Demand for Intercity Passenger Transportation by VTOL Aircraft

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Number of aircraft demanded vs price and selling price vs number of aircraft produced were estimated for six types of VTOL aircraft: conventional helicopter, compound helicopter, tilt rotor, tilt wing, stowed rotor, and fan or jet lift. The relationship between these two functions indicates the total aircraft program profit or loss as a function of the number of aircraft produced. Results were calculated for the 90 seat size of all six types. The aircraft demand was calculated separately for each domestic city pair and then summed to obtain total domestic demand. The domestic demand was then increased by a constant ratio to account for export sales. Demand is based on air traffic for 1985, the estimated final year of production for these first generation intercity VTOL aircraft. None of the VTOL aircraft types appear to be economically self-sustaining by 1975; by 1985 three of the six types appear capable of economical operation.

Introduction

THIS paper presents an analysis of the demand for city-center-to-city-center passenger transport service by vertical takeoff and landing (VTOL) aircraft; it summarizes a study recently completed at the Institute for Defense Analyses.[1]

In this study, we have assumed the VTOL's have overcome some very real problems involved in operating large aircraft in densely populated city centers—noise, air pollution, safety, and the availability of city-center vertiports. Even if the aircraft are economically attractive under these favorable assumptions, these problems must still be solved before actual service can be realized.

Aircraft demand results in this study are estimated for the year 1985. The initial operational date for VTOL aircraft is estimated to be around 1975. Based on the past pattern of successful civil aircraft production programs, it is estimated that the production program would continue through 1985 before the following generation of aircraft would enter service. Final demand for the aircraft will therefore be determined by the 1985 level of passenger demand.

The types of aircraft included in the study and their cruise speeds are shown in Table 1. The helicopter and compound helicopter types are assumed to have a design range of 250 miles; the other VTOL types are assumed to have a design range of 500 miles.

Method of Analysis

The basic method of analysis is illustrated in Fig. 1, which presents the flow diagram for determining city-center-to-city-center VTOL passenger transport demand. The principal steps in the analysis are discussed below.

Air Traffic Forecast by City Pair

Our method of analysis involves the use of actual passenger traffic by city pair. 1965 origin and destination (OD) traffic by city pair was obtained from published Civil Aeronautics Board data.[2] Our total domestic traffic forecast based on conventional takeoff and landing aircraft (CTOL) service indicated traffic in 1975 would be 3.1 times that of 1965, and traffic in 1985 would be 6.5 times that of 1965. Traffic by each city pair has been assumed to increase by these same ratios, the ratios for city pairs with higher-than-average traffic growth rates offsetting those with lower-than-average growth rates. Traffic was estimated by this method for the top ranking 86 city pairs with intercity distances under 500 miles.

Although a few additional aircraft might be demanded if more city pairs were considered, the number of additional aircraft compared with the demand for these top 86 city pairs would generally be less than 10%. It is felt that this small additional demand would be offset by unavailability of vertiports in some of the top 86 city pairs and that therefore the demand as shown for these city pairs closely represents the total domestic demand.

Breakdown of City-Pair Air Traffic by Segment Pair

Local OD's of passengers were related to radial distance from the center of the city. For eight cities where survey data were available, cumulative OD's were plotted against radial distance (in percent of the total city radius) from the central business district (CBD). The similarity of results among the cities for which OD surveys were available was sufficient to permit a generalized distribution to be obtained (Fig. 2). For a typical city, this curve may be used as an approximation of the distribution of local OD's. Investigation of the cities generating the most air traffic under 500 miles showed that several cities were not typical; for these cities modified OD distributions were used.

Because the local OD's are a function of the distance from the city center, a method of segmenting the city by rings centered on the CBD was developed. Figure 3 shows Dallas and Houston as a sample city pair. In this particular case, both cities were segmented into a central core plus three

Table 1 Aircraft types and cruise speeds

Type	Cruise speed, miles/hr
Helicopter	190
Compound helicopter	260
Tilt rotor	380
Tilt wing	430
Stowed rotor	460
Fan or jet lift	530

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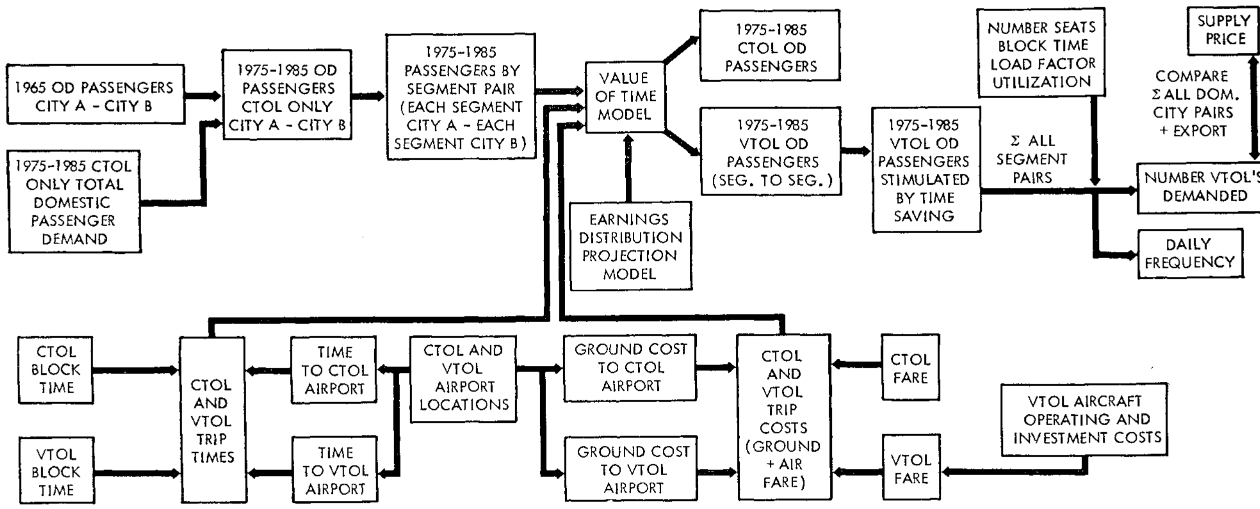

Fig. 1 Relationships of models, city A to city B.

rings. Each of the outer rings was divided into quadrants by the north-south and east-west axes, resulting in 13 segments for each city. For Dallas and Houston a total of 13 × 13 = 169 segment pairs result.

For each city the following data were developed:

1) The radius from the city center to each of the circles: depending on city size, from two to six circles were used.

2) The inhabited percentage of each segment's area: this is especially important for cities located on large bodies of water where the pattern of passenger OD's is greatly altered by local geography.

3) Straight-line distances to the nearest CTOL airport and to the city-center vertiport, including a notation stating whether the trip involves travel through heavy city traffic areas.

These basic inputs, together with the distribution of local OD's vs radius and the ground times and costs vs distance, permit the breakdown of total traffic into segment-pair traffic and the calculation of ground travel times and costs by segment pair.

Trip Times and Costs

The CTOL and VTOL trip times and costs between segment pairs of a city pair are the sum of the following: 1) ground time and cost from the segment of the origin city to the airport or vertiport, 2) CTOL or VTOL block time and fare between the city pair, and 3) ground time and cost from the airport or vertiport to the segment of the destination city. Determination of fare levels for the CTOL and VTOL aircraft is an essential part of the study, because passengers will make mode choices primarily on the basis of fares and trip times. Fares are projected as a function of the direct and indirect operating costs of the aircraft, and the capital costs of the aircraft. The passenger fare must be such that all costs of operating the system are covered, and a "normal" rate of return on investment is achieved.

Splitting Passenger Demand between CTOL and VTOL

The value that passengers place on their time must be estimated in order to split passenger demand between a faster, more expensive service and a slower, cheaper service. The VTOL service will be faster but more expensive than CTOL for travelers between most segment pairs. From the relative trip times and costs, one can determine the cost of saving time by VTOL. For example, if the VTOL service saves 0.5 hr but costs \$3.00 more than CTOL, between a particular segment pair, the cost of saving time by VTOL would be \$3.00/0.5 = \$6.00/hr. One must then determine what percent of the passengers value their time at \$6.00/hr or more in order to split the total passenger demand between VTOL and CTOL.

A recent IDA study involving passenger demand for supersonic transport service encountered this value of time problem.[3] Results of the value of time analysis are summarized in Fig. 4 which shows the distribution of value of time for domestic air passengers as a function of calendar year.

Stimulation of Air Travel by VTOL

We can expect VTOL not only to capture some of the CTOL market, but also to increase the total amount of air travel because of the time saving of VTOL over CTOL. This increase

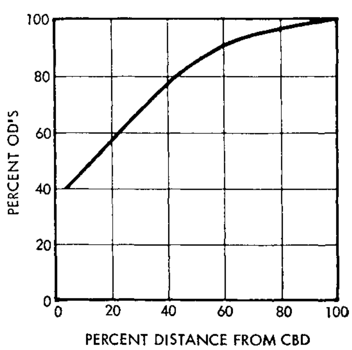

Fig. 2 Distribution of OD's by distance from CBD.

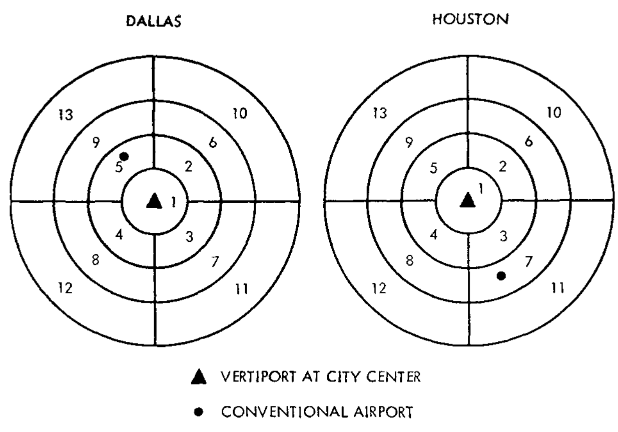

Fig. 3 Passenger local origin and destination segments for Dallas and Houston.

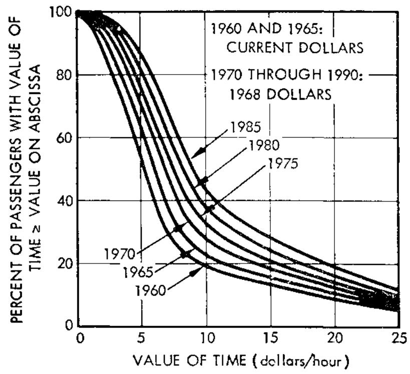

Fig. 4 Value of time distribution of air passengers, U.S. domestic routes.

is derived from two sources: a shift from ground modes of travel to VTOL travel and an increase in the average number of trips by former CTOL passengers who switch to VTOL.

Three methods were used to determine the extent of this stimulation and to serve as cross checks on each other. One method is based on the relationship between trip distance and the percent of passengers taking the air mode; another is constructed on a statistical relationship between the number of air trips, trip time, and other independent variables, and a third is based on the implications of the effect of the 1947 change in the location of the airport serving Detroit on air travel between Detroit and other cities.

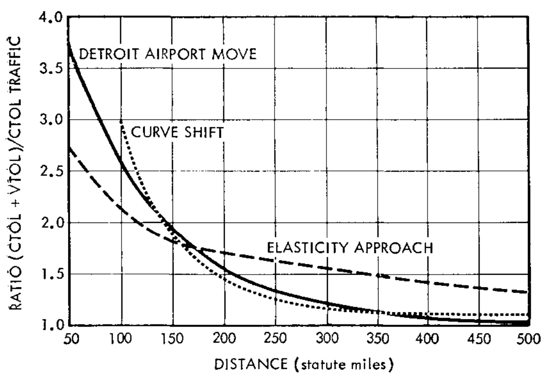

Fig. 5 Comparison of three approaches for 50-min time saving.

A comparison of the results of all three methods for a 50-min time saving is shown in Fig. 5. We decided to use the Detroit Airport move as the basis for determining the effect of a 50-min time saving because it directly reflects the effect of airport location on air travel. The equation based on the Detroit Airport move was generalized to permit calculation for any time saving. The resulting generalized traffic stimulation is illustrated in Fig. 6, which shows the ratios of CTOL plus VTOL to CTOL traffic only for 20, 40, 60, and 80-min time saving. Figure 6 is based on equal CTOL and VTOL fares. This traffic stimulation is applied only to passengers selecting VTOL service on a value of time basis; in this way, the total traffic stimulation is reduced as VTOL fares are increased above CTOL fares.

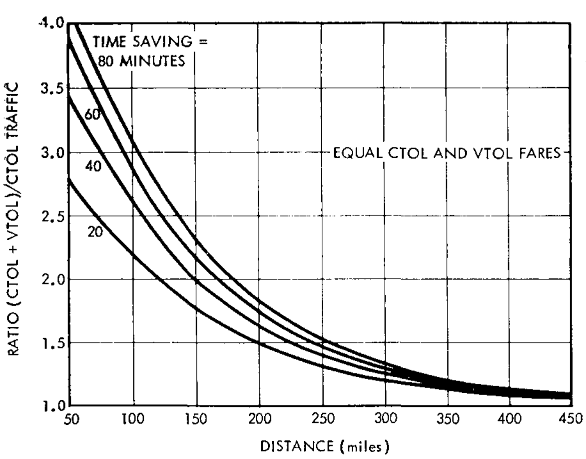

Fig. 6 Generalized traffic stimulation for 20, 40, 60, and 80-min time saving.

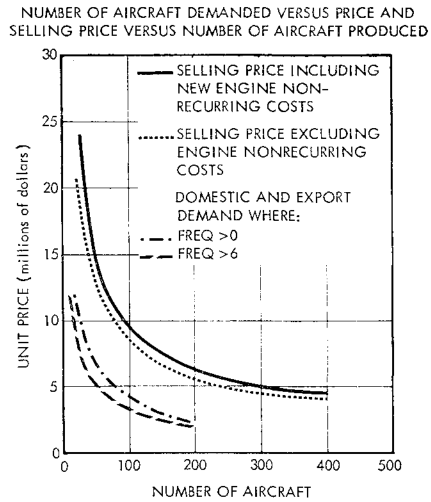

Fig. 7 Ninety seat conventional helicopter, 1985 demand

Calculation of Domestic Aircraft Demand

The aircraft productivity (number of seats, block time, load factor, utilization) determines the number of aircraft required to carry the city-pair passenger demand. The aircraft demand for all domestic city pairs is summed to obtain the total domestic aircraft demand.

Export Market

To establish the total market for VTOL passenger transports, it is necessary to include an export quantity. Based on the ratio of total to domestic sales for U.S. short- and medium-range jet transports, the total market is estimated at 1.37 × domestic market.

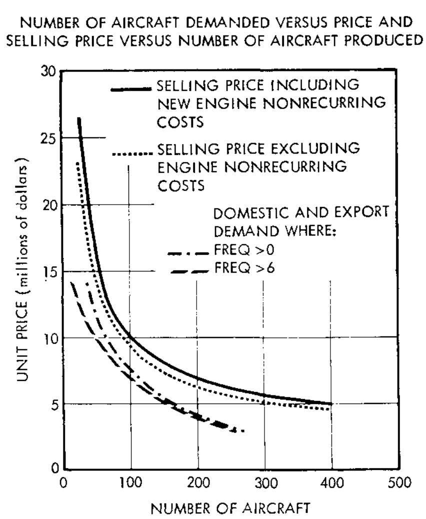

Fig. 8 Ninety seat compound helicopter, 1985 demand.

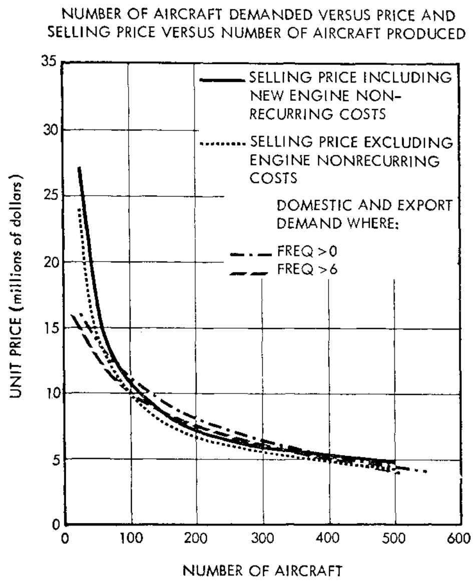

Fig. 9 Ninety seat tilt rotor, 1985 demand.

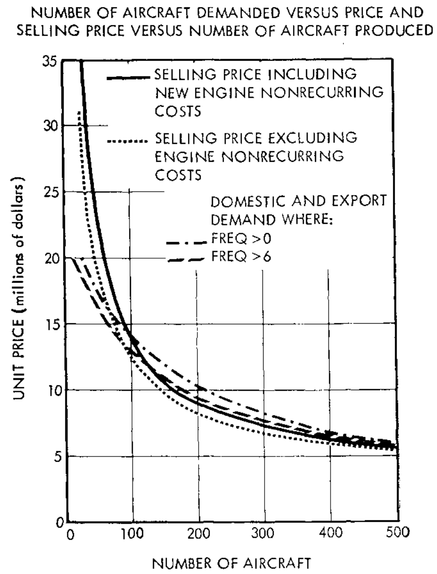

Fig. 10 Ninety seat tilt wing, 1985 demand.

Aircraft Demand and Supply Curves

The aircraft demand as a function of aircraft price is compared with the supply price of the aircraft to determine the economic feasibility of the program. The aircraft price is varied; this changes the VTOL fare, which changes the demand for aircraft. In this way, the number of aircraft demanded can be determined as a function of the price of the aircraft. The supply price curve is determined with nonrecurring costs being averaged over varied production numbers of aircraft and recurring costs being estimated with applicable learning curves.

Results

Results are shown in Figs. 7–12 for the 90 seat size of each VTOL. Aircraft demand is shown both with a frequency requirement of six round trips per day between city pairs and with no frequency requirement. The frequency requirement results in only a small percentage change when the numbers of aircraft demanded are large (at low prices for the faster types) but it does result in a significant percentage change when the demand is small (at high prices for the slower types).

The selling price of each aircraft type is shown both with and without engine nonrecurring costs. The selling price is based on production of each type for the civil market only. If a common basic aircraft could be sold in the military market as well, the civil selling price would be lower than shown.

All results shown in these figures are based on the assumption that the entire VTOL market is satisfied by production of a single aircraft type (and size). If more than one aircraft split this market, the selling price curve for each competing type would remain as shown, but the demand curve would be lower. (For instance, it would be half as great if two competing aircraft split the market equally.)

Helicopter and Compound Helicopter (*Figs. 7 and 8*): These types do not appear attractive economically, basically because they are too slow. Being slow, they lose their initial time saving over the conventional fixed wing transport at around 250 miles. As a result, the number of city pair routes on which they can compete is greatly reduced. Further, the city pairs on which they can compete are at the shorter distances and, therefore, relatively few aircraft are required to carry large numbers of passengers on these routes. A high percent of subsidy would be required for a helicopter or compound helicopter program. This program would be vulnerable to the introduction of one of the faster VTOL types which would be both faster and cheaper than either of the helicopter types.

Tilt rotor (*Fig. 9*): This type appears to be marginally profitable. Since its disk loading is comparable to that of helicopters, its noise characteristics should be in the most acceptable class. The tilt rotor has been flown experimentally so its technical risk is moderate.

Tilt wing (*Fig. 10*): This type is somewhat more attractive economically than the tilt rotor type. However, its noise characteristics are considerably worse than those of the tilt rotor. The tilt wing aircraft has been flown experimentally so its technical risk is moderate.

Stowed rotor (*Fig. 11*): This type lies between the tilt rotor and tilt wing economically and its noise characteristics should be in the most acceptable class. However, the stowed rotor has never been flown so its technical risk is high.

Fan or jet lift (*Fig. 12*): The poor showing of the fan or jet lift is due to its relatively high engine costs. Its noise characteristics should be considerably worse than any of the rotor types and somewhat worse than the tilt wing. This type of aircraft has been flown experimentally so its technical risk is moderate.

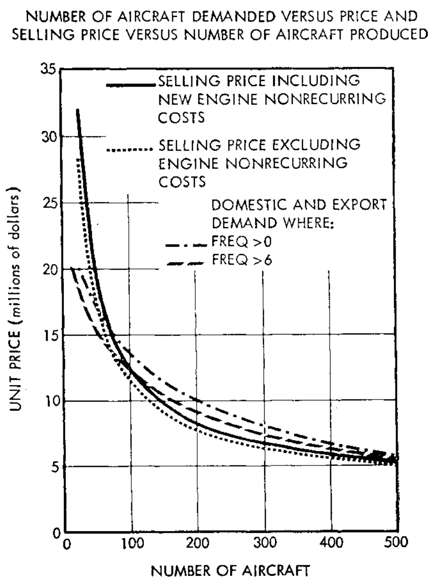

Fig. 11 Ninety seat stowed rotor, 1985 demand.

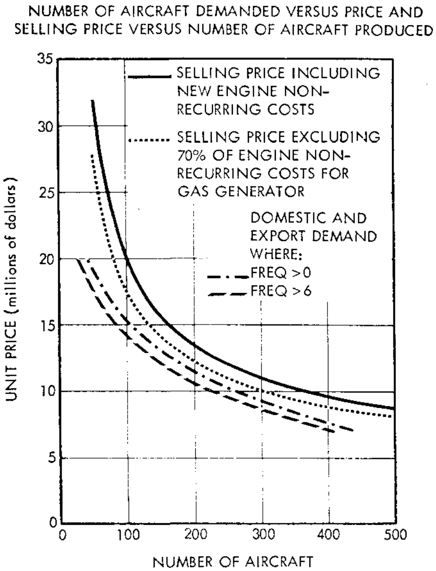

Fig. 12 Ninety seat fan or jet lift, 1985 demand.

The six VTOL types are ranked in Table 2. The first column is based on Figs. 7–12 and shows economic ratings—determined only by the fare and speed characteristics of the aircraft. The second column ranks noise and air pollution levels in landing and takeoff. Since both are basically a function of disk loading, the amount of air pollution increases with noise level. Four of the types hover like a helicopter and should have helicopter-like noise and air pollution levels. High noise levels would have a major adverse effect on passenger demand for VTOL service if the aircraft were forced to operate from vertiports well removed from the city centers. The third column deals with technical risk. The two helicopter types involve little technical risk; the stowed rotor, the only type that has not been flown, involves the highest technical risk.

The final over-all ranking requires a subjective weighing of the three basic categories. We have ranked the tilt rotor highest because it is only slightly worse economically than the tilt wing or stowed rotor; furthermore, it produces considerably less noise and air pollution than the tilt wing and involves much less technical risk than the stowed rotor.

Nevertheless, the stowed rotor seems to offer the greatest potential if it can be successfully developed, since economically it is better than the tilt rotor and is much quieter than the tilt wing. Because it may offer the greatest potential, it would be valuable to validate its characteristics by a flight test program. It should then be reevaluated before a production program is undertaken. Depending on the time required for stowed rotor development, the tilt rotor or one of the other types might be produced as a first generation vehicle and the stowed rotor might replace it as the second generation vehicle.

None of the VTOL aircraft types appear to be economically self-sustaining by 1975; by 1985 three of the six types appear capable of economical operation. By then it is estimated that a market for 200–300 90 seat VTOL's will exist. These aircraft will serve approximately 50 US cities on 70 city-pair routes as well as some foreign routes. The next major step toward realizing VTOL service should be the construction and testing of prototype aircraft to reduce the substantial uncertainties in aircraft performance, investment costs, operating costs, and noise acceptability.

Table 2 Ranking by aircraft type

Aircraft	Economic (fare/speed)	Noise/air pollution	Technical risk	Over-all
Helicopter	6	1	1	6
Compound helicopter	5	1	2	5
Tilt rotor	3	1	5	1
Tilt wing	1	5	3	3
Stowed rotor	2	1	6	2
Fan or jet lift	4	6	4	4

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[2] "Domestic Origin Destination Survey of Airline Passenger Traffic," 1965, Civil Aeronautics Board.

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