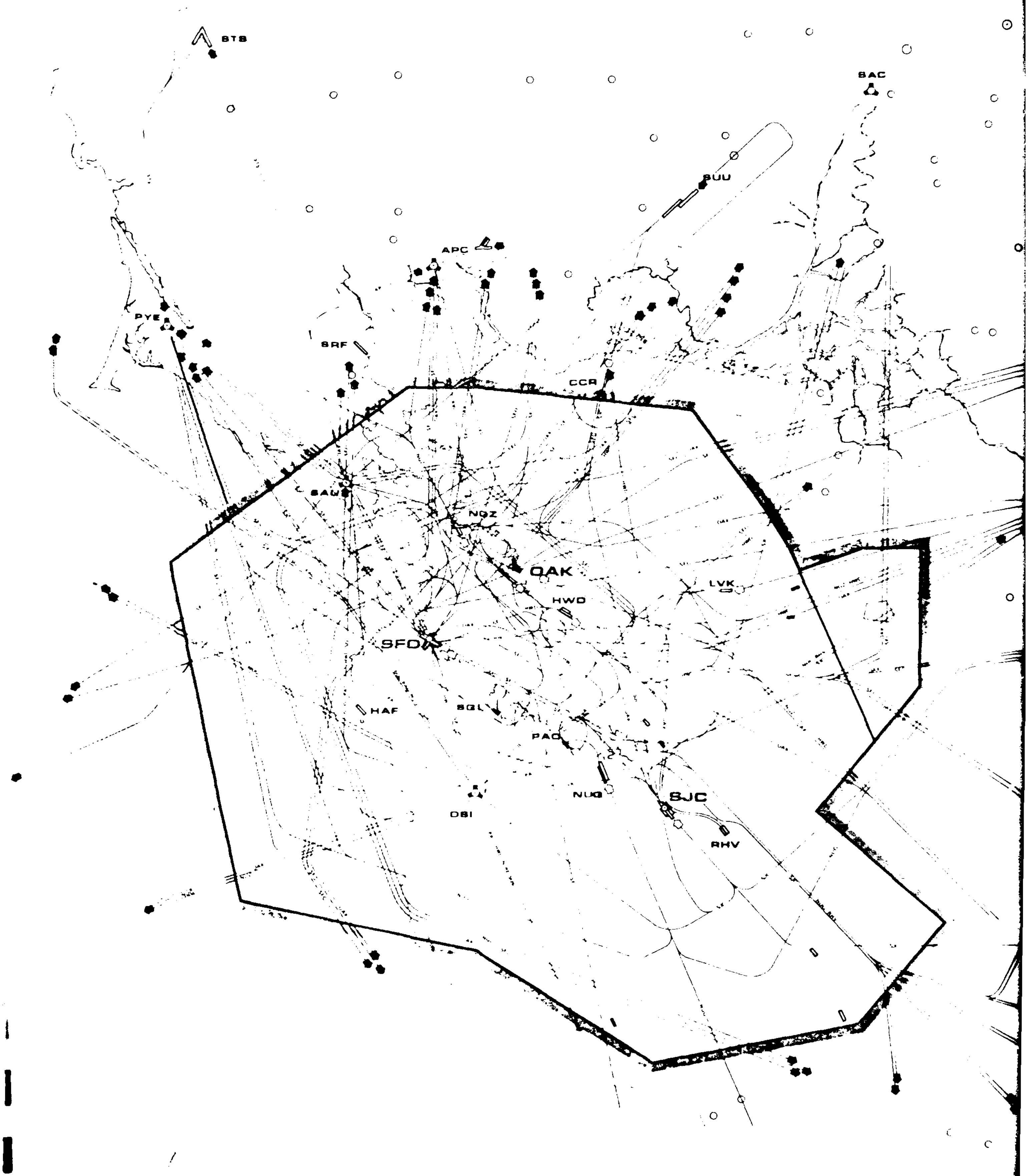

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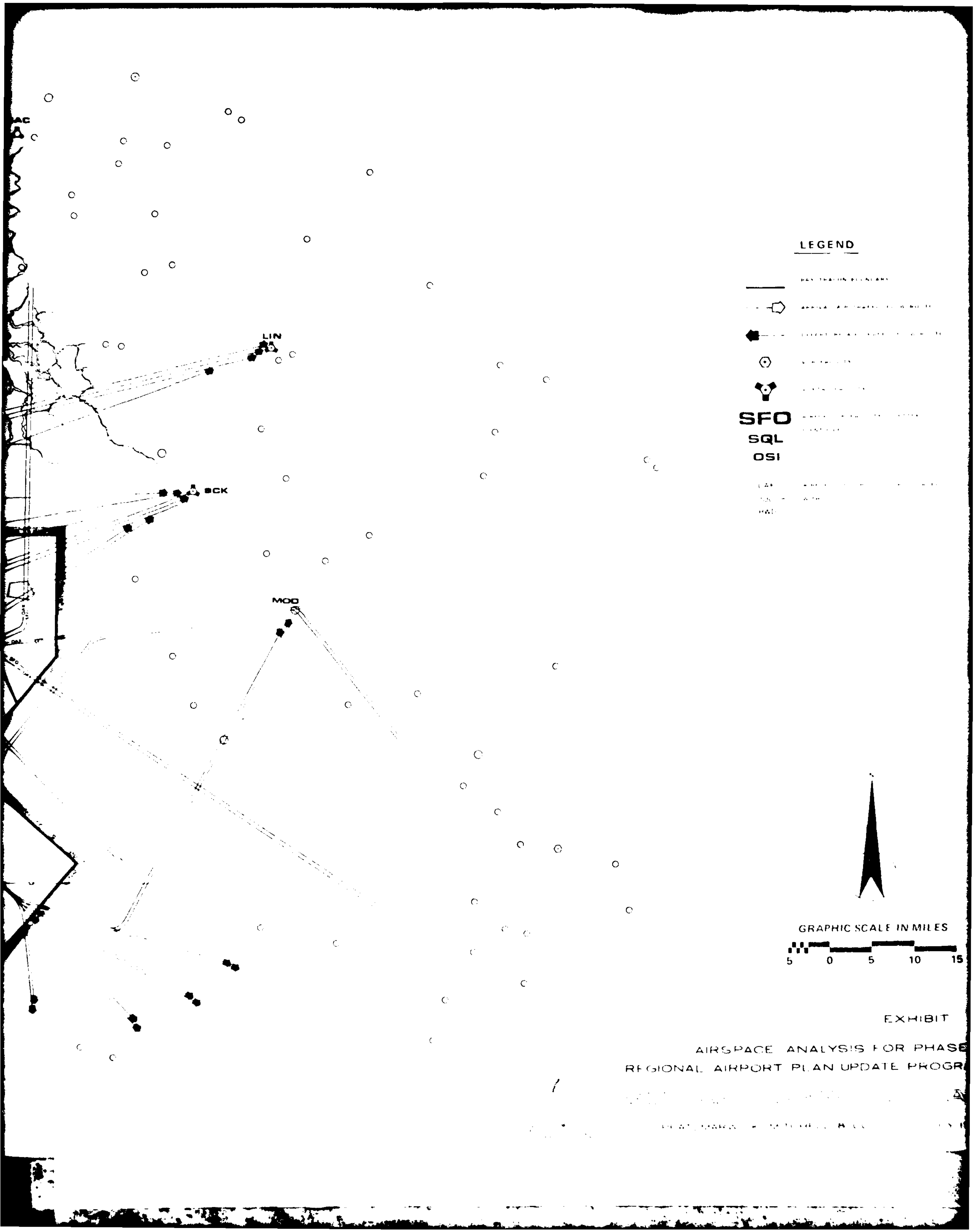

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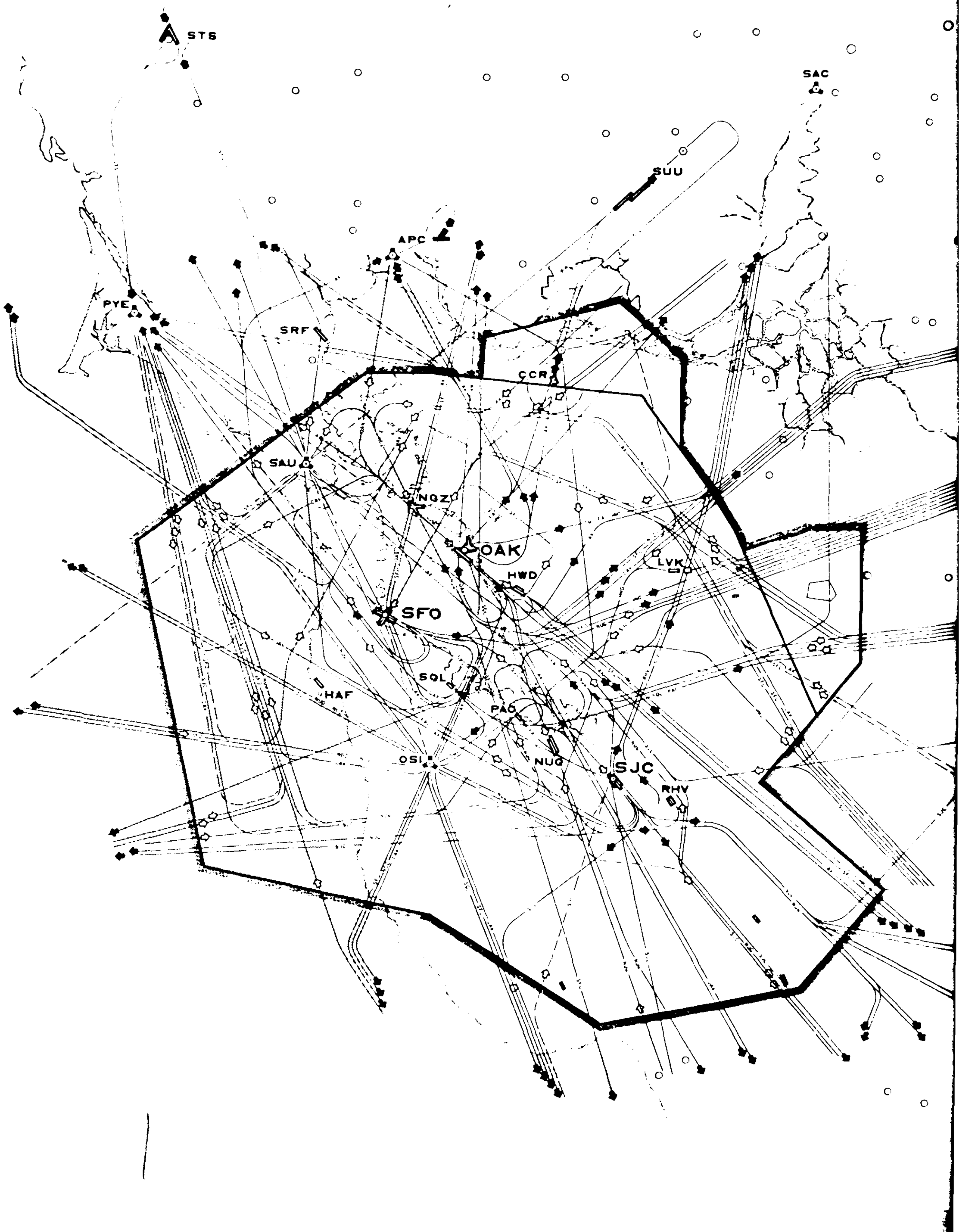

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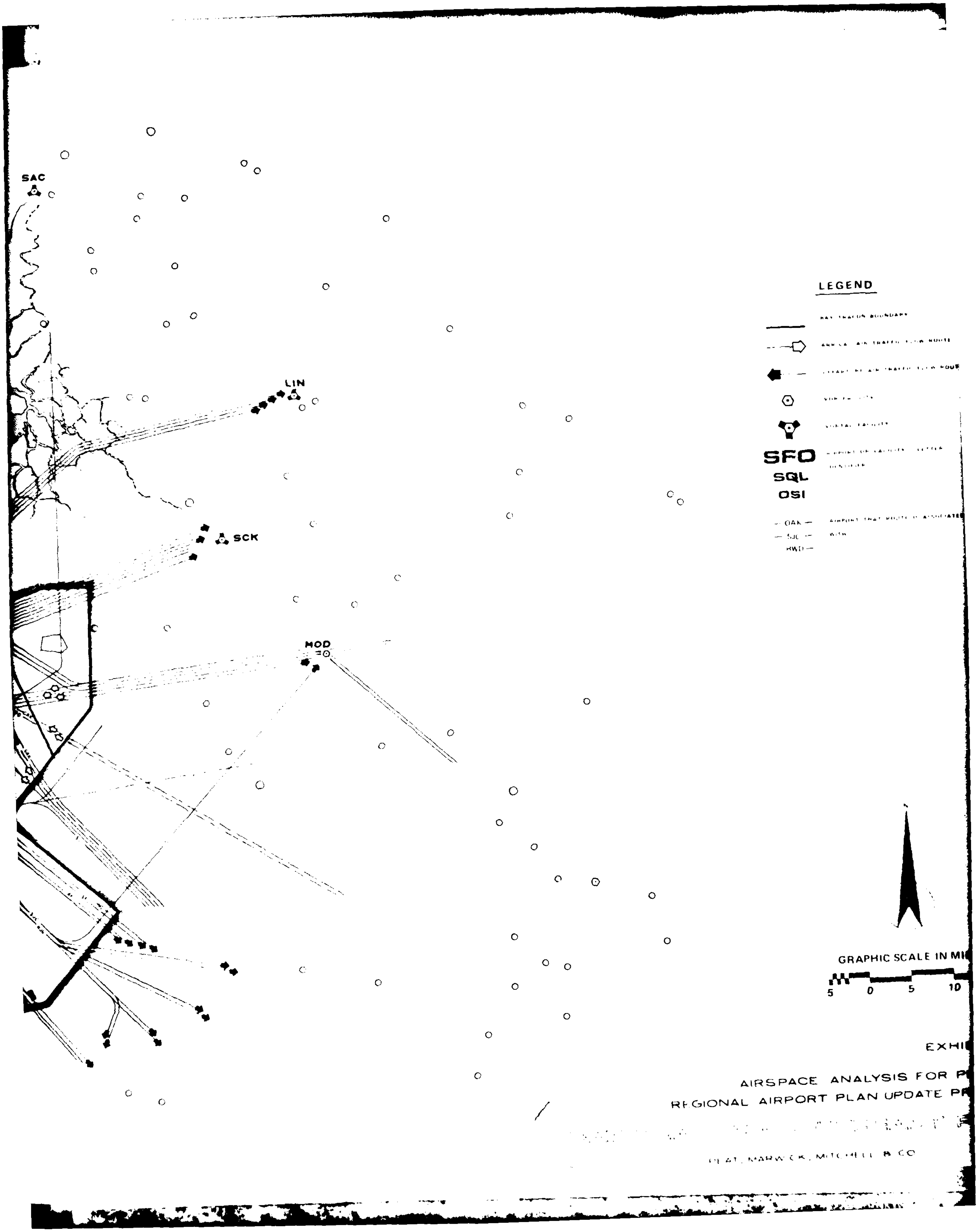
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which has the responsibility of controlling arriving aircraft to a final approach course to the specific airport of intended landing. In a radar environment, the air traffic controller accomplishes this by radar vectoring the aircraft.

Prior to transferring control, ARTCC sequences arriving aircraft to descend from en route altitudes spaced no closer than 5 nautical miles in trail (one behind the other). Bay TRACON may request a 10-nautical-mile separation when traffic volume, controller workload, airport, or other conditions require. After transfer of control, TRACON guides aircraft from the various arrival gates through the terminal area airspace so that they are sequenced onto a final approach course to the airport of intended landing, maintaining an aircraft separation of not less than 3 nautical miles in trail.* The aircraft are cleared to descend to approximately 2,000 feet above ground level. At approximately 5 nautical miles out from the runway, TRACON gives clearance for final approach, and the aircraft then contacts the control tower of the airport of intended landing.

Arriving aircraft are separated from departing aircraft on separate routes that are spaced at least 3 miles apart horizontally and/or 1,000 feet apart vertically.

VFR Operations. Unlike IFR flights, VFR flights are not controlled by the ATC system except in the airport traffic areas and TCA described earlier. In addition to airports with airport traffic areas, many other noncontrolled airports also contribute to the level of VFR operations in the San Francisco Bay Area.

In visual weather conditions, and outside of the San Francisco TCA and the airport traffic areas, pilots are free to navigate by visual reference and without interaction with ATC. Because of the terrain, the San Francisco TCA, and the number of airport traffic areas, the space for uncontrolled VFR flight in the Bay Area is quite limited. This limitation tends to channelize VFR traffic in certain areas. During times when low ceilings prevail, the limitations are more

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*FAA Air Traffic Control Handbook 7110.65 specifies greater minimum separations for certain leading and following aircraft combinations, depending on weight classifications. Minimum longitudinal radar separations range from 3 to 6 nautical miles to avoid wake turbulence problems. Where a USAF aircraft is in trail behind certain aircraft, the minimum separation is 10 nautical miles.

severe and additional channelization occurs. VFR aircraft transit the TCA or airport traffic area with ATC approval, but some do not meet equipment or pilot requirements for the TCA or simply do not wish to enter the TCA or airport traffic areas. For these aircraft it is difficult to transit the Bay Area in a northerly or southerly direction. Exhibit G shows the TCA, airport traffic areas, and major terrain features. Also shown are routes where VFR traffic tends to be channelized.

The Bay Area General Aviation Airport Managers Group has been formed to aid and advise MTC on general aviation matters. One of the concerns of this group is compatibility of the use of airspace. This group is developing a chart that will identify airspace for training areas that are compatible with other traffic routes. The group conducted a survey to determine the training areas and airports currently used by Bay Area flight training schools. The group submitted charts and descriptions to MTC for the ten airports generating the greatest amount of general aviation training traffic. PMM&Co. plotted these responses on a Sectional Aviation Chart, and developed a preliminary diagram showing training areas that could have the least interaction with other traffic in the area. These charts are on file at MTC.

Review of the responses indicates that Oakland International and San Jose Municipal Airports are used for IFR training by essentially all of the training schools in the nine-county Bay Area. These airports are used extensively for precision Instrument Landing System (ILS) training. Buchanan Field, Hayward Air Terminal, Napa County and Livermore Municipal Airports are used for nonprecision IFR training as well. Some schools in the north bay use Sacramento Executive Airport for ILS training; Stockton Metro Airport is used occasionally by almost all of the other training schools. However, the time lost in transit to and from these airports for training is discouraging. Air carriers also use both Oakland International and Stockton Municipal Airports for ILS training.

A new ILS facilitiy at a location convenient to the majority of flight schools could relieve Oakland International and San Jose Municipal Airports in their role as ILS training facilities used by general aviation. An ILS at a general aviation airport would have the added benefit of separating general aviation ILS training from air carrier activity.

Review of the responses also indicates concentrations of airborne flight training areas to the south and east of San Francisco Bay. Overlapping flight training areas exist from the San Jose area and the Santa Clara Valley northward through Newark and Fremont, into the Livermore, San Ramon, and Danville areas, to the east of the coastal hills north of Tracy, and in the area of Byron and Brentwood. The relationship of airborne flight training areas to IFR routes can best be understood by review of the charts on file at MTC.

Interactions

Interactions between VFR aircraft not under ATC control are resolved on a see-and-avoid basis. These VFR interactions can occur anywhere but are somewhat concentrated in the channelized routes shown in Exhibit G. Interactions created by VFR airport traffic patterns, though not severe, do exist between several airports in the Bay Area. However, procedures are established that maintain safe and expeditious movement. IFR procedures, on the other hand, have interactions that tend to limit IFR capacity.

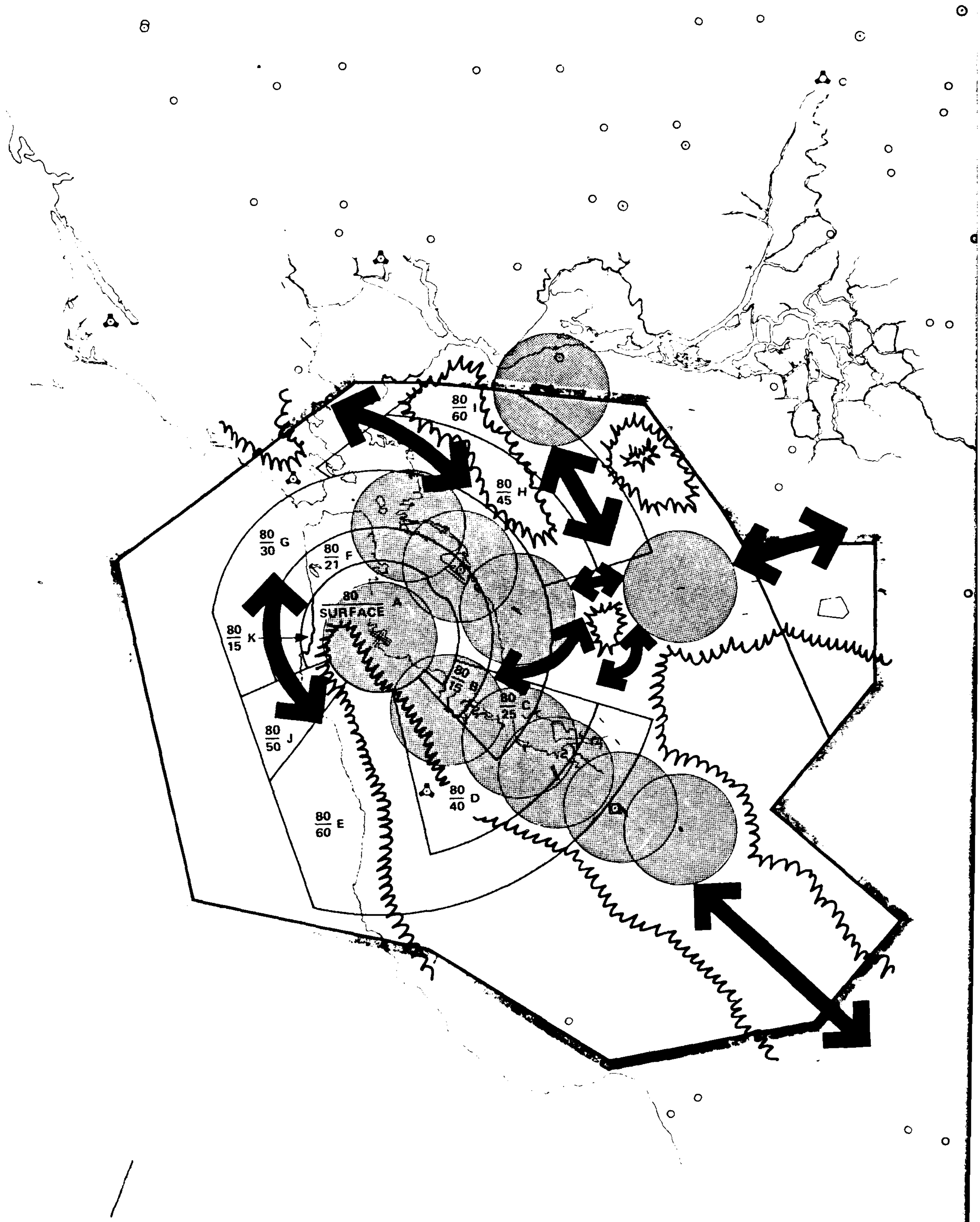
In the Travis RAPCON airspace, there are IFR interactions between Travis AFB, Buchanan Field, and the Nut Tree Airport. During the Travis Joint Use Feasibility Study, PMM&Co. determined that the existing procedures could handle forecast traffic volumes, including joint use of Travis AFB by civil air carriers.

Within the Bay TRACON airspace, interactions that tend to limit IFR capacity occur between airports in the south bay and the east bay areas.

South Bay. In the south bay, there are four main IFR interactions. During West Plan operations, IFR departures from San Jose Municipal Airport (San Jose) and Moffett Naval Air Station (Moffett) require coordination to insure proper separation. If departures from Moffett are coordinated to coincide with an arrival to San Jose, the loss is negligible. Otherwise, the loss can be on a one-for-one basis.

During Southeast Plan operations, the proximity of the airports is such that IFR arrivals to San Jose and Moffett do not have adequate separation for independent operations. During Southeast Plan operations, ceilings and visibilities are usually sufficient to permit visual separation. With visual separation, aircraft can be much closer than with IFR separation and independent operations can take place.

During Southeast Plan operations, IFR departures from Palo Alto Airport interact with arrivals to Moffett. At present, the number of IFR departures from Palo Alto is rather limited, and consequently, the interaction is not significant.



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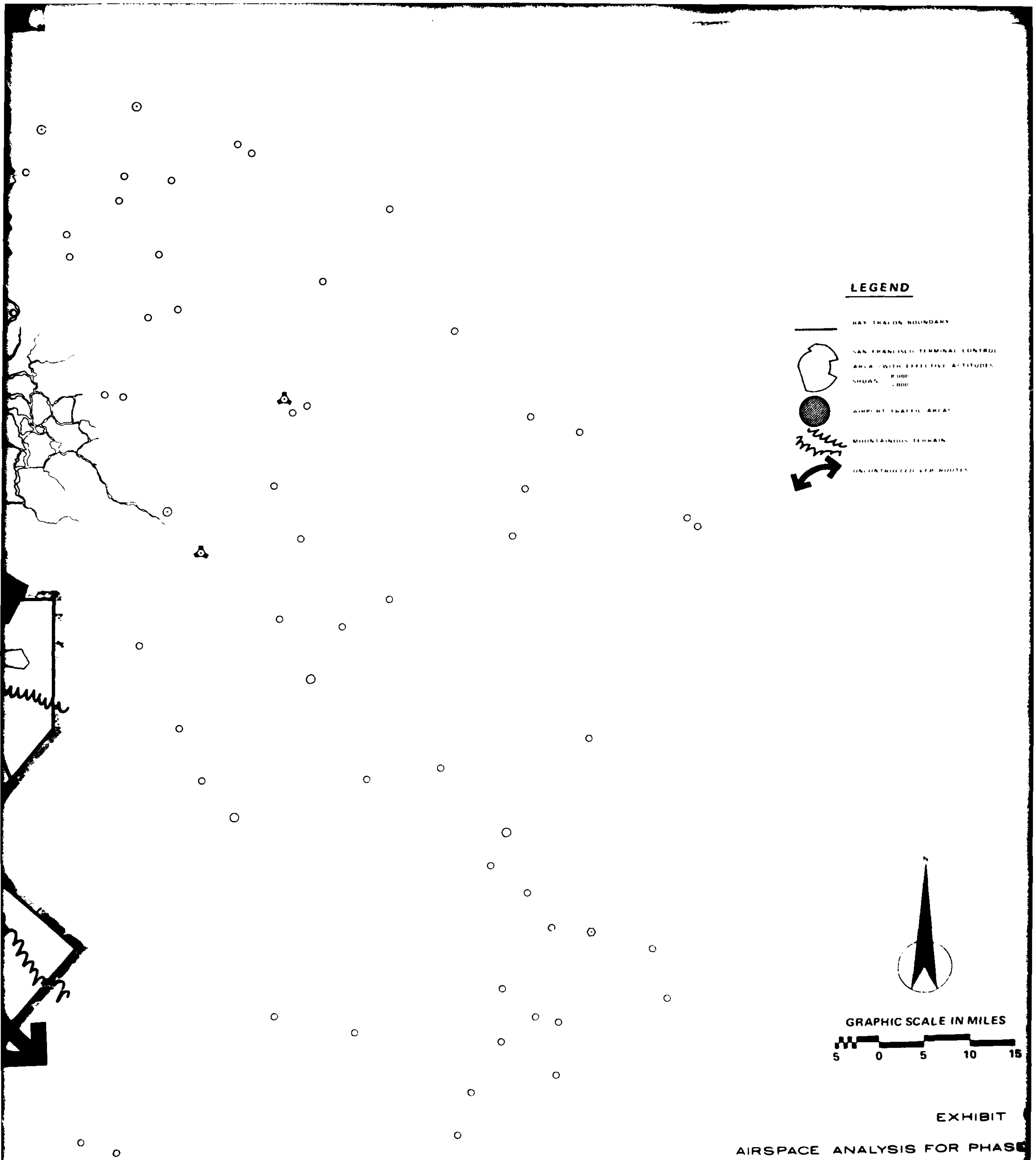

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During both West Plan and Southeast Plan operations, IFR departures from Reid-Hillview Airport must turn toward and pass over San Jose Municipal Airport, resulting in some loss of capacity. The number of IFR departures from Reid-Hillview is at present rather limited, and consequently, the interaction is not significant.

East Bay. In the east bay, there are several IFR interactions. During West Plan operations, IFR arrivals to Runway 31 at Alameda Naval Air Station (Alameda) limit departures from Runway 29 at Metropolitan Oakland International Airport (Oakland). Similarly, IFR arrivals to Runway 25 at Alameda limit departures from Runways 27L or 27R at Oakland. When weather is below circling approach minimums, missed approach airspace must be protected. During these weather conditions, approaches to Runway 29 at Oakland and Runway 31 at Alameda interact and must be staggered, and approaches to Runway 27 at Oakland and Runway 25 at Alameda must be staggered to insure that missed approach airspace will be available if needed.

During West Plan operations, IFR approaches to Hayward Air Terminal (Hayward) interact with IFR approaches to Runway 29 at Oakland. These approaches must be staggered to provide adequate radar separation of 3 nautical miles.

During Southeast Plan operations, IFR arrivals to Oakland and Runway 13 at Alameda can be conducted independently. However, when missed approach airspace at Alameda must be protected the approaches are staggered.

Also during Southeast Plan operations, Hayward IFR approaches interact with IFR operations at Oakland. It is usually preferable for Hayward-bound aircraft to make an approach to Runway 11 at Oakland and proceed visually to Hayward and land. This operation has to be staggered with IFR approaches to Oakland and interrupts departures from Runway 11 at Oakland. However, there are times when the Hayward approach must be made from the south. When this occurs, departures from Runway 11 at Oakland are interrupted for a longer period of time.

Other Interactions. Other interactions occur within Bay TRACON airspace between various segments of the air traffic flow routes shown in Exhibits E and F and between some of these segments and aircraft transiting the area via the low-altitude Victor airway structure. These interactions are, however, resolved by altitude and/or horizontal separation through radar vectors. Resolution of these interactions is possible with today's air traffic volume, but will become increasingly more difficult with increased air traffic demand loads.

Conclusions

The review of the organization of the Bay Area airspace identified and evaluated the complexities of the existing condition of the Bay Area airspace. Many factors influence and constrain air traffic flows, altitudes, and flight paths in the airspace, including jurisdictional relationships, airport locations, terrain, weather, and air traffic demand. It appears that the established procedures and air traffic control facilities currently provide for safe, orderly, and expeditious flow of aircraft for today's volume of air traffic demand. Future capabilities and capacities are compared with forecast aviation demand in Chapter II.

II. AIRSPACE CAPACITY ASSESSMENT

As described in this Chapter, the capacity of the Bay Area airspace was assessed under a variety of different operating conditions. The airspace capacity was compared with alternative forecasts of aviation demand in 1997 to determine (1) the extent to which the Bay Area airspace will be able to accommodate future aviation activity, and (2) the location of critical capacity constraints and airspace interactions.

Airspace Capacity Model

The PMM&Co. airspace capacity model is a computerized analytical model that calculates the capacity of the airspace system and its elements. The model assesses the relative aircraft flows on different routes in the airspace and considers the interactions between aircraft along the routes, at the airspace fixes, and on the runways, as defined in a three-dimensional airspace network.

The airspace network, consisting of links and nodes, represents the existing traffic flows in the TRACON airspace. Individual elements represent all applicable runway systems, arrival and departure routes, aircraft diverging and merging points, and aircraft flow crossing points. The characteristics associated with each element were defined in terms of horizontal distance and altitude, aircraft flow distributions, clearance times, etc.

The model uses a set of input parameters to determine the minimum separation required between aircraft operations throughout the airspace system. The separations are computed for different types of aircraft and for different types of operations (arrivals and departures), taking into account ATC rules and aircraft operating characteristics. For example, the separation between a Boeing 747 and a Cessna 150 must be at least 6 miles on final approach in IFR conditions.

In addition to computing the capacity of the airspace system, the model also computes the ratio of demand to capacity for each individual element of the airspace system.

Definition of Airspace Capacity

Hourly airspace capacity is the maximum number of aircraft operations that can be served by the airspace system in an hour.

Hourly airspace capacity depends on a number of operating conditions, including:

- Demand levels
- Distribution of demand
- Weather conditions
- Airspace configuration and traffic flow

Airspace system capacity represents the summation of the airspace capacities of the most critical links in the airspace system. (Critical links in the Bay Area airspace include the final approach paths into and initial departure paths from the major air carrier airports.)

Inputs to Airspace Capacity Model

Information on each of the operating conditions was developed and converted into inputs for the airspace capacity model.

Demand Levels. MTC defined seven San Francisco Bay Area airport system alternatives (Alternatives 1, 2, 3, 4a, 4b, 4c, and 4d) for assessment in the Regional Airport Plan Update Program. The amount and distribution of general aviation and third-level air carrier activity was held constant in each alternative, but different allocations of passengers (and hence air carrier aircraft operations) were made for the three major airports--San Francisco International Airport (SFO), Oakland International Airport (OAK), and San Jose Municipal Airport (SJC)--and a potential additional air carrier airport was included at one of four existing locations in the north bay.

The seven alternatives were:

Alternative 1:	Existing traffic distribution
Alternative 2:	Defer expansion of OAK and SJC until SFO is saturated
Alternative 3:	Regional Airport Planning Committee (RAPC) recommendation (limit SFO, expand service at other airports)
Alternative 4a:	Limit SJC, expand service at SFO
Alternative 4b:	Limit SJC, expand service at OAK

Alternative 4c: Limit SJC, expand service in North Bay

Alternative 4d: Limit SJC and North Bay, expand service at SFO and OAK

Selected Alternatives. On the basis of a preliminary review of the airspace and other implications of these seven alternatives, MTC selected two (Alternatives 1 and 3) for detailed airspace analysis.

Alternative 1 maintains the same relative distribution of passengers among the Bay Area airports that exists today. Alternative 3 has a revised distribution based on the Regional Airport Planning Committee (RAPC) recommended allocation of traffic among the Bay Area airports. For purposes of this study, the year 1997 was selected as the planning forecast year.

The number of passengers at the four airports for the two selected alternatives in 1997 is given in Table 1. As shown, in Alternative 3, the activity at San Francisco International Airport is reduced (compared with Alternative 1), and the activity at the other airports is increased accordingly.

MTC also specified two additional theoretical alternatives to provide further quantitative data on airspace capacity. The theoretical alternatives concern a "balanced" system where it is assumed that each air carrier airport experiences the same ratio of demand to capacity for arrivals in instrument flight rules (IFR) weather conditions.

The two additional theoretical alternatives, referred to as X and Y, provide further redistribution of traffic from San Francisco. Alternative X redistributes additional traffic from San Francisco to Oakland and San Jose to achieve a balance in the ratios of demand to capacity at these three airports. Alternative Y redistributes additional traffic from San Francisco and San Jose to Oakland and a new potential north bay airport to assure that demand does not exceed IFR airspace capacity.

Peak Periods. The time period selected by MTC for analysis is the busiest period of aircraft operations at the Bay Area airports, which occurs during the evening peak arrival period between 6 p.m. and 8 p.m. Arrivals represent approximately two-thirds of all operations during the selected evening time period. A morning peak with approximately two-thirds departures was also assessed to determine if a peak departure period might be more critical than the selected peak arrival period. MTC derived the number of aircraft instrument operations during this peak period corresponding to the annual passenger levels in Table 1. The total number of instrument operations for 1997, as shown in Table 2, is significantly higher than it is today. For example, there were 44 instrument aircraft operations per hour at San Francisco in August 1977, during the time period selected for the study. The number forecast for 1997 is 87. Large increases are also forecast for Oakland and San Jose. Appendix A contains a summary of the forecasts of passenger and instrument operations provided by MTC.

North Bay Airport Operations. At the north bay airport, in addition to the air carrier operations, there may be general aviation and military aircraft operations. Each of the four potential sites identified by MTC for the north bay air carrier airports (Travis Air Force Base; and Hamilton, Sonoma County, and Napa County Airports) is comparable in terms of airspace capacity and is located outside the delegated airspace of the Bay TRACON.*

In previous studies, and in discussions with personnel of the Oakland Air Route Traffic Control Center during this study, it was learned that air traffic destined to and from any of the four north bay airports considered could overfly and hence bypass Bay TRACON airspace. It was therefore assumed that traffic from the north bay airport would not travel in the delegated airspace of the Bay TRACON, and no detailed analysis of airspace capacity was performed in this study for the north bay airport.

If the aircraft redistributed to the north bay airport were to stop at San Francisco, Oakland, or San Jose to load additional passengers or to combine two Bay Area airports as destination airports, the airspace capacity benefits gained by redistribution would be eliminated.

Distribution of Demand. The forecast demand for airspace instrument operations was distributed to individual airspace routes, in accordance with a sample of real-world field data on the use of airspace, arrival/departure fixes, and airports. The sample of real-world field data was collected from information provided by the Oakland Air Route Traffic Control Center.

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*Note that the airspace adjacent to Hamilton would need to be restored to one of its previous configurations (with a TRACON shelf over Hamilton Approach airspace at 4000 feet and below) for an ILS to be reestablished.

Table 1

ANNUAL PASSENGERS AT FOUR BAY AREA AIRPORTS
IN 1997

Airport	Millions of annual passengers[a]	
	Alternative 1	Alternative 3
San Francisco International Airport	43.6	31.0
Oakland International Airport	5.5	13.0
San Jose Municipal Airport	6.9	10.0
North bay airport[b]	0.0	2.0
Total	56.0	56.0

a. Total of enplaned and deplaned passengers.
b. North bay airport (potential site: Hamilton, Sonoma County, Napa County, or Travis Air Force Base).

Source: Metropolitan Transportation Commission.

Table 2

AIRCRAFT INSTRUMENT OPERATIONS AT BAY AREA AIRPORTS IN 1997[a]

Airport	Aircraft instrument operations per hour[b] Alternative 1	Alternative 3	Alternative X[c]	Alternative Y[d]
San Francisco International Airport	87	68	48	39
Oakland International Airport	31	44	62	50
San Jose Municipal Airport	43	49	51	40
Others[e]	31	31	31	63
Total	192	192	192	192

a. Air carrier, commuter, air taxi, general aviation, and military operations.

b. Average number of arrival and departure aircraft per hour in period 6 p.m. through 8 p.m., average day, 1997.

c. Traffic is redistributed from San Francisco to Oakland and San Jose.

d. Traffic is redistributed from San Francisco and San Jose to Oakland and a north bay airport.

e. General aviation and military airports, including any air carrier operations at a potential north bay airport.

The demand was distributed by aircraft mix to the various elements of the system to reflect the different aircraft operating characteristics (such as aircraft velocity, and descent and climb-out performance) and ATC separation criteria. The aircraft mix consists of four classifications (A, B, C, and D) according to aircraft operational characteristics and air traffic control requirements. A and B aircraft are small (maximum gross takeoff weight less than 12,500 pounds); C aircraft are large (maximum gross takeoff weight between 12,500 and 300,000 pounds); and D aircraft are heavy (maximum gross takeoff weight more than 300,000 pounds).

Weather Conditions. Airspace capacity depends on the cloud ceiling and visibility conditions that occur at a particular time. For the San Francisco Bay Area, three weather conditions have a major influence on airspace capacity, as shown below with their approximate annual occurrence:

VFR1--ceiling at least 6,000 feet and visibility at least 6 miles (79%)

VFR2--ceiling between 1,000 and 6,000 feet and /or visibility between 3 and 6 miles (13%)

IFR--ceiling less than 1,000 feet and/or visibility less than 3 miles (8%)

Airspace capacity decreases as the ceiling and visibility decrease. Therefore, MTC selected for this study the two weather conditions with the lowest capacities--VFR2 and IFR. IFR represents the condition with the lowest capacity; the VFR2 capacity is higher because of the ability to use visual separation for approaches and departures at the Bay Area Airports.

Airspace Configuration and Traffic Flow. The airspace configuration within the jurisdiction of Bay TRACON is directly related to the runways in use at the airports in the San Francisco Bay Area. Wind direction and speed influence the runways that can be used for arrivals and departures, and hence the traffic flow plan used by the Bay TRACON. Because the airports in the Bay TRACON airspace are close to each other, the direction of IFR aircraft operations at each airport cannot be considered independently.

As noted previously, two major air traffic flow plans have been established: the West Plan and the Southeast Plan. Bay TRACON determines when the air traffic flow will change from one plan to the other plan and notifies each ATC tower. The decision is based primarily on weather conditions, particularly wind direction and velocity. For more that 90% of the year, winds permit use of the West Plan, and this Plan was selected by MTC for use in this study. (Exhibit E shows the traffic flows for the Bay TRACON West Plan.)

Results of Airspace Capacity Assessment

Several computer runs of the airspace model were performed for the Bay Area airspace system assuming the air traffic distributions of Alternatives 1, 3, X, and Y; VFR2 and IFR weather; and evening and morning peak traffic.

The results of these computer runs were transferred to large-scale drawings that illustrated the locations of bottlenecks or critical points. The bottlenecks were identified by measures of the ratio of demand to capacity for each element of the airspace system.

Exhibit H presents an example of these drawings for Alternative 1 in IFR weather conditions for both the evening and morning peak periods.* The elements of the airspace system are color-coded. The colors correspond to the ratios of demand to capacity that apply for individual elements of the airspace network. The evening peak is indicated by solid color lines and the morning peak by dashed lines.

Exhibit H shows that (1) for much of the airspace network, demand is significantly less than capacity (elements not colored), and (2) for some elements, demand approaches capacity (green, brown, or yellow elements) or exceeds capacity (orange elements).

For example, Exhibit H shows that for one airspace element, the final approach into San Francisco, demand exceeds capacity in the evening peak (orange solid line), and demand approaches capacity in the morning peak (yellow dotted line).

The analysis of the large-scale drawings and the detailed computer output from the model runs is presented in the following paragraphs.

Comparison of Demand with Airspace Capacity. Table 3 shows demand levels and capacities for Alternatives 1 and 3 under different operating conditions for the year 1997. The table also shows the ratio of demand to capacity (D/C ratio).

As shown, the overall system demand exceeds airspace capacity for each set of operating conditions, except for Alternative 3

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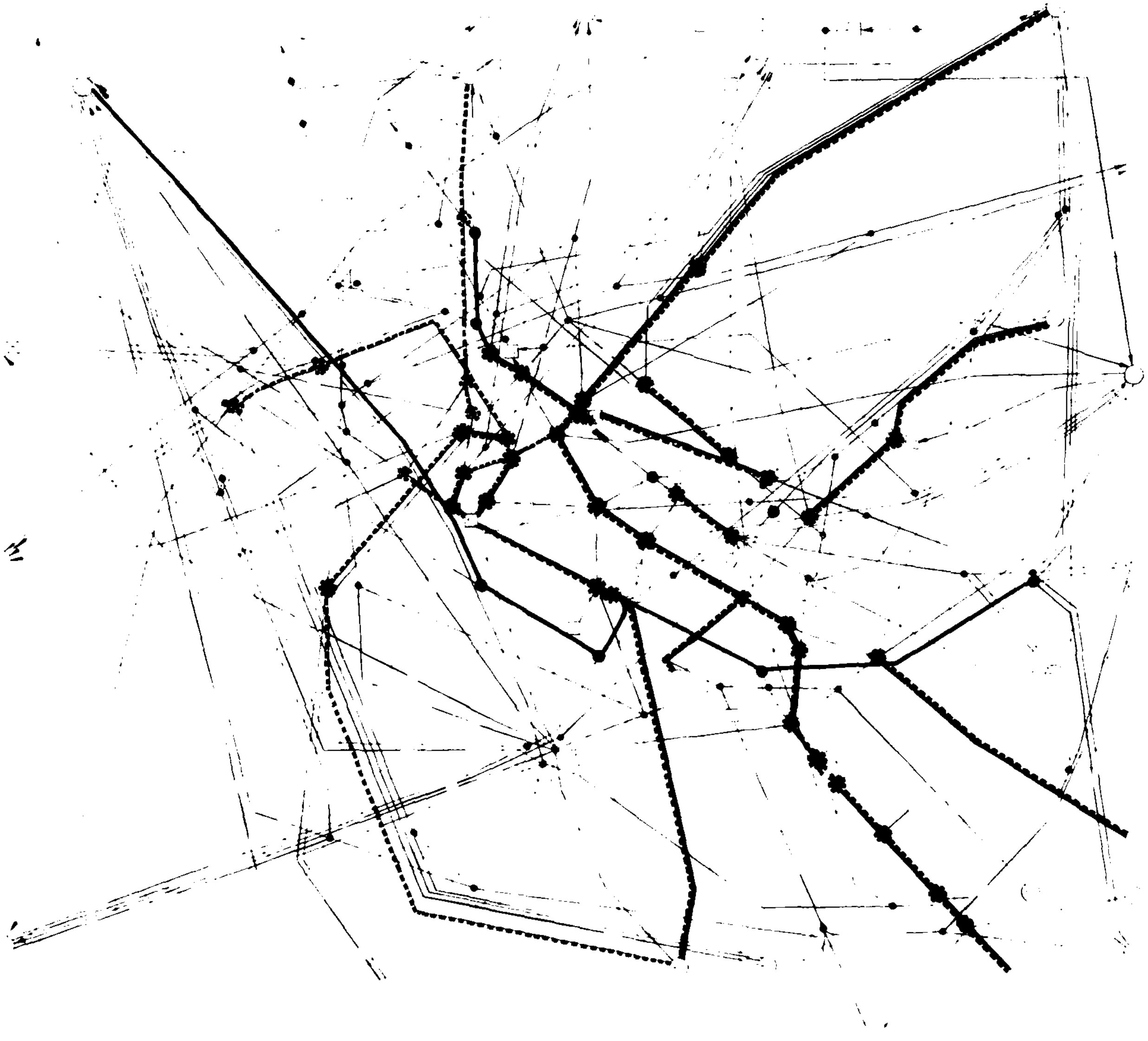
*The full set of large-scale drawings is currently on file at PMM&Co.

MTC AIRSPACE CAPACITY ANALYSIS
EXISTING TRAFFIC DISTRIBUTION
1997 IFR WEST FLOW



IFR AIRSPACE CAPACITY

ARRIVAL PEAK: 83 OPS/HR
DEPARTURE PEAK: 93 OPS/HR

LEGEND

ARRIVAL DEPARTURE

- D/C ≥ 1.0 UNACCEPTABLE DELAYS
- .75 ≤ D/C < 1.0 HIGH DELAYS (CONGESTED)
- .50 ≤ D/C < .75 MEDIUM DELAYS (SOME CONGESTION)
- .25 ≤ D/C < .50 AVERAGE DELAYS
- D/C < .25 NO DELAYS

EXHIBIT H

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Table 3

COMPARISON OF DEMAND WITH AIRSPACE CAPACITY IN 1997
Overall TRACON Airspace System During Arrival Peak
Alternatives 1 and 3

Alternative	Overall system demand	IFR conditions Capacity	D/C[a]	VFR2 conditions Capacity	D/C[a]
1	192	83	2.3	163	1.2
3	192	117	1.6	231	0.8

a. D/C = ratio of demand to capacity in period 6 p.m. through 8 p.m., average day, 1997.

under VFR2 conditions. For Alternative 1, demand exceeds capacity by 109 aircraft operations in IFR conditions (D/C ratio 2.3) and by 29 aircraft operations in VFR2 conditions (D/C ratio 1.2). Also, for Alternative 3, demand exceeds capacity by 75 aircraft operations in IFR conditions (D/C ratio 1.6) but demand is less than capacity by 39 aircraft operations in VFR2 conditions (D/C ratio 0.8).

Note that for both weather conditions, D/C ratios are lower for Alternative 3 than for Alternative 1. For comparison, with today's demand, the D/C ratio is approximately 1.1 in IFR and 0.5 in VFR2.

These significant overloads can be attributed to relatively few elements of the Bay Area airspace system, particularly the final approach paths to the major airports.

Table 4 shows the ratio of demand to capacity for the final approaches into San Francisco International, San Jose Municipal, and Oakland International Airports. The ratio of demand to capacity varies widely among the three airports. It should be noted that the airspace capacity of Oakland International Airport includes the capacity associated with the North Field general aviation runways. Therefore, only part of this capacity is available for air carrier activity.

Assessment of Alternatives 1 and 3. As shown in Table 3, Alternative 3 has a significantly higher airspace system capacity than Alternative 1 (117 compared with 83 in IFR conditions; 231 compared with 163 in VFR2 conditions). This increase is obtained by reallocating some of the San Francisco demand to Oakland and San Jose. As shown in Table 4, this reallocation increases the D/C ratios for Oakland and San Jose.

From Table 4, it is clear that further reallocation of demand could reduce the imbalance of the D/C ratios. For Alternative 3, where demand was reallocated from San Francisco to Oakland and San Jose, the D/C ratio at Oakland is only 0.6 in IFR weather. Thus, additional capacity for the overall airspace system could be gained by further allocation of demand to Oakland.

Although the reallocation associated with Alternative 3 reduces the D/C ratio for San Francisco, it increases the D/C ratio at San Jose. In IFR weather, the D/C ratio increases from 1.0 to 1.2. Therefore, Alternative 3 shifts some of the congestion from San Francisco to San Jose and creates an excess of demand over capacity at San Jose in IFR weather.

Table 4

RATIO OF ARRIVAL DEMAND TO CAPACITY IN 1997
Final Approach to the Air Carrier Airports
During Arrival Peak, Average Day

Airport	IFR conditions Alternative 1	IFR conditions Alternative 3	VFR2 conditions Alternative 1	VFR2 conditions Alternative 3
San Francisco International Airport	2.3	1.6	1.1	0.8
San Jose Municipal Airport	1.0	1.2	0.5	0.6
Oakland International Airport	0.4	0.6	0.2	0.3

Consequently, although Alternative 3 is an improvement over Alternative 1 in terms of overall airspace system capacity, it increases airspace congestion for San Jose and does not fully use potential airspace capacity at Oakland. (Note that airspace constraints are only one of many factors to be considered in developing the Regional Airport Plan Update.)

Assessment of Theoretical Alternatives X and Y. Table 5 shows the demand for use of the Bay TRACON airspace, the capacity of the Bay TRACON airspace, and the ratios of arrival demand to capacity for Alternatives 1, 3, X, and Y.

For Alternative X, the redistribution of demand from San Francisco to Oakland and San Jose causes a significant increase in IFR airspace capacity from 83 (with today's distribution) to 154 operations per hour. This increase derives from full use of the IFR capacity of the three air carrier airports. The IFR D/C ratio is 1.3, which implies that severe congestion would occur at each of the airports during busy hours. However, the 1.3 ratio is significantly lower than the D/C ratios for both today's distribution (2.3, Alternative 1) and the RAPC recommended distribution (1.6, Alternative 3). Therefore, Alternative X would yield lower overall delays to aircraft than either Alternative 1 or Alternative 3.

For Alternative Y, the reallocation of demand from San Francisco and San Jose to Oakland and a north bay airport results in a slightly further increase in IFR airspace capacity (compared with Alternative X). The overall demand drops from 192 to 160 operations per hour because 32 aircraft operations are redistributed to the north bay airport outside of the airspace under consideration. The IFR D/C ratio is reduced to 1.0, which implies that delays with Alternative Y would be significantly less than with any of the other alternatives considered.

Location of Airspace Congestion. Lack of sufficient airspace capacity to accommodate forecast demand for any element of the airspace system can cause delays to occur in other parts of the airspace system.

For example, during the evening arrival peak, much of the lack of airspace capacity can be attributed to the final approaches into the three major airports. Lack of capacity at those locations will cause congestion to back up throughout the TRACON approach airspace and will cause additional congestion in the air routes outside the TRACON airspace.

Table 5

COMPARISON OF DEMAND WITH AIRSPACE CAPACITY IN 1997
Overall TRACON Airspace System Capacity During Arrival Peaks
Theoretical Alternatives

Alternative	Overall system demand	IFR conditions Capacity	IFR conditions D/C[a]	VFR2 conditions Capacity	VFR2 conditions D/C[a]
1	192	83	2.3	163	1.2
3	192	117	1.6	231	0.8
X	192	154	1.3	308	0.6
Y	160[b]	160	1.0	320	0.5

a. D/C = ratio of demand to capacity.

b. Thirty-two aircraft per hour are allocated to a north bay airport outside the TRACON airspace.

During the morning departure peak, some congestion will occur in the departure airspace leading from San Francisco. The ratios of demand to capacity in the departure peak are shown in Table 6.

Comparison of Tables 4 and 6 shows that D/C ratios during a departure peak are considerably lower than those occurring during an arrival peak.

During a departure peak, interactions between Oakland departures, Alameda Naval Air Station arrivals, and northbound mid-bay traffic combine to cause congestion over Oakland. The D/C ratio for the Oakland departure leg is slightly higher during a departure peak (Table 6) than the D/C ratio for the Oakland final approach during an arrival peak (Table 4).

One potential airspace improvement would be to reroute some of the mid-bay traffic from south bay airports over airspace routes to the east that have low D/C ratios. This rerouting would lower the departure leg (D/C ratio shown for Oakland in Table 6, and would reduce congestion in the vicinity of Oakland International Airport.

Interactions occur between Hayward, Oakland, and Alameda Naval Air Station during an arrival. Because of the need to protect airspace for missed approaches on Runways 27R and 29 at Oakland in some IFR weather conditions, the full capability of the approach airspace to Runway 29 cannot be used. In turn, this protected airspace leaves sufficient gaps in the Runway 29 approach to permit IFR approaches to Hayward Air Terminal. When the weather does not require missed approach protection, arrivals into Hayward conflict with the approach to Runway 29 at Oakland. Airspace reconfiguration would be needed to relieve this conflict.

In IFR weather conditions, significant interactions occur in the vicinity of San Jose Municipal Airport. Departures from Reid-Hillview interact with operations at San Jose, as do departures from Moffett Naval Air Station. Careful controller coordination is needed to minimize the adverse impacts of these interactions.

Delays to Aircraft. This study was restricted to computation of airspace capacity; quantification of delays to aircraft resulting from an excess of demand requires the application of additional analysis tools, such as the airspace simulation model. Quantification of delays would allow a more comprehensive airspace analysis, including an assessment of alternative improvements and quantification of economic benefits.

Table 6

RATIO OF DEPARTURE DEMAND TO CAPACITY IN 1997
Initial Departure Leg From Air Carrier Airports
During the Morning Departure Peak

Airport	IFR conditions Alternative 1	IFR conditions Alternative 3	VFR2 conditions Alternative 1	VFR2 conditions Alternative 3
San Francisco International Airport	1.5	1.1	0.8	0.6
San Jose Municipal Airport	0.6	0.7	0.4	0.5
Oakland International Airport	0.5	0.7	0.3	0.4

The following tabulation gives an indication of the order of magnitude of average delays to aircraft for various ratios of demand to capacity (D/C):

D/C	Average delay in minutes
Greater than 1.00	10 to 90
0.5 to 1.00	2 to 10
0.0 to 0.50	0 to 2

The average delay to aircraft is defined as the total delay experienced by all aircraft in an hour divided by the number of aircraft involved. Actual delays to individual aircraft may vary considerably from the average delay.

The D/C ratios computed by the airspace capacity model indicate that significant congestion and delays will occur. In some cases the delays are as high as 90 minutes for both Alternatives 1 and 3. These high delays can cause significant impacts on the operation of the national aviation system, such as:

- Cancellation of scheduled flights
- Delays at the origin airport for flights with destinations in the San Francisco Bay Area
- Diversions of arriving aircraft to airports other than their planned destination
- Reduced airspeed during the air route phase of flight
- Delays in holding patterns at points along the air routes
- Imposition of quotas on the maximum number of aircraft that can use the airport during peak hours of the day

The significance of these potential impacts strongly suggests the need for further analysis to:

- Quantify future delays
- Develop estimates of the cost of these delays
- Assist in reviewing the allocation of traffic to Bay Area airports

- Assist in developing revised airspace configurations and procedures

- Assess the need for airport improvements to relieve airspace congestion (e.g., new runways)

- Review general aviation VFR training areas

- Review the need for ILS facilities at general aviation airports to relocate general aviation IFR training away from air carrier airports

Appendix A

FORECASTS OF PASSENGER AND INSTRUMENT OPERATIONS

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FORECASTS OF PASSENGER AND INSTRUMENT OPERATIONS

This Appendix contains forecast data provided by MTC to PMM&Co. for the airspace capacity analysis for the Regional Airport Plan Update Program. Three tables provide 1997 forecasts of instrument operations between 6:00 p.m. and 8:00 p.m. by destination and aircraft type for the Bay Area Airports of interest:

Table A-1	1997 Instrument Operations by Major Air Carriers
Table A-2	1997 Instrument Operations by Third Level Air Carriers
Table A-3	1997 Instrument Operations by General Aviation Aircraft

Table A-4 provides a summary of air carrier airport system alternatives in terms of millions of annual passengers.

Table A-1

1997 INSTRUMENT OPERATIONS BY MAJOR AIR CARRIERS

Alternative	Airport	Aircraft Class	Ave. Daily Operations Between 6:00 p.m. and 8:00 p.m. North	East	South	West	Sacramento	Stockton	Modesto	Monterey	Fresno	Total
1 (Existing Distri-bution)	SFO	C	19.432	13.456	39.383	2.214	2.117	0.371	0.158	0.529	2.459	80.119
		D	14.557	13.630	25.922	0.686						62.795
	OAK	C	3.875	3.677	9.489	0.486	.105			.011		17.643
		D	0.967	0.852	2.080	0.185						4.084
	SJC	C	4.426	3.732	10.703	0.570	.570					20.001
		D	1.461	1.223	2.977	0.289						5.950
3 (RAPC)	SFO	C	14.318	9.881	28.051	1.628	1.464	0.256	0.110	0.366	2.459	58.533
		D	10.847	10.035	19.127	6.477						46.486
	OAK	C	7.265	5.756	16.340	0.861	0.596			.060		30.878
		D	3.826	3.559	6.825	2.249						16.459
	SJC	C	5.786	4.531	13.716	0.736	.949					25.718
		D	2.750	2.496	5.206	1.186						11.638

Table A-2

1997 INSTRUMENT OPERATIONS BY 3RD LEVEL AIR CARRIERS

Airport	Aircraft Class	Ave. Daily Operations Between 6:00 p.m. and 8:00 p.m.							
		Livermore	Paso Robles San Luis Santa Maria	Monterey	Stockton	Modesto	Total		
SJC	A+B	0.33	0.86	1.26	0.69	0.17	3.31		
		Napa	Novato	Concord	Eureka	Chico	Redding	Modesto	Total
OAK	A+B	0.82	2.07	2.07	1.33	1.24	0.60	0.15	8.28
		Livermore	Napa	Sonoma	Buchanan	Eureka	Chico	Redding	
SFO	A+B	2.00	2.00	3.98	3.98	3.15	2.94	1.39	
		Marysville	Visalia	Total					
		0.12	0.36	19.92					

Note: Assumes 17% of Daily Commuter Aircraft Operations occur between 6:00 p.m. and 8:00 p.m.

Table A-3

1997 INSTRUMENT OPERATIONS BY GENERAL AVIATION AIRCRAFT

Airport	Aircraft Class	Annual Ops.	Annual Inst. Ops.	Ave. Daily Inst. Ops. Between 6:00 p.m. and 8:00 p.m.
San Francisco	A+B	50,000	(1)	(2)
Oakland	"	600,000	106,200	32.6
San Jose	"	660,000	141,150	56.5
Hayward	"	540,000	44,300	10.0
Reid-Hillview	"	380,000	14,000	1.7
Palo Alto	"	346,000	23,500	16.1
San Carlos	"	270,000	9,200	2.7
Moffett	Mixed	55,000(3)		(3)
Alameda	Mixed	80,000		(4)

(1) To be estimated by PMM.
(2) Analysis of survey data shows 7.4% of the GA departures occurred between 6:00 p.m. and 8:00 p.m. For limited arrivals sample, 4.8% of the GA operations occurred between these two hours.
(3) Relocation of Air National Guard to Moffett (from Hayward) will increase activity at Moffett from 51,000 to 55,000 annual operations.
(4) Use existing numbers.

Table A-4

SUMMARY OF AIR CARRIER AIRPORT SYSTEM ALTERNATIVES
(Millions of Annual Passengers)

Scenario	Airport	Alternative 1	Alternative 2	Alternative 3	Alternative 4a	Alternative 4b	Alternative 4c	Alternative 4d
LOW 37 MAP	SFO	28.8	28.8	24.0				
	OAK	3.6	3.6	7.0				
	SJC	4.6	4.6	6.0				
	N.B.							
	Total	37.0	37.0	37.0				
HIGH 43 MAP	SFO	33.5	31.0	27.0				
	OAK	4.2	6.7	8.0				
	SJC	5.3	5.3	7.0				
	N.B.			1.0				
	Total	43.0	43.0	43.0				
LOW 45 MAP	SFO	35.0	31.0	27.0				
	OAK	4.4	8.4	10.0				
	SJC	5.6	5.6	8.0				
	N.B.							
	Total	45.0	45.0	45.0				
HIGH 56 MAP	SFO	43.6	31.0	31.0	33.0	31.0	31.0	33.0
	OAK	5.5	13.0	13.0	13.0	15.0	13.0	15.0
	SJC	6.9	8.0	10.0	8.0	8.0	8.0	8.0
	N.B.		(4.0)*	2.0	2.0	2.0	4.0	
	Total	56.0	56.0	56.0	56.0	56.0	56.0	56.0

Alternative 1. Status Quo
Alternative 2. Defer Expansion of OAK/SJC until SFO is saturated
Alternative 3. RAPC Recommendation

Alternative 4a. Limit SJC/Expand Service at SFO
Alternative 4b. Limit SJC/Expand service at OAK,
Alternative 4c. Limit SJC/Expand service in North Bay
Alternative 4d. Limit SJC and North Bay/ Expand service at SFO and OAK

* ATA Forecasts do not extend beyond 52.0 million annual passengers in 1994.