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J. Y. Lu, J. R. Gebman, T. F. Kirkwood,
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PREFACE

This report is the first of a four-volume study analyzing the socioeconomic and environmental effects of an intraurban air transportation system for the San Francisco Bay Area. The study was sponsored by the National Aeronautics and Space Administration, Advanced Concepts and Missions Division, under contract NAS2-6480.

The Rand work is based on an earlier study for NASA by the Boeing Company, which determined the hardware and economic requirements for a vertical/short takeoff and landing aircraft (V/STOL) commuter-transport system to serve the nine-county San Francisco Bay Area in 1975-1985 and 1985-1995.[1] Rand's charter was to investigate the indirect benefits and disadvantages of such a system on the community it would serve.

This volume presents the major findings and an overview of the study. The other reports in the series discuss in detail the specific effects of the V/STOL system envisaged by the Boeing study: distribution of primary costs and benefits, impact on road congestion, and long-run effects on residence and commuting. Together, the four volumes provide a comprehensive view, for transportation planners and policymakers, of the likely consequences of the installation of a V/STOL commuter system. Specifically, they should aid NASA's R&D policy decisions about aircraft with the ultra-short-range mission.

The complete series includes the following reports:

1. R-1074-NASA, *External Impacts of an Intraurban Air Transportation System in the San Francisco Bay Area—Summary Report,* by J. Y. Lu, J. R. Gebman, T. F. Kirkwood, P. T. McClure, and J. P. Stucker.
2. R-1075-NASA, *Effects of a V/STOL Commuter Transportation System on Road Congestion in the San Francisco Bay Area,* by T. F. Kirkwood.
3. R-1076-NASA, *Distribution of Primary Benefits and Costs of Intraurban Air Transportation in the San Francisco Bay Area,* by J. P. Stucker.

[1] The Boeing Company, *Study of Aircraft in Intraurban Transportation Systems: San Francisco Bay Area,* Seattle, Washington, September 1971.

4. R-1077-NASA, *Long-Run Effects of an Intraurban Air Transportation System on Residential Location and Commuting in the San Francisco Bay Area,* by J. P. Stucker.

SUMMARY AND CONCLUSIONS

This study attempts to identify and estimate the effects of an intraurban V/STOL commuter system on the economic, social, and physical environment of the community it would serve, here, the San Francisco Bay Area. The Bay Area was chosen mainly for a case study; the real intent of the analysis is to develop methods by which the effects of such a system could be evaluated for any community.

The quantitative estimates per se should be viewed as suggestive rather than definitive. After all, we are dealing with the second- and third-order effects of a hypothetical transportation system designed to play a completely new role in air transportation, i.e., to serve as a means of mass transit in a metropolitan area. Furthermore, as indirect effects have rarely been quantified in transportation studies, the data base is hardly adequate.

Implementing an intraurban transport system in a region would touch many aspects of community life. Some of the effects would be realized as installation began or shortly thereafter; others would be felt over a longer period of time and probably would have a more permanent imprint. Some effects are readily quantifiable; others are not, and quantitative estimates may be tenuous at best. This study concentrates on near-term effects that can be meaningfully quantified. But it also examines an important long-run effect that any new transportation alternative would have on a region, the effect on patterns of residential location and regional growth. Tentative conclusions from our analysis of these effects follow.

NEAR-TERM EFFECTS

Income and Employment. The installation of an air transport system of the scale envisioned in the Boeing study would be a sizable development project and might benefit the Bay Area economy. Unlike most ground transportation systems, the air system would probably take a relatively short time to install, say, three years. During that period, several thousand jobs would be created in the Bay Area, and Bay Area payrolls would increase by an amount almost equal to the total expenditures for installation. However, the effect of these employment and income increments on the entire Bay Area economy would be relatively minor. Whether the income and employment effects would benefit or disrupt the local economy would depend on overall economic conditions at the time of installation. In a time of full employment, the installation expenditures would be slightly inflationary; in a time of underemployment, they would be mildly stimulating.

Primary Benefits and Costs. Since the development of the intraurban air system would probably have to be undertaken as a public investment, and since a subsidy might be required to sustain its operation, the question of equity may arise. The system, as currently envisioned, would directly benefit mainly middle- and upper-income travelers. Consequently, any of the usual forms of subsidy would probably involve a slight upward redistribution of income. That conclusion is quite tentative, however, and is sensitive to a number of underlying assumptions. If the cost of air travel is reduced, if automotive costs increase, if commuting trips become longer—air travel may appeal to the lower-income traveler. Any of those changes would also increase the patronage of the system, perhaps enough to reduce or eliminate the need for a subsidy.

Noise. Our analysis indicates that the noise generated by intraurban air operations would be troublesome only at certain terminals. At the smallest and largest terminals the effects would be minimal. Small terminals located in rural areas and having few operations would generate little noise. The downtown V/STOL terminals with heavy traffic would generate much noise, but because the level of background noise would be quite high, the incremental noise attributable to intraurban air operations would have little effect on the commercial activities in the vicinity. And at the major air terminals, with much conventional-takeoff-and-landing aircraft (CTOL) traffic, the additional noise generated by even a high number of intraurban operations would be insignificant compared with present noise levels.

Several of the intermediate-sized V/STOL terminals might experience severe noise problems, however. They would be at the heart of the system, located in the larger, more heavily populated residential suburbs generating over half the passenger traffic. With those terminals being so heavily used yet necessarily situated in residential suburbs, the noise from the frequent flights would affect many nearby households. That problem warrants further study.

Air Pollution. V/STOL aircraft are expected to produce fewer emissions per passenger mile than cars. Thus, air pollution by the aircraft in flight would probably be minimal. However, our preliminary analysis, which calculated the pounds of pollutants emitted, indicated that there might be an air-pollution problem in the terminal areas and in the immediate vicinities of several of the heavily used downtown terminals. That is only a possibility; the likelihood of a problem cannot be ascertained until emission characteristics are related to the ambient air quality (expressed as parts per million of an emitted air pollutant in the atmosphere) and compared with federal (EPA) standards.

Road Congestion. The number of motorists who would be removed from the road by the operation of a V/STOL system is a small fraction of the entire Bay Area auto traffic. Nevertheless, because commuter traffic is highly concentrated in the morning and evening rush hours and funnels through a few freeways, an intraurban

V/STOL system would substantially reduce the amount of future highway expansion required. The cost saving resulting from this reduction could be sizable and is an important advantage for V/STOL.

LONG-RUN EFFECTS

A transportation improvement may, over time, alter residential and commuting patterns. We attempted to determine whether the introduction of the proposed intraurban air transport system might induce commuters employed in the city of San Francisco to change their residences, and if so, whether the effect would be substantial enough to influence the utility or the design of the air transport system.

Our findings indicate that the introduction of the intraurban air system to the Bay Area would affect the residential and commuting behavior of many commuters. Workers employed in the city of San Francisco who commute 30 miles or more would find it to their benefit, in total commuting costs (cost of transportation plus cost of time spent commuting), to switch to air transport if an air terminal were located close to their homes. Furthermore, many of those commuters would be willing to move short distances to be closer to an air terminal. Those effects would be more pronounced in the larger and more affluent households. Naturally, the more the air fares were reduced, the stronger the effects would be.

The major effect of the introduction of air transport service, however, would undoubtedly be in shaping the future growth of the region. Air terminals established in the distant suburbs that provided acceptable service could be expected to attract significant numbers of new families to reside in the surrounding area.

The Bay Area Transportation Study Commission estimated that employment in the city of San Francisco will increase by about 50 percent in the next 25 years [1]. As the region grows and is more densely developed, the percentage, as well as the actual number, of workers commuting 30 or 40 miles would probably increase. If so, and if the air terminals could attract new residents to outlying areas, as expected, then a small number of fairly remotely situated air terminals installed in the next several years could be expected to serve a large number of travelers by 1990.

IMPLICATIONS FOR FUTURE RESEARCH

The foregoing results provide a fairly comprehensive overview of the likely social, economic, and environmental effects of a V/STOL commuter system. Combined with the results of the Boeing and Lockheed studies [2,3], which explored the configurations and basic feasibility of such a V/STOL system, our results suggest the overall shape and implications of intraurban air transport. They also illuminate topics that need further investigation.

Specialized Research. Four special problems deserve further research. First, our results indicate that emissions from aircraft may constitute a severe air-pollution problem around the terminals with very heavy air traffic. Research should be conducted to relate the emissions of the proposed V/STOL aircraft to ambient air quality, and the results compared with present and prospective EPA standards. Only then can the potential severity of the problem be determined and its implications assessed for aircraft design, terminal location, operating procedures for aircraft on the ground, and, perhaps, the scheduling of air operations.

Second, the problem of noise pollution around heavily used suburban air terminals should be addressed by detailed scrutiny of the proposed terminal sites and consideration of the possibility of controlling land use in the adjacent territory.

Third, our tentative study of the safety of a V/STOL system compared with that of the auto system was inconclusive. There is too much uncertainty in projecting future accident rates for both systems. The topic of safety should be addressed again when better data are available.

Fourth, our analysis indicates that the introduction of air transport would significantly affect the choice of residence and the commuting patterns of many commuters. We were unable, however, to estimate empirically the full force of those effects. Further research is necessary to quantify those tendencies more accurately and thoroughly.

Comprehensive Modeling and Evaluation. After the foregoing topics have been studied and the overall effects clarified, the next logical step is the comprehensive planning of terminal locations to maximize their convenience to, and minimize their detrimental effects on, the communities they would serve.

The final study, taking account of all prior results, would be the detailed redesign of a V/STOL commuter system to serve the nine-county San Francisco Bay Area. Our preliminary results have indicated that air transport could compete well with surface transport for commuting trips of 30 to 40 miles. The preliminary evidence also suggests that if air transport were made available to a few residential suburbs of that distance from San Francisco, it would substantially affect their growth patterns. The promise of fast, congestion-free travel could attract large numbers of commuters to the "air-convenient" suburbs, and the patronage of the air system could increase substantially each year.

If the terminal-location study corroborates these tentative conclusions, it would be worthwhile to assess the economic feasibility of a smaller version of the air-transport system studied here—one serving a small number of residential suburbs on the fringes of the Bay Area. The design and economics of a smaller-scale system might differ substantially from the design and economics of the larger-scale system studied here. Our guess is that the former would be more economically viable than the latter.

ACKNOWLEDGMENTS

The authors wish to express their appreciation to a number of organizations and individuals who have contributed to this study. George Kenyon of the Advanced Concepts and Missions Division, NASA, has been continuously helpful. The Metropolitan Transportation Commission (MTC), Berkeley, California, and Noreen Roberts and W. Patrick Hackett of the District IV Office of the California State Highways Division supplied us with comprehensive travel data based on interviews of 36,000 households in the nine-county San Francisco Bay Area. Those data enabled analysis at a much finer level of detail than would otherwise have been possible. Within The Rand Corporation, we want to thank Burke Burright, Joseph De Salvo (now with the University of Wisconsin), Gene Fisher, and Giles Smith. Their suggestions and critical comments have improved the work.

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I. INTRODUCTION

ORIGIN AND APPROACH OF THE STUDY

This report summarizes the results of a study to identify and estimate the effects of a proposed intraurban air transportation system on the economic, social, and physical environment of the community it would serve. Those effects are called spillover effects or *external*[2] impacts because they would be felt not only by the operators and passengers of the system but also by the community as a whole. This impact analysis is part of a larger study sponsored by NASA's Advanced Concepts and Missions Division to explore the potential of air transportation systems to serve commuters in large urban areas. Traditionally, attempts to solve the transportation ills of our metropolitan areas have been based on improving or expanding the established surface systems of commuter service, such as the automobile, train, subway, and their more advanced derivatives. Those systems have served growing urban areas well in the past, but they require expensive facilities and heavy usage of land. As more people migrate into urban areas and public concern about environmental protection rises, the expansion of freeway networks and even of rail networks becomes less and less attractive to the public. Under such circumstances, it would appear that air transport, which has the advantages over surface systems of flexible routing, rapid network expandability, and minimal disruption of land use, could help solve urban transportation problems.

In 1971, the Boeing Company, in response to a request from NASA, undertook a design and feasibility study of an ultra-short-range, commuter-oriented V/STOL system for the nine-county San Francisco Bay Area in 1975-1985 and 1985-1995. It focused on the hardware and hard economics—total costs and revenues—of such a system. The Boeing study concluded that an intraurban air system is a technically feasible alternative to ground transportation systems, but that its economic viability may be in doubt.

The present study can be regarded as a follow-on to the Boeing study. Boeing found that its "best system" could serve a large number of people but would probably

[2] The term "externalities" refers to certain broader costs (or benefits) of an action that are not taken into account in the decision to take the action.

require a subsidy. It is the intent of the present study to determine, in addition to the obvious benefits to the passengers, what other benefits and disadvantages the system would bring to the entire community.

OBJECTIVES

The Rand study has three specific objectives. The first and the most important is to develop a methodology for assessing the external impacts of intraurban air transport on a region. The methodology should be useful for identifying the broader implications of a new technology. The second objective is to apply that methodology to the Boeing-designed V/STOL commuter system for the San Francisco Bay Area, in effect to perform a case study. Finally, we want to identify problems needing additional research to shed light on the potential contributions of air transport to short-range travel.

The installation of a new commuter-oriented air transport system in a region would touch many aspects of community life. Some of the effects would be realized as installation began or shortly thereafter; others would be felt gradually and probably would have a more permanent imprint. Some effects are readily quantifiable; others are not, and quantitative estimates may be tenuous at best. Attempting to arrive at meaningful quantitative estimates, we first examined the near-term economic, social, and environmental impacts.

Economic Impact

The installation of a V/STOL commuter system would have a significant short-range effect on regional employment and income. We estimated net changes in employment and wages over the expected three years it would take to install the system.

Social Impact

Boeing's finding that intraurban air transport would require some form of subsidy to sustain its operations raised two questions for this study: Who will be the direct recipients of the system's benefits? and, Who will be burdened with the cost of subsidizing the system? To answer them, we examined the income profiles of potential passengers and of the taxpayers who are most likely to be asked to subsidize the system.

Environmental Impact

We were concerned about potential noise annoyance and air pollution in the neighborhoods of the proposed air terminals. Noise contours around the potentially troublesome terminals were calculated, and the characteristics of the households within the contours were examined. As for air pollution, the emission fluxes of several different pollutants at two major terminals were computed. We also examined the impact of a V/STOL commuter system on street and highway congestion and on parking availability in downtown San Francisco.

As for the long-term effects of an intraurban V/STOL system, we considered its influence on the residential locations and, hence, the commuting patterns of the community. How a household would react to a change in the cost of commuting has a bearing on the design of an air transport system. To gauge that reaction, we estimated the elasticity of travel distance with respect to travel cost, i.e., the percentage change in commuting distance brought about by a one-percent change in travel cost.

Sections II through VII describe in greater detail our work and findings with regard to those external effects. (The material in each section is further elaborated in the separate volumes of this series, as noted in the Preface.) First, however, it is useful to look at the main features of Boeing's V/STOL commuter system on which Rand's study is based.

AN INTRAURBAN AIR TRANSPORT SYSTEM FOR SAN FRANCISCO

Boeing postulated a commuter-oriented air transport system for the nine-county San Francisco Bay Area and analyzed its technical, operational, and economic characteristics. The system was considered for two time periods. Configurations for the near-term period, 1975-1985, use technology now in the design stage. Those for the long-term period, 1985-1995, assume a level of technology that could be incorporated in aircraft starting service in 1985.

Five aircraft were posited. Two are STOL aircraft: a short-field conventional STOL utilizing a fairly simple flap system, a low wing loading, and a relatively high power loading to achieve 2000-ft field performance; and an augmentor-wing aircraft that uses powered lift to achieve the same field length. The VTOL concepts include a helicopter, a tilt-rotor, and an ejector-wing aircraft. All configurations were developed in three nominal capacities: 50, 100, and 150 passengers.

Originally, 30 terminals were postulated, one for each so-called superdistrict in the Bay Area, but later some were eliminated for expected lack of passenger demand. Eventually 24 terminals were settled on for the STOL configurations, at a total estimated construction cost of $609 million, and 26 were set for the VTOL system, at a total cost of $255 million. The final proposed STOL port sites are depicted in Fig. 1.

It is expected that air-traffic control systems capable of managing as many as 82 operations per hour at one port with acceptable safety and reliability will be operational by 1975-1985.

To estimate passenger demand for the V/STOL system, Boeing applied a simple modal-split model to traffic survey data obtained from the Bay Area Transportation

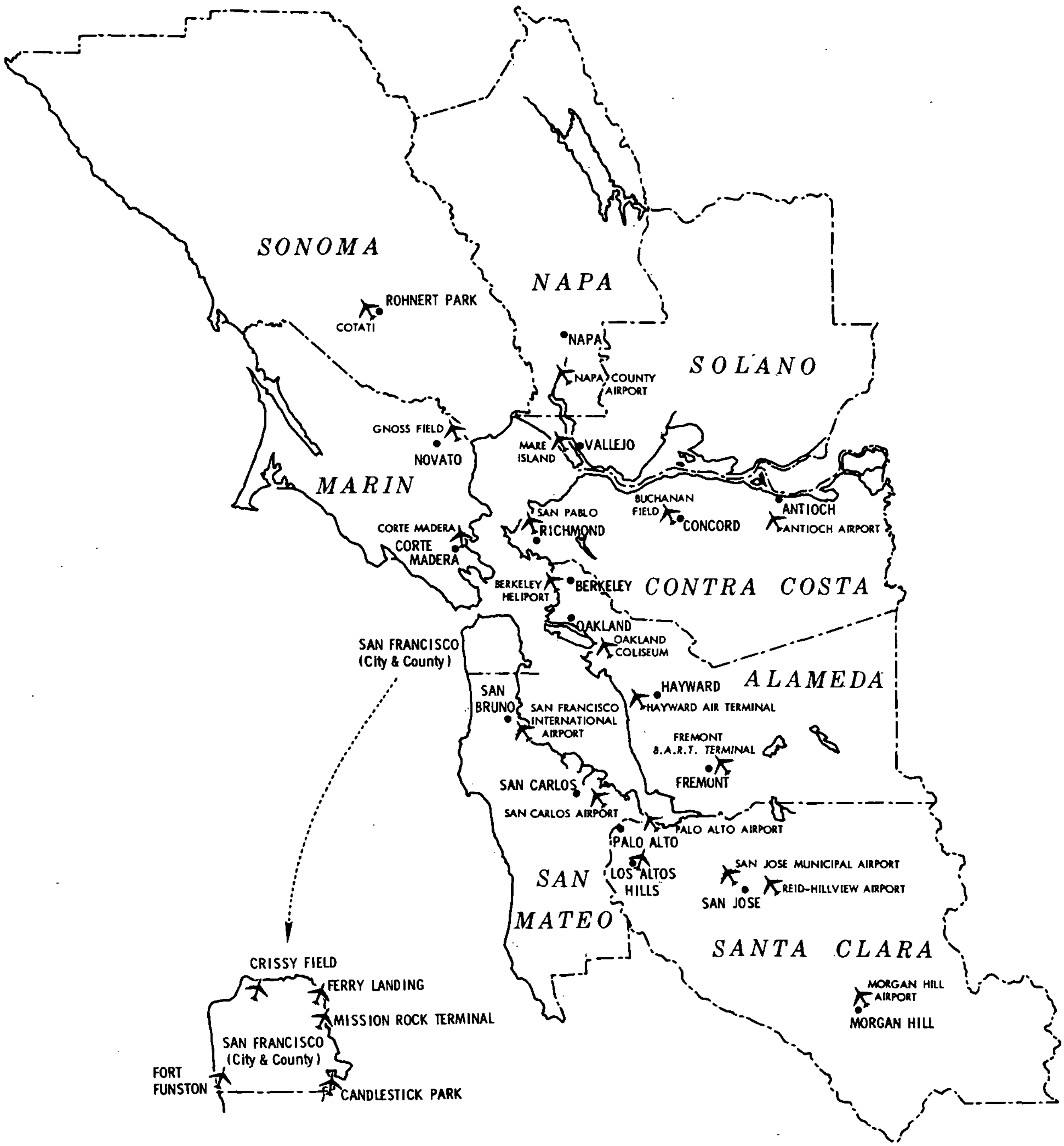


Fig. 1—Proposed network of STOL ports

Table 1

FOUR CONFIGURATIONS OF AN INTRAURBAN AIR TRANSPORT SYSTEM
FOR THE SAN FRANCISCO BAY AREA

Aircraft	Characteristics					Financial Loss	
	Daily Person-Trips (000's)	Termi-nals	Gates	Fleet Size	Initial Invest-ment[a]	Annual[a]	Per Person-Trip ($)
1980 Operations							
50-seat helicopter	52.5	26	49	77	392	40	2.45
49-seat augmentor-wing STOL	48.6	24	48	75	728	62	4.05
1990 Operations							
50-seat tilt-rotor VTOL	108.2	26	76	133	554	13	0.40
49-seat augmentor-wing STOL	79.7	26	64	113	985	64	2.55

[a] In 1970 $ million.

Study Commission (BATSC). Boeing postulated that for each trip a passenger would have to pay a fare of at least $3.50, or $1.75 plus $.064 per mile.

Those figures, combined with the detailed cost and performance data for each of the aircraft configurations, provided the basis of Boeing's economic analysis. Table 1 shows the characteristics of the four most "profitable" configurations revealed by that analysis. As can be seen, each incurs an annual loss and would require some subsidy for sustained operation. Our external-impact analyses are based on the characteristics of these four systems.[3]

[3] Though all four configurations were initially taken into account in the analyses of specific impacts, the four were in some cases telescoped to two or one for detailed consideration. In a few cases it was because there was little difference between the configurations for the impact being studied; in another case it was because only the upper bound of the impact needed to be shown. As regards the dating of the V/STOL system, hereinafter we refer to the time periods 1975-1985 and 1985-1995 as "1980" and "1990," respectively, merely for convenience.

II. EFFECTS ON INCOME AND EMPLOYMENT

The installation of any of the four Boeing configurations would be a large-scale development project and would have short-term and long-term effects on employment and income in the Bay Area. This section estimates the short-term employment and income effects and briefly considers the possible economic impacts of the long-term operation of the system.

SHORT-TERM ECONOMIC EFFECTS

The short-term effects are those expected to accrue while the system is being installed. Table 1 showed the initial investment requirements for the four most profitable systems. Those figures are disaggregated by major cost categories—aircraft, land, and facilities—in Table 2.

Since the Bay Area has no major aircraft manufacturer, we are concerned only with the effects of spending on land and facilities. However, we did not consider the entire amount spent on acquiring land to have beneficial effects on income and employment but reserved five percent to represent the demand for services rendered by the finance, insurance, and real-estate sectors.

In the following discussion, all impact estimates are given in 1970 dollars.

Method

Both direct and indirect impacts were studied. Direct impacts include changes in sales, wages, salaries, and employment levels in industries directly engaged in installing the system. Indirect impacts include the cascading effect of re-spending by prime contractors for the system, spending by their employees, and, eventually, expenditures by consumers.

Estimates of the direct impact were obtained by calculating the initial investment expenditures for the configuration under study and the distribution of the expenditures among the industries directly involved. To estimate the indirect impact, we employed an input-output model.

Table 2

INITIAL INVESTMENT FOR V/STOL COMMUTER SYSTEMS
(In 1970 $ million)

Configuration	Aircraft	Land	Facilities	Total
1980 Operations				
50-seat helicopter	137	13	242	392
49-seat augmentor-wing STOL	127	169	432	728
1990 Operations				
50-seat tilt-rotor VTOL	221	36	297	554
49-seat augmentor-wing STOL	192	308	485	985

Input-output analysis is an econometric technique that focuses on the interdependencies among the various industries or sectors of the economy and the relations of the sectors, as sellers, to final consumers. The core of the analysis is an interindustry-transactions table that displays the flow of goods and services by industries of origin and destination. Manipulating that table creates a second table, which is made up of so-called technical coefficients. Entries in the second table represent direct purchases (input) per dollar of output. Further manipulation of the table of technical coefficients creates a third table, composed of direct and indirect requirements. This last table determines direct and indirect requirements for industrial output per dollar of final consumption. Constructing a V/STOL system implies increases in the levels of final consumption for the sectors directly involved. We can use the table of direct and indirect requirements to trace the result of changes in the demand for output from certain sectors through the rest of the Bay Area economy.

We used an input-output model developed by J. S. Bargur et al. [4].[4] In it, the Bay Area economy is represented by 14 sectors. Although the grouping of industries is highly aggregative, the model can provide, as a first approximation, estimates of the direct and indirect impacts of the construction phase.

To estimate impacts, it was necessary to make specific assumptions about events in the manufacturing and construction phase. Some of those assumptions are arbitrary but plausible. It is assumed that three years would be required to plan and

[4] The table of direct and indirect requirements is not reproduced here. If one wishes to experiment with impact projections based on different sets of final demand figures, the table can be found on p. 26 of Ref. 4.

construct the air transport system, as well as to expand the road system. All prime contracts, with the exception of aircraft purchases, are assumed to be placed with firms in the Bay Area. That assumption tends to maximize the regional income and employment impacts.

Results

Direct Impacts. Table 3 shows the estimated direct expenditures for installing the four V/STOL systems. The expenditures for each system are spread over a three-year period, with the greatest expenditures occurring in the last year.

The impact of direct expenditures can be better appreciated if the expenditure in each industrial sector is compared with the total sales volume of the sector in some base period. We chose 1967, the latest year for which manufacturers' census data are available, as the base year. For each industry, we took the expenditure in the peak year of the system's construction (year 1 in Table 3) and computed an index as follows:

$$\text{Index} = \frac{\text{Direct expenditure in peak year} + \text{1967 value of shipment}}{\text{1967 value of shipment}}$$

The results are presented in Table 4.

As Table 4 indicates, the direct expenditures for any one of the V/STOL systems are a relatively small portion of total Bay Area industrial sales, even under the assumption that all prime contracts are placed with firms in the region. Given the small relative impacts and the possibility of placing the contracts outside the Bay Area, there is no reason to expect the installation of the V/STOL systems to strain the capacities of Bay Area industries.

Multiplier Effects. To measure the consequences of a change in the level of final consumption, the multiplier effect is a useful concept. Expenditures for installing a V/STOL system would initially boost the Bay Area economy by increasing the purchase of goods and services from sectors directly engaged in building the system. That increase constitutes the direct impact. In addition, for the directly affected sectors to increase their outputs, they have to purchase more materials and services from other sectors. The level of output for the Bay Area economy would thus rise more than the amount of the original expenditures. That is the output multiplier effect. Table 5 shows that the installation of a V/STOL system would have an output multiplier of about 1.8 for the Bay Area.[5] It should be noted that increased output includes interindustry sales and is not the same as value added.

A more useful way of viewing the results of V/STOL installation expenditures is to examine their effects on income and employment. The income effect includes direct, indirect, and induced effects. The direct effect is the increase in wages and salaries in the industrial sectors directly associated with building the system. The indirect effect is the increase in wages and salaries in all other sectors that supply

[5] The four "candidate" configurations have multiplier effects of about the same size because they all would affect the various industries similarly. The only difference would be in the level of operation.

Table 3

DIRECT EXPENDITURES FOR INSTALLING V/STOL SYSTEMS, BY INDUSTRY AND CONSTRUCTION YEAR

(In 1970 $ million)

	1980 Systems					
	Helicopter			Augmentor-Wing STOL		
Industry	3[a]	2	1	3	2	1
Planning and engineering	16.1	---	---	28.7	---	---
Contract construction	---	72.6	72.6	---	129.6	129.6
Electric equipment	---	12.4	12.5	---	22.2	22.3
Mechanical equipment	---	12.9	13.0	---	22.4	22.5
Fabricated metal	---	7.5	7.6	---	13.5	13.5
Cement, stone, etc.	---	7.7	7.8	---	13.8	13.8
Finance, insurance, and real estate	.7	---	---	8.5	---	---
Total	16.8	113.1	113.5	37.2	201.5	201.7

	1990 Systems					
	Tilt-Rotor VTOL			Augmentor-Wing STOL		
Industry	3[a]	2	1	3	2	1
Planning and engineering	19.8	---	---	32.2	---	---
Contract construction	---	89.1	89.1	---	145.5	145.5
Electric equipment	---	15.3	15.3	---	25.0	25.0
Mechanical equipment	---	15.4	15.5	---	25.2	25.2
Fabricated metal	---	9.3	9.3	---	15.1	15.1
Cement, stone, etc.	---	9.5	9.5	---	15.5	15.5
Finance, insurance, and real estate	1.8	---	---	15.4	---	---
Total	21.6	138.6	138.7	47.6	226.3	226.3

[a]Year from completion of the system.

Table 4

INDEX OF THE IMPACT OF PEAK-YEAR DIRECT V/STOL EXPENDITURES ON BAY AREA INDUSTRIAL SALES

(Base year = 1967)

	1980 Systems		1990 Systems	
Industry	Helicopter	Aug.-Wing STOL	Tilt-Rotor VTOL	Aug.-Wing STOL
All industries	1.018	1.027	1.023	1.032
Contract construction	1.021	1.038	1.026	1.043
Electric equipment	1.012	1.021	1.014	1.023
Mechanical equipment	1.015	1.025	1.018	1.029
Fabricated metal	1.011	1.019	1.013	1.021
Cement, stone, etc.	1.026	1.045	1.031	1.051

Table 5

MULTIPLIER EFFECTS OF PEAK-YEAR V/STOL INSTALLATION EXPENDITURES

V/STOL System	Change in Final Demand ($ million)	Change in Output ($ million)	Multiplier
1975 helicopter	113.5	205.5	1.81
1975 aug.-wing STOL	201.7	364.3	1.81
1985 tilt-rotor VTOL	138.7	251.8	1.82
1985 aug.-wing STOL	226.3	411.2	1.82

the original sectors. The induced effects are those that follow when consumers move up their consumption functions as a result of increases in their income and spend more on goods and services.[6]

To measure the employment effects of a change in final demand, we applied each sector's employment-output ratio to the direct and indirect changes in the sector's level of output. Our projections of income and employment impacts are summarized in Table 6. The employment figures in the table are not cumulative from one year to the next. They represent the net change from a base year during which there was no installation work. In the peak year (year 1), the increase in employment runs from 7,000 to 14,000. The STOL systems would generate more employment than the VTOL systems because the former would require greater investment expenditures. The overall effect of such employment increments on the total Bay Area employed population of nearly two million would be minor. Whether the income and employment impacts would be beneficial or disruptive to the Bay Area economy would depend on other economic circumstances at the time of installation. In a time of full employment, the V/STOL expenditures would be slightly inflationary; in a time of underemployment, they would be mildly stimulating.

LONG-TERM ECONOMIC EFFECTS

Beyond the effects that would be felt immediately as system installation began, we can visualize at least three kinds of long-term economic impacts: intersectoral shifts, geographic shifts, and aggregate growth.

Intersectoral Shifts

The installation of any of the Boeing-designed V/STOL systems would, in principle, affect the allocation of resources within the transportation industry. The V/STOL system would divert some commuter travel from auto to air, thus removing some resources from the economic sectors that serve automobiles. However, the shift is not expected to be significant. Table 7 compares the maximum number of V/STOL passengers estimated by Boeing with projections of auto commuting trips by the Bay Area Transportation Study Commission for the two periods under analysis. Even allowing for a dramatic shift in our auto-oriented society—say, a 25-percent drop in the auto's share of work-oriented travel—we find that the V/STOL systems would replace only about 2.6 to 4.4 percent of the work trips by auto.[7] Therefore, the overall effect of any intersectoral shifts would probably be minor.

[6] The reader will find extensive discussion of the concept of indirect income changes in Refs. 5 and 6.

[7] It was assumed that V/STOL passengers would ride one to an auto if they were to commute by auto.

Table 6

IMPACT OF V/STOL INSTALLATION ON BAY AREA INCOME AND EMPLOYMENT, BY CONSTRUCTION YEAR

	Year from Completion					
	3		2		1	
V/STOL System	Income Increase ($ million)	Employment Increase (thousands)	Income Increase ($ million)	Employment Increase (thousands)	Income Increase ($ million)	Employment Increase (thousands)
1975 helicopter	15.3	1.2	104.5	7.3	104.8	7.3
1975 aug.-wing STOL	35.1	3.2	185.2	12.9	185.1	12.9
1985 tilt-rotor VTOL	19.8	1.7	128.0	8.9	128.1	8.9
1985 aug.-wing STOL	45.8	4.4	209.0	14.5	209.1	14.5

Table 7

ESTIMATED V/STOL PASSENGER DEMAND COMPARED WITH PROJECTED NUMBER OF BAY AREA COMMUTING TRIPS

(In thousands)

Period	Maximum V/STOL Passengers[a]	Commuting Trips		
		Total[b]	By Auto[c]	Auto less 25%
1980	53	3952	3241	2430
1990	108	4761	3904	2928

[a]The Boeing study, pp. 458, 460.

[b]Ref. 1, p. 50.

[c]It is assumed that 82 percent of the work trips are by auto. The projection is based on a 1965 survey reported in Ref. 1.

Geographical Shifts Within the Bay Area

The installation of a new transport system in a given region would affect the region's geographic pattern of economic activity. Transport-dependent industries might relocate to take advantage of the new system. In the present case, however, that effect would not likely be perceptible because the proposed intraurban air systems are geared primarily to passengers.

One interesting possibility is that some light industries might be induced to relocate in suburbs or on the urban fringes, where land is still relatively cheap. The V/STOL system could transport the necessary labor force from the central cities to the new work places. In that way, the V/STOL system could be used more intensively.

Aggregate Growth Within the Bay Area

Theoretically, a new, improved transportation system would increase the production efficiency of Bay Area industries. The Bay Area would become more attractive to business, and new industries might be induced to move in, raising employment and output. To achieve that kind of effect, however, the air system would have to have fares substantially lower than our estimates.

SUMMARY

Our findings about the effects of V/STOL installation on Bay Area income and employment are summarized below.

- Installation of the V/STOL system would be beneficial to the Bay Area economy because it would create more jobs and income.
- Direct V/STOL expenditures would be a small fraction of total Bay Area industrial sales, even assuming that all prime contracts (other than for aircraft manufacture) were placed with Bay Area firms.
- Thus, installing any of the Boeing-designed systems would probably not create serious bottlenecks in Bay Area industries.
- An amount almost equal to initial expenditures would be generated as salaries and wages in the peak construction year.
- Employment in the peak construction year would increase by 7,000 to 14,000, depending on the system installed. That represents about 0.35 to 0.70 percent of total Bay Area employment in 1970.
- The long-term effects—intersectoral shifts, geographic shifts, and aggregate growth—are more difficult to quantify. Our intuitive feeling is that the V/STOL system's significance in that regard would probably be overshadowed by other economic circumstances.

III. DISTRIBUTIONS OF PRIMARY BENEFITS AND COSTS

Transport systems do not serve or affect all people in the same way, especially novel, expensive modes. As noted earlier, the Boeing study found that the four most "profitable" configurations of a V/STOL system would operate at a loss. Thus, the system would have to be developed as a public investment requiring some form of subsidy. That suggests the importance of inquiring about the social significance of implementing an intraurban air system: Which Bay Area residents would be the recipients of the primary benefits of the system, and who would underwrite the subsidy?

To help answer that question, we developed a methodology for characterizing the economic status, in terms of annual income, of the probable passengers of the system and of the people who would most likely be asked to subsidize the system, the taxpayers. The methodology is applicable to any proposed transport system. Here, we have applied it to the passenger profiles produced by the Boeing study. All of our quantitative conclusions rest critically on those profiles.

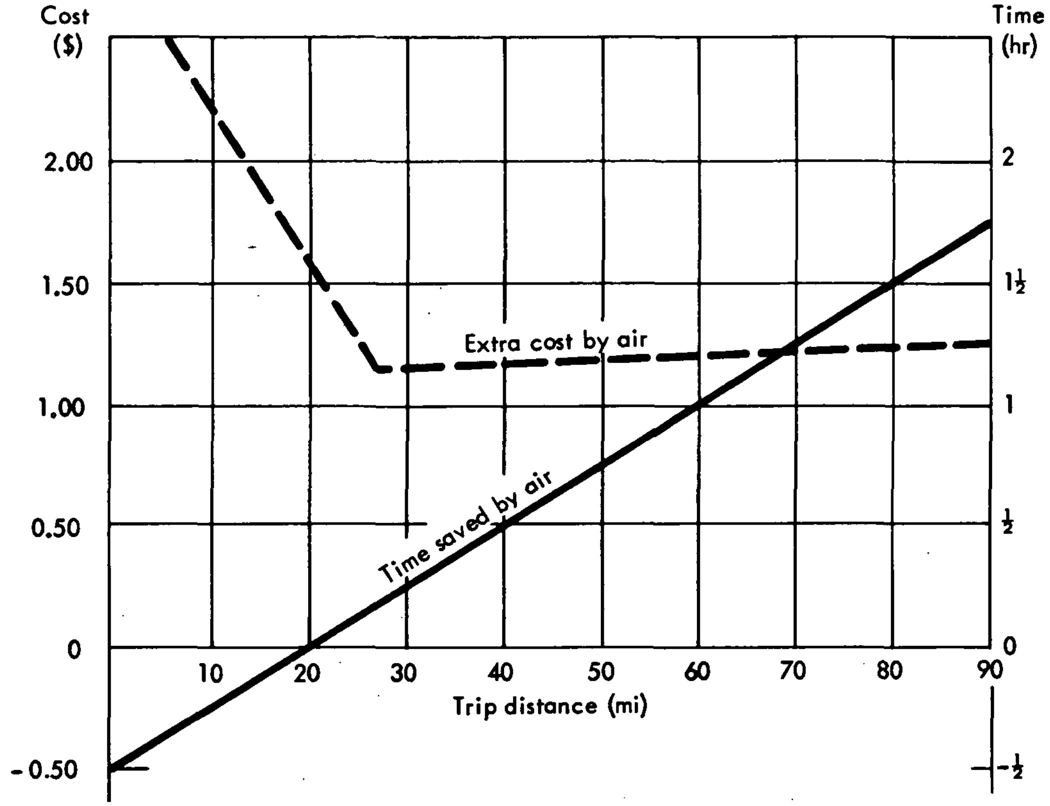
PRIMARY BENEFITS

Income Profiles of Potential V/STOL Passengers

Income profiles for the potential V/STOL passengers are based principally on the Boeing modal-split model. Our main contribution was to work out its *value of time* implications. The modal-split model is basically a simple equation[8] with two inputs: the extra cost required to travel by air instead of by automobile, and the time that air travel saves. Curves illustrating the two components are presented in Fig. 2, which compares 1980 commuting trips by air (augmentor-wing STOL) and by auto, assuming that a bridge is encountered on every auto trip.[9]

[8] The dependent variable in the equation is the percent of person-trips diverted from single-occupancy auto to air.

[9] That assumption makes auto travel slightly more costly.



Source: The Boeing study, modal-split model.

Fig. 2—Extra cost of, and time saved by, a commuting trip by air (1980 STOL) versus one by auto (assumes a bridge encountered every auto trip)

As Fig. 2 suggests, Boeing's travel cost relationships show air travel as substantially more expensive than auto travel for distances up to about 25 mi. Beyond that, the cost difference is fairly constant at about $1.25. The travel time relationships are basically linear. Since the air system, like other public transportation, would need to allow for waiting time, and since the Boeing calculations allow for minimum turnaround times, air travel actually takes longer than travel by private automobile for distances of 20 mi or less. For the longer distances, however, air travel saves appreciable time.

Under such conditions the traveler has two simple options. He can spend more money to travel by air; in return, at least for the longer trips, he gets to his destination quicker. Or, he can drive his car; it is cheaper, but it takes him longer. As the tradeoff is between cost and time, it is informative to combine the extra-cost and time-saved relationships into a single function relating the cost of the time saved by using air transport to trip distance. That is done by dividing the time saved (for each trip distance) by the extra cost of air travel (for that trip distance), which yields the cost of the time saved in normalized units of dollars per hour. The results of that computation for the four V/STOL systems are given in Table 8. The costs are quite similar except for the 1980 VTOL system. It would use helicopters, which are assumed to travel at significantly slower speeds than the other aircraft, saving appreciably less time for roughly equal costs. As expected, the cost of the time saved is quite reasonable for the longer trip distances—$1-$3 per hour. For the shorter distances it is much less reasonable, because shorter air trips cost substantially more than auto trips but save little, if any, time.

Using the cost-of-time-saved function (as in Table 8) and the trip-distance distribution of the travelers who were assumed to switch to air transport (see the cumulative percentage estimates in Table 9), we derive the minimum income distributions of V/STOL passengers. The derivation is based on two assumptions. The first assumption—the revealed-preference hypothesis—is quite straightforward. It is simply that if a traveler spends, say, $1 to save an hour, he must value that hour at least $1. The second assumption is that there is a relation between the value that a traveler places on his travel time and his wage rate. There has been rather substantial empirical study of this topic. The two relationships most widely accepted are that a business traveler values his time at his wage rate, and that a commuter values his time at about 40 percent of his wages. We calculated the income profiles of passengers for both value-of-time relationships, as shown in Table 10.[10] These profiles show that practically all travelers that switch to the air mode for commuting must earn over $25,000 per year; the income profile of business travelers is slightly lower, but still at least three-quarters of them must earn $25,000 per year. This means that if Boeing's estimated fare structure[11] were adopted, the V/STOL system would attract only a select group of travelers.

Sensitivity of Income Profiles to Cost Changes

The income profiles of the users of intraurban air transport are thus quite high. They would be sensitive, however, to a change in the difference between the cost of air travel and auto travel (for example, should auto costs rise or air fares decrease). To determine the sensitivity of the income profiles of V/STOL passengers, we explored the effects of two alternative reductions in 1980 STOL fares, deriving two additional income profiles for the passengers of that system. The lower fares examined are reductions of $1 and of 30 percent off the STOL fare for all distances. The income profiles associated with those reductions are compared with those associated with the base fare in Table 11.

As can be seen from Table 11, either a $1 or a 30-percent reduction in STOL fares profoundly affects passengers' income profiles. For business travel, STOL service would appeal strongly to the low-income travelers, who could possibly account

[10] For a complete discussion of the derivation of income profiles, see Ref. 7.

[11] Base fare (maximum) = $3.50, or $1.75 + $0.064 per mile.

Table 8

COST OF THE TIME SAVED BY USING AIR TRANSPORT

Trip Distance (mi)	Cost of Time Saved ($/hr)			
	1980		1990	
	STOL	VTOL	STOL	VTOL
25	10.91	19.19	10.89	10.40
30	4.70	6.34	4.69	4.61
35	3.12	3.92	3.12	3.09
40	2.34	2.85	2.34	2.33
45	1.88	2.24	1.88	1.87
50	1.57	1.85	1.57	1.57
55	1.36	1.58	1.36	1.36
60	1.19	1.38	1.19	1.19

NOTE: Assumes that a bridge is encountered on every auto trip.

Table 9

ESTIMATED DEMAND FOR INTRAURBAN AIR TRANSPORT PER DAY FOR TWO-WAY PASSENGERS

Trip Distance (mi)	1980			1990		
	Number of Passengers	Percent of Total	Cumulative Percent	Number of Passengers	Percent of Total	Cumulative Percent
			STOL Systems			
Under 15	10,324	17	17	15,445	16	16
16-20	8,713	15	32	13,745	14	30
21-25	15,173	25	57	20,830	22	52
26-30	15,774	26	83	25,594	27	79
31-35	4,775	8	91	9,060	9	88
36-40	3,512	6	97	6,449	7	95
41-45	1,834	3	100	4,957	5	100
Total	60,105	100	---	96,082	100	---
			VTOL Systems			
Under 15	18,562	30	30	30,565	24	24
16-20	10,907	18	48	21,031	16	40
21-25	14,617	23	71	26,189	20	60
26-30	11,327	18	89	26,465	20	80
31-35	3,283	5	94	12,828	10	90
36-40	2,871	5	99	6,948	5	95
41-45	522	1	100	6,210	5	100
Total	62,089	100	---	130,287	100	---

SOURCE: The Boeing study, Tables 11-7 and 11-8.

Table 10

INCOME DISTRIBUTION OF V/STOL PASSENGERS

Minimum Annual Income ($)	Percentage of Total V/STOL Passengers: Commuters (VT* = 0.40w**) 1980	Commuters 1990	Business Travelers (VT = 1.00w) 1980	Business Travelers 1990
STOL Systems				
5,000	100	100	97	95
10,000	100	100	93	92
15,000	100	100	88	85
20,000	99	99	83	75
25,000	90	90	70	65
VTOL Systems				
5,000	100	100	100	95
10,000	100	100	97	90
15,000	100	100	94	85
20,000	100	99	90	75
25,000	98	90	80	65

NOTE: As revealed in Table 9, Boeing's modal-split analysis shows one third of all passengers using the air system for trips of 20 mi or less. For those distances, Fig. 2 indicates that air takes longer than auto and is much more expensive. It is unrealistic to assume that such travelers would actually switch to air, but it is precisely that assumption that causes these passenger income profiles to be so high.

*VT = value of time.

**w = wage rate.

for up to one-half of all passengers. The income profile of commuters is slightly higher. However, perhaps as many as 30 to 40 percent of them might need to earn only about $5,000 per year.

The above analysis is based on the assumption that the number of air travelers remains constant. However, it is likely that a decrease in air fares would divert more travelers to air transport. What would that do to the sensitivity analysis? Most additional STOL passengers would likely be those making the shorter trips (under 20 mi), given current residential patterns in the Bay Area. Few people now travel the longer distances, and they are assumed already to have changed to STOL in the base case. Thus, the addition of extra passengers would tend to raise the income

Table 11

EFFECT OF REDUCED FARES ON THE INCOME DISTRIBUTION OF V/STOL PASSENGERS

(1980 STOL System)

Minimum Annual Income ($)	Percentage of Total V/STOL Passengers					
	Commuters			Business Travelers		
	Base Fare	Reduced $1	Reduced 30%	Base Fare	Reduced $1	Reduced 30%
5,000	100	70	60	97	60	50
10,000	100	65	60	93	--	--
15,000	100	65	60	88	--	--
20,000	99	65	60	83	--	--
25,000	90	65	60	70	55	45

profiles in the reduced-fare cases because the cost-time tradeoffs are less favorable for the shorter commuting distances. In spite of that peculiar outcome, we would still expect a reduction in the air fare as sizable as those considered here to make STOL attractive to a much greater segment of the Bay Area population.

COSTS

By far the largest portion of the costs of the air transport system would be recovered through passenger fares. However, as shown in Table 1, each of the four configurations would incur a significant annual deficit and would require a continuing subsidy. Estimates of the amount of annual subsidy run from $13 million to $64 million.

In ascertaining how such a subsidy could be obtained, we considered local (county), federal, and statewide means. The most likely sources are, respectively, (1) property tax, (2) federal income tax, and (3) gasoline tax (it has often been suggested that the Highway Trust Fund be tapped to subsidize other forms of transportation). The estimated income distribution of those who pay the three kinds of taxes is given in Table 12.

The table indicates that these three taxes, the most likely sources of the subsidy, are borne mainly by people of middle and lower incomes.

Our analysis thus indicates that it is possible to estimate income profiles for the recipients of the benefits and the bearers of the costs of a transportation improve-

Table 12

ESTIMATED INCOME DISTRIBUTION OF TAXPAYERS LIKELY TO SUBSIDIZE THE V/STOL SYSTEM

Taxpayers' Minimum Annual Income ($)	Cumulative Percentage of Total Tax Receipts			
	Local Property Tax	Federal Income Tax		Highway Trust Fund
		Case I[a]	Case II[b]	
5,000	--	8	6	--
10,000	30	37	30	47
15,000	--	60	50	--
20,000	75	70	60	85

[a]Corporate income tax fully shifted.

[b]Corporate income tax not shifted.

ment. The profiles for the recipients of the benefits are, however, quite sensitive to the assumptions of the modal-split model producing the traffic projections, which are the basic input to our analysis. Using the Boeing projections, we estimate that the introduction of a V/STOL commuter air transport system would probably give rise to a slight upward redistribution of income. This conclusion is quite tentative, however. If the costs of air travel are reduced, if the cost of automobile travel increases, or if fewer of the short trips are diverted to air, the income profile of the passengers, and the redistribution of income, will be lower. Specifically, Boeing's modal-split analysis shows that fully one-third of all passengers would use the air system for trips of 20 mi or less. For those distances, however, air takes longer than auto and is much more expensive; therefore it is unrealistic to assume that such travelers would actually switch to air. If those travelers were removed from our analysis, the income profile of the passengers of the air transport system would be substantially lower.

IV. NOISE EFFECTS

We examined the effects of the noise generated in the operation of an intraurban V/STOL system designed for the San Francisco Bay Area by (1) calculating noise contours for each of the 24 STOL ports, (2) determining the demographic characteristics of households within the contours (by means of census data), and (3) analyzing the cost and attractiveness of several possible remedies for noise annoyance.

Although all four V/STOL configurations were initially considered in this noise-impact analysis, we investigated in detail only the 1980 STOL system so as to keep the task of computing noise contours manageable. Another reason for selecting STOL aircraft is that they are likely to yield larger contours. If STOL noise effects are found to be relatively minor, we would conclude with some assurance that the noise generated by the other configurations would not pose a serious community problem.

NOISE-CONTOUR CALCULATIONS

The primary noise measure used in this analysis is Noise Pollution Level (NPL).[12] NPL was chosen over the more widely used Noise Exposure Forecast (NEF) measure, because (1) NPL more adequately accounts for the slower flyover duration of STOL aircraft, and (2) it takes ambient noise into consideration.

However, NPL, like NEF, does not properly account for the infrequent operation of very noisy aircraft, e.g., one or two business jet operations daily from a general-aviation field. To remedy that lack, the NPL scale was augmented by another measure, Perceived Noise Level (PNL). First, a PNL contour was calculated for the noisiest type of aircraft operating from an airport. Then an NPL contour was calculated. The larger of the two contours was adopted as the noise contour for that airport.

[12] NPL was developed by D. W. Robinson at the National Physical Laboratory, London, England [8]. It was evaluated by Serendipity, Inc., which considered it the only available noise measure applicable to all community noise sources [9].

The contours were computed for 87 NPL and 98 PNL.[13] Those levels are roughly equivalent to 30 NEF, at which point 50 percent of the residents within the contour would be expected to be severely annoyed, enough to organize in opposition or perhaps engage in litigation against the airport.

To assess STOL noise in the proper perspective, two scenarios were considered: (1) a base case of 1980 CTOL aircraft operations, and (2) the STOL case, 1980 STOL operations added to the base case.

The operational data used for base-case noise calculations were extrapolated from 1970 figures. The mix of aircraft, runway use patterns, and day-night ratio remained the same. The number of flights was calculated by assuming no growth for the first two years, then 8-percent annual growth for the remaining years. The two-year no-growth period reflects the actual leveling-off or decline of aviation activities at most airports since 1970, due to the slowdown in the U.S. economy. The 8-percent growth rate is based on the growth rate of aviation activity in the Bay Area during the 1960s. Assumptions regarding the noise characteristics of engines in operation in 1980 are presented in Fig. 3.

For each of the 24 STOL airports, we used the 87 NPL contour or 98 PNL contour, whichever was appropriate, for both the base case and the STOL case. Table 13 summarizes the noise situation for the STOL case.

More than half the proposed airports either would have no contour, because of an extremely low level of operations, or would contain no households because the airport would have been built on undeveloped land. The only contours of interest are those containing households. Of them, three airports—San Francisco International, San Jose Municipal, and Buchanan Field—have contours so dominated by conventional jets that additional STOL noise would be trivial. A potential noise problem does exist at the last seven airports listed in Table 13. Minor changes in airport layout and aircraft takeoff and approach patterns could move the noise contour away from households near three of them—Ferry Landing, Oakland Coliseum, and San Pablo. That leaves San Carlos, Palo Alto, Reid-Hillview, and Hayward as the noise-impacted airports. Together, they would be expected to handle 27,500 passengers per day, 57 percent of the total 1980 STOL passenger load. Figures 4 through 7 show the city and county jurisdictions over the noise-contour areas around the four airports. They indicate the variety of governments that are likely to be concerned over the noise aspects of a V/STOL system.

[13] Both measures based on the PNdB scale.

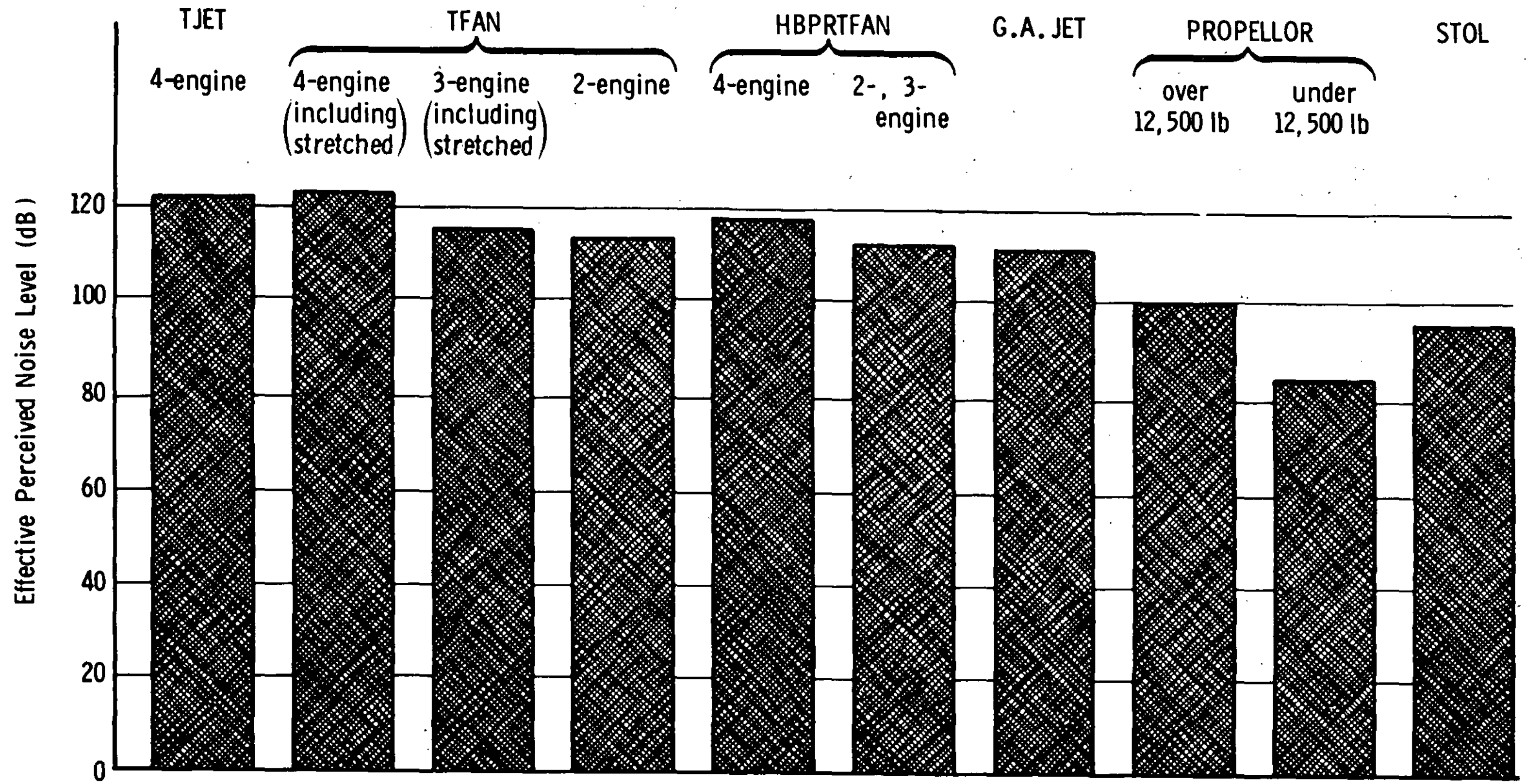


Fig. 3—Assumed effective perceived noise levels of 1980 aircraft at 500-ft distance, takeoff power setting

Table 13

STOL NOISE AT INDIVIDUAL TERMINALS

Noise Situation	*Terminal*
No contour	Antioch Morgan Hill
No households in contour	Crissy Field Mission Rock Candlestick Park Fort Funston Los Altos Hills Fremont Berkeley Heliport Mare Island Napa Cotati Gnoss Field Costa Madera
CTOL dominance	San Francisco San Jose Buchanan Field
Possibly noise-impacted	Ferry Landing Oakland Coliseum San Pablo
Noise-impacted	San Carlos Palo Alto Reid-Hillview Hayward

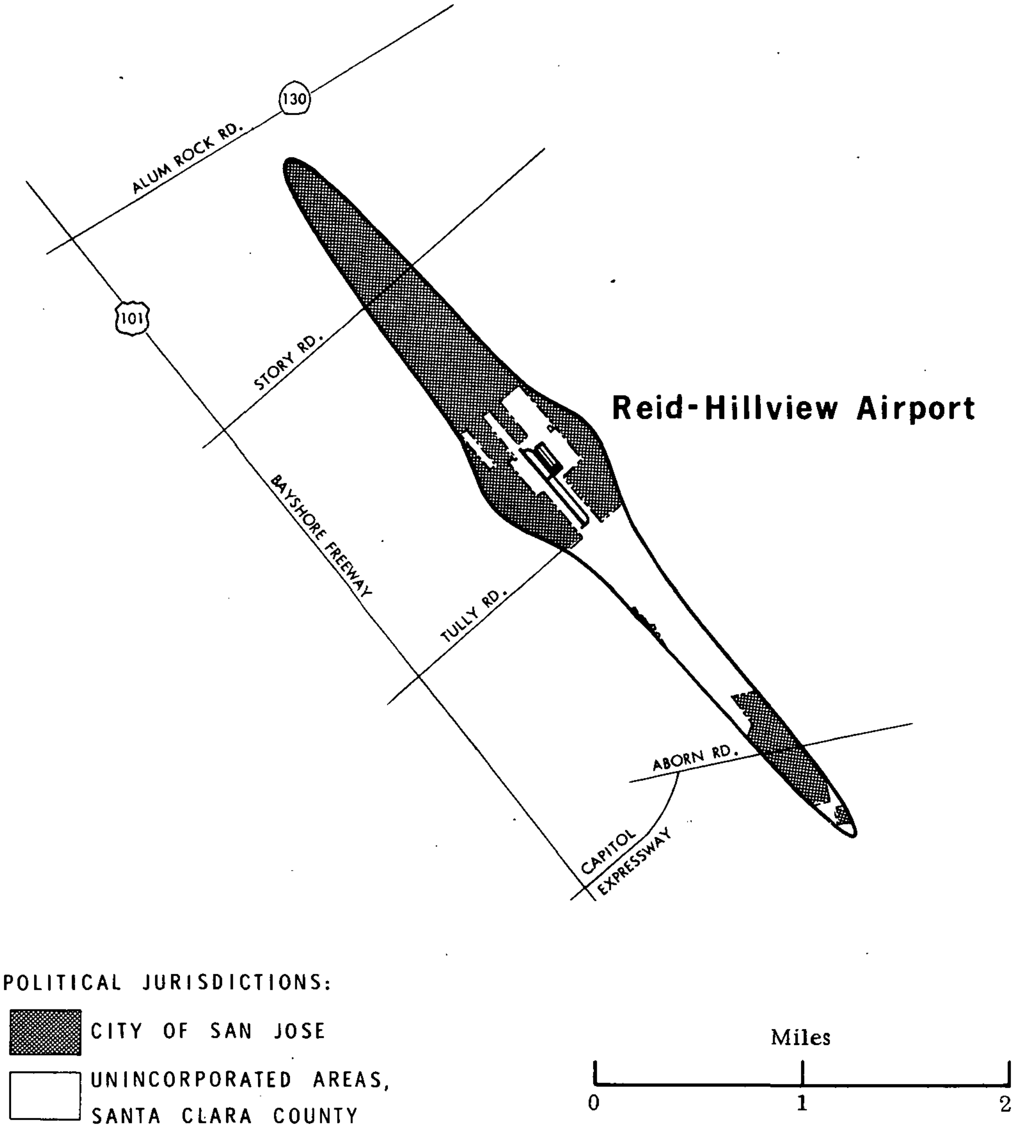


Fig. 4—Political jurisdictions in the Reid-Hillview noise contour

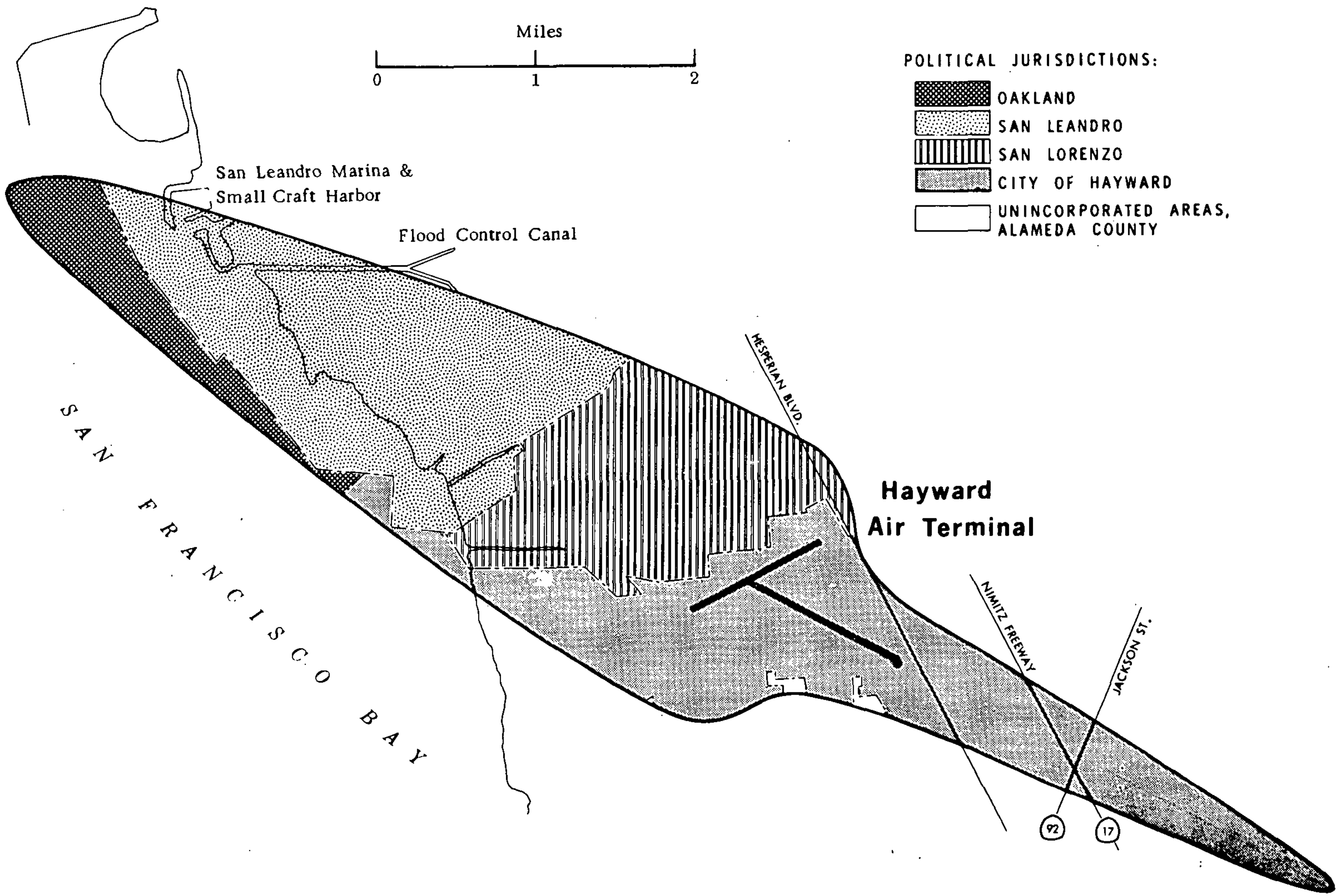


Fig. 5—Political jurisdictions in the Hayward noise contour

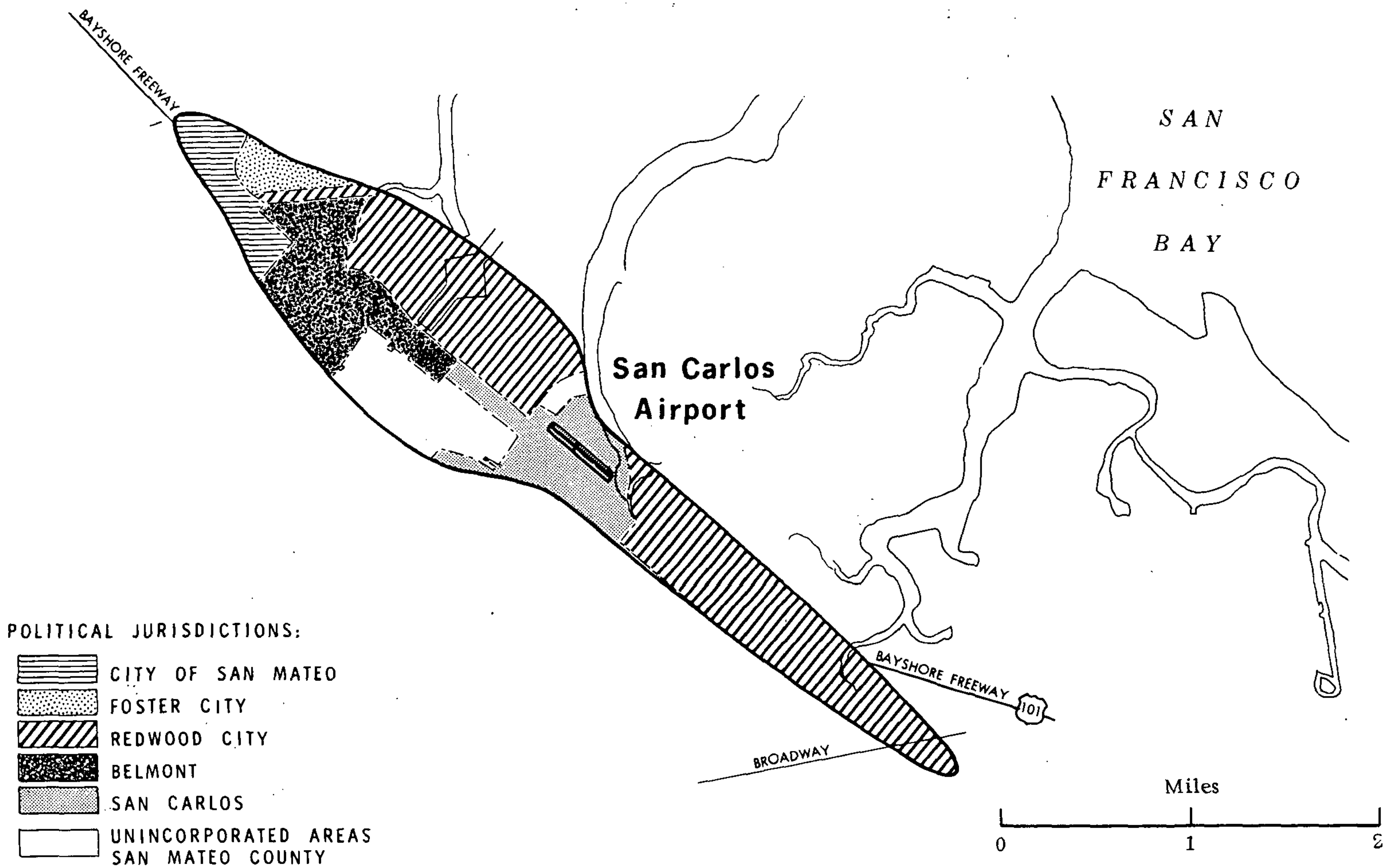


Fig. 6—Political jurisdictions in the San Carlos noise contour

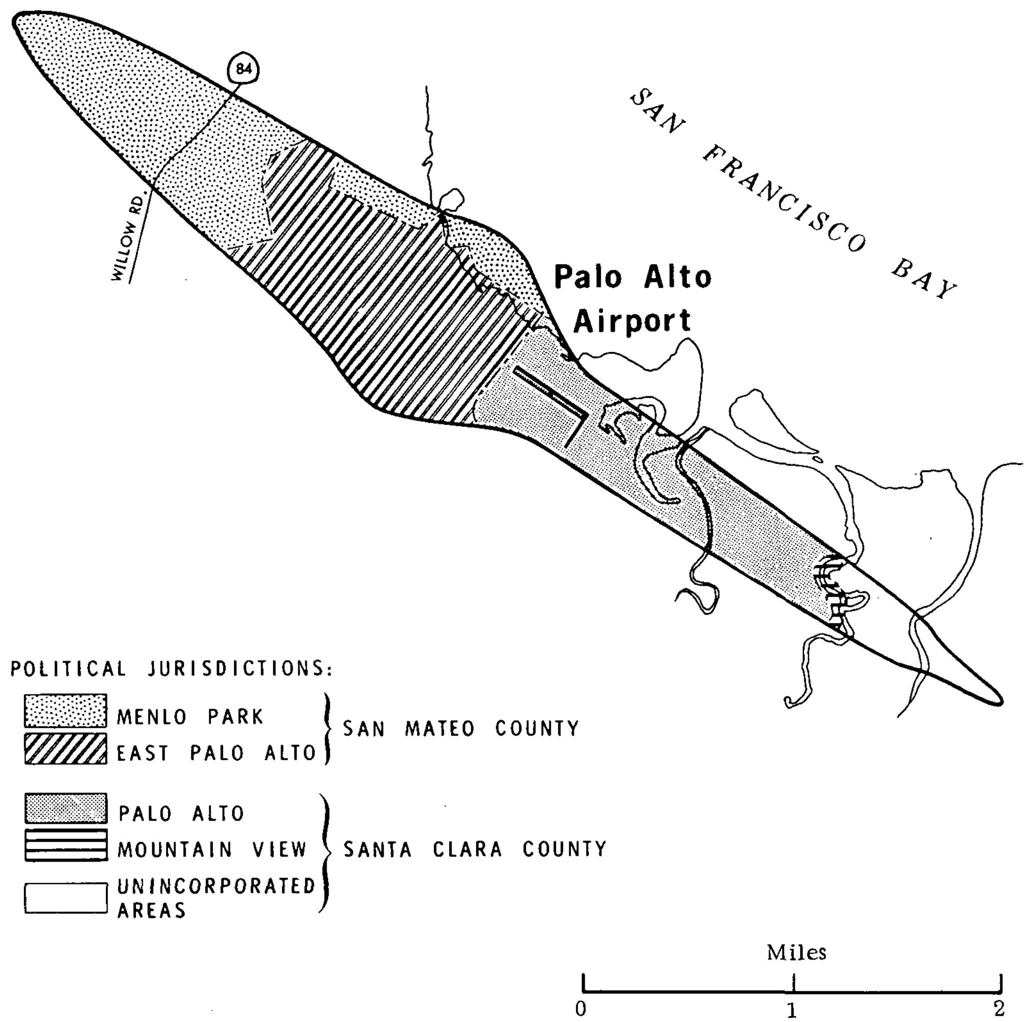


Fig. 7—Political jurisdictions in the Palo Alto noise contour

DEMOGRAPHIC CONTENTS OF NOISE CONTOURS

Our assessments of noise impact are based on 1970 census data; we made no attempt to project demographic data to the 1975-1985 period. We did that, posing the question of how 1980 STOL technology would affect the 1970 population, on the premise that if STOL noise seemed likely to have little adverse effect on the *current* population, proper planning could minimize the *future* noise problem by restricting the construction of residences in contour areas.

Based on the 1970 census data, the following statistics were obtained for each noise contour: (1) the number of households, and for each, (2) race (white, black, other), (3) income (low, below $6,000 per year; medium, $6,000-$15,000; high, above $15,000), and (4) residential property value.

To determine the contours and their demographic profiles, we used a set of programs, interlinked as shown in Fig. 8. Given the operations data, aircraft parameters, ambient noise level, and airport characteristics, the noise programs generated contours for each of the proposed STOL ports in the Bay Area. The noise contours were then fed into the GRIDS[14] data program via the Rand Tablet[15] and a coordinate trace program. The GRIDS program determined the number of affected households and other variables of interest within each contour.

Table 14 summarizes our findings for the four impacted airports in the 1980 STOL case.

To find out whether any racial or income group would be exposed to more than its share of noise, we compared the racial and income characteristics of all Bay Area households with those in the noise contours of base-case operations (see p. 23) and the noise-impacted STOL ports. Those statistics are shown in Table 15.

Table 15 indicates that the addition of STOL operations to those of the base case would affect about 3000 households in the Bay Area, of which slightly over 600 are black households. Those black households are found primarily in the Palo Alto contour. We also found that a relatively large number of medium-income households (about 3000) would be affected by the STOL noise increment. Most of them are located in Reid-Hillview and Hayward.

EVALUATION OF NOISE REMEDIES

There are two classes of remedies, those that *reduce noise* and those that *reduce the impact* of noise. Remedies that reduce noise include:

- Quieter engines.
- Steeper glide slope and angle of climb.
- Different approach and takeoff patterns.

[14] Grid Related Information Display System (GRIDS) is a computer program designed primarily for use with census data. It tabulates and maps the contents (e.g., number of households) of any arbitrary polygon. It was developed by M. A. Jaro for the Southern California Regional Information Study [10].

[15] Rand Tablet is a graphic input device to Rand's IBM 360/65 computer.

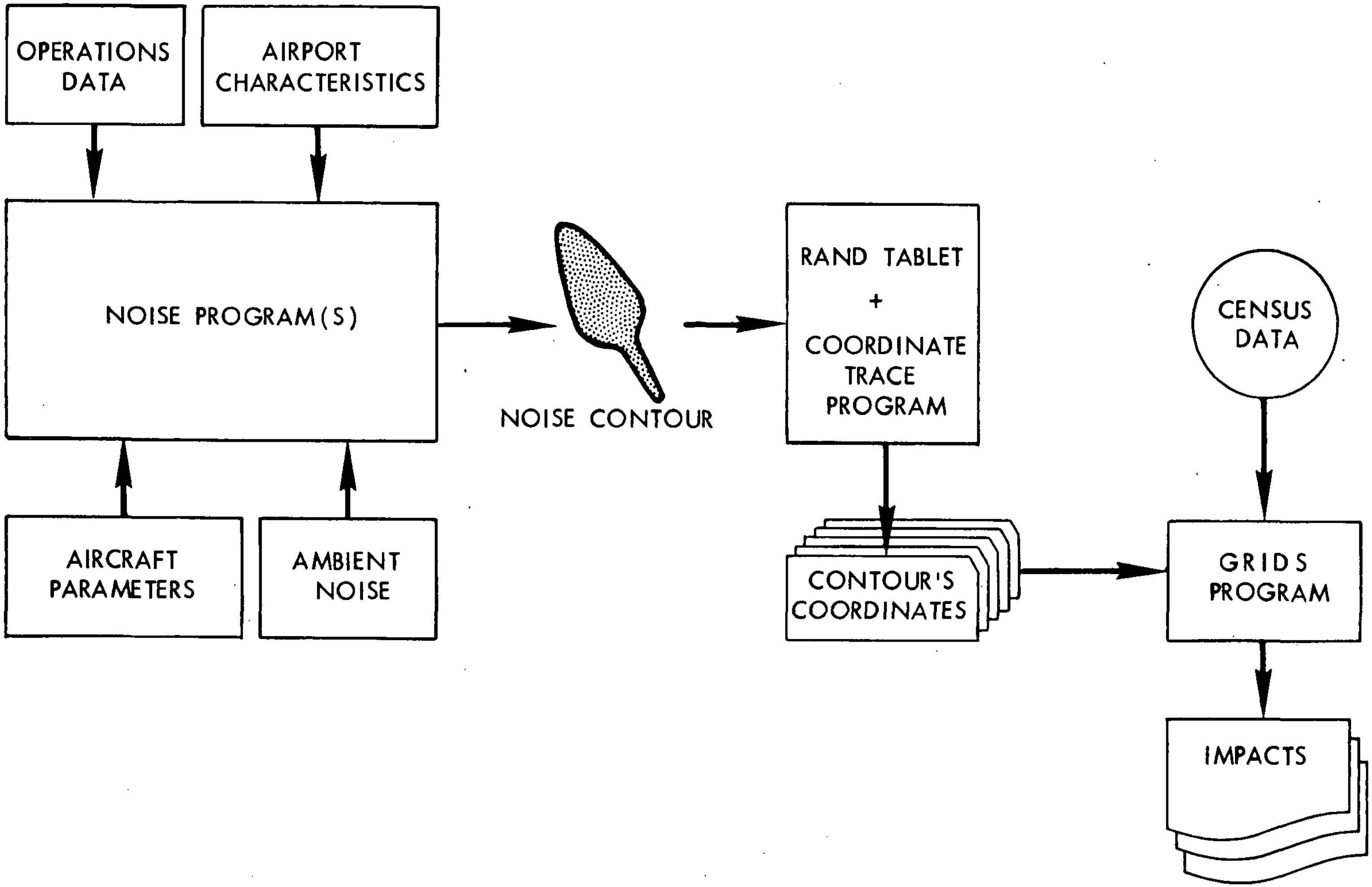


Fig. 8—Noise impact methodology

Table 14

CENSUS DATA FOR THE CONTOURS OF NOISE-IMPACTED AIRPORTS

Airport	Number of Households							Property Value ($ million)
	Total	Race			Income			
		White	Black	Other	Low	Medium	High	
San Carlos	272	272	0	0	8	276	8	6.2
Palo Alto	633	50	570	13	41	640	1	12.1
Reid-Hillview	1514	1352	96	66	40	1590	52	36.7
Hayward	4182	4032	24	126	127	4243	43	76.7
Total	6601	5706	690	205	216	6749	104	131.7

NOTE: There is a discrepancy between the sums of households reported by race and those by income because not every household provided both racial and income information.

Table 15

RACE AND INCOME OF HOUSEHOLDS IN BAY AREA AND IN NOISE CONTOURS OF BASE-CASE AND NOISE-IMPACTED STOL PORTS

Case	Number of Households						
	Total	Race			Income		
		White	Black	Other	Low	Medium	High
Bay Area	1,541,913	1,355,727	114,019	72,167	174,273	1,192,776	194,994
Percent	100	88	7	5	11	77	12
Base case	3,610	3,450	50	110	75	3,738	42
Percent	100	96	1	3	2	97	1
STOL case	6,601	5,706	690	205	216	6,749	104
Percent	100	86	11	3	3	95	2

- Changed airport configuration and location.
- Different aircraft mix.
- Reduced flight frequencies.
- Curfews.
- Attenuation devices.

Since those measures pertain to the engineering characteristics of aircraft and engines and to airport operation, we did not consider them proper subjects for this study. Instead, we concentrated on the second class of remedies. They include:

- Acquisition of property to be resold for private development.
- Acquisition of property for public development.
- Rezoning.
- Navigation easements.
- Insulation.

We evaluated those remedies in terms of dollar cost and general attractiveness to local government. The latter was based on a subjective judgment, taking into account factors such as ease of adoption, speed of execution, political acceptability, land-use control, economies of scale in parcel size, and expected complaints and litigation.

Dollar cost to local government refers to the cash-flow gain or loss, over a 20-year lifetime, that accrues to local government from putting a certain remedy into effect. Principal variables in determining the cash flow are as follows: on the plus side—lease revenues, additional property tax on land and improvement, and increased property tax on surrounding land; on the negative side—purchase price of land, discontinuation of existing property tax, decreased property tax, price of insulation, and price of purchasing easement rights.

Reliable data for making each cash-flow evaluation were often lacking, and numerous assumptions had to be made. Our preliminary analysis indicated that the acquisition of residential property, to be later resold for private, noise-compatible redevelopment, appears to be the most attractive means of softening the STOL noise impact. Its key advantage is that more property tax can be collected on commercial and industrial property than on residential property, and that the property tax on privately owned property is greater than the possessory interest tax on a leasehold. Another advantage is that it may allow homeowners a pro rata share of any gain obtained by reselling their property to developers.

SUMMARY

The foregoing analysis indicates that the noise generated by intraurban air operations would be troublesome only at certain terminals. At the smallest and largest terminals the effects would be minimal. Small terminals located in rural areas and having few operations would simply generate little noise. The downtown

V/STOL terminals with intensive operations would generate much noise, but the ambient noise level would be quite high and the incremental noise attributable to intraurban air operations would have little effect on commercial activities in the vicinity of the terminals. At the major air terminals, with much CTOL traffic, the additional noise generated by even a high number of V/STOL operations would be an insignificant increment to current noise levels.

Several of the intermediate-sized V/STOL terminals might experience severe noise problems, however. They would be at the heart of the system, located in the larger, more heavily populated residential suburbs generating over half the passenger traffic. With those terminals so heavily used yet necessarily situated in residential suburbs, the noise from the frequent flights would affect many nearby households. That problem warrants further study.

V. STOL POLLUTANT EMISSIONS

Rand's analysis of V/STOL air pollution focused on the pollutant emissions in the immediate vicinity of the STOL terminals. It complements the Boeing study, which considered the air-pollutant emissions of STOL aircraft while in flight. The Boeing study indicated that STOL aircraft emitted less pollution per passenger mile than the automobile. Thus, the introduction of a STOL commuter system would reduce a community's total air pollutant emissions, provided the average commuting distance did not increase.

The twofold objective of our analysis was to investigate the potential significance of STOL emissions in the terminal areas and in the communities immediately adjacent to the busiest terminals. It is always desirable to relate emission characteristics to the ambient air quality, which is expressed in parts per million (ppm) of a particular air pollutant in the atmosphere. The Environmental Protection Agency (EPA) has sponsored the development of some computer models to convert data from pounds of emission to ppm in the atmosphere for an airport and its adjacent community. Unfortunately, those models were not available within the time constraints of this study, nor could we develop our own models with the available resources. Thus, the following analysis considers the pounds of pollutants emitted rather than the resultant concentration of pollutants in the atmosphere. Any observations or conclusions drawn from it should be regarded as tentative.

Our approach was to consider two cases, first, the busiest STOL airport, and second, the busiest CTOL airport with STOL operations added. The airport representing the first case is the Ferry Building terminal, with 788 STOL commuter operations per day, and the second-case airport is San Francisco International Airport, with 1002 CTOL operations and 350 STOL operations per day.[16]

The CTOL operations are based upon 1980 projections of fleet composition and airport activity, allowing for the introduction of new aircraft such as the DC-10 and 747s. The STOL operations are based upon 1980 forecasts by Boeing. All CTOL and STOL aircraft are assumed to be fitted with the new smokeless combustor currently being installed in the CTOL fleet. The emission indices[17] for the STOL and CTOL aircraft are based on the emission indices of new engines currently being produced.

[16] One landing and takeoff cycle is equivalent to two operations.

[17] For a particular air pollutant, the emission index is pounds of pollutant per 1000 lb of fuel.

Those indices are not expected to vary much by 1980. The emission indices for the STOL engines are slightly more optimistic than are those for the CTOL engines, owing to the different data sources rather than to any intrinsic difference between STOL and CTOL engines.

METHOD

Two estimates of aircraft emissions were made, one for the pollutants emitted directly over the airport property and the other for those emitted over the adjacent community (including the airport property). Then, an estimate of the emissions per unit of exposure area was determined, using the airport property and the adjacent community as the two exposure areas.

The pollutant species considered were carbon monoxide, nitric oxides, sulfur oxides, hydrocarbons, and particulates. That list includes all major pollutant species except oxidants. Oxidants, which are related to photochemical smog, result from a chemical process that requires reactive hydrocarbons and nitric oxides. Thus, by considering hydrocarbons and nitric oxide emissions, we are indirectly considering oxidants.

The airport exposure area is approximated by a minimum-radius circle that encloses the runway complex. The adjacent community's exposure area is defined by a circle large enough that all the emissions from aircraft operations up to 3500-ft altitude will occur over it.[18]

Applying those exposure-area definitions, we determined that the community exposure area of San Francisco International Airport is approximately 4 times that of the Ferry Building. The airport exposure area of the International Airport is approximately 70 times that of the Ferry Building.

The exposure-area dimensions were combined with the basic emission characteristics of each aircraft type (see Table 16) to calculate the total daily emissions for the two exposure areas at the Ferry Building and the International Airport. The emission flux[19] was then determined by dividing the total emissions by the area over which the emissions took place.

RESULTS

The total daily emissions, of all pollutant species, were greater at International Airport (CTOL plus STOL operations) than at the Ferry Building STOL airport, over both airport and community exposure areas (see Table 17). That is a reflection of the

[18] Aircraft emissions at altitudes greater than 3500 ft are not considered significant at ground level because of the effect of the inversion layer.

[19] Pounds of a particular pollutant emitted per unit area.

Table 16

EMISSIONS FROM A SINGLE AIRCRAFT BELOW 3500 FT DURING ONE LANDING AND TAKEOFF CYCLE

(Lb)

Aircraft Type	Pollutant Species				
	Carbon Monoxide	Nitric Oxides	Sulphur Oxides	Hydro-carbons	Particulates
STOL commuter	6	1	0.4	1	0.2
4-engine turbojet	30	10	4	108	15
4-engine turbofan	24	12	4	159	15
4-engine stretch turbofan	24	12	4	159	15
3-engine turbofan	18	9	3	120	11
3-engine stretch turbofan	18	9	3	120	11
2-engine turbofan	12	6	2	80	7
4-engine, high-bypass-ratio turbofan	24	12	4	159	14
2-, 3-engine, high-bypass-ratio turbofan	18	9	3	119	11
Business jet	2	1	0.4	16	1
2-engine propeller (takeoff weight > 12,500 lb)	2	1	0.3	13	1
2-engine propeller (takeoff weight < 12,500 lb)	1	1	0.2	8	1

SOURCES: Refs. 11, 12, 13.

Table 17

TOTAL DAILY EMISSIONS

(Thousands of lb)

Area	CO	NO_x	SO_2	Hydro-carbons	Partic-ulates
Airport Exposure Area:					
San Francisco Intl.	10	0.2	0.2	60	0.6
Ferry Building	2	0.1	0.05	0.4	0.02
Community Exposure Area:					
San Francisco Intl.	10	5	2	60	6
Ferry Building	2	0.4	0.2	0.4	0.06

larger number of operations at International Airport and the greater distances required by CTOL aircraft to achieve 3500-ft altitude.

Emission Flux

In terms of emission flux (pounds of pollutant per million square feet), however, emissions in the airport exposure area of the Ferry Building airport are greater than those at International Airport (see Table 18). The two airports have approximately equal emission flux levels in their community exposure areas. The high emission flux at the Ferry Building owes to the large number of STOL operations in a relatively compact area.

Table 19 compares our airport estimates with the daily recorded emission fluxes of two other urban areas. The average carbon monoxide emission flux in Los Angeles County during 1970 resulted in carbon monoxide concentrations in excess of the EPA's standard over 50 percent of the time. That suggests that the estimated emission flux at the Ferry Building could lead to a violation of the EPA standard in the immediate vicinity of the terminal. High as it is, however, the emission flux level at the Ferry Building is not nearly as significant as that recorded at the Army Street interchange of Route 101 in San Francisco.

Air Quality

To avoid some of the uncertainties of considering only emission flux, we attempted to estimate the concentration of carbon monoxide (CO) that would result at the Ferry Building. A simple box-diffusion estimate indicates that the incremental change in the CO concentration due to STOL operations at the Ferry Building would be between 0.2 and 20 ppm. The EPA standard is 9 ppm, averaged over 8 hr. Our lower-bound estimate of 0.2 ppm would represent a small incremental impact, but the upper bound of 20 ppm would be twice the EPA standard for all sources in the community.

The maximum CO concentration in downtown San Francisco in 1967 (8-hr average) was 21 ppm (see Table 20). Most of the CO emissions were attributable to automobile traffic. The Ferry Building is located in a heavily commercial area, and the maximum annual CO concentration is very likely on the order of 20 ppm. The enforcement of strict emission controls could reduce automobile emissions so as to bring the ambient CO concentration down to, say, 7 ppm. That would leave a nominal 2 ppm margin for emissions around the STOL port. The EPA standard is defined in such a way that the ambient concentration of CO due to all sources should not exceed 9 ppm at any location in the community. It would therefore be difficult to justify the installation of a busy STOL commuter terminal in an area already having an air-pollution problem if the STOL terminal were likely to produce more than about 2 ppm of carbon monoxide.

A 1966 study attempted to relate the CO flux (pounds/million square feet) to the CO concentration (ppm) at the John F. Kennedy International Airport [14]. For an

Table 18

DAILY EMISSION FLUXES

(Lb/million sq ft)

Area	CO	NO_x	SO_2	Hydro-carbons	Partic-ulates
Airport Exposure Area:					
San Francisco Intl.	100	2	2	600	6
Ferry Building	1000	60	30	200	10
Community Exposure Area:					
San Francisco Intl.	1	0.7	0.2	0.9	0.9
Ferry Building	1	0.2	0.08	0.2	0.03

Table 19

DAILY EMISSION FLUXES OF CARBON MONOXIDE

(Lb/million sq ft)

Ferry Building, aircraft emissions only (1980)	1,000
San Francisco International, aircraft, including STOL, emissions only (1980)	100
Los Angeles County (average, 1970)	160
San Francisco Freeway (Route 101, Army Street interchange) (maximum, 1970)	59,000

Table 20

CARBON MONOXIDE IN THE AMBIENT AIR (ppm)

(Maximum annual concentration,
8-hour average)

Downtown San Francisco (1967)	21
Hollywood Freeway, Los Angeles (1967)	38
Lennox, Los Angeles (1967)	34
Downtown Los Angeles (1967)	26
EPA standard, not to be exceeded more than once per year at any point in the community	9

emission flux of 430 lb/million sq ft, which is about half that estimated at the Ferry Building, the study found that in the immediate vicinity of the terminals the CO concentration peaked at about 23 ppm, though around the runways it was 9 ppm. One explanation is that the 9 ppm owes to the influence of the ambient air in the surrounding community and that perhaps 14 ppm of the observed 23 near the terminal are directly attributable to the operations there. At JFK, the emissions from the aircraft alone were higher than what the EPA standard allows for all sources in the community. Since the Ferry Building emission flux is twice that observed at JFK, there may be a significant air-pollution impact at the busy STOL commuter terminals. As stated earlier, these conclusions are tentative. Additional study of meteorological and geographic factors is required to establish more accurately the impact of STOL operations on the ambient air quality.

VI. EFFECTS ON ROAD CONGESTION

By the time the V/STOL systems considered here would be fully operational, 1980 and 1990, the existing freeway and highway systems may have been considerably extended. BATSC's estimates of future traffic levels indicate that even with improved rail commuter service, upgraded bus service, and the expansion of BART (Bay Area Rapid Transit system) to its full extent, the freeway system will have to be substantially expanded if future road congestion is to be avoided.

Our analysis of the impact of a V/STOL system on road congestion assumes that the freeway system will have to be expanded, but that the presence of the V/STOL system might reduce the amount of expansion required. V/STOL's reduction of auto-traffic congestion is estimated by assuming that if the V/STOL system did not exist, passengers would use their autos to make the same number of trips between points of origin and destination near the V/STOL ports.

From that basic assumption, the V/STOL system's effects on road congestion are assessed for: (1) the main freeway and highway systems in the Bay Area, (2) the road systems in the neighborhoods of V/STOL ports, and (3) the downtown San Francisco parking requirement.

Of the four V/STOL system configurations considered in the overall study, we chose two cases—the 1980, 50-passenger helicopter, and the 1990, 50-passenger, tilt-rotor VTOL—for estimating the impact of V/STOL on road congestion. Since those two configurations would have more passengers than their STOL alternatives, assessing their effects would indicate the upper bound on the V/STOL system's contribution to reduced road congestion.

The Boeing study estimated the number of daily V/STOL passengers for the above two cases at 62,000 and 130,000, respectively. Boeing also estimated the variation in demand for V/STOL service throughout the day, based on household survey data obtained in the Bay Area. The results are represented approximately by the curves shown in Fig. 9. It can be seen that the flow into downtown San Francisco would be extremely highly peaked and asymmetric; that is because the potential V/STOL passengers are primarily business commuters.

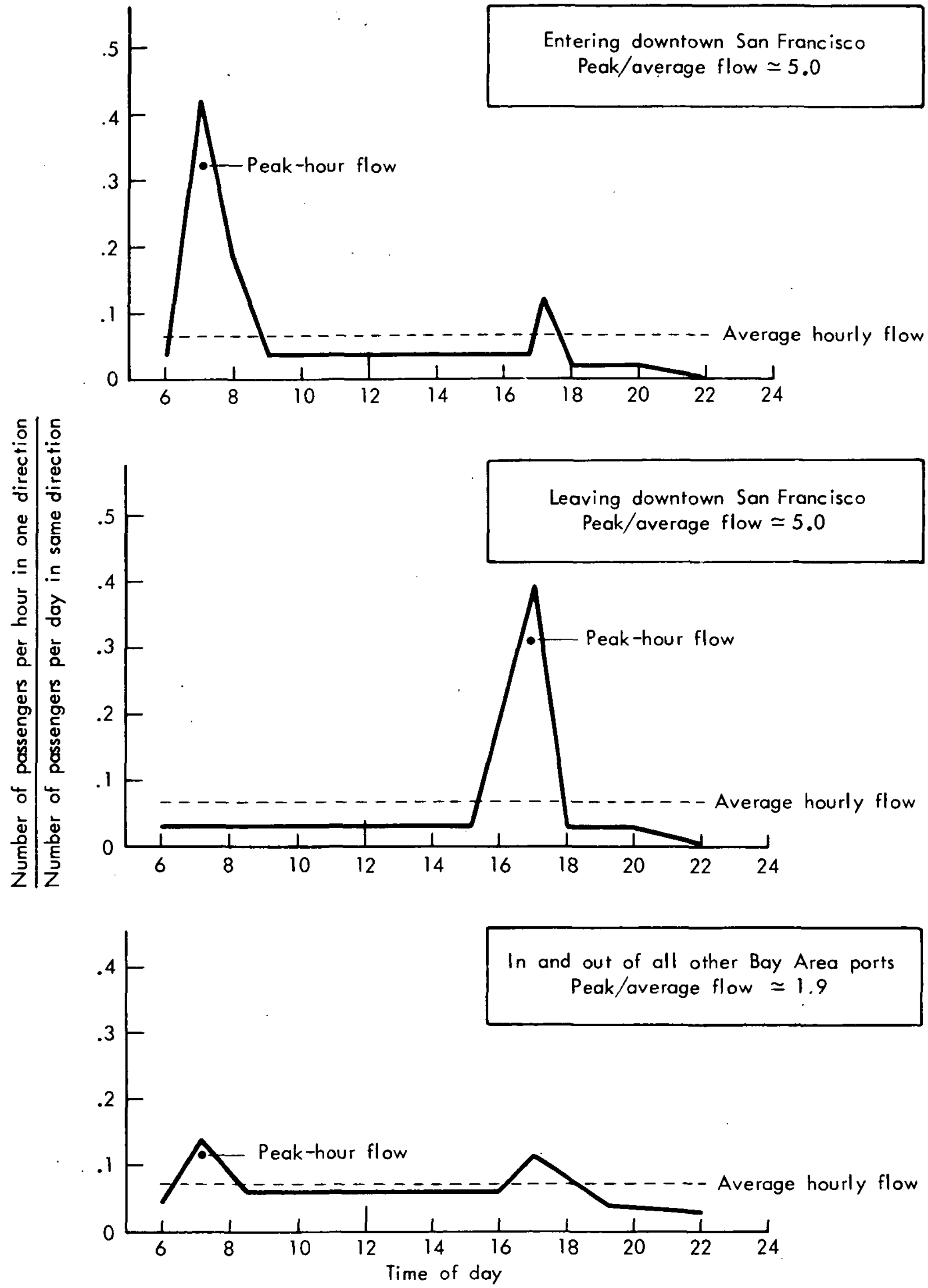


Fig. 9—V/STOL passenger demand throughout the day

EFFECTS ON THE MAIN FREEWAYS AND HIGHWAYS

A model was built to determine the amount of traffic removed from each link in the road system by the use of V/STOL. The road network was broken into a number of links, and the links forming the best route between specified points of origin and destination were identified with the associated daily demand. On each "best route," we determined the auto traffic due to the daily V/STOL passengers, i.e., the amount of traffic the V/STOL system would remove from each link in the road network. In determining the number of vehicles involved, one person was assumed per auto.

The reduction in the number of vehicles that use each link can then be translated into a reduction in the number of lane-miles of freeway that must be built in the future.

Because V/STOL traffic would be so strongly peaked, the number of lanes freed by removing a specified number of vehicles per day is highly dependent on assumptions regarding the acceptable congestion level during the peak hour. If we assume that future freeways are designed to allow vehicles to travel an average of 47 mph during the peak hour, the lanes that would be freed by the V/STOL system can be determined by assuming that each lane handles 1000 autos per hour. That assumption, however, represents "deluxe" conditions compared with current highways. A more austere assumption is that the future freeways would operate at their maximum capacity during the peak hours. That means an average speed of 30 mph during the peak hour, with some traffic instability; i.e., drivers would be forced to accelerate and decelerate at times in order to stay with the traffic. The capacity of a lane under those conditions would be about 2000 vehicles per hour. The number of lanes freed by the use of V/STOL under the "austere" assumption would thus be half the number freed under the "deluxe" assumption.[20]

The number of freeway lanes freed on the more critical links of the Bay Area road net is shown in Table 21 for both assumptions of lane capacity.

The distribution of the freed lane-miles over the entire network in 1980 and 1990 is shown in Figs. 10 and 11, respectively. They are based on the austere assumption. It can be seen that V/STOL most immediately relieves the Bayshore and East Bay freeways and the Bay Bridge. With further V/STOL system growth, those links are further lightened, and relief spreads to the Golden Gate Bridge, North Berkeley Freeway, and Highway 24, which passes through the Caldecott Tunnel. Possibly the most important benefit is relief of traffic on the Bay Bridge. Currently the bridge has 10 lanes (5 each way); if the 1990 V/STOL demand develops as assumed and the austere criteria are met, the V/STOL system might free about half the present bridge capacity.

The total number of lane-miles saved in required road expansion is given in Table 22 for the 1980 and 1990 systems, under both austere and deluxe assumptions of freeway development. Table 22 also shows the saving in freeway expansion cost

[20] At present, traffic on the Bay Bridge and on major freeways during the weekday peak hours is between 1800 and 1950 vehicles per lane per hour—approximating our "austere" assumption.

Table 21

NUMBER OF LANES ON CRITICAL FREEWAY LINKS FREED
BY V/STOL SYSTEM OPERATION

Link	Lanes Freed			
	"Deluxe" Rush-Hour Speed (47 mph)		"Austere" Rush-Hour Speed (30 mph)	
	1980	1990	1980	1990
Bay Bridge	4.9	8.0	2.5	4.0
Golden Gate Bridge	1.3	3.2	0.7	1.6
Caldecott Tunnel	1.2	2.6	0.6	1.3
Bayshore Freeway	2.7	4.9	1.4	2.5
East Bay Freeway	2.1	3.5	1.1	1.6
North Berkeley Freeway	1.2	2.6	0.6	1.3

resulting from these lane-mile savings. The saving is based on the following cost estimates for constructing one lane-mile in the Bay Area: freeway, $1.5 million; bridge, $4.5 million; and tunnel, $5.6 million.

GROUND CONGESTION NEAR V/STOL PORTS

Study of the flow of passengers through each V/STOL port per day and in the peak hours shows that, in the 1990 V/STOL system, ten terminals would handle over 10,000 passengers a day; seven terminals would handle over 1000 passengers during the peak morning hour and a comparable but slightly smaller number of passengers in the peak evening hour. To examine congestion in the neighborhood of the V/STOL ports, two ports were selected: the downtown San Francisco terminal (Ferry Island) and the terminal at Palo Alto, the latter representing the terminals that would handle approximately 10,000 passengers a day without the asymmetry associated with the San Francisco terminal.

Study of those terminals indicated that, with proper airport design and proper expansion of the road system near the terminals, congestion in the neighborhood should not be serious. Furthermore, the road construction necessary to achieve that result would cost little compared with the saving in freeway expansion due to the use of V/STOL.

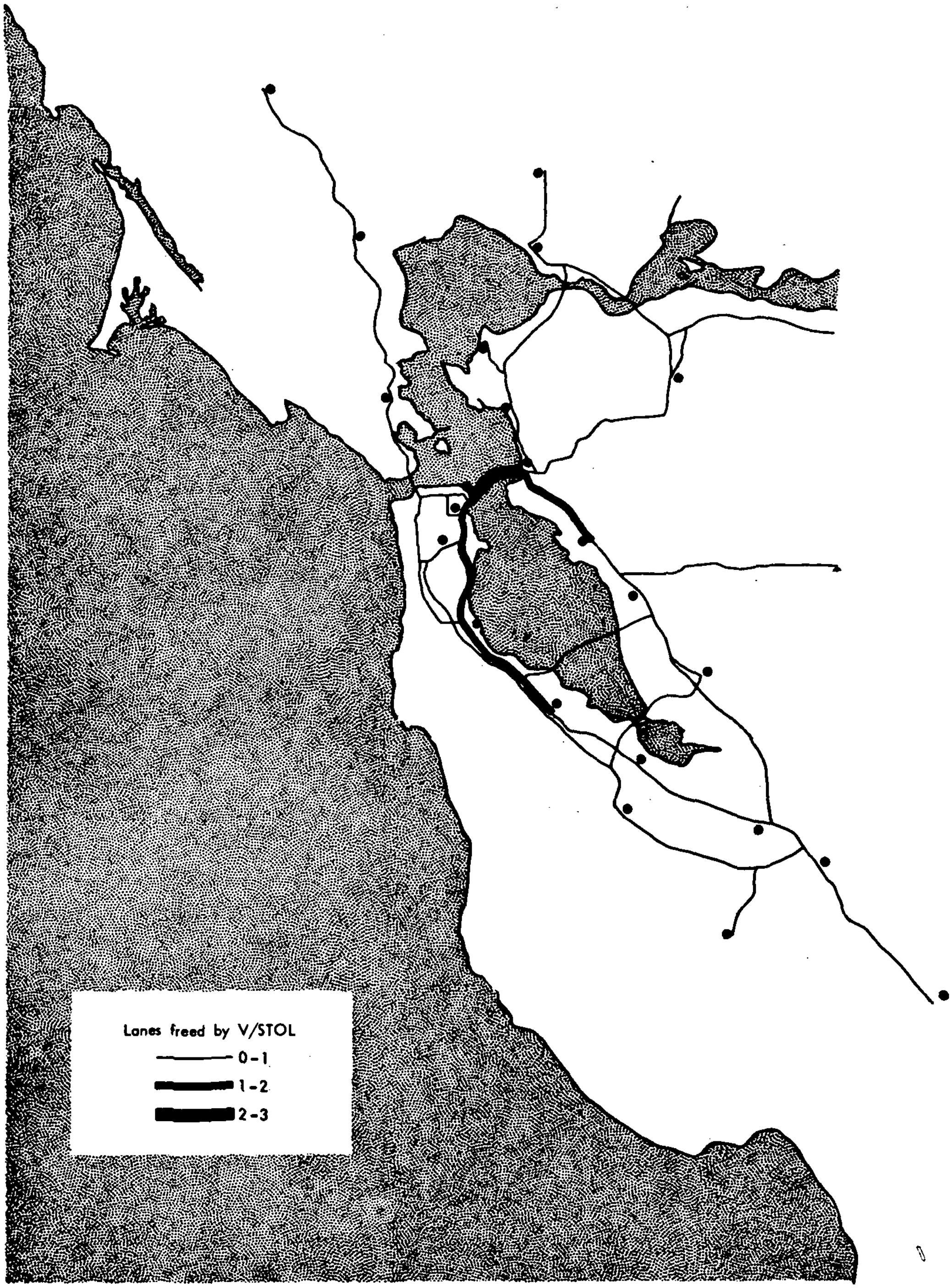


Fig. 10—Lanes freed on major Bay Area highways by the operation of the 1980 VTOL system

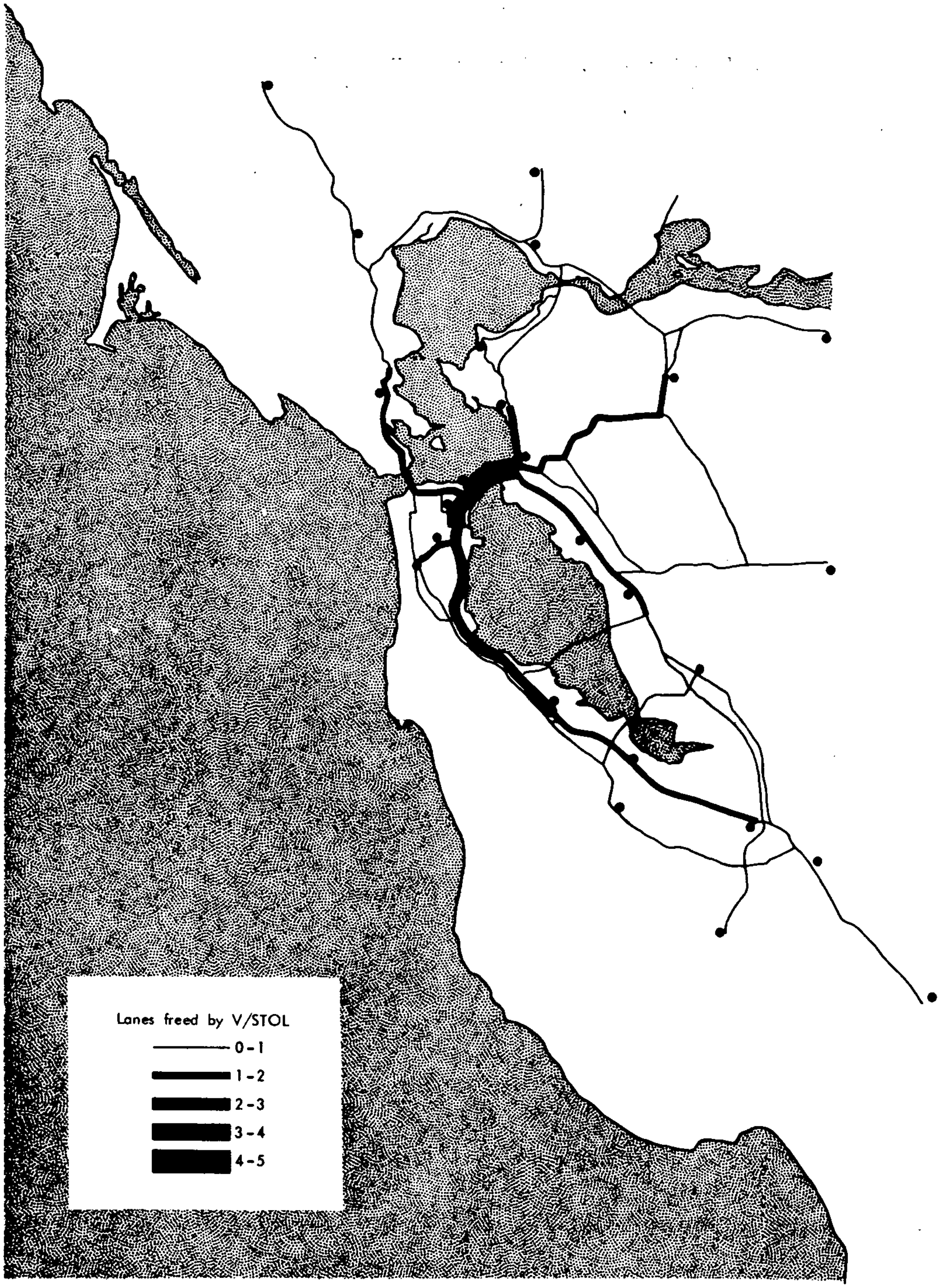


Fig. 11—Lanes freed on major Bay Area highways by the operation of the 1990 VTOL system

Table 22

LANE-MILES OF FREEWAY AND FREEWAY EXPANSION COSTS SAVED BY V/STOL SYSTEM OPERATION

	1980	1990
Number of V/STOL passengers per day ...	67,231	131,250
Lane-miles saved		
Austere assumption	128	233
Deluxe assumption	257	465
Expansion costs saved (1970 \$ million)		
Austere assumption	256	459
Deluxe assumption	510	763

PARKING IN DOWNTOWN SAN FRANCISCO

The V/STOL system considered here would deliver slightly over 10,000 passengers per day into downtown San Francisco in 1980 and 17,500 passengers per day in 1990. If those people were to drive their automobiles instead of using the V/STOL system, they would require 35 acres of parking space in 1980 and about 62 acres in 1990. The V/STOL system would free this area for other uses. The other uses might, however, attract additional traffic to the downtown area.

Analysis indicated that if the area freed by the use of V/STOL were converted to retail stores, the total number of autos per day drawn to the central business district (CBD) would remain about the same as if the V/STOL system were not implemented and its potential passengers drove their cars to the CBD. Street congestion, however, would be improved during peak hours, since the traffic generated by retail customers would not be as highly peaked as that generated by commuters.

If the freed space were used for professional services, appreciably fewer autos would come into the CBD, and traffic would be distributed more randomly, which would reduce the commuter peak-hour rush.

Using the freed space for manufacturing and warehousing would achieve the largest reduction in the number of autos daily entering the CBD, but much of the associated traffic (workers going to and from work) might occur during the rush hours. That use might also increase the number of heavy trucks in the downtown area.

SUMMARY

Because commuter auto traffic is so strongly peaked and tends to concentrate on a few freeway links, a V/STOL commuter system could significantly reduce the amount of future highway expansion necessary.

Its most important impact in that respect would be the diversion of future traffic from the Bay Bridge. Our estimates indicate that, by 1990, V/STOL might divert almost half of the present bridge capacity. Sizable cost savings could result from the reduced need for future freeway expansion and should be considered an important advantage in having a V/STOL system.

The V/STOL system would require some highway and road construction near the V/STOL ports if road congestion is to be avoided, but the amount required would be small compared with the saving in freeway construction.

Finally, the V/STOL system would free 35 to 62 acres of off-street parking space in downtown San Francisco, which space could then be put to commercial uses. While the other uses would induce some additional traffic, the net effect appears to be a reduction of traffic in downtown San Francisco.

VII. LONG-RUN EFFECTS ON RESIDENTIAL LOCATION AND COMMUTING

The previous sections have dealt primarily with the near-term effects of the V/STOL system, those that would be realized at the time of installation or shortly thereafter. This section examines the important question of the system's influence on the community over a longer period of time: Would its introduction induce the workers employed in the city of San Francisco to change their residences and increase the length of their commuting trips? Air transport promises fast and congestion-free travel for distances over 25 mi; many families currently commuting shorter distances by car might want to move to more distant suburbs where they could obtain better housing at no greater cost. If the number that did so were substantial, the pattern of regional growth would be affected.

APPROACH

Our approach in addressing this question is based on a theory of residential location. It assumes that each household, in choosing its residence, faces a three-way tradeoff among the site, the quality and quantity of housing located on the site, and a composite commodity representing all other goods and services. The household bases its decision—its choice of site and type of housing and consumption of the other goods and services—on its income, the prices of the three "goods," and its personal preferences for the three goods.

The theory also assumes that the general level of rents varies more or less regularly over the region; that is, a particular housing unit on a lot of a certain size will be more expensive in a central urban location than in a suburban location. If that is true, the household may trade off a central location against more or better housing or against more of the "other goods and services." Thus, the variation in rents throughout the region is one aspect of the price of location.

The other aspect of the price of location is the commuting costs incurred by the head of the household. The head of the household is assumed to commute from his home to his place of work each day, and the location of his home determines the length of his commuting trip. The farther he lives from his place of work, the more of his income is spent on commuting, and the less is available to purchase other things.

A simple model of household location and consumption based on the above theory was formulated.[21] The model can be manipulated to explore the effects of a change in transport costs arising from the introduction of a new mode of commuter transportation. The prices of all three goods in the model influence each household's preferred residence. Thus, a change in any of the prices may induce the household to change its chosen site.

The effect on preferred residential site of a change in transport cost is composed of an "income effect" and a "substitution effect." The income effect of a decrease in transport costs may be viewed as an increase in the family's disposable income. However far the family head is currently commuting, the family now has some surplus income that was previously spent on commuting. According to family preferences, some portion of the surplus may be allocated to a change in the family's residence. That is, it may choose a more desirable location, with a higher rent, or a location farther from the place of employment, with a higher commuting cost.

The substitution effect operates in a slightly different manner but with similar results. A change in transport cost typically includes a change in the cost per mile of commuting—the marginal cost or price—as well as a change in the fixed element of transport cost. That change in the marginal price of transport (hence of residence) affects the household's marginal tradeoffs between location and other goods and may well encourage it to make a change in residence.

Each of those effects can be expressed in terms of an "elasticity" and a "multiplier." The income effect can be expressed as the income elasticity of commuting distance—the percentage change in commuting distance brought about by a one-percent change in money income—deflated by the income multiplier. The income multiplier refers to the apparent change in income due to a change in transport cost; it depends on the household's income, the distance the head of the household has been commuting, and the old and new travel costs. Similarly, the substitution effect can be expressed as the real price elasticity of commuting distance deflated by the price multiplier. The real price elasticity is the percentage change in commuting distance brought about by a one-percent change in the price of commuting (marginal travel cost). The price multiplier depends on the household's income, the distance the head of the household has been commuting, and the old and new travel costs.

Using the model, we attempted to estimate the locational response of commuters employed in the city of San Francisco but residing throughout the Bay Area to the introduction of a V/STOL air transport service of the type described in the

[21] The model is adapted from the work of W. Alonso and R. F. Muth, Refs. 15 and 16, but is much simpler, with a slightly different emphasis. Alonso was concerned with establishing and explaining the equilibrium relationships between the supply of land and the demand for land for housing, industry, and agriculture. Muth was concerned with understanding the myriad details of the interactions between the demand for and supply of housing. Our interest, on the other hand, is simply in the relationship between the costs of transportation and the actual commuting patterns in one particular city. The derivation of the model and the associated empirical work are reported more fully in Ref. 17.

preceding sections. The response was estimated in three steps. First, the income elasticity of commuting distance was estimated from data collected in a survey of 30,000 households by the Bay Area Transportation Study Commission (BATSC) in 1965.[22] Second, the income and price multipliers were estimated for several levels of household income and commuting distance from auto- and air-travel time and cost functions in the 1971 Boeing study and a value-of-travel-time concept developed by a group of economists over the last fifteen years.[23] Finally, since it was not possible to estimate the price elasticity with the available data,[24] we postulated several plausible values, by which we calculated the total effect of a change in travel cost on commuting distance.

FINDINGS

The residential distribution of the heads of households employed in San Francisco conformed to our expectations. About two-thirds of them live within 10 mi of their place of work. Another 20 percent live 10-20 mi from the city. The remaining 10 to 15 percent reside throughout the nine-county region and commute appreciable distances each day.

When those workers are grouped by family income, we see that the more affluent commuters, on the average, commute farther than the lower-income commuters. With regard to family size, the heads of larger families are more dispersed residentially; unmarried workers reside mainly in the city.

The relation between higher family income and increased commuting distance was estimated separately for five family sizes. Though the estimates of the income elasticity of commuting distance differed somewhat, they were closely grouped around 0.5. Hence, that value was chosen to represent the entire sample. That is, on the average, for all family sizes, a 1.0-percent increase in family income would be associated with a 0.5-percent increase in commuting distance.

Income and substitution effects were estimated for four levels of family income, for commuting distances of 20, 40, and 60 mi, and for three levels of air fare. The base air fare is that assumed in the Boeing study ($3.50, or $1.75 plus $0.064/mi), and we set the other two fares arbitrarily to reflect a substantial lowering of the base fare.

Table 23 presents our estimates of income-induced changes in trip distance. The

[22] Approximately 30,000 households selected randomly throughout the Bay Area were surveyed to obtain detailed information on the household and on all trips made by household members over 4 years of age on a given day. The information included residential location, each member's mode of transportation, worksite, and characteristics of housing, family, and income.

[23] For example, see Refs. 18 through 24.

[24] The data, while covering families and locations quite adequately, contain no usable information on variations in travel cost. The data are cross-sectional, collected at essentially one point in time, and represent only the private automobile, as a mode of transportation, adequately enough for analysis. Consequently, it is not possible to explore variations in cost among the modes.

Table 23

INCOME-INDUCED CHANGES IN V/STOL TRIP DISTANCE (mi)

Minimum Family Income ($)	Commuting Trips (mi)			Business Trips (mi)		
	20	40	60	20	40	60
Base Fare						
5,000	--	--	--	--	--	--
10,000	--	--	0.1	--	0.5	5.9
15,000	--	--	0.4	--	0.7	4.8
20,000	--	--	0.7	--	0.9	4.9
Fare Reduced $0.50						
5,000	--	--	0.8	--	1.4	8.6
10,000	--	--	0.9	--	1.2	6.3
15,000	--	0.8	1.0	--	1.2	5.6
20,000	--	0.2	1.1	--	1.2	5.5
Fare Reduced $1						
5,000	--	0.4	2.6	--	2.8	11.3
10,000	--	0.5	1.9	--	1.9	7.6
15,000	--	0.5	1.6	--	1.7	6.5
20,000	--	0.5	1.6	--	1.6	6.2

blanks for all of the 20-mi trips and some of the 40-mi trips indicate that, based on the travel time and cost functions used for analysis, the income effect is not operative; i.e., air travel would be more expensive than travel by automobile for those trips. Even the estimates of the income multiplier for 60-mi trips and some of the 40-mi trips are so small that, when combined with the estimated income elasticity of 0.5, the estimated effects are rather modest. They range from 0.1 to 11.3 mi, with the most probable value being slightly more than 1 mi. The effect is greater for the longer trips and, of course, for the lower air fares.

We then combined the income effect with the substitution effect; the results are presented in Table 24. As noted earlier, the available data did not permit us to estimate the price elasticity. Hence, a value of 0.5 was assumed for these calculations.[25]

[25] Although we have no evidence concerning the actual value of the price elasticity of most other goods and services, an empirical price-elasticity estimate of 1.0 is not uncommon, and an estimate of 0.5 is usually considered low.

Table 24

TOTAL INDUCED CHANGES IN V/STOL TRIP DISTANCE (mi)

(Price elasticity = 0.5)

Minimum Family Income ($)	Commuting Trips (mi)			Business Trips (mi)		
	20	40	60	20	40	60
Base Fare						
5,000	--	--	--	--	8.9	20.3
10,000	--	--	9.1	--	10.9	21.7
15,000	--	--	11.3	--	12.4	23.4
20,000	--	7.9	13.3	--	13.6	25.3
Fare Reduced $0.50						
5,000	--	--	8.4	--	10.7	23.4
10,000	--	6.0	10.4	--	12.0	23.4
15,000	--	7.2	12.2	--	13.1	24.7
20,000	--	8.4	14.0	5.7	14.2	26.2
Fare Reduced $1						
5,000	--	5.5	10.6	4.2	12.4	26.5
10,000	--	6.8	11.6	5.0	13.0	25.1
15,000	--	7.8	13.1	5.5	13.9	25.9
20,000	4.0	8.9	14.8	6.0	14.9	27.2

The combined income and substitution effects are quite striking. That is because the estimates of the price multiplier are substantially higher than the estimates of the income multiplier. That owes, in turn, to the travel time and cost functions. The costs of auto and air are not greatly dissimilar, but the times are quite different. Airplanes travel much faster than automobiles once they leave the terminals. Hence, marginal travel times, and therefore marginal total travel costs that are based on both direct travel costs and travel times, are much lower for air transport.

The income multiplier is based on the saving in total travel costs (by switching from auto to air transport) as a percentage of the commuter's real income. Our estimates of these percentages range from 0 to over 25, but most are less than 5. The price multiplier is based primarily on the percentage change in marginal total travel costs. Our estimates are quite evenly distributed from 26 to 61 percent. With such a difference in the size of the income and price multipliers, any reasonable value for the price elasticity of commuting distance—say, above 0.2—will produce a price effect that is at least as large as the income effect, and possibly much larger.

These findings can be summarized as follows: First, the air mode would save travel costs only for the longer trip distances. Second, the income effect, where it is operative, produces mild tendencies for locational change. Third, the substitution effect is probably stronger than the income effect. Fourth, consequently, the total combined influence of the two effects may well be quite significant.

IMPLICATIONS

Our findings indicate that if intraurban air transport were introduced into the nine-county San Francisco Bay Area, the residential and commuting behavior of commuters would be affected. Workers employed in the city of San Francisco who had to commute 30 or 40 mi would find it to their benefit, considering their total commuting costs, to switch to air transport if an air terminal were located close to their homes. Furthermore, many of these commuters would be willing to move short distances to gain access to an air terminal. Those effects would be strongest for larger and more affluent households. And, of course, the more the air fares were reduced, the stronger the effects would be.

The present residential patterns of the long-distance commuters, however, are based on the present transportation system of the region. Commuters are dispersed throughout the areas served by the freeways and the major highways. Consequently, a number of widely scattered air terminals would be required if a majority of those commuters were to be diverted from their automobiles. And each terminal would serve a rather small number of travelers. The cost difference between auto and air travel and the magnitude of the locational effects indicates that each terminal would influence only those commuters that lived within, say, 8 or 10 mi of a terminal located 40 mi from downtown San Francisco. Under those conditions, the major effect of the introduction of air terminals would undoubtedly be to shape the future growth of the surrounding region. Any air terminals established in the distant suburbs that provided an acceptable level of service would likely attract significant numbers of the new V/STOL commuters to reside in the regions they served.

The Bay Area Transportation Study Commission estimates that employment in the city of San Francisco will increase by about 50 percent in the next 25 years. As the region grows and is more densely developed, we would expect the percentage, as well as the actual number, of workers commuting over 30 or 40 mi to increase. If that occurs, and if the air terminals could attract residents to outlying areas, as expected, then a small number of fairly remotely situated air terminals installed over the next several years could each be expected to serve a large number of travelers by 1990.

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