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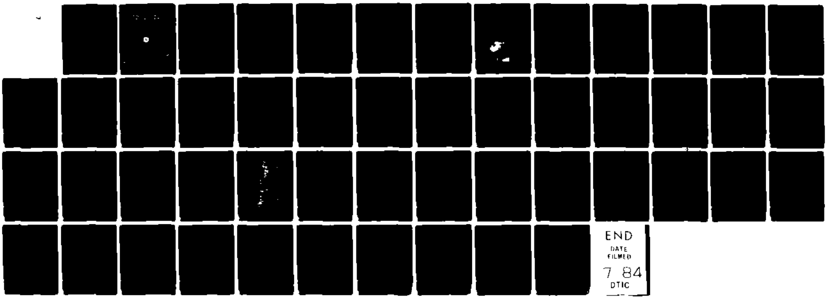

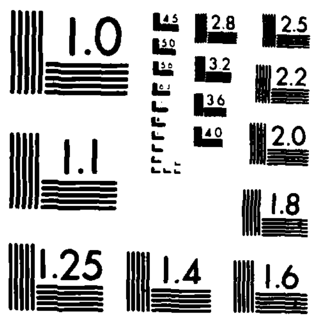

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AIRCRAFT TRAFFIC DENSITY IN THE LOS ANGELES BASIN

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16. Abstract

An estimate of the number of aircraft flying in the Los Angeles basin was made using airborne and ground-based radar measurements. These estimates are combined with FAA projections of traffic growth to predict the future aircraft density as seen by an airborne Traffic Alert and Collision Avoidance System (TCAS). Results include the findings that (a) peak density decreases approximately linearly with radius, (b) the number of aircraft increases linearly with the sum of tower operations, (c) for year 2000, within a radius of 5 nmi, the projected maximum density is 0.45 aircraft/nmi^2, the projected maximum number of aircraft is 35, and the projected maximum number of ATCRBS aircraft is 20, and (d) within a radius of 10 nmi, these figures are 0.24, 75, and 43, respectively.

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TABLE OF CONTENTS

1. INTRODUCTION

This report describes the method used to obtain an estimate of the aircraft density in the Los Angeles airspace, both for the present time and well into the future. The need for these estimates arose from the requirement to specify the airborne environment for the Traffic Alert and Collision Avoidance System (TCAS), so that the system could operate in all airspace.

The Los Angeles basin represents the most severe region in the United States in terms of airborne traffic density and extent, and has traditionally been used as a standard against which to judge whether systems will survive the load. Earlier models of traffic have become outmoded and inaccurate; at the same time available instrumentation for measuring the airborne traffic has been improving. Accordingly, the FAA, together with substantial assistance from the U.S. Air Force, undertook steps to obtain a new estimate of the airborne environment in the Los Angeles Basin and a forecast of how it will change in the future.

Models of aircraft traffic can take many forms. The most comprehensive would provide a moment-by-moment picture of every aircraft for an extended period of time. Such a dynamic model has been used in the past for many purposes; however, creating such a model again would require resources well beyond those presently available. Instead, it was realized that with reasonable resources the primary TCAS requirements could be satisfied with a simpler model, which would focus only on aircraft density.

2. BACKGROUND

In 1969 the Air Traffic Control Advisory Committee (ATCAC) of the Department of Transportation provided a major analysis of the air transportation system, and arrived at a number of important conclusions which have influenced the course of the system ever since (Reference 1). In the ATCAC report, an estimate was made of the traffic in the Los Angeles basin (120 nmi x 120 nmi centered on the Los Angeles airport as in the outlined box of Figure 2-1), but there were few details as to the actual spatial distribution of the aircraft.

In 1972 the FAA Technical Center undertook a coordinated survey of the towers in the Los Angeles basin (Reference 2). From this survey they produced a model of the approximate flight profiles during typical high activity periods. The MITRE Corporation then combined that baseline data together with growth in operations, as forecast by the FAA, to produce a number of different models for different years (References 3 and 4). For example, the baseline data indicated 495 aircraft in the basin in 1972; a projection to 1982 indicated 804 aircraft; and a projection to 1995 indicated 1840 aircraft.*

In 1976, while the Mode S sensor (formerly denoted DABS, Discrete Address Beacon System) was being developed, M.I.T. Lincoln Laboratory assembled a transportable Mode S sensor, called the Transportable Measurement Facility (TMF). Data was

* Note: These numbers varied somewhat for different "snapshots".

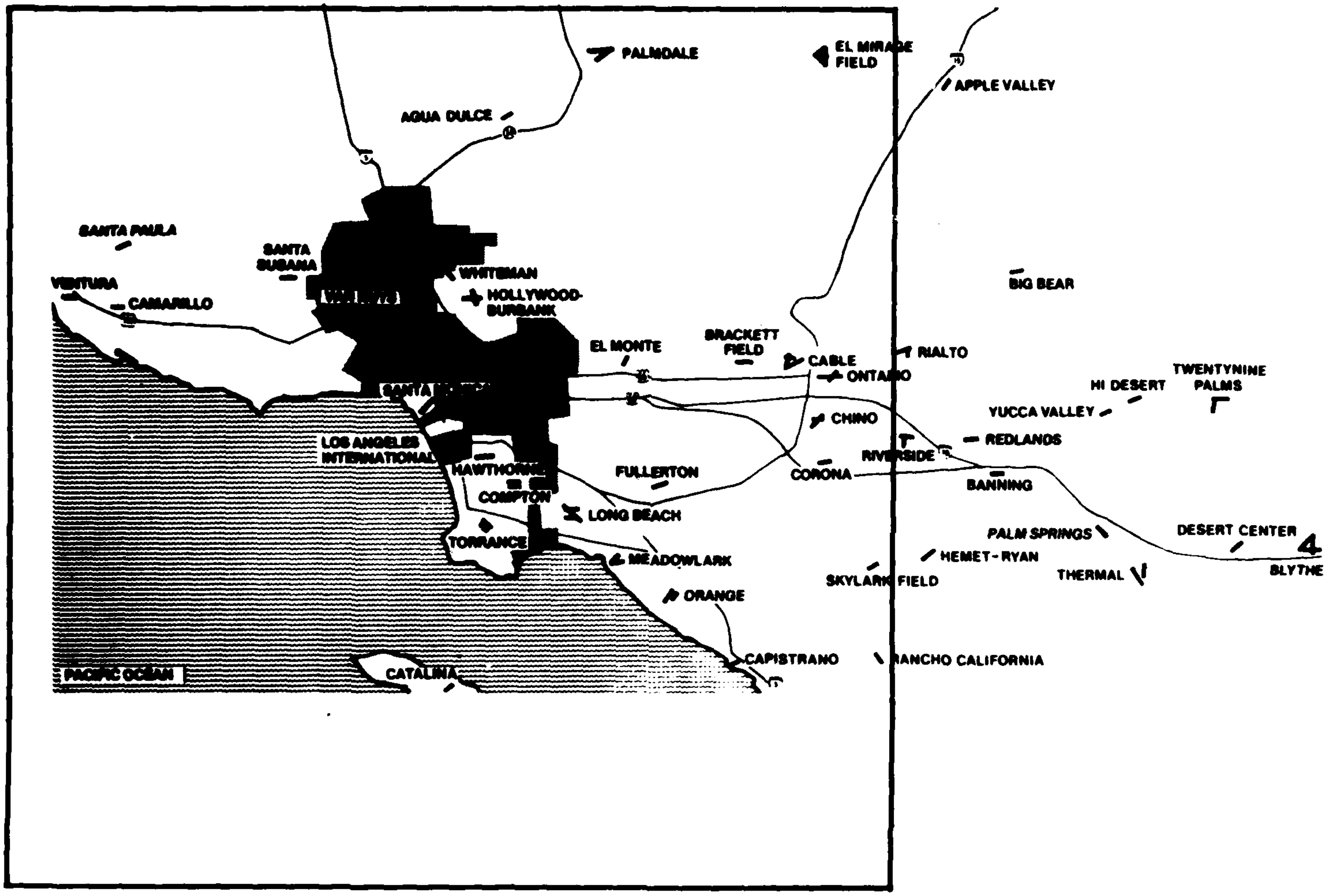

FIGURE 2-1
THE LOS ANGELES BASIN

collected at various places around the country, including Los Angeles (Reference 5). There, it was found that the average value of the instantaneous airborne count (IAC) was about 160 beacon equipped aircraft within a range of 60 nmi of the TMF -- there was no way of knowing the number of non-beacon equipped aircraft. The TMF data also provided important observations on the actual distribution of aircraft -- a great improvement over any distribution inferred from the 1972 survey. From the TMF data, the peak measured density of beacon equipped aircraft within a 10 nmi radius circle was .10 aircraft per square nautical mile.

By 1981 it was recognized that both the forecasts and the baseline figures used in the models made in 1972 should be reassessed. This was so not only because it was 10 years later, but also because of the fuel embargos and the wide-body revolution in aircraft design. Since ongoing work still required traffic models, but no new baseline had been produced, the 1972 model was modified by correcting for the actual growth that was known to have occurred between 1972 and 1981, using the current FAA projection to the year 1995. That was the basis for the model which was called LAX-1100 (Reference 6).

As the development of the airborne Traffic Alert and Collision Avoidance System (TCAS) required an up-to-date estimate of the projected traffic density, an initiative was undertaken early in 1982 to obtain a new baseline of the present level of traffic in the Los Angeles Basin. This information was needed to aid in setting standards which had to account for such things as specifying an adequate size of track file, providing for garble processing, and assessing the impact of automatic interference limiting measures.

3. APPROACH TO A NEW MODEL OF TRAFFIC DENSITY

It was decided to build the new model on the basis of airborne surveillance measurements, which was expected to provide a substantial improvement over the best previous means, the 1972 survey. While the airborne measurements are ideal for detecting beacon equipped aircraft (the coverage is not blocked by terrain features), it is not as effective for non-beacon equipped aircraft (it must compete with ground clutter and with ground vehicle clutter). Accordingly, the fraction of non-beacon aircraft was estimated from special recordings of ground Air Traffic Control radars. Thus, the total Instantaneous Airborne Count (IAC) was determined by a combination of both airborne data (beacon aircraft) and ground based data (non-beacon aircraft).

The time of the measurements was arranged to be near the peak traffic of the day. However, the day-to-day activity varies and this factor had to be taken into account. The measure used for activity is the sum of the daily operations count collected for every tower in the basin. The approach to obtaining an estimate of the peak density is therefore, first to measure the IAC, then to account for peak day activity by using the daily operations count, and finally to project to a future year by using the yearly operations count as forecast by the FAA. A complicating factor -- the air traffic controller's strike of 1981 -- also had to be taken into account.

4. AIRBORNE SURVEILLANCE DATA

Through the cooperation of the U.S. Air Force, airborne surveillance data was gathered in the vicinity of Los Angeles and, as a comparison, in the vicinity of New York City. Table 4-1 shows the local conditions for the four Los Angeles flights and for one New York flight. The flights were scheduled and coordinated principally by the U.S. Air Force Liason Officer attached to the FAA Office of System Engineering Management.

Data was scheduled to be collected during the expected high activity periods of the day. This was for the most part successful. Aircraft activity as measured by operations recorded at some of the towered airports confirmed this. Examples of the hourly data are shown in Appendix A. In general the weather was good, only one day having periods of light showers (11 March).

The measurements typically lasted for about one-half hour to one hour, during which a continuous stream of target reports on beacon aircraft was recorded. These reports included the positions of all detected aircraft in latitude, longitude, and altitude. Further, they provided the time, Mode A code, Mode A and Mode C validity status, and several other parameters.

The data was transcribed to nine-track tapes at the U.S. Air Force facility and sent to the FAA Technical Center. There they were preprocessed by the Data Engineering and Development Division for the Engineering Management Staff. The resulting tapes were then sent both to the FAA Office of System Engineering Management, where a "quick-look" was conducted (Reference 7 for example) and subsequent flights planned, and to the MITRE facility where the detailed analysis being reported here was conducted.

TABLE 4-1
LOCAL CONDITIONS DURING DATA COLLECTION FLIGHTS

PLACE	LOCAL CONDITIONS
Los Angeles	15 December 1981 Tuesday, 1100 local time 5 mile visibility
	11 March 1982 Thursday, 1600 local time light rain 7 mile visibility
	3 June 1982 Thursday 1400 local time 10 mile visibility
	23 July 1982 Friday 400 local time 12 mile visibility
New York	9 July 1982 Friday, 1300 local time 10 mile visibility

At MITRE, the data was then processed to retain only those target reports lying within a 120 nmi square centered on the Los Angeles airport (LAX), and they were divided into scan intervals. A typical plot of the number of beacon reports per scan is shown in Figure 4-1, both for those aircraft reporting Mode C altitude (called Mode C aircraft) and for those aircraft not reporting Mode C (called non Mode C). For each flight, a time was chosen when the number of beacon reports was both high and consistent -- this became the base scan for further analysis.

In the base scan there are instances of spurious reports, which should not be attributed to aircraft, as well as occurrences of missing reports. The process used to reveal real aircraft was to plot sequential scans, after the base scan, for an interval of about one minute. When a string of sequential reports lined up, that indicated the presence of an aircraft, and the target report in the base scan was either retained, discarded, or a new one was added according to whether an aircraft was present or not. Figure 4-2 shows such a plot, with the arrows indicating the presence of an aircraft. When several aircraft are in a close cluster, such as near the zero-zero point over Los Angeles airport, the consequences of synchronous garble often appear.

With the base scan thus manually "cleaned up", we have some assurance that the target reports are valid. Figure 4-3 shows the result for the 3 June flight, where the squares indicate Mode C aircraft and the plus signs indicate non-Mode C aircraft. Initially, these were a total of 189 beacon aircraft; after cleanup this dropped to 179 beacon aircraft. The concentration of aircraft near the Los Angeles airport, especially along the Long Beach -- Los Angeles -- Van Nuys corridor is apparant, as is the lack of aircraft over the ocean and over the mountains. The scale of these plots is the same as that of the map in Figure 2-1; the Los Angeles airport is the large cross at the midpoint of the plot.

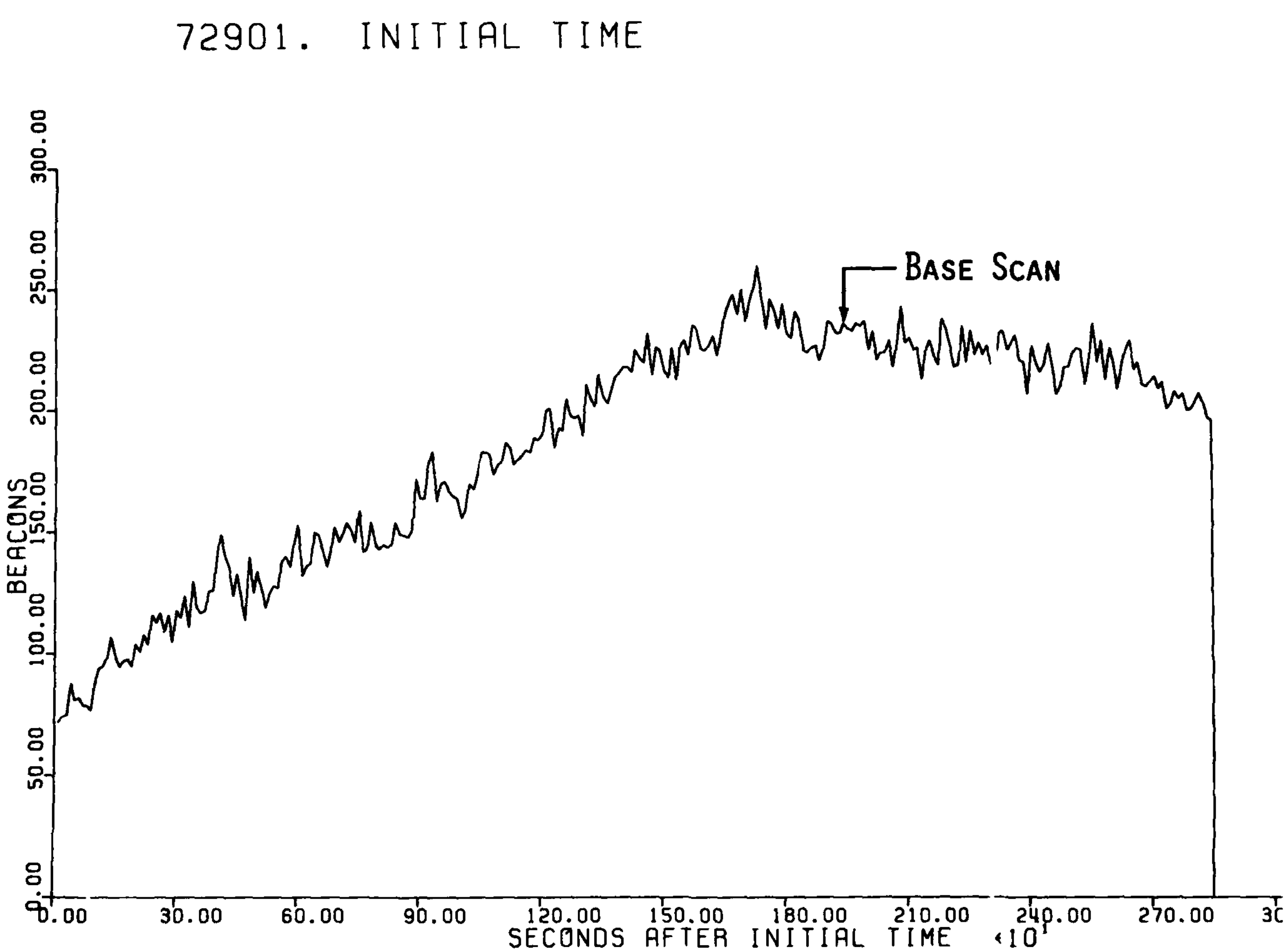

FIGURE 4-1
BEACON REPORTS PER SCAN
(23 JULY 1982)

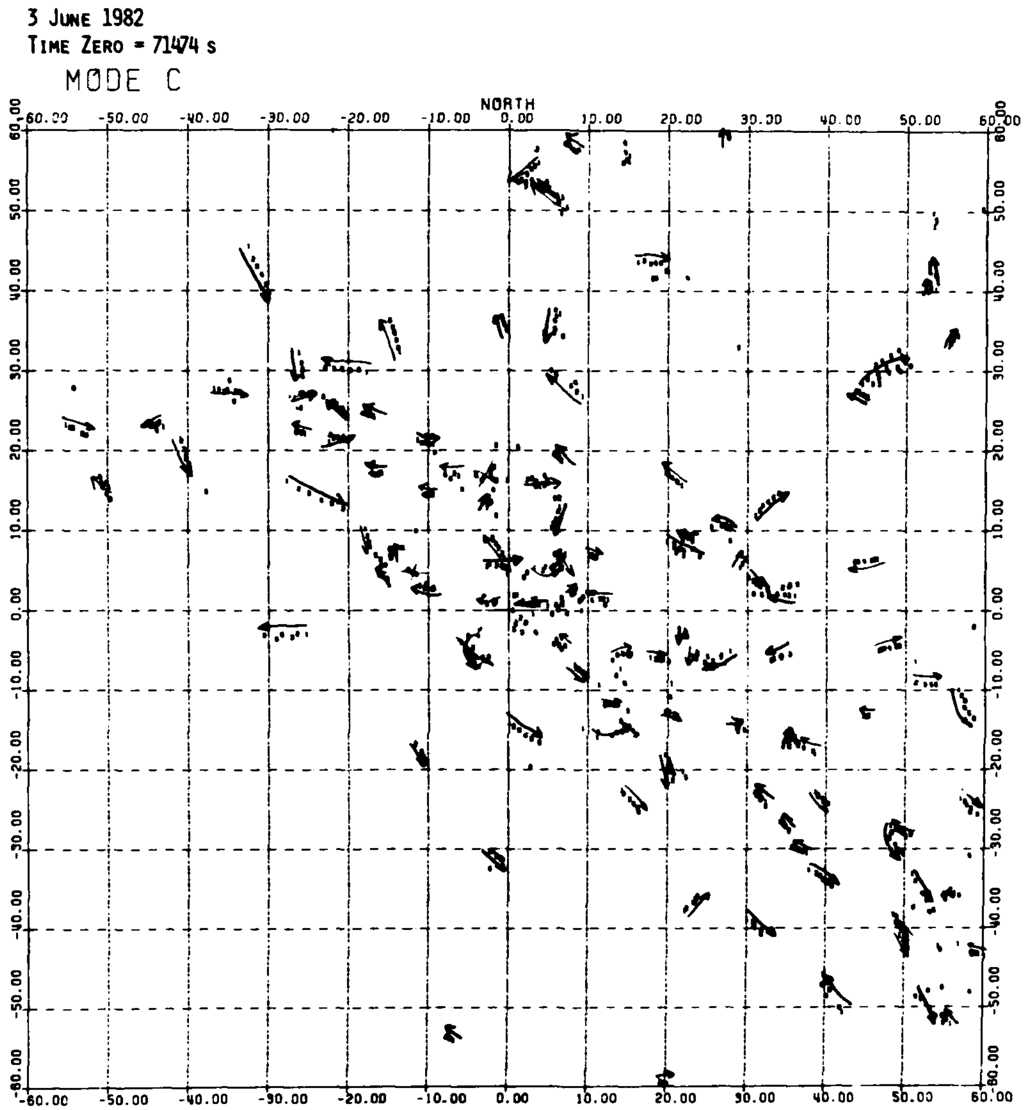

FIGURE 4-2
SEQUENTIAL STRINGS OF TARGET REPORTS

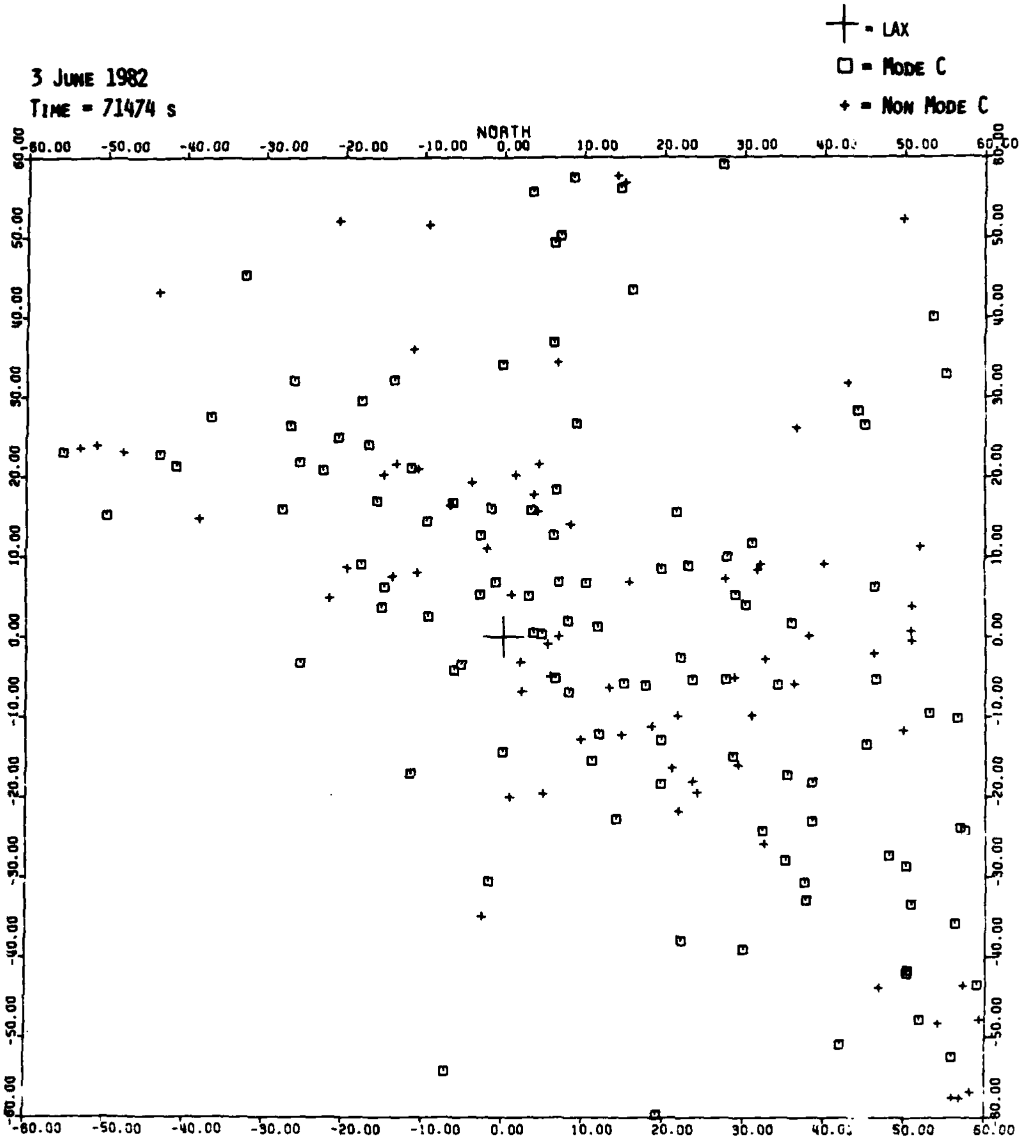

FIGURE 4-3
POSITIONS OF BEACON AIRCRAFT

Having the locations of beacon aircraft, we can now analyze the density of the Los Angeles basin by dividing it into a square grid of 5 nmi boxes as in Figure 4-4. There, every number represents the number of beacon aircraft within that particular 5 nmi x 5 nmi box. A square "cell" will be defined as an area having a "radius" (the radius of the inscribed circle), and the number of aircraft within that square cell will be determined from Figure 4-4. For example, in Figure 4-4, the total number of aircraft in the entire Basin, a square cell of 60 nmi radius, is 179. The number of aircraft in the most dense 10 nmi radius square cell (dotted outline) is 23. This process was continued for a variety of square cell sizes, each time finding the location of the cell of highest density and noting the number of aircraft in it.

When all four Los Angeles flights were thus treated, and plotted as in Figure 4-5, it was found that they could be adequately characterized by the simple relation given there. The relation applies very well at a cell radius of about 10 nmi, and with fair but conservative accuracy at a radius of 5 nmi. The value of having this heuristic relation is that one formula averages all of the variations that existed over the four flights: the specific aircraft localities, and the many operational conditions (takeoff, cruise, IFR, etc.) The peak density in any given size cell is seen to be directly proportional to the IAC of the entire Los Angeles basin. This enables one to take the average of a large amount of data, rather than to use directly only a small amount of data in a localized area. The nearly linear variation of the number of aircraft with radius (exponent is 1.1) is quite different from that for a uniform random distribution, which would follow a square law instead.

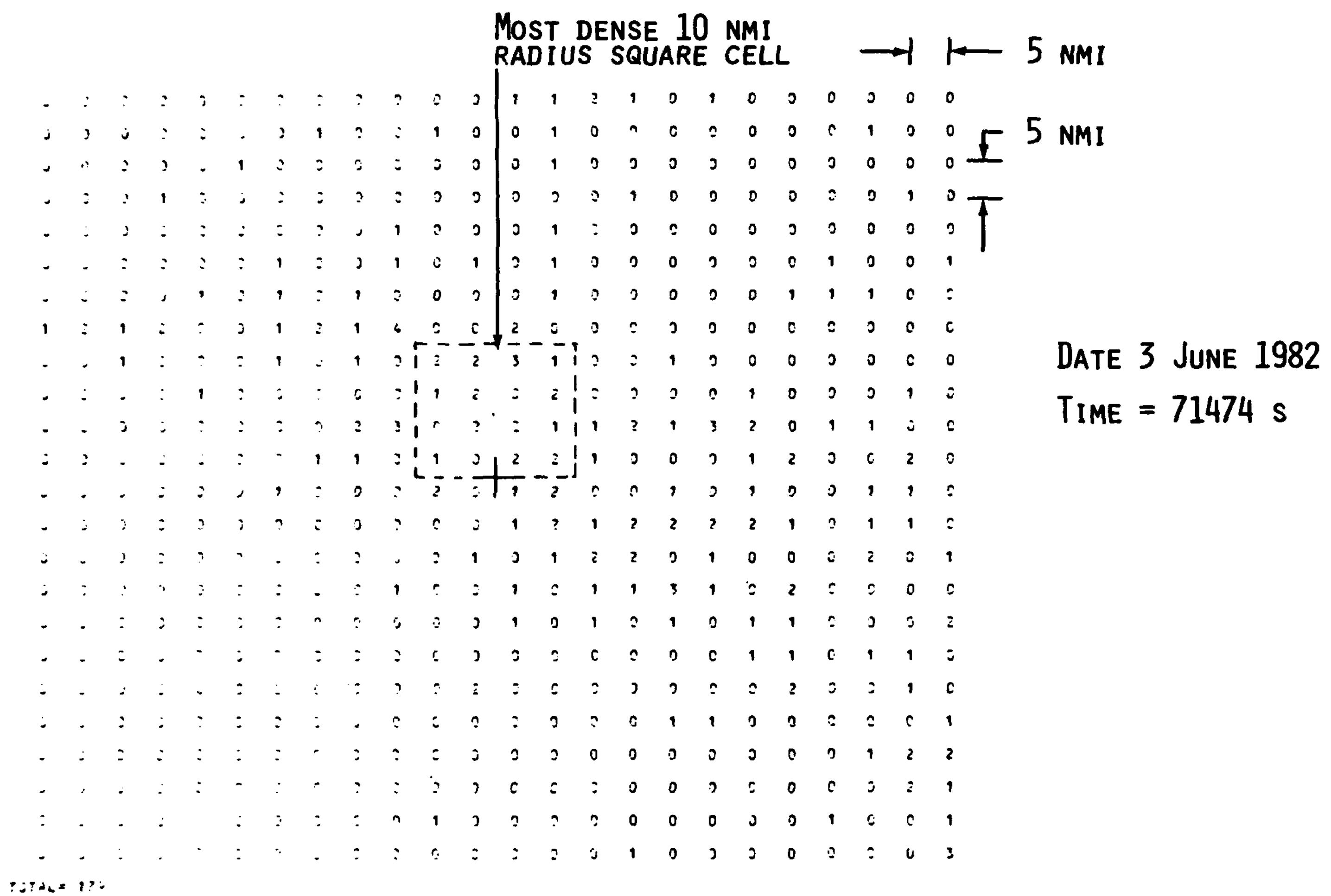

FIGURE 4-4
AIRCRAFT DISTRIBUTION

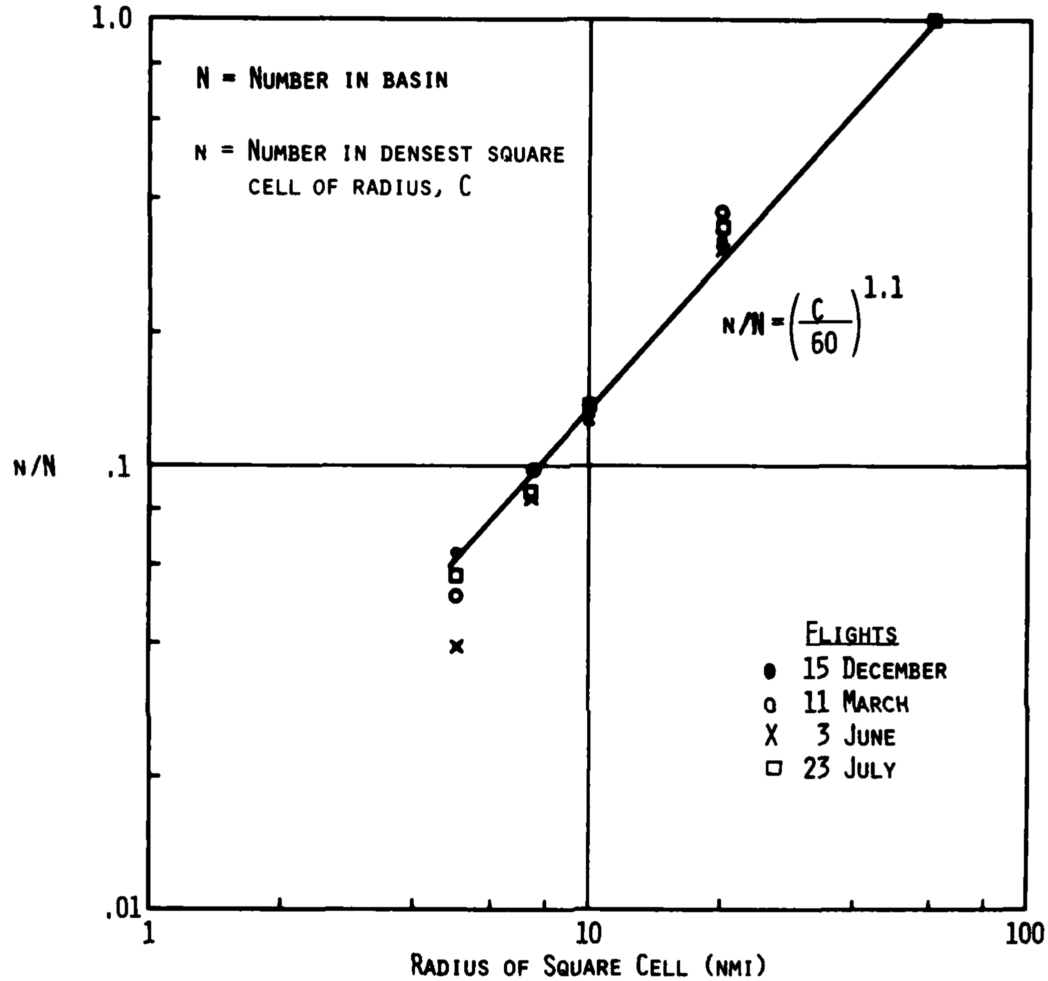

FIGURE 4-5
RELATIVE DISTRIBUTION OF AIRCRAFT AT LOS ANGELES

While the number of aircraft within a given surveillance radius is the important physical parameter for TCAS design, the associated density parameter is convenient to use when characterizing the airspace. Figure 4-6 converts the data of Figure 4-5 into density — that is, density of aircraft in the maximum density square cell of the given radius. The curve cannot be extrapolated below a square cell radius of 5 nmi because of the technique of analysis; however, for radii greater than 5 nmi, the maximum density in a square cell is nearly inversely proportional to radius. Thus, the maximum density within 10 nmi of an aircraft is about one-half of that within 5 nmi.

It is to be noted that the highest density actually measured within a 5 nmi radius square cell was .18, and within a 10 nmi radius square cell it was .07, both of these measurements were on 23 July 1982. This latter measurement is comparable with the 1976 measurement of maximum density with the TMF, which varied from .08 to .10 within a 10 nmi circular radius.

The relation shown in Figure 4-5 is one of the important results of this study. However, other inferences can also be drawn from the results of the four LAX flights. About 68 percent of the beacon aircraft were reporting Mode C. (If the data from the marginal day of 11 March were excluded, the fraction would drop to 63 percent.) This is a significant increase from the 45 percent found in 1976 during the TMF tests, and corresponds more closely with the results found when the TMF was moved to Washington and Philadelphia. It was also found that about one-half of the aircraft were squawking code 1200, and about one-half of those were Mode C. This is depicted in Table 4-2.

The altitude distribution of the Mode C aircraft is shown in Figure 4-7. About 50 percent of these aircraft reported below 5,000 ft, 75 percent below 10,000 ft, and 90 percent below 20,000 ft.

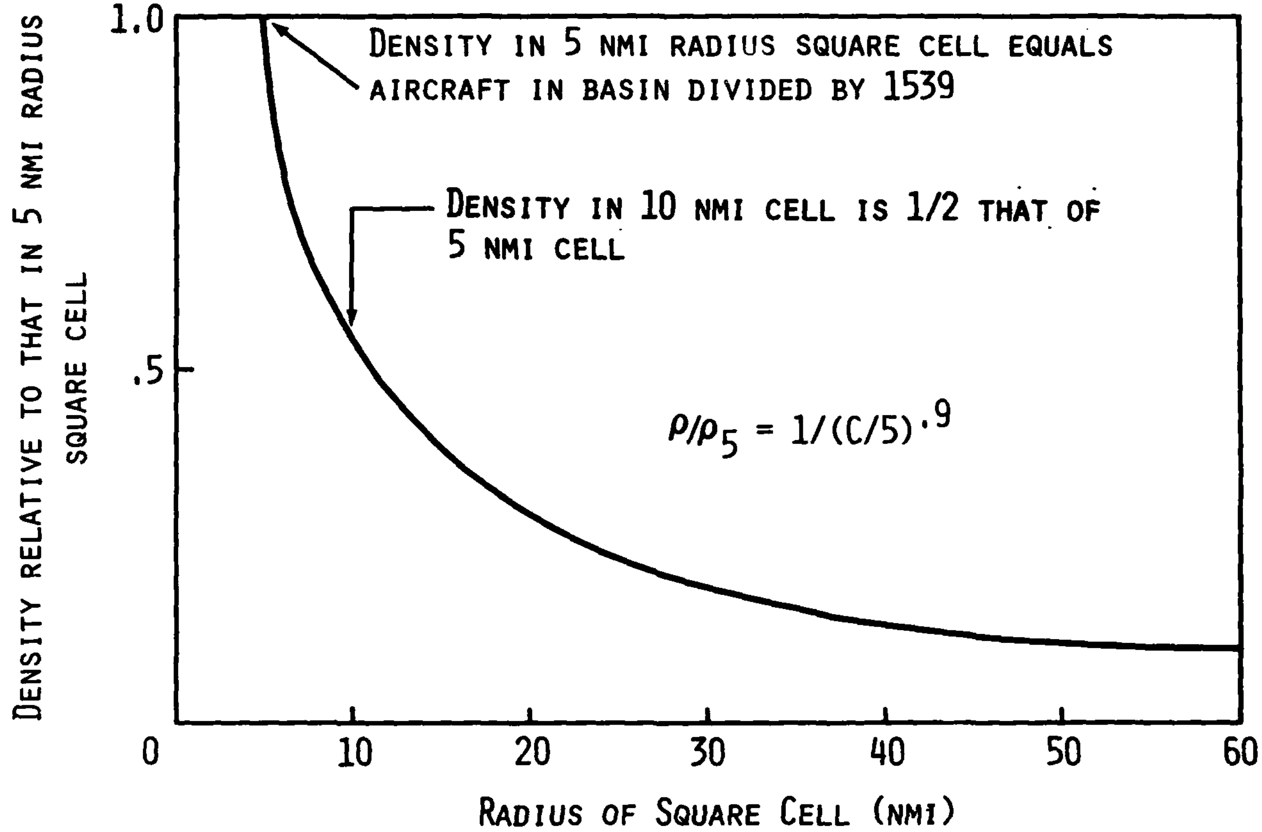

FIGURE 4-6
VARIATION OF DENSITY WITH CELL RADIUS

TABLE 4-2

SOME CHARACTERISTICS OF THE LOS ANGELES BEACON ENVIRONMENT

	MODE C	NON MODE C	TOTAL
FRACTION SQUAWKING CODE 1200	.23	.24	.47
FRACTION SQUAWKING OTHER CODES	.45	.08	.53
TOTAL	.68	.32	1.00

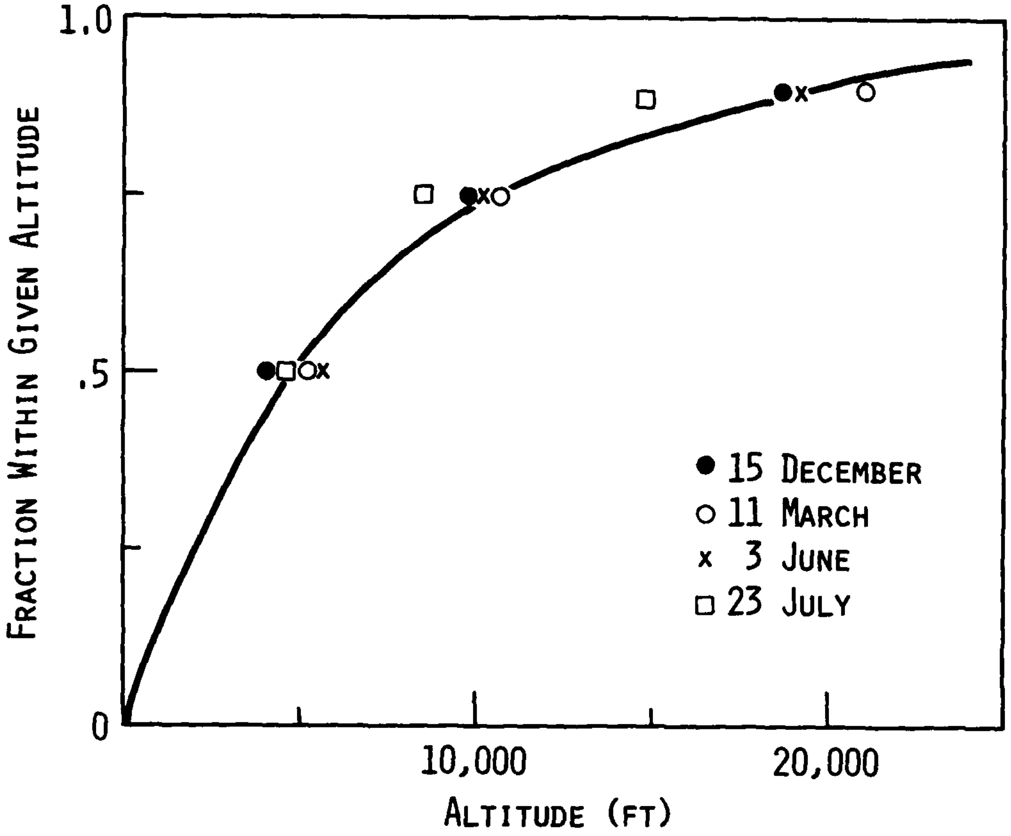

FIGURE 4-7
ALTITUDE DISTRIBUTION OF MODE C AIRCRAFT

5. GROUND BASED SURVEILLANCE DATA

The airborne surveillance data was used to determine the IAC of beacon aircraft, both Mode C and non-Mode C. To obtain an estimate of the number of aircraft flying without transponders, an analysis was made of a common digitizer (CD) recording, which was obtained by the FAA Western Region from the San Pedro long range radar, just a few miles away from the Los Angeles airport. This tape was reformatted by the Automation Engineering Division at the FAA Technical Center and then sent to MITRE for further analysis.

Since the ground based radar does not have an unobstructed view of the whole basin, we cannot use it to check the entire IAC, but within its surveillance view we can determine the fraction of aircraft having operating transponders to the total population (with transponders and without transponders).

The CD recording was made on 23 July approximately two hours earlier than the airborne measurement. While the two measurements were not at exactly the same time, they both occurred around the busy midday peak, and so can be considered to be samples of the same population. Although this circumstance is not ideal, any error should be small, and it will be seen that the impact on TCAS is minimal.

The same technique of observing correlatable strings of reports is used as for the airborne data. In this case, however, unassociated radar reports were plotted as well as all beacon reports. Since unassociated radar reports include all the radar clutter, the correlation process is considerably more difficult. Table 5-1 shows the end result of this process.

TABLE 5-1
AIRCRAFT SEEN BY SAN PEDRO RADAR

TYPE	NUMBER
Mode C	91
non-Mode C	62
Total Beacon	153
Radar	27
Total Aircraft	180

Date: 23 July 1982
Time: 1136 (local)

There were 153 beacon targets and 27 non-beacon targets. This gives us the rule that the total IAC is 1.18 times the beacon IAC.

Another use which can be made of the ground data is to cross-check the airborne beacon data. Accordingly, a grid similar to Figure 4-4 was made. The number of aircraft within the peak 5 nmi radius square cell and within the peak 10 nmi radius square cell agreed with those from the airborne data within one aircraft. This close correspondence, together with the self consistency among the four airborne measurements increases confidence in the overall series of measurements.

6. IS LOS ANGELES UNIQUE?

Having made the measurements of IAC in the Los Angeles basin and having developed some level of confidence in them, it is reasonable to ask if that locality is similar to others or is it so unusual that it is different in kind? To explore that question, several flights were scheduled in the vicinity of New York City. One of these, 9 July, was briefly analyzed to examine the density characteristics. For this analysis the step of visual correlation was omitted. That is, the beacon data for the selected scan was used as it came, recognizing that there would be some extraneous reports as well as missing reports. Other ground based data and operations data were recorded as well for possible future use.

As a result of this analysis it was found that the New York area has roughly similar characteristics to that of Los Angeles. Figure 6-1 is a plot of the New York beacon data. The variation of number of aircraft with radius follows a 1.2 power relation rather than the 1.1 power of Los Angeles. This results in slightly lower densities for a local area when a given number of aircraft are in a large area (e.g. 120 nmi x 120 nmi).

Thus the measured traffic in Los Angeles appears to be representative of other places in the country, although it has a somewhat higher density.

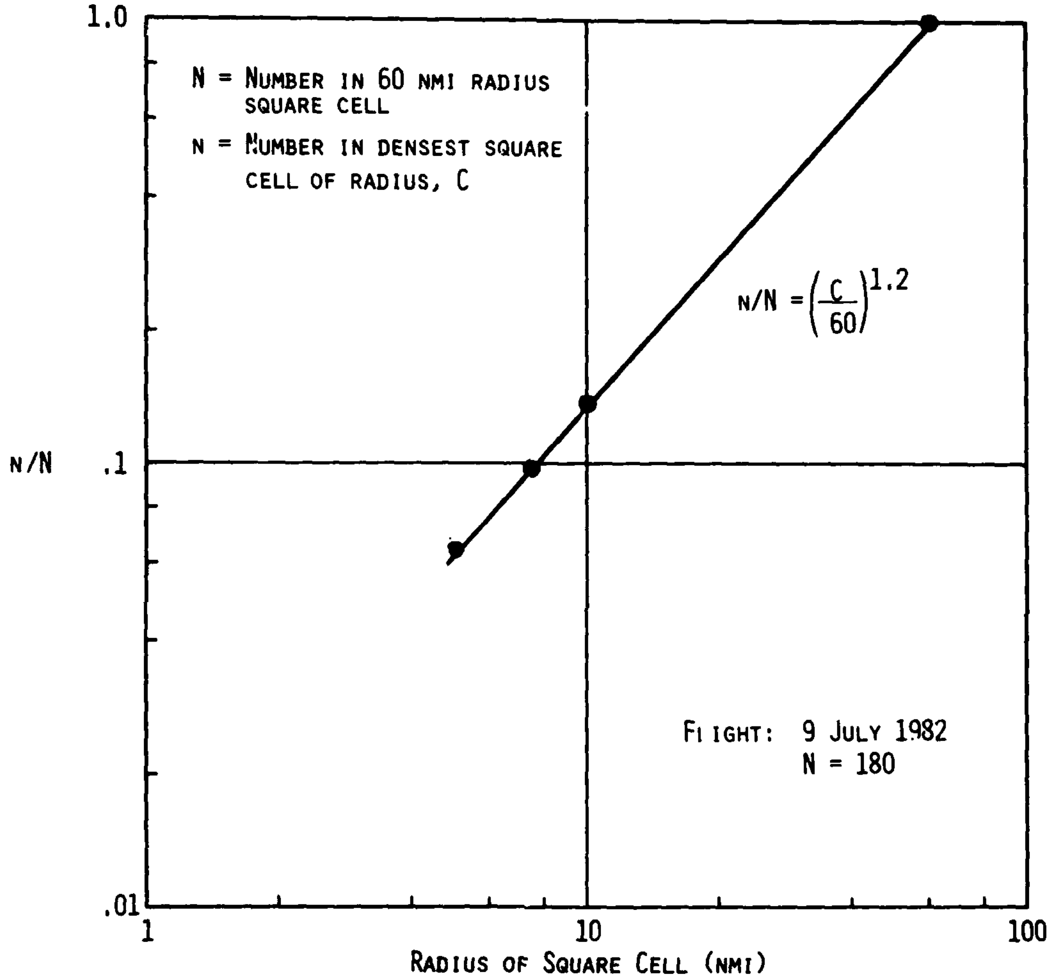

FIGURE 6-1
RELATIVE DISTRIBUTION OF AIRCRAFT IN NEW YORK

7. UTILIZATION OF TOWER OPERATIONS DATA

Although the variation of density with distance was consistent from day to day, each of the four day's flights had a different IAC, corresponding to different activity for that day. The next step in this analysis was to determine a way to account for these varying levels of activity.

The approach used here is to obtain daily operations data from each of the 17 towers in the Los Angeles basin, and to use the sum of these operations as an indicator of aviation activity. The FAA Western Region and the Office of Aviation Policy and Plans provided this information for the dates of the flights as well as for an extended period of time in the past. Appendix A shows the list of towered airports as well as examples of some of the data collected during the program.

Figure 7-1 shows the measured beacon IAC plotted with the sum of the tower operations in the basin. The four measurements are plotted, and an average line is drawn through them. The measured slope of the average line is 180 beacon IAC for every 10,000 operations. Since the total IAC includes both beacon and non beacon aircraft, the 1.18 factor from Section 5 should be included. This makes the expected total IAC 212 for every 10,000 total tower operations.

It can be seen that the scatter about the average line is fairly tight, being about the same level as the variation in hourly operations. This provides a fair degree of confidence that the variation in IAC can be represented by the variation in the daily operations count. The next step is simply to apply this information to the historical operations count so that we can estimate the peak IAC on the busiest day of the year.

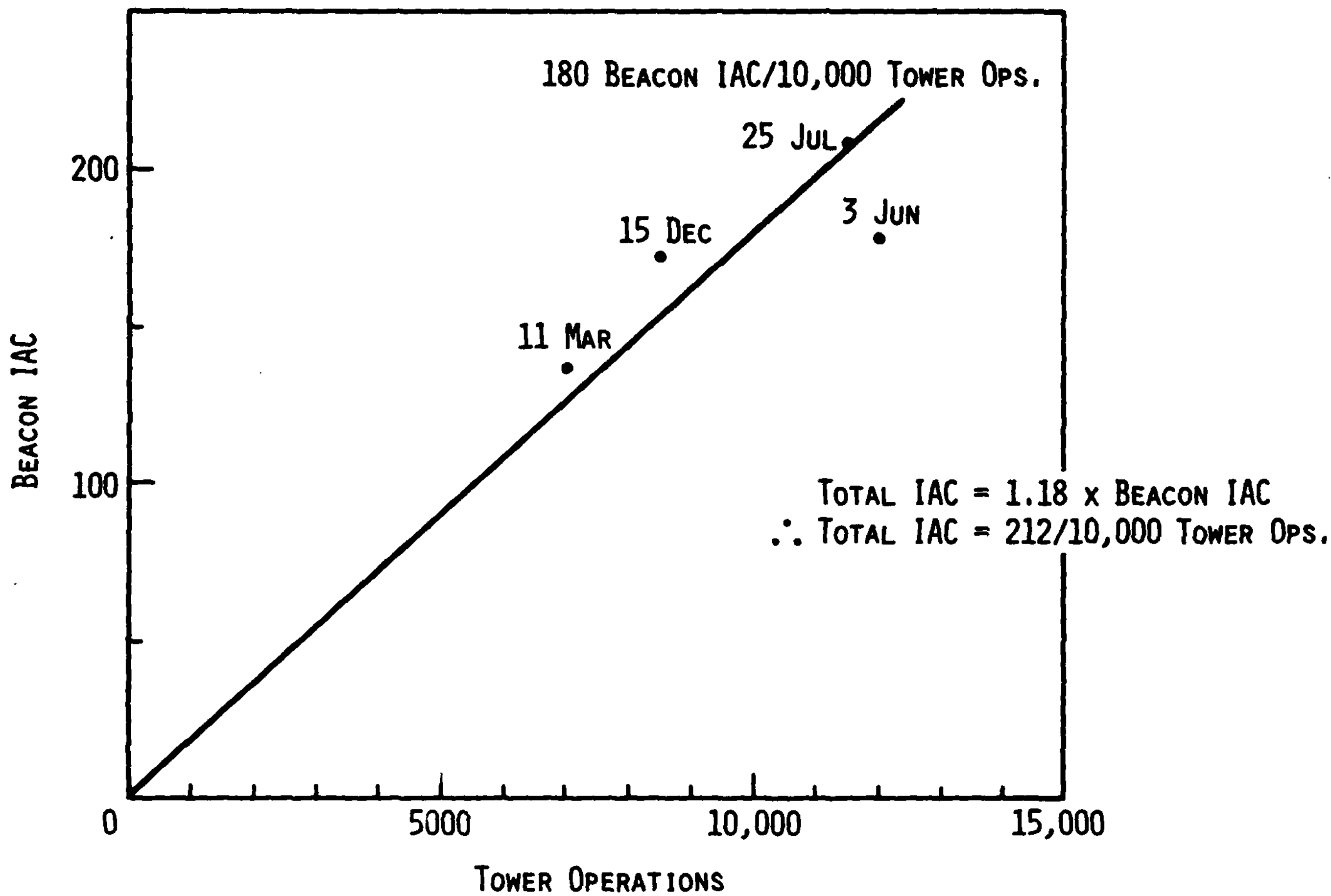

FIGURE 7-1
VARIATIONS OF IAC WITH OPERATIONS

Figure 7-2 is a plot of the total daily tower operations for 1980 through the period of measurement. With the exception of a short gaps in the data base, the plot is pretty much what would be expected. The most outstanding feature is the sharp drop of operations in August 1981, when air traffic controllers went on strike. Because of this action, and because of the downturn of the economy in 1981, the peak day in 1981 was below normal. Accordingly, the peak day in 1980 is chosen to represent "the present time".

To make this correction, we use the 212 IAC per 10,000 operations just determined, and multiply that by the total tower operations (16,868) for the peak day, 19 January 1980. The computed peak total IAC for the peak day in 1980 is 358 aircraft in the Los Angeles basin.

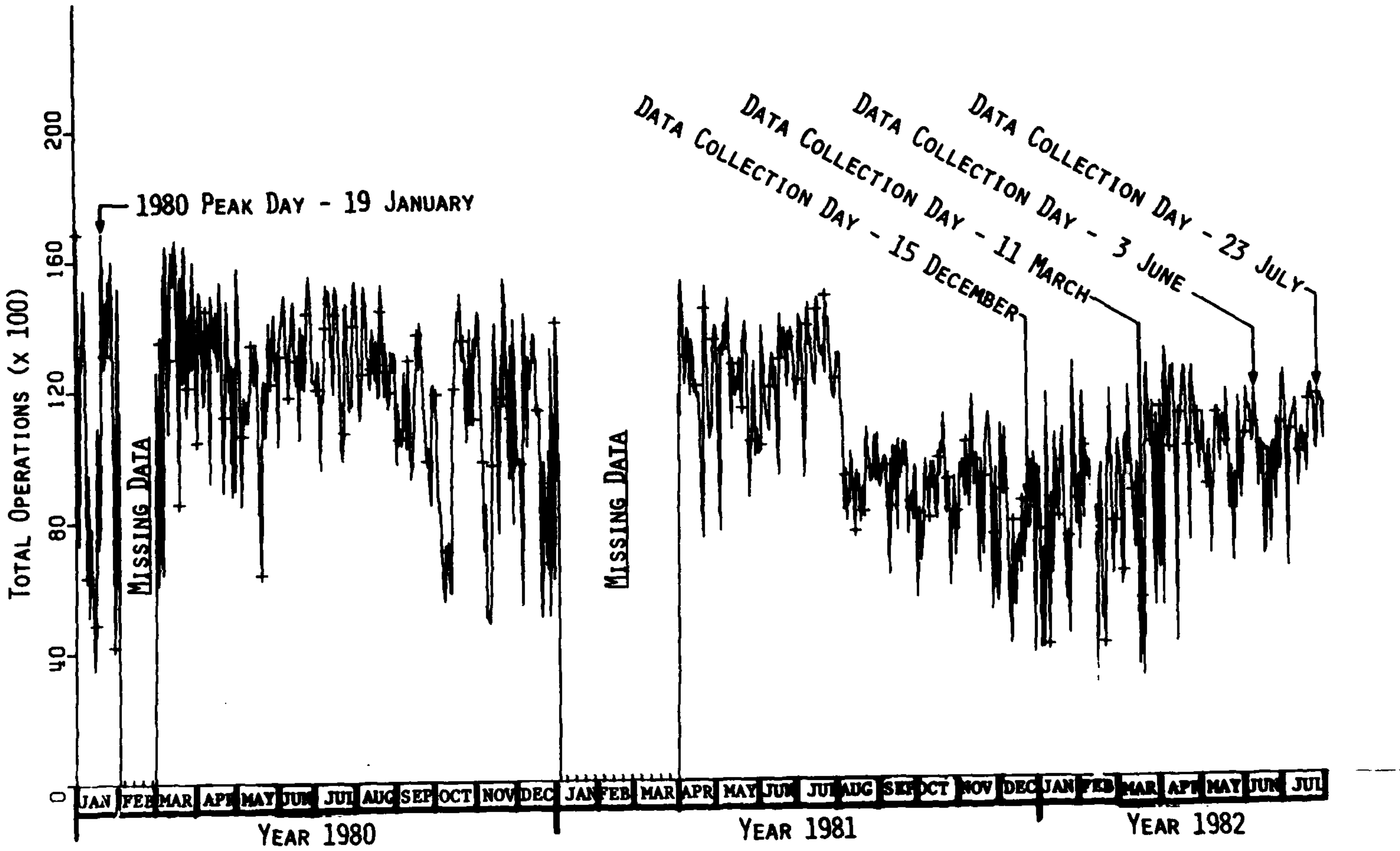

FIGURE 7-2
LOS ANGELES BASIN TOWERS DAILY OPERATIONS

8. FUTURE GROWTH PROJECTIONS

Having found the variation of density with distance together with the peak IAC, we have the required characterization of the airborne environment for the current period of time. To obtain a forecast of the environment into the future, we will use the annual operations forecast for towered airports.

Table 8-1 is a list of yearly operations supplied by the FAA Office of Aviation Policy and Plans. In addition, the IAC just computed for 1980 is shown, and is scaled for the succeeding years by the ratio of annual operations. The overall projected growth from 1980 to 2000 averages to 3.5% per year, starting slowly and gaining in the last decade. It is noted that the forecast peak IAC is only about 50 percent of the value used in the LAX-1100 model for 1995. This confirms the need that was recognized at the start of this project -- to redefine the baseline figures.

TABLE 8-1

FUTURE GROWTH PROJECTIONS

YEAR	ANNUAL OPERATIONS AT TOWERED AIRPORTS IN THE L.A. BASIN	IAC
1980	5.07 Million	358
1985	5.50	388
1990	6.40	452
1995	7.90	558
2000	9.73	687

9. ESTIMATES OF AIRBORNE ENVIRONMENT OVER TIME

In order to be useful for the TCAS design, the airborne population must be divided into three classes: ATCRBS transponders, Mode S transponders, and no transponders. The preceding section gave the basis for obtaining the total IAC over time; this section will break out the three classes.

Three scenarios will be developed to characterize equipage. The first scenario will be called the Baseline Scenario. This postulates a middle-of-the-road deployment of Mode S transponders. The second scenario is a more aggressive one, (Agressive Scenario) and the third scenario delays implementation by five years (Delayed Scenario). These employ differing assumptions about the rate of Mode S deployment; the total number of transponders is the same for all three scenarios. The assumptions are as follows:

1. Baseline Scenario

    a. The number of non-transponder aircraft remains constant until 1990, and then decreases linearly to zero by year 2000.

    b. The number of ATCRBS transponders continues to grow until 1985, and thereafter remains constant at that level.*

*ATCRBS transponders could be further subdivided into Mode C and non-Mode C for this exercise, but TCAS is planned to track both, so the distinction will not be made here.

   c. The number of Mode S transponders (all are assumed to be altitude reporting) starts from zero in 1985 and accounts for all increases in transponder equipage thereafter.

2. Aggressive Scenario

   a. Non-transponders: the same as Baseline

   b. ATCRBS transponders: the same as Baseline until 1990, and then decreases linearly to zero in year 2000.

   c. Mode S transponders: the same as Baseline until 1990, and then replaces all ATCRBS by year 2000, as well as accounting for all growth.

3. Delayed Scenario

   a. Non-transponders: the same as Baseline

   b. ATCRBS transponders: continue to grow until 1990, and thereafter remain constant at that level.

   c. Mode S transponders: starts from zero in 1990 and accounts for all increases in transponder equipage thereafter.

These scenarios are depicted in Figure 9-1 and in Table 9-1 for the forecast IAC of the Los Angeles basin. The total IAC numbers come from Table 8-1 of the preceding section.

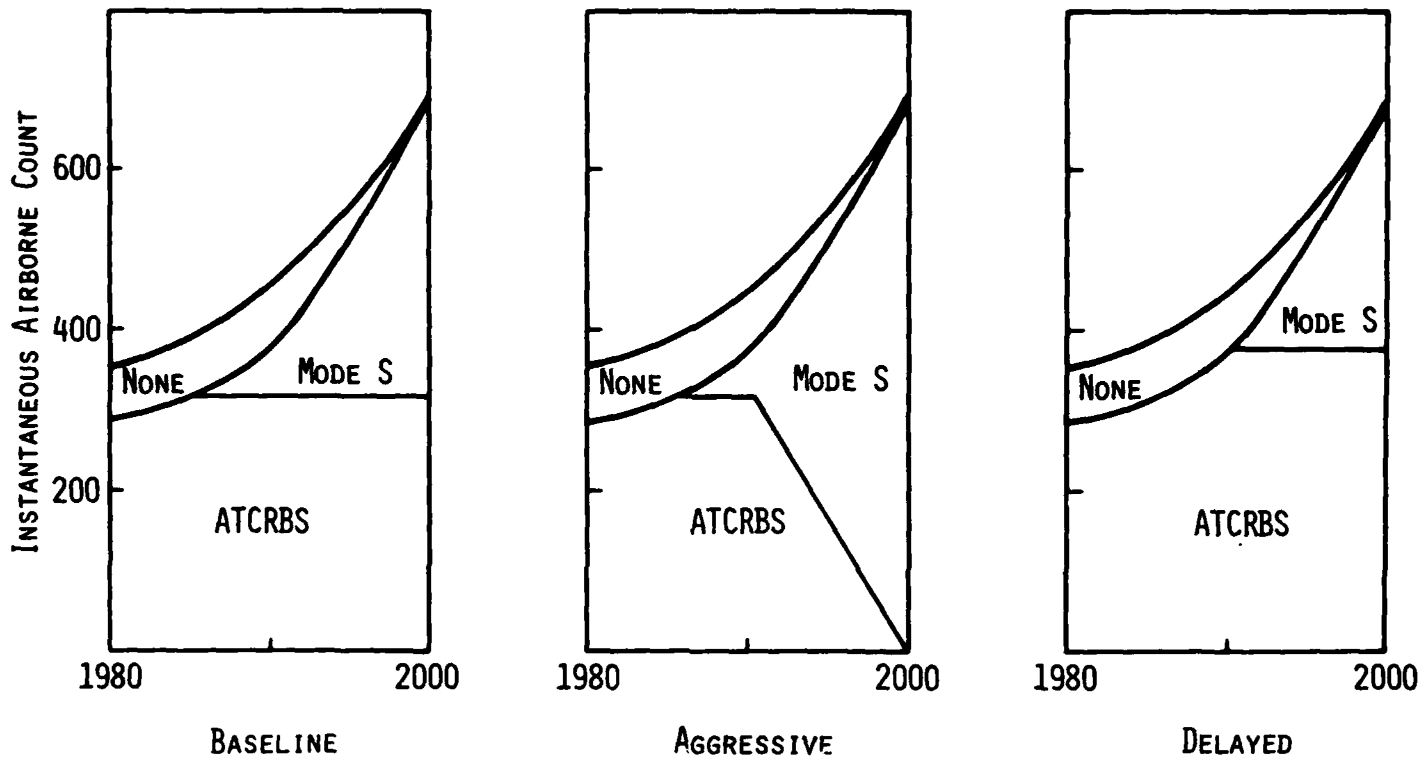

FIGURE 9-1
TRANSPONDER EQUIPAGE SCENARIOS

TABLE 9-1
LOS ANGELES ENVIRONMENT

SCENARIO	YEAR	TOTAL IAC	ATCRBS	MODE S	NO TRANSPONDER
Baseline	1980	358	303	0	55
	1985	388	333	0	55
	1990	452	333	64	55
	1995	558	333	197	28
	2000	687	333	354	0
Aggressive	1980	358	303	0	55
	1985	388	333	0	55
	1990	452	333	64	55
	1995	558	167	363	28
	2000	687	0	687	0
Delayed	1980	358	303	0	55
	1985	388	333	0	55
	1990	452	397	0	55
	1995	558	397	133	28
	2000	687	397	290	0

Having the total IAC, the equipage breakdown, and the distribution of aircraft with distance, we are finally able to obtain the results that are most meaningful for the TCAS design. These are presented in Tables 9-2, 9-3, 9-4.

The densities in a 5 nmi radius square cell and a 10 nmi radius square cell are presented for each of the three scenarios, showing the densities of all aircraft -- ATCRBS equipped aircraft, Mode S equipped aircraft, and non-transponder aircraft. These figures describe the airspace. Possibly more interesting values, however, are obtained by converting the handy but not-too-meaningful "density" figures into "number of aircraft". This is done in the last four columns for a circular region about the TCAS aircraft in the most dense location. For example, in the year 2000, a five-mile system in the most dense Los Angeles environment should be able to track at least 35 aircraft; whereas, a 10-mile system should be able to track 75 aircraft. Assuming the Delayed Scenario, the largest number of ATCRBS tracks that should be handled for a 5-mile system is 20, and for a 10-mile system, 43. (See Table 9-4.) It is to be noted that the number of ATCRBS tracks to be handled is independent of the measurement made of non-transponder aircraft since, under the assumptions, these aircraft ultimately equip with Mode S transponders.

TABLE 9-2

TCAS ENVIRONMENT FOR BASELINE SCENARIO

		DENSITY WITHIN SQUARE CELL OF RADIUS X				NUMBER OF AIRCRAFT WITHIN CIRCULAR RADIUS X			
X	Year	Total	ATCRBS Equipped	Mode S Equipped	Not Equipped	Total	ATCRBS Equipped	Mode S Equipped	Not Equipped
5 nmi	1980	.23	.20	0	.03	18	15	0	3
	1985	.25	.22	0	.03	20	17	0	3
	1990	.29	.22	.04	.03	23	17	3	3
	1995	.36	.22	.13	.01	28	17	10	1
	2000	.45	.22	.23	0	35	17	18	0
10 nmi	1980	.12	.10	0	.02	39	33	0	6
	1985	.14	.12	0	.02	42	36	0	6
	1990	.16	.12	.02	.02	49	36	7	6
	1995	.19	.12	.06	.01	61	36	22	3
	2000	.24	.12	.12	0	75	36	39	0

TABLE 9-3

TCAS ENVIRONMENT FOR AGGRESSOVE SCENARIO

		DENSITY WITHIN SQUARE CELL OF RADIUS X				NUMBER OF AIRCRAFT WITHIN CIRCULAR RADIUS X			
X	Year	Total	ATCRBS Equipped	Mode S Equipped	Not Equipped	Total	ATCRBS Equipped	Mode S Equipped	Not Equipped
5 nmi	1980	.23	.20	0	.03	18	15	0	3
	1985	.25	.22	0	.03	20	17	0	3
	1990	.29	.22	.04	.03	23	17	3	3
	1995	.36	.11	.24	.01	28	8	19	1
	2000	.45	0	.45	0	35	0	35	0
10 nmi	1980	.12	.10	0	.02	39	33	0	6
	1985	.14	.12	0	.02	42	36	0	6
	1990	.16	.12	.02	.02	49	36	7	6
	1995	.19	.06	.12	.01	61	18	40	3
	2000	.24	0	.24	0	75	0	75	0

TABLE 9-4

TCAS ENVIRONMENT FOR DELAYED SCENARIO

		DENSITY WITHIN SQUARE CELL OF RADIUS X				NUMBER OF AIRCRAFT WITHIN CIRCULAR RADIUS X			
X	Year	Total	ATCRBS Equipped	Mode S Equipped	Not Equipped	Total	ATCRBS Equipped	Mode S Equipped	Not Equipped
5 nmi	1980	.23	.20	0	.03	18	15	0	3
	1985	.25	.22	0	.03	20	17	0	3
	1990	.29	.26	0	.03	23	20	0	3
	1995	.36	.26	.09	.01	28	20	7	1
	2000	.45	.26	.19	0	35	20	15	0
10 nmi	1980	.12	.10	0	.02	39	33	0	6
	1985	.14	.12	0	.02	42	36	0	6
	1990	.16	.14	0	.02	49	43	0	6
	1995	.19	.14	.04	.01	61	43	15	3
	2000	.24	.14	.10	0	75	43	32	0

10. SUMMARY AND CONCLUSIONS

From a family of four surveillance flights in the Los Angeles basin, it was found that a relatively consistent relation exists between the number of airborne aircraft in the entire basin and the number in the most dense localized area. The highest localized density of transponder equipped aircraft actually measured was 0.18 aircraft per square nautical mile, within a square cell of 5 nmi radius. The density was found to vary approximately inversely with radius. From measurements made with a ground radar, the fraction of non-transponder aircraft was estimated. The total aircraft population in the Los Angeles basin today appears to be approximately 1.18 times the transponder equipped population.

It was also found that, over the range of variation encountered, the peak instantaneous airborne count of aircraft in the Los Angeles basin is directly proportional to the number of daily operations recorded at all towers within the basin. Using this information, together with FAA projections extending to year 2000, the predicted peak density that might be encountered is estimated to be 0.45 aircraft per square nautical mile within a square cell radius of 5 nmi, an extrapolation of about three times the maximum measured density of today. Within a square cell radius of 10 nmi, the predicted value drops down to 0.24 aircraft per square nmi. The location of the highest density region is along the line from Long Beach to Los Angeles to Van Nuys, where the traffic from these three highly active airports is concentrated.

With various assumptions made for aircraft transponder equipage, the maximum number of ATCRBS equipped aircraft that a TCAS would encounter is less than 43 within a 10 nmi circle, and less than 20 within a 5 nmi circle.

These values of peak density and numbers of aircraft represent an upper bound estimate for three reasons. First, evidence of aircraft saturation was not observed, so no account was made of it in the model. It may be expected that with increased operations, congestion of the airspace will ultimately place a limit on the maximum density. The second factor is that the growth in operations was modelled as occurring uniformly over all classes of the present mix of aircraft. If the mix of aircraft changes more to uncontrolled general aviation, for instance, they may increase the population of the outlying regions of airspace more than the dense regions. Third, all new aircraft in the model are assumed to have transponders. If this is not so, the density of transponder equipped aircraft will be less than predicted here.

APPENDIX A

SAMPLES OF OPERATIONS DATA USED IN THE ANALYSIS

The following tables present samples of data collected from towers in the Los Angeles basin. The list of towers is given in Table A-1. A sample of the daily operations summary data is shown in Table A-2. Table A-3 shows a special logging of hourly operations conducted at each of the towers. Table A-4 is a copy of the standard data log of Los Angeles tower (this is the only hourly data routinely collected in the area).

TABLE A-1

LIST OF TOWERS IN THE LOS ANGELES BASIN

Burbank
Chino
El Monte
Fullerton
Hawthorne
Long Beach
Los Angeles
Ontario
Palm Dale
La Vern
Brackett
Riverside
Santa Monica
Santa Anna
Orange City
Torrence
Van Nuys

TABLE A-2
DAILY OPERATIONS FOR LONG BEACH TOWER

FEDERAL AVIATION ADMINISTRATION
PREPARED BY APO-130 -- P302
DAILY OPERATIONS BY TOWERS
FOR SELECTED DATES

9:29 THURSDAY, MAY 13, 1982 49

LOCID	YEAR	MONTH	DAY	AIR CARRIERS OPERATIONS	AIR CARRIER PERCENT	AIR TAXIS OPERATIONS	AIR TAXI PERCENT	GENERAL AVIATION OPERATIONS	GENERAL AVIATION PERCENT	MILITARY OPERATIONS	MILITARY PERCENT	TOTAL OPERATIONS
LGB	82	01	25	13	1	3	0	1655	99	4	0	1675
LGB	82	01	26	11	1	9	1	1699	98	7	0	1726
LGB	82	01	27	11	1	11	1	1833	99	2	0	1857
LGB	82	01	28	10	1	11	1	1235	98	0	0	1256
LGB	82	01	29	10	1	16	1	1490	98	0	0	1516
LGB	82	01	30	15	1	6	0	1497	98	6	0	1524
LGB	82	01	31	11	1	5	0	1580	99	0	0	1596
LGB	82	02	01	9	1	6	0	1616	98	16	1	1647
LGB	82	02	02	8	0	12	1	1643	99	0	0	1663
LGB	82	02	03	13	1	10	1	1789	98	6	0	1818
LGB	82	02	04	13	1	9	1	1676	98	4	0	1702
LGB	82	02	05	11	1	17	1	1616	98	0	0	1644
LGB	82	02	06	10	1	7	1	1349	98	15	1	1381
LGB	82	02	07	14	1	9	1	1606	99	0	0	1629
LGB	82	02	08	11	1	5	0	1422	98	6	0	1444
LGB	82	02	09	7	0	11	1	1403	98	16	1	1437
LGB	82	02	10	7	3	8	4	211	93	0	0	226
LGB	82	02	11	12	1	5	0	1535	98	8	1	1560
LGB	82	02	12	11	1	17	1	1669	98	1	0	1698
LGB	82	02	13	13	1	14	1	1417	98	0	0	1444
LGB	82	02	14	6	1	9	1	635	98	0	0	650
LGB	82	02	15	9	1	29	2	1148	96	15	1	1201
LGB	82	02	16	7	1	19	3	693	96	0	0	719
LGB	82	02	17	7	0	16	1	1654	98	12	1	1689
LGB	82	02	18	10	1	21	1	1946	98	5	0	1982
LGB	82	02	19	8	0	15	1	1797	98	12	1	1832
LGB	82	02	20	14	1	11	1	1574	98	3	0	1602
LGB	82	02	21	9	1	10	1	1477	99	0	0	1496
LGB	82	02	22	10	1	16	1	1087	97	2	0	1115
LGB	82	02	23	6	0	23	1	1701	98	0	0	1730
LGB	82	02	24	7	0	17	1	1642	98	2	0	1668
LGB	82	02	25	7	0	17	1	1743	98	6	0	1773
LGB	82	02	26	8	0	13	1	1606	99	3	0	1630
LGB	82	02	27	14	1	20	1	1803	98	0	0	1837
LGB	82	02	28	6	1	12	1	903	98	0	0	921
LOCID TOTAL				2723	1	4171	1	519712	98	1305	0	527911
LOCID AVERAGE				143.3		219.5		27353		68.7		27785

TABLE A-3
HOURLY OPERATIONS FOR LONG BEACH TOWER

FEDERAL AVIATION ADMINISTRATION — WESTERN REGION

HOURLY TRAFFIC COUNT

FACILITY: Long Beach Tower — DATE: 6/2/82

HOUR	ITINERANT					LOCAL			GRAND	
LOCAL TIME	AIR CARRIER	AIR TAXI	CIVIL	MIL	TOTAL	CIVIL	MIL	TOTAL	TOTAL	ALTIMETER
0000-0100										
0100-0200										
0200-0300										
0300-0400										
0400-0500										
0500-0600										
0600-0700										
0700-0800										
0800-0900										
0900-1000										
1000-1100	1	2	35	2	40	64	0	104	291	29.96
1100-1200	0	3	33	0	36	131	0	167	458	29.97
1200-1300	0	0	41	3	44	41	0	85	543	29.97
1300-1400	0	1	43	0	44	25	0	69	612	29.95
1400-1500	0	1	69	0	70	54	0	54	736	29.94
1500-1600										
1600-1700										
1700-1800										
1800-1900										
1900-2000										
2000-2100										
2100-2200										
2200-2300										
2300-0000										

WE Form 7210-14(8-71) (Replaces WE 7210-9 & WE 7232-2)

TABLE A-4
HOURLY OPERATIONS FOR LOS ANGELES TOWER
(Performance Measurement System)

FACILITY: LAX TWR — PMS SUMMARY — DATE: 6-2-82

(1) TIME LOCAL	(1) TIME GMT	(2) PI %	(3) EPS	(4) TOTAL ACTUAL	(4) VFR	(5) MODIFIED DEMAND	(6) ACTUAL ARR	(6) ACTUAL DEP	(7) OAG SCHED AC/AT ARR	(7) OAG SCHED AC/AT DEP	(8) ACTUAL GA/MIL ARR	(8) ACTUAL GA/MIL DEP	(9) RUNWAY CONFIGURATION ARR	(9) RUNWAY CONFIGURATION DEP	(10) DELAYS ARR MINS	(10) DELAYS ARR FAC	(10) DELAYS DEP MINS	(10) DELAYS DEP FAC	(11) FACTORS RELATED TO PERFORMANCE, CAUSE FOR DELAYS	(12) INITIALS
0700	1400		104	78	✓	97	36	42	43	42	6	6	25	24L			–	–	Low Demand	SM
0800	1500	96	"	100	✓	108	44	56	25	62	13	8	"	"			–	–	Low Demand	RM
0900	1600	85	"	88	✓	89	32	56	39	39	5	6	"	"			21	9	30 EDCT JFK 2, NATL FLOW 5, LOCAL FLOW 2	RM
1000	1700	86	"	90	✓	103	52	38	39	44	13	7	"	"			–	–	Low Demand	SM
1100	1800	81	"	84	✓	81	44	40	38	34	6	3	"	"			16	1	16 1 NATL FLOW	RM
1200	1900		"	90	✓	77	48	42	29	35	6	7	"	"			–	–	Low Demand	RM
1300	2000	87	"	90	✓	102	43	47	41	49	7	5	"	"			25	1	25 1 EDCT JFK	RM
1400	2100	88	"	92	✓	76	44	48	31	35	4	6	"	"			26	8	45 6 LOCAL FLOW 2 NATL FLOW	LM
1500	2200	79	"	82		76	38	44	28	30	8	10	"	"			15	2	15 1 LOCAL & 1 NAT	GS
1600	2300			88		75	50	38	31	26	11	7	"	"			–	–	Low Demand	GS
1700	0000			87		83	42	45	33	28	7	15	"	"			–	–	Low Demand	LL
1800	0100			84		92	51	33	42	42	6	2	"	"			–	–	Low Demand	JR
1900	0200			88		87	49	39	43	36	4	4	"	"			–	–	Low Demand	JR
2000	0300			69		62	37	32	36	23	2	1	"	"			–	–	Low Demand	JR
2100	0400			65			39	26	–	–	–	–	–	–			–	–	Low Demand	MK
2200	0500																			

Number of Measurement Hours 3

Totals for Measurement Hours 280 ACTUAL – 312 EPS = 89.7 DAILY P.I.

21 A/C
20 AVG LONGEST 45
JFK 3 NATL FLO 9 LOC [illegible]

TABLE A-4
(Concluded)

(13)		(14)	
TIME		IFR OR VFR	WEATHER
LOCAL	GMT		HOURLY SEQUENCE
0700			
0800			
0900	16Z	V	15SCT M23OVC10 1906
1000			
1100	18Z	V	17SCT E25BKN 10 3206
1200			
1300	20Z	V	20SCT F28 BKN 10 3111
1400	21	V	CLR 10 2710
1500	22	V	CLR 15 2214
1600			
1700			
1800			
1900			
2000			
2100			
2200			

ADDITIONAL REMARKS

TYPES OF CAUSAL FACTORS AFFECTING PERFORMANCE AND/OR DELAYS

FACTOR	SPECIFY
WEATHER	Below minimums, surface winds (tail/cross) fluctuating visby, rwy clsd (snow, ice, plowing, sanding) thunderstorms.
CONSTRUCTION	Maintenance or construction causing limitation to runway in use. Taxi-way construction.
NOISE	Abatement procedures imposed, causing runway change
AIRPORT SATURATION	Gates/penalty boxes saturated depts spacing.
EQUIPMENT OUTAGES	FAA equipment out of service (shed or failure). Partial outage under particular wx conditions may restrict.
AIRCRAFT DISRUPTION	User equip problem, lost comm, blown tire, lost acft. blocked rwy/taxiway.
EMERGENCY	Disruption due to emergency procedures giving priority to acft in distress, etc.
VOLUME	When demand rate is in excess of capacity and no other cause applies.
UNKNOWN	Generally used when no cause factor known. Research requires follow-up action.
OTHER	Specify

NOTE: Report "low demand" when actual operations are less than 95% of EPS with no reportable delays during measurement hours.

QUICK REFERENCE

COLUMN 1..TIME, local and Greenwich Mean time (GMT)

COLUMN 2..Performance Index (PI) a percentage determined by dividing the actual operations by the Engineered Performance Standard (EPS) which coincides with the runway configuration (PI = Column 4 divided by Column 3)

COLUMN 3..EPS, Expected runway capacity (departures and arrivals)

COLUMN 4..TOTAL ACTUALS, the number of arrivals and departures including VFR. Also indicate in parentheses the number of VFR aircraft handled during that hour.

COLUMN 5..MODIFIED DEMAND..Official Airline Guide (OAG) Schedule of Air Taxi/Air Carrier (Column 7 AT/AC) plus the Actual General Aviation/Military (Column 8 GA/MIL).

COLUMN 6..ACTUALS, the actual traffic handled, arrivals and departures tabulated separately.

COLUMN 7..OAG SCHEDL, Scheduled Air Carrier & Air Taxi operations extracted from Official Airline Guide & provided by ATCSCC.

COLUMN 8..ACTUAL GA/MIL, the General Aviation & Military operations handled and tabulated separately.

COLUMN 9..Runway Configuration, all runways in use (Arrivals/Departures)

COLUMN 10..DELAYS, reportable arrival & departure delays (separately tabulated) average number of delay minutes, & number of aircraft delayed.

COLUMN 11..FACTORS related to performance & causes for delays. Remarks pertinent to delays or performance. Show cause when PI% is under 95. (See types of causal factors).

COLUMN 12..INITIALS of the employee inserting data.

COLUMN 13..TIME, Local and GMT.

COLUMN 14.. WEATHER, hourly sequence, specify IFR or VFR preceding the report. Significant special weather reports affecting the operation should be reflected in additional remarks.

APPENDIX B

REFERENCES

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