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AN ECONOMIC ANALYSIS OF FUTURE SHORT-HAUL TRANSPORTATION

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16. Abstract

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The simplified approach allowed a qualitative assessment of the relative merits of transportation modes. Specifically, the results for 1968 indicated that the auto, bus, and subsonic jet were competitive while the train was not. The helicopter could be competitive at ranges between 50 and 150 miles for time values above $5/hour. The light aircraft was particularly attractive for multiple travelers. Results for 1975 and 1982 indicated that: (1) the auto will remain the major mode for short distances; (2) the bus will remain competitive at low time values; (3) the high speed train will not be competitive unless heavily subsidized; and (4) the STOL transport will be a major transportation mode until it is replaced by the VTOL. An intensive level of R&D effort will be required to produce a competitive VTOL transport by 1982. The light aircraft mode, particularly with STOL performance and multiple travelers, appears very promising.

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SUMMARY

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INTRODUCTION

The NASA is charged with the responsibility of supporting, by basic and applied research, the improvement of civil and military aeronautics. The greatest impact on new aircraft design can be achieved if an adequate technology base is established at a sufficiently early date. Since the development of a new aircraft concept may require 7 to 10 years, and a given aircraft may have a productive life of as much as 15 years, research must be oriented toward the mission requirements 5 to 20 years hence. Increasing use is being made of advanced vehicle and mission synthesis, usually including economic or market factors, to guide such research. The Advanced Concepts and Missions Division is engaged in such synthesis of future aeronautical missions to identify attractive missions and accompanying technological problems. An effective assessment of the attractiveness of aeronautical transportation modes must include consideration of competing nonaeronautical modes. Thus, the studies are somewhat broader than mere aircraft studies, and include analyses of auto, bus, and rail systems. The studies are not complete – indeed will probably never be complete – but will be revised year by year as part of a continuing study effort in research planning.

This report presents the results of a preliminary analysis of intercity short-haul business passenger transport for the years 1968, 1975 and 1982. Two different levels of aeronautical R&D have been assumed for both 1975, and 1982, and the vehicle characteristics derived from the resulting technologies are incorporated in the analysis. The detailed analyses of the vehicle characteristics are reported separately in the appendix to facilitate the presentation of the alternate mode comparisons in the body of the paper.

The study procedure was essentially to determine the total trip cost for each transportation system by making use of a simplified economic descriptor, time value. Time value as used here is the value in dollars per hour of transit time to a traveler or his employer. Simplification of this descriptor is perhaps misleading in that the value of time can be an extremely subjective variable. Efforts have been made to establish a function for the value of time saved in travel (e.g., ref. 1), but no unequivocal results have been obtained. Therefore, the results of this study are presented in terms of time value as a parameter, leaving the reader free to assign his own significant level. By investigating the changes in the travel modes that affect the travel costs, some indication of mode attractiveness and sensitivity can be obtained. A similar analysis of a wider range of general aviation aircraft and their missions is presented in reference 2.

GENERAL TRANSPORTATION CONSIDERATIONS

Figure 1 provides a background of historical trends of U.S. growth in population, gross national product (GNP), and transportation (in passenger miles). It is apparent that transportation is growing three times faster than the population, and at a comparable rate to GNP. Furthermore, there is no apparent reason, other than continually increasing congestion or possibly an advancement in communications technology, to expect these trends to change greatly in the next decade. The dashed curves show the growth that would result from the indicated annual rates of increase.

The annual expenditures in the United States for transportation are about 20 percent of the GNP, and more than half of this is expended for passenger transportation. The breakdown of these expenditures is given in figure 2, which was developed from data in reference 3. The total cost is divided into private and for-hire categories, with the for-hire category being further divided into local, intercity, and international segments. The major expenditures are in the private category, primarily private auto; while in the for-hire category, the largest single element is intercity air.

As indicated previously, the study considered only intercity trips. The historical division of the intercity market among transportation modes is shown in figure 3, with a projection to 1980. These projections are based to a certain extent on the results of the current study, and are discussed in detail in the appendix; the basic data were obtained from reference 3. The private auto is responsible for the overwhelming majority of passenger miles, although its share may have decreased slightly in recent years. The next largest element is commercial air, then bus and rail. It is likely that the air modes, both commercial and private, will continue to increase their share in the future; bus will retain about a constant percentage; and rail will lose ground initially and then remain constant. Note that the respective shares of rail and private air transportation are expected to be equal for 1969.

The emphasis on air modes in this paper results, then, not only from the NASA commitment to aeronautical research but from the primary importance of air travel, both commercial and private, to the total transportation system.

RESULTS AND DISCUSSION

Mode comparisons are presented in figures 4 through 14 for 1968, figures 15 through 17 for 1975, and figures 18 through 20 for 1982. For easy reference, figures 21 through 31 summarize the results for the individual modes. The transportation modes considered are as follows:

Mode	1968	1975	1982
Ground			
Auto	√	√	√
Bus	√	√	√
Train	√	√	
Rapid train		√	√
Air			
Light aircraft	√	√	√
Helicopter	√	√	√
STOL		√	√
VTOL		√	√
Subsonic jet	√	√	√
Third level	√	√	√

Method of Comparison

In performing the evaluation of the alternative transportation modes, each mode is assumed to be utilized in the business trip model shown in figure 4. Each round trip consists of two major trip segments and four interfaces. The interfaces include all the local transportation costs and "fumble" times required to get the traveler to and from his major trip segment. The interface times and costs for all conditions studied are given in table I and discussed in the appendix. The total trip cost is then considered to be the transportation cost plus the value of the traveler's time. Although there is no agreement as to the value of a traveler's time (values from \$0 to \$40/hr have been quoted), the value of time was a useful parameter for the purposes of this study.

The economic and performance characteristics of each mode and its interfaces were estimated; charts such as figure 5 were generated in which the traveler's time value is given as the ordinate and trip distance as the abscissa. The trip cost results for each mode into areas were used to divide the charts representing minimum-cost transportation modes. The dividing lines represent loci of points of equal cost between two modes. Thus, for the case shown in figure 5 (single business traveler, standard interface, 1968) at a time value of \$5/hr, the most economic mode is the auto for trips shorter than 50 miles, the light aircraft for trips between 50 and about 160 miles, and the subsonic jet for greater distances. The results in figure 5 are believed to be representative of the situation as it exists today, with the auto, bus, light aircraft, helicopter, and subsonic jet sharing the time value and distance spectrum if it is assumed that the traveler's employer owns the auto or light aircraft and the traveler drives (pilots) himself. Lines of constant total trip cost (including time value) are also shown. Auxiliary scales have been added to show the cumulative total (ref. 4) of travelers in terms of distance and income. These scales indicate the relative importance of the various chart regions if salary is considered as a measure of time value.

Charts such as figure 5 are used herein to evaluate the impact of changes in technology, economics, and interface characteristics, and hence the relative attractiveness of modes and their potential for improvement. This analysis, simplified for purposes of the present study, necessarily ignores many subjective elements in transportation selection and makes no attempt to define the actual market for a particular transportation mode.

1968 Single Traveler

Urban interface and mode availability- The situation in figure 5 utilizes a particular combination of interface characteristics called "standard interface" (see appendix) and assumes full availability of all travel modes. The effects of changes in these conditions are examined in figure 6. For example, the use of the "urban interface" characteristics (derived from the specific characteristics of a trip from Boston Common to Rockefeller Center in New York City) results primarily in a large expansion of the helicopter region and a lesser expansion of the bus region (fig. 6(b)). This expansion completely eliminates the light aircraft mode and substantially reduces the subsonic jet and auto regions. It is quite apparent that for the interface situation currently existing in many urban areas, particularly in the northeast, the helicopter offers considerable potential for stage lengths between 50 and 250 miles. Helicopter service today is basically intracity, serving in an airport feeder function, as shown by the distribution of present stage lengths in figure 32. The great majority of stages occur at distances of less than 20 miles. In fact, only three stages fall in the region indicated as most favorable to the helicopter for intercity travel. Thus, there is no real verification of the indicated promising utility of the helicopter in this distance regime.

The actual situation in urban areas is more nearly represented in figure 6(c) where the helicopter is assumed to be unavailable as an intercity transport mode. In this case, the bus takes over most of the high traffic (low time value) portion of the helicopter area except at the longer ranges. (The vertical line at 165 mile distance is associated with an overnight stop.) That the bus is an economical mode in this intermediate range is reflected in intercity travel statistics, reference 3, which show that buses carry the greatest *number* of passengers of all common carriers. The average bus passenger trip is 50 miles, however; for all air travelers, it is 630 miles (≈ 220 miles for all local airlines), and the airlines, therefore, account for a greater number of passenger miles. The number of bus passengers has remained fairly constant with time, although the average trip length has increased slightly; while the number of rail passengers is decreasing, and air passengers is increasing considerably. The poor growth picture for the bus is a result, of course, from the fact that it competes directly with the auto, the use of which has doubled since 1950 and which accounts for almost 90 percent of all intercity transportation. If the bus is omitted from consideration in figure 6(c), the dashed lines are obtained showing that the auto takes over the majority of the bus area. The auto has advantages of privacy, independence, and flexibility that considerably offset the economic advantages of other modes, although these factors in turn are partially offset by traffic congestion, parking, and similar problems.

It might be noted that when the bus is eliminated from figure 6(c), the train finally appears at the lowest time values. The primary deficiencies of the train in the present transportation picture result from its very low block speed, high fare (relative to the bus), and inflexible routing.

The poor showing of the light aircraft in the transportation picture with the urban interface results from its extreme access time and cost. However, interface time and cost can be reduced if a business enterprise is able to take advantage of current STOL light-aircraft performance, which permits operation from moderate sized parking lots or building roofs. As shown in figure 6(d), despite an increase in first cost of about 35 percent or more, such an aircraft would be the most economic transportation mode to a distance of about 140 miles at all time values above $4/hr. At greater ranges, the commercial helicopter, if available, offers a lower per mile cost, making it the preferred mode.

Fare structure- The standard case utilized fare structures based on particular situations. For example, the subsonic jet fare was based on current jet coach fares. The effects of a considerably modified fare structure on the data in figure 5 were studied using a fare structure based on that existing in the "California Corridor," resulting primarily from the activities of PSA (Pacific Southwest Airlines, an intrastate carrier). Such a fare structure, of course, would require a higher load factor (about 67 percent according to ref. 5) to break even than would the standard fare structure (about 50 percent). The results shown in figure 7(b), indicate substantial penetration by the subsonic jet to shorter trip distances at all time values. This improved competitive situation is verified to some extent by the very pronounced traffic growth actually experienced by PSA and its competitors in the California Corridor.

Figure 7(c) indicates the effects of certain improvements in helicopter. In this case the fare is reduced, and the speed is increased. These improvements, discussed in the appendix, are representative of proposed civil versions of current military aircraft, and although modest, they result in substantial improvement in the helicopter's competitive position, mainly at the expense of the light aircraft and subsonic jet. Under these circumstances the helicopter appears attractive even at low time values at distances to 200-250 miles.

If the effect of cost increases (toll roads) on auto travel are considered (fig. 7(d)), it is found, as would be expected, that the auto region is reduced at all time values, with the greatest reduction occurring at low time values where the bus takes over.

Light aircraft utility- At the start of the study, the light aircraft with its known high costs and low utilization was not expected to be a particularly strong contender as an economic mode of transportation. Indeed, as shown in figure 33, the average personal light aircraft is flown less than 100 hr/yr, and the average business light aircraft is flown less than 300 hr/yr. These figures compare unfavorably with the average for personal auto use, which is estimated to be 250 to 400 hr, depending on geographical location. However, the speed of the light aircraft considerably offsets its high operating cost, and in many situations it is shown to be quite competitive. The general aviation portion of these studies is presented in far greater detail in reference 2.

The attractiveness of the light aircraft is greatly affected by its utilization as shown in figure 8(b). In this case, a reduction of utilization from 300 to 200 hr/yr has increased the light aircraft per mile costs to such an extent that it is virtually eliminated as an economic mode. Similarly, if the use of a light aircraft requires the use of a rental car (100 miles rental) at destination, figure 8(c), its attractiveness is reduced. This situation may result from airspace restrictions near large traffic hubs or from a lack of convenient general aviation airports.

The STOL light aircraft discussed previously for the urban interface (fig. 6(d)) is considered in figure 8(d) for the standard interface; again, very good potential is indicated.

1968 Four Travelers

Number of travelers- Figure 9 shows the transportation situation involving four travelers. The light aircraft with the standard interface is the most economic mode over the majority of the ranges and time values, even to 500 miles at the lowest time values. If the light aircraft is unavailable, the effect of multiple travel is for the auto to be preferred at the expense of the bus and helicopter (and, at low time values, at the expense of the subsonic jet).

Light aircraft hire- The light aircraft appears to be quite attractive as an economic mode of transportation if, as has been assumed previously, one of the travelers is a pilot and the business owns the aircraft. Although this practice is increasing, it is still exceptional. The situation that exists if a full-time professional pilot must be hired is shown in figure 10(b), and it can be seen that the pilot costs (see appendix) render the light aircraft unattractive. If, on the other hand, one of the travelers is a pilot and the aircraft is rented, a considerably more favorable situation results, as shown in figure 10(c). Finally, a complete charter (pilot and light twin aircraft), figure 10(d), is shown to be attractive in the 50-200-mile range at time values above about $5/hr.

Clearly, the utility of light aircraft would be greatly improved if the factors that force the hiring of the professional pilot were alleviated. Primary among these factors is piloting, which involves expert skills in which proficiency must be maintained, particularly if IFR flight is required. Research in the fields of handling qualities, avionics, training, and simulation has been in progress for a long time, yet this remains a fertile field holding promise of increased light aircraft utility.

Urban interface- When the urban interface is considered for the case of four travelers (fig. 11(b)), somewhat the same effects as for the single traveler are noted. The helicopter is a dominant mode, and the auto takes over virtually the entire low time value area. The light aircraft, bus, and train are noncompetitive.

The STOL light aircraft with the urban interface (fig. 11(c)) is even more attractive with four travelers than with one. In fact, with four travelers even the cost of a professional pilot (fig. 11(d)) may not be prohibitive.

Light aircraft economic benefit - The significance of the light aircraft as a transportation mode may depend on the magnitude of potential savings, which in turn depends on the individual traveler's time value and length of trip, as well as situations peculiar to different businesses. A rather simplified case has been considered, and the results are shown in figure 12. In this case, it was assumed the light aircraft was operated 300 hr/yr and always carried four passengers whose average annual salary was between $7,500 and $15,000. Both normal and STOL light aircraft were considered in the standard and urban interfaces. The annual savings are shown as a function of trip length for bands bounded by the two salary levels. It is apparent that the distance is of primary importance, with maximum savings being obtained between 100 and 200 miles, and appreciable savings indicated out to 300-400 miles. Savings in the urban interface situation are possible only with the use of STOL light aircraft. The rather abrupt cutoff at 450-500-mile distance reflects range limitations of the aircraft. Greater range required in a particular situation could be obtained at a slight economic premium. The distribution of savings agrees reasonably well with the distribution of trips shown in figure 34. Of course, each business would have its own peculiar trip patterns, but it appears that the savings that might be expected through use of a light aircraft, particularly of a STOL type, are great enough to warrant serious consideration of such aircraft as a routine transportation mode.

The savings discussed above assume operation of the aircraft without a professional pilot, whose salary would absorb a large portion of such savings. For the full potential of the light aircraft to be realized, it must be easier to fly, have better performance (primarily STOL), have better (lower-cost) electronics, and be designed for greater crashworthiness and higher reliability. Although actual IFR weather conditions exist only about 15 percent of the time, IFR capability is desirable for schedule reliability as well as to satisfy requirements for operation in congested areas; this greatly increases the electronic and training/proficiency problems.

In addition, for maximum utility and reduction of congestion, a considerably increased number of conveniently located general aviation airports would be required. The congestion that would result from the availability of aircraft having such high utility would probably require substantial advances in avionics, particularly for air traffic control, collision avoidance, and all weather equipment, to attain an acceptable safety record while still maintaining utility. These systems would affect operating costs of the aircraft and might tend to degrade its competitive advantage. This is considered in the 1975 and 1982 portions of this study.

Third-level airlines - The time-value analysis is also applicable to different types of transport operations. An example of this is shown in figure 13 for two third-level airline missions: mission A, from a remote general-aviation airport to a city STOLport or general aviation airport (subsonic jet service not available); and mission B, intercity between STOLports or general aviation airports (subsonic jet service competing, but at an interface disadvantage). A comparison of figure 13 with figures 10 and 11 shows that the helicopter cannot compete with the third-level airline operation. The third-level airline cannot compete with the light aircraft for four travelers; however, if the light aircraft is not available (as shown by the dashed lines), the third-level airline is quite competitive.

The potential of third-level operations is being reflected in a rapid increase in the level of such operations. An indication of this growth is given in figure 14, which shows the situation in California as of October 1968, when 9,021 route miles of such service were operational and another 6,500 were proposed. Similar growth is being experienced in other areas of the United States.

1975

When considering the air transportation picture for the future, the mode characteristics depend to a considerable extent on the R&D emphasis that each mode receives. This, of course, is the primary reason the Advanced Concepts and Missions Division is performing this study; it is hoped that by examining the relative merits of various aeronautical modes at several levels of R&D emphasis, some guidance can be obtained as to the promising modes and the level of R&D required. Two levels of R&D have been considered in this study: Level I, evolutionary development of each mode; and Level II, intensive R&D directed toward specific mode. It should be noted, however, that no technological breakthroughs or revolutionary modes of transportation are postulated. The improvements in technology that have been assumed are discussed in the appendix. In the evaluation of the relative merits of the air and ground modes, the latter have been assumed at Level II in every case.

Level I technology- The effects of number of travelers and type of interface are shown on figure 15 for Level I technology in 1975. Comparison of figure 15 with figure 6(a) indicates that for the standard interface and a single traveler, the helicopter of 1968 has largely been supplanted by the light aircraft and STOL transport in 1975. The effects of an 8¢/gal aviation fuel tax on all air modes was considered and, as shown, had little effect. When the fuel tax was applied, the 5 percent excise tax on the commercial air mode fares was removed. If four travelers are considered, figure 15(b), the light aircraft is the most economic mode beyond 40 miles. The dashed lines indicate the situation in which the light aircraft is unavailable, with STOL, helicopter, subsonic jet, and auto sharing the area.

For the urban interface, single passenger, figure 15(c) shows no light aircraft. Bus, STOL, and subsonic jet are the main transport modes. The helicopter appears at high time values, and there is a small train area near $10/hr and 30 to 60 miles. When four travelers are considered, figure 15(d), the auto takes over most of the bus area, and light aircraft hold a small share beyond the 100-mile range.

Because the appearance of the train in the figure was felt to warrant a more detailed examination, an analysis of the train was made (see appendix). Figure 16(a) shows that if the fare were reduced 20 percent (equivalent to either 60 percent load factor or twice as many seats per day), a small train area appears on the standard interface chart. If no light aircraft were available, a small train area would be found at about 40-50 miles, figure 16(b). In the urban interface, figure 16(c), an increase of 20 percent in the train fare eliminates the train, and a reduction of 20 percent extends the area to a 150-mile distance and a low time value of $4/hr. It should be pointed out that the stop interval used here is 40 miles, so the shorter ranges introduce penalties. In fact, a stop distance of 20 miles, figure 16(d), renders the train uneconomic.

Level II technology- The major effect of going to a high technology level, figure 17, is to increase greatly the attractiveness of the light aircraft, even to the exclusion of the automobile at distances as short as 20 miles. This results primarily from the great improvement in airport performance expected with this aircraft. Such performance would permit the use of close-in airports, with corresponding reduction in interface time. The future short business trip with such aircraft could well be by air from factory parking lot (or roof) to factory parking lot (or roof). Again, in figure 17, if the light aircraft is not available (shown by the dashed lines), the helicopter and the STOL are the primary air modes.

1982

Level I technology- Figure 18 shows that 1982 Level I is quite similar to 1975 Level II, with the light aircraft being a major element. If it is not available, the helicopter and STOL are the major air modes as shown by the dashed lines; and the bus is economic over a larger area at low time values (third-level airlines are considered in fig. 19). As in 1975, the rapid train does not appear with the nominal fare structure (the 1975 train was also considered in the 1982 case, but it offered even less competition). The effects of arbitrary reductions in the train fare are shown in figure 19; at reduced fares, the train becomes economic at high time values and short ranges.

Level II technology- In 1982 Level II (fig. 20), the VTOL has finally become sufficiently economic to appear. It and the light aircraft divide the short-haul market. If the light aircraft is unavailable, the VTOL area expands to meet the auto and bus at the shortest ranges. The STOL is competitive at distances beyond 500 miles; in fact it and the subsonic jet may merge into a single mode, particularly in an urban environment such as the New York-Chicago route.

Summary of Transportation Mode Characteristics and Results

Characteristics and results for the individual modes are summarized in this section; detailed analyses and the assumptions included for each mode are covered in the appendix.

Auto- The auto is summarized in figure 21. It is apparent that no major changes to the auto are expected in the next 15 years, although improved highways will allow a small speed increase. The auto will remain the major mode for short distances, although in the latest time period at Level II its competitive range will be substantially reduced by the light aircraft and VTOL.

Bus- The intercity bus, figure 22, is quite similar to the auto in performance; however, some improvement results from nonstop operation and increased capacity. It is competitive at low time values at distances of up to 250 miles throughout the time period. In 1982, the bus will be competitive only at zero time value.

Train- The train, figure 23, will undergo considerable change in assumed performance as a result of advanced technology, attaining cruise speeds of 125 mph in 1975 and 200 mph in 1982. The train is expected to be generally noncompetitive under the nominal assumptions of the study. The only case where it will be competitive is for a single traveler in the 1975 urban interface, where it is shown to be the preferred mode at about $10/hr time value and 40-mile range. A fairly detailed look was taken at the train because of its current interest. It was found that if the fares were reduced 20 percent (by subsidy, a load factor of 60 percent, or doubling the assumed seats at 50 percent load factor), a considerably improved competitive situation was obtained for 1975, down to $5/hr time value and to a 120-mile range. In 1982, however, the train will be noncompetitive even at 200 mph cruise unless heavily subsidized, because of the high right-of-way costs incurred by the high speed operation. It should be pointed out that subsidy makes the train economic for people having time value near $10/hr and traveling short distances, perhaps suburb dwellers commuting to work.

Helicopter- The helicopter, figure 24, is generally competitive at time values above $5 to $10/hr at distances up to 100 miles. In 1982, the compound helicopter is noncompetitive at Level II due to the greatly superior performance of the VTOL.

Light aircraft- The light aircraft, figure 25, is one of the modes in which the greatest response to R&D can be expected. Only moderate improvements of speed performance were postulated in this report, but major improvements in airport performance and aircraft cost were projected. As indicated, the light aircraft could be a major competitive mode in each time period and out to the longest ranges with multiple travelers. In fact, if only performance and economics are considered, the light aircraft appears to take over from the auto as the logical mode at ranges beyond those for strictly local transportation. The qualification above is important; there are problems with light aircraft that have little to do with operating cost or performance: Ease of piloting must be improved, dependence on good weather reduced, etc. Certainly if this promise is to be realized, there must be a great expansion in airport facilities and some completely new approaches in air traffic management.

Figure 26 compares the traffic capacity at a major airport handling a high proportion of air carrier traffic under IFR conditions with general aviation airports handling VFR traffic. It is apparent that under VFR conditions, even small, simple airports have the potential of handling much higher general aviation traffic levels than are considered normal today. Neither of the general aviation airports is particularly well designed for high traffic level. Rockford is particularly poor, yet on several occasions it has demonstrated a capacity for conducting 600 operations per hour. Examination of these and other experiences should point the way toward major airport improvements. Clearly, large traffic-handling benefits could result from avionics improvements oriented towards making IFR flight more similar to VFR operations.

STOL- Although not in service today, the STOL aircraft, figure 27, is expected to be a major competitive mode at all time periods and technology levels until, in 1982 at the highest technology level, it will probably merge with the subsonic jet at greater than short-haul ranges.

VTOL- The VTOL, figure 28, is noncompetitive until 1982 at the high level of technology. Although VTOL concepts are available for earlier application (and may be used), they will probably be unable to compete economically with advanced helicopters or STOLs until 1982, even with concentrated effort in advancing their technology. However in 1982 and beyond, the VTOL will probably be the major short-haul intercity mode of transportation. Note that if the light aircraft is not available, the commercial VTOL and the auto divide the short-haul market except for a small bus area near zero time value.

Subsonic jet- The subsonic jet, figure 29, is always at the top end of the short-haul range. In 1982, its minimum competitive range will be above 500 miles, considered the short-haul limit and it holds a considerable area between the 500-mile range and the point where the SST takes over.

Third level- As a matter of interest, the third-level airline operations have also been considered in the same time period, figure 30. These operations appear to be competitive throughout the time period. One caution should be noted, however. The economy of these operations is extremely sensitive to government regulatory policies, crew costs, and safety requirements.

The part of the Federal Air Regulations under which such aircraft are certificated (and whether the 12,500-lb limit remains) can have a strong effect on the initial cost of the aircraft involved. The direct operating costs of third-level carriers can be drastically affected by change in crew costs. If the FAA should specify higher standards for the crew, its direct operating cost increase may make the service uneconomic. State Public Utility Commission control over routes and service, and local government control over terminals noise restrictions etc. can also have a profound effect on the overall system economics.

CONCLUDING REMARKS

A major objective of the Mission Analysis Division in conducting these studies has been to identify promising research areas among the various air modes. Promising research areas are listed in figure 31 for near term (i.e., areas requiring immediate attention) and longer term, which includes areas believed critical in the period starting about 5 years from now. The list is not exhaustive but is intended primarily to give a general feel for the type and phasing of research efforts. For example, the current helicopter problem areas are indicated, but longer term problems are primarily related to the VTOL aircraft that will supplant the helicopter for the short-haul mission. Immediate light aircraft problems are in man/machine dynamics relating to ease of flight, safety, and low cost. If work in these areas is moderately successful, the longer term problems will result from the extreme popularity that general aviation will attain. The immediate problems of STOL aircraft relate to problems of operation and establishing economic service, and longer term efforts relate to improving efficiency. Current VTOL studies should be oriented toward attaining basic research on various approaches and systems to provide the base on which high performance, economic systems can be developed.

National Aeronautics and Space Administration
Moffett Field, Calif., 94035, Dec. 7, 1970

APPENDIX

ANALYSIS OF VEHICLE CHARACTERISTICS

The individual transportation mode characteristics assumed for the study are presented in this appendix, along with a discussion of traffic growth and traffic projections made in the study. Speed and cost are the necessary inputs to the time value analysis; however, several distinctions are drawn among the various modes as to presentation of speed and cost. The costs (in 1968 dollars) for privately owned, rented, and chartered vehicles (auto and light aircraft) are shown as vehicle cost per mile, and the passenger cost for common carriers is presented as fare per seat mile. Speed is presented as block speed, varying with range, except for the automobile, intercity bus, and standard train, which have fixed block speeds. A nominal cruise speed is also indicated for the various modes. The block speeds, unless quoted from other sources, are calculated from a combination of fixed maneuver time, acceleration at 0.1 g to cruise speed, and cruise for appropriate range.

Common carrier fares for 1968 are taken from published tariffs, and, unless otherwise indicated, fares for the 1975 and 1982 common carriers are based on equating indirect operating cost (IOC) to direct operating cost (DOC) and assuming that the fare is equal to the total operating cost (TOC = DOC + IOC) divided by the load factor, plus a 10 percent profit. A 5 percent excise tax is included in the fares shown for the airborne common carriers. A 10 percent discount for round trips is included in the computations for the train modes. Table II summarizes the assumed intercity costs and speeds for all the transportation modes. These assumptions are discussed individually for each mode.

Table I presents the assumed interface costs and times that are added to the calculated intercity costs and times to obtain the total inputs for the comparisons. Data for two interfaces are shown: a "standard," considered applicable to most of the country, and an "urban," which was based on an assumed round trip from Boston Common to Rockefeller Center in New York City. The standard times include access time from the point of origin to a terminal or, in the case of the automobile, an intercity highway. The times shown also include risk allowances for ticketing, embarking and disembarking, baggage handling, walk through the terminal, etc. The light aircraft times differ in that allowances are made for preflight, clearance, tiedown, etc. The access times and allowances are duplicated for the return leg of the trip. The interface costs assumed were for automobile expenses for pickup and delivery at the beginning and end of each leg of the trip (no driver costs or parking fees were assumed).

For the urban interface, the costs and times are those specifically established for the round trip from Boston Common to Rockefeller Center. Taxis and airport limousines (where appropriate) were used for all modes except the automobile and STOL light aircraft. When it was more economical (multiple travelers), taxis were considered instead of airport limousines.

A unique consideration for both standard and urban interfaces was given to the STOL light aircraft in that a STOLport was assumed to be adjacent to both the origin and destination with consequent reduced times, and a landing fee at the destination was charged as an interface cost.

The 1968 modes presented are for a nominal economic performance, typical of current practice. For the 1975 and 1982 air modes, two levels of economic performance are shown, resulting from the two levels of R&D assumed for the study.

TRAFFIC PROJECTIONS

The rationale behind the intercity passenger-mile projections presented in figure 3 are discussed below for each mode of travel.

Total Traffic

The total intercity passenger miles will continue to increase, at an assumed 4 percent rate (compared with the current rate of 4½ or 5 percent) until 1975, after which, as congestion reduces automobile utilization, the rate will be 3 percent. By 1980, the yearly increase may again be at a higher rate due to greater use of advanced aircraft, both commercial and private.

Water

It is assumed that waterborne traffic will increase at a rate greater than the projected population increase (assumed to be 1 percent herein), due to increasing use of GEM and hydrofoil equipment and increasing popularity of boating and available leisure time. A 2 percent growth rate was used (twice the assumed population rate).

Rail

Rail passenger traffic will continue to decrease for the next few years as uneconomic runs are discontinued. It is expected that the rail traffic share will level off about 1975 as the decrease is counteracted by the introduction of new equipment. Rail traffic, as a percentage of the total, will remain static as the increase due to new equipment will be insufficient to offset greater increases in air, bus, and auto.

Bus

The bus system will increase its share slightly as the interstate highway system is completed and the secondary road systems are improved. Further increases in the 1980s will depend on new techniques (such as automated highways and special bus lanes) or perhaps regulatory restriction of automobiles. New technology will probably not increase the bus percentage, since the technical developments would apply to the automobile as well. It is assumed that the bus share would remain constant after 1980.

Private Air

The general aviation share is probably the most uncertain projection. The estimate in figure 3 was made by extrapolating the FAA projection of aircraft population (ref. 6) of 203,000 in 1979 to 270,000 in 1985. The current (refs. 6 and 7) utilization of 200 hr, average speed of 180 mph, and average occupancy of 3.1, were extended to 300 hr, 200 mph, and 3.5 occupants for 1985. The FAA aircraft population projections are considered conservative; a more recent projection (ref. 8) expects 260,000 aircraft by 1980. The enlarged share ascribed to general aviation assumes that there will be no additional restrictive regulations imposed.

Airlines

Reference 9 estimates that airlines will produce 420 billion passenger miles in 1985, based on 14.9 percent annual growth to 1970, 9.4 percent to 1975, 7 percent to 1980, and 5.6 percent to 1985. This 420 billion passenger-mile estimate is considered reasonable; the probable increase in the number of people using private air will not offset the larger number transferring from auto to commercial air.

GROUND TRANSPORT MODES

Automobile

Costs and speeds for this mode are summarized below.

	1968	1975	1982
Cost per mile	$0.07	$0.07	$0.07
Cruise speed, mph	58	62	65.5
Block speed, mph	44	47	49

The nominal automobile costs include $0.038/mile operating cost (ref. 10) and $0.032/mile depreciation. The automobile is depreciated 42 percent for 2 years and 40,000 miles (fig. 35). The initial cost of $3,045 for a standard U.S. four door sedan and the depreciation were taken from reference 11. Although the nominal cost per mile is projected to remain constant, the nominal speed continues to increase (fig. 36) as a result of highway improvements. A poor economic performance model considered a 1.5 cent/mile or 2.5 cent/mile cost increase, reflecting possible costs of pollution control or highway improvement (through toll charges). Although cruise speeds for the automobile were relatively high as shown above, a rest stop of 15 min every 2 hr and a 30-min meal stop every 4 hr were included, resulting in the indicated block speeds that were used in the computation of overall speed and trip times.

Intercity Bus

Fares and speeds are summarized below.

	1968	1975	1982
Fare per seat mile	$0.03	$0.03	$0.0368
Cruise speed, mph	58	62	65.5
Block speed, mph	44	62	65.5

The current bus fare was taken from reference 12, and the 1975 and 1982 fares are simple extrapolations of previous fares from reference 13 (see fig. 37) in 1968 dollars plus a 10 percent surcharge for nonstop service, using an 80-passenger articulated unit.

The simplified fare projection model based on 50 percent load factor and 10 percent profit was examined for the bus. Data from reference 13 show for 1965 intercity buses:

Direct Operating Cost	Dollars (in thousands)
Equipment, maintenance, and garage	$ 76,604
Transportation	189,690
Depreciation	35,108
Amortization	46
Toll, tax, and license	41,495
Rent	9,585
	$374,405
Indirect Operating Cost	
Station expense	$ 79,826
Advertising and solicity	17,757
General and administrative	46,128
	$143,712
Total Operating Cost	$518,117
DOC	72.3%
IOC	27.7%
Operating revenue	$611,861
TOC + income tax	$556,000

$$\frac{\text{Revenue}}{\text{Total cost}} = 1.10$$

These figures show that the 10 percent profit assumption is applicable to the bus mode. Reference 13 indicates that average revenue per seat mile for 1965 was $0.0288. Reducing this figure by the 10 percent profit and 50 percent load factor gives a TOC of $0.0131 per available seat mile. For a 40-passenger bus, the operating cost would be $0.524/mile, which compares reasonably well with the $0.542/mile reported in reference 13.

The bus speeds were assumed to be the same as the automobile, including the rest stops and meal stops for 1968. However, a nonstop bus was postulated for 1975 and 1982, and the block speeds were the same as the cruise speed.

Standard Train

Fares and cruise speeds of the standard train are as follows:

	1968	1975
Fare per seat mile	$0.0373	$0.0383
Cruise speed, mph	40	45

The 1968 train average block speed was assumed to be 40 mph from reference 14. The current train fare was based on reference 15 (a 1966 train timetable) and extrapolated as shown in figure 38, which is based on references 16 and 17. The extrapolation is displaced from the average data shown to account for the usual 10 percent round trip discount for train passengers (the discount is included in the computations for this study). The 1975 standard train fare is a simple extrapolation of these data. The 1975 train speed was arbitrarily assumed to increase to 45 mph to account for possible car improvements.

Rapid Train

To establish the rapid-train system characteristics, a model was assumed consisting of a 500-mile linear route having 13 stops (at approximately 40-mile intervals), three of which were major centers, one at each end of the system and one in the middle. Half-hour frequency of service on weekdays and hourly on weekends from 6 a.m. to midnight was assumed from each of the major centers. The average train consisted of six cars having a total of 500 seats. This service results in 9.984×10^6 train miles/yr; 16,000 seats/day in each direction (weekdays); and 4.992×10^9 seat miles/yr. The daily total of 16,000 seats can be compared with the 1960 total, for all transportation modes, of 19,000 trips/day in each direction between Boston, New York, and Washington (ref. 18).

The rapid train in 1975 was assumed to have 125-mph cruise speed. Since this train was assumed to operate on the existing right of way, four slowdowns to 75 mph in each 40-mile segment were included, even though the roadbed was materially upgraded, to account for curves and sections too costly to reroute. The 1982 rapid train had a cruise speed of 200 mph, and, since a new right of way and roadbed were assumed, no slowdowns between stations were included. Block speeds for these trains are shown on figure 39. Both the 1975 and 1982 trains stopped 2 min at each station and accelerated at 0.1 g. Stop duration and train acceleration rate were varied systematically (1 to 5 min and 0.05 to 0.15 g) and were found to have only secondary effects on the economic performance of the train system.

The basic economic assumptions used in the 1975 and 1982 train analyses are given in table III. Most of the cost numbers are based on ref. 19. Costs for 1982 are shown for both a direct step from the current system and for an upgraded 1975 system. The yearly capital costs differ by little more than 1 percent, so only the direct (from 1968) system was used in the comparisons for 1982. It was assumed that the 1975 system would not require the purchase of additional right of way beyond that of the existing rail system. The 1982 system, however, would require considerably more land in order to straighten curves and provide more separation between passing trains. Consequently, an average acquisition cost based on reference 19 was used. Land work for 1975 is correspondingly small; however, track costs are almost as great as for the 1982 train. Rolling stock costs were based on the following relationship obtained from the DOT: cost = $\$10.6 \times (\text{weight})^{0.86}$, or \$286,000.The car weight (142,000 lb) was assumed the same as for the Budd "Metrocars" (ref. 20). The higher cruise speed for the 1982 train results in a reduction (from 156 to 102) in the number of cars required to provide the stipulated service.

Operating costs for the 1975 and 1982 trains are shown in table IIIb. Again, the costs shown are based on reference 19. The direct operating costs were taken to include the same items as for airline DOC:

Crew

Fuel (electricity) and lubricants

Insurance

Maintenance

Rolling stock depreciation

Some of the background used in deriving these costs is given in the table. The indirect costs include:

Right of way maintenance

Fixed installation maintenance

Maintenance burden

General traffic management

Miscellaneous

The rapid-train fare structure is shown in table IIIc for varied capacity and load factor. The fares were obtained by combining the above operating costs and capital costs, dividing by the load factor, and allowing 10 percent for profit, taxes etc.

Helicopter

Fares and cruise speeds for the helicopter are summarized below.

	1968		1975		1982	
	Nominal	Improved	Level I	Level II	Level I	Level II
Fare	$4.56 + 0.083/mi	$ 4.33 + 0.0707/mi	$2.10 + 0.118/mi	$2.14 + 0.089/mi	$2.03 + 0.085/mi	$2.03 + 0.085/mi
Cruise speed, knots	122	148	195	220	280	280

The 1968 helicopter block speed and fare were taken from reference 21, and are shown in figures 40 and 41, respectively. Figure 42 presents a DOC curve for the 1968 helicopter that was derived from the fare structure of figure 41, by assuming 50 percent load factor, no profit, and a fixed $1.50 per available seat IOC. A DOC figure of $0.065 per available seat mile for the helicopter airline (ref. 22) used as a reference in this study is shown on the figure for comparison. Reference 23 indicates that a 65-passenger civil version of current heavy military helicopters would have a DOC 15 percent less at 250-mile range than the current 28-passenger helicopter used by the reference helicopter airline. Figure 42 shows a DOC curve for this larger helicopter based on this 15 percent reduction. Using this DOC and the above assumptions of IOC, 50 percent load factor, and no profit, the fare structure was estimated for the larger helicopter. Block speeds for the two helicopters are compared in figure 40.

The 1975 Level I helicopter assumed for this study is a 90-passenger compound similar to that proposed in reference 24. A DOC for this helicopter was calculated by the use of the ATA formula, modified for V/STOL aircraft (ref. 25), and is shown in figure 42; block speed is shown in figure 40. The fare for this vehicle was based on setting IOC = DOC and using 50 percent load factor and 10 percent profit. The 1975 Level II helicopter was assumed to be a 90-passenger jet-flap rotor, incorporating improved structures, increased rotor L/D, drag reduction (hub area), and advanced avionics. A reduction in maneuver time (air and ground) from 6 min (for Level I) to 4 min was also assumed in calculating block speed (see fig. 40). The chosen cruise speed of 220 knots was arbitrary, but considered to be representative of performance that could be available. The DOC was based on the 1985 helicopter costs predicted in reference 26, but increased 15 percent because it was felt that structures would not be as advanced. The fares were obtained by setting IOC = DOC, and using 50 percent load factor and 10 percent profit.

The 1982 Level I helicopter was assumed to be a jet-flap rotor similar to the above, but with more advanced structures and a higher cruising speed. The DOC, again based on reference 26, was increased only 10 percent. The fare was derived in the usual way; IOC = DOC, 50 percent load factor, and 10 percent profit. For 1982 Level II, the pure helicopter was not competitive and was replaced by the VTOL. For Level II, the Level I helicopter was assumed but with fully advanced structures.

Light Aircraft

The light aircraft cost breakdowns are presented in table IV, and block speeds are presented in figure 43.

The 1968 standard light aircraft is representative of several popular, single-engine, four-place aircraft. The first cost includes a $2,000 allowance above that of the average for additional optional equipment (avionics). The cost of the STOL aircraft included a $3,500 first-cost increment, based on current costs of a light aircraft STOL conversion (ref. 27), resulting in a cost per mile of $0.115, or $0.435 if a professional pilot is required. The rental aircraft cost per mile of $0.128 results from assuming a $16/hr rental charge (3 hr/day minimum) based on a local survey indicating that $15-17/hr is typical for aircraft of this class. The charter aircraft costs are based on published rates for chartering a light twin-engine aircraft (ref. 28). The pilot cost for the standard light aircraft ($12,000/yr) is obtained by assuming an $8,000 salary and a 50 percent overhead.

The 1975 Level I, standard, light-aircraft first cost is based on current cost of a retractable-gear, single-engine aircraft of comparable performance, plus $1,600 for optional avionics. Although this avionics cost is less than in 1968, the capabilities projected for the avionics equipment are substantially greater than for 1968 equipment. The utilization in 1975 is projected to have increased to 400 hr/yr, cruise speed increased to 156 knots and field length reduced to 1,400 ft. Hourly costs breakdowns are presented in table IV. It should be noted that the inspection, maintenance, and engine overhaul costs assumed in table IV are only 60 percent of current costs in anticipation of improved aircraft design and increased engine TBO. Reference 2 indicated that an increase in cruise speed to 174 knots had a relatively small effect on the economic attractiveness of the light aircraft. The STOL conversion cost ($3,500) and the pilot cost ($12,000/yr) were assumed to be the same as for 1968. The effect of an additional $0.08/gal tax was considered in the study; this tax assumption resulted in an increased cost of $0.0046/mile for the standard 1975 light aircraft.

The 1975 Level II light aircraft, resulting from an intensive R&D program is assumed to incorporate considerable drag reduction, raising the cruise speed to 165 knots. A high lift system is assumed to provide STOL capability engine characteristics. Finally, the 1975 Level II aircraft was assumed to have major components made of plastics. It was felt that the increased attractiveness of the improved aircraft would increase the growth rate of general aviation aircraft and facilities, leading to reduced storage and insurance costs. The 1982 Level I light aircraft, resulting from evolutionary development, incorporates a plastic airframe and an advanced engine. It was assumed that new production techniques and high production rates would reduce the initial cost (from 1975 Level I by $5,000). Again, a greatly increased aircraft population is expected to lead to reduced insurance and storage costs. A moderate improvement in cruise performance is postulated (to 174 knots), but field performance is not as good as for the 1975 Level II (1,000 ft versus 500 ft).

The 1982 Level II light aircraft is assumed to be a VTOL, possibly a rigid rotor type, incorporating advanced structures, engine, avionics, ATC, etc. The cruise speed postulated was only 150 knots, but due to the short interface time associated with this vehicle, it is most competitive at shorter ranges where the cruise speed becomes less important. Although the initial cost has increased (as has the operating cost), the economic attractiveness remains.

STOL

Fares and cruise speeds for this aircraft are summarized below.

	1975		1982	
	Level I	Level II	Level I	Level II
Fare	\$5.00 + 0.066/mi	\$4.70 + 0.047/mi	\$5.10 + 0.029/mi	\$4.26 + 0.024/mi
Cruise speed, M	0.5	0.9	0.9	1.0

Block speeds for the STOL transports are presented in figure 44 and the DOC curves in figure 45. Of course, STOL transports are not in service at this time. The 1975 Level I STOL was assumed to be a 90-passenger transport of the deflected slipstream type considered in reference 29. Reference 29 presents DOCs for 60- and 120-passenger STOL transports and a DOC curve for the 90-passenger aircraft considered herein was interpolated between these reference curves. The 1975 Level II STOL (90 passenger) was considered to be of the blown-flap turbofan type, with some improved structures and reduced maneuver time. The high cruise speed, M = 0.9, resulted from using advanced airfoils. DOC was taken from reference 26 but increased 12 percent because this vehicle did not incorporate as complete an advanced structure as the reference aircraft. 1975 STOL fared were derived by setting IOC = DOC, using 50 percent load factor and 10 percent profit.

The 1982 Level I STOL was similar to the 1975 Level II, but was sized for 120 passengers and incorporated more advanced structures. Again, the DOC was based on reference 26, but only increased 8.5 percent. In this case the IOC from reference 26 was used to calculate the fare. The 1982 Level II STOL was the 200-passenger, high acceleration aircraft of reference 26, and the reference IOC and DOC were used in deriving the fare (50 percent load factor, 10 percent profit). The maneuver time was reduced as technology increased, and by 1982 a supercritical wing was assumed to be used.

VTOL

Fares and cruise speeds for this aircraft are summarized below.

	1975		1982	
	Level I	Level II	Level I	Level II
Fare	\$7.45 + 0.104/mi	\$6.41 + 0.085/mi	\$5.77 + 0.0676/mi	\$3.33 + 0.275/mi
Cruise speed	325 knots	365 knots	390 knots	M = 0.9

VTOL block speeds and DOCs are presented in figures 46 and 47, respectively. (The current VTOL, of course, is the helicopter, covered previously.) The 1975 Level I VTOL was considered to be a 60-passenger, propeller-driven, tilt-wing configuration, based on reference 25. IOC was set equal to DOC taken from reference 25. The fare was derived in the usual manner; 50 percent load factor, 10 percent profit. The 1975 Level II VTOL was a 90-passenger, tilt-rotor aircraft, based on reference 29. The reference DOC was reduced 5 percent because improved structures (meaning lighter weight) were assumed. The fare came from assuming IOC = DOC, 50 percent load factor and 10 percent profit.

The 1982 Level I VTOL was similar to the 1975 Level II tilt rotor, but a larger (120-passenger) aircraft was considered. More advanced structures were assumed so the reference DOC was reduced 10 percent. The 1982 Level II VTOL was a 200-passenger, folding tilt-rotor aircraft taken from reference 26. The reference DOC and IOC were used to derive the fare structure using 50 percent load factor and 10 percent profit. As VTOL technology level advanced the cruise speed was increased and the assumed maneuver time was reduced from 10 min to 3 min (1975 Level I to 1982 Level II).

Subsonic Jet

Fares and cruise speeds for this aircraft are summarized below.

	Technology		1975		1982	
	Nominal	Low Cost	Level I	Level II	Level I	Level II
Fare	\$5.22 + 0.0578/mi	\$3.00 + 0.03/mi	\$5.00 + 0.039/mi	\$4.63 + 0.037/mi	\$3.52 + 0.027/mi	\$3.00 + 0.023/mi
Cruise speed, M	0.82	0.82	0.86	0.90	0.95	1.0

The 1968 subsonic jet block speeds and fares are taken from reference 21 and are shown in figures 48 and 49, respectively. The 1968 high economic performance fare (low cost) is representative of actual PSA fares as reported in reference 21 and shown in figure 49. The 1975 and 1982 subsonic jet coach fares are based on the direct operating costs shown in figure 50. IOC was set equal to DOC, and 50 percent load factor and 10 percent profit were used. The costs shown in figure 50 for the 1975 Level I subsonic jet are based on reference 30, which projected DOCs for 227- and 300-passenger air/bus configurations. In this study, the DOC for a 250-passenger transport was interpolated between the two reference curves. For 1975 Level II, the size was kept the same (250-passenger) but the DOC was reduced 5 percent to account for the lower weight resulting from advanced structures. Maneuver time for Level II was reduced from 26.5 min (Level I) to 16 min.

The 1982 Level I subsonic jet was enlarged to 350 seats. The DOC was based on reference 30 above, but reduced 10 percent to account for increased use of advanced structures and improved engine maintenance costs. The increased cruise speed in 1982 resulted from assumed use of the advanced supercritical wing. The 1982 Level II subsonic jet was assumed to be a 500-seat version of the low maneuver time CTOL of reference 26. The reference DOC was used.

Third-level Aircraft

Fares and cruise speeds for third-level aircraft are summarized below.

	1968	1975	1982
Fare	\$2.50 + 0.10/mi	\$2.00 + 0.082/mi	\$1.67 + 0.049/mi
Cruise speed, knots	220	220	250

The third-level aircraft were not included in the Level II intensive R&D category. Therefore, the characteristics presented are essentially comparable to the Level I technology. Block speeds are presented in figure 51, and current fares in figure 52. DOC curves for 1975 and 1982 are shown in figure 53. These curves were developed from extrapolations of current hourly cost breakdowns of typical third-level aircraft and modified for increased size and utilization. The cruise speeds and maneuver times represent moderate improvements.

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TABLE I.– ROUND TRIP INTERFACE COST AND TIME
(a) Standard

Technology	Allowance	Auto		Bus, train, helicopter, VTOL		Light aircraft		STOL		Subsonic jet	
		min	$	min	$	min	$	min	$	min	$
1968 and 1975 Level I	Access	15	0.35	15	0.70	15	0.70	20	0.93	30	1.40
	Risk	–		15		17		15		30	
	Risk	–		12		7		12		15	
	Access	15	.35	15	.70	15	.70	20	.93	30	1.40
	One-way	30	.70	57	1.40	54	1.40	67	1.86	105	2.80
	Round trip	60	1.40	114	2.80	108	2.80	134	3.72	210	5.60
1975 Level II	Access	15	.35	15	.70	4		20	.93	30	1.40
	Risk	–		12		12		12		24	
	Risk	–		9		7		9		9	
	Access	15	.35	15	.70	4		20	.93	30	1.40
	One-way	30	.70	51	1.40	27	1.50[1]	61	1.86	93	2.80
	Round trip	60	1.40	102	2.80	54	1.50	122	3.72	186	5.60
1982 Level I	Access	15	.35	12	.70	12	.56	18	.93	24	1.40
	Risk	–		12		12		12		24	
	Risk	–		9		7		9		9	
	Access	15	.35	12	.70	12	.56	18	.93	24	1.40
	One-way	30	.70	45	1.40	43	1.12	57	1.86	81	2.80
	Round trip	60	1.40	90	2.80	86	2.24	114	3.72	162	5.60
1982 Level II	Access	15	.35	10	.70	–		15	.93	20	1.40
	Risk	–		10		10		10		20	
	Risk	–		8		5		8		8	
	Access	15	.35	10	.70	–		15	.93	20	1.40
	One-way	30	.70	38	1.40	15	1.00[1]	48	1.86	68	2.80
	Round trip	60	1.40	76	2.80	30	1.00	96	3.72	136	5.60

[1]Landing fee

TABLE I.- ROUND TRIP INTERFACE COST AND TIME
(b) Urban

Mode	1968				1975								1982							
	Interface				Level I				Level II				Level I				Level II			
	Standard		Urban		Standard		Urban		Standard		Urban		Standard		Urban		Standard		Urban	
	hr	$	hr	$	hr	$	hr	$	hr	$	hr	$	hr	$	hr	$	hr	$	hr	$
Auto	1.00	1.40	1.00	1.84	1.00	1.40	1.0	1.84	1.00	1.40	1.00	1.84	1.00	1.40	1.00	1.84	1.0	1.40	1.00	1.84
Train, bus, helicopter, VTOL	1.90	2.80	1.67	2.00	1.90	2.80	1.67	2.00	1.70	2.80	1.67	2.00	1.50	2.80	1.67	2.00	1.27	2.80	1.67	2.00
Light aircraft	1.80	2.80	4.00	8.00[1]	1.80	2.80	4.00	8.00[1]	.90	1.50	.90	1.50	1.43	2.24	.90	1.50	.50	1.00	.50	1.00
STOL	---	---	---	---	2.23	3.72	2.00	3.00	2.02	3.72	2.00	3.00	1.90	3.72	2.00	3.00	1.60	3.72	2.00	3.00
Subsonic jet	3.50	5.60	4.75	6.50[1]	3.50	5.60	4.75	6.50[1]	3.10	5.60	4.16	6.50[1]	2.70	5.60	4.16	6.50[1]	2.28	5.60	4.16	6.50[1]

[1] Cost for 4 travelers: light aircraft $20.50, subsonic jet $19.00.

TABLE II – VEHICLE COST AND SPEED
(a) Ground Transport Modes

Mode	Year	Seats	V_{cr}, mph	Stage length, mi	Fare, ¢/mi
Auto	1968	6	58	---	7.0
	1975	6	62	---	7.0
	1982	6	65.5	---	7.0
Bus	1968	40	58	---	3.0
	1975	80	62	Nonstop	3.5
	1982	80	65.5	Nonstop	3.7
Train	1968	300	60-80	---	3.7
	1975	500	125	40	7.0
	1982	500	200	40	12.4

TABLE II.- VEHICLE COST AND SPEED
(b) Airborne Transport Modes

Mode	Year	Technology level	Seats	V_{cr}, knots	Maneuver time, min	Field length, ft	Fare
Helicopter	1968	--	28	122	6	---	\$4.56 + 8.3¢/mi
	1975	I	90	195	6	---	2.10 + 11.8
	1975	II	90	220	4	---	2.14 + 8.9
	1982	I	90	280	4	---	2.03 + 8.5
	1982	II	90	280	3	---	2.03 + 8.5
Light aircraft	1968	--	4	113	---	1600	9.8 ¢/mi
	1975	I	4	156	---	1400	7.7
	1975	II	4	165	---	500	6.1
	1982	I	4	174	---	1000	5.6
	1982	II	4	150	---	VTOL	8.9
Subsonic jet	1968	--	150-200	0.82M	26.5	7000	\$5.22 + 5.8¢/mi
	1975	I	250	0.86M	26.5	6600	5.00 + 3.9
	1975	II	250	0.90M	16	4000	4.63 + 3.7
	1982	I	350	0.95M	16	4000	3.52 + 2.7
	1982	II	500	1.0M	13	4000	3.00 + 2.3
STOL	1968	--	---	---	---	---	---
	1975	I	90	0.5M	10	2200	\$5.00 + 6.6¢/mi
	1975	II	90	0.9M	7.5	1700	4.70 + 4.7
	1982	I	120	0.9M	7.5	1700	5.10 + 2.9
	1982	II	200	1.0M	5.0	1400	4.26 + 2.4
VTOL	1968	--	---	---	---	---	---
	1975	I	60	0.55M	10	---	\$7.45 + 10.4¢/mi
	1975	II	90	0.61M	6	---	6.41 + 8.5
	1982	I	120	0.66M	6	---	5.77 + 6.8
	1982	II	200	0.90M	3	---	3.33 + 2.8
Third-level aircraft	1968	--	15	220	10	2500	\$2.50 + 10 ¢/mi
	1975	--	30	220	10	2000	2.00 + 8.2
	1982	--	30	250	7	2000	1.67 + 4.9

TABLE III.- RAPID TRAIN COSTS

(a) Capital Investment

	1975					1982 (Upgrade 1975)				1982 (direct from '68)			
	Deprec. Period, yr	Initial Cost, mill.$	Deprec. Cost	Interest Cost*	Total Capital Cost	Incremental Cost, mill.$	Deprec. Cost	Interest Cost*	Total Capital Cost	Initial Cost, mill.$	Deprec. Cost	Interest Cost*	Total Capital Cost
			millions/mi/yr				millions/mi/yr				millions/mi/yr		
Acquisition of property		---	---	---	---	0.132/mi	---	0.0066	0.0066	0.132/mi	---	0.0066	0.0066
Landwork (cut, fill bridges, tunnels, etc.	20	0.4/mi	0.02	0.02	0.04	2.15/mi	0.129	.1275	.2565	2.58/mi	0.129	.129	.258
Track cost (rails, ties ballast, elect., signals)	12	.3/mi	.025	.015	.04	0.16/mi	.0417	.023	.0647	.5/mi	.0417	.025	.0667
Automatic control	12	.1/mi	.0083	.005	.0133	.0047/mi	.00984	.0052	.015	.118/mi	.00984	.0059	.0157
Terminals – maintenance	20	20											
3 major	20	30	.006	.006	.012	5.3	.007	.0065	.0135	70	.007	.007	.014
10 minor	20	10											
Planning, engineering		5	---	.0005	.0005	20	0	.0025	.0025	25	0	.0025	.0025
Total millions/mile		.93	.0593	.0465	.1058	2.5	.1875	.1713	.1588	3.72	.1875	.176	.3634
millions/system		465	29.7	23.3	(52.9)	1250.	93.75	85.65	179.4	1760	93.75	88	181.75
			millions/yr				millions/yr				millions/yr		
Rolling stock	12												
156 cars		44.6	3.72	2.23	5.95								
102 cars						-6.5	2.43	1.46	3.89	29.2	2.43	1.46	3.89
Total investment		509.6				1243.5				1789.2			
Capital costs			33.4	25.53	58.9		96.18	87.11	183.29		96.18	89.46	185.6

*All interest rates 5 percent.

TABLE III.- RAPID TRAIN COSTS
(b) Operating Costs

DIRECT OPERATING COSTS	1975		1982	
Crew cost total, ¢/mi	.167		.117	
Crews required		55		38.5
Crew size		10		10
Electricity and lube total, ¢/mi	.126		.138	
Cruise power (2/3 throttle), hp/train		4800		7500
Electricity cost, $/kw hr		.015		.015
Electricity cost, ¢/mi		.108		.118
Lube cost, ¢/mi		.018		.02
Insurance (2% acquisition cost/yr) ¢/mi	.018		.012	
Maintenance (burden is in IOC), ¢/mi	.285		.258	
Regular car maintenance ($ .10/car mile), ¢/mi		.125		.125
Powerplant (1 man-hr/rolling hr), ¢/mi		.09		.063
Cleaning (1 man-hr/trip), ¢/mi		.011		.011
Light car repair, ¢/mi		.059		.059
Depreciation ¢/mi	.075		.049	
Total direct, ¢/mi	.671		.574	
INDIRECT OPERATING COSTS				
Right-of-way maintenance, ¢/mi	.427		.427	
Fixed installation maintenance total ¢/mi	.722		.722	
Yards, switching, storage, ¢/mi		.252		.252
Station facilities, ¢/mi		.47		.47
Maintenance burden, ¢/mi	.057		.051	
General traffic manangement, misc. ¢/mi	.195		.195	
Total Indirect, ¢/mi	1.401		1.395	
TOTAL OPERATING COST ¢/mi	2.072		1.969	

TABLE III.- RAPID TRAIN COSTS

(c) Fares

Capacity	1975 Load Factor, %			1982 Load Factor, %		
	30	50	60	30	50	60
16,000 seats/day	11.6	7.0	5.8	10.6	6.3	5.3
32,000 seats/day	9.6	5.8	4.8	8.7	5.2	4.4

TABLE IV.- LIGHT AIRCRAFT COSTS

	1968	1975		1982	
	—	Level I	Level II	Level I	Level II
First cost ($)	10,800	18,500	17,300	13,400	29,000
Utilization, hr/yr	300	400	500	500	600
Fuel and oil, $/hr	3.60	5.12	5.12	5.62	6.10
Inspection and maintenance, $/hr	1.25	1.00	.75	.75	.50
Engine overhaul, $/hr	.80	.70	.40	.40	.33
Reserve for life retirement items	---	---	---	---	1.45
DIRECT, $/hr	5.65	6.82	6.27	6.77	8.38
Hangar, $/yr	360	360	300	240	180
Insurance, $/yr	540	585	500	400	400
Depreciation, 8 yr to 20 percent, $/yr	1080	1850	1730	1340	2900
INDIRECT, $/yr	1980	2795	2530	1980	3480
Total hourly cost	$12.25	$13.81	$11.33	$10.73	$14.18
Cost per mile	$ .098	$ .077	$ .061	$ .056	$ .089

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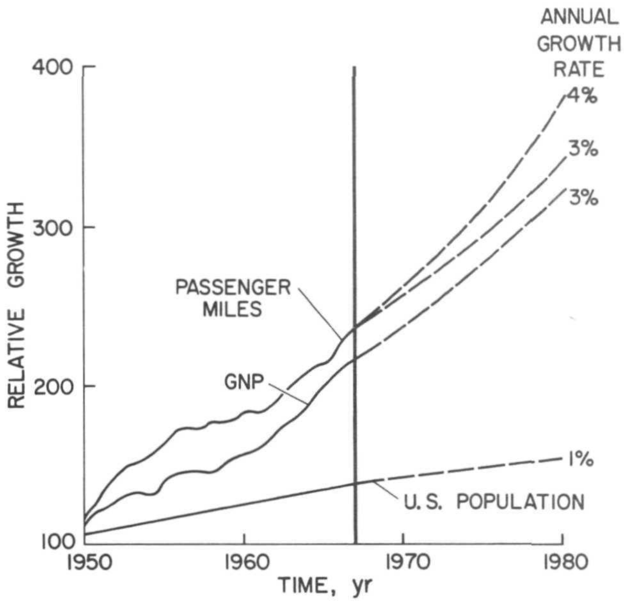


Figure 1.- Historical trends of U.S. growth in population, Gross National Product, and transportation.

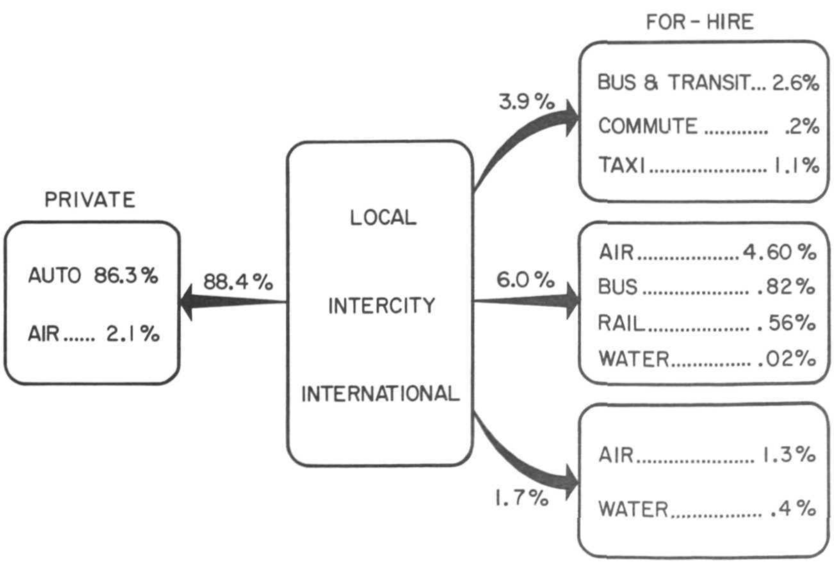


Figure 2.- U.S. expenditures for passenger transportation in 1967.

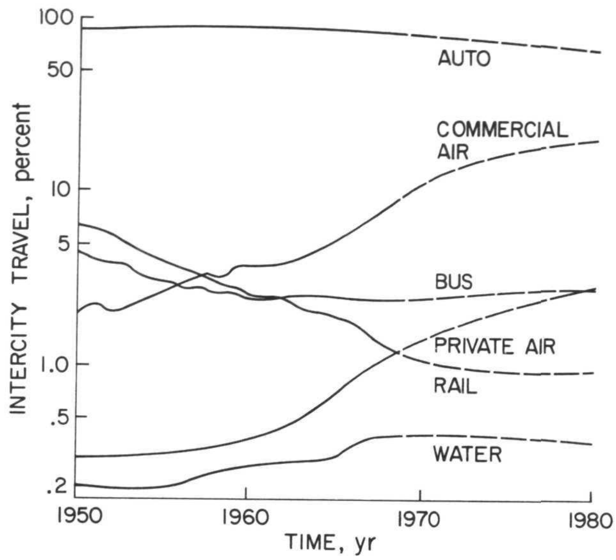


Figure 3.- The historical division of the intercity passenger travel market.

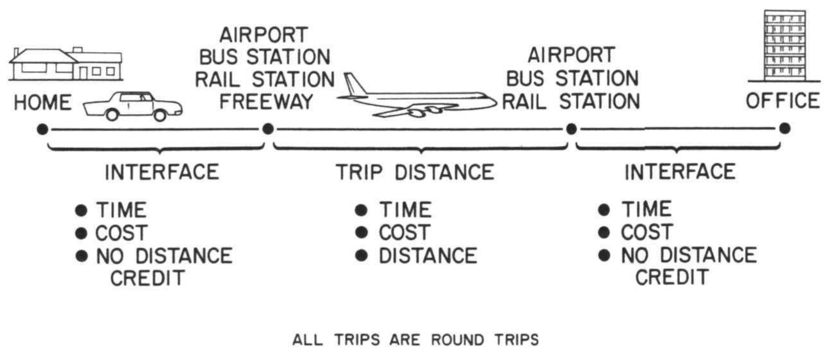


Figure 4.- Three-segment intercity trip model.

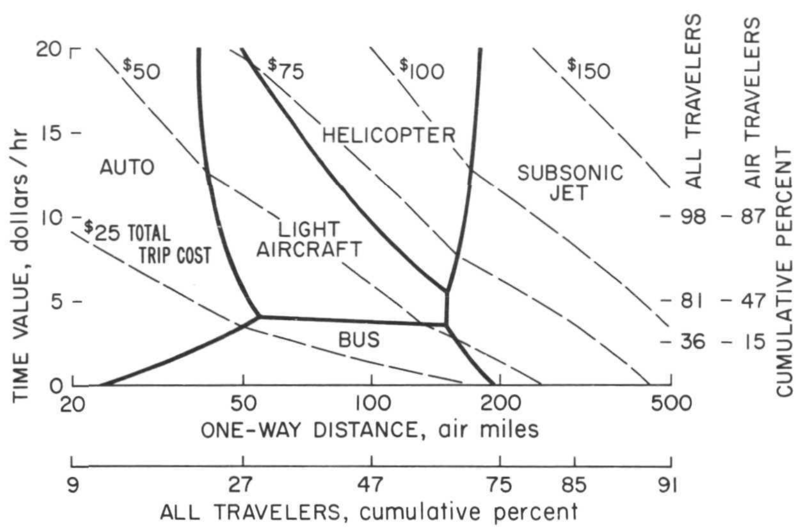


Figure 5.- Minimum-cost transportation modes; single traveler, 1968, standard interface, round trip.

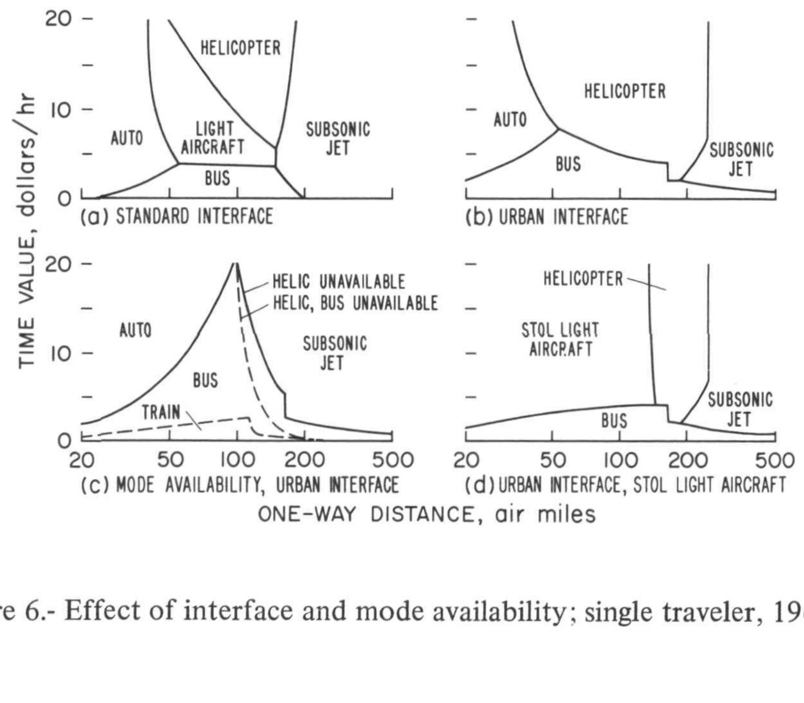


Figure 6.- Effect of interface and mode availability; single traveler, 1968.

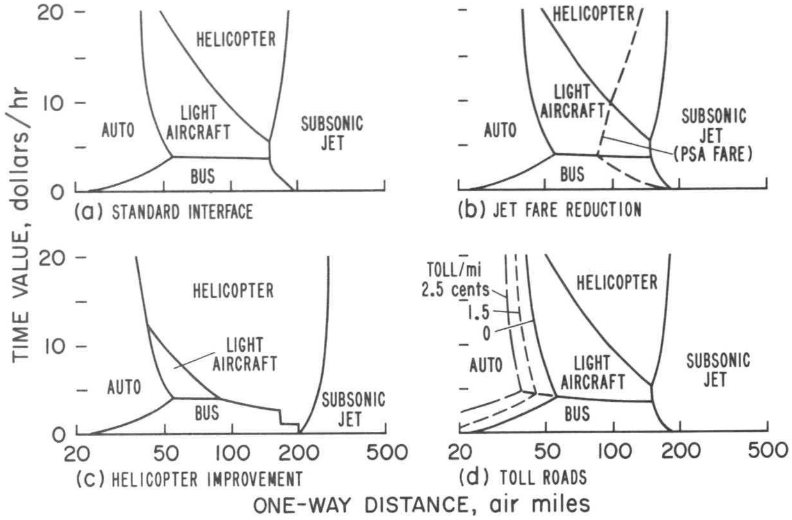


Figure 7.- Effect of fare changes; single traveler, 1968.

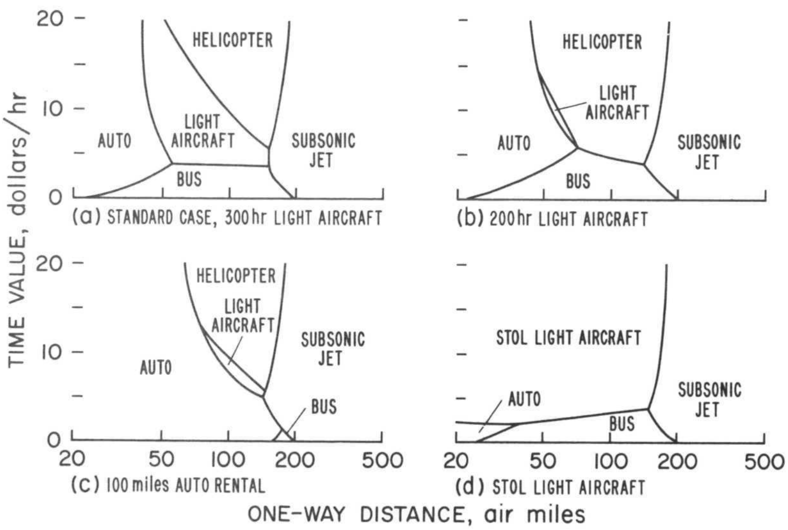


Figure 8.- Effect of light aircraft utility; single traveler, 1968, standard interfaces.

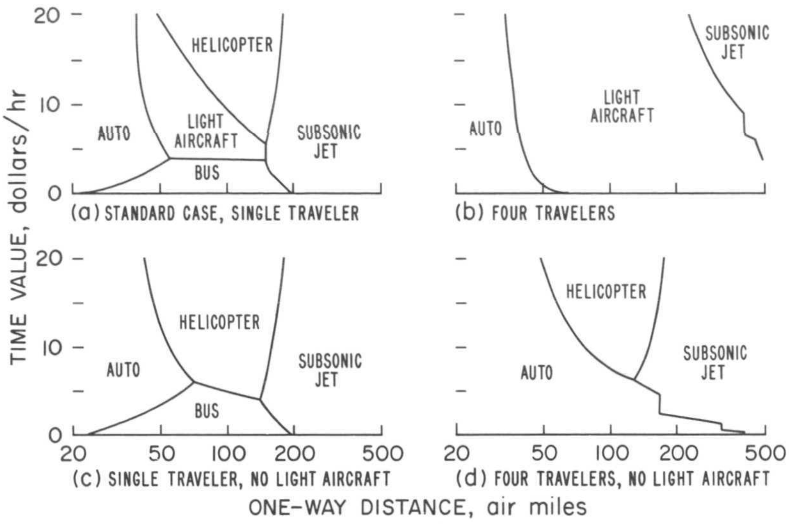


Figure 9.- Effect of number of travelers and availability of light aircraft; 1968.

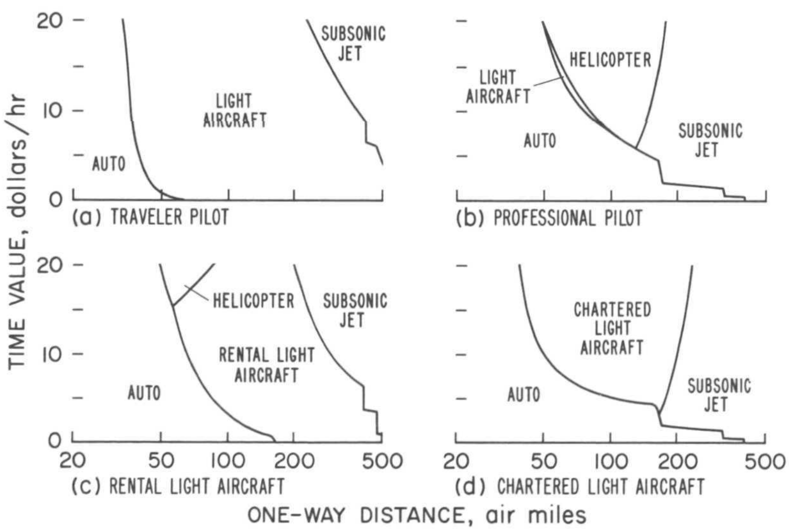


Figure 10.- Effect of light aircraft hire; four travelers, standard interface, 1968.

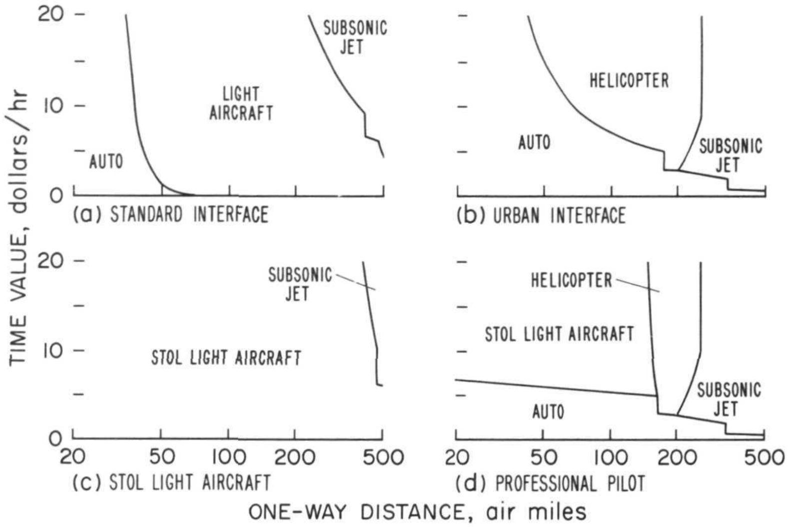


Figure 11.- Effect of interface and STOL light aircraft; four travelers, 1968.

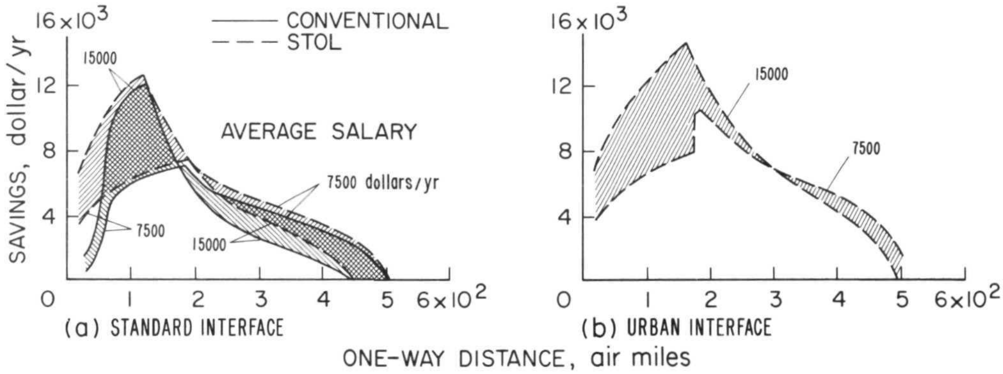


Figure 12.- Estimated savings from light aircraft use; four travelers, 300 hr/yr, 1968.

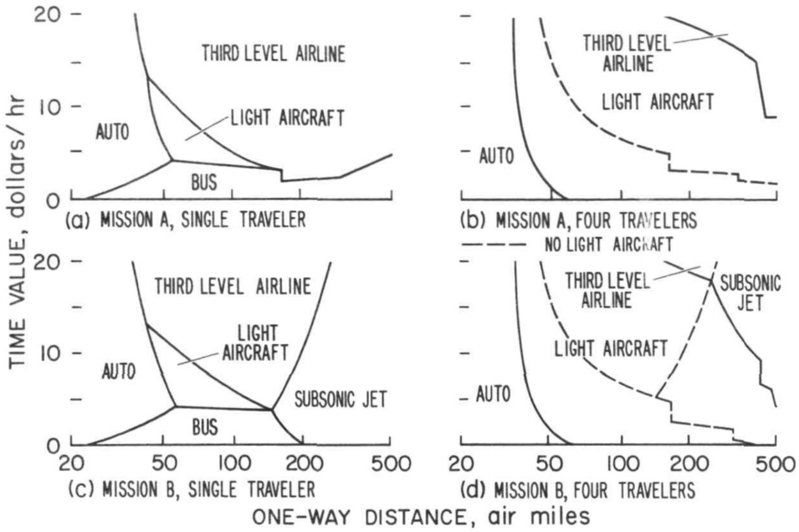


Figure 13.- Effect of third level airlines; standard interface, 1968.

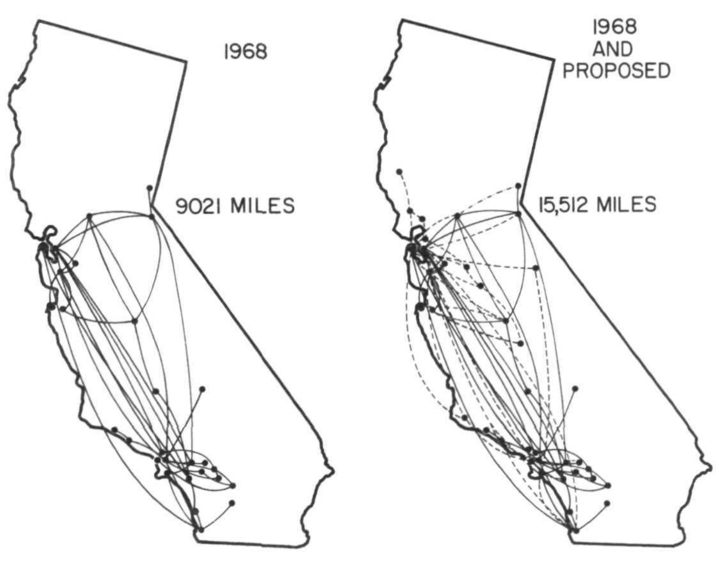


Figure 14.- California intrastate passenger air carriers; October 1968.

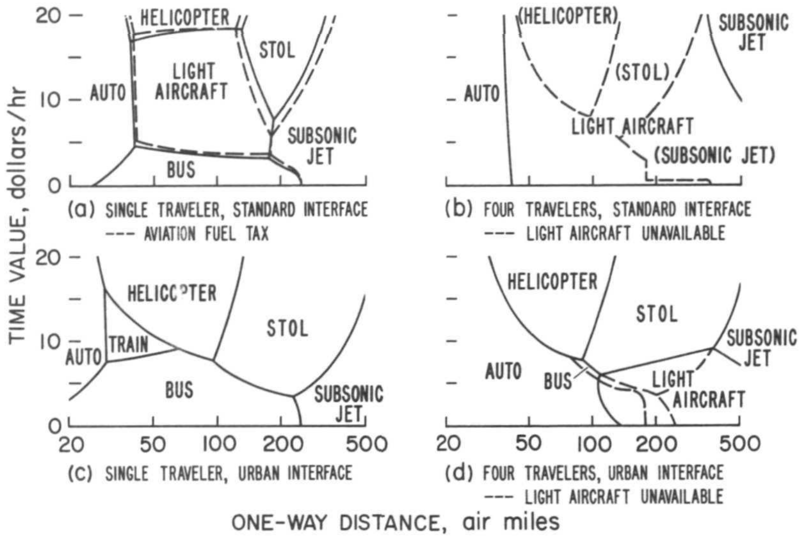


Figure 15.- Effect of number of travelers and interface; 1975, Level I.

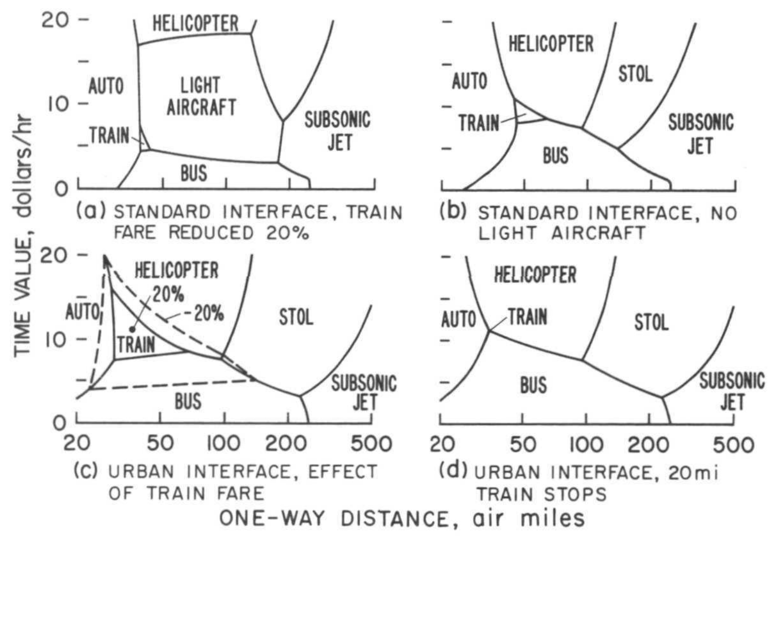


Figure 16.- Effect of train fares and light aircraft availability; single traveler, 1975, Level I.

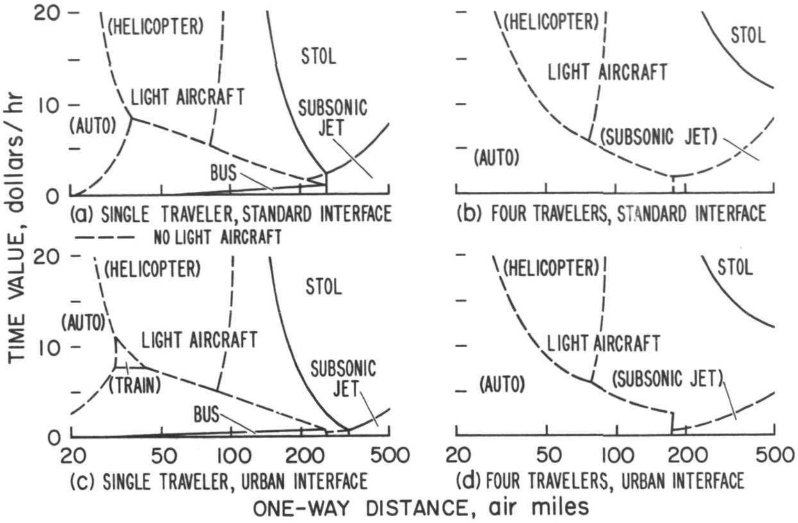


Figure 17.- Effect of number of travelers and interface; 1975, Level II.

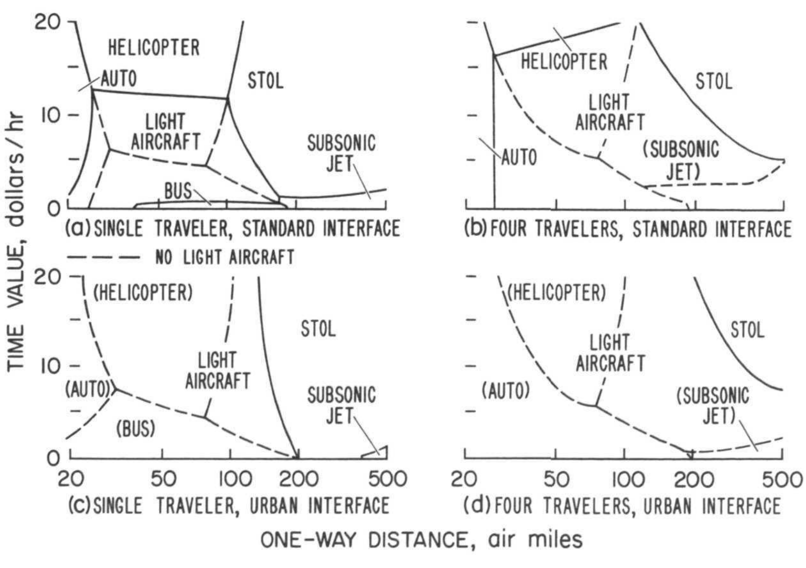


Figure 18.- Effect of number of travelers and interface; 1982, Level I.

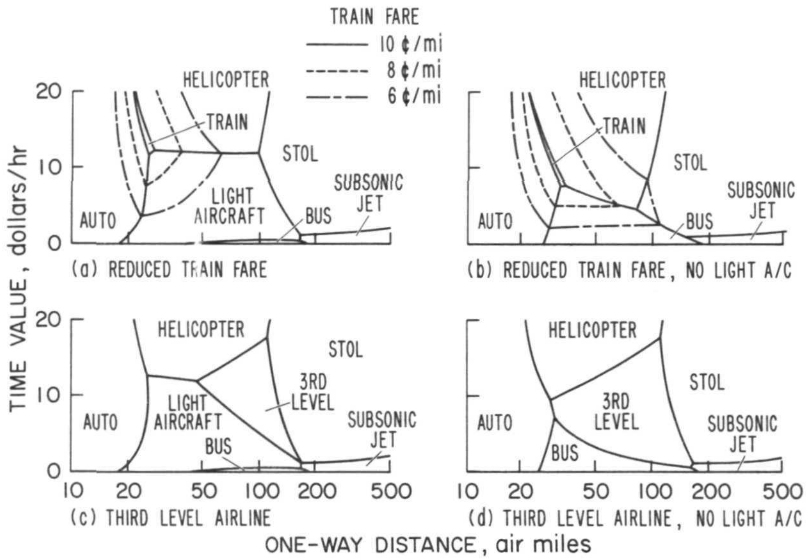


Figure 19.- Effect of train fare and third level airline; single traveler, 1982, Level I.

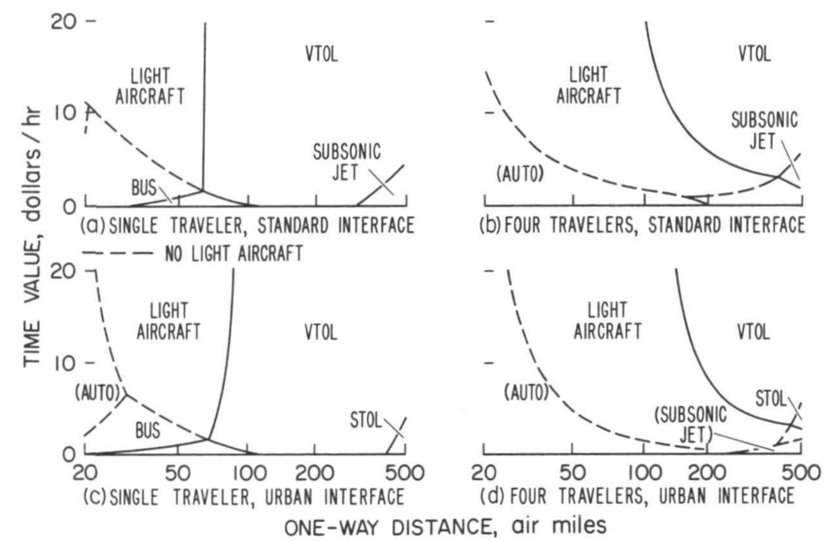


Figure 20.- Effect of number of travelers and interface; 1982, Level II.

YEAR	1968	1975	1982
CAPACITY	6	6	6
PERFORMANCE CRUISE SPEED, mph BLOCK SPEED	 58 44	 62 47	 65.5 49
ECONOMICS COST	7¢ / mile	7¢ / mile	7¢ / mile
TECHNOLOGY	CURRENT	IMPROVED HIGHWAY	IMPROVED HIGHWAY
CONCLUSIONS	COMPETITIVE AT SHORT RANGE, <50 mile	I, II AS IN 1968	I AS IN 1968 II COMPETITIVE <20 mile

NOTE: I AND II DENOTE TECHNOLOGY LEVEL

Figure 21.- Summary of the automobile characteristics and results.

YEAR	1968	1975	1982
CAPACITY	40	80	80
PERFORMANCE CRUISE SPEED, mph BLOCK SPEED STAGE LENGTH	 58 44 	 62 62 NONSTOP	 65.5 65.5 NONSTOP
ECONOMICS FARE, 50% LOAD FACTOR	3¢ / mile	3.5¢ / mile	3.7¢ / mile
TECHNOLOGY	CURRENT	ARTICULATED UNIT 2-MAN CREW IMPROVED HIGHWAY	IMPROVED HIGHWAY
CONCLUSIONS	COMPETITIVE AT LOW TIME VALUE, PARTICULARLY IN URBAN INTERFACE (1 TRAVELER) NONCOMPETITIVE FOR 4 TRAVELERS	I COMPETITIVE TO HIGHER TIME VALUES BUT SHORTER RANGE (<250 mile) II COMPETITIVE FOR 0 TIME VALUE AND RESTRICTED RANGE (LIGHT AIRCRAFT SUPERIOR)	I AS IN 1975 - II II AS IN 1975 - II

NOTE: I AND II DENOTE TECHNOLOGY LEVEL

Figure 22.- Summary of the intercity bus characteristics and results.

YEAR	1968	1975	1982
CAPACITY	300	500	500
PERFORMANCE CRUISE SPEED, mph BLOCK SPEED STAGE LENGTH ACCELERATION, g SERVICE	 60-80 40 HOURLY	 125 100 40 0.1 1/2 HOUR	 200 157 40 0.1 1/2 HOUR
ECONOMICS ROW COST FARE, 50% LOAD FACTOR	 3.7¢/mile	 $0.93 × 10^6/mile 7¢/mile	 $3.52 × 10^6/mile 12.4¢/mile
TECHNOLOGY	CURRENT	UPGRADE CURRENT ROADBED ADVANCED SUSPENSION AIRCRAFT STRUCTURE	NEW ROADBED
CONCLUSIONS	NONCOMPETITIVE EXCEPT IN SPECIAL CASES	COMPETITIVE ONLY FOR 1 TRAVELER AT HIGH TIME VALUES AND AT ABOUT 40miles (STAGE LENGTH)	NONCOMPETITIVE

Figure 23.- Summary of the train characteristics and results.

YEAR	1968	1975 I	1975 II	1982 I	1982 II
CAPACITY	28	90	90	90	90
PERFORMANCE CRUISE SPEED, knots MANEUVER TIME, min RELATIVE STRUCTURAL WEIGHT	 122 6 1.0	 195 6 0.98	 220 4 0.92	 280 4 0.85	 280 3 0.69
ECONOMICS FARE, 50% LOAD FACTOR	$4.56 + 8.3¢/mile	$2.10 + 11.8¢/mile	$2.14 + 8.9¢/mile	$2.03 + 8.5¢/mile	$2.03 + 8.5¢/mile
TECHNOLOGY	CURRENT	COMPOUND RIGID-ROTOR POWER TRANSMISSION	JET FLAP ROTOR ROTOR L/D DRAG IMPROVEMENT IMPROVED STRUCTURES ADVANCED AVIONICS	ADVANCED STRUCTURE	COMPLETE ADVANCED STRUCTURE
CONCLUSIONS	COMPETITIVE, 50-200 miles, PARTICULARLY URBAN AND ONE TRAVELER	COMPETITIVE ONLY AT HIGH TIME VALUES	AS IN 1975 I (IF NO LIGHT AIRCRAFT)	AS IN 1975 II	NONCOMPETITIVE

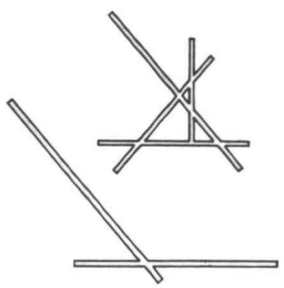
NOTE: I AND II DENOTE TECHNOLOGY LEVEL

Figure 24.- Summary of the helicopter characteristics and results.

YEAR	1968	1975 I	1975 II	1982 I	1982 II
CAPACITY	4	4	4	4	4
PERFORMANCE CRUISE SPEED, knots FIELD LENGTH, ft RELATIVE TBO	 113 1600 1	 156 1400 1.25	 165 500 2	 174 1000 2	 150 VTOL 2.5
ECONOMICS FIRST COST OPERATING COST	 \$10,800 9.8 ¢ / mile	 \$18,500 7.7 ¢ / mile	 \$17,300 6.1 ¢/mile	 \$13,400 5.6 ¢/mile	 \$29,000 8.9 ¢/mile
TECHNOLOGY	CURRENT FIXED GEAR	RETRACTABLE GEAR IMPROVED ENGINE AND PROPELLER IMPROVED AVIONICS	MAJOR PLASTIC COMPONENTS HIGH LIFT DRAG REDUCTION	NEW PRODUCTION TECHNIQUE PLASTIC AIRFRAME ADVANCED ENGINE	RIGID ROTOR ADVANCED STRUCTURE ADVANCED AVIONICS
CONCLUSIONS	COMPETITIVE EXCEPT IN URBAN INTERFACE	AS IN 1968	COMPETITIVE, MAJOR MODE < 500 miles	COMPETITIVE, < 200 miles SINGLE TRAVELER < 500 miles FOUR TRAVELERS	COMPETITIVE, < 80 miles SINGLE TRAVELER < 500 miles FOUR TRAVELERS (LOW TIME VALUES)

NOTE: I AND II DENOTE TECHNOLOGY LEVEL

Figure 25.- Summary of the light aircraft characteristics and results.



	O'HARE CHICAGO, ILL.	VAN NUYS CALIF.	ROCKFORD ILL.
AIR CARRIER, percent	86	8.8 (HELICOPTER)	3.5
TOTAL OPERATIONS 1967	588,527	543,324	180,778
PEAK DAY	1900	3100	7050
PEAK HOUR	≈130	450	600 est.
POTENTIAL OPERATIONS (18 hr day)	850,000	2,900,000	3,900,000

Figure 26.- Air traffic at three typical airports.

YEAR	1968	I 1975	II	I 1982	II
CAPACITY		90	90	120	200
PERFORMANCE CRUISE SPEED, M FIELD LENGTH, ft MANEUVER TIME, min RELATIVE STRUCTURAL WEIGHT		 0.5 2200 10 1.0	 0.9 1700 7.5 0.90	 0.9 1700 7.5 0.83	 1.0 1400 5.0 0.65
ECONOMICS FARE, 50% LOAD FACTOR		\$5.00 + 6.6¢/mile	\$4.70 + 4.7¢/mile	\$5.10 + 2.9¢/mile	\$4.26 + 2.4¢/mile
TECHNOLOGY		DEFLECTED SLIP STREAM IMPROVED OPERATIONS (ATC, AIRPORT, AVIONICS)	BLOWN FLAP IMPROVED STRUCTURES	BLOWN FLAP ADVANCED STRUCTURES	HIGH ACCELERATION COMPLETE ADVANCED STRUCTURES ADVANCED ENGINES ADVANCED OPERATIONS (ATC, AIRPORT, AVIONICS)
CONCLUSION		COMPETITIVE, > 100 miles, PARTICULARLY IF NO LIGHT AIRCRAFT	AS IN 1975 I	AS IN 1975 I	NONCOMPETITIVE (AT SHORT-HAUL RANGES)

NOTE: I AND II DENOTE TECHNOLOGY LEVEL

Figure 27.- Summary of STOL characteristics and results.

YEAR	1968	I 1975	II	I 1982	II
CAPACITY		60	90	120	200
PERFORMANCE CRUISE SPEED, M MANEUVER TIME, min RELATIVE STRUCTURAL WEIGHT		 0.55 10 1.0	 0.61 6 0.90	 0.66 6 0.83	 0.90 3 0.66
ECONOMICS FARE, 50% LOAD FACTOR		\$7.45 + 10.4¢/mile	\$6.41 + 8.5¢/mile	\$5.77 + 6.8¢/mile	\$3.33 + 2.8¢/mile
TECHNOLOGY		TILT WING IMPROVED PROPELLERS CONTROL	TILT ROTOR IMPROVED STRUCTURES ADVANCED BLADE IMPROVED OPERATIONS (ATC, AIRPORT, AVIONICS)	TILT ROTOR ADVANCED STRUCTURES	FOLDING TILT ROTOR COMPLETED ADVANCED STRUCTURES CONVERTIBLE ENGINE ADVANCED OPERATIONS (ATC, AIRPORT, AVIONICS)
CONCLUSIONS		NONCOMPETITIVE	NONCOMPETITIVE	NONCOMPETITIVE	COMPETITIVE, PRIMARY MODE BEYOND 75 miles

NOTE: I AND II DENOTE TECHNOLOGY LEVEL

Figure 28.- Summary of VTOL characteristics and results.

YEAR	1968	I 1975	II	I 1982	II
CAPACITY	150–200	250	250	350	500
PERFORMANCE CRUISE SPEED, M FIELD LENGTH, ft MANEUVER TIME, min RELATIVE STRUCTURAL WEIGHT	 0.82 7000 26.5 1.00	 0.86 6600 26.5 0.98	 0.90 4000 16 0.90	 0.95 4000 16 0.82	 1.0 4000 13 0.64
ECONOMICS FARE, 50% LOAD FACTOR	\$5.22 + 5.8¢/mile	\$5.00 + 3.9¢/mile	\$4.63 + 3.7¢/mile	\$3.52 + 2.7¢/mile	\$3.00 + 2.3¢/mile
TECHNOLOGY	CURRENT	NOISE REDUCTION SMOKE REDUCTION SYSTEM MONITORING COLLISION AVOIDANCE	SUPERCRITICAL WING ADVANCED STRUCTURES IMPROVED ENGINES IMPROVED SYSTEMS *IMPROVED OPERATIONS* (ATC, AIRPORT, AVIONICS)	IMPROVED SUPERCRITICAL WING DRAG REDUCTION	FULL ADVANCED STRUCTURES ADVANCED SUPERCRITICAL WING ADVANCED OPERATIONS (ATC, AIRPORT, AVIONICS)
CONCLUSIONS	COMPETITIVE, >150–200 miles	COMPETITIVE, >200 miles PARTICULARLY IF NO LIGHT AIRCRAFT	AS IN 1975 I FOR LOW TIME VALUES	SAME AS 1975 II	NONCOMPETITIVE (AT SHORT-HAUL RANGES)

NOTE: I AND II DENOTE TECHNOLOGY LEVEL

Figure 29.- Summary of subsonic jet characteristics and results.

YEAR	1968	1975	1982
CAPACITY	15	30	30
PERFORMANCE CRUISE SPEED, knots UTILIZATION, hr MANEUVER TIME, min	 220 1200 10	 220 2000 10	 250 2500 7
ECONOMICS FARE, 60% LOAD FACTOR	\$2.50 + 10¢/mile	\$2.00 + 8.2¢/mile	\$1.67 + 4.9¢/mile
TECHNOLOGY	CURRENT	INCREASED SIZE IMPROVED AVIONICS IMPROVED TBO	IMPROVED AERODYNAMICS IMPROVED ENGINES IMPROVED OPERATIONS (ATC, AIRPORT, AVIONICS)
CONCLUSIONS	COMPETITIVE, > 50miles PARTICULARY IF NO LIGHT AIRCRAFT	AS IN 1968	COMPETITIVE, 50-150miles

Figure 30.- Summary of third-level aircraft characteristics and results.

INTERCITY PASSENGER TRANSPORT

	IMMEDIATE	LONGER TERM
HELICOPTER	LIFT SYSTEMS; PERFORMANCE, LIFE, RELIABILITY, VIBRATION NOISE	(SEE VTOL)
LIGHT AIRCRAFT	MAN-MACHINE DYNAMICS; TRAINING, PILOTING, PROFICIENCY, AVIONICS SAFETY; CRASH WORTHINESS, HANDLING QUALITIES, PWI LOW COST; STRUCTURES, PROPULSION, AVIONICS	ATC PERFORMANCE; STOL, VTOL FACILITIES
STOL	OPERATING PROBLEMS; LOW SPEED HANDLING QUALITIES, CERTIFICATION REQUIREMENTS NOISE ECONOMICS; MAINTENANCE FACILITIES; AIRPORTS, ATC AVIONICS	ADVANCED STRUCTURES
VTOL	LIFT SYSTEMS; PERFORMANCE, RELIABILITY, LIFE NOISE HANDLING QUALITIES	ECONOMICS OPERATING PROBLEMS FACILITIES SAFETY AVIONICS
SUBSONIC JET	SAFETY; LANDING AND TAKE OFF, COLLISION AVOIDANCE, FIRE ELIMINATION PERFORMANCE; CRUISE, LANDING NOISE FACILITIES	

Figure 31.- Research implications for airborne transportation modes.

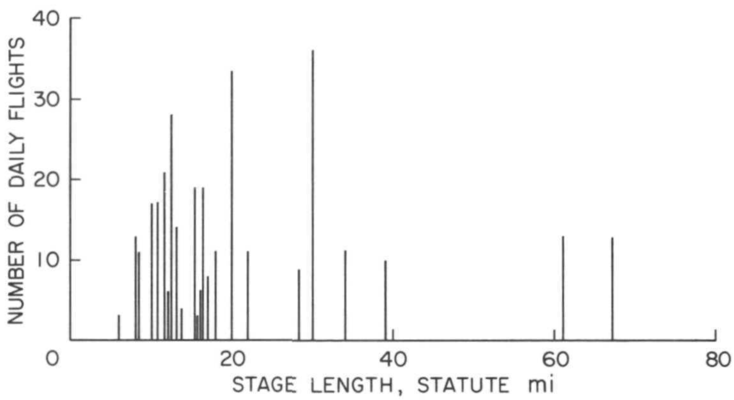


Figure 32.- Distribution of helicopter flights for 1968 scheduled helicopter airlines (336 total daily flights from ref. 21).

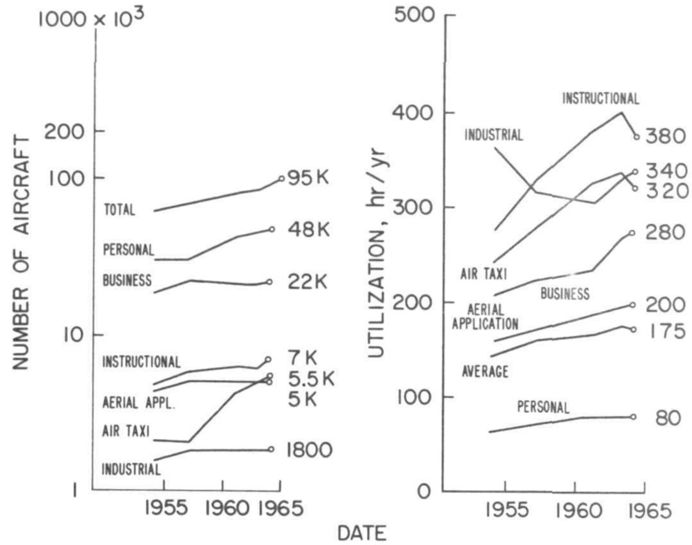


Figure 33.- Number and utilization of general aviation aircraft from reference 31.

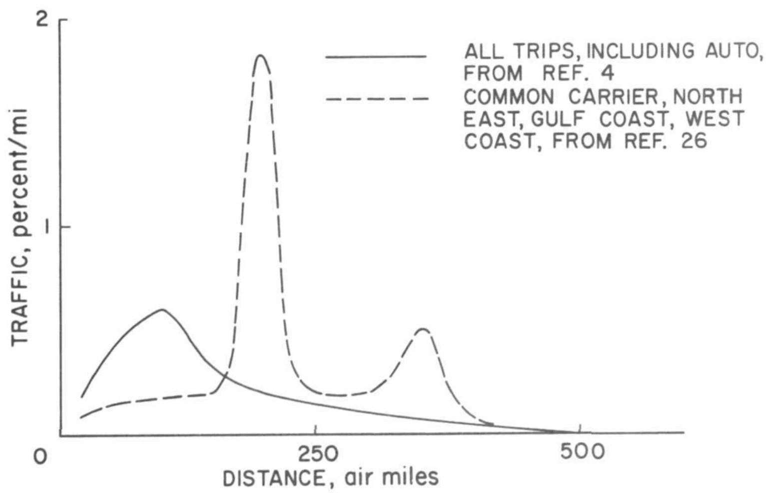


Figure 34.- Distribution of short-haul passenger trips.

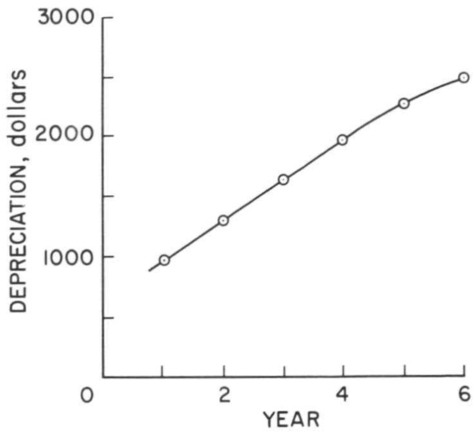


Figure 35.- Depreciation of the standard American four-door sedan.

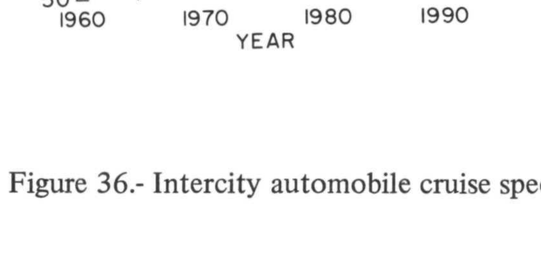


Figure 36.- Intercity automobile cruise speeds.

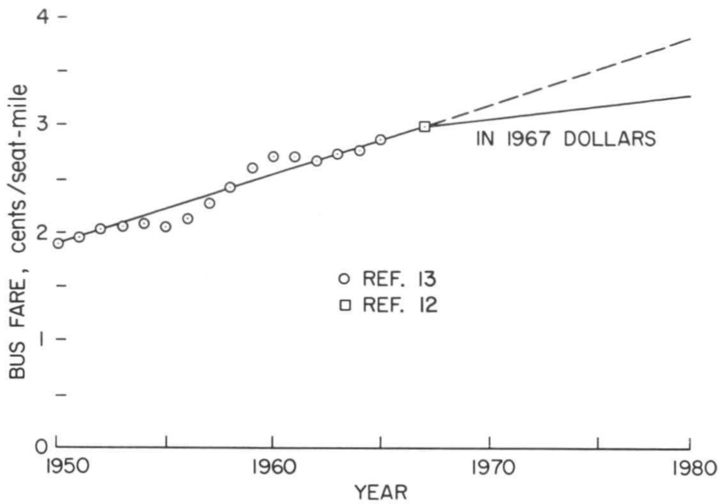


Figure 37.- Intercity bus fare.

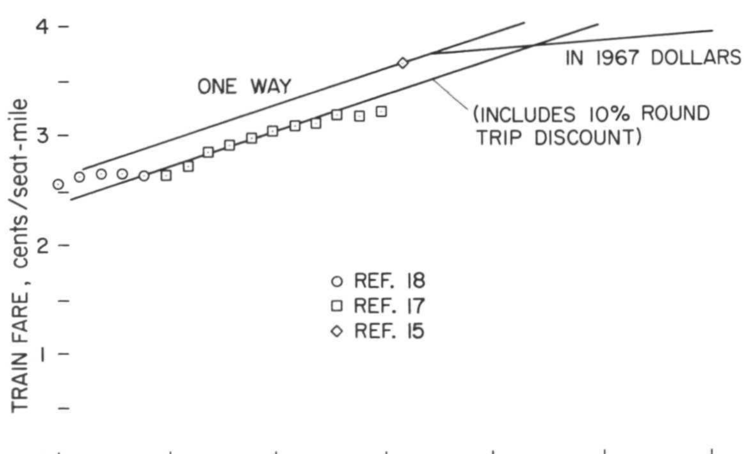


Figure 38.- Intercity train fare.

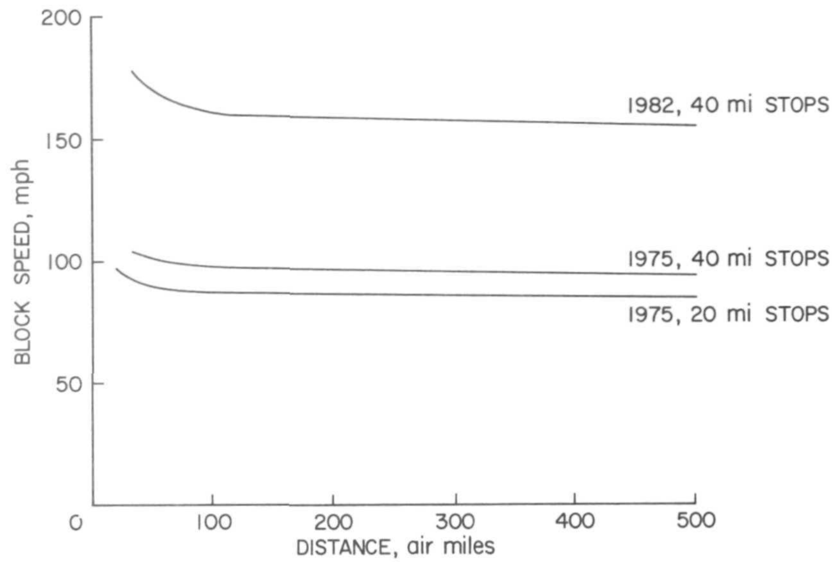


Figure 39.- Train block speeds.

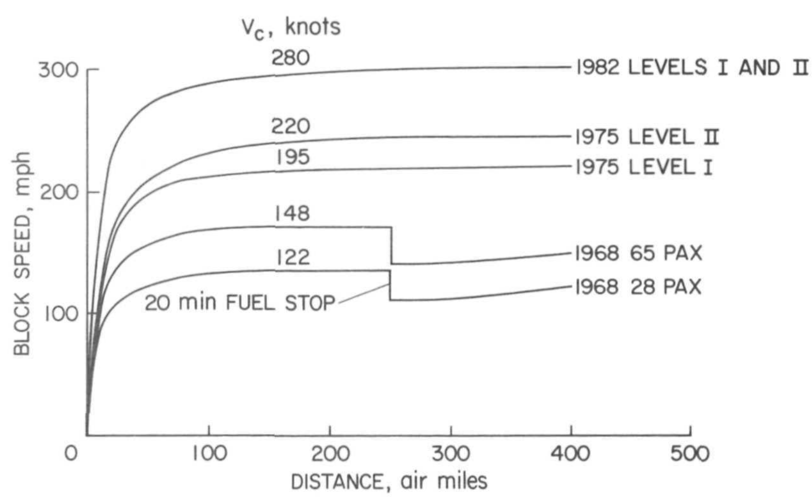


Figure 40.- Helicopter block speeds.

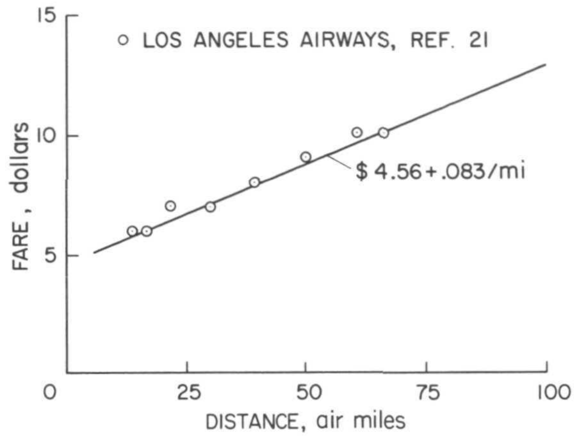


Figure 41.- 1968 helicopter fares.

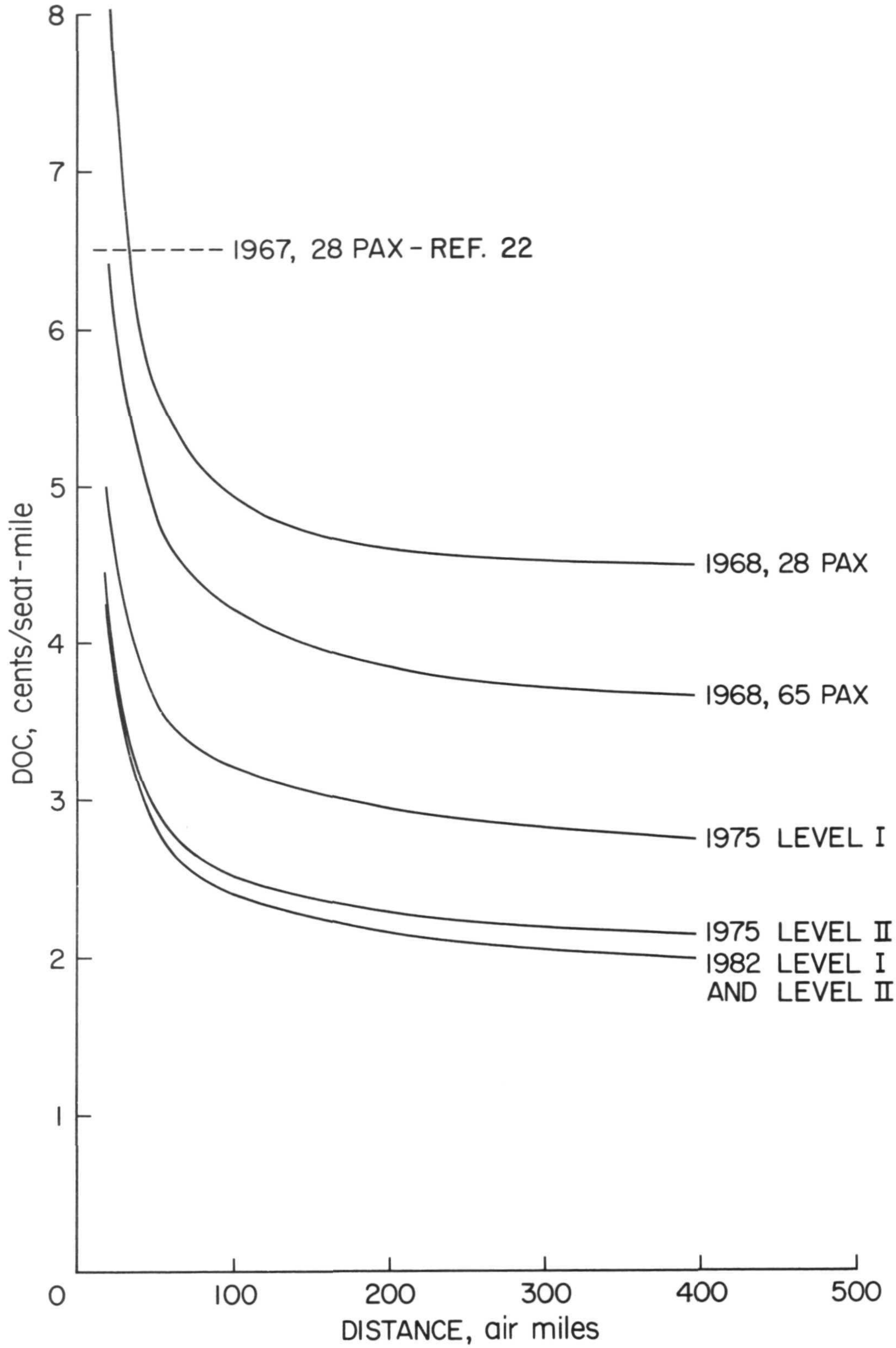


Figure 42.- Helicopter direct operating costs.

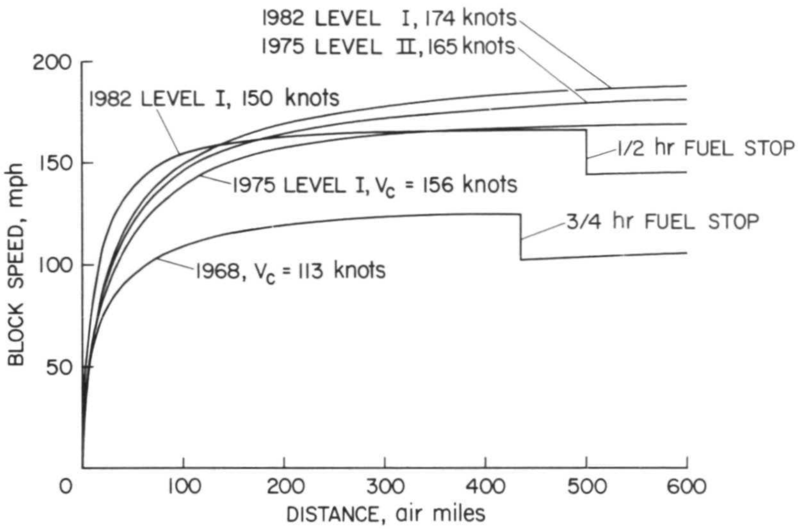


Figure 43.- Light aircraft block speeds.

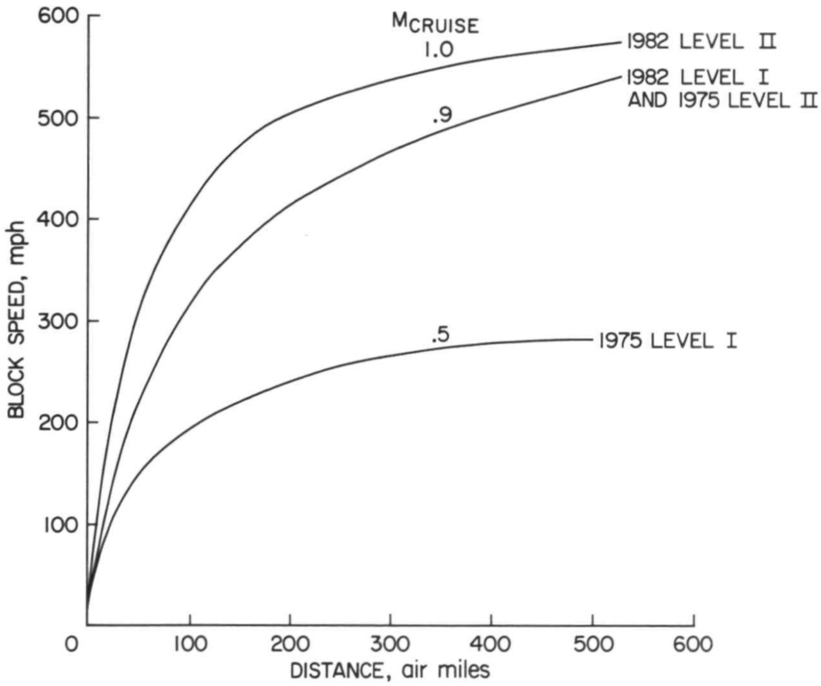


Figure 44.- STOL block speeds.

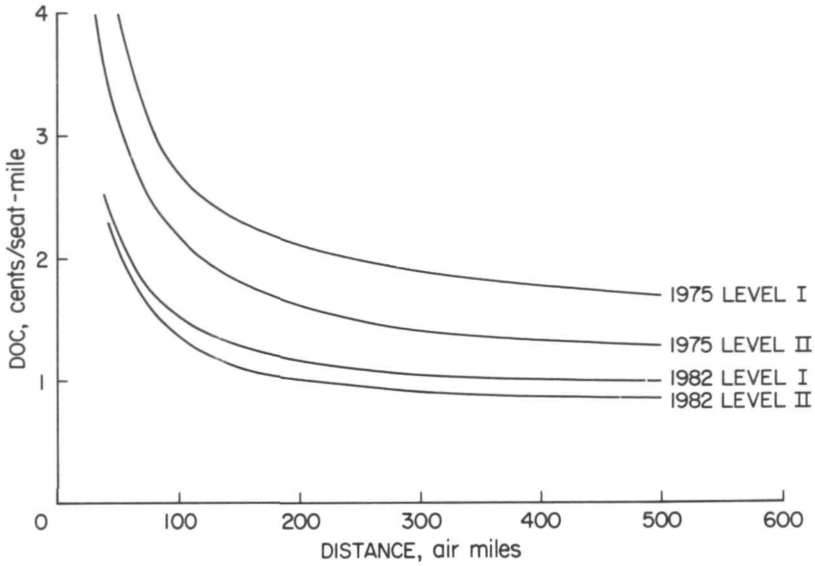


Figure 45.- STOL direct operating costs.

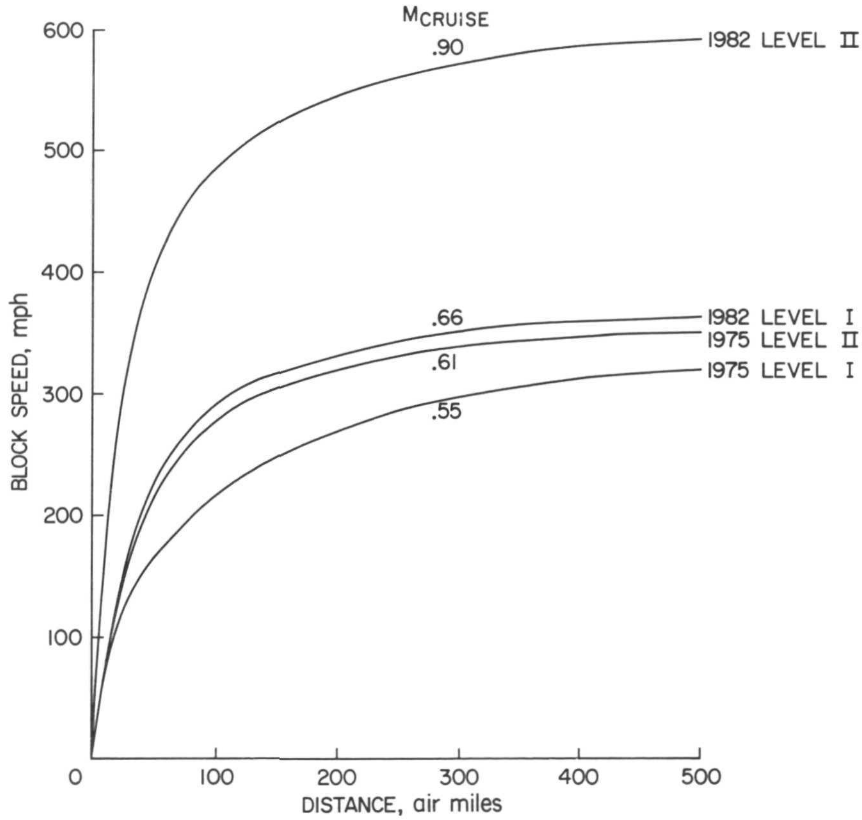


Figure 46.- VTOL block speeds.

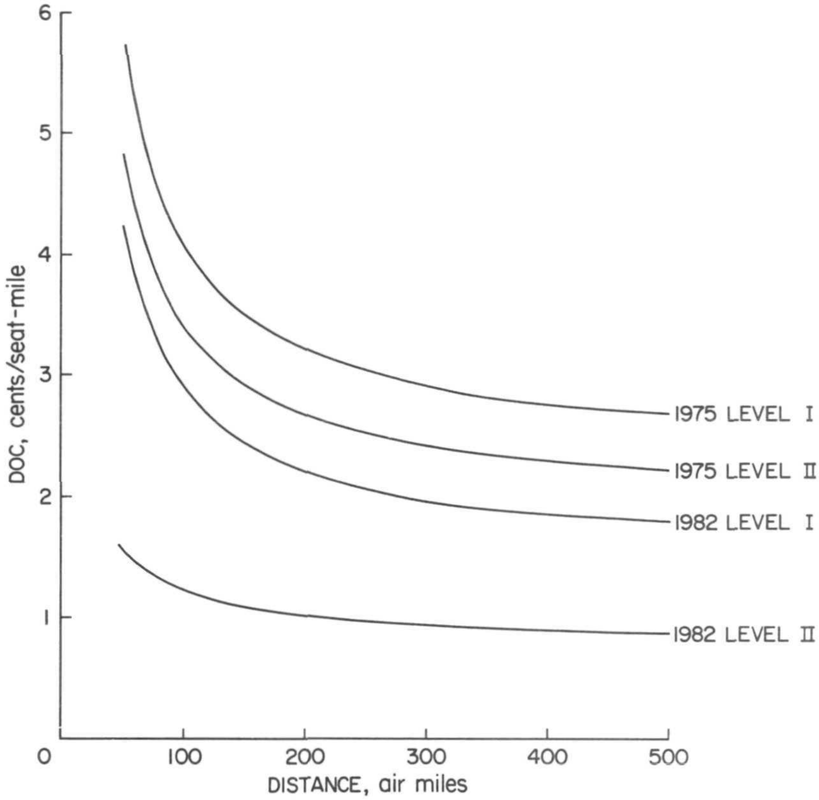


Figure 47.- VTOL direct operating costs.

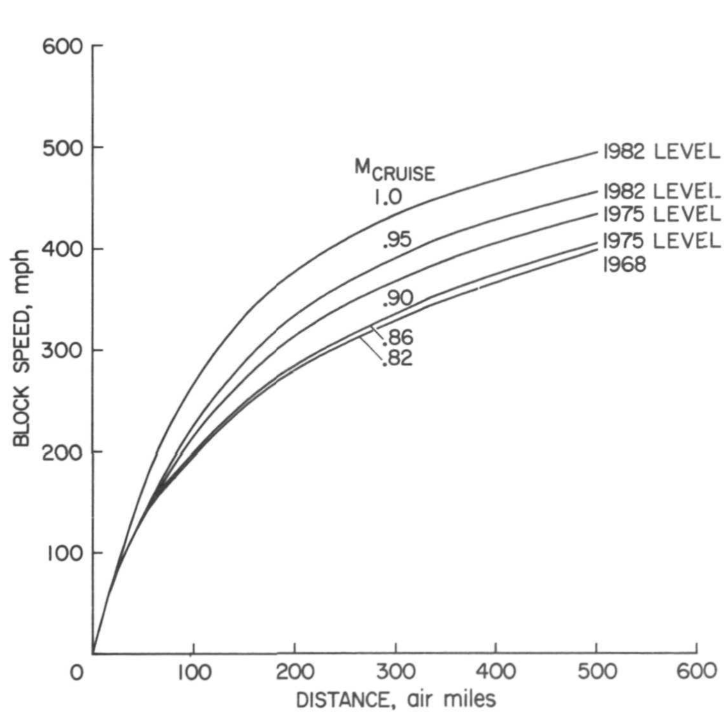


Figure 48.- Subsonic jet block speeds.

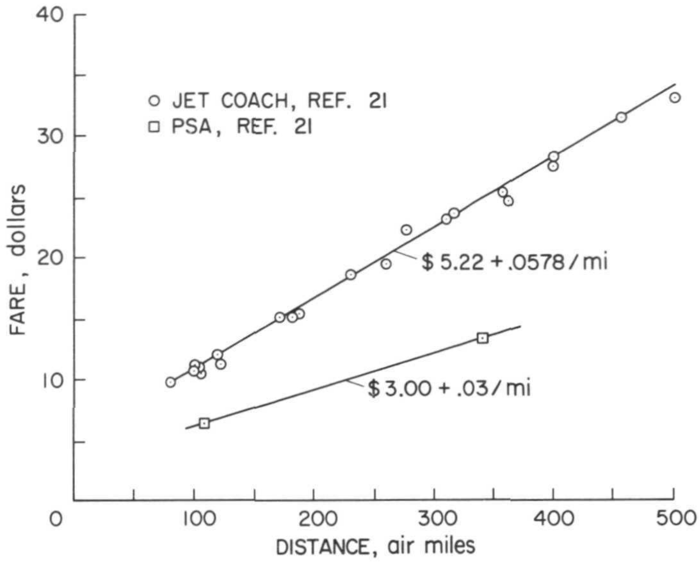


Figure 49.- 1968 subsonic jet fares.

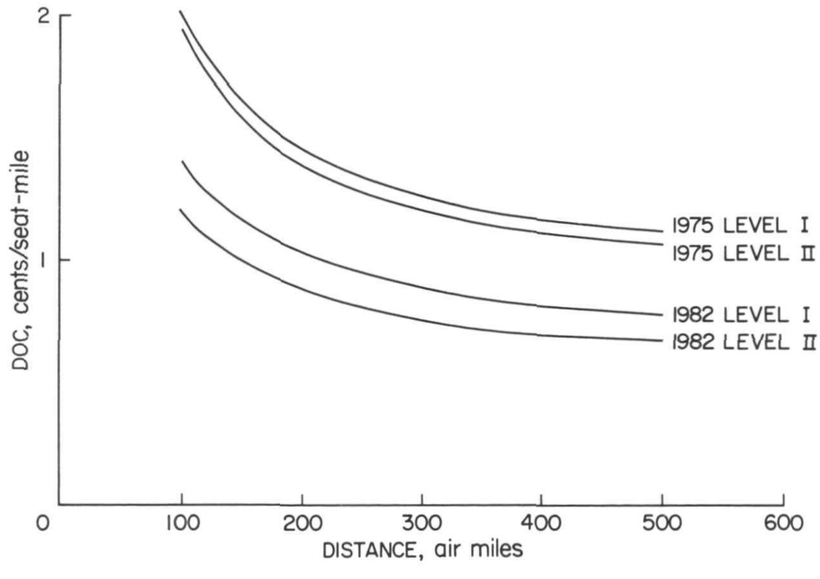


Figure 50.- Subsonic jet direct operating costs.

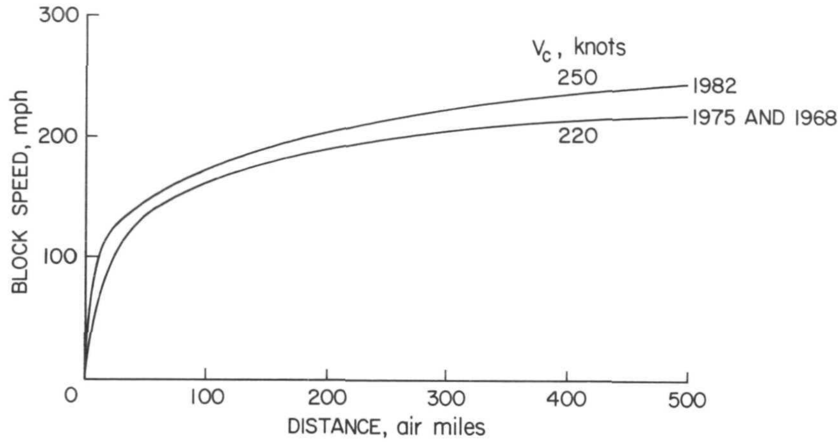


Figure 51.- Third level aircraft block speeds.

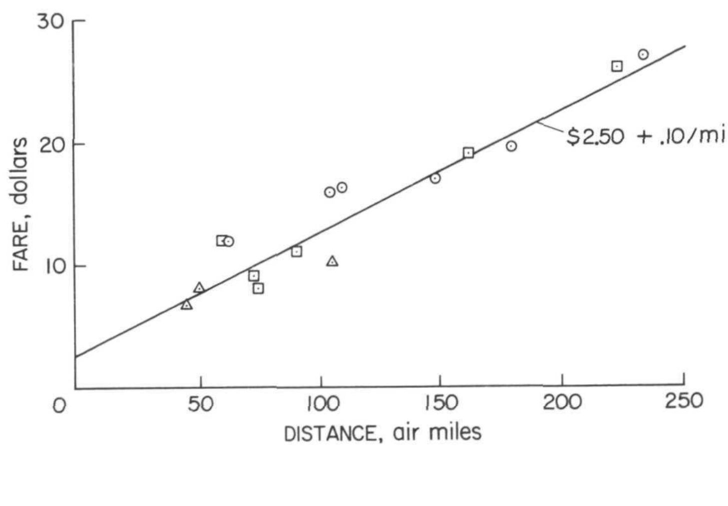


Figure 52.- Third level airline fares, 1968 (ref. 10).

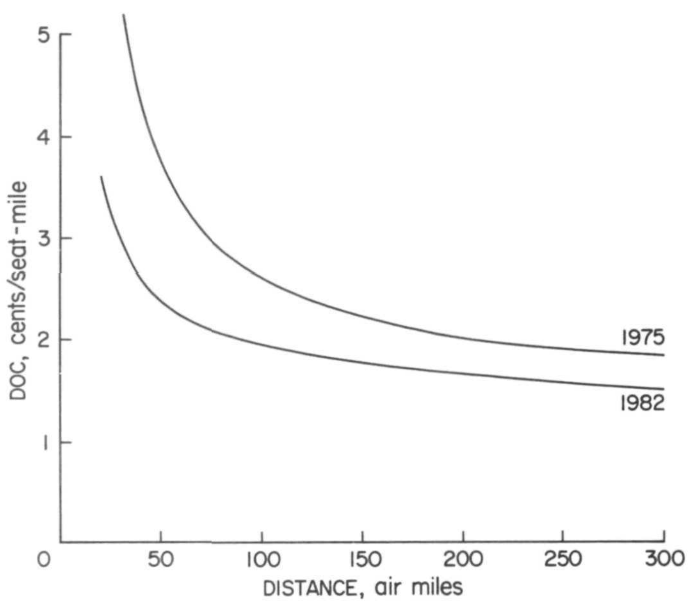


Figure 53.- Third level aircraft direct operating costs.

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